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16. Abstract

This report documents the data collection at and analysis of 77 fatal work zone crash sites throughout Texas from February 2003 through April 2004. The methodology used to collect the data for this project included a site analysis after notification by the Texas Department of Transportation (TxDOT) of each fatal crash. This project allowed an in-depth analysis of fatal work zone locations in Texas by supporting the collection of data regarding work zone configuration and characteristics that are generally not made available through the Department of Public Safety Crash Database or traditional police crash report forms. Based on these investigations, researchers concluded that only 8 percent of the investigated crashes had a direct influence from the work zone, whereas 39 percent of the investigated crashes had an indirect influence from the work zone. Researchers also concluded that 45 percent of the investigated crashes appeared to have no influence from the work zone (included in this subset are the 16 percent of the investigated crashes which occurred in work zones that were work zones in name only, such as work zones that consisted only of project limit signing). The crash investigations also provided unique insights into how and what characteristics of the work zones might have played some type of role in the overall chain-of-events for each crash. Researchers utilized this information in generating a series of possible crash countermeasures to intervene in the crash chain-of-events where plausible. Researchers critiqued each countermeasure and arrived at a final list of eight strategies that TxDOT should consider adopting or pursue further with research and development efforts.

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# AN ANALYSIS OF FATAL WORK ZONE CRASHES IN TEXAS

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# CHAPTER 1:
# INTRODUCTION

The need to repair, resurface, or replace sections of roadway or roadway structures will always exist. Work zones are required in order for workers to perform this work on an existing roadway with traffic in close proximity, as it is often not possible or feasible to completely close a roadway during the required work. When planning a work zone traffic control plan, there are three considerations:

- that drivers travel safely and expeditiously through and around work areas,
- that road workers be provided maximum safety, and
- that work activity progress as rapidly and efficiently as possible (*1*).

Over time, work zones have evolved from simple layouts that may not have been particularly effective in promoting safety into modern designs that attempt to maximize safety whenever possible. However, despite the best efforts of transportation officials, work zone crashes still occur, as detailed in Table 1. In 2003 there were 919 reported fatal work zone crashes reported in the Fatality Analysis Reporting System (FARS) database, resulting in 1028 fatalities. In Texas there were 144 fatal work zone crashes reported in the FARS database, resulting in 161 fatalities in the same period (*2*). The values presented in this table show several points. First, the absolute number of fatal crashes nationally has increased from 1994 through 2003 by 27 percent. This may be the result of a combination of increasing vehicle-miles traveled and an increase in the number of work zones present on the roadway. Second, the proportion of the reported fatalities that came from Texas has remained consistent throughout this time period, ranging from 12 to 17 percent of the national figure.

However, simple numbers and percentages do not reflect the complexity of the issues associated with performing highway work safely and efficiently. The values presented in Table 1 are tabulated from peace officer accident investigation reports, which vary widely in quality and accuracy between states and even within different jurisdictions within states. Researchers believe that some crashes may occur in work zones but are not recorded as such by peace officers, and regional variations in this reporting process can skew results. Different states also

**Table 1. 2003 Number of Fatal Crashes Nationally and in Texas, 1994-2003.**

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|
| **National*** | 721 | 665 | 635 | 594 | 681 | 770 | 966 | 877 | 1035 | 919 |
| **Texas** | 102 | 101 | 96 | 69 | 113 | 109 | 133 | 129 | 166 | 144 |

From *Fatality Accident Reporting System* U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington D.C.
* Including Texas.

use different reporting forms, which may skew some results pertaining to work zone crash data (*3*). In addition, peace officer training in areas of work zone traffic control plans and work zone terminology varies greatly, so some officers may not recognize when a safety issue is present due to the work zone traffic control. As a result, a peace officer's report may not reflect all the work zone issues that might be related to the crash. Adding to this potential problem, engineers and researchers reviewing peace officer crash reports at a later date are unlikely to gain insight into the work zone-related issues by visiting the site because the work zone may no longer be present. Regardless of the reporting issues inherent in the FARS database, the fact remains that there are crashes and fatalities in work zones nationally and in Texas. It was the purpose of the researchers conducting this research to investigate the work zone crashes that occurred in Texas during the study period, determine what factors the Texas Department of Transportation (TxDOT) can control that affect these crashes, and recommend improvements to the standard practices applied by TxDOT to increase safety.

## REPORT ORGANIZATION

This report is divided into several chapters. Chapter 2 contains a review of the pertinent literature that provides background material for this research. Chapter 3 details the methodology used in the data collection process, with Chapter 4 detailing the results of the data collection. Finally, Chapter 5 contains recommendations for changes that have the potential to increase safety in Texas work zones and can potentially reduce the number of fatal crashes experienced.

# CHAPTER 2:
# LITERATURE REVIEW

Several areas of literature were reviewed to gain background knowledge for this research. Specific areas that were reviewed in the literature included: previous analyses of work zone crash statistics, human factors aspects related to work zone driving, crash investigation research, and risk analysis techniques.

## WORK ZONE CONCEPTS AND TERMINOLOGY

The Manual on Uniform Traffic Control Devices lists five distinct areas within a work zone *(4)*. Each of these has a specific purpose and may vary in size and location depending on the specifics of each work zone. The five areas are: advance warning area, transition area, activity area, buffer space, and termination area. Each of these terms were developed to convey clear meaning of the purpose of the traffic control at that portion of the work zone *(5)*, and these areas are shown in Figure 1.

The advance warning area notifies motorists that they are approaching a work zone and to increase their alertness. The area may provide information on which lane (if any) is closed, the nature of the work involved, the potential for delay, and other information to aid motorists in understanding generally what to expect once the work zone is reached. The transition area is the location where a lane drop or lane shift actually occurs; if no lane drop or shift occurs, then no transition area is needed in that work zone. The activity area is defined as the location in a work zone where the closure exists and where workers and equipment are present. Locations within the work zone with no activity or workers are known as buffer areas. The termination area is simply the end of the work zone.

Pain and Knapp described the process by which motorists see and avoid hazards during normal driving *(6)*. In the Positive Guidance and stopping sight distance models, work zone lane drops or traffic control devices are termed "hazards" that must be identified and reacted to in order to avoid a crash. Pain and Knapp pointed out that some work zone traffic control devices in the past did not always provide sufficient information for motorists to know the appropriate action to take. Additionally, due to inconsistent application of work zone traffic control devices, motorists were likely to develop a general suspicion of even clear work zone traffic control messages. According to the authors, motorists would adopt an "I'll slow down or change lanes

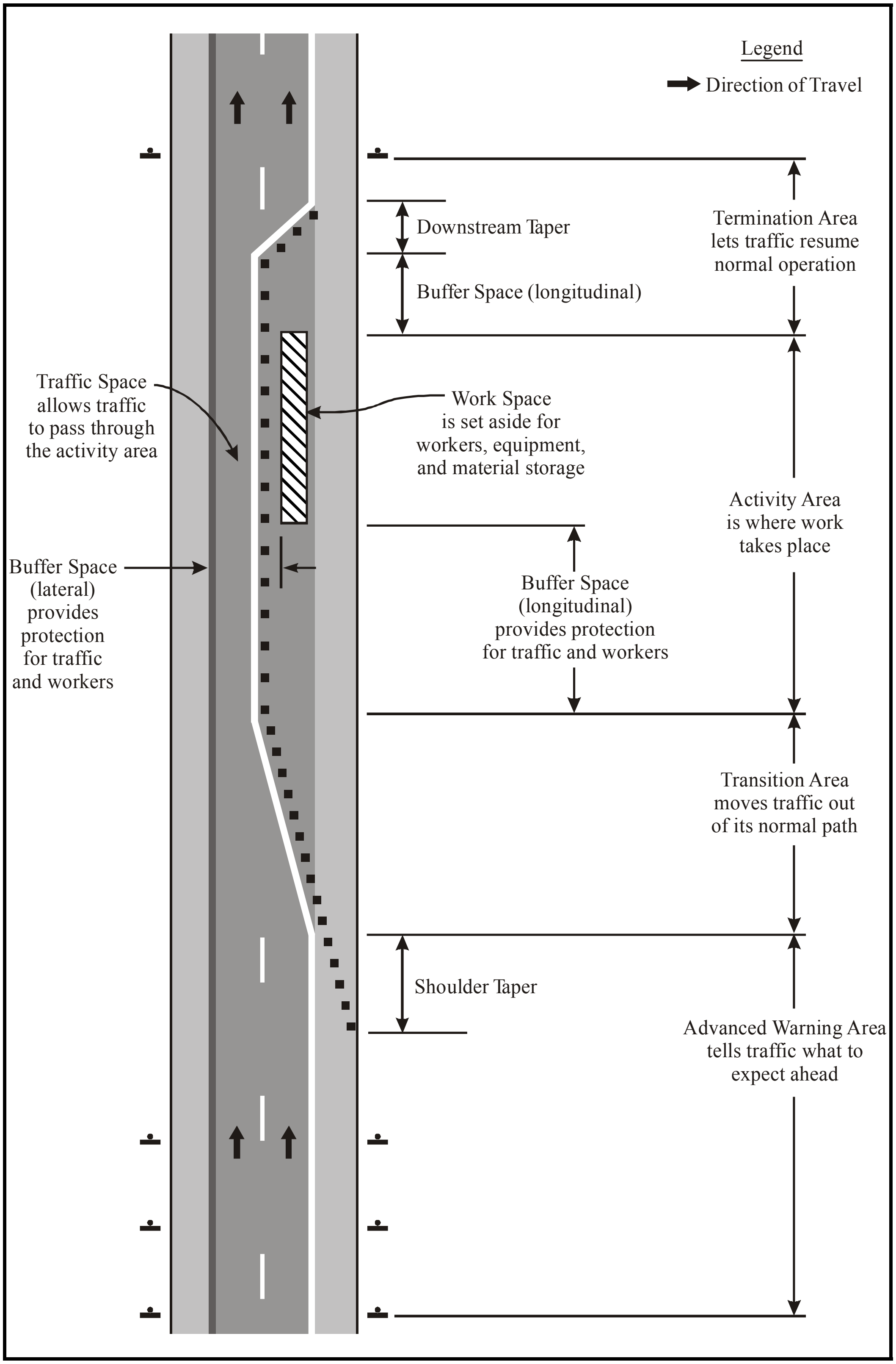



**Figure 1. Traffic Control Zone and Components (from *4*)**

when I see it" attitude regarding messages presented in or about work zones. Clearly, long-term consistency at all work zones is required in order to overcome this tendency.

## PREVIOUS ANALYSIS OF WORK ZONE CRASHES

The literature provided several strategies for finding pertinent data from various crash reporting databases. The majority of previous research efforts utilized state crash databases. Another research strategy identified utilized private insurance claims databases. Some of the identified shortcomings of the use of these databases as well as national databases for examining crash databases in work zone research are discussed in the following sections.

### Use of State or National Databases for Work Zone Research

A study was undertaken in the 1970s by the Midwest Research Institute, where accident records were reviewed for 79 construction projects in seven states *(7)*. Of the sites investigated, 31 percent showed a reduction in accident rates, while 69 percent increased. Perhaps most striking, 24 percent of the sites experienced an accident rate increase of 50 percent or more.

In 1978, Nemeth and Migletz reported results of a review of the crash rates at work zone locations in Ohio *(8)*. In this study, the researchers reviewed accident rates at 21 locations that covered a total of 384 miles of rural interstate highway, and the crash rates were compared in the year prior to the work activity (1972), the year the work took place (1973), and the year after (1974). The researchers concluded that during the year the work was taking place, these areas of roadway had an overall increase in accidents of 7 percent from the previous year. However, in the year after the work was completed, there was a decrease of 31 percent compared to the crashes before work started. This research clearly showed both that while the crash rates tend to increase during the presence of work zones, safety benefits can be ultimately realized once work is completed. In other words, getting the work done as quickly as possible can also contribute to safety. A summary of the crash statistics presented by the researchers can be found in Table 2.

Additionally, Nemeth and Migletz reviewed 151 accident reports from crashes in these 21 work zone locations to determine if any patterns existed. The researchers reported the following observations:

**Table 2. Accident Rates at 21 Work Zone Locations in Ohio (8).**

| Year | Aggregate Accident Rate from all 21 Locations | Percentage Change from "Before" (1972) Data |
|---|---|---|
| 1972 | 112.9 accidents/million vehicle miles traveled | --- |
| 1973 (Year that work zones were in place) | 120.8 | +7% |
| 1974 | 77.9 | -31% |

- Excess speed was noted in 88 of the 151 accidents (58 percent).
- Nighttime accidents were concentrated in the taper areas.
- The severity of the accidents tended to be greater in the activity areas.
- Equipment or traffic control devices were more likely to be hit at night than during the day.

In a study examining the effects of short-term work zones on before-and-after accident rates, Rouphail, Yang, and Fazio examined records from three long-term and 23 short-term work zones on the Chicago Area Expressway System from 1980 to 1985 (9). The researchers found that at the three long-term work zone locations, accident rates (calculated as crashes/mile-day of construction) increased by an *average* of 88 percent. However, one of the locations experienced significantly more crashes than the other locations, and this average value was skewed by this one crash-prone location. When examining the short-term locations, the researchers found that the crash rate increased by 69 percent from the rate prior to the emplacement of the work zone.

One other interesting fact from the Rouphail, Yang, and Fazio study was the comparative accident rates between long-term and short-term work zones. The long-term locations experienced crash rates from 0 to 0.219 accidents per mile-day of work, while the short-term work zones had an average crash rate of about 0.8 accidents per mile-day, and seemed to be independent of other factors such as project duration or length of the work zone (9). The authors reasoned that it would be expected for short-term work zones to have higher accident rates for the following reasons:

- Discrepancies between traffic control standards and what was actually in place was greater at short-term work zones.
- Short-term work zones tend to be in place during off-peak hours, resulting in higher speeds.
- Working during off-peak hours may mean a lower proportion of commuters, which in turn may mean more unfamiliar drivers passing through the work zone.
- Rapidly changing work zones may mean that the traffic control plan and even the location of the work zone changes often, possibly resulting in driver confusion.

