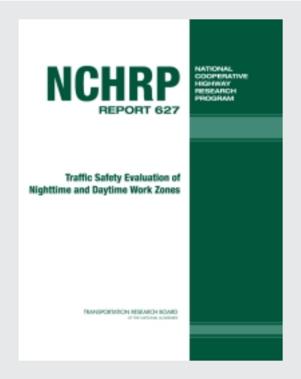

Traffic Safety Evaluation of Nighttime and Daytime Work Zones

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 627

Traffic Safety Evaluation of Nighttime and Daytime Work Zones

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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The researchers wish to express their gratitude to the members of the project panel for their guidance and patience during the performance of this research. In addition to the project panel members, the authors gratefully acknowledge the assistance of numerous state department of transportation (DOT) personnel who participated in a survey of state practices. Finally, this research could not have been completed without the special assistance of several members of the New York State DOT, California DOT, North Carolina DOT, Ohio DOT, and Washington DOT who coordinated access to the many project files that the research team reviewed and collected data from during the course of this research.

FOREWORD

By Charles W. Niessner
Staff Officer
Transportation Research Board

This report presents the findings of a research project to determine the crash rates for nighttime and daytime work zones, develop management practices that promote safety and mobility in work zones, and develop work-zone crash reporting recommendations to further improve the data collected on work zone crashes. The report will be of particular interest to practitioners responsible for work zone safety.

The Intermodal Surface Transportation Efficiency Act established a documentation procedure for crashes in work zones for daytime and nighttime operations. Yet the various crash databases maintained by state departments of transportation (DOT) and other agencies (for example, the Fatal Analysis Reporting System [FARS]) fail to yield data that can lead to explicit conclusions concerning the relative danger of nighttime construction operations versus daytime operations. The data are plagued by uncertainties on issues such as (1) the level of detail contained in the data, (2) the relationship of crashes to specific work zone locations, and (3) the variation in reporting practices. Cottrell, B.H., Jr., "Improving Night Work Zone Traffic Control," Virginia Transportation Research Council, August 1999, concluded that, "although there is a perception that night work zones are less safe than daytime work zones, evidence to substantiate this perception, such as higher accident rates, was not available because of lack of traffic exposure data." Information is needed to assess the characteristics of these crashes in both daytime and nighttime work zones.

Subsequent research suggested that nighttime work zones have traffic-related crash rates up to three times higher than daytime work zones. If in fact nighttime operations are as dangerous as the data and perceptions suggest, more significant resources should be directed at ensuring worker and driver safety in nighttime work zones. The importance of this issue is magnified by recent operational efforts by DOTs to increase nighttime work operations in order to decrease work-zone traffic congestion.

Under NCHRP Project 17-30, "Traffic Safety Evaluation of Nighttime and Daytime Work Zones," researchers at the Texas Transportation Institute developed the crash rates for nighttime and daytime work zones; determined the nature of, and identified similarities and differences between traffic related crashes in nighttime and daytime work zones; identified and evaluated management practices that promote work zone safety and mobility; and developed work-zone crash reporting recommendations to further improve the data collected on work zone crashes. The New York State DOT work zone accident data base was used to conduct the analysis of the differences and similarities of traffic crashes and highway worker construction accidents occurring during nighttime and daytime periods in that state. Project work activity and crash data from 64 projects in California, North Carolina, Ohio, and Washington were also analyzed to determine similarities and differences in crash risks experienced during nighttime and daytime operations. The researchers also critiqued and prioritized various highway agency management policies, procedures, and practices believed capable of mitigating work zone crashes and developed detailed recommendations regarding the collection and analysis of work zone crashes by highway agencies.

Overall, working at night does not result in significantly greater crash risk for an individual motorist traveling through the work zone than does working during the day. In addition traffic crashes that occur in nighttime work zones are not necessarily more severe than those that occur in similar daytime work zones, when compared across similar work operations. The implications of these findings are that work activities that require temporary lane closures on moderate to high-volume roadways have substantially lower total safety impact to the motoring public if the work is done at night. The lower traffic volumes present on roadways at night result in a much lower number of crashes occurring over a work operation of a given duration.

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SUMMARY

Traffic Safety Evaluation of Nighttime and Daytime Work Zones

This project was initiated to objectively determine and document how nighttime and daytime work zones affect traffic safety. More and more, agencies are doing roadway work on high-volume facilities at night to reduce adverse traffic impacts and complaints by the public that typically occur when the same work is being done during the day. Nighttime travel is commonly characterized by lower traffic volumes, a higher percentage of truck traffic, higher operating speeds, reduced visibility, and higher concentrations of drowsy and impaired drivers. Arguments exist on both sides of the question as to whether working at night is more or less safe than working during the day.

