Road Construction Safety Audit for Interstate Reconstruction

(Volume 1)

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October 1998

ACKNOWLEDGEMENT

This research was sponsored by the U.S. Department of Transportation's University Transportation Centers Program, the Wyoming Department of Transportation and the University of Wyoming. The authors greatly appreciate this support.

DISCLAIMER

ABSTRACT

Traffic control alternatives associated with reconstruction projects on a rural interstate have been investigated in this research. Slab replacement projects, milling/resurfacing projects, and traffic controls in the vicinity of interstate ramps were analyzed. The recommendations obtained from a national focus group assisted in development of the Road Construction Safety Audit [RCSA] process. The RCSA process evaluates the traffic control plan [TCP], traffic control devices and strategies before an interstate work zone is established on the roadway. This process consists of six steps and a series of checklists used in the planning stage of a TCP to contrast interstate work zone traffic control alternatives while considering issues of the roadway and project. Checklists for slab replacement projects, milling/resurfacing projects and traffic control in the vicinity of interstate ramps were developed as part of this research. The key to the RCSA process and checklists is to ensure that major safety considerations of the project have not been overlooked, and alternative devices and/or strategies have been considered.

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INTRODUCTION

Work zone traffic control is used when an existing facility is to be maintained or reconstructed and the right-of-way is to be shared by workers and motorists. Four-lane divided interstate reconstruction projects are occurring throughout the interstate system. Associated with these projects is a need for temporary traffic control. Temporary traffic control takes on many shapes and forms, and many guidelines and layouts are available. Guidelines, such as the Manual on Uniform Traffic Control Devices [MUTCD], are used to layout work zones and redirect traffic in conjunction with the project's characteristics. However, a formal process to contrast work zone traffic control alternatives presently does not exist. In this project, a Road Construction Safety Audit [RCSA] was designed to consider interstate work zone traffic control alternatives for various roadway geometric factors and the type of reconstruction project.

Today's U.S. road construction has shifted from construction of new facilities to the reconstruction of existing facilities. The facilities are being rebuilt for many reasons, including safety improvements, resurfacing, capacity improvements, and repair of deteriorating pavement structures. Nationally this shift is illustrated by noting that between 1983 and 1985, the number of miles of highways and bridges resurfaced, restored, rehabilitated, or reconstructed was more than 15 times the number of newly constructed miles. With this shift in road construction projects, increasing conflicts between the driver and construction workers, and equipment is inevitable.

Conflicts between the motorist and work zone in road reconstruction projects often result in crashes. Crashes associated with work zones range from property damage only to fatalities. National statistics indicate that crashes and fatalities in work zones continue to increase. According to the American Traffic Safety Services Association, in 1991 there were 680 fatalities in highway work zones. Iin 1995 this number increased to 771. An increased focus on work zone safety is needed.

The objectives of this research project were to:

- evaluate the traffic control alternatives illustrated in the MUTCD manual and the alternatives used by the Departments of Transportation [DOTs] in the western United States.
- develop a safety audit checklist for selected rural interstate reconstruction projects.

LITERATURE REVIEW

After years of using the interstate system, the motorist becomes accustomed to the geometrics, signs, markings, and other elements of the roadway. In a work zone, some or all of the elements are absent and the roadway is often shared with equipment and workers.

Work zone traffic control protects the motorists and workers from work zone hazards while guiding the motorists through unfamiliar areas. Through the use of traffic control devices and a traffic control plan, a safe work zone is established. To ensure safety of the motorist and worker, eight fundamental principles are used as the guiding philosophy during the life of the work zone traffic control system. These principles (Part VI of the MUTCD) follow:

1. Make traffic safety an integral and high priority element of every project.
2. Avoid inhibiting traffic as much as possible.
3. Guide motorists in a clear and positive way.
4. Perform routine inspection of traffic control elements.
5. Give constant attention to roadside safety.
6. Provide proper training for the individuals in charge.
7. Acquire the proper authority when implementing regulatory devices.
8. Maintain a good public image.

Focus groups were established for this research project to determine practices used in different states and also to research alternative suggestions made by practicing DOT professionals. Twenty engineers employed by the Wyoming Department of Transportation (referred to as WYDOT) and a member from the other 23 state departments of transportation (referred to as DOTs) west of the Mississippi River were asked to participate in this research.

A written survey method was used to collect input from the two focus groups. The surveys used a modified Delphi technique. The Delphi survey technique is the combination of a polling procedure and an inquiry survey. The general methodology involves a questionnaire in which the respondent is asked for input or answers to questions based on their own judgment and professional knowledge. Separate surveys were designed and analyzed for a slab replacement project, a milling/resurfacing project, and work in the vicinity of exit and entrance ramps.

ANALYSIS AND RESULTS

Delphi surveys on traffic control preferences were obtained for a slab replacement project, interstate ramp traffic control, and a milling/resurfacing project. Results from the surveys and concurrent traffic studies were used to develop prototype checklists for each type of work zone area. Principle findings for each area are summarized in the next subsections.

Traffic Control for Slab Replacements on a Rural Interstate

The first Delphi survey examined work zone traffic control associated with slab replacements on rural interstates. Thirty of 47 surveys were returned, including 10 of 24 from WYDOT and twenty from DOTs outside of Wyoming.

The survey examined issues of traffic control and compared Wyoming responses between the two groups. Findings from the survey follow.

1. Both groups favored a single lane closure (SLC) strategy instead of a two-lane, two-way operation (TLTWO) strategy for a slab replacement project.
2. A drum was the channeling device preferred by the two groups in the transition area, buffer space, work space, and termination area when controlled by a SLC strategy.

3. The drum was the channeling device recommended most frequently by the two groups in the merging area, and the single lane closure area of a work zone controlled by a TLTWO strategy.
4. Roadway and project characteristics affected the type(s) of channeling devices recommended by both groups. Terrain, roadway, and geometric characteristics were primary factors in changing the recommended channeling devices.
5. State DOTs other than WYDOT favored the use of a positive barrier system for separating the opposing traffic lanes on a TLTWO strategy, while members from WYDOT recommended use of a drum for separating the opposing traffic lanes on a TLTWO strategy. It should be noted that the types of channeling devices actually used varied widely from positive barriers to tubular markers or short wands on projects with TLTWO strategies as long as 17 miles.
6. Finally, both groups generally recommended speed reductions in the work zones.

Ramp Traffic Control on a Rural Interstate Reconstruction Project

The second Delphi survey was conducted for traffic control in the vicinity of entrance and exit ramps located in a work zone on a rural interstate. A total of 28 surveys were returned, including 11 from WYDOT and 17 from DOTs outside of Wyoming. The important findings associated with ramp traffic control follow.

1. Using a STOP sign on an entrance ramp was influenced by the characteristics of the traffic volumes, sight distance, and the ramp geometry.
2. A STOP line was suggested when a STOP sign is employed on an entrance ramp.
3. The drum was the most used channeling device to guide traffic from an entrance ramp to the mainline.

4. Driver observance studies conducted at four different entrance ramps in construction areas in Wyoming indicated that only 10 percent of the motorists complied with a STOP sign at the end of the entrance ramp.
5. The drum was the most used channeling device for directing traffic onto an exit ramp.
6. WYDOT recommended additional exit signs for warning motorists of a temporary exit ramp in the work zone. The DOTs' group suggested that reducing the spacing of channeling devices in the vicinity of an exit ramp was a suitable method for warning motorists of an exit ramp.

Traffic Control for a Milling/Resurfacing Project on a Rural Interstate

Twenty-six surveys were returned, including 11 from WYDOT and 15 from the DOTs, which were used to study milling and resurfacing projects. Important findings included the following:

1. Both groups favored a SLC strategy instead of a TLTWO strategy for a milling/resurfacing project.
2. Widths of the travelway influenced the types of channeling devices recommended for a milling/resurfacing project. Group members suggested the use of a tubular marker or a smaller device when width of the travel lane was too narrow for a drum.
3. Members from the two groups strongly recommended placing the channeling device at the edge of the unmilled lane on a milling/resurfacing project and not in, or alternating in and out of, the milled area.
4. A positive barrier system was recommended by WYDOT when the drop off depth was at least 6.30 inches (STDEV = 3.74 inches). Members from the other DOTs recommended use of a positive barrier system when the minimum drop off depth was at least 2.95 inches (STDEV = 1.91 inches).

5. A full-time traffic control device maintainer often was recommended for a milling/resurfacing project.

ROAD CONSTRUCTION SAFETY AUDITS

Other objectives associated with this project were to develop a Road Construction Safety Audit [RCSA] process and a series of checklists for these interstate reconstruction projects and the entrance and exit ramps traffic control.

The RCSA evaluates the traffic control plan, devices and strategy before the interstate work zone is established. This checklist also has utility in considering alternative work zone traffic control issues. There are two stages where the RCSA process and the checklists primarily are beneficial for interstate construction projects. These are the planning stage (i.e. during the design of the traffic control plan [TCP]) and the pre-opening stage (i.e. after the TCP has been completed). The RCSA process and checklists were developed for transportation professionals that have knowledge and experience in interstate work zone design.

The RCSA checklists developed were based on the various and often different recommendations from the three Delphi surveys. The checklists ensure that major safety considerations have not been overlooked. Specific values for speed limits, milling drop off depths, and types of devices have been considered with the RCSA. However, state practices, tort liability, and preference also are factors to consider in modifying the different RCSA values or devices indicated. For this reason, a second set of the RCSA checklists was developed without specific values or specific types of devices. This allows for agencies using checklists, to input their device preferences, speed limits and drop off heights. An independent auditor or a team of auditors using the RCSA is recommended. The auditor(s)' knowledge in road safety engineering, traffic engineering, construction safety, and work zone design is essential.

The process recommended for an RCSA consists of six steps (modified from Road Safety Audits, Austroads 1994).

1. Select auditor(s).
2. Provide information about the project and the facility.
3. Obtaining the TCP for the project or plan the TCP using the RCSA checklists.
4. Evaluate the project using the corresponding CHECKLISTS to assist evaluation.
5. Submit comments indicating suggestions.
6. Incorporate RCSA checklists during routine inspections of the Work Zone to check safety associated with the TCP implemented.

Completing the RCSAs during the planning stage of a project will enable auditors to point out problems and/or recommend suggestions and to consider alternatives before the work zone is operational. The last step will help to assure that the implemented TCP does not overlook important safety issues.

CONCLUSIONS

This section presents conclusions associated with work zone traffic control practice obtained from analysis of the survey results. For ease of presentation, they are listed by type of project.

Slab Replacement Project

1. The SLC strategy is most often recommended for a slab replacement project on a rural interstate.
2. Closing one entire traffic lane at a time and repairing all the slabs in that lane is the preferred lane closure option for slab replacement projects control by a SLC strategy.
3. The DOTs' group recommended a concrete barrier system for separating two opposing traffic lanes on a project controlled by a TLTWO strategy.
4. Lowering speed limits in a work zone for the SLC and TLTWO strategies is recommended.

Ramp Traffic Control

1. Location for a STOP sign on an entrance ramp in the work zone area (on the ramp or at the ramp entrance) was not consistent.
2. Striping the stop line was recommended when a STOP sign is used.
3. Either STOP or YIELD control was recommended at the end of an entrance ramp when the acceleration lane is not present due to the work activity on the mainline.
4. When there is no deceleration lane and only one lane is open on the mainline, decreased device spacing or an alternative type of channeling device was recommended in the vicinity of an exit ramp.

Traffic Control for a Milling/Resurfacing

1. SLC strategy was most often recommended for a milling/resurfacing project on a rural interstate.
2. There was no consistent traffic control recommended for milling/resurfacing projects.
3. Channeling devices generally were not used when an edge drop off of 1.5 inches or less exists on a milling/resurfacing project.
4. Cones, tubes, and drums were recommended for drop off depths up to 3.5 inches.
5. Placing channeling devices at the edge of an unmilled lane, and not in the milled lane, was recommended where the milled lane is closed to traffic.
6. Use cones as the primary channeling device for daytime operations only. For projects with an exposed milled lane left overnight, use drums or tubular markers.
7. A full-time traffic control device maintainer was recommended on a milling/resurfacing project when traffic control devices are left overnight.

Road Construction Safety Audit [RCSA] Checklists

1. Using the RCSA procedure on an interstate reconstruction project will help focus on traffic control alternatives and devices. Audit issues were based on safety and a consensus recommendation of the states surveyed.
2. Formatting the RCSA checklists with agency policies to help achieve consistency within interstate work zones is recommended.
3. Adapting a consistent national RCSA process is needed.

RECOMMENDATIONS

Presented in this section are recommendations for additional research concerning work zone traffic control on a rural interstate.

1. Further research is needed to determine the effect of traffic volumes on implementation of traffic control strategies and devices. Actual application of the RCSA checklists, refinement of RCSA checklists, and documentation of their safety benefits is needed.
2. Similar surveys on other reconstruction projects such as bridge deck repair and roadway realignment are needed to develop additional checklists.
3. Additional research on ramp traffic control in work zones is needed, including traffic control studies on driver compliance with YIELD signs on interstate entrance ramps, traffic studies on driver observance of STOP signs, the affect of adding portable rumble strips, and determining optimal sign location on an interstate entrance ramp.
4. A national documentation procedure for work zone crashes is needed to determine where crashes are occurring in the work zone.

CHAPTER 1

INTRODUCTION

Work zone traffic control is used when an existing facility is to be maintained or reconstructed and the right-of-way is to be shared by workers and motorists. Reconstruction projects on four-lane divided interstate roads are occurring throughout the interstate system. Associated with the projects is the need for temporary traffic control. Temporary traffic control takes on many shapes and forms, and there are numerous guidelines and layouts available. Traffic control plan guidelines from the Manual on Uniform Traffic Control Devices [MUTCD] generally are used to layout work zones and redirect traffic in conjunction with the project's characteristics. A number of variations and types of devices exist and often are used. A formal process to contrast work zone traffic control alternatives and the consideration of traffic issues does not exist. Using Road Construction Safety Audits [RCSA] designed for specific types of reconstruction projects have been developed in this research project.