Another approach to quantifying work zone accidents was undertaken by Hall and Lorenz in New Mexico (*10*). The researchers reviewed 114 work zone locations in New Mexico that started between 1982 and 1985 and compared the number of accidents at these locations with the same locations one year previously. The researchers then used contingency tables to test the statistical significance of difference between the times when the work zones were present and the year previous based on alignment type, time of day, light condition, grade, day of week, number of vehicles involved in the accident, heavy truck involvement, pedestrians, accident severity, weather, roadway surface (wet, dry, snow, etc.), collision type, and principal contributing factor. For the locations examined, a crash was significantly more likely to have occurred under dry conditions when a work zone was present. Once again, these data reinforce the conclusions made by previous authors that work zones tend to increase the likelihood of a crash on a specific section of roadway.

Bryden, Andrew, and Fortuniewicz reviewed 494 crashes that took place in New York State Department of Transportation work zones between 1994 and 1996 (*11*). They found that roughly one-third of these crashes involved a vehicle impacting a traffic control device or other features introduced into the roadway environment due to the presence of the work zone.

Several previous studies into work zone crashes have emphasized data taken from peace officer crash reports. In one such study, Garber and Zhao examined crash reports from each work zone crash in Virginia from 1996 through 1999 (*12*). A total of 1484 useable reports were included in the study. The objectives for the study included identifying the predominant crash locations within work zones, identifying the predominant crash type and severity at major locations within these work zones, identifying trends in collision type with respect to roadway type and vehicular characteristics, and comparing the distributions of work zone and non-work zone crashes.

Garber and Zhao found that the most reported locations for crashes were the work zone activity areas, followed by the transition, advance warning, and buffer areas. The proportions of crashes at each location are shown in Table 3. It should be noted that while the advance warning, transition, and termination areas tend to be fairly limited (and consistent from work zone to work zone), the length of activity and buffer areas can vary widely from project to project and may be much longer than the other three areas. Thus, the distribution of crashes is somewhat skewed due to differences in exposure. Even so, the researchers also found that rear-end collisions tended to be the dominant crash type in all work zone areas, and that these were even more dominant in the advance warning areas. Of the 17 fatalities reported, 11 people were vehicle occupants and six were workers.

**Table 3. Proportions of Work Zone Crash Locations in Virginia Work Zones (*12*).**

| Work Zone Area | Number of Crashes at Area | Proportion of Crashes at Area (%) |
|---|---|---|
| **Advance Warning** | 149 | 10 |
| **Transition** | 200 | 13 |
| **Longitudinal Buffer** | 81 | 5 |
| **Activity** | 1030 | 70 |
| **Termination** | 24 | 2 |

N=1484.

Daniel, Dixon, and Jared used the crash report database from Georgia to evaluate all fatal work zone crashes from 1995 to 1997 (*13*). They reviewed a total of 181 crash reports for crashes of this type to determine where and under what conditions the crashes occurred. The researchers found that about 30 percent of fatal crashes occurred while work was in progress, 50 percent when the work zone was idle, and the remainder occurred when the work zone had not started, not zoned, or other unknown time. Additionally, single-vehicle crashes represented 49 percent of all fatal crashes.

Heavy trucks were overrepresented in Georgia work zone fatal crashes with 20 percent of fatal crashes involving trucks, compared with only 13 percent in non-work zone fatal crashes.

Researchers also found that fatal crashes in work zone were more likely to involve a collision with another object, including other vehicles, equipment, and traffic control devices.

### Use of Other Databases for Analysis

Sorock, Ranney, and Letho took a different approach to studying work zone crashes (*14*). These researchers used automobile insurance crash database records from the Liberty Mutual Insurance Company to analyze work zone crash characteristics. They queried claims filed from 1990 through 1993 for the term "construction" in the narrative section of the claim form. Over 2.8 million forms were searched, and this database provided 6333 claims that included the word "construction." Each of these claims was reviewed, and about 59 percent of the crashes appeared to have taken place in a work zone of some type. Similar to other crash studies, rear-end collisions were most common, occurring in 31 percent of the work zone claims. In comparison, all Liberty Mutual insured vehicles showed that only 17 percent of crashes involved rear-end collisions, indicating that this type of crash was overrepresented in work zones. Depending on the year, between 83 and 92 percent of all work zone crashes occurred in daylight hours.

### Issues Regarding the Use of Crash Report Databases

The FARS fatal crash report database relies on data provided by peace officers through crash report forms used in each state. With regards to work zone crashes, these data have some distinct limitations and imperfections. Perhaps most significant of these limitations is the fact that crash report forms themselves vary from state to state. Previous research has categorized state report forms into one of three categories:

- states where an explicit variable or field denotes a work zone crash (27 percent of states),
- states where the road condition, traffic control, or other field denotes a work zone crash. This approach requires each officer to note the presence of the work zone on the form, and can vary by officer training (42 percent of states), and
- states where the crash report form had no place to note a work zone crash as such (31 percent of states) (*15*,*16*).

Research into the implications of this disparity estimated that the number of fatal work zone crashes reported in FARS may be underrepresented by as much as 10 percent (*3*). Another limitation is that only that information which is requested on the crash report form is available for analysis. Generally speaking, specific information pertaining to a work zone (such as type of work, changes in capacity or geometrics, amount and condition of traffic control, etc.) are not captured on the form. Obviously, the differences in report forms as well as in actual investigation and reporting processes from state to state make it difficult to truly assess fatal work zone crash characteristics and trends at the needed level of detail.

## "CHAIN-OF-EVENT" CRASH ANALYSIS TECHNIQUES

Crashes are rare and unique events that make direct comparisons of the various factors difficult. Even when similar in nature, two crashes may have different contributing factors. This complicates any efforts to generalize and group several crashes into an overall category. One method of analyzing crashes in a rational manner is to apply the concept of prototypical scenarios to the analysis process. Prototypical scenarios can be defined as the prototype of the accident process corresponding to a series of crashes that are similar in terms of the chain of events and the causal relationships found throughout the various crash stages (*17*). By considering the "chain of events" that led to a particular crash, it is possible to group similar crashes and provide an in-depth analysis, even though some of the facts of the crashes vary somewhat. Baker and Ross defined a factor as, "Any circumstance connected with a traffic accident without which the accident could not have occurred (*18*)." An extension of this could be that if the factor was removed the crash might still have occurred, but could have been less severe. This method can be a useful simplification process that allows the grouping of crashes in a manner that can allow safety researchers to gain additional insight that may not have been otherwise possible.

Mercier published an article in a French publication in which he used this prototypical concept to analyze work zone crashes on roadways in the Salon-de-Provence region of France (*19*). He developed a standardized method of reviewing the crash information, developed five prototypical scenarios, and then reviewed all available data from 118 crashes. He was able to categorize 71 percent of these crashes into one of the following five general scenarios:

- misunderstanding by motorists about the expected path through the work zone,
- motorist was surprised by the work zone's presence or an obstacle in the work zone,
- motorist was surprised by an unusually complex situation in the work zone,
- low reaction time by the motorist when approaching a queue before or in the work zone, and
- motorist lost control of the vehicle due to unsafe pavement conditions (oil, gravel, etc.) *(19)*.

Using these scenarios as a framework for analyzing the crashes, Mercier was able to recommend a series of countermeasures, including improving the visual warnings at critical locations, implementing speed reduction measures, and improving lighting. The long-term impacts of any implemented changes were not reported as part of Mercier's study.

**SUMMARY**

The following points were made from the literature review:

- Work zones by their very presence tend to increase the likelihood of a crash on a specific section of roadway *(7,8,9)*.
- As many as 50 percent of fatal work zone crashes in Georgia occurred when no work was present and 20 percent when the work zone had not been started, was not zoned, or some other unknown time *(13)*.
- Heavy trucks were overrepresented in fatal work zone crashes in Georgia in previous research *(13)*.
- Crash reporting for work zone fatal crashes may be underrepresented by as much as 10 percent in national databases. This may indicate that relying solely on police crash report forms to investigate work zone crashes may skew any analysis *(3,15,16)*.
- Prototypical scenarios can be useful in understanding the influence a work zone has on the "chain of events" of a crash *(17)*.

These points were useful in developing an appropriate data collection methodology and in understanding the potential shortcomings of relying on crash databases for research of this type. The researchers determined that a new approach was needed to get a better grasp of the characteristics of the work zone crash locations as well as the extent to which the work zone's presence influenced the crash. The methodology used for this research is presented in the Chapter 3.

# CHAPTER 3: DATA COLLECTION METHODOLOGY

Early in the research process, data collection for this project was recognized as a potentially delicate task. Concerns existed about the most efficient, consistent, and sensitive way to investigate, analyze, and document fatal crash locations where TxDOT or a TxDOT contractor may have had a negative impact on the chain of events of the crash.

## SITE INVESTIGATION PROTOCOL

### Procedures

In order to collect data for this project, a new methodology was developed that would rely on site reviews and narrative descriptions of what was observed by the Texas Transportation Institute (TTI) researcher(s) during the investigation process. The main goals of each site review and narrative report were to:

- detail the facts about how, when, and/or why the crash happened,
- detail the physical presence and condition of the work zone, traffic control devices, or other appurtenances,
- describe any deficiencies observed in the work zone layout or traffic control plan, and
- describe any possible countermeasures that could reduce the severity of future crashes of this type at TxDOT work zones.

The analysis approach adopted followed the practices of the Fatality Assessment and Control Evaluation (FACE) Program, developed by the National Institute for Occupational Safety and Health, which focuses on investigations of fatal accidents in any work setting (*20*). This data collection methodology must be flexible and somewhat open-ended due to the diverse nature of the types of investigations that the FACE Program must perform. The basic principles of a typical FACE Program report include:

- a factual summary of the fatality,
- the cause of death, and
- recommendations about changes to work practices that could minimize repeats of these fatalities.

For this project, the data collection methodology was developed in order to review as many fatal work zone crashes as possible as soon after the crash as practical and to maximize the information gathered by the research team. The research team strove to minimize any differences between the conditions of the work zone at the time of the crash and the time of the data collection. In some cases, researchers expected that several days might pass between the time of the crash and the site investigation, but that in most cases the work zone itself would be as it was at the time of the crash. After the report was written, the TTI research team would determine the extent to which the particular wok zone influenced the crash.

## Training

On February 19-20, 2003, the five-member TTI data collection team met in College Station for a two-day training session with the aim of standardizing the field data collection process in order to minimize any data collection differences based on the researcher. Issues such as the kinds of data to be collected, the methods of analysis, and the methods to be used to document the data collection and analysis were discussed. At that time, the first two fatal crash locations had already been investigated by part of the research team. The site investigations from these two locations were reviewed by the group, and lessons learned were discussed.

Additionally, the team visited two work zones in Brazos County and conducted practice exercises simulating three fatal crash locations, as shown in Figure 2. Each location had temporary paint markings on the pavement and on the adjacent shoulders to represent the kinds of markings that law enforcement would likely leave behind after a crash. Other than these, no other changes were made from the existing work zones. Each team member conducted an independent analysis, which was reviewed to compare the extent that each team member


**Figure 2. TTI Research Team Conducting Group Training**

collected data in a similar manner and came to similar conclusions regarding the simulated crash location. Any variations in data collection or analysis were discussed and rectified prior to the end of the meeting.

### Notification

Researchers contacted the district safety officers in each of the 25 TxDOT districts to develop a contact network. These officers were TxDOT personnel who would typically be notified of any fatal crashes on TxDOT roadways in their respective districts. These contacts were asked to notify the TTI research team in the event that a work zone fatality occurred in their district. The notifications from TxDOT to TTI typically happened within one or two days after the crash occurred, although in some cases notification occurred on the same day as the crash itself. In a few instances, researchers were not notified for a week or so, due to TxDOT contacts being out of the office for a period of time or the contacts themselves not being notified in a timely manner.

At the time of initial notification, researchers took preliminary information, including the place and manner of the crash, the time of day and weather, and the appropriate contact within TxDOT to show the researcher the location. The TTI research team conferred to determine which researcher would travel to the location. This was often dictated by location; if a researcher was located near the crash location, it was likely that researcher would be sent to investigate. Arrangements were then made to visit the site within a few days time.

**Investigation**

The TTI researcher responsible for reviewing the crash site attempted to view the site within a few days after the crash in order to see the work zone with as few changes as possible compared with the conditions when the crash occurred. After meeting with TxDOT personnel, the TTI researcher was directed to the site. Any documentation, such as law enforcement crash reports, that were available at the time of the site visit was provided to the researchers.

Upon arriving at the site, the researcher investigated many factors that may have been relevant to the particular site. TxDOT and contractor personnel were asked to point out any changes in the work zone traffic control or activity that had occurred between the time of the crash and the time of the site visit. A brief list of data collected includes:

- a traffic control equipment condition survey,
- a pavement condition survey,
- a Positive Guidance information loading survey, and
- a diagram of the crash location.

The site review took place under the same lighting conditions as when the crash occurred. If the crash occurred at dusk, dawn, or night, the site review was first completed under daylight conditions for safety, and then briefly re-reviewed under the crash lighting conditions to determine how the (typically) degraded visibility affected the outcome of the crash. The full protocol used in the course of this research is detailed in Appendix A.

# CHAPTER 4:
# RESULTS

Data were collected for this research project from February 1, 2003, through April 30, 2004 – a period of 15 months. During that time, the TTI research team received notification and responded to 77 fatal work zone crash locations in 21 of the 25 TxDOT districts. The incidents resulted in the deaths of 77 motorists or passengers, one bicyclist, two pedestrians, six contractor workers, one police officer, and one TxDOT employee, for a total loss of 88 people. Each of these sites was reviewed in detail, and TTI staff prepared narrative reports for each site visit for use in later analysis.