Previous literature indicates that increased crash risks at a given project location are a combination of temporary changes in geometrics and influences due to work activity. Work activity influences can be from drivers distracted by work operations and equipment, turbulence created by work vehicle or equipment access to and from the work area, and temporary lane closures that increase traffic densities (possibly to the point of congestion) and require drivers to maneuver around the closure. However, efforts to better understand the relative contributions of work zone design and work activities to the increased crash risk are fairly limited in the literature.

One of the key issues that had to be addressed early on in this research was the choice of appropriate measures of crash risk when assessing and comparing the safety implications of nighttime and daytime work. Traditional crash rates normalize crashes on the basis of vehicular-miles of travel or similar measure of exposure. This rate reflects a level of risk to an individual driver traversing that particular roadway segment. Percentage changes in this rate or similar indicators, such as the percentage change between actual and expected number of crashes in a given time period, thus indicate how individual driver risk is affected by the presence of the work zone. Certainly, this indicator of motorist risk is an important consideration. However, from the practitioners' perspective, when making the decision whether to work at night or during the day, they must also consider the consequences of increased crash risk to the driving population as a whole. Whereas the increase in crash risk to an individual motorist may, in theory, be greater at night than during the day, the much lower traffic volumes (and thus, vehicle exposure) that typically exist at a given location at night may more than offset this incrementally higher risk. Higher traffic volumes during the day mean that the same number of crashes will produce a much lower crash rate per million-vehicle-miles (mvm). If the day versus night decision is for a given work zone, then it would appear that the practitioner will want to minimize the number of crashes (assuming equal severity). Thus, crash rate per mile of work zone was deemed an important comparison metric. Certainly, differences in the severity of the increased crashes may also exist between daytime and nighttime work operations, which also must be considered in the

analysis. Together, this implies that the use of additional crash costs, normalized on the basis of amount of work activity required at a given project location, most closely reflects the information that highway agencies must weigh in their decisions of whether or not to work at night.

A two-pronged investigation was adopted for this research project. The first prong utilized the New York State Department of Transportation (NYSDOT) Work Zone Accident database. This database is a one-of-a-kind resource developed in the 1980s and expanded over the years, specifically for use in tracking all types of work-zone-related traffic crashes and worker accidents on NYSDOT construction projects statewide. For this study, relative differences were examined in the types and severities of traffic crashes and worker construction accidents during both daytime and nighttime work operations on New York freeway and expressway facilities. Even more importantly, the database included specific information on various types of worker-involved traffic crashes and construction accidents sustained during both day and night work activities, something that is not available at the present time nationally in any other database.

The second prong of the research effort was the collection and analysis of crash experiences of work zones performed in California, North Carolina, Ohio, and Washington. For some of the projects, work activities were done predominantly during the daytime; for other projects, work activities were done mainly at night. For other projects, some work activities were done during the day (mainly those activities that did not require the temporary closure of travel lanes), and other activities that required travel lanes to be closed for several hours were performed at night.

The results of these investigations were very insightful. Overall, working at night does not result in a significantly greater crash risk for an individual motorist traveling through the work zone than does working during the day. The percentage increases in crash risk for work operations requiring the temporary closure of travel lanes were essentially identical when done at night or during the day. In addition, traffic crashes that occur in nighttime work zones were not necessarily more severe than those that occur in similar daytime work zones, again when compared across similar work operations. The implications of these findings are that work activities that require temporary lane closures have substantially lower total safety impacts to the motoring public if the work is done at night. The lower traffic volumes present at night result in a much lower number of crashes occurring over a work operation of a given duration.

Although the increased risk of a crash is similar, differences do exist in the types of crashes that occur at nighttime and daytime work zones. For example, based on the NYSDOT work zone traffic crash and worker accident database, those traffic crashes involving workers, construction vehicles or equipment, and construction materials and debris (both intrusion and non-intrusion crashes) comprise a greater percentage of crashes at night than during the day. Although the relative percentage of these crashes was higher at night, it should be noted that they were only a small proportion of the total work zone crashes experienced in either time period.

The recent National Cooperative Highway Research Program (NCHRP) 500 Report, *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 17: A Guide for Reducing Work Zone Collisions,* recommends a systematic process intended to reduce the frequency and severity of traffic crashes during roadway work zone operations. A number of specific strategies are named in that report that are believed to offer the potential to reduce work zone crashes, but information on the possible magnitude of such crash reductions was generally unavailable at that time. Using the findings from this research, a critique of those strategies was undertaken, and recommendations were made as to which strategies have the greatest potential to reduce work zone crashes. Strategies that appeared to offer the greatest potential for crash cost reduction included the following items:

- Practices to reduce the number and duration of work zones required,
- Use of full directional roadway closures via median crossovers or detours onto adjacent frontage roads,
- Use of time-related contract provisions to reduce construction duration,
- Movement of appropriate work activities (i.e., those that require temporary lane closures) to nighttime hours,
- Use of demand management programs to reduce volumes through work zones, and
- Use of enhanced traffic law enforcement.