Background

Today's road construction has shifted from construction of new facilities to reconstruction of existing facilities. These facilities are being rebuilt for many reasons, including safety improvements, resurfacing, capacity improvements, and repair of deteriorating pavement structures. Nationally this shift is illustrated by noting that between 1983 and 1985, the number of miles of highways and bridges resurfaced, restored, rehabilitated, or reconstructed (4R) was more than 15 times the number of miles newly constructed [1]. With this shift in road construction projects, increasing conflicts between the driver and construction workers and equipment is inevitable.

Conflicts between the motorist and work zone in road reconstruction projects often result in crashes. Crashes associated with work zones range from only property damage to fatalities. National statistics indicate that crashes and fatalities in work zones continue to increase. In 1991 there were 680 fatalities in highway work zones, in 1995 this number increased to 771 [2]. This data shows the need for an increased focus on work zone safety.

Crashes in road reconstruction work zones in Wyoming also are increasing. According to the Wyoming Transportation Department, total crashes in work zones increased 169 percent from 1991 to 1995 [3].

The rise in crashes associated with road construction zones is related to the growing number of highway miles being reconstructed yearly. While current guidelines and standards clearly layout work zones, a greater focus on safety is needed. Auditing practice alternatives to compare and evaluate benefits, costs and trade-offs of various work zones and traffic redirection alternatives has been developed based on practice, alternatives, and recommendations of surveyed state departments of transportation.

Objectives

The specific objectives of this research project were to:

1. evaluate traffic control alternatives illustrated in the MUTCD manual and alternatives used by the Departments of Transportation [DOTs] in the western United States.
2. develop safety audit checklists for the rural interstate reconstruction projects researched in this project.

Report Organization

Chapter 2 includes a literature review of work zone traffic control guidelines and related information on work zone traffic control. Included in Chapter 3 is an overview of the methodology used for this project. Chapter 4 contains the results and findings of the project. Road Construction Safety Audit Checklists are presented in Chapter 5. The summary, conclusions, and recommendations are contained in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

Work Zone Traffic Control

After years of using the interstate system, motorists become accustomed to geometrics, signs, markings, and other elements of the roadway [2]. In a work zone, some or all of the elements are absent and the roadway is being shared with equipment and workers.

Work zone traffic control protects the motorists and workers from the work zone hazards while guiding the motorists through an unfamiliar area [4]. A safe work zone is established through the use of traffic control devices and a traffic control plan. To ensure safety of the motorist and the worker, eight fundamental principles are used as a guiding philosophy during the life of the work zone traffic control system. Fundamental principles of work zone traffic control are listed in Part VI of the MUTCD. The principles follow:

1. Make traffic safety an integral and high priority element of every project.
2. Avoid inhibiting traffic as much as possible.
3. Guide motorists in a clear and positive way.
4. Perform routine inspection of traffic control elements.
5. Give constant attention to roadside safety.
6. Provide proper training for individuals in charge.
7. Acquire the proper authority when implementing regulatory devices.
8. Maintain a good public image [4,5].

In addition to the fundamental principles, other aspects are kept in mind when planning a work zone traffic control plan including:

"A. All traffic control devices used must be in conformance with the provisions of the MUTCD.

B. Contact in advance of the plan should be effected with transit systems, emergency response organizations, utilities, schools, businesses, residents, and others that may be potentially impacted by their operations.

C. The nature and composition of the traffic flow should be analyzed to determine the need to reroute permit loads and possibly restrict HAZMAT vehicles" [2].

Maintenance and inspection of a work zone's components also is vital. Doing so provides a safer and smoother transition for the motorists traveling through the work zone. Inspection and maintenance of the work zone is continuous throughout the life of the project. The steps to a successful inspection program follow.

"Step 1: Review of contract documents and preparation for inspection

Step 2: Yard inspection (i.e. inspect devices before they are installed in the field)

Step 3: Drive-through inspection of traffic control zone

Step 4: Stationary observation of traffic operations in traffic control zone

Step 5: Walk-up inspections of major safety hardware items

Step 6: Document inspection and check on needed changes or repair [6]."

Elements of a Work Zone

When normal function of a roadway is suspended, temporary traffic control must be implemented for the roadway to continually function for movement of traffic and/or pedestrians. Before traffic control techniques are implemented, a Traffic Control Plan [TCP] must be designed. "A traffic control plan is a scheme for handling traffic through a specific highway or street work zone or project"[4]. Due to the various roadway characteristics, numerous plans and guidelines have been developed over the years. "These plans may range in scope from a very detailed TCP designed solely for a specific project, to a reference to a typical plan or section of the MUTCD"[4]. The characteristics of the roadway and/or the project will effect the complexity and detail of the TCP.

Areas of an Interstate Work Zone

"The temporary traffic control zone includes the entire section of roadway between the first advance warning sign through the last traffic control device, where traffic returns to its normal path and conditions" [5]. This section is then broken into four basic components: 1. advance warning area, 2. transition area, 3. activity area, and 4. termination area. Figure 2.1 is an illustration of interstate work zone components.

The **Advance warning area** provides the motorist with necessary information in preparation to enter the remainder of the work zone [2,4,5]. The information is provided to the motorists through a series of signs or changeable message boards.

The **Transition area** is where traffic is channeled from the normal path to a new path. Devices such as drums, cones, tubular markers, and barricades are used to channel the traffic from the normal path to a new path [2,4,5].

The **Activity area** is an area of the roadway where work is going on or is going to be done. It is composed of the work space, the traffic space, and one or more buffer spaces [2,5].

> "The work space is the portion of the roadway closed to traffic and set aside for workers, equipment, and material. The traffic space is the portion of roadway in which traffic is routed through the activity area. The buffer space is an optional feature in the activity area that separates traffic flow from the work activity or a potentially hazardous area and provides recovery space for an errant vehicle" [5].

The **Termination area** is a portion of the work zone where lanes transition back to normal traffic lanes. It extends from the end of the work space to the END CONSTRUCTION or END ROAD WORK sign [2,4,5].

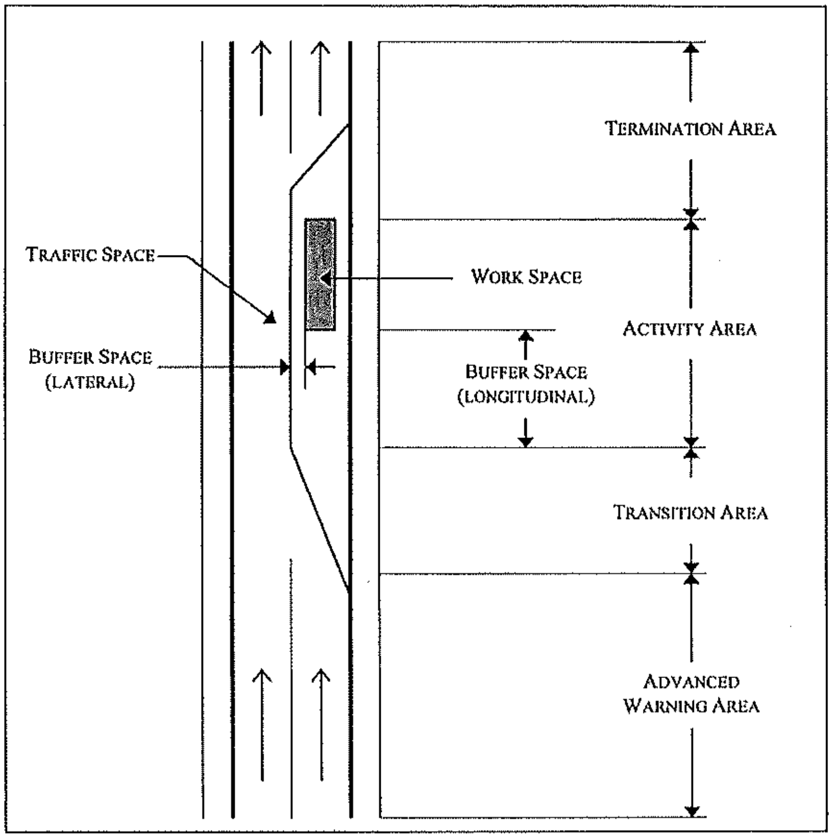

Figure 2.1 Component Parts of an Interstate Work Zone [5]

Traffic Control Devices

After the traffic control plan has been designed, the next step is to choose traffic control devices that will be used on the reconstruction project. "A traffic device is a sign, signal, marking or other device placed on or adjacent to a street or highway (by authority of a public body or official having jurisdiction) to regulate, warn, or guide traffic"[5]. For a work zone traffic control device to be effective, it must meet five basic requirements.

1. Fulfill a need.
2. Command attention.
3. Convey a clear, simple meaning.
4. Command respect of road users.

5. Give adequate time for proper response [4,5].

To ensure that these requirements are met, five basic considerations are employed: design, placement, operation, maintenance, and uniformity [4,5]. Descriptions of these considerations are presented in Part VI of the MUTCD.

Types of work zone traffic control devices consist of, but are not limited to, signs, portable changeable message signs, arrow displays, high-level warning devices, channeling devices, pavement markings, lighting devices, temporary traffic signals, and other devices. Numbers and types of devices employed on an interstate work zone are influenced by the project's characteristics and the traffic control strategy employed.

"Signs are extremely versatile devices that generally provide the driver with the greatest amount of information about what lies ahead"[2]. The devices relay general and specific messages by means of words or symbols. There are three categories of signs that apply to work zone traffic control: regulatory signs, warning signs, and guide signs. Guidelines for placement and design of work zone signs are presented in Part VI of the MUTCD.

A regulatory sign informs the highway user of traffic laws or regulations (i.e. speed limit). The public body or official possessing jurisdiction authorizes the signs, which impose legal obligation [5].

The most common sign category in a work zone is the warning sign. It informs the motorist of general or specific conditions on or adjacent to the roadway [5]. Examples of these signs include a ROAD WORK Sign, and a LANE CLOSED sign. A work zone warning sign possesses a black legend on an orange background.

Work zone guide signs provide the motorist with information about the route through the project. The signs consist of standard route markings, directional signs (e.g. motor service signing, recreational signs, etc.), and special information signs (i.e. relating to the work being done) [5].

An arrow display panel is an extremely useful work zone trafficcontrol device often used to inform the motorist of a lane closure or a moving lane closure. The arrow display, which has a flashing arrow or a chevron, [2, 4, 5] also informs the motorist to merge into another lane.

The function of channeling devices is to warn and alert motorists of conditions created by the work activities, to protect workers in a work zone, and to guide motorists safely [5]. Cones, drums, tubular markers, vertical panels, temporary raised islands, and barricades are channeling devices. The devices have two distinct purposes: "...(1.) In a taper; they help to force movement of traffic from one lane to another or from one position on the roadway to another, and (2.) In delineation; they provide visual guidance to the motorist to assist in identifying the lateral limits of travel"[2].

Design characteristics of channeling devices are important since they have the potential of being struck by a vehicle. "If struck, they should yield or break away, and the fragments or other debris from the device should not penetrate the passenger compartment of the vehicle or be a potential hazard to workers or pedestrians in the immediate area" [5]. Channeling devices also are required to possess retroreflective sheeting or be illuminated, so they are visible at night.

Portable barrier systems are devices that may be used for channeling purposes in a work zone. Their primary purpose is to provide protection for the motorists and workers by denying access of motor vehicles into certain portions of the roadway [2]. The barrier provides this protection by redirecting the motor vehicle back into the travel lane, instead of the device yielding and allowing the vehicle to proceed into the work area. The most widely used barrier is a concrete precast New Jersey "safety shape" barrier, although note-filled plastic and sand-filled metal barriers also are used.

The most understood and popular type of traffic control device is pavement markings. Pavement markings inform motorists of travel lane boundaries, passing zones and pedestrian crosswalks. In a work zone, markings are used to make temporary changes in the travel paths. Temporary pavement markings consist of paints, retroreflectorized tapes, and retroreflective- and non-retroreflective raised pavement markers.

Work zones often create situations on or near travel paths that are particularly unexpected at night, when the motorist's visibility is sharply reduced [5]. Lighting devices bring motorists' attention to the work zone and its obstacles. Four types of lighting devices are floodlights, hazard identification beacons, steady burning electric lamps, and warning lights.

Three types of warning lights are used in conjunction with channeling devices: Type A - low-intensity flashing lights, Type B - high-intensity flashers, and Type C - steady burning lights. These devices are beneficial where "...retroreflective panels are covered with dust or snow, in times of decreased visibility due to rain, snow or fog, and on barricades on curves" [2].

Part VI of the MUTCD also presents a section on other devices including impact attenuators (truck mounted and roadside), screens, and rumble strips [B]. Impact attenuators lessen the effects of an errant vehicle approaching the workers [5]. Screens block the motorist's view of activities or prevent glare from oncoming traffic [2]. Rumble strips are used to alert motorists of "...unusual or unexpected traffic conditions or geometrics"[5].

Today, new and innovative traffic control devices are being introduced into the field of work zone traffic control. Direction indicator barricades, opposing traffic lane dividers, portable rumble strips, intrusion alarms, and remotely-driven vehicles are examples [7]. Materials of work zone traffic control devices also are changing. Devices once constructed of wood and metal now are being manufactured out of plastics.

Interstate Work Zone Traffic Control

Interstate work zone traffic control is required to handle situations caused by construction, reconstruction or maintenance. Characteristics associated with the project type heavily influences the number and type of devices used in temporary traffic control zones. These characteristics are type of work, duration of work, location of work, and roadway type.

Today, there are many types of work being completed on the interstate system. Reasons for that include safety improvements, resurfacing, capacity improvements, and repair of deteriorating pavement structures. Project types associated with these improvements include concrete pavement recycling/overlay, concrete pavement restoration, asphalt concrete pavement overlay, bridge deck replacement/widening, reconstruction, and new interchange/construction [8,9]. The types of work activities focused on in this research project were concrete slab replacements (i.e. concrete pavement restoration) and asphalt milling/resurfacing (i.e. asphalt concrete pavement overlay).