Seventy-seven crashes were less than the approximately 150 predicted based on a trend analysis of both the FARS database (shown in Table 1) and the Texas Department of Public Safety (DPS) Crash Database. Possible reasons for this include:

- TxDOT personnel would not be in a position to report fatalities in non-TxDOT work zones, which would still be present in national and state-level databases,
- miscommunication with TxDOT district officials regarding the aims of this research and the help that was asked of them,
- TxDOT officials not receiving notification from law enforcement officers of fatal crashes that occurred in work zones, and
- a lower than average number of work zones during the research data collection period.

Regardless, the 77 sites that were reviewed are believed to accurately represent the characteristics of fatal work zone crashes typically occurring on Texas highways. As shown in the following section, researchers found that the site investigations obtained for this project compare well to historical trends of fatal work zone crashes that can be extracted from the DPS Crash Database. The key variables examined for comparability between the two data sets included:

- roadway type,
- weather conditions,
- lighting conditions,
- alcohol and/or drug involvement, and
- large truck involvement.

## COMPARABILITY OF SITE INVESTIGATIONS TO HISTORICAL CRASH DATA TRENDS

The 77 fatal crash sites were analyzed for trends based on roadway type, work zone crash location, work zone activity, weather conditions, lighting conditions, alcohol involvement, and large truck involvement. Where possible, the data were compared with previous research or available database statistics.

### Roadway Type

Researchers compared the distribution of the 77 crashes investigated during this project by roadway type to historical data gathered from the Texas DPS Crash Database from 1995 through 2001. The comparison of these fatal crash values is shown in Table 4. The data indicate that although the absolute number of investigated sites was below the trend of crashes from 1995 through 2001, the percentages of fatalities that occurred on different roadway types fit well with historical database values. Based on this consistency, researchers believe that the crashes evaluated during this project were a representative sample of crashes statewide, based on roadway type.

### Crash Location within a Work Zone

Crash location within a work zone is not incorporated into the Texas DPS Crash Database (although it may be estimated from the actual crash report narrative if the investigating officer chose to include such information). Consequently, such information has not been previously known for Texas work zone crashes. For the crashes examined as part of this project, researchers determined the distribution of crash locations within the work zones. The results of

**Table 4. Comparison of Work Zone Fatal Crashes by Roadway Type.**

| Roadway Type | 1996* | | 1997* | | 1998* | | 1999* | | 2000* | | 2001* | | Data Collection Period 2/03-4/04 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # | % | # | % | # | % | # | % | # | % | # | % | # | % |
| **Interstate** | **39** | 40 | **31** | 29 | **40** | 34 | **34** | 32 | **32** | 27 | **43** | 33 | **24** | 31 |
| **US Highway** | **21** | 21 | **36** | 33 | **39** | 33 | **32** | 31 | **39** | 32 | **45** | 35 | **26** | 34 |
| **State Highway** | **17** | 17 | **24** | 22 | **20** | 17 | **20** | 19 | **29** | 24 | **23** | 18 | **16** | 21 |
| **Farm to-Market Highway** | **18** | 18 | **17** | 16 | **17** | 14 | **17** | 16 | **21** | 17 | **17** | 13 | **10** | 13 |
| **Other** | **4** | 4 | **0** | 0 | **2** | 2 | **2** | 2 | **0** | 0 | **1** | 1 | **1** | 1 |
| **Total** | **99** | 100 | **108** | 100 | **118** | 100 | **105** | 100 | **121** | 100 | **129** | 100 | **77** | 100 |

* Historical data from Texas DPS Crash Database.

the analysis are shown in Table 5. For comparison purposes, these results were compared to previous research completed by the Virginia Transportation Research Council (VTRC) on Virginia work zone crashes (not necessarily fatal crashes) (*12*). The designation of buffer area and activity area were grouped together, as there was often a blurred boundary between these categories at several long locations with activity spread throughout the length of the work zone.

**Table 5. Comparison of Work Zone Fatal Crashes by Work Zone Location.**

| Work Zone Location | VTRC Research* | | Data Collection Period 2/03-4/04 | |
|---|---|---|---|---|
| | # | % | # | % |
| **Advance Warning Area** | **149** | 10 | **2** | 3 |
| **Transition Area** | **200** | 13 | **9** | 15 |
| **Longitudinal Buffer Area & Activity Area** | **1111** | 75 | **48** | 77 |
| **Termination Area** | **24** | 2 | **3** | 5 |
| **Total** | **24** | 100 | **62**** | 100 |

* From *Crash Characteristics at Work Zones* (*12*).
** Three non-traffic fatal crash sites and 12 locations where the work zone consisted only of project limit signs were removed from this analysis.

Twelve locations did not fit the standard work zone definitions. These were located at work zones that only met the definition of a work zone in a technical sense, such as if the project limit signs defining the work zone were present, but the contractor had not started any work or placed any other traffic control devices. Likewise, if a work zone was essentially completed or closed down for the winter and no traffic control was present other than the project limit signs, it would fit into this category. These are referred to as "work zones in name only" in Table 5. Additionally, there were three fatality locations that did not involve traffic, where a contract worker was killed by construction equipment in the activity area. All together, 15 of the fatality locations were thus not analyzed in this section.

The comparison shown in Table 5 clearly shows that the designations of work zone location for this research match the proportions by work zone area as determined by the VTRC research. The most notable difference is the slight underrepresentation of crashes from this current project in the advance warning area. Researchers hypothesize that some of the crashes examined were captured in the transition area category instead, which is slightly overrepresented. In addition, researchers surmise that differences in collection methods may also be somewhat responsible for the small variations observed between data sets. Specifically, in the VTRC research, the use of police crash reports rather than actual site observations by the researchers may have resulted in slightly different categorizations of some of the Virginia crashes. Overall, however, the comparison in Table 5 does suggest good agreement between data sets. It is important to note that in both data sets, the predominance of crashes in the buffer/activity area most likely reflects differences in vehicle exposure relative to the other areas. Specifically, buffer/activity areas are often much longer than any of the other segments listed, and so would include more vehicle-miles of exposure than the other areas.

### Work Zone Activity Type

The crash sites were also examined to determine trends in the type of work activity that was being undertaken at the work zone. Work zone activities included construction, resurfacing, bridgework, maintenance, or other (i.e., traffic signal installations, freeway management system installation, etc.). As stated above, there were 12 instances where only project limit signs were present at the time of the crash (i.e., it was a work zone in name only). These 12 are categorized separately in Table 6.

**Table 6. Comparison of Work Zone Fatal Crashes by Work Zone Activity Type.**

| Work Zone Activity Type | Investigated Crashes Data Collection Period 2/03-4/04 | | % of Work Zones by Activity Type, 2001 (22) |
|---|---|---|---|
| | # | % | |
| Construction Activity | 27 | 35 | 28 |
| Resurfacing Activity | 18 | 23 | 33 |
| Bridgework Activity | 10 | 13 | 15 |
| Maintenance Activity | 9* | 12 | 13 |
| Other Activity | 1** | 1 | 11 |
| Work Zone in Name Only | 12 | 16 | --- |
| Total | 77 | 100 | 100 |

* Including 6 static work zones and 3 moving/mobile work zones.
** Traffic signal installation.

This analysis cannot be compared directly with the Texas DPS Crash Database, as these data are not recorded by the peace officers and are thus not available in the database. However, researchers did compare the trends with recent estimates of national work zone exposure data (the Bryan District of TxDOT was one of the regions sampled in that effort) (*21*). These data are also shown in Table 6. Generally speaking, the crash trends are relatively consistent with the national trends of work zone exposure by type of work activity. The only substantial variation is in the "other" work zone activity type category. However, it is possible that many of the crashes observed at work zones that were "in name only" would have fallen under the "other" category of work zones in the national study. The national study did not differentiate between locations that were fully under way and those that were a work zone "in name only."

## Weather Conditions at Time of Crash

Researchers compared the weather conditions to determine the extent that fatal work zone crashes may have been influenced by adverse weather. There were six instances where adverse weather may have influenced the crash. As shown in Table 7, five of these crashes occurred during rain, and one occurred during conditions of blowing dust. These values compare favorably with the values taken from previous years in the Texas DPS Crash Database.

**Table 7. Comparison of Work Zone Fatal Crashes by Weather Conditions.**

| Weather Conditions | 1996* | | 1997* | | 1998* | | 1999* | | 2000* | | 2001* | | Data Collection Period 2/03-4/04 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # | % | # | % | # | % | # | % | # | % | # | % | # | % |
| **Clear** | **90** | 91 | **98** | 91 | **107** | 91 | **99** | 94 | **113** | 93 | **113** | 88 | **71** | 92 |
| **Raining** | **8** | 8 | **8** | 7 | **8** | 7 | **5** | 5 | **5** | 4 | **12** | 9 | **5** | 7 |
| **Snowing** | **0** | 0 | **0** | 0 | **1** | 1 | **0** | 0 | **0** | 0 | **0** | 0 | **0** | 0 |
| **Fog** | **1** | 1 | **2** | 2 | **2** | 1 | **0** | 0 | **4** | 3 | **4** | 3 | **0** | 0 |
| **Blowing Dust** | **0** | 0 | **0** | 0 | **0** | 0 | **1** | 1 | **0** | 0 | **0** | 0 | **1** | 1 |
| **Total** | **99** | 100 | **108** | 100 | **118** | 100 | **105** | 100 | **121** | 100 | **129** | 100 | **77** | 100 |

* Historical data from Texas DPS Crash Database.

In each case of rain, the rain could have influenced the crash, as it may have limited visibility, the ability to maintain control, and the ability to brake or swerve effectively to avoid the collisions. It should also be noted that the one instance of blowing dust was due to the work activity of the contractor within the work zone, and so was also considered an influence on the crash.

## Lighting Conditions

An analysis of lighting conditions was conducted to see if there was a predominant period when crashes were more likely. As shown in Table 8, neither daylight nor dark conditions appeared to be more likely to be present at the time of a fatal work zone crash. Compared with historical data, this trend seems consistent from 1996 through 2001, and also for the data collection period for this project.

## Alcohol Involvement

The data were also analyzed to determine the extent of alcohol involvement in fatal work zone crashes. Researchers found that 22 percent of all of the fatal crashes investigated involved

**Table 8. Comparison of Work Zone Fatal Crashes by Lighting Conditions.**

| Lighting Conditions | 1996* | | 1997* | | 1998* | | 1999* | | 2000* | | 2001* | | Data Collection Period 2/03-4/04 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # | % | # | % | # | % | # | % | # | % | # | % | # | % |
| **Daylight** | **50** | 51 | **51** | 47 | **63** | 53 | **51** | 48 | **60** | 50 | **63** | 49 | **35** | 45 |
| **Dawn/Dusk** | **3** | 3 | **4** | 4 | **4** | 3 | **4** | 4 | **4** | 3 | **7** | 5 | **2** | 3 |
| **Night** | **46** | 46 | **53** | 49 | **51** | 43 | **50** | 48 | **57** | 47 | **59** | 46 | **40** | 52 |
| **Total** | **99** | 100 | **108** | 100 | **118** | 100 | **105** | 100 | **121** | 100 | **129** | 100 | **77** | 100 |

* Historical data from Texas DPS Crash Database.

alcohol and/or drugs. As shown in Table 9, this value, while at the low end of the range, is consistent with the values found historically from 1996 through 2001 in the Texas DPS Crash Database.

**Table 9. Comparison of Work Zone Fatal Crashes by Alcohol Involvement.**

| Weather Conditions | 1996* | | 1997* | | 1998* | | 1999* | | 2000* | | 2001* | | Data Collection Period 2/03-4/04 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # | % | # | % | # | % | # | % | # | % | # | % | # | % |
| **Alcohol/Drug Presence** | **35** | 35 | **41** | 38 | **33** | 28 | **36** | 34 | **25** | 21 | **32** | 25 | **17** | 22 |
| **No Presence** | **64** | 65 | **67** | 62 | **85** | 72 | **69** | 66 | **96** | 79 | **97** | 75 | **60** | 88 |
| **Total** | **99** | 100 | **108** | 100 | **118** | 100 | **105** | 100 | **121** | 100 | **129** | 100 | **77** | 100 |

* Historical data from Texas DPS Crash Database.

Alcohol involvement was one variable that the researchers had to rely entirely on the police crash reports provided by the officers who responded to the crash. Often the crash report forms that were provided indicated that a blood alcohol test had been taken, but that the results were still pending. Attempts to follow up on these results did not always yield useful data, as several DPS offices across Texas appear to have a policy of not releasing data of this type prior to its entry into the Texas DPS Crash Database. As a result, the researchers had to infer if alcohol or drugs were present. In order to be consistent in the analysis, a particular crash was considered to have alcohol or drug presence if:

- the blood alcohol content or drug presence was so stated on the crash report form,
- a follow-up article could be obtained from local newspapers that indicated alcohol or drug involvement,
- verbal reports were received from TxDOT officials to that effect, or
- the crash report indicated that blood alcohol and drug tests were pending, combined with factual evidence from the crash consistent with drunk driving, including:
  - vehicle leaving the appropriate traveled lane, and/or
  - reports of erratic driving prior to the crash.

It is likely that because of the problems in clearly identifying the extent of alcohol and/or drug involvement in the investigated crash sites, future values obtained from the Texas DPS Crash Database may be different from those presented in this research.