Strategies that appeared to offer a moderate work zone crash reduction potential included the following:

- Design of adequate future work zone capacity into highways,
- Use of full roadway closures that require traffic detours onto adjacent surface streets,
- Use of intelligent transportation system (ITS) strategies to reduce congestion and improve safety,
- Improvement of work zone traffic control device visibility,
- Efforts to reduce flaggers' exposure to traffic, and
- Efforts to reduce workspace intrusions and their consequences – primarily at long-term, high-volume work zones.

Although these strategies appear capable of having positive impacts on work zone safety, determining the extent to which they meet these expectations can only be determined objectively through the improved collection and use of work zone crash data. Highway agencies have access to their state crash reporting databases and can usually develop some fairly basic metrics such as total work zone fatalities or injuries. Beyond that, however, the data are generally not sufficient to be useful for many of the potential applications. Although no work zone crash data system currently in use fully addresses the needs of effective work zone safety management, it appears that such a system can be developed by combining the desirable features of the Model Minimum Uniform Crash Criteria (MMUCC) guidelines that have been developed nationally with an agency construction accident reporting program similar in concept to the one now in use in NYSDOT. However, revisions and improvements to both of these are considered essential to achieving the goal of providing comprehensive, timely, and consistent data for crashes, construction accidents, and other harmful events in and related to highway work zones. In addition to enhancing the actual crash data being collected, the collection of exposure data at work zones is particularly needed to improve process-level work zone crash analysis.

CHAPTER 1

Background

Problem Statement

Most roadwork today involves reconstruction, rehabilitation, and maintenance of existing roadways and often occurs in or near moving traffic. More and more, agencies are doing roadway work on high-volume facilities at night to reduce adverse traffic impacts and complaints by the public that typically occur when the same work is done during the day. Minimizing traffic impacts of roadwork activities is a key emphasis of the Federal Highway Administration (FHWA) (*1*).

Nighttime travel is commonly characterized by the following:

- Lower traffic volumes,
- A higher percentage of truck traffic,
- Higher operating speeds,
- Reduced visibility, and
- Higher concentrations of drowsy and impaired drivers.

Traffic volumes at night on a roadway facility are typically much lower than during daylight hours, which is often the main reason that work is performed at night. Lower traffic volumes yield reduced vehicular exposure to the work zone, which is a key determinant associated with crash frequencies. Furthermore, working during nighttime hours reduces the likelihood and extent of traffic congestion that could result from performing that work. Traffic congestion has been associated with higher crash frequencies and rates by several researchers (*2*, *3*).

However, lower volumes provide greater maneuverability to drivers, and can allow higher operating speeds to occur into and through the work zone than would have been possible had the work been done during the day. Obviously, lower light levels at night reduce visibility for drivers and workers relative to what would be available during the day. Based on crash data and other collected information, it is well recognized that greater concentrations of impaired drivers are on roadways at night than during the day (*4*, *5*, *6*). Driver expectancy to encounter roadwork activity may also be less at night than during the day in some areas, depending on how extensively night work has been embraced by those regions in recent years and how well the night work is publicized to drivers. Each of these factors may have the potential to increase crash risk per vehicle and crash severity at night, compared to daytime conditions.

The fact that arguments exist on both sides of the question as to whether working at night is more or less safe than working during the day emphasizes the need for this research. Rather than continuing to rely on conjecture and subjective opinion, NCHRP initiated this project to objectively determine and document how nighttime and daytime work zones affect traffic safety. Four specific objectives were identified:

- Determine the crash rates for nighttime and daytime work zones;
- Determine the nature of, and identify similarities and differences between, traffic-related crashes in nighttime and daytime work zones;
- Develop management practices that promote safety and mobility in nighttime and daytime work zones; and
- Develop work zone crash reporting recommendations to further improve the data collected on work zone crashes.