The second characteristic of a reconstruction project is work duration. Work duration is a major factor in determining the number and types of devices used in a temporary traffic control zone. Five categories of work duration are listed in MUTCD Part VI. This research project focused on long-term stationary and intermediate-term stationary work zone durations. Long-term stationary is work that occupies a location for more than three days [2,4,5]. Examples of long-term stationary include roadway reconstruction, realignment, and bridge deck repair. Intermediate-term stationary is work that occupies a location from overnight to three days [2,4,5]. Examples of this include pavement rehabilitation, and slab replacements.

Location of work also influences which traffic control strategy and devices are used on the project. In Part VI of the MUTCD, four locations are listed. All of the locations are applicable to interstate reconstruction. Work may take place in several places: outside of the shoulder edge, on or near the shoulder edge, on the median of a divided highway, and on the travel way. Work on the travel way requires the most devices because workers are sharing the roadway with motorists.

Methods to Improve Nighttime Conditions in a Work Zone

Although the majority of interstate reconstruction work is completed during the day, the work zone often exists overnight and during adverse weather. Motorists who use the roadway during nonworking hours require a safe and smooth transition through the work zone. To achieve this, additional methods are required.

Reasons for additional methods include motorists' vision and visibility of the devices. The motorists' visions may be affected by factors including eyesight, quality of eyeglass lenses, quality and brightness of the headlights, dirt on the windshield, rain, snow fog, and headlight/driver location [6].

Visibility refers to the traffic control device's ability to get the motorists' attention. Visibility of the device may be affected by factors including target value-based on the size of the device, brightness of the device, and positioning of the device, which affects the ability of the device to catch and reflect the light [6].

Considering these factors, nighttime work zone traffic control requires special consideration. Examples include: "Are the traffic control devices visible enough? Can they be easily seen? Do they demand attention?"[6]. There also are several methods available to improve visibility of night work zones: adding lights, arrow panels, cones with retroreflective collars, adding steady burn lights or reflectors to channeling devices, retroreflective sheeting, delineators, and lighted work areas [6].

Interstate Traffic Control Strategies

Construction of the national interstate system began in the late 1950s. By the 1970s, there was a need to rehabilitate the system, especially the pavement structure [9]. Currently, parts of the interstate system are being restored, rehabilitated, resurfaced or reconstructed. This reconstruction often requires that one or more of the lanes be closed. On a four lane interstate system, two basic alternative traffic control strategies exist — Single Lane Closure [SLC] and Two-Lane, Two-Way Operation [TLTWO].

An SLC strategy is when one lane in one direction is closed resulting in little or no disruption of traffic in the opposite direction [2,4,5,8,9]. Figure 2.2 displays an illustration of an SLC.

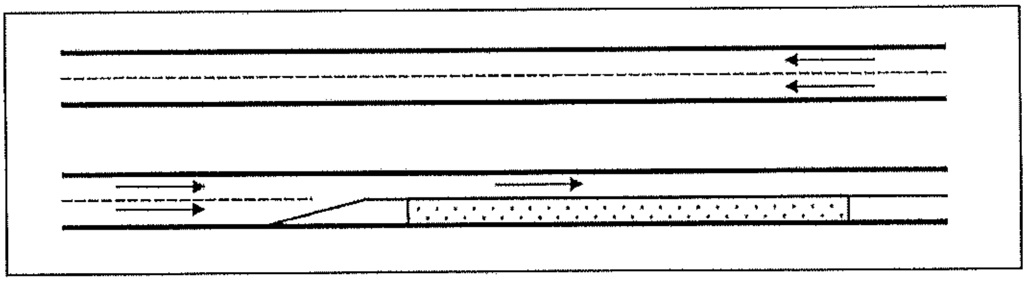

Figure 2.2 Single Lane Closure on a Four-Lane Interstate

"Two-Lane, Two-Way Operation [TLTWO] occurs where one directional roadway is closed on a four-lane divided highway and both directions of travel use the remaining roadway with one lane in each direction" [10]. As shown in Figure 2.3, the TLTWO section is achieved with use of a median crossover in advance of the closed roadway [10].

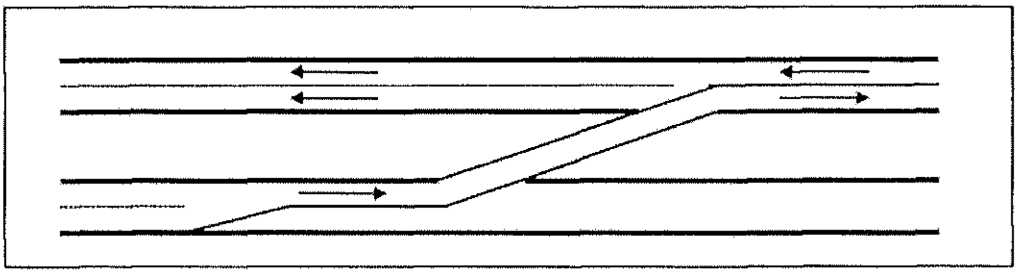

Figure 2.3 Two-Lane, Two-Way Operation on a Four-Lane Interstate

Another option that is used on a four-lane interstate is detouring traffic to a parallel highway [2,4,5,8,9].

Initially the TLTWO was used most often on four-lane highways. "However, the concern for serious head-on vehicle collisions on the temporary two-way operation prompted the Federal Highway Administration (FHWA) to issue Emergency Regulations in 1978, which required positive barriers to separate opposing traffic flows" [9]. The result of regulations was that most state agencies changed their traffic control plans and began to use the SLC more due to high costs associated with the positive barriers.

In 1982, the FHWA modified the Emergency Regulations due to the growing states' concerns. The modified regulations permitted use of alternative separation devices (other than positive barriers) in the TLTWO section of the work zone [9]. Today use of tubular markers is a common option to separate traffic lanes.

As indicated in this research and other research, some agencies use type of construction as a means for determining traffic control strategy; others use the roadway and project's characteristics. There is no easy answer when choosing a traffic control strategy. Many projects researching traffic control strategies and implementation have been completed, however results are inconclusive. Examples have been presented in the following section.

Construction Costs and Safety Impacts of Work Zone Traffic Control Strategies

E. N. Burns and Associates completed a study on traffic control strategies in 1989. Objectives of this project were to: 1) determine the costs and safety impacts associated with SLC verses TLTWO and 2) prepare an information guide to assist contractors in selecting the most cost-effective traffic control strategy [9].

Fifty road reconstruction projects on rural four-lane divided highways were studied. The projects entailed various types of work [9]. Data collected at these sites were accident data and traffic volumes. Road user and vehicle operating costs were estimated based on traffic volumes, capacity of the roadway, length of the work zone, and percentage of trucks.

Results from this project indicated "... that there are many variables associated with construction work zones that limit the development of guidelines for selecting the most cost-effective traffic control strategy"[9]. Some recommendations made based on this research project are summarized in Table 2.1 and based on the type of construction.

Table 2.1 Suggested Traffic Control Strategies by Construction Type [9]

Type of Construction	Traffic Control Strategy
Concrete Pavement Recycling/Overlay	TLTWO
Concrete Pavement Restoration	SLC (Analysis)*
Asphalt Concrete Pavement Overlay	SLC
Bridge Deck Overlay	SLC
Bridge Deck Replacement/Widening	TLTWO
Reconstruction	TLTWO
New Interchange/Construction	Analysis*

* Road User Cost Analysis should be performed for work delays

A procedure for determining road user costs also was included as part of the findings. Road user costs are affected at the work zone due to decreased speeds, which affect motorist travel times and vehicle operating costs.

Problems Associated with Work Zone Traffic Control

When the roadway is shared by workers and motorists, conflicts often occur. Work zones:

> "Confront the motorists and pedestrians with situations which they normally do not expect, cannot anticipate, and often find confusing. (They) tend to create hazards with which the road user can collide or otherwise encounter, tend to divert the motorist's attention from the driving task, and tend to expose workers to traffic flow"[2].

Consequences of these hazards sometimes result in crashes. National work zone-related crashes account for approximately 2 to 3 percent of all police reported crashes [11]. Figure 2.4 displays the estimated number of highway construction and maintenance fatal crashes in the United States from 1991 to 1995.

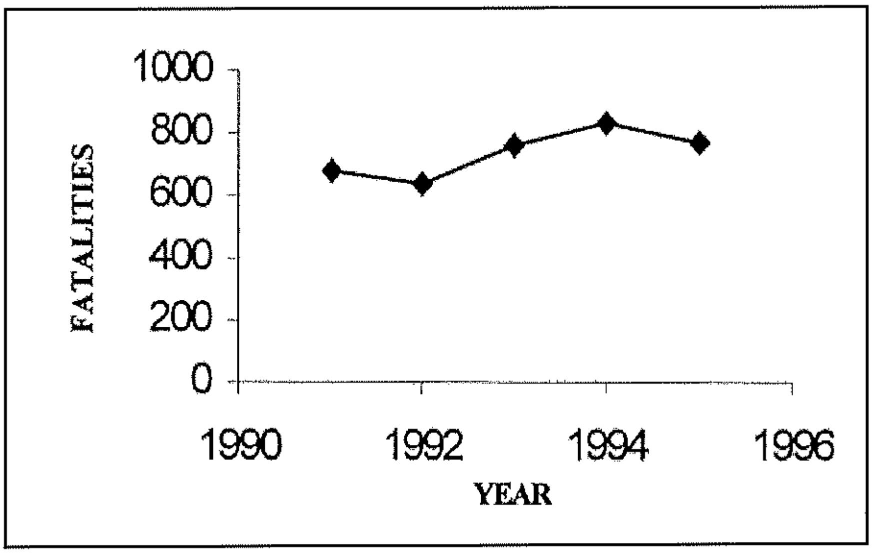

Figure 2.4 U.S. Fatalities in Work Zones [2,11]

Although the Wyoming Department of Transportation reported no fatality crashes from 1991 to 1995, the number of total crashes in work zones on the interstate system did increase (See Figure 2.5).

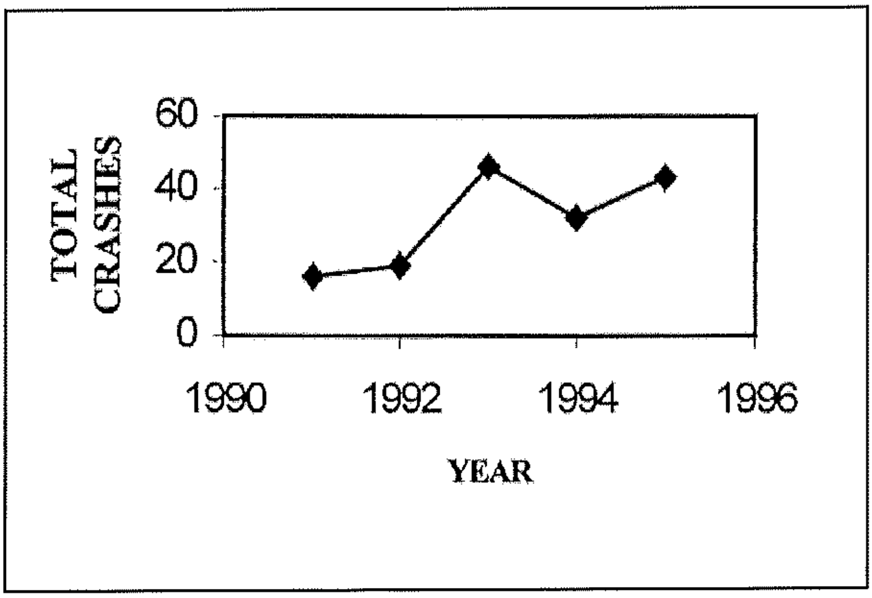

Figure 2.5 Wyoming Construction Crashes [3]

Driver error frequently is sited as the major cause of motor vehicle crashes. "It is estimated that some 75 percent of all crashes are caused by driver error [2]. These crashes occur for a number of reasons. Excessive speed, passing in no-passing situations, and motorists observing work activities are just a few of the driver errors that often cause accidents.

Studies on work zone crashes have indicated the most common types of crashes are rear-end, side-swipe, and fixed object crashes [11,12]. "It is believed that most rear-end collisions occur when a vehicle collides with another vehicle as the leading vehicle slows or stops in response to work activity" [11]. This may indicate that the speed differentials among vehicles at work zones is a primary contributor to work zone crashes [11]. Vehicles making illegal passing maneuvers in a work zone cause the majority of the side-swipe crashes in work zones. The fixed object crashes are related to equipment, traffic control devices or other obstacle located within the right-of-way.

Another major problem in interstate work zones is speed. Many techniques and devices are used in an attempt to slow the motorists. Flagging, law enforcement, changeable message signs, effective lane width reductions, and rumble strips are examples of treatments used to slow traffic. However, before the speed limit or reduction is set for a work zone, factors or characteristics of the work zone need to be addressed (see Table 2.2). Table 2.2 illustrates a procedure for determining the speed limit in a work zone.