**Large Truck Involvement**

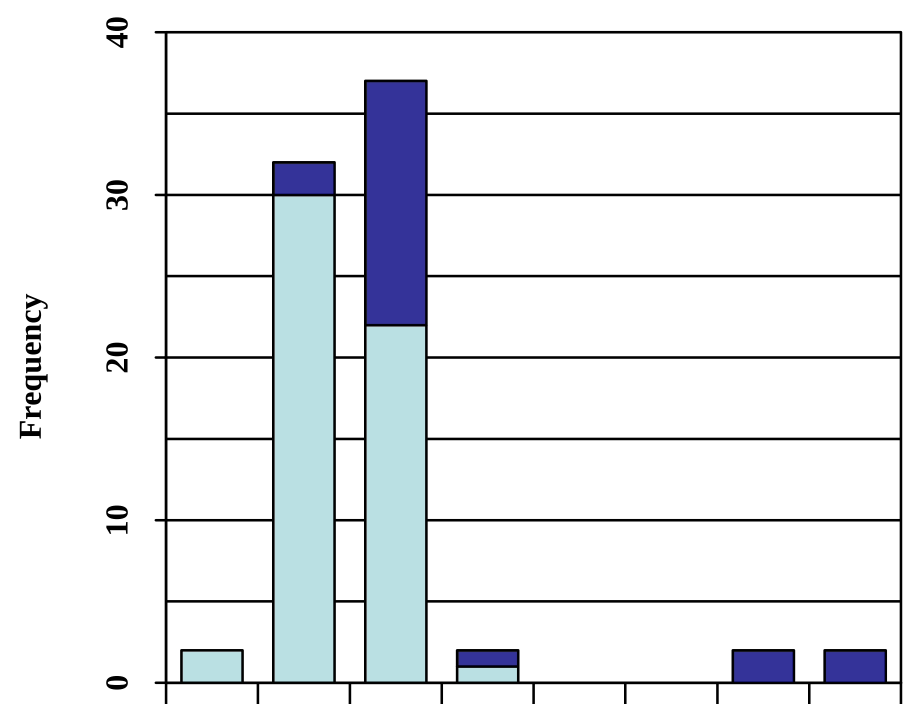
The data were also analyzed to determine the extent of large truck involvement in fatal work zone crashes. Researchers found that 29 percent of all of the fatal crashes investigated included a large truck, typically with the vehicle striking another vehicle or vehicles. As shown in Table 10, this value, while at the low end of the range, is also consistent with the values found historically from 1996 through 2001 in the Texas DPS Crash Database.

In addition, there appeared to be a trend in the data that large truck-involved crashes were more likely to involve more than two vehicles. Figure 3 reveals that large truck crashes represented five of the six crashes that involved three or more vehicles. These crashes were predominantly occasions where a large truck failed to stop in time to avoid queued traffic at a work zone transition or activity area. This seems reasonable because the energy that a large truck can transfer to other vehicles in a crash make it more likely to hit multiple vehicles than if the out-of-control vehicle were an automobile.

**Table 10. Comparison of Work Zone Fatal Crashes by Large Truck Involvement.**

| Weather Conditions | 1996* | | 1997* | | 1998* | | 1999* | | 2000* | | 2001* | | Data Collection Period 2/03-4/04 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # | % | # | % | # | % | # | % | # | % | # | % | # | % |
| Large Truck Involvement | **40** | 40 | **32** | 30 | **32** | 27 | **42** | 40 | **50** | 41 | **46** | 36 | **22** | 29 |
| No Large Truck Involvement | **59** | 60 | **76** | 70 | **86** | 73 | **63** | 60 | **71** | 59 | **83** | 64 | **55** | 71 |
| **Total** | **99** | 100 | **108** | 100 | **118** | 100 | **105** | 100 | **121** | 100 | **129** | 100 | **77** | 100 |

* Historical data from Texas DPS Crash Database.




| | Other | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Large Truck-Involved | 0 | 2 | 15 | 1 | 0 | 0 | 2 | 2 |
| Passenger Vehicle Only | 2 | 30 | 22 | 1 | 0 | 0 | 0 | 0 |

**Figure 3. Analysis of Large Truck Involvement by Number of Vehicles Involved in Crash.**

## ASSESSING THE LEVEL OF WORK ZONE INFLUENCE ON CRASHES

In the previous section, researchers demonstrated the comparability of the data collected during the site investigations to traditional work zone crash characteristics monitored through available crash database information. In the remaining sections of this chapter, the researchers emphasize the key findings that were obtainable only through the collection and analysis effort undertaken during this project.

One of the major factors that was of interest in this research was the extent to which the presence of a work zone contributed to a specific crash. One hypothesis was that a portion of the crashes that occur in work zones would have *no influence* at all by the presence of the work zone. Stated another way, it was expected that the work zone's presence played no part in the chain of events of at least some of the crashes; there is no reason to expect that these crashes would have been altered at all if the work zone had never been there, or was already completed and removed from the roadway. Examples of this might include a fatal crash in an area zoned as a work zone, but no work had yet been done, and only the project limit signs were present. A second example would be if a fatal crash occurred in a long buffer area within the work zone where no activity and minimal temporary traffic control devices were present.

At the other extreme, there was the potential that some of the crashes were *directly influenced* by the presence of the work zone. For example, a direct influence would be if the traffic control plan was improperly laid out, a key traffic control device was missing, or if the traffic control was misleading to drivers. Researchers expected the number of direct influences from work zones would be low, as such obvious discontinuities between these problems and accepted traffic control plans would be rarely found on the roadway.

In between these two extremes lies the area of analysis where the work zone indirectly influenced the chain of events of the crash. Several examples that follow help to properly define this type of crash. First, the work zone provided an indirect influence in the case where a contractor's worker was struck and killed in a work zone, but no problems were observed with the traffic control plan of the work zone. The work zone layout cannot be faulted as a direct influence, but the work zone still played a part in the chain of events of the crash: if there was no work zone there would have been no worker to hit. Other examples would be if a vehicle struck a traffic control device or temporary barrier that would not have been present if the work zone was not present, or if the work zone required the removal of one or more permanent roadside devices, such as pavement striping, overhead lighting, or similar features that might have slightly altered the chain of event of a crash.

Two additional categories added to the analysis were non-driving work zone fatalities and fatalities that occurred during work zone traffic control setup or tear-down. Non-driving fatalities were reported for times when some special circumstances occurred that were not affected by traffic control or traffic. An example would be if a worker was killed in a work zone activity area by a piece of construction equipment or construction material. Traffic control setup and tear-down periods are recognized as unique times during a work zone where workers are more likely to be in close proximity to traffic, and so researchers separated these fatal crashes from the others.

Each crash was analyzed to determine the extent of the work zone's influence. The results of this analysis can be found in Figures 4 and 5. Figure 6 shows the breakdown of the crashes by work zone influence. As can be seen, 45 percent of the investigated fatal crashes were categorized as having no influence from the work zone. Indirect influences were identified in 39 percent of the crashes, direct influences in 8 percent of the crashes, with non-traffic fatalities and work zone setup or tear-down accounting for 4 percent of crashes, respectively.

The current DPS Crash Database does include a data field to indicate whether a crash identified as occurring in a work zone was related or unrelated to the work zone, but such determinations appear to be made by data entry staff coding in the crash based on the narrative of the crash report form provided by the investigating officer. In 2001, 90 percent of the crashes coded as occurring in a work zone were also coded as being unrelated to the work zone (with 10 percent coded as being work zone related). One of the areas of interest to this research team was the level of agreement between the site assessments performed in this project and the DPS Crash Database with regards to whether the work zone was related to the crash in some fashion. This is shown numerically in Table 11. Interestingly, the percentage of work zone crashes identified as being work zone related in the DPS Crash Database (10 percent) is very similar to the percentage of crashes investigated in this project that researchers indicated had either a direct work zone influence (8 percent) or that occurred during the traffic control setup or removal (4 percent). Meanwhile, the large percentage of work zone crashes coded as unrelated to the work zone in the DPS database (90 percent) is much larger than the 45 percent of crashes investigated in this project that researchers concluded had no direct work zone influence. The