Previous Research

Work Zone Effects on Traffic Safety

Over the past 30 years, numerous researchers have examined the influence of work zones on roadway crashes, primarily in terms of how normal crash rates or the likelihood of crashes changes when a work zone is installed at a particular location. In recent years, one finds that crashes typically increase approximately 20 to 30 percent within work zones relative to the normal crash experience for those locations, although the amount of the increases varies from study to study (*7*, *8*, *9*, *10*, *11*, *12*, *13*, *14*, *15*, *16*, *17*, *18*, *19*, *20*, *21*, *22*, *23*, *24*). Differences in work zone designs, quality of traffic control device maintenance, types of work performed, and other roadway and traffic characteristics probably contribute to the varying results observed. In addition, recent studies have shown that the relationship between work zone crash likelihood and roadway (i.e., average daily traffic [ADT], lane and shoulder widths, etc.) and work zone characteristics (i.e., duration, length, etc.) are nonlinear (*24*, *25*).

As to whether such crash increases are more significant at night, the evidence is less clear. Some studies have found that nighttime crashes in work zones increase by a greater percentage than daytime crashes (*21*, *26*, *27*), but other studies have found the increases in daytime and nighttime crashes to be similar (*8, 19, 28*).

In essentially all studies described above, the changes in crashes were computed over the entire duration of a long-term roadway rehabilitation or reconstruction project, during times when work was occurring as well as when the work area was inactive. Projects involving major rehabilitation or reconstruction of the roadway often require temporary degradations in roadway geometry such as narrowed lanes, shortening of entrance or exit ramps, and the placement of temporary concrete barriers immediately adjacent to the travel lanes. These degraded geometric changes are left in place when work is occurring as well as when the work zone is inactive. Consequently, the changes in crashes reported in these studies actually represent the combined effect of both the degraded geometric conditions in the work zone and the influence of work activity itself.

Although some consensus exists that overall crash rates increase during roadway repair and reconstruction activities (even if the amount of the increase is of some debate), the literature is less definitive with regards to whether or not crashes tend to be more severe, less severe, or as severe as under non-work zone situations. Several researchers have concluded that work zone crashes are no more severe than non-work zone crashes (*8, 9, 13, 18*, *19*, *29*, *30*). However, others (*21*, *31*, *32*) have found that work zone crashes were more severe than non-work zone crashes or increased more significantly than property-damage-only (PDO) crashes in the work zone in the databases they examined. Once again, differences in the type of analysis used and the characteristics of roadways and work zones examined may be at least partially responsible for the divergent findings.

Despite the difficulties in properly attributing changes in crashes to the effects of the work zone design or to the actual presence of work activity itself, rear-end crashes are often found to be overrepresented in the crashes that do occur. The percentage of work zone crashes that involve rear-end impacts increased 7 to 83 percent, depending on the study cited and location of the work zone examined in that study (*8, 18, 21, 27, 33*, *34*). The creation of traffic and congestion during work activities is usually hypothesized as the major reason for the observed increase in rear-end crashes. Traffic and congestion can be created by temporary lane closures, other reductions in roadway capacity (i.e., narrowed lanes, lane shifts, etc.), drivers who are confused about their proper travel path and slow down, or the movement of construction equipment into and out of the work area.

Nighttime versus Daytime Work Zone Crashes

Decisions about whether to perform work in travel lanes during daylight hours or at night should be based, in part, on which approach is likely to yield the lowest crash costs over the duration of the project (*35*). Previously, only three small studies were identified that attempted to examine this question directly. In the first study, researchers in California examined eight construction projects where work was performed at night to minimize traffic disruptions (*36*). Researchers found that crash rates per million-vehicle-miles (mvm) of travel exposure were consistently and substantially higher at night when work activity was present. The magnitude of increases ranged from 67 to 156 percent, with an overall average crash rate increase of 87 percent. Researchers further stratified the data based on whether or not travel lanes were closed during the period of work activity each night. They found the crash rates at night during lane closures to be an additional 75 percent higher than during periods of work activity at night when travel lanes were not required to be closed. Researchers also examined crash rates on the basis of crashes per million hours (per mile per lane to normalize data between projects) and found the rates to increase an average of 122 percent during periods of night work activity (as compared to non-work hours). Unfortunately, the analysis could not answer the ultimate question as to whether or not crash rates per mile of work zone and/or crash costs would have been higher or lower than this had the work been performed during the day instead.

A second study used Illinois fatal work zone crashes and national estimates of work activity occurring during daytime and nighttime periods to assess the relative safety of daytime and nighttime work zones (*37*). The estimates of exposure came from a sampling process of scheduled work activity information posted online by state and local transportation agencies (*38*). Based on their analyses, the researchers concluded that night work was five times more hazardous than daytime work activity. However, the lack of actual exposure data from Illinois work zones for use in the comparison was noted as a key limitation of the analysis.