Table 2.2 Work Zone Speed Limit Procedure [13]

Condition	*Suggested Amount of Speed Reduction*	*Factors Affecting Work Zone Speed Limits*	
Activities that are more than 10 ft from the edge of the pavement	None, unless unusual situations are present	1	Workers present in traveled way or within 10 ft of traveled way unprotected by barrier
Areas that encroach closer than 10 f., but not closer than 2 ft to the edge of the pavement	10 mph, where Factors 1 or 2 are present	2	Horizontal curvature that might increase vehicle encroachment rate (could include mainline curves, ramps, and turning roadways)
Activities that encroach the area from the edge of the pavement to 2 ft from the edge of the pavement	10 mph, where Factors 1,2,3,4, or 5 are present	3	Barrier or pavement edge drop-off within 2 ft of traveled way
Activities that require an intermittent movement or moving operation on the shoulder	None, unless unusual situations are present	4	Design speed for stopping sight distance
Activities that encroach the area between the center line and the edge of pavement (lane closure)	10 mph, where Factors 1,2,3,4, 5,6,7,8,9, or 10 are present	5	Unexpected conditions
Activities requiring a temporary detour to be constructed	10 mph, where Factors 5,6 or 11 are present	6	Lane with reduction of 1 ft or more with a resulting lane width less than 11 ft
Activities that encroach the area on both sides of the center line of a roadway or lane line or a multilane highway	10 mph, where Factors 1,5, or 12 are present	7	Traffic control devices encroaching on a lane open to traffic or within a closed lane but within 2 ft of the edge of the open lane
		8	Design speed of taper length or speed change lane length
		9	Design speed of horizontal curve
		10	Traffic congestion created by a lane closure
		11	Design speed or detour roadway and transitions
		12	Remaining lane plus shoulder width is less than 11 ft because of a restriction due to work in the traveled way

Relating speed control to work zone traffic control devices is an ongoing issue. In a study completed by Patrick McCoy and James A. Bonneson, five traffic control devices were tested to determine their effect on speed reduction. The devices tested were portable rumble strips, speed monitoring display, innovative flagging, flagging with Yellow-Green Apparel, and law enforcement. "All of the traffic control devices, except the portable rumble strips, resulted in statistically significant reductions in the average speed of traffic approaching the work zone" [14]. The largest reductions in speed were associated with the innovative flagging procedure [14]. In this procedure, the flaggers held a 45 MPH sign paddle (instead of holding a STOP/SLOW sign paddle) in one hand and motioned the traffic to slow down with the other hand. The next most effective method in reducing speeds was law enforcement, followed by the speed monitoring display and rumble strips, respectively.

With the many issues identified in the previous sections, this project used current practices to develop a road safety audit procedure for interstate construction areas. The first road safety audits were conducted in the United Kingdom in the 1980's. In 1990, New South Wales introduced road safety audits and several other states in Australia followed [16].

Road Safety Audit

A road safety audit has been defined as "...a formal examination of an existing or future road or traffic project, or any project which interacts with road users, in which an independent, qualified examiner reports on the project's accident potential and safety performance"[15]. Road safety audits identify potential safety problems for road users and others affected by a road project, and ensure that measures to eliminate or reduce the problems are considered fully [15].

Austroads indicates five stages where a road safety audit may be conducted: feasibility stage, draft design stage, detail design stage, pre-opening stage, and an audit of an existing road [15,16]. The earlier that audit procedures are completed in the project the greater potential benefits. (The RSA for all stages of major project also are indicated appropriate audits). Note that using audits for investigating work zone traffic control projects was not identified.

The auditors are key elements of road safety audits. Auditors should possess experience in road safety engineering, accident investigation and prevention, traffic engineering, and road design [15]. A team of auditors, rather than a single auditor often is more beneficial to the project if they possess diverse backgrounds and different approaches toward problem solving. The cross-fertilization of the group is sited as a benefit of group audits [15]. A series of standard checklists were developed by Austroads and individual agencies for evaluating safety at each stage of the audit process [16]. The process of conducting a successful road safety audit consists of seven fundamental steps:

1. Select an auditor(s).
2. Provide the background information.
3. Hold a commencement meeting.
4. Assess the documents and/or inspecting the site.
5. Create the report.
6. Hold a completion meeting.
7. Follow up [15,16].

Data used while conducting a road safety audit include plans and drawings of the site being investigated. Depending on the audit stage, site information includes a detailed accident history, traffic volumes, design standards, and consideration of environmental issues [16]. After the initial data has been gathered, an on-site inspection of the project is completed. The following chapter includes the methodology used to analyze specific interstate work areas and incorporate the findings into an RSA format.

CHAPTER 3

METHODOLOGY

This research has evaluated the traffic control alternatives and developed a set of safety audit checklists for rural interstate reconstruction projects. A national focus group survey of transportation engineers and a modified Delphi survey procedure was used. Through the Delphi surveys, the focus group provided input on guidelines and traffic control device usage. In addition, driver observance studies were conducted on interstate entrance ramps located within a work zone.

Road Construction Safety Audit Focus Group

The focus group established for this research project consisted of two groups of transportation professionals; the first group was made up of 20 engineers employed by the Wyoming Department of Transportation (labeled as WYDOT). The second group was composed of transportation professionals associated with other state agencies (labeled DOTs). Geographically, a member from every state department of transportation west of the Mississippi River was asked to participate in this research. Twenty-three states are included in the second group.

Delphi Survey Technique

A written survey and a modified Delphi technique was used. The Delphi survey technique is the combination of a polling procedure and an inquiry survey. "The general methodology involves a questionnaire in which the respondent is asked for input or answers to questions based on their own judgement and professional knowledge"[17]. "The Delphi process is often used in situations where there are limited facts available and the results of the responses are not generally qualitative in nature"[19]. In situations such as these, "expert" opinions are used. By using a focus group of traffic engineers, an "expert" opinion for determining which devices and guidelines are used in interstate reconstruction was provided [18,19].

Contingency Tables

Many of the questions in the three Delphi surveys yielded dichotomous responses. "Dichotomous responses are those that have two possible outcomes – often they are yes and no"[20]. Because there were two groups, a 2 x 2 contingency table resulted when a dichotomous answer also was provided (See Table 3.1). The 2 x 2 contingency table is one of the most common ways to summarize categorical data. Chi-square test statistics are used to test a possible association between the two groups and their responses.

Table 3.1 2 x 2 Contingency Table [20]

Column Levels	Row Levels		Total
	1	2	
1	n_{11}	n_{12}	n_{1+}
2	n_{21}	n_{22}	n_{2+}
Total	n_{+1}	n_{+2}	n

The hypothesis for the chi-square tests are stated as:

Ho: There is no association between column levels and row levels
Ha: There is an association between column levels and row levels

For testing the association, the chi-square test statistic was used:

$$\chi^2 = \Sigma_i \Sigma_j \frac{(n_{ij} - m_{ij})^2}{m_{ij}}$$

where:

The expected frequency of the cell, m_{ij} is provided by: $m_{ij} = \frac{(n_{i+})(n_{+j})}{n}$

The degrees of freedom, DF, equals (# rows-1)(# columns-1);

For a 2 x 2 table, the DF is one. For the one-sided chi-square test, a level of significance of $\alpha = 0.10$ was used. The critical region was then given by: $\chi^2 > \chi^2_\alpha$ [22,23].

Wald Confidence Levels

Wald confidence intervals for difference in proportions were used for the responses that resulted in a 2 x 2 contingency table. The level of significance used for the Wald confidence interval was $\alpha = 0.10$. The following steps determine confidence intervals.

1. Calculate the Point Estimates.

   A. Maximum Likelihood estimate of $(p_1 - p_2) = (x_1/n_1 - x_2/n_2)$

2. Estimate Standard Errors.

   A. $SE(p_1 - p_2) = [p_1(1 - p_1) / (n_1 - 1) + p_2(1 - p_2) / (n_2 - 1)]^{1/2}$

3. Determine the Wald Confidence Interval for $p_1 - p_2$.

   A. $100(1\text{-}\alpha)\%$ lower limit $= p_1 - p_2 - z_{\alpha/2}\,[SE(p_1 - p_2) + 0.5(1/n_1 + 1/n_2)]$

   B. $100(1\text{-}\alpha)\%$ upper limit $= p_1 - p_2 + z_{\alpha/2}\,[SE(p_1 - p_2) + 0.5(1/n_1 + 1/n_2)]$

   Here: n_1 is the sample size in sample 1, and X_1 is the number of units in sample 1 that have the trait[21]

Contingency Tables (2 x r)

Some of the questions in the three surveys sent out to the focus group ask members to choose from three or more options. Results tallied from these questions produced 2 x r tables, where 2 represent the two samples and r represents the number of response variables (See Table 3.2).

Table 3.2 2 x r Contingency Table [20]

	Column Variables				Total
	1	2	...	r	
Group 1	n_{11}	n_{12}	...	n_{1r}	n_{1+}
Group 2	n_{21}	n_{22}	...	n_{2r}	n_{2+}
	n_{+1}	n_{+2}	...	n_{+r}	n

The chi-square test statistic also was employed on the responses whose data yielded a 2 x r table. The same formulas illustrated in Section 3.3 apply to a 2 x r contingency table and the degrees of freedom in this case are r – 1.

Two-Sample t-Test

For responses that required a numerical value as opposed to a categorical tally in the three surveys, two-sample t-tests were used to test the means of the two samples. The hypothesis of the two-sample t-tests were as follows:

Ho: $\mu_1 = \mu_2$

Ha: $\mu_1 \neq m_2$

Notation for the two-sample t-tests were:

μ_i = population mean; $\hat{u}_i$ = sample mean; s_i = sample standard deviation; and n_i = sample size for sample i, i = 1, 2, ··· n.

Separate variance estimates were used in these tests because the two populations were assumed to have unequal variances. Therefore, the standard deviations of ($\hat{u}_1$ - $\hat{u}_2$) were estimated by:

$$\underline{s} = [s_1^2 / n_1 + s_2^2 / n_2]^{1/2}$$

Degrees of freedom for the two sample t-tests were given by Satterthwaites approximation:

$$DF = \frac{(VAR_1 + VAR_2)^2}{[(VAR_1)^2 / (n_1 - 1)] + [(VAR_2)^2 / (n_2 - 1)]}$$

where $VAR_i = s_i^2 / n_i$, i, i = 1, 2, ⋯ n

The t-test statistics were then determined as:

$$t^* = \frac{(S_1 - S_2)}{S}$$

For the t- test completed here, the two-sided alternative hypothesis, Ha: $\mu_1 \neq \mu_2$, at the level of significance of $\alpha = 0.10$ was used. The critical region was then given by

$$t^* < -t_{\alpha/2} \text{ or } t^* > t_{\alpha/2}$$ [20, 22,23].

The confidence intervals used for the two-sample t-test were:

$$(\hat{u}_1 - \hat{u}_2) - ts$$

$$(\hat{u}_1 - \hat{u}_2) + ts$$

Where s is the standard deviation of $\hat{u}_1 - \hat{u}_2$, and t is a value from the t distribution table with a significance level of $(1 - \alpha/2)$.

Methodologies in this chapter were used to evaluate the data submitted by the two groups. Analyses of the Delphi surveys are contained in Chapter 4. The results of the analysis provide the basis for creating Road Construction Safety Audit Checklists and the conclusions and recommendations of this project.

CHAPTER 4

ANALYSIS AND RESULTS

Results from the three Delphi surveys and the traffic studies were used to develop prototype checklists for a slab replacement project, a milling/resurfacing project, and work in the vicinity of exit and entrance ramps. Presented in this chapter are results from the three Delphi surveys, and the driver observance studies.

As stated in Chapter 3, the focus group consisted of two sub-groups. The first group consisted of 20 engineers that were employed by the Wyoming Department of Transportation (WYDOT). The second group was composed of transportation professionals associated with state agencies outside of Wyoming (DOTs).

Traffic Control for Slab Replacements on a Rural Interstate

The first Delphi survey examined work zone traffic control associated with slab replacements on a rural interstate. A total of 30 out of 47 surveys were returned, including 10 out of 24 from the Wyoming Department of Transportation and 20 out of 23 from state agencies outside of Wyoming. The survey questions and summary results are located in Appendix A. Key findings of the first Delphi survey are outlined below.

The two groups agreed that a Single Lane Closure [SLC] strategy was the most suitable strategy for a slab replacement project on a rural interstate (see table 4.1). Using a 90 percent confidence interval ($\alpha = 0.10$) with one degree of freedom, the chi-square distribution value of 2.705 was compared to the chi-square test statistic value of 1.248. There was no association between strategies and agencies (i.e. the chi-square distribution value was greater than the chi-square test statistic). The 90 percent Wald confidence interval presented in Table 4.1 showed that the difference between the proportion of WYODT members that preferred the TLTWO minus the proportion of DOTs members that preferred the TLTWO is estimated to be between –0.557 and 0.183.

Table 4.1 Traffic Control Strategies for a Slab Replacement Project

AGENCIES	OPTIONS		CHI-SQUARE
	TLTWO	SLC	1.248
WYDOT	4	7	
Proportions	0.364	0.636	P-VALUE
DOTs	3	14	0.264
Proportions	0.177	0.823	
90 % Wald Confidence Interval = (-0.557, 0.183)			

The second question in the first round of the Delphi survey listed 18 characteristics associated with an interstate reconstruction project. Members of the focus group were asked to identify which characteristics of the roadway or project influenced their traffic control strategy recommendation. The majority of the responders in both groups indicated that characteristics were more relevant in the SLC strategy. Characteristics of the project and roadway that were most important in conducting a SLC strategy were:

1. a low traffic volume roadway
2. a project with interchanges within the work zone
3. a project duration lasting less than three months
4. the length of construction less than four miles
5. slab replacement depths less than four inches

Single Lane Closure Strategy [SLC]

The next section of the survey contained a series of questions relating to a SLC strategy. The final section of the first Delphi survey pertained to a TLTWO strategy. Members of the two groups selecting the SLC strategy were instructed to indicate which lane closure option they would use. Both groups strongly agreed that closing one lane and completing all work in that lane was a better approach than staggering lane closures and completing many slab replacements in both lanes (See Table 4.2).

Table 4.2 Lane Closure Options for SLC Strategy

AGENCY	OPTIONS		TOTAL
	Close one entire lane	*Stagger the lane closures*	
WYDOT *Proportions*	**7** 0.875	**1** 0.125	**8**
DOTs *Proportions*	**12** 0.857	**2** 0.143	**14**

In Table 4.3 are the means provided by members of the two groups when asked, "At what distance would you consider slab replacements separate work spaces?" A two-sample t-test was used on the data to see if the two means were similar. Results from the t-test indicate that means of the two groups were statistically different. The 90 percent confidence interval for the estimated difference of $\hat{u}_{WYDOT}$ - $\hat{u}_{DOTs}$ was –1.36 to –0.23 miles.