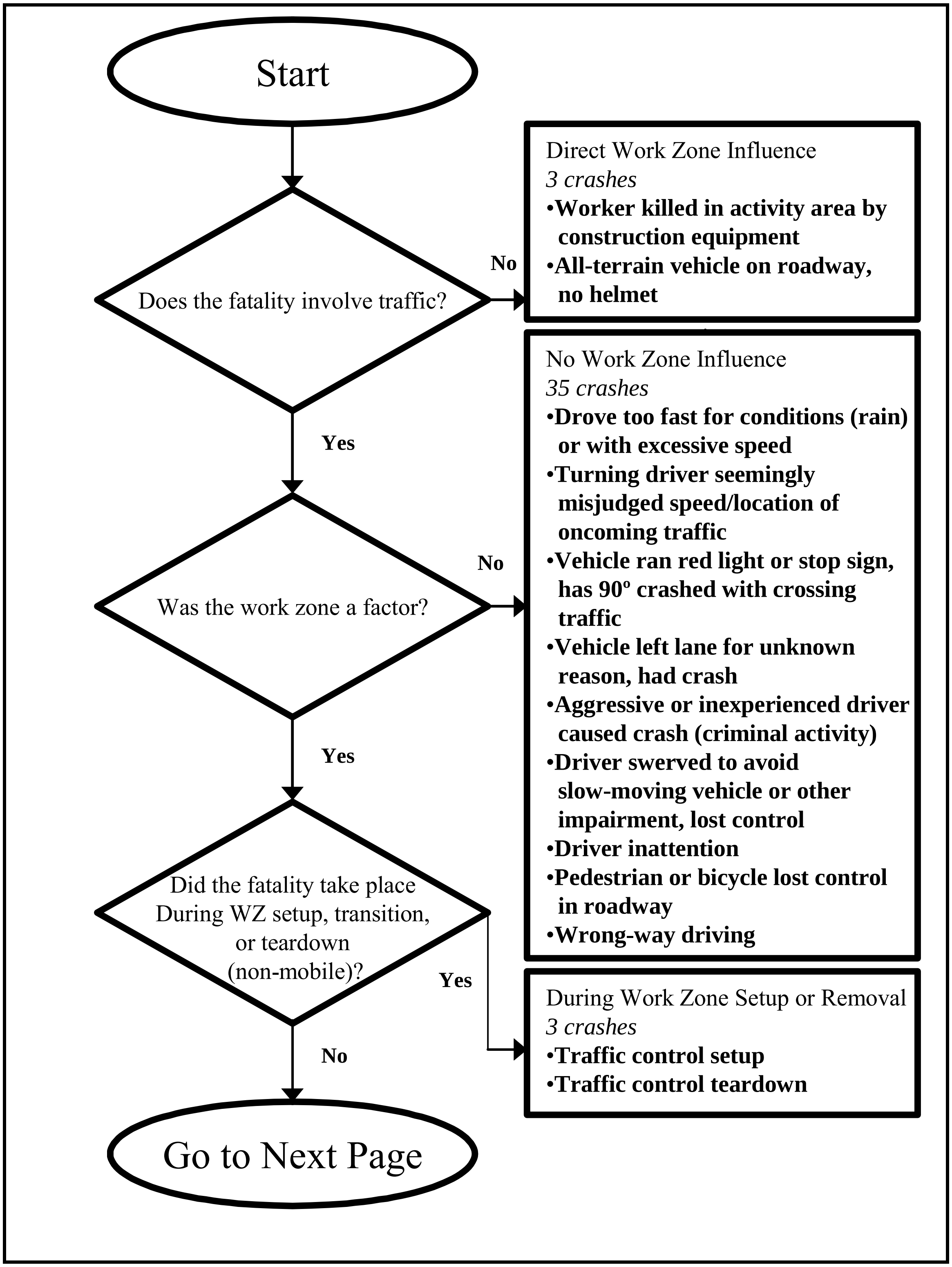



**Figure 4. First Part of the Data Analysis Flowchart with Final Data.**

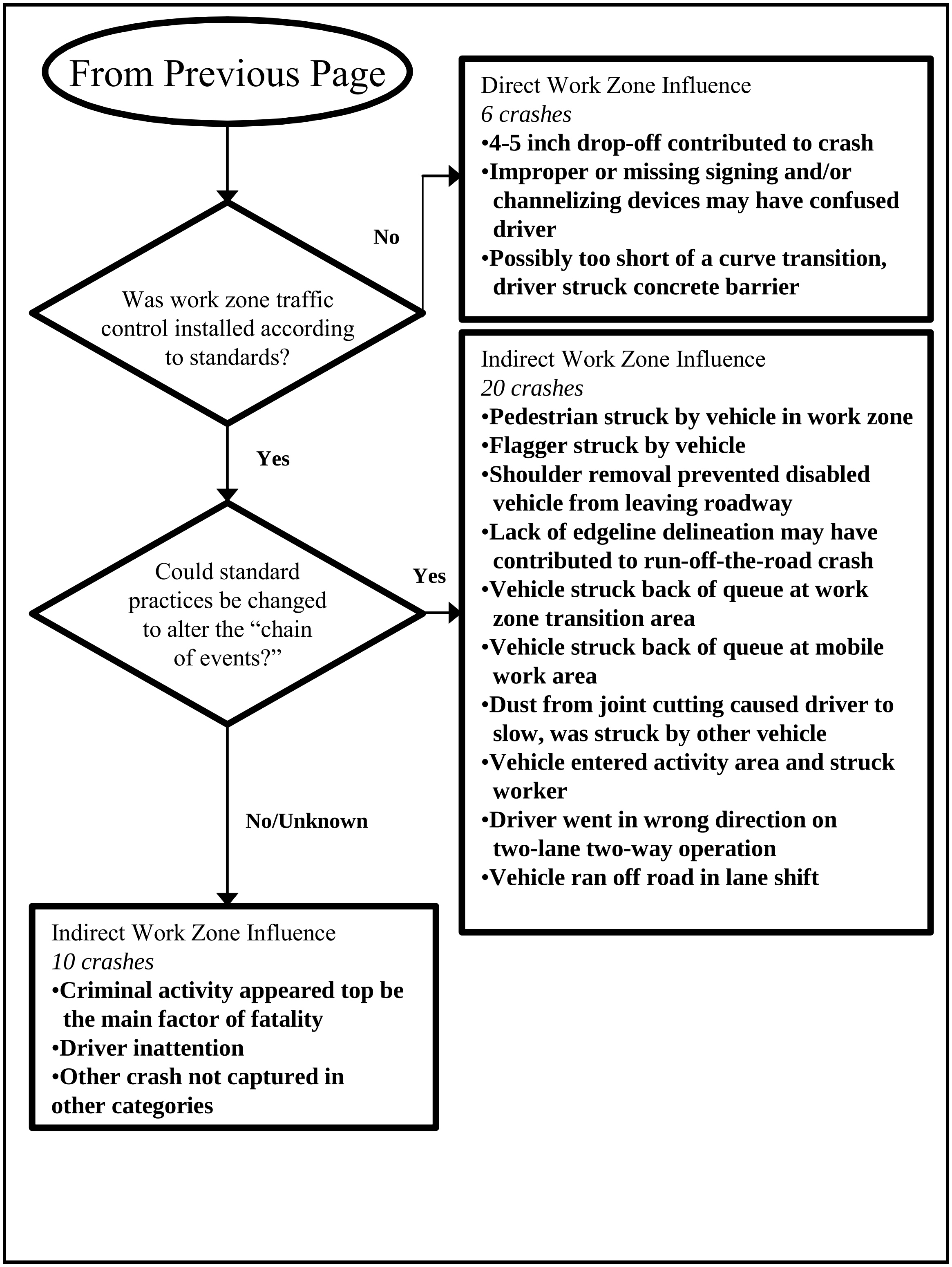



**Figure 5. First Part of the Data Analysis Flowchart with Final Data.**

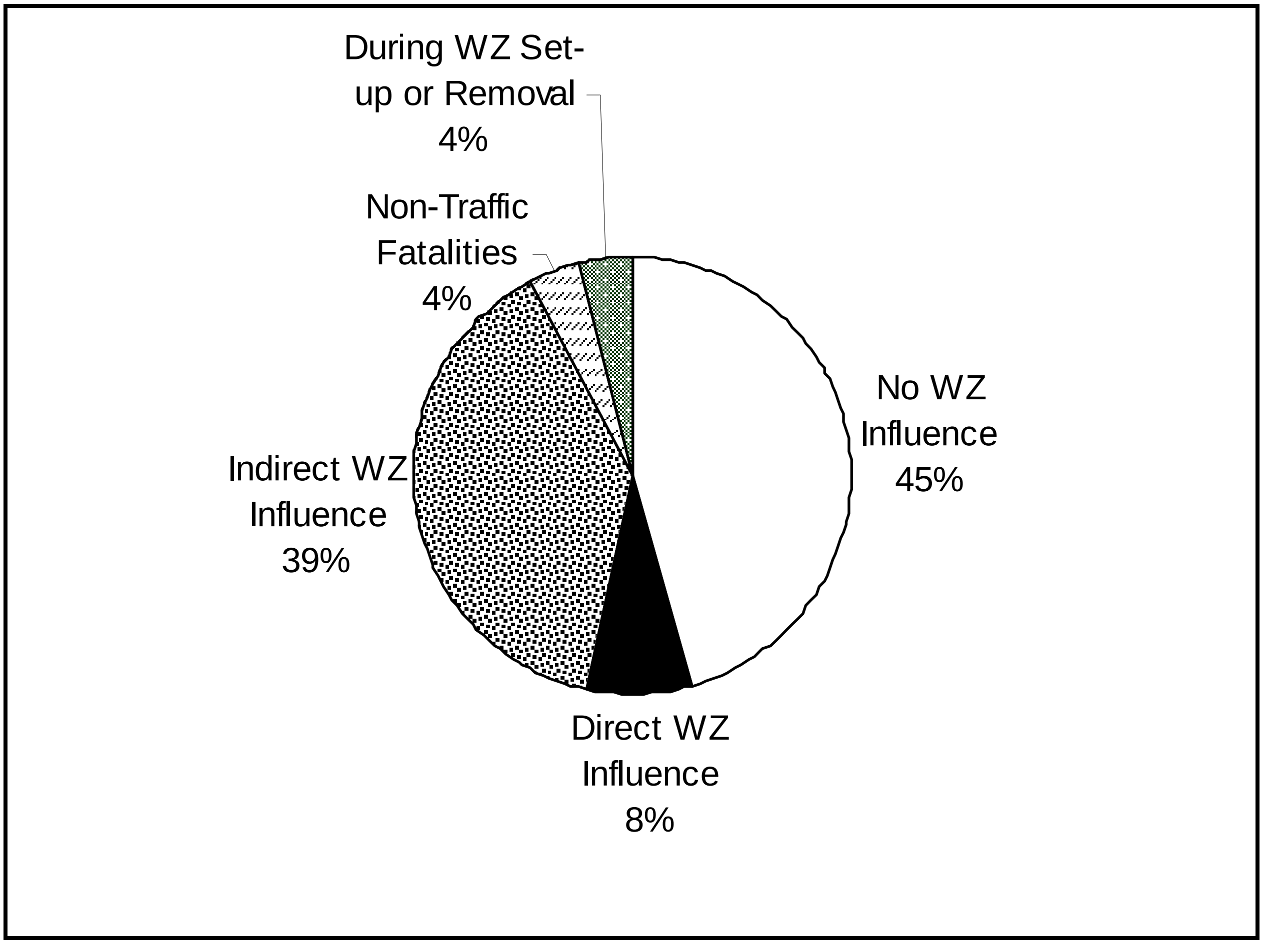



**Figure 6. Proportion of Work Zone Fatal Crashes by Level of Work Zone Influence.**

**Table 11. Comparison of Work Zone Influence Categories on Crashes.**

| Work Zone Conditions | Texas DPS Crash Database* | | Data Collection Period 2/03-4/04 | |
|---|---|---|---|---|
| | # | % | # | % |
| **Direct Influence/ Related** | **1049** | 10 | **6** | 8 |
| **During Traffic Control Setup or Removal** | | | **3** | 4 |
| **Indirect Influence** | **9488** | 90 | **30** | 39 |
| **No Influence/ Not Related** | | | **35** | 45 |
| **Non-Traffic Fatalities** | **---** | --- | **3** | 4 |
| **Total** | **10,537** | 100 | **77** | 100 |

* 2001 data (all work zone crashes).

most likely reason for this discrepancy is the sizeable proportion (39 percent) of investigated crashes that researchers in this project attributed to an indirect work zone influence. Such a difference is understandable, as DPS data entry personnel who make the determination of whether a crash is work zone related in the database do not have the same site-specific work zone knowledge available as obtained by the researchers in this project. In addition, researchers hypothesize that most information about a work zone included in an officer's crash report form is likely to be there because it has some causal (in the investigating officer's opinion, anyway) implications, and so is naturally included in the crash narrative provided by that officer.

# CHAPTER 5:
# POSSIBLE COUNTERMEASURES TO IMPROVE WORK ZONE SAFETY

From the analysis of the site review reports, 26 possible countermeasures were identified with at least the possibility altering the chain of events at one or more of the investigated crash sites. As would be expected given the distribution of crashes illustrated in Figures 4 and 5, most of the suggested countermeasures address indirect work zone influences. Each of these 26 possible countermeasures were further considered, with the potential advantages and disadvantages detailed. The full listing of possible countermeasures is listed in Appendix B. Upon further consideration, researchers judged that many of these countermeasures have disadvantages that were too significant and/or numerous to merit further evaluation. In this chapter, researchers present those countermeasures that truly appear to have feasible crash mitigation potential at work zones statewide.

## Possible Countermeasures Recommended for Further Development

The full list of possible countermeasures was reduced to include only those possible countermeasures that could be expected to provide an overall safety improvement for TxDOT work zones. In order to make the final list, the possible countermeasures had to meet the following basic criteria:

- TxDOT could control or specify the implementation of the change.
- The countermeasure would not significantly change fundamental traffic control plans (such as not requiring the elimination of moving/mobile work zone or other infeasible recommendations).
- Engineering judgment by the research team provided a belief that the possible countermeasure would provide a safety benefit in excess of the cost of implementation, even though quantifiable numbers for costs or benefits were not available.
- Any technology needed to implement the change (if any) was commercially available or could reasonably be created or modified to suit TxDOT's needs.

The final list comprises the following eight possible countermeasures:

- Encourage flaggers to have audible warning devices (i.e., horns) with them at flagger stations to warn the work crew of an out-of-control vehicle that appears unable to stop and is about to encroach into the activity area.
- Encourage additional research into panic button-type safety clothing to be worn by all workers to warn each other of out-of-control vehicles that may encroach upon the activity area.
- Consider experimentation and eventual implementation of a highly mobile barrier system for short-term work zone activity areas, such as that currently under development in California.
- Consider requiring the use of channelizing devices to continuously delineate roadway edges at night when rumble strips and/or edgeline pavement markings are removed or missing temporarily due to pavement resurfacing or replacement.
- Require that a mobile work operation being performed on a paved shoulder be capable of switching to the appropriate traffic control for a mobile operation moving in an active travel lane, if the facility has periodic shoulder discontinuities due to bridges or other constraints that will require the operation to occasionally move into or encroach upon the travel lanes.
- Consider requiring exits or break-down refuge areas be made available at regular intervals (2 miles or less) in work zones where both shoulders are removed for construction.
- At work zones where the direction of travel is changed temporarily in one or more lanes (i.e., a four-lane facility that is converted to two-lane, two-way operation), encourage the use of opposing lane dividers or lane use arrow pavement markings to reinforce the fact that the travel direction for the lane has changed.
- Discourage traffic control plan designs that include transition areas for the work zone on an existing horizontal curve, and encourage that the transition be accomplished on a tangent section instead.

*Audible Warning Device and Personal Warning Device Technology*

During the course of this research, there was one instance where a vehicle encroached directly into the activity area of a work zone and killed a TxDOT contractor employee. The work zone in question was a flagger-controlled moving/mobile operation. The flagger was unable to stop the vehicle, which went on to strike a worker in the activity area. Had the flagger been equipped with an audible warning system, he could have attempted to warn the workers in the activity area in time to prevent the fatality.

Several devices are currently available on the market that could be used or modified for use in this situation. Automated systems, such as that shown in Figure 7, incorporate $CO_2$-powered alarm technology attached to cones and barrels (*22*). When the cones or barrels are overturned, a loud alarm sounds. Such a system could be used as is by placing the device next to a flagger or could be modified to create a handheld device for the flagger. A similar system could also be built around even more basic technology such as handheld air horns developed for boating and wilderness safety. Other technology that could be modified includes those available that make use of infrared beams, with the system broadcasting an alarm if the beam is broken, as shown in Figure 8 (*23*).

Another version of an audible warning technology incorporates personal body alarms such that when a cone or barrel is struck, a warning is radioed to an alarm worn on each worker's body. Workers in the vicinity of loud equipment can get the same warning inside a pair of ear-covering hearing protectors. Examples of this technology can be found on the Internet (*24*). Systems of this type are largely unproven and have had limited field use to date. While their potential safety benefits seem clear, field trials would be necessary prior to requiring their use in Texas.

*Highly Mobile Barrier System Technology*

During the course of this research, there was one instance where a vehicle encroached directly into the activity area of a work zone and killed a TxDOT contractor employee. The work zone in question was a flagger-controlled moving/mobile operation. Some type of barrier technology that could have been quickly installed and removed at the activity area could have prevented this fatality. There is one currently available commercial portable barrier system that consists of steel barrier sections on wheels that can be repositioned quickly (*25*). The system has


**Figure 7. Example of an Audible Warning Vehicle Intrusion System *(22)*.**


**Figure 8. Example of Line-of-Sight Intrusion Warning Technology *(23)*.**

been successfully tested according to the National Cooperative Highway Research Project (NCHRP) Report 350 test levels 2 and 3. This system, once erected, can be towed behind a pickup truck or equivalent along the roadway at low speed to allow for ease of movement. An example of this system being relocated is shown in Figure 9. A second system has been developed by Caltrans, which incorporates a barrier system built on a large truck chassis, allowing workers on short-term projects with small activity areas to work within the confines of the system *(26)*. The system is a rigid rail that deflects any vehicle that attempts to encroach upon the activity area, and in conjunction with a truck-mounted attenuator vehicle behind provides both side and rear protection to workers. A photo of the Caltrans system in use is shown in Figure 10.


**Figure 9. Example of a Highly Mobile Barrier System.**

The advantage of either of these systems or another similar system is the positive protection afforded to workers. Any encroaching vehicle would likely be deflected or stopped before striking a worker. Disadvantages in their use would include the increased cost of their

**Figure 10. Caltrans Highly Mobile Barrier System (*26*).**

implementation and use and some corresponding modest increase in setup and removal of such a traffic control system. The research team believes that short-duration work zone safety can be improved through the use of traffic control devices such as the ones listed here.

*Temporary Traffic Control Devices to Delineate Roadway Edges When Other Edgeline Delineation Is Not Present*

There were five crash investigations during the course of this research where a vehicle left the roadway at night in a work zone where edgeline striping had been removed due to repaving operations. While other factors may have played primary roles leading to the crash, the fact that the striping was absent may have indirectly played a role. Additionally, there was one daytime crash at a work zone with similar characteristics where there were no edgeline rumble strips. If additional traffic control had been present at the edges of the roadway, the chain of events may have been altered, which could reduce the possibility of a fatality.

The use of temporary traffic control devices such as cones, barrels, and/or vertical panels at locations where edgeline striping and edgeline rumble strips are removed could provide a safety benefit by better indicating the edge of the traveled lanes. There is, however, no evidence that this action will result in a quantifiable reduction in work zone fatalities or crashes, and this possible countermeasure should be further evaluated prior to large-scale implementation.

*Enhanced Traffic Control Plans for Shoulder Operations*

At one fatal work zone location, a mobile work convoy was moving along the shoulder of the highway. When the convoy moved onto a several mile-long bridge, the shoulder was too narrow to accommodate the convoy, so the work convoy moved slightly into the right-hand lane, requiring traffic to vacate that lane. However, due to heavy traffic, a queue subsequently formed behind the work convoy. A vehicle struck the back of the queue, killing a motorist. The work convoy reportedly acted according to current standards, which seems to indicate that an additional countermeasure is needed in instances such as these to provide traffic additional warning that they are approaching a slow-moving convoy in their lane.