A third study examined five urban freeway reconstruction projects in Texas where all work activities that required lane closures were done at night, and other types of work activities off the travel lanes occurred during the daytime (*39*). Two other smaller projects that involved nighttime lane closures for pavement resurfacing activities were also examined. Researchers found that the major reconstruction projects experienced some increase in crashes during both daytime and nighttime periods, indicating that temporary geometric degradations (closure of shoulders, reduced acceleration lane lengths at ramps, concrete barriers immediately adjacent to travel lanes, etc.) had an effect on crash likelihood. Crash increases were even larger during periods of work activity (day or night), on average, with the increase in crashes during night work activities somewhat higher than during daytime work activities. Given that the daytime work activities at these projects did not involve lane closures whereas the nighttime work activities did, this finding was expected. Unfortunately, as with the previous study, these results do not provide any indication of how crashes might have been affected had the lane closures and work that was done at night actually been instead performed at each site during the day.

Nighttime versus Daytime Worker Safety

Although not all worker accidents involve traffic crashes, working at night does significantly impact the lives of highway workers and so is of at least some relevance to the goals of this study. Overall, the safety impacts of performing roadwork at night (relative to daytime operations) on highway workers have not previously been examined in detail. Workers generally perceive traffic speeds past the work site to be higher at night and so also perceive their level of safety to be diminished (*40*). The limited amount of accident data available on highway workers has not necessarily confirmed this perception, however. A study by the National Institute of Occupational Safety and Health (NIOSH) examined fatal occupational injuries for highway construction workers between the years 1992 and 2000 (*41*). Based on their assessments, the NIOSH researchers concluded that "working at night is not responsible for the overall increase in highway worker deaths." However, it should be noted that there were insufficient data to actually compare highway worker accident rates at night versus during the day.

Implications for This Study

There is a strong general consensus in the literature that work zones increase the likelihood of crashes that occur on a particular segment of roadway. Less agreement exists as to whether work zones result in more severe, less severe, or equally severe crashes as before work began. Certain types of crashes appear to be more affected by work zone presence than others, but again, the amount of influence is heavily site dependent. Such variability in studies to date is not surprising; work zones themselves are highly variable entities.

The literature does imply that the amount of increased crash risk at a given project location is a combination of temporary changes in geometrics and influences due to work activity. Work activity influences can be drivers distracted by work operations and equipment, turbulence created by work vehicle or equipment access to and from the work area, and temporary lane closures that increase traffic densities (possibly to the point of congestion) and require drivers to maneuver around the closure. However, efforts to better understand the relative contributions of work zone design and work activities to the increased crash risk are fairly limited in the literature.

An even more critical factor that has not been previously evaluated in the literature with any degree of success is the actual difference in safety between performing a particular work activity or project at night versus doing that same activity or project at the same location during the day. Relative safety is one of the key recommended considerations that practitioners face when assessing whether or not to do a particular project or project task at night (*35*). A few studies have provided some insight into the amount by which the normal nighttime crash rate increases if work is performed at night. However, the increase that would have occurred in the daytime crash rate at those locations if the work had been done during the day instead has not been quantified. Unfortunately, opportunities to evaluate this question directly at individual project sites are almost nonexistent. In most cases, the primary reason that an agency and highway contractor work at night at a location is that there is a need to close one or more travel lanes for a temporary period to complete the work, and doing so during daytime hours would generate unacceptable traffic delays and queues as well as severely limit the contractor's ability to move work vehicles and materials into and out of the workspace. Unacceptable impacts on adjoining properties may also occur from temporary lane closures during daytime hours.

Related to this comparison of nighttime-daytime crash risk increase is the choice of appropriate measures of risk to use, i.e., should it be crash rate per mile of work zone or crash rate per mvm? Traditional crash rates normalize crashes on the basis of vehicular-miles of travel or a similar measure of exposure. This rate reflects a level of risk to an individual driver traversing that particular roadway segment. Percentage changes in this rate or similar indicators, such as the percentage change between actual and expected number of crashes in a given time period, thus indicate how individual driver risk is affected by the presence of the work zone. Certainly, this indicator of motorist risk is an important consideration. However, from the practitioners' perspective, the decision whether to work at night or during the day must also consider the consequences of increased crash risk to the driving population as a whole. Whereas the increase in crash risk to an individual motorist may, in theory, be greater at night than during the day, the much lower traffic volumes (and thus vehicle exposure) that typically exist at a given location at night may more than offset this incrementally higher increased risk. Higher traffic volumes during the day mean that the same number of crashes will produce much lower crash rates per mvm. If the day versus night decision is for a given work zone, then it would appear that the practitioner will want to minimize the number of crashes (assuming equal severity). Thus, crash rate per mile of work zone would appear to be a better comparison metric. Certainly, differences in the severity of the increased crashes may also exist between daytime and nighttime work operations, which also must be considered in the analysis. Together, this implies that the use of additional crash costs, normalized on the basis of the amount of work activity required at a given project location, will most closely reflect the information that highway agencies must weigh in their decisions of whether or not to work at night.