Table 4.3 Slab Replacements Considered Separate Work Spaces

AGENCY	**WYDOT**		**DOTs**
UNITS	MILES		MILES
Mean (μ)	0.982		1.778
Standard Deviation	0.582		0.984
TWO SAMPLE T-TEST ($\alpha = 0.10$) H_0: $\mu_{WYDOT} = \mu_{DOTs}$ vs. H_1: μ_{WYDOT} not $= \mu_{DOTs}$			
T-test Statistic		*DF*	*p-value*
-2.43		20	0.024
90% C.I. for $\hat{u}_{WYDOT}$ - $\hat{u}_{DOTs}$: (-1.36, -0.23)			

Data gathered from the first round of the Delphi survey also yielded recommended speed limits for areas in a SLC strategy. Table 4.4 illustrates that the mean of the two groups were similar. Two sample t-tests were used on these data to see if the means of the two groups were equal (See Appendix

A). Results from two sample t-tests yielded that the null hypothesis (Ho: $\mu_1 = \mu_2$) was accepted for all three t-tests. Hence, the means of the two groups were statistically equivalent.

Table 4.4 Speed Limits in Areas of a Work Zone

AGENCY	WYDOT		DOTS	
-	MEAN (μ)	STDEV	MEAN (μ)	STDEV
UNITS	MPH	MPH	MPH	MPH
Transition Area	59	5.8	57	7.8
Buffer Space	56	5.2	55	9.2
Work Space	53	7	52	10.6

The use of channeling devices in an SLC strategy also was included in the first Delphi survey. Members of the two groups were asked to indicate which characteristics of a project controlled by a SLC strategy would influence their choice when choosing a channeling device. Members also were asked to rank characteristics that influenced their decision. Geometrics of roadway and traffic volume characteristics displayed little influence. Characteristics having the most influence and the highest rank were as follows:

1. drop off height
2. travelway width
3. location of workers

Two project illustrations were provided to have the members layout the devices they thought were suitable for the reconstruction project. The first of two project illustrations is displayed in Figure 4.1. Members of the focus group used many traffic control devices on the project illustration. Complete lists of devices used with respect to each area of the work zone are presented in Appendix A.

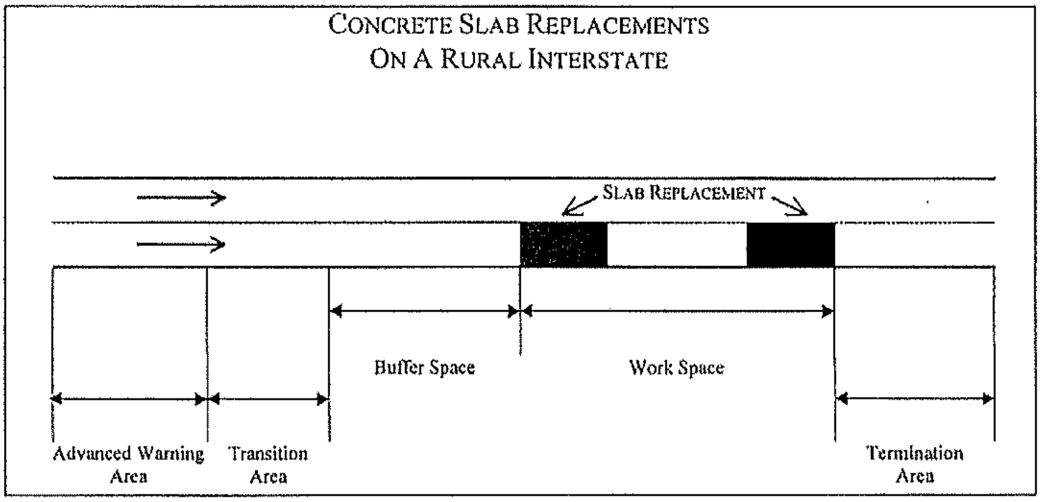

Figure 4.1 Single Lane Closure Strategy Project Illustration

Summarized in Table 4.5 are the channeling devices indicated by area of work zone. The drum was the favored channeling device of both groups. The concrete barrier system also was utilized for the SLC strategy illustration. The concrete barrier system primarily was used by the WYDOT's group. Use of the concrete barrier systems is contained in standard plans when the drop off depth is greater than 20 centimeters.

Table 4.5 Employment of Channeling Devices on a Single Lane Closure

AGENCIES	CHANNELING DEVICES						
	Cones	Tubular Markers	Vertical Panels	Drums	Barricade	Portable Barriers	Concrete Barriers
	Advanced Warning Area						
WYDOT	0	0	0	3	0	0	0
DOTs	0	0	0	0	0	0	0
	Transition Area						
WYDOT	0	0	0	8	0	0	3
DOTs	4	0	2	13	0	1	1
	Buffer Space						
WYDOT	0	0	1	4	4	0	3
DOTs	1	2	2	12	3	2	2
	Work Space						
WYDOT	0	0	1	4	3	0	4
DOTs	1	2	2	11	1	3	2
	Termination Area						
WYDOT	0	1	1	4	0	0	3
DOTs	2	3	1	11	0	1	1

Two-Lane, Two-Way Operations [TLTWO] Strategy

Data gathered from the first round of the Delphi survey yielded speed limits for areas of a TLTWO strategy. The data in table 4.6 indicates that the mean responses from the two groups were similar. Two results from the two sample t-tests showed no statistical differences between group means (See Appendix A).

Table 4.6 Speed Limits in Areas of a Work Zone

AGENCY	WYDOT		DOTs	
-	MEAN (μ)	STDEV	MEAN (μ)	STDEV
UNITS	MPH	MPH	MPH	MPH
Merging Area	60	4.1	57	11.1
Median X-Over	53	8.9	54	11.2
TLTWO	60	4.1	59	9.1

The recommended channeling devices in a TLTWO strategy also were obtained. Members of the two groups were asked to indicate which characteristics of a project controlled by a TLTWO strategy influenced their choice of channeling device. Members also were asked to rank the characteristics. Characteristics that possessed the greatest influence were as follows:

1. travelway width
2. opposing traffic volumes
3. potential problems with channeling devices that are hit

Members of the two groups also provided additional characteristics, which influenced their decision to use a certain type of channeling device. Below are the characteristics received from the DOT's group:

1. worker/driver safety
2. curvature
3. urban verse rural

The second section of the first Delphi survey displayed a section of four-lane divided highway that requires slab replacements controlled by a TLTWO strategy (See Figure 4.2). Members of the two groups were instructed to layout a traffic control plan for the project illustration. The types of channeling devices used on this illustration are listed in Table 4.7. Complete lists of the devices used with respect to each work zone are presented in Appendix A.

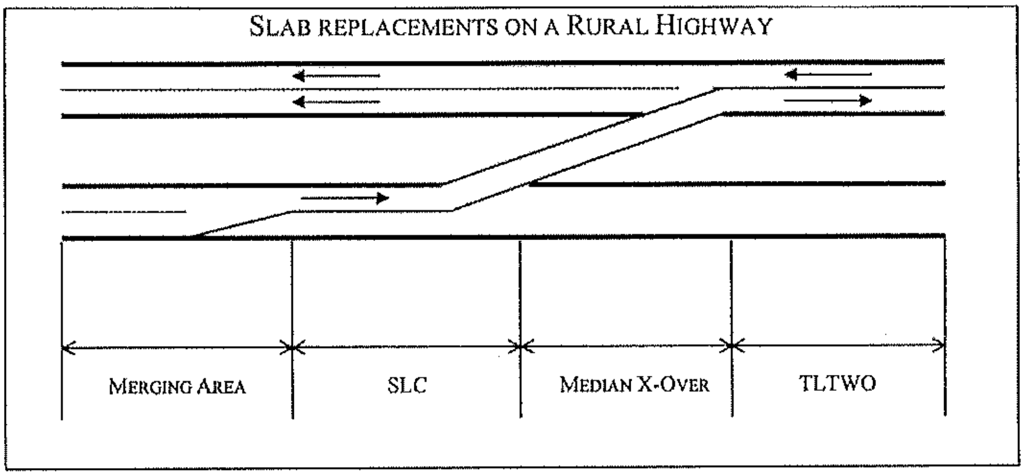

Figure 4.2 Two-Lane, Two-Way Operation Strategy Project Illustration

In Table 4.7 are summaries of channeling devices. The drum was the preferred channeling device of both groups. Concrete barrier systems also were recommended for the TLTWO area of the project.

Table 4.7 Employment of Channeling Devices on a Two-Lane, Two-Way Operation

AGENCIES	CHANNELING DEVICES						
	Cones	Tubular Markers	Vertical Panels	Drums	Barricade	Portable Barriers	Concrete Barriers
	Merging Area						
WYDOT	1	0	0	7	0	0	0
DOTs	0	2	1	14	0	1	0
	Single Lane Closure						
WYDOT	1	0	0	8	2	0	0
DOTs	0	2	1	14	5	1	0
	Median Cross Over						
WYDOT	0	0	0	5	2	0	0
DOTs	0	0	2	9	9	3	0
	Two-Lane, Two-Way Operation						
WYDOT	0	2	1	6	0	0	0
DOTs	0	8	2	2	1	4	7

Summary of First Delphi Survey

The primary purpose of the first Delphi survey was to examine issues of traffic control on a slab replacement project. The secondary purpose was to compare the Wyoming Department of Transportation responses with responses from DOTs outside of Wyoming. Overall, results of the first Delphi survey were beneficial. Generally, the two groups agreed on most of the issues. Responses received from the first Delphi survey also helped in developing the RCSA checklist for a slab replacement project. Important findings from the survey follow.

1. Both groups favored the SLC strategy instead of the TLTWO strategy for a slab replacement project.
2. The drum is the most used channeling device.
3. Characteristics of the roadway and project affected which type(s) of channeling devices were recommended.
4. Speed reductions in work zones were recommended.

In the next section, issues of traffic control in the vicinity of entrance and exit ramps are discussed. Again a Delphi survey was used.

Ramp Traffic Control on A Rural Interstate Reconstruction Project

A total of 28 surveys were returned, including 11 from the Wyoming Department of Transportation and 17 from state agencies outside of Wyoming. The survey questions and summary results are contained in Appendix B. Key findings of the second Delphi survey are outlined below.

Entrance Ramps

Three types of traffic control options were analyzed for the entrance ramp: stop, yield, and no control. Members of the focus group were asked to indicate which characteristics of a temporary entrance ramp and the project directed them towards employing a specific control (See Appendix B for a complete list of the characteristics and responses). Characteristics that directed members of the two groups toward using **stop control** included the following:

1. no acceleration lane
2. limited sight distance
3. high traffic volumes on the mainline
4. two-lane, two-way operations

Some members from the DOT's group stated that this was not a feasible traffic control option, while other members of the same group strongly favored this type of control.

Characteristics of a long-term reconstruction project that directed the members of the two groups toward using **yield control** include:

1. low traffic volumes on the ramp,
2. two-lane, two-way operations
3. low traffic volumes on the mainline.

Only two characteristics displayed significant influence for the **no control** option on an entrance ramp.

1. low traffic volumes on the ramp
2. two-lane, two-way operations

Many WYDOT engineers stated that this was not a viable option for an entrance ramp, while some members of the DOT's group supported this option by stating that this was the type of control normally used. Comments from the WYDOT group included:

- I think no control isn't an option.
- I would always have control.
- Always have some type of control.

While comments from the DOT's group included:

- No control is normal.
- As long as an adequate acceleration lane is provided.
- This (no control) would be the standard installation.

After characteristics of the three types of control were established, placement of the control devices was evaluated. In Table 4.8 location of stop control are summarized before merging onto the mainline. The responses suggest that the placement of a STOP sign must be studied in a case by case basis.

Table 4.8 Location of a STOP Sign on an Entrance Ramp

AGENCY	OPTIONS		CHI-SQUARE
	On the ramp	*At the entrance of the mainline*	0.022
WYDOT	**5**	**5**	
Proportions	0.5	0.5	P-VALUE
DOTs	**9**	**8**	0.833
Proportions	0.53	0.471	

The implementation of temporary STOP lines also was investigated. Response from the two groups indicated that use of temporary STOP lines on an entrance ramp was an acceptable practice.

The use of channeling devices in the vicinity of an entrance ramp also was addressed. The members of the two groups were asked, "Do you think that the spacing of the channeling devices should be reduced in the vicinity of an entrance ramp?" The responses to this question are contained in Table 4.9. There was no association between the two groups and their responses (χ^2 distribution < χ^2 test statistic @ $\alpha = 0.10$). For the members of the two groups that answered "No" to this question, a follow up question was used to evaluate actions that they would use instead of reducing the device spacing. For both groups, the most common response was, use of a merge sign.

Table 4.9 Channeling Device Spacing – Entrance Ramp

AGENCY	OPTIONS		CHI-SQUARE
	Yes	*No*	0.480
WYDOT	**5**	**6**	
Proportions	0.454	0.546	P-VALUE
DOTs	**10**	**7**	0.488
Proportions	0.588	0.412	

Figure 4.3 displays the first project illustration that relates to traffic control in the vicinity of an entrance ramp when controlled by a SLC. Members of the two groups were instructed to layout a traffic control plan for the illustration. Complete lists of the devices used with respect to an area of the work zone are presented in Appendix B.

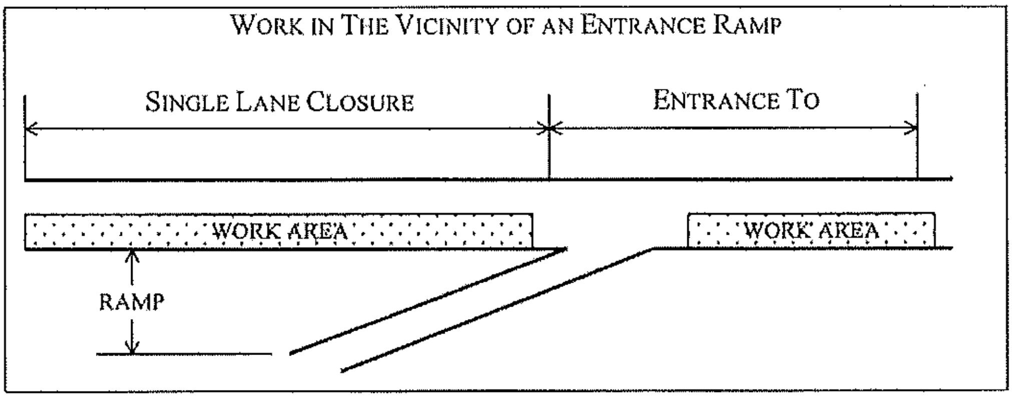

Figure 4.3 Entrance Ramp Located in a Work Zone

Presented in Table 4.10 are channeling devices chosen by the two groups for an entrance ramp located in a work zone. The most preferred device was the drum. Barricades also were frequently indicated. However, barricades were generally used to keep ramp traffic from proceeding into the work area on the mainline instead of channeling the traffic.