One recommended countermeasure to address this issue would be a change in the traffic control plan for shoulder mobile operations to what would be used if the convoy was operating entirely in the traveled lanes. Specifically, this would be a change from using Typical Application 4 ("Short-Duration or Mobile Operation on Shoulder") found in Part VI of the MUTCD to using Typical Application 35 ("Mobile Operation on Multi-lane Road") *(4)*. This could be especially beneficial at locations where discontinuities or narrow sections of shoulder (such as on bridges) force the work convoy into the adjacent lanes.

*Break-Down Refuge Areas at Removed Shoulder Locations*

There was one instance at a work zone activity area where a vehicle suffered a breakdown and was unable to continue on through the work zone. The work zone had two lanes open in this particular direction, but the outside shoulder was blocked by concrete barriers to provide additional work space for the contractor. With no shoulder space to move into, the disabled vehicle came to rest in the right-hand lane, causing a traffic queue behind it. The driver of a large truck did not notice the queue until it was too late to avoid a collision and struck the stopped vehicles at the back of the queue. One possible countermeasure that could avoid future crashes of this type would be to provide some way for drivers of disabled vehicles to get out of the traveled lanes, thereby eliminating any queue formation altogether. Ideally, leaving continuous shoulders would be the best alternative, but this approach does not take into consideration times when narrow rights-of-way require removal of shoulder space just so the contractor has room to work. However, leaving occasional shoulder space throughout the work zone to provide emergency breakdown space could be a viable alternative.

Previous research found that placing work zone enforcement areas (essentially the same concept but reserved for law enforcement use) every two miles in work zones with removed shoulders could minimize impacts to the contractor's work activity on the other side of the concrete barrier and still provide room for motorists to get out of the traveled lanes when necessary (*27*,*28*). This previous research could reasonably be used as a starting point for further developing the concept of designing and placing breakdown areas.

*Additional Traffic Control at Locations Where Traffic Is Reverse the Non-Work Zone Direction*

One work zone fatality occurred at a location where a four-lane concrete barrier-separated facility was converted to a two-lane two-way operation. A vehicle turned onto the roadway from an intersection within the work zone and entered into the wrong lane. Due to an existing crest vertical curve, the driver who made the wrong maneuver could not see approaching traffic until it was too late to avoid a crash. The work zone was laid out according to current standards, and traffic control was in accordance with the traffic control plans. It is believed that the driver who selected the wrong lane could have been accustomed to selecting that lane under non-work zone operations and did not notice the work zone traffic control indicating that the lane was operating in the opposite direction. Getting such a driver's attention in time to prevent a crash can result in an overall safety improvement at Texas work zones.

Researchers recommend that additional traffic control be required at locations where a driver turning into a work zone may go the wrong direction. Simple traffic control devices, such as the lane direction arrows shown in Figure 11, have been shown to have beneficial safety influences on wrong-way driving in other situations, and it is believed that the same safety benefit can be realized in work zone situations (*29*). Other additional traffic control measures,

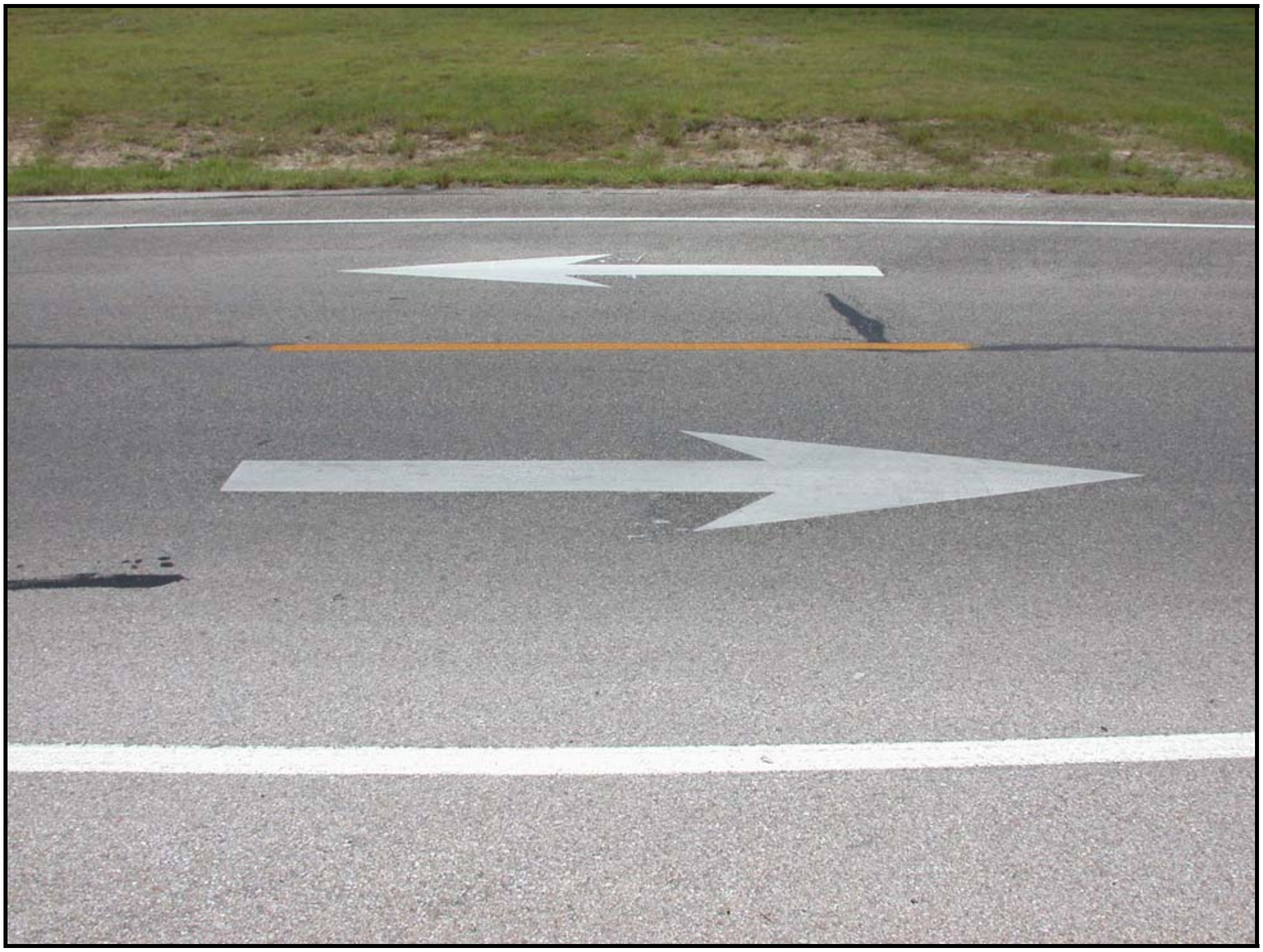


**Figure 11.  Example of Lane Direction Arrows to Reduce Wrong-Way Driving.**

such as opposing lane dividers, may have similar safety benefits as well, and any simple device that can minimize such wrong turns should be investigated for possible use.

It should be recognized that current work zone standards may not address every situation where work zones affect intersections.  Special efforts should be made by designers, engineers, and inspectors to recognize these situations (either in design and/or during construction) to make appropriate changes in work zones in a timely manner.  In some cases, designers and engineers may become complacent in thinking that the design standards cover all possible situations.  In reality, intersections should be individually considered to ensure that Positive Guidance is given to motorists in situations where a driver expectation or familiarity is violated.

*Move Transition Areas Upstream from Horizontal Curve*

One work zone fatality occurred when a vehicle left the roadway at a work zone transition area. The transition area occurred in a horizontal curve, and the transition itself required a sharper curve in the same direction, resulting in a tightening of the curve, which may have caught the driver unaware. While these transitions are often essential in order to relocate traffic away from the activity areas, it should be possible to locate transition areas only on tangent sections of roadway so that drivers only have to deal with one geometric change at a time. The potential cost increase should be minimal, as in most cases this would only require additional temporary traffic control such as cones, barrels, etc., to be extended upstream to the nearest tangent section.

**Possible Countermeasures That Could Be Beneficial But Are Not Completely under TxDOT Control**

There were also 11 countermeasures that met many of the above-mentioned criteria and had the potential for improving safety, but had some drawback that may limit the likelihood of successful implementation or, if implemented, may inhibit the anticipated safety benefit. These countermeasures are listed here due to the potential for a safety improvement, recognizing that the possible countermeasures could have more significant drawbacks than those in the previous list. These possible countermeasures include:

- enact legislation to increase fines for pedestrians trespassing in or across work zones, and
- require traffic-responsive warning of stopped or slowed traffic at a work zone transition area.

*Enact Legislation to Increase Fines for Pedestrians Trespassing in or across Work Zones*

There were three instances of fatalities involving pedestrians or persons driving vehicles not intended to be driven on the roadway. In each of these instances, the persons were crossing or traveling along the roadway where the work zone was present and were struck by a vehicle. Two out of the three instances occurred at night when the pedestrians were less visible due to diminished lighting. The pedestrians may not have realized that in addition to this reduced visibility, the drivers of the passing vehicles had other objects in the vicinity to keep track of, such as temporary traffic control and other traffic. In addition, motorists have come to expect that any person in a work zone would be a worker wearing high-visibility apparel.

In order to discourage pedestrians from moving across or along highway work zones, the researchers suggest that legislation creating a penalty for this action could reduce the number of pedestrians in work zones. This law would also provide law enforcement with legitimate reason for stopping and warning a pedestrian of the dangers of moving through work zones when passing motorists may not realize they are there. Any locations where pedestrians would have a legitimate need to cross the work zone would still have approved crossing locations, such as crosswalks, which should be allowed in any legislation.

This possible countermeasure may reduce the number of pedestrians who choose to walk across or along a work zone area at locations other than crosswalks. However, no data exist to determine the extent of the safety improvement. Additionally, because any legislative change requires the action of the Texas legislature, TxDOT has no direct control over this possible countermeasure's implementation. Regardless, the need to keep pedestrians out of work zone areas remains an issue that this possible countermeasure could address.

*Traffic-Responsive Warning of Stopped or Slowed Traffic at a Work Zone Transition Area*

Several fatal crashes occurred during the study at the work zone activity area and/or merge area where traffic slowed down, a queue formed, and subsequent traffic rammed the back of the queue. In every instance of this type of crash, the traffic control was installed according to current standards and in accordance with the project traffic control plans, which provides an indication that more warning is needed to alert traffic of slow or stopped traffic ahead. Ideally, this warning would be only used when needed, in other words, such a warning would be traffic responsive.

Commercial models are currently available that provide traffic-responsive warning *(30)*. These systems use Doppler radar or some other remote-sensing technology to analyze the speed of traffic at critical points in the work zone, and when a breakdown in traffic speeds occurs, the system relays warnings to one or more upstream dynamic message signs.

The costs of implementing this countermeasure could be high, as it would require the use of quantities of new equipment in a work zone. The resources may not be available to implement this type of technology at every work zone that could experience a breakdown in traffic flow, so some type of prioritization would have to be developed to determine which work zones could benefit the most from such systems. There is currently no process in place to perform this statewide prioritization, so that would have to be developed in order to gain the maximum use of this possible countermeasure.

## CONTINUING THE FATAL WORK ZONE CRASH DATA COLLECTION AND ASSESSMENT PROCESS

The data collected for this research project over the past two years have provided important insights into the characteristics and influences of work zone fatal crashes in Texas. These insights would not have been possible with traditional crash report forms and resulting databases. Specific emphasis on identifying and assessing work zone features present at the time of the crash allows an analyst to distinguish between those crashes that are indeed "influenced" by the characteristics of the work zone and those that are not and would have likely occurred even if the work zone had not been in place. This assessment is different than attempting to identify a crash as "work zone related," as is done by DPS staff during the database coding process of the actual crash report form (typically entered in the database several months or even years after the crash). Rather than attempt to identify the primary or even secondary causational factor, the emphasis is on determining whether some aspect or feature of the work zone potentially played any role in the overall crash chain-of-events. Expertise in work zone traffic control, roadway geometrics (permanent and temporary), and driver information processing trends are all valuable in this assessment process.

The assessment process as described allows differentiation between work zone features and conditions that directly influence or contribute to a crash (such as a missing warning device or a work zone location positioned just over a crest vertical curve) and those that have an indirect influence (by reducing or eliminating a possible recovery area if the driver inadvertently leaves the travel lane, for example). The latter category may be where the greatest improvements in work zone safety can be made, as the analysis discussed in this report indicates that only a small portion of work zone fatalities are directly influenced by work zone features themselves. In other words, incorrect or improper work zone configurations or traffic control are not necessarily associated with the majority of fatal work zone crashes. Rather, it is the more subtle degradations in such things as roadway capacity, refuge and recovery areas, and guidance information (i.e., edgeline delineation, continuous shoulder rumble strips) that allow work activities to be accomplished in as timely and cost-effective manner as possible, but which still indirectly appear to influence work zone crash likelihood and consequences. Identification and assessment analyses of these indirect influences has already helped to better understand the trade-offs being made between accomplishing the work as quickly and efficiently as possible and the potential crash consequences of the degradations accepted during construction.

Now that the research project has been completed, it is appropriate to consider whether TxDOT should continue to pursue and analyze these data internally. An ongoing analysis of work zone fatal crashes is likely to continue to bring to light new areas where low-cost countermeasures might be deployed to improve work zone safety. Other state highway agencies have decided that collection and analysis of work zone-specific crash data are valuable enough to commit labor and financial resources to the process. For example, the New York State Department of Transportation (NYSDOT) has had a rigorous internal work zone accident data collection program in place since the early 1990s (*11*,*31*). The process is more rigidly structured with limited data fields and pre-determined codes for those fields, similar to a standard crash report form (*16*). Even so, regular analyses of those data have led to the adoption of a number of new policies and practices by NYSDOT to improve work zone safety (*32*). Likewise, the Iowa Department of Transportation has reportedly established procedures to internally collect, code, store, and evaluate work zone-specific crash data. In addition to providing useful insights into the safety problems being experienced in various work zone types and activities and the possible countermeasures that could be implemented to address them, the researchers believe that having the data available to support whatever changes are adopted assists in acceptance and compliance by highway contractors and others who must ultimately implement and abide by those new countermeasures.