Finally, although emphasis is traditionally placed on understanding and measuring the safety impacts of highway work zones to the motoring public, when considering the differences between daytime and nighttime work operations, the consequences to highway workers also need to be taken into consideration. Unfortunately, very little data on this issue exist. The highway contracting community perceives working at night to be a significantly greater risk to workers than working during the day. National databases (such as the Bureau of Labor Statistics) do not allow for a thorough comparison of nighttime and daytime highway work condition safety. Data sources that provide at least some insight into differences in highway worker risks during these work periods are sorely needed.

Study Overview

Researchers ultimately adopted a two-pronged investigation for this research project, based on data sources available to the research team. The first prong utilized the NYSDOT Work Zone Accident database. This database is a one-of-a-kind resource developed in the 1980s and expanded over the years, specifically for use in tracking all types of work-zone-related traffic crashes and worker accidents on NYSDOT construction projects statewide. The database has been a valuable asset to both NYSDOT personnel and other researchers in examining various questions about work zone features and crash characteristics that cannot be examined through traditional state traffic crash records and databases (*42*, *43*, *44*, *45*, *46*). For this study, researchers explicitly examined the relative differences in the types and severities of traffic crashes and worker construction accidents during both daytime and nighttime work operations on New York freeway and expressway facilities. Even more importantly, the database included specific information on various types of worker-involved traffic crashes and construction accidents sustained during both day and night work activities; this is something that is not available at the present time nationally in any other database.

The second prong of the research effort was the collection and analysis of crash experiences of a four-state sample of work zones. For some of the projects, work activities were done predominantly during the daytime; for other projects, work activities were done mainly at night. For still other projects, some work activities were done during the day (mainly those activities that did not require the temporary closure of travel lanes), and other activities that required travel lanes to be closed for several hours were performed at night. Four states were included in the analysis:

- California,
- North Carolina,
- Ohio, and
- Washington.

These states were selected because they provide access to their statewide traffic crash and roadway inventory databases through FHWA's Highway Safety Information System (HSIS) and because they reportedly had sufficient numbers of night work projects ongoing during the time period of interest in this study.

CHAPTER 2

NYSDOT Work Zone Accident Database Analysis

Database Description

In the mid-1980s, the Construction Division of NYSDOT initiated a program to compile detailed information on traffic crashes and worker construction accidents that occur on their construction projects. Since the mid-1990s this procedure has generated reports for nearly all traffic crashes and worker construction accidents, with the reports initiated by department staff and contractors. These reports are supplemented by standard police accident reports for many traffic crashes and some worker accidents. NYSDOT maintains a detailed database that is used to generate annual reports of work zone accidents, track overall safety trends, and prepare special reports addressing specific safety issues.

The entire database is rather extensive. Researchers focused on the following variables for analysis:

- Time of accident occurrence (day or night);
- Time when work activities were typically performed (day, night, or both);
- Facility type;
- Work zone situation type at the time of the traffic crash (flagging, lane closure, mobile operation, etc.);
- Accident severity;
- Type of traffic crash occurring if applicable (rear-end, sideswipe, single vehicle, vehicle intrusion [a passenger vehicle traveling through the work zone and entering the workspace], vehicle impact with worker, etc.);
- Type of worker construction accident if applicable (falls, equipment accidents, trenching accidents, accidents between work vehicles and workers, etc.); and
- Contributing factors to the traffic crashes (driver inattention, poor driver judgment, etc.).

Generally speaking, accidents occurring between 6 am and 6 pm were coded as daytime accidents, and those from 6 pm to 6 am were coded as nighttime accidents. Information about the work zone situation at the time of the crash, whether the vehicle intruded into the workspace, and whether the vehicle impacted a highway worker are all items not easily obtained (if available at all) from typical statewide traffic crash records systems. It should be noted that statewide statistics on the amount of day and night work operations each year in New York were not available to allow development of any type of crash rate measure.

Data Reduction and Analysis

Researchers obtained 6 years of NYSDOT work zone incidents (traffic crashes and construction accidents) for calendar years 2000 through 2005. The majority of projects that involved night work activity were performed on freeway and expressway facilities. Therefore, all freeway/expressway work zone incidents were first extracted from the full NYSDOT database for each year, using a combination of a "highway type" data field and extensive knowledge of the New York roadway network by a member of the research team. The goal of this step was to develop a consistent basis for comparison of daytime versus nighttime traffic crashes and construction accidents. Researchers reviewed each incident report to verify the accuracy of the codes used in each of the data fields relative to the brief narrative of the accident included in each record. In cases of obvious miscoding or where a code was not provided, researchers reviewed the descriptive narrative of the incident and manually inserted the correct code(s). Ultimately, more than 3,400 traffic crashes and construction accidents over a six-year time period (2000 through 2005) were available for analysis. Table 1 summarizes how these incidents were distributed across traffic crashes and highway worker construction accidents in both daytime and nighttime working conditions.