Table 4.10 Channeling Devices Deployed in the Vicinity of an Entrance Ramp

AGENCIES	CHANNELING DEVICES						
	Cones	Tubular Markers	Vertical Panels	Drums	Barricade	Portable Barriers	Concrete Barriers
	Single Lane Closure						
WYDOT	1	2	1	6	1	1	0
DOTs	2	2	1	8	2	1	2
	Ramp						
WYDOT	1	0	0	8	0	0	0
DOTs	2	1	0	7	0	2	0
	Entrance to Mainline						
WYDOT	1	1	0	9	6	1	0
DOTs	2	2	1	9	9	1	2

Members of the two groups also used regulatory signing in the vicinity of the entrance to the mainline. The use of a STOP sign with a STOP line was used most frequently (See Table 4.11). The majority of signs were placed at the end of the ramp at the lane closure, where motorists would have a clear view of oncoming traffic.

Table 4.11 Traffic Control Options Used on an Entrance Ramp

CONTROL OPTIONS	STOP Sign	STOP Line	YIELD Sign
Ramp			
WYDOT	1		
DOTs			1
Entrance to Mainline			
WYDOT	7	6	5
DOTs	7	6	3

Driver Observance Studies

Driver observance studies were conducted at four entrance ramps on an I-80 reconstruction project, in Laramie, Wyo. The studies determined percentage of motorists that complied with a STOP sign on an entrance ramp in a construction zone. The studies were completed between September and October 1997. Results are listed in Appendix C and summarized in Table 4.12. The sample for first studies conducted at locations 1 and 2 (in BOLD in Table 4.12) contained 235 entering vehicles. The other two studies at location 1 and 2 and locations 3 and 4 were based on 110 vehicle movements. The average voluntary full stop for the study was only 10 percent. The majority of driver actions were non-stopping. Use of portable rumble strips before the STOP sign to increase the percentage of voluntary stops was not investigated.

Table 4.12 Driver Compliance with STOP Signs

LOCATION	DRIVER ACTION			
	Non-Stopping	*Practically Stopped*	*Stopped By Traffic*	*Voluntary Full Stop*
1	**34.9%**	**36.6%**	**11.5%**	**17.0%**
1	45.5%	35.5%	9.1%	10.0%
2	**54.5%**	**30.2%**	**10.2%**	**5.1%**
2	53.6%	25.5%	16.4%	4.5%
3	40.9%	30.9%	20.0%	8.2%
4	39.1%	36.4%	11.2%	11.8%
Averages	44.7%	32.8%	12.6%	9.9%

Exit Ramps

The second section of the ramp survey investigated traffic control options associated with exit ramps located in an interstate work zone. The project illustration was an exit ramp located in a work zone controlled by an SLC strategy (see figure 4.4).

This was used to determine which channeling devices and locations were recommended to warn and guide motorists when there was no deceleration lane. Complete lists of the devices used with respect to an area are presented in Appendix B. The summary of devices used are presented in Table 4.13.

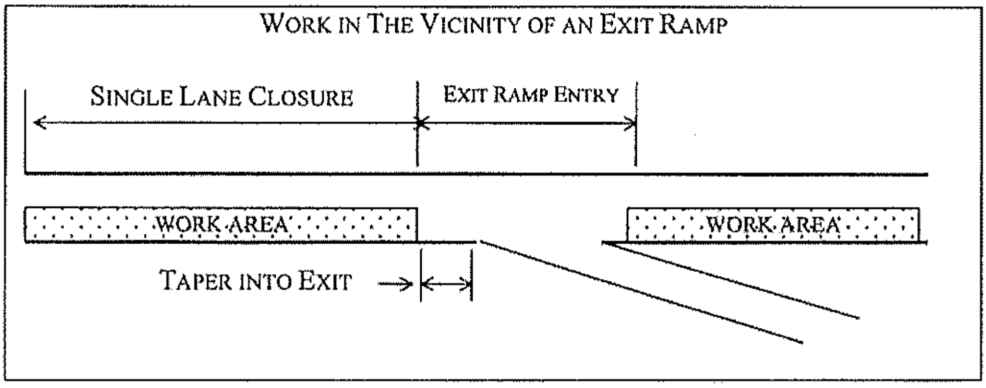

Figure 4.4 Exit Ramp Located in a Work Zone

Once again the drum was the most often used channeling device. Barricades also were used to mark out of the work area's beginning. Temporary pavement markings (i.e. paint and raised pavement markings) also were often used to outline the path toward the exit ramp. Additional exit signs to warn motorists of the upcoming ramp, also were frequently illustrated.

Table 4.13 Channeling Devices Deployed in the Vicinity of an Exit Ramp

AGENCIES	CHANNELING DEVICES						
	Cones	Tubular Markers	Vertical Panels	Drums	Barricade	Portable Barriers	Concrete Barriers
	Single Lane Closure						
WYDOT	0	2	1	8	1	1	0
DOTs	2	2	1	8	2	1	2
	Taper into Exit Ramp Entry						
WYDOT	0	2	1	9	3	1	0
DOTs	3	2	1	9	7	2	2

Responses to the spacing of channeling devices in the vicinity of an exit ramp were not consistent. Data in Table 4.14 reveals that the members of the DOT's group strongly favored the practice of decreased device spacing, while engineers from WYDOT were split. The chi-square test statistic exceeds the chi-square cutoff at a level of significance of (α = 0.10), indicating that there was an association between the groups and their responses.

Table 4.14 Spacing of Channeling Devices in the Vicinity of an Exit Ramp

AGENCY	OPTIONS		CHI-SQUARE
	Yes	*No*	3.161
WYDOT	**5**	**5**	
Proportions	0.500	0.500	P-VALUE
DOTs	**14**	**3**	0.075
Proportions	0.824	0.176	

Members of the two groups who were against reducing the spacing of channeling devices in the vicinity of an exit ramp were instructed to indicate what alternative measures they would recommend to alert motorists of an exit. Responses received from the WYDOT group follow:

- use advanced signing
- use of a different channeling device in the vicinity of an exit ramp
- relocated exit signs

Summary of Second Round Delphi Survey

Data acquired from the second survey provide current practices associated with ramp traffic controls. While some of the responses were split between the two groups, the devices used on the project illustrations were similar.

The responses received from the second Delphi survey and the traffic studies were beneficial toward developing the RCSA checklist for ramps in a work zone. Important findings from the survey included the following:

1. Placement of a STOP sign on an entrance ramp was influenced by characteristics of the traffic volumes, sight distance, and the ramp.
2. Use of a STOP line was suggested when a STOP sign is employed on an entrance ramp.
3. The drum was the most used channeling device for traffic control in the vicinity of interstate ramps.
4. Use of additional exit signs for temporary exit ramps were suggested.
5. Only 10 percent of the studied motorists using entrance ramps in the construction areas complied with the STOP sign at the end the ramp.

Traffic Control for a Milling/Resurfacing Project on a Rural Interstate

The next step of this research project was to examine issues of traffic control for a rural interstate milling/resurfacing project. Twenty-six surveys were returned, including 11 from the Wyoming Department of Transportation and 15 from other state agencies outside of Wyoming. The survey questions and summary results are located in Appendix D. The key findings of the third Delphi survey are outlined here.

The two traffic control strategies that were examined in the first Delphi survey also were investigated in this survey. Presented in Table 4.15 are the two groups' responses when asked if the traffic volumes of a rural interstate would influence which traffic control strategy is used. The traffic volume characteristic of the roadway did not influence members from the DOTs group. However, traffic volume did influence members from WYDOT. Chi-square test statistics were used to determine an association between the two groups and their responses. Test results from the responses associated with a roadway with high traffic volumes indicated no association between the two groups and their responses.

When the chi-square test was applied to the second question, the test indicated that the results were invalid (the expected values were less than 1.0).

Table 4.15 Traffic Strategies for Milling/Resurfacing Projects

High Traffic Volumes			
AGENCY	OPTIONS		CHI-SQUARE
	TLTWO	*SLC*	1.896
WYDOT	**4**	**7**	
Proportions	0.36	0.64	P-VALUE
DOTs	**2**	**13**	0.169
Proportions	0.13	0.87	
Low Traffic Volumes			
WYDOT	**1**	**10**	CHI-SQUARE
Proportions	0.09	0.81	Invalid
DOTs	**1**	**14**	
Proportions	0.07	0.93	

Milling Phase of a Milling/Resurfacing Project

The milling/ resurfacing projects produced differing comments. Comments from WYDOT on the project with high traffic volumes included:

- Do in 5 to 6 mile segments.
- Mill only that amount which can be placed to full depth within two days.
- Concurrent milling and overlay operation.

Comments from DOTs on the project with high traffic volumes included:

- Mill and repave the milled area the same day.
- Mill one lane for four miles, resurface and then go onto the next section.

Table 4.16 Order of Operation for a Milling/Resurfacing Project

HIGH TRAFFIC VOLUMES				
Agency	Options			CHI-SQUARE
	Mill the entire length of one lane, resurface that lane, then move to the other lanes.	*Mill all of the lanes, then resurface all of the lanes*	*Other (please list)*	1.688
WYDOT	**3**	*5*	*3*	
Proportion	0.27	0.46	0.27	P-VALUE
DOTs	**8**	*3*	*4*	*0.430*
PROPORTION	0.53	0.20	0.27	
LOW TRAFFIC VOLUMES				
WYDOT	**3**	*5*	*3*	1.967
Proportion	0.27	0.46	0.27	
DOTs	**9**	*3*	*3*	P-VALUE
Proportion	0.53	0.20	0.27	*0.374*

The use of channeling devices on a milling/resurfacing project was investigated. Members of the two groups were asked to indicate which characteristics of a milling/resurfacing project would influence their choice of channeling device. The members also were asked to rank these characteristics. Results indicated that the basic drop off height, the height left overnight, and motorists' safety had the strongest influence when choosing a device. Narrowing the travel lane width influenced the TCD selected (see table 4.17). Members of the two groups who indicated that the travelway width does influence the type of channeling device were asked to indicate the criteria that their agency used when choosing a channeling device for a milling/resurfacing project. Most of the responders implied that they would use a smaller device (i.e. tubular marker or vertical panel) when the travelway was too narrow for a drum.

Table 4.17 Travel Lane Width's Influence on the Type of Channeling Device Used

AGENCY	OPTIONS	
	Yes	*No*
WYDOT	**8**	**3**
Proportions	0.73	0.27
DOTs	**9**	**6**
Proportions	0.60	0.40

Post Milling Operations

The final section of this survey focused on the traffic control for a milling/resurfacing project after milling one lane. Allowable drop off depths, the location of the channeling devices, and the need for a full time traffic control device maintainer were investigated.

Figure 4.5 illustrates the first of three roadway cross sections used to ask the maximum drop off depth.

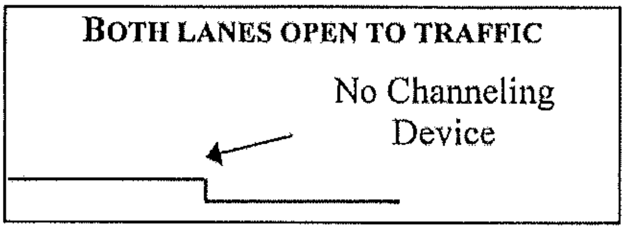

Figure 4.5 Drop off Existing with Both Lanes Open to Traffic

The two group means were similar (see table 4.18). The two-sample t-test indicated that the null hypothesis (H_o: $m_{WYDOT} = m_{DOTs}$) was accepted.

Table 4.18 Maximum Drop off Depths When Both Lanes are Open to Traffic

AGENCY	WYDOT	DOTs	
UNITS	INCHES	INCHES	
Mean (μ)	1.82	1.52	
Standard Deviation	1.17	0.85	
TWO SAMPLE T-TEST (A = 0.10)			
T statistic	T value	P	DF
0.72	1.740	0.48	17
90 % C.I. for $\hat{u}_{WYDOT} - \hat{u}_{DOTs}$:(-0.42, 1.02)			

The maximum drop off height where the drop off channeling devices are shielded also was evaluated (see Figure 4.6 and Table 4.19).

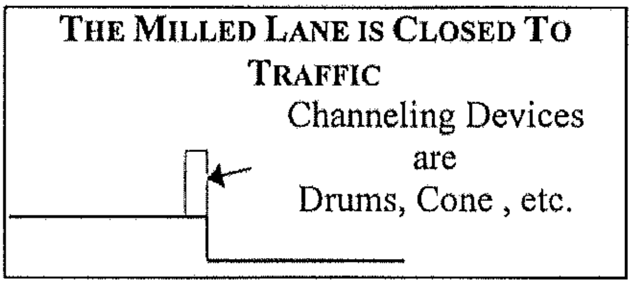

Figure 4.6 Drop off Shielded by Channeling Devices

Variation is evident in the two means. The two-sample t-tests indicated that the null hypothesis (H_o: $\mu_{WYDOT} = \mu_{DOTs}$) was rejected. The t-test statistic (2.31) was greater than the t cutoff value (1.721), at α = 0.10.

Table 4.19 Maximum Drop off Depths When Shielded by Channeling Devices

AGENCY	WYDOT	DOTs	
UNITS	INCHES	INCHES	
Mean (μ)	5.09	3.46	
Standard Deviation	1.64	1.81	
TWO SAMPLE T-TEST (A = 0.10)			
T statistic	T value	p	DF
2.31	1.721	0.031	21
90 % C.I. for $\hat{u}_{WYDOT} - \hat{u}_{DOTs}$:(0.42, 2.84)			

Table 4.20 presents the recommended maximum drop off depths for five types of channeling devices. There was little relation between the means. Two-sample t-tests were used on data to determine if the means of the two groups were equal. The results of the t-tests indicated that the means were not equal (See Appendix D).