For these reasons, the researchers recommend that TxDOT adopt a similar approach to the continued collection of work zone data through internal processes. The research project has demonstrated the viability of relying on responsible field personnel in the districts to identify when work zone crashes have occurred. The field evaluation used in this research and presented in Appendix A could easily be adopted to help direct those field personnel in an evaluation of each fatal work zone crash that occurs. These evaluations could then be sent to the TxDOT Traffic Operations Division or a similar group for collation and periodic interpretation of the results.

# CHAPTER 6: SUMMARY

This project undertook an in-depth analysis of fatal work zone locations in Texas by supporting the collection of data regarding work zone configuration and characteristics that are generally not made available through the DPS Crash Database or traditional police crash report forms. The data, which could be compared with previous research results and data, were largely in line with those data, indicating that the sample of data obtained was reasonably representative of work zone crashes in Texas, although likely not exhaustive in terms of the total number of fatal crashes that occurred statewide during the data collection period. Additionally, the data collection methodology allowed analyses not previously available through other methods. For example, the following points were determined that would not have been possible otherwise through state or national crash databases:

- only 8 percent of the investigated crashes had a direct influence from the work zone,
- 4 percent of the crashes involved highway workers during traffic control setup or removal (these crashes represented more than 40 percent of the total worker fatalities investigated during the project),
- 39 percent of the investigated crashes had an indirect influence from the work zone, and
- 45 percent of the investigated crashes appeared to have no influence from the work zone (included in this subset are the 16 percent of the investigated crashes that occurred in work zones that were work zones in name only).

The crash investigations also provided unique insights into how and what characteristics of the work zones might have played some type of role in the overall chain-of-events for each crash. Researchers utilized this information in generating a series of possible crash countermeasures to intervene in the crash chain-of-events where plausible. Researchers critiqued each countermeasure and arrived at a final list of eight strategies that TxDOT should consider adopting or pursue further with research and development efforts. Some of those involve examination of new technologies:

- flagger audible warning devices,
- worker-activated panic button warning systems worn by all personnel in the work area, and
- highly mobile barrier system for short-term work zone activity areas.

Other potential countermeasures recommended by the researchers make use of traditional work zone traffic control devices, but suggest additional applications or strengthened guidance to ensure their proper use in non-standard situations:

- Use channelizing devices to continuously delineate roadway edges at night when rumble strips and/or edgeline pavement markings are removed or missing temporarily due to pavement resurfacing or replacement.
- Require that mobile work operations being performed on a paved shoulder switch to the appropriate traffic control for a mobile operation moving in an active travel lane whenever encroaching into an actual travel lane.
- Consider requiring exits or break-down refuge areas be made available at regular intervals (2 miles or less) in work zones where both shoulders are removed for construction.
- Encourage the use of opposing lane dividers or lane use arrow pavement markings at sites where travel direction in a particular lane has changed temporarily (such as when lanes are closed on multi-lane facilities and two-way traffic is handled in the remaining open lanes).
- Discourage traffic control plan designs where lane shift transition areas occur on an existing horizontal curve, and encourage that the transition be accomplished on a tangent section instead.

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# APPENDIX A: DATA COLLECTION AIDS USED DURING FATAL CRASH LOCATION SITE REVIEWS

The following protocol was used when investigating fatal work zone crash locations during this research. Not every work zone site required a response for each section listed. Rather, this was intended as a review for the investigator to consider during the course of the site review in order to uncover any deficiencies or inconsistent factors at the site. The final result for each location was a technical internal memorandum that described the results of the pertinent points of the protocol.

## FIELD DATA COLLECTION PROTOCOL

### Equipment to Have:

- TTI hardhat
- Reflective vest
- Protocol form
- Data collection form
- Graph paper
- Pens
- 100-foot tape measure
- Screwdriver or heavy nail
- 6-foot folding wood ruler
- Global Positioning System (GPS) receiver if work zone is in high volume location where you can't get out of vehicle safely
- Texas Quality Guidelines for Work Zone Traffic Control Devices pamphlet
- Business cards
- Copy of TxDOT letter
- Copy of project proposal
- Copy of phone number list
- Copy of TMUTCD Part VI
- Flashing yellow strobe for car

### Equipment You Do NOT Want to use. Don't Even Have them in the car:

- Cameras
- Video cameras
- Tape recorders

## Data Collection Plan

*Getting Your Bearings*

1. Arrive at the district safety engineer's office, or wherever you have made arrangement to meet with TxDOT personnel. You should have already let them know to expect you, and if possible, you should have an appointment. If the TxDOT personnel have already received a copy of the law enforcement crash report, ask for a copy; otherwise make arrangements for them to send it to you at a later date.
2. Every person you meet needs to understand the following:
   - We are conducting this study on behalf of TxDOT.
   - We are here to find facts, not to interview anyone. We do not want anyone to offer opinions.
   - We will need someone to lead us to the site so we can see exactly where the crash occurred. After that, we do not need TxDOT involvement.
3. Once at the site, paint a reference mark off on the edge of the shoulder so you may more easily find your way back to the spot. If the crash occurred at an easily identifiable location, such as in an intersection, this is not necessary.
4. Determine the speed limit of the roadway. This will help you determine the Decision Sight Distance (DSD), which will determine how far upstream from the crash location you will be investigating.
5. Take a few minutes to drive around and get your bearings so that you can have a good feel for all of the places that traffic can come from. Think about your personal safety before you get out of the car. Is this a location that you can safely leave the car and take measurements with a measuring wheel? Or do you need to use a GPS receiver and stay in the car?
6. Find somewhere to sit and observe traffic. Take 5 minutes and perform a simple traffic count to help get an estimate of traffic volumes at the location. It would be best to do this if you are there at the same time of day as the crash, especially if the crash occurred during a peak period or during times of extreme volumes (high or low).

*Getting Started*

7. The first step will be to sketch out the study area and fill out the preliminary information on the worksheet.
8. Fill in section 1 on the worksheet. This will include such information as who is collecting the data, the date, location, and weather conditions at the time of the survey. General descriptions of the roadway and work zone are also filled in on the worksheet at this time.

*The Equipment Survey*

9. If you are in a high-volume location or otherwise in a location where it would not be safe to leave the vehicle, use the GPS receiver to collect the location data. Drive and stop each 0.01 miles traveled according to the GPS receiver; record the features of the roadway and any traffic control devices. If there is room to safely be outside the car, perform the same process

using a measuring wheel or similar measurement device. Don't try to evaluate the devices yet; simply make note of what they are and where they are.

10. When you reach the crash location, go back to the upstream location.
11. Move through the site a second time, stopping at each traffic control device. Evaluate if it is in the proper location and if it is in appropriate condition. Record these observations on the survey worksheet.
12. When you reach the crash location, return to the upstream location.

*The Pavement Survey*

13. Conduct a review of the pavement through the study area. Pay particular attention to potholes, debris, ponding, rutting, and pavement edge drop-offs. Record any occurrences on the worksheet.
14. Also evaluate the condition of the pavement markings. Pay particular attention to how the existing pavement markings and any temporary pavement markings provide conflicting information, and for any missing or degraded markings. Describe in words what any conflicts are and how drivers might misinterpret them.
15. When you reach the crash location, get out of your vehicle and examine the roadside. Describe the cross-section of the roadway, including the cross-slope of the roadside.

*Positive Guidance Survey*

16. For the Positive Guidance portion of the survey it is best to drive several miles upstream from the crash location and start your drive from there. This will give you the best feel for the overall conditions of the roadway. Drive through the study area at speed several times to determine if any Positive Guidance issues have been violated. Positive Guidance issues you should be looking for include:
    - Hazard visibility (are there any hidden hazards?),
    - Expectancy violations (does the work zone do something unexpected?),
    - Information load (how many places must one look to get all the information?), and
    - Information needs (are the warnings placed to warn drivers in time?).
17. Record your findings from the Positive Guidance survey on the worksheet.

*Completion of Survey*

18. Make sure you call your TxDOT contact and let them know that you are done with the location, and thank them for the assistance.

*Write-Up of Analysis*

19. Write a technical memorandum detailing the facts of the crash, what was found at the crash site, a review of the analysis of the contributing factors, and list potential countermeasures that could prevent similar crashes of this type in the future.
20. Provide a detailed sketch or drawing of the site.

# APPENDIX B: OBSERVED PROBLEMS AND POTENTIAL REMEDIES

The following tables represent suggested countermeasures that were developed based on TTI research personnel viewing specific fatal crash locations during the course of this project, or developed through discussions at TTI project meetings. These possible countermeasures are not automatically intended as a recommendation for development by TxDOT. Merely, they were developed in order to better grasp the potential advantages and disadvantages to the state and to the driving public if they were adopted. Many of these were found upon reflection to have several disadvantages that would likely preclude their use or perhaps have little or no safety benefit in return for the effort of implementation in TxDOT work zones. The full report contains detailed discussions about the possible countermeasures that were deemed to have the best potential advantages for reducing fatalities, and the fewest potential disadvantages. It is the possible countermeasures listed in the body of the report that are recommended for further development.

**Table B1. Possible Countermeasure Considerations for Pedestrian Issues.**

**Problem: Pedestrians trespassed through highway work zone, struck and killed by motorist.**

**Possible Countermeasure #1**: Provide fencing to keep pedestrians out of work zones.

| Advantages | Disadvantages |
|---|---|
| • Provides warning to pedestrians to stay out of the work zone.<br>• Provides a barrier to physically keep pedestrians out of the work zone. | • While likely only needed in urban or suburban locations, there is currently no methodology to determine which work zones would benefit from this countermeasure.<br>• Hard to maintain continuous fencing at driveways, interchanges, etc.<br>• Quantities of fencing could be prohibitive on long work zones.<br>• Adds to traffic control set-up, maintenance, and tear-down requirements.<br>• Will not be 100 percent effective in all cases (determined pedestrians are still likely to get past fencing and trespass into work zone). |

| | |
|---|---|
| **Possible Countermeasure #2**: Add glare screens onto existing concrete barriers to discourage pedestrians from crossing over barriers. | |
| **Advantages**<br>• Can also reduce headlight glare at night from oncoming traffic.<br>• Can be added directly to existing work zone traffic control devices (concrete barriers), and so does not add additional traffic control devices into the work zone that could be struck. | **Disadvantages**<br>• While likely only needed in urban or suburban locations, there is currently no methodology to determine which work zones would benefit from this countermeasure.<br>• Adds to traffic control set-up, maintenance, and tear-down requirements.<br>• Determined pedestrians could still trespass into work zone.<br>• Glare screens have been found to be a significant maintenance issue, especially in constricted work zones where the barrier is positioned close to moving traffic and susceptible to vehicle overhangs. |
| **Possible Countermeasure #3**: Enact legislation increasing fines for trespassing in work zones. | |
| **Advantages**<br>• Little agency or contractor cost for additional work zone traffic control, possibly only a few signs explaining the new law. | **Disadvantages**<br>• Signing for pedestrians warning them of any law may be difficult as pedestrians tend to come from many different locations.<br>• Only a stiff fine would likely act as a deterrent to trespassing.<br>• Effort will require legislative action that is outside of agency or contractor control. |

| **Possible Countermeasure #4**: Public awareness campaign educating pedestrians of the dangers of trespassing in work zones. | |
|---|---|
| **Advantages**<br>• No changes in traffic control plans would be necessary. | **Disadvantages**<br>• Effectiveness of public awareness campaigns vary significantly.<br>• Effecting changes in behavior typically requires an ongoing commitment of resources over significant periods of time (such as efforts to increase seat belt usage). It is not apparent that this issue is worthy of such a resource commitment.<br>• No additional notice at the work zone warning pedestrians of the issue. |
| **Possible Countermeasure #5**: Provide additional lighting at urban work zones to help pedestrians understand that a work zone is present and open to traffic at night. | |
| **Advantages**<br>• Additional lighting would make it easier for motorists to locate pedestrians at night inside a work zone.<br>• Pedestrians at night may be more likely to realize that they are in a work zone that is open to traffic if they can see the area around them. | **Disadvantages**<br>• Determined pedestrians could still trespass into work zone.<br>• Cost of installing lighting and electrical service to all work zones could be high, with low potential safety benefit.<br>• No research has been conducted that indicates that this possible countermeasure will result in an increased level of pedestrian compliance and a resulting increase in safety. |

**Table B2. Possible Countermeasure Considerations for Flagger Issues.**

| **Problem: Flagger hit by errant vehicle.** | |
|---|---|
| **Possible Countermeasure #6**: Replace flagger with portable traffic signal. | |
| **Advantages** | **Disadvantages** |
| • Can provide stop-and-go traffic control similar to a flagger.<br>• Provides traffic control readily understood by motorists.<br>• Removes flagger from the traffic stream, improving worker safety. | • Not suitable for all scenarios where a human flagger could be used.<br>• Less portable than a human flagger, resulting in reduced efficiency at short-term or work zones.<br>• Lack of human control over traffic may embolden motorists to ignore the temporary traffic signal. Not an issue if system is used with human controller.<br>• Introducing traffic signals to a location creates a driver expectancy violation. High potential for approaching motorists to not "see" the signal and fail to stop before entering into the work area (creating potential for head-on collisions).<br>• Initial cost of portable traffic signal higher than equipment for a human flagger. |

| **Possible Countermeasure #7**: Replace flagger with mechanical flagger. | |
|---|---|
| **Advantages**<br>• Can provide similar traffic control as a flagger.<br>• Removes flagger from the traffic stream, improving worker safety. | **Disadvantages**<br>• Mechanical flagger is not suitable for all scenarios where a human flagger could be used.<br>• Mechanical flagger is less portable than a human flagger, resulting in reduced efficiency at short-term or work zones.<br>• This new traffic control device may result in poor motorist understanding of what the message conveyed.<br>• The lack of human control over traffic may embolden motorists to ignore the mechanical flagger.<br>• Initial cost of mechanical flagger higher than equipment for a human flagger. |
| **Possible Countermeasure #8**: Modify traffic control plans when possible to eliminate need for flagger. | |
| **Advantages**<br>• Improves safety by eliminating the need for a flagger altogether. | **Disadvantages**<br>• Not practical for many stop-and-go or other short-term work zones.<br>• Agencies and contractors already restrict flagger usage to only those situations that require them. Such a countermeasure may not significantly alter risk of flagger injuries and fatalities on a statewide basis. |

| **Possible Countermeasure #9**: Expand flagger training to emphasize bailing out of the way of errant vehicles. | |
|---|---|
| **Advantages** | **Disadvantages** |
| • Provide flaggers with information about potential crashes and how best to avoid being hit when a vehicle leaves the roadway. | • Flagger training already stresses safety, and it is unclear what safety benefit can be gained from additional training. |