Researchers then systematically segregated the data according to incident time period (day or night) and typical period

Table 1. Summary of NYSDOT work zone traffic crashes and construction accidents on freeways and expressways (2000-2005).

	Daytime Work Periods, Daytime Accidents	Nighttime Work Periods, Daytime Accidents	Nighttime Work Periods, Nighttime Accidents	Daytime Work Periods, Nighttime Accidents	Total
Traffic Crashes	1762	9	316	102	2189
Construction Accidents	931		114		1045
Total	2693	9	430	102	3234

of work operation (day, night, or both). While most of the crashes and accidents included in the database occurred during active work periods, some did occur during periods when the work zone was inactive. Statistical distributions of the other data fields were then computed separately for daytime incidents at daytime work operations and for nighttime incidents at nighttime work operations. Further stratification was made to examine lane closure work operations as its own distinct subset. As previously noted, temporary closure of one or more travel lanes on a freeway-type facility is often limited to night hours in order to avoid high traffic volume time periods. Direct comparison of incident characteristics of this particular work zone situation during the day to the same situation at night was thus of primary interest to the research team.

Researchers then computed statistical distributions of the various data field elements and used chi-square statistical tests of independence to check whether the differences in the distributions between daytime and nighttime incidents were significant. As previously noted, exposure data were not available to allow traffic crash or construction accident rates to be calculated from these data.

Findings

Work Zone Traffic Crash Analysis

Work Zone Conditions Where Crashes Occur

Daytime and nighttime work zone crashes on NYSDOT freeways and expressways differed significantly in how they were distributed among the common work zone traffic control operations utilized on these facilities. As shown in Table 2, a substantially higher percentage of nighttime crashes occurred during lane closure operations than of daytime crashes (57.6 vs. 50.4 percent, respectively). On the other hand, a higher percentage of daytime crashes occurred where there was only minor traffic control present and no work was occurring (17.2 percent vs. 7.6 percent of nighttime crashes). As previously stated, the typical reason for working at night is that one or more travel lanes must be closed for several hours to perform the work, and doing so during the day would cause unacceptable traffic impacts.

The greater relative frequency of temporary lane closures at night is also a likely explanation of the higher percentage of nighttime crashes during traffic control setup and takedown

Table 2. NYSDOT work zone crashes by traffic control conditions.

Type of Work Zone Traffic Control in Use	Daytime Work Operations, Daytime Crashes (n = 1757)	Nighttime Work Operations, Nighttime Crashes (n = 316)
Lane Closure	50.4%	57.6%
Minor Traffic Control, Work Inactive	17.2%	7.6%
Minor Traffic Control, Work Active	8.3%	9.5%
Flagging	8.0%	3.2%
Shoulder Closure	5.4%	0.9%
Median Crossover	3.3%	1.3%
Lane Shift	3.2%	0.9%
During Traffic Control Setup/Takedown	3.1%	14.2%
Full Road or Bridge Closure	0.7%	3.8%
Other	0.4%	1.0%
Chi-Square Test Results	Daytime and nighttime distributions are significantly different from each other [a]	

[a] $X^2 = 94.510 > X^2_{Crit\,(6,\,0.05)} = 12.592$

relative to daytime crashes (14.2 percent vs. 3.1 percent, respectively). Temporary lane closures require setup and takedown activities each night so that all travel lanes are returned to service for peak travel periods, which would imply a higher relative frequency of these activities occurring during nighttime hours compared to daytime hours. Nevertheless, the percentage of such crashes during nighttime hours seems rather high given that the amount of time typically required for such setup and removal is typically much less than the duration of the actual temporary lane closure. It is also noted that crashes at flagger-controlled sites are more frequent in daytime operations, which most likely reflects the relatively lower usage of flaggers for traffic control at night.

Severity of Work Zone Crashes

The comparative effect of day versus night work on crash severity is illustrated in Table 3. Overall, work zone crash severities trend slightly higher at night when consolidated across all types of work zone situations and for lane closure traffic crashes specifically. However, if only non-worker-involved crashes are considered, no significant differences in severity are detected between daytime and nighttime crashes. As can be seen in the table, worker-involved crashes tend to be more severe at night than during the day. Whereas 29.6 percent of worker-involved crashes during daytime lane closure operations resulted in fatalities or injuries, 50.8 percent of such crashes at nighttime lane closure operations resulted in injuries or fatalities. A similar trend is evident when worker-involved crashes are examined across all work zone types. Over one-half of the worker-involved crashes at night resulted in injuries or fatalities, and only about one-third of those types of crashes during the day involved fatalities and injuries.

The designation of a crash as being worker involved does not automatically imply that the worker was actually hit by the vehicle and sustained the injury. In fact, for many of the worker-involved crashes, the driver or other occupants of the vehicle sustained the most serious injuries. In these instances, the worker was involved but somehow managed to avoid being struck. If the crash did involve a vehicle striking a worker, the result was usually quite severe. Overall, 93 percent of those workers who were struck by a vehicle during the

Table 3. NYSDOT work zone crash severity.

Injury Severity	All Work Zone Traffic Control Types		Lane Closure Traffic Control Work Zones Only	
	Daytime Work Operations, Daytime Crashes	Nighttime Work Operations, Nighttime Crashes	Daytime Work Operations, Daytime Crashes	Nighttime Work Operations, Nighttime Crashes
All Traffic Crashes:	(n = 1762)	(n = 304)	(n = 886)	(n = 182)
Fatal	1.4%	3.3%	1.1%	2.7%
Injury	36.4%	43.4%	32.5%	41.2%
PDO	62.2%	53.3%	66.4%	56.1%
Chi-Square Test Results	Daytime and nighttime distributions are significantly different[a]		Daytime and nighttime distributions are not significantly different[d]	
Traffic Crashes: No Workers Involved	(n = 1423)	(n = 195)	(n = 771)	(n = 123)
Fatal	1.5%	3.6%	1.3%	2.4%
Injuries	37.3%	40.0%	32.9%	38.2%
PDO	61.2%	56.4%	65.8%	59.3%
Chi-Square Test Results	Daytime and nighttime distributions are not significantly different[b]		Daytime and nighttime distributions are not significantly different[e]	
Traffic Crashes: Workers Involved	(n = 339)	(n = 107)	(n = 115)	(n = 59)
Fatal	0.9%	2.8%	0.0%	3.3%
Injuries	32.7%	49.5%	29.6%	47.5%
PDO	66.4%	47.7%	70.4%	49.2%
Chi-Square Test Results	Daytime and nighttime distributions are significantly different[c]		Daytime and nighttime distributions are significantly different[f]	

[a] $X^2 = 12.609 > X^2_{Crit\ (2,\ 0.025)} = 7.378$
[b] $X^2 = 4.757 < X^2_{Crit\ (2,\ 0.025)} = 7.378$
[c] $X^2 = 12.068 > X^2_{Crit\ (1,\ 0.025)} = 5.024$
[d] $X^2 = 8.671 > X^2_{Crit\ (2,\ 0.025)} = 5.024$
[e] $X^2 = 1.912 < X^2_{Crit\ (1,\ 0.025)} = 5.024$
[f] $X^2 = 7.596 > X^2_{Crit\ (1,\ 0.025)} = 5.024$

day sustained injury, as did 100 percent of workers who were struck at night.

Types of Traffic Crashes Occurring

Significant differences were detected in the types of collisions that occurred on freeways and expressways during daytime versus nighttime work zone operations. Table 4 illustrates the distribution of daytime and nighttime collision types for all types of work zone situations and also for lane closure work zone operations only. The percentage of the crashes that involve rear-end collisions is substantially lower at night for all work zone traffic control types combined and for work zone lane closure operations in particular. Presumably, the lower traffic volumes present at night allow work activities to be accomplished with fewer disruptions in traffic flow and fewer abrupt speed changes by vehicles. The decrease in rear-end crashes at night is offset by small increases in the percentage of intrusion crashes, impacts with truck-mounted attenuators (TMAs), and impacts with work equipment, materials, and/or debris outside of the work area.

One possible explanation for these increases is that in daytime conditions, the traffic congestion that is created migrates the majority of the crashes (most of them rear-end collisions) upstream away from the work area to where drivers first have to make significant adjustments in their speed. At night, this crash impetus does not exist upstream, and so the consequences of driver inattention congregate in and around the area of work activities themselves. Add to this the fact that drivers at night are more likely to be impaired than during the day, and it is fairly easy to understand why intrusions and impacts with TMAs would make up a greater proportion of nighttime work zone crashes. Statistically, the differences between daytime and nighttime periods shown in Table 4 are highly significant when all work zone traffic control types are considered together. Limiting the analysis to lane closure traffic control work zone crashes, differences between daytime and nighttime conditions are still statistically significant but not by as large of an amount.

Table 4 also illustrates that the percentage of intrusion crashes involving workers is substantially higher at night work operations than during daytime work operations. The amount of