Table 4.20 Maximum Drop off Depths for Channeling Devices

AGENCY	WYDOT		DOTs	
UNITS	Mean (μ)	STDEV	Mean (μ)	STDEV
Cones	4	2.35	3.0	1.52
Tubular Markers	4	1.77	3.1	1.57
Vertical Panels	4.75	2.22	3.2	1.79
Drums	6	1.89	2.5	1.23
Barricades	8	0	3.2	1.79

Members of the two groups also were asked to indicate where they wanted the channeling devices to be placed with respect to the milled lane (See Figure 4.7). Results of this question are presented in Table 4.21.

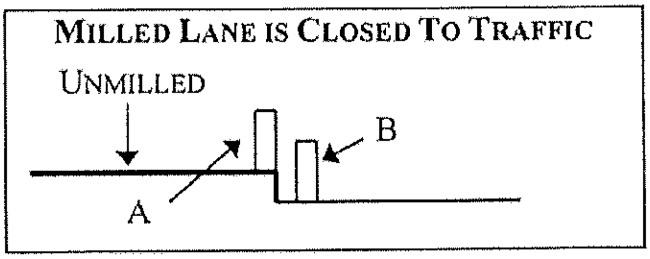

Figure 4.7 Location of Channeling Devices

Placing the channeling device at the edge of the unmilled lane was the preferred location for both groups (See Table 4.21). However, three respondents from the DOT's group did prefer placing the device in the milled lane. Members who preferred placing the devices other than at the edge of the milled lane were asked to indicate what type of device they would use. The drum was the device chosen by these three respondents.

Table 4.21 Placement of Channeling Devices on a Milling/Resurfacing Project

AGENCY	OPTIONS			CHI-SQUARE
	At the edge of the unmilled lane	*In the milled lane*	*In both the milled & unmilled lane*	Invalid
WYDOT	9	1	1	
Proportions	0.82	0.09	0.09	P-VALUE
DOTs	12	3		
Proportions	0.80	0.20	0.0	

Use of a positive barrier system on a milling/resurfacing project was examined (See Figure 4.8) to determine the drop off depths recommended for a positive barrier system (see Table 4.22).

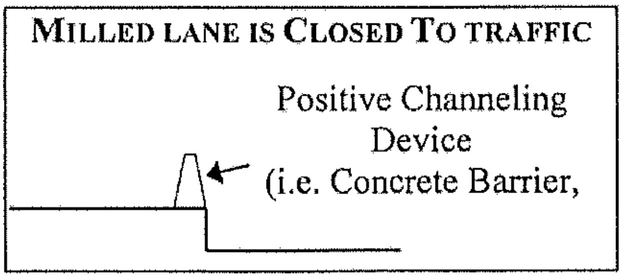

Figure 4.8 Drop off Shielded by a Positive Barrier System

There was little relation between the two means. The standard deviations displayed in Table 4.22 indicated that there also was a wide range of responses.

Table 4.22 Minimum Drop off Depths Recommended for Positive Barriers

AGENCY	WYDOT	DOTs
UNITS	INCHES	INCHES
Mean (μ)	6.30	2.95
Standard Deviation	3.74	1.91

Use of a full-time traffic control device maintainer was the last issue explored. Responses to this issue were mixed. Members of WYDOT clearly favored use of a full-time traffic control device maintainer, while members of the DOT's group were almost split on the issue (See Table 4.23).

Table 4.23 Implementation of a Full-Time Traffic Control Device Maintainer

AGENCY	OPTIONS		CHI-SQUARE
	Yes	*No*	3.082
WYDOT	**10**	**1**	
Proportions	0.91	0.09	P-VALUE
DOTs	**9**	**6**	0.079
Proportions	0.6	0.4	

Summary of Third Round Delphi Survey

Results attained from the third round Delphi Survey associated with milling/resurfacing indicated the majority of responses from the two groups concurred. However, when issues of drop off depths were addressed, there was more variation present between the two groups' responses.

The responses received were used in developing the RCSA checklist for milling/resurfacing projects on a rural interstate. The RCSA checklist for the two project types and the entrance and exit ramps were examined. Important findings from the third survey included:

1. Both groups favored the SLC strategy instead of the TLTWO strategy for a milling/resurfacing project.
2. Traffic volume possessed little influence on which traffic control strategy was recommended.
3. Widths of the travelway influenced which types of channeling devices were recommended.
4. For drop off depths that are left overnight and are greater than six inches, a positive barrier system was recommended.

5. A full-time traffic control device maintainer most often was recommended for a milling/resurfacing project.

CHAPTER 5

ROAD CONSTRUCTION SAFETY AUDIT CHECKLISTS

Another major objective was to develop a Road Construction Safety Audit [RCSA] process and a series of checklists for each interstate reconstruction project and the ramps examined. Data received from the three Delphi surveys and the traffic studies aided in formulating the RCSA processes and checklists.

Road Construction Safety Audit [RCSA]

The purposes of the RCSA are to aid in evaluating an alternative traffic control plan, devices and strategies before the interstate work zone is established, and to aid in evaluating these areas during and after work activity. The RCSA process and checklists were developed for transportation professionals that have knowledge and experience in interstate work zone design.

Although Part VI of the MUTCD clearly illustrates TCPs for interstate reconstruction projects, the TCPs presented in the manual still provide many choices and the need to modify them often exist. Characteristics such as the roadway's geometrics, topography and traffic volumes must be taken into consideration. Using the RCSA checklists during the planning stage of a TCP will help to take the characteristics into consideration.

The RCSA process contrasts interstate work zone alternatives while considering issues such as safety trade-offs between traffic control devices and strategies, and characteristics of the roadway and the reconstruction project. Safety trade-offs include, but are not limited to the following:

1. use of drums verses tubular markers on a SLC strategy
2. use of a positive barrier system verses the use of a drum system for TLTWO
3. use of a STOP sign at the end of an entrance ramp verses the use of a YIELD sign
4. varying types and patterns of devices at various locations and work zone areas

The RCSA checklists developed were based on the various and often differing recommendations from the three Delphi surveys. The specific values (i.e. speed limit, drop-offs) and types of devices have been considered with the RCSA. However, state practices, tort liability, and preference also are factors to consider in modifying the different RCSA values or devices indicated. For this reason, a second set of the RCSA checklists has been developed without values or specific devices. This allows for the agencies using the checklists, to input device preferences, speed limits and drop-off heights.

RCSA CHECKLIST – Slab Replacement (SR) Project on a Rural Interstate

The first RCSA checklist focuses on traffic control issues associated with a slab replacement project. The auditor is instructed to complete the audit using the PRILIMINARY CHECKLIST, then proceeding to CHECKLIST –SR and any of the supplemental checklist(s) that apply to the project at hand. For reference, examples of alternative traffic control plans of a SLC and a TLTWO strategy are included.

RCSA CHECKLIST - Slab Replacements (SR)

PART A: GENERAL INFORMATION

PROJECT:______________________________ AUDITOR:______________________________

DATE: ______________________________ EMERGENCY CONTACT:____________________

Part B: Characteristics of the Project & Roadway

Length of project:__________(miles): Duration of Project: ______(days)

Number of Slab Replacements:_______ Depth of Slab Replacements:________(inches)

Width of Slab Replacements: ________(feet)

Lanes where the Slab Replacements are located:______Left ______Right ______Both

Maximum Distance between Slab Replacements: ______(feet)

Travel lanes width:_________(feet) Shoulder widths (Left & Right)______ _____(feet)

ENGINEERING PRELIMINARY CHECKLIST			
FOCUS AREA	ISSUES TO BE CONSIDERED	CHECK	COMMENTS
1. PAST PROJECTS	Check past slab replacement projects and determine what problems (i.e. traffic delays, worker injuries) occurred throughout the duration of the project.		
	Evaluate the problems and develop solutions to correct the problems.		
	Check to see if the agency's standards plans may be used for the slab replacement project.		
2. LOCATION	Use the solutions that were obtained from past projects on the existing project's Traffic Control Plan [TCP].		
	Check that the eight Fundamental Principles of work zone traffic control have been applied to the TCP.		
	Check the crash history of the project location to see if applying special considerations is needed.		
	Check for areas on the roadway that may interfere with the function of the work zone (i.e. crest curves or compound horizontal curves).		
3. SLAB REPLACEMENT PROJECT	Go to CHECKLIST – SR		

CHECKLIST – SR			
FOCUS AREA	ISSUES TO BE CONSIDERED	CHECK	COMMENTS
1. SITE	Check that the time allowance between the removal and replacement of the slabs has been defined within the project's contract.		
	Check that the traffic control plan follows the current regulations.		
	Check to see if there are any entrance or exit ramps located in the work zone.		
	If entrance or exit ramps exist, go to CHECKLIST – ER		
	Check the need for access routes for equipment and workers.		
	Check that all parking and storage areas will not conflict with the travelway.		
	Check that the speed reduction(s) leading into and within the work zone is lowered in 10 mph increments		
	Check that the speed limit in the work zone does not alter the normal traffic flows.		
	Encompass traffic volumes, geometrics, project characteristics and the topography of the roadway when determining the speed limit for a project.		
2. TRAFFIC CONTROL STRATEGIES	Check which traffic control strategy will be used on the project. SLC (Proceed) TLTWO (Go to CHECKLIST – TLTWO)		
SINGLE LANE CLOSURE [SLC]			
3. TRANSITION AREA	Check that the taper and the signing in the transition area are placed correctly on the traffic control plan.		
	Check that an arrow panel is used in the taper to alert the motorists of the lane closure.		
	Check that drums or another type of channeling device are used.*		
	Check that the entire length of one lane is closed at one time and that the work is completed in that lane before the other lane is closed and repaired.		
	Check that changeable message boards or warning signs are used to alert the motorists of the work activity ahead.		
4. WORK AREA	Check that adequate buffer spaces and/or truck attenuators are provided for the safety of the workers.		
	Check to see if the travelway width will be at least 12 feet wide through the work area.*		

CHECKLIST – SR – PG 2			
FOCUS AREA	ISSUES TO BE CONSIDERED	CHECK	COMMENTS
4. WORK AREA CONTINUED	Check the need for filling in the drop off at the end of the work day		
	Check that the travel way width is wide enough for the proposed channeling devices.		
	Check that drums or another type of channeling device are used.*		
	Check the need for a positive barrier system when the drop off is greater than 4.5 inches and it is present overnight.*		
5. TRAFFIC CONTROL DEVICES	Check that backup devices will be available in the event that one is lost.		
	Check that all channeling devices and pavement markings meet current standards.		
	Check that the channeling device spacing is reduced on horizontal curves.		
	Check the need for an alternative channeling device to highlight changes in the geometrics of the roadway.		
	Check that the warning signs are spaced correctly and mounted at the correct location.		
	Check the need for lighting the project with floodlights or other means.		
	Check that all traffic control devices will possess retroreflective strips.		
	Check that the channeling devices prescribed correlate with the drop off and lane width requirements for that device.		
	Check that the devices demand the motorists' attention.		
	Check that the devices will be easily seen.		
	Check that warning lights will be readily available for areas where adverse weather conditions may occur.		
6. MAINTENANCE	Check the need for a full-time traffic control device maintainer,		
	Check that an inspection schedule and system is prescribed for the entire duration of the project.		
	Check that an emergency contact is readily available 24 hours a day.		

* Values presented in this checklist were based on the recommendation received from the two groups. In instances where the values and/or devices do not correspond to an agency's policies, use the checklists provided in Appendix E.

RCSA CHECKLIST – Milling/Resurfacing (MR) Project on a Rural Interstate

RCSA CHECKLIST - MR

PART A: GENERAL INFORMATION

PROJECT:________________________ AUDITOR:________________________

DATE: ________________________ EMERGENCY CONTACT:________________

Part B: Characteristics of the Project

Length of project:__________(miles): Duration of Project: ______(days)

Depth of Milling:__________(inches)

Lanes where the milling/resurfacing is proposed:__________Left ______Right ______Both

Travel lanes width:__________(feet) Shoulder widths (Left & Right)______ ______(feet)

ENGINEERING PRELIMINARY CHECKLIST			
Focus Area	Issues to be Considered	Check	Comments
1. Past Projects	Check past slab replacement projects and determine what problems (i.e. traffic delays, worker injuries) occurred throughout the duration of the project.		
	Evaluate the problems and develop solutions to correct the problems.		
	Check to see if the agency's standards plans may be used for the milling/resurfacing project.		
2. LOCATION	Use the solutions that were obtained from past projects on the existing project's Traffic Control Plan [TCP].		
	Check that the eight Fundamental Principles of work zone traffic control have been applied to the TCP.		
	Check the crash history of the project location and apply special consideration to the area(s) with crash history.		
	Check for areas on the roadway that may interfere with the function of the work zone (i.e. crest curves or compound horizontal curves).		
3. MILLING/ RESURFACING PROJECT	Go to CHECKLIST – MR		

RCSA CHECKLIST – MR			
Focus Area	Issues to be Considered	Check	Comments
1. Site	Check that the traffic control plan meets the current regulations.		
	Check to see if there are any entrance or exit ramps located in the work zone.		
	If entrance or exit ramps exist, go to CHECKLIST – ER		
	Check the need for access routes for equipment and workers		
	Check that all parking and storage areas do not affect the traffic flow.		
	Check that the speed reduction(s) leading into and within the work zone is lowered in 10 mph increments		
	Check that the speed limit in the work zone does not alter the normal traffic flows.		
	Encompass traffic volumes, geometrics, project characteristics and the topography of the roadway when determining the speed limit for a project.		
2. Strategies	Check which traffic control strategy the project will be using to control the traffic. SLC (Proceed) TLTWO (Go to CHECKLIST - TLTWO)		
Single Lane Closure [SLC]			
3. Transition Area	Check that the taper and the signing in the transition area are placed correctly on the traffic control plan.		
	Check that an arrow panel is used in the taper to alert the motorists of the lane closure.		
	Check that drums or another type of channeling device are used.*		
	Check that changeable message boards or warning signs are used to alert the motorists of the work activity ahead.		
4. Work Area	Check that the entire length of one lane is closed at one time and that the work is completed in that lane before the other lane is closed and repaired.		
	Check to see if the travelway width will be at least 12 feet wide in the work area.*		
	Check that the travel way width is wide enough for the proposed channeling devices.		
	Check that drums or another type of channeling device are used.*		
	Check the need for filling in the drop off at the end of the workday.		