**Table B3. Possible Countermeasure Considerations for Worker Issues.**

<table>
<tr><td colspan="2">Problem: Vehicle entered activity area, struck worker at short-term work zone.</td></tr>
<tr><td colspan="2">Possible Countermeasure #10: Provide audible warning device for flagger to warn work crew.</td></tr>
<tr><td>Advantages<br>• Flagger or other designated worker could alert others when an errant vehicle or other danger is present at a work zone.<br>• Improvement over current standard or no warning device.<br>• Could use or modify existing intrusion alarm systems currently available.</td><td>Disadvantages<br>• Sound warnings may be drowned out by equipment operating close to workers.<br>• Provides limited protection only in the vicinity of the warning device. Complex communications systems would be needed to activate a warning over a large area.<br>• Relies on workers or site supervisors recognizing the hazard in time to send out the alarm.</td></tr>
<tr><td colspan="2">Possible Countermeasure #11: Develop and implement a highly mobile barrier system for short-duration work zones.</td></tr>
<tr><td>Advantages<br>• Portable barrier would allow positive protection to be provided for more mobile operations.<br>• Allows the work crew to move to a new location without time-consuming set-up and tear-down of the equipment.</td><td>Disadvantages<br>• Systems of this type are still under development and have not been proven crashworthy and safe for use.<br>• Costs of such a system are likely to be high, at least initially.<br>• Use of this type of protection will likely result in some loss of productivity due to access restrictions, longer setup and removal times, etc.</td></tr>
</table>

| **Possible Countermeasure #12**: Require truck-mounted attenuator in lane of all short-term work zones. | |
|---|---|
| **Advantages**<br>• Positive barrier would protect workers from errant vehicles, increasing the safety of workers.<br>• Properly installed attenuators would safely stop the motorist as well as increasing safety of motorists.<br>• Little set-up or removal required for these devices, allowing quick relocation of short-term work activities. | **Disadvantages**<br>• Increased equipment costs for small work zone operations.<br>• Does not prevent errant vehicles from entering activity area from adjacent lanes.<br>• Shadow vehicles with truck-mounted attenuators are already a regular component of many work operations. Thus, the actual incremental benefit of safety of this countermeasure may be minimal. |

**Table B4. Possible Countermeasure Considerations for Queuing Issues.**

| **Problem: Large truck struck back of queued traffic at work zone, killed motorists in queued vehicle.** | |
|---|---|
| **Possible Countermeasure #13**: Require traffic responsive warning of stopped/slowed traffic to provide warnings of stopped/slowed traffic ahead. | |
| **Advantages**<br>• Only provides warning when actually needed, limiting the familiarity of the warning to motorists.<br>• Can provide a specific warning with the indication that slow/stopped traffic is directly ahead. | **Disadvantages**<br>• Existing systems are expensive and equipment intensive.<br>• Such a system still depends on alert drivers reading and understanding the message. |

**Table B5. Possible Countermeasure Considerations for Temporary Pavement Marking Issues**

| | |
|---|---|
| **Problem: Vehicle left roadway at night where temporary pavement markings (tabs) only delineated centerline or lane lines, motorist(s) killed.** | |
| **Possible Countermeasure #14**: Expand temporary pavement markings to include edgeline delineation. | |
| **Advantages**<br>• Increased edgeline and path delineation may help provide early warning for motorists of curve or hazard in roadway.<br>• Delineate right-hand lane and shoulder to improve safety of vehicles parked on shoulders. | **Disadvantages**<br>• No research on how motorists would interpret and react to temporary tabs on shoulder.<br>• Does not change the chain of events if motorist falls asleep or is otherwise inattentive.<br>• Cost could be high, especially if this is done for every lift of a multi-lift pavement replacement or similar project. |
| **Possible Countermeasure #15**: Expand temporary traffic control to include cones, barrels, and/or vertical panels to provide edgeline delineation. | |
| **Advantages**<br>• Increased edgeline and path delineation may help provide early warning for motorists of curve or hazard in roadway.<br>• Delineate right-hand lane and shoulder to improve safety of vehicles parked on shoulders.<br>• Would not have to be replaced for every lift on a multi-lift pavement project. | **Disadvantages**<br>• Increased costs for traffic control installation and maintenance throughout the project. |

| **Possible Countermeasure #16**: Maintain edgeline rumble strips on roadway throughout pavement work. | |
|---|---|
| **Advantages** | **Disadvantages** |
| • Improved delineation and tactile warning could help motorists understand where the lane edges are and remain on the road.<br>• Rumble strips are equally effective at all times of day and night. | • Cost of installing rumble strips for each pavement lift on a multiple-lift repaving project could be cost prohibitive.<br>• No guarantee that a driver can recover and avoid a crash after being alerted by the rumble strips. |

**Table B6. Possible Countermeasure Considerations for Construction Issues.**

| **Problem: Pavement joint-cutting operation causes dust across traveled lanes, causes slow traffic and collision, killing motorist.** | |
|---|---|
| **Possible Countermeasure #17**: Require wetting of pavement joint during cutting operation to minimize dust. | |
| **Advantages**<br>• Improves visibility for adjacent motorists. | **Disadvantages**<br>• May not prevent slow traffic for other reasons, such as curious motorists watching the construction.<br>• Additional equipment and personnel for joint-cutting operations would likely be required to wet the joint area, increasing construction costs.<br>• Bringing large quantities of water to a work zone for this purpose may be expensive and logistically problematic. |
| **Possible Countermeasure #18**: Prohibit joint-cutting operations or other dust-causing work when dust would carry across the traveled lanes. | |
| **Advantages**<br>• Improves visibility for adjacent motorists. | **Disadvantages**<br>• May not prevent slow traffic for other reasons, such as curious motorists watching the construction.<br>• Joint-cutting operations are time-sensitive operations and may not be able to wait for optimal weather conditions.<br>• Would likely increase costs and project duration due to added delay days due to unacceptable weather conditions.<br>• Currently no standard defining when construction dust is “too much” for motorists to safely drive through. |

## Table B7. Possible Countermeasure Considerations for Mobile Work Zone Issues.

| **Problem: Mobile work zone on shoulder moves into right lane on narrow causeway, causing traffic queue. Traffic struck back of queue, killing motorist.** | |
|---|---|
| **Possible Countermeasure #19**: Provide additional shadow vehicle to remain at beginning of a long bridge or causeway on shoulder to provide additional warning. | |
| **Advantages**<br>• Provides additional upstream warning that the convoy is ahead, providing more time for motorists to move from adjacent lane.<br>• May only be necessary at long causeway bridges, not for every mobile work zone.<br>• Allows a moving/mobile work zone convoy to keep moving at the current pace, while providing additional guidance to drivers. | **Disadvantages**<br>• Additional cost of providing an additional vehicle for this countermeasure.<br>• Not a guarantee that motorists will comply and leave the adjacent lane. |
| **Possible Countermeasure #20**: Close adjacent lane in order to more safely work on shoulder. | |
| **Advantages**<br>• Provides maximum likelihood of keeping the traffic separated from the moving convoy.<br>• Provides consistent non-moving traffic control for motorists to understand and follow.<br>• Provides the opportunity to add in additional maintenance activities in the adjacent lane during the closure. | **Disadvantages**<br>• Additional cost of providing traffic control for this countermeasure.<br>• The capacity loss from the loss of a traveled lane could result in congestion upstream from the closure under heavy traffic volumes.<br>• Would convert a moving/mobile operation into a short-duration |

| | |
|---|---|
| • May only be necessary at long causeway bridges, not for every mobile work zone. | work zone, requiring more time and effort.<br>• Placement and removal of traffic control adds different kind of risk to workers. |
| **Possible Countermeasure #21**: Provide police escort upstream from mobile operation in order to provide additional warning to motorists to move out of the adjacent lane. | |
| **Advantages**<br>• Provides additional upstream warning that the convoy is ahead, providing more time for motorists to move from adjacent lane.<br>• Law enforcement presence is recognized as a superior manner of gaining motorist compliance with traffic control.<br>• May only be necessary at long causeway bridges, not for every mobile work zone.<br>• Allows a moving/mobile work zone convoy to keep moving at the current pace, while providing additional guidance to drivers. | **Disadvantages**<br>• Additional cost of providing a police escort for this countermeasure.<br>• Police officer is then at risk as he/she would not likely have an attenuator like a construction vehicle performing the same task.<br>• Not a guarantee that motorists will comply and leave the adjacent lane. |

**Table B8. Possible Countermeasure Considerations for Vehicle Breakdown Issues.**

<table>
<tr><td colspan="2">Problem: Vehicle breakdown in work zone where shoulders or breakdown areas are provided causes traffic queue, rear-end crash kills motorist.</td></tr>
<tr><td colspan="2">Possible Countermeasure #22: Provide continuous shoulders through all work zones to allow vehicles in distress to get out of the traveled lanes.</td></tr>
<tr><td>Advantages<br>• Provides a motorist with a disabled vehicle a place to get out of the traveled lanes and reduces the potential of that vehicle being rear-ended.<br>• Reduces the likelihood of capacity bottlenecks and the resulting queues.<br>• Reduces the likelihood of a queue and any secondary crashes.</td><td>Disadvantages<br>• May not be feasible in all work zones, especially in areas of narrow right-of-way.<br>• May add significantly to construction costs as these areas may encroach into activity or materials storage areas.<br>• Presumably, shoulders are removed from work zones only when absolutely necessary, so there are likely few work zones that would be affected by this possible countermeasure.</td></tr>
<tr><td colspan="2">Possible Countermeasure #23: Provide breakdown refuges at regular intervals through all work zones where shoulders are removed to allow vehicles in distress to get out of the traveled lanes.</td></tr>
<tr><td>Advantages<br>• Providing a motorist with a disabled vehicle to get out of the traveled lanes reduces the potential of that vehicle being rear-ended.<br>• Reduces the likelihood of capacity bottlenecks and the resulting queues.</td><td>Disadvantages<br>• May not be feasible in all work zones.<br>• May add to construction costs as these areas may encroach into activity or materials storage areas.<br>• Not all motorists with disabled vehicles may make it to a breakdown area before stopping.</td></tr>
</table>

| | |
|---|---|
| • Reduces the likelihood of a queue and any secondary crashes.<br>• Refuges can be used by law enforcement to monitor traffic within the work zone as well, increasing law enforcement effectiveness along the work zone corridor. | • Not all motorists may understand what the breakdown area is for, and either use it when they should not, or not use it when they should. |

**Table B9. Possible Countermeasure Considerations for Wrong-Way Driving Issues.**

<table>
<tr><td colspan="2">Problem: Motorists turned into a work zone that used to be two-lane divided, now is two-lane, two-way operation. Motorist gets into wrong lane and is struck head-on, killed.</td></tr>
<tr><td colspan="2">Possible Countermeasure #24: Provide additional Positive Guidance at locations where traffic can turn onto two-lane, two-way operation to minimize inadvertent wrong-way driving.</td></tr>
<tr><td>Advantages<br>• Providing motorists with additional information may reduce the number of wrong-way driving events in work zones, thereby improving safety.<br>• Simple traffic control devices could supplement existing traffic control plans. Beneficial results have been found in previous research where lane marking arrows significantly reduced drivers selecting the wrong lanes on two-lane roadways.*</td><td>Disadvantages<br>• May not be possible in all situations.<br>• Motorists may still make incorrect decisions, even with additional guidance.</td></tr>
</table>

* TTI Research Report 0-4471-2, expected to be published in 2005.

**Table B10. Possible Countermeasure Considerations for Transition Issues.**

<table>
<tr><td colspan="2">Problem: Work zone transition began in existing horizontal curve, resulting in tightening spiral curve, driver left roadway and was killed.</td></tr>
<tr><td colspan="2">Possible Countermeasure #25: Keep continuous curve radii on work zone transitions.</td></tr>
<tr><td>Advantages<ul><li>Providing consistent curvature can help drivers from overestimating the appropriate speed, resulting in fewer run-off-the-road crashes.</li></ul></td><td>Disadvantages<ul><li>May not be possible in all situations.</li><li>Many traffic control designs presumably already do this when possible, so the impact of this possible countermeasure may be minimal.</li></ul></td></tr>
<tr><td colspan="2">Possible Countermeasure #26: Move transition upstream so that it does not start in an existing horizontal curve.</td></tr>
<tr><td>Advantages<ul><li>Provides consistent traffic control plan for motorists to follow.</li><li>Installing transitions on tangent locations should maximize safety and allow for increased speeds and efficiency on the transitions.</li><li>Cost increase should be minimal, presumably including a small amount of temporary traffic control to extend the work zone upstream from the horizontal curve.</li></ul></td><td>Disadvantages<ul><li>Moving transitions upstream to a tangent section in order to accomplish this may increase traffic control costs.</li><li>Some geometric constraints may prevent this from being universally applied.</li></ul></td></tr>
</table>