RCSA CHECKLIST – MR – PG 2			
Focus Area	ISSUES TO BE CONSIDERED	CHECK	COMMENTS
4. WORK AREA CONTINUED	Check the need for a positive barrier system when the drop off is greater than 4.5 inches and it is present overnight.*		
	Check that the milled lane is open to traffic and there are no channeling devices when the drop off depth is less than 2.0 inches.*		
	Checks that the milled lane is closed to traffic and channeling devices are used to a maximum drop off depth of 4.5 inches.*		
5. TRAFFIC CONTROL DEVICES	Check that backup devices will be available in the event that one is lost.		
	Check that all channeling devices and pavement markings meet current standards.		
	Check that the devices demand the motorists' attention.		
	Check that the devices will be easily seen.		
	Check that all traffic control devices will possess retroreflective strips.		
	Check that the warning signs are spaced correctly and mounted at the correct location.		
	Check that the channeling device spacing is reduced on horizontal curves.		
	Check the need for an alternative channeling device to highlight changes in the geometrics of the roadway.		
	Check the need for lighting the project with floodlights or other means.		
	Check that warning lights will be readily available for areas where adverse weather conditions may occur.		
6. MAINTENANCE	Check the need for a full-time traffic control device maintainer,		
	Check that an inspection schedule and system is prescribed for the entire duration of the project.		
	Check that an emergency contact is readily available 24 hours a day.		

*Values presented in this checklist were based on the recommendation received from the two groups. In instances where the values and/or devices do not correspond to an agency's policies, use the checklists provided in Appendix E.

RCSA CHECKLIST –TLTWO & ER – Supplemental Checklists

The two checklists in this section focus on the TLTWO strategy and ramp traffic control. The checklists are used in conjunction with the RCSA CHECKLISTS – SR or MR. CHECKLIST - TLTWO evaluates the traffic alternatives associated with a TLTWO strategy. CHECKLIST – ER is used to evaluate control options and devices affiliated with an entrance or exit ramp in the work zone.

RCSA - TLTWO

RCSA CHECKLIST – TLTWO			
FOCUS AREA	ISSUES TO BE CONSIDERED	CHECK	COMMENTS
1. SINGLE LANE CLOSURE	Check that the lane closures in both directions are properly signed and the channeling devices are correctly in place on the traffic control plan.		
	Check to see if the travelway width will be at least 12 feet wide.*		
2. MEDIAN CROSSOVER	Check that the proposed posted speed limit in the median crossover is not greater than design speed limit.		
	Check that drums or an alternative channeling device are used to guide the motorists into and out of the median crossover.		
	Check that raised pavement markers or painted line is used in conjunction with the drums or another type of channeling device.		
	Check that barricades or other devices are used to keep motorists from proceeding on the closed roadway.		
	Check that channeling devices and pavement markings define the path on and off the median crossover.		
3. TLTWO	Check the need for a positive barrier system to separate the two opposing traffic volumes.		
	Check that drums or an alternative channeling device are used if a positive barrier system is not required.		
	Check for signing that instructs the motorists not to pass.		
	Check that the existing pavement markings are to be removed.		
4. Traffic Control Devices	Go to CHECKLIST – SR or MR, Focus Area # 5		
5. Maintenance	Go to CHECKLIST – SR or MR, Focus Area # 6		

* Values presented in the TLTWO checklist and the ER checklist were based on the recommendation received from the two groups. In instances where the values and/or devices do not correspond to an agency's policies, use the checklists provided in Appendix E.

RCSA CHECKLIST -ER

RCSA CHECKLIST - ER			
	ISSUES TO BE CONSIDERED	CHECK	COMMENTS
1. ENTRANCE RAMP	What is the type of control for the ramp traffic? STOP Control (Go to #2) Yield Control (Go to #3) No Control (Proceed to #4))		
2. STOP CONTROL	Check the traffic volumes of the mainline and determine if sufficient gaps in the traffic will be available for the ramp traffic.		
	Check that the STOP sign is placed where the motorist will have an unobstructed view of the mainline traffic.		
	Check that a STOP line is utilized in conjunction with a STOP sign.*		
	Go to #4		
3. YIELD CONTROL	Check that the YIELD sign is positioned at or near the entrance of the mainline.		
	Go to #4		
4. ENTRANCE RAMPS	Check that barricades or other devices are positioned at the entrance of the mainline so the motorists will not proceed into the closed section of the roadway.		
	Check that warning signs are place at the beginning of an entrance ramp to warn the motorists of the construction on the mainline.		
	Check the need for warning signs on the entrance ramp to warn the motorist of the construction and/or the TLTWO on the mainline.		
	Check that the channeling device spacing is reduced in the vicinity of the entrance ramp or a different device is used to alert the motorists of merging traffic.		
EXIT RAMPS			
5. EXIT RAMPS	Check that barricades or other devices are positioned on the mainline so the motorists will not proceed into the closed section of the roadway.		
	Check the need for addition exit signs on the mainline where the existing exit sign is covered or removed.		
	Check that the channeling device spacing is reduced in the vicinity of the entrance ramp or a different device used to alert the motorists to merging traffic.		

The six checklists presented in this chapter were based on the literature review and data acquired from the focus group and traffic studies. Located in the appendices of this report are results obtained from the three surveys. They include listings of device types and alternative traffic control plans for the two project types studied, and a second set of the RCSA checklists. The checklists developed considered the inputs and recommendations. In the next chapter are the summary, conclusions, and recommendations for this project.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This research addressed the need for an audit approach on interstate reconstruction projects. While states possess their own set of guidelines and standards, a formal process to evaluate traffic control alternatives generally does not exist. The objectives of this research were to evaluate the practiced traffic control alternatives and develop Road Construction Safety Audit [RCSA] process and checklists for interstate reconstruction projects. Using checklists during the planning stage of a traffic control plan is recommended so that problems or concerns are evaluated and corrected before the work zone is operational.

A literature review of the issues associated with temporary traffic control showed that there are many options and layouts available for interstate work zones. However, a process to evaluate the alternatives was not found. To develop the RCSA checklists, a focus group of traffic engineers with experience in work zone design was established. The focus group consisted of two groups whose responses were compared to each other. The first group represented the Wyoming Department of Transportation and the second group consisted of engineers outside of Wyoming. Input from the focus group was acquired through the use of a modified Delphi procedure. Additional data was gained from traffic studies completed on an I-80 reconstruction project near Laramie, Wyo.

The first Delphi survey examined issues of traffic control on a slab replacement project. Responses received from the first Delphi survey were beneficial toward developing the RCSA checklist for a slab replacement project. Important findings from the survey follow.

1. The SLC strategy was strongly recommended for a slab replacement project by both groups. Members of the two groups who favored the SLC over the TLTWO recommended closing the entire lane and completing all the work in that lane instead of staggering the lane closures.

2. The drum was the channeling device used most by the two groups in the transition area, the buffer space, the work space, and the termination area when controlled by a SLC strategy.

3. Speed reductions that were recommended for a SLC strategy are listed below.

AGENCY	WYDOT		DOTS	
-	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
UNITS	MPH	MPH	MPH	MPH
TRANSITION AREA	59	5.8	57	7.8
Buffer Space	56	5.2	55	9.2
Work Space	53	7	52	10.6

4. The drum was the channeling device most used by the two groups in the merging area and single lane closure area of a work zone controlled by a TLTWO strategy.

5. Members from the DOT's group favored use of a positive barrier system for separating opposing traffic lanes on a TLTWO strategy. Members from WYDOT recommended use of a drum for separating opposing traffic lanes on a TLTWO strategy.

6. Speed reductions that were recommended for a TLTWO strategy are listed below.

AGENCY	WYDOT		DOTS	
-	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
UNITS	MPH	MPH	MPH	MPH
MERGING AREA	60	4.1	57	11.1
Median X-over	53	8.9	54	11.2
TLTWO	60	4.1	59	9.1

Responses received from the second Delphi survey and traffic studies were used to develop the RCSA checklist for ramps located in a work zone. Important findings from the survey follow.

1. Placement of a STOP sign on an entrance ramp was influenced by characteristics of the traffic volumes, sight distance, and the ramp geometry.

2. Use of a STOP line was recommended when a STOP sign is employed on an entrance ramp.
3. The drum was the most used channeling device to guide traffic from an entrance ramp to the mainline.
4. The drum was the most used channeling device for directing traffic onto an exit ramp.
5. WYDOT recommended use of additional exit signs for warning motorists of a temporary exit ramp in a work zone. Members from DOTs suggested that reducing the spacing of channeling devices in the vicinity of an exit ramp was a suitable method for warning motorists of an exit ramp.
6. Only 10 percent of motorists using entrance ramps in construction areas studied complied with the STOP sign at the end the ramp.

Results attained from the survey associated with the milling/resurfacing project indicate that the majority of responses from the two groups concurred. Important findings included the following points:

1. The SLC strategy was recommended by both groups for a milling/resurfacing project.
2. Widths of the travelway influenced which types of channeling devices were recommended for a milling/resurfacing project. Members from both groups suggested use of a tubular marker or a smaller device when width of the travel lane was too narrow for a drum.
3. Members from the two groups strongly recommended placing the channeling device at the edge of the unmilled lane on a milling/resurfacing project.
4. A positive barrier system was recommended by WYDOT when the drop off depth was at least 6.30 inches (STDEV = 3.74 inches). Members from DOTs recommended the use of a positive barrier system when the minimum drop off depth was at least 2.95 inches (STDEV = 1.91 inches).
5. A full-time traffic control device maintainer was most often recommended for a milling/resurfacing project.

Using the input from the two groups, a series of prototype checklists were developed. The checklists that were developed are listed below.

1. RCSA Checklist- for a Slab Replacement (SR) Project on a Rural Interstate.
2. RCSA Checklist - for a Milling/Resurfacing (MR) Project on a Rural Interstate.
3. RCSA Checklist-TLTWO-for Work Zones controlled by TLTWO strategy.
4. RCSA Checklist - for Entrance Ramps (ER) located within a Work Zone.

The primary purpose of the proposed RCSA is to evaluate alternative traffic control plans, devices and strategies before the interstate work begins. The RCSA checklists developed were based on various and often different recommendations obtained. The checklists help to ensure that major safety considerations have not been overlooked. The specific values (i.e. speed limit, drop-offs) and types of devices have been considered with the RCSA. However state practices, tort liability, and preference also are factors to consider in modifying different RCSA values or devices indicated.

The next section of this chapter presents conclusions of the project. Conclusions for the three areas that were analyzed in this project and the RCSA process are considered in separate subsections of Section 6.2.

Conclusions

Slab Replacement Project on a Rural Interstate

1. The SLC strategy is recommended for a slab replacement project on a rural interstate.
2. Closing one entire traffic lane at a time and repairing all slabs in that lane is the recommended practice.
3. The DOT's group recommended a concrete barrier system for separating the two opposing traffic lanes on a project controlled by a TLTWO strategy.

4. Lowering speed limits for both the SLC and TLTWO strategies were recommended by both groups.

Ramp Traffic Control on a Rural Interstate

1. Further research on the location of a STOP sign at an entrance ramp in the work area is needed.
2. A STOP line is recommended when a STOP sign is used at the end of an entrance ramp located in a work zone.
3. Either Stop or Yield control is recommended for the traffic control at the end of an entrance ramp when the acceleration lane is not present due to the work activity on the mainline.
4. Decreased device spacing or an alternative type of channeling device are recommended in the vicinity of an exit ramp when there is no deceleration lane and only one travel lane is open on the mainline.

Traffic Control for a Milling/Resurfacing Project on a Rural Interstate

1. The SLC strategy is recommended for a milling/resurfacing project on a rural interstate.
2. Traffic control for milling/resurfacing projects depended on the states' practices or policies.
3. Channeling devices were not recommended when an edge drop off of 1.5 inches or less existed on a milling/resurfacing project.
4. Non-positive channeling devices (i.e. drums) are recommended for drop off depths up to 3.5 inches (based on the practice in states outside of Wyoming).
5. Place channeling devices at the edge of an unmilled lane when the milled lane is closed to traffic (i.e. not in the milled lane).
6. Use cones as the primary channeling device for daytime operations only. For projects with an exposed milled lane left overnight, use drums or tubular markers.

7. When the devices are left overnight, a full-time traffic control device maintainer is recommended on a milling/resurfacing project when the devices are left overnight.

Road Construction Safety Audit [RCSA] Checklists

1. Use checklists to ensure that major construction issues have been considered.
2. Formatting the RCSA checklists to agency policies, to achieve traffic control design consistency in interstate work zones, is recommended.
3. Adapting a consistent national RCSA process is needed.

Recommendations

This section contains recommendations for additional research concerning work zone traffic control on a rural interstate.

1. Further research is needed to determine the effect of traffic volumes on implementation of traffic control strategies and devices. Actual application of RCSA checklists and modifications based on application and documentation of their safety benefits is needed.
2. Similar surveys on other reconstruction projects are needed to develop additional checklists. Bridge deck repair and roadway realignment are examples for future studies.
3. Traffic studies on the drivers' compliance with YIELD signs on interstate entrance ramps evaluating alternative sign locations are needed.
4. Additional traffic studies on the drivers' observance of STOP signs with use of portable rumble strips to increase the number of drivers that observe a STOP sign and to help determine the STOP sign's optimum location on an interstate entrance ramp also are recommended.
5. Additional research on ramps located in a work zone is needed before precise recommendations can be given.

6. A national documentation procedure for work zone crashes is needed to determine where crashes are occurring in the work zone.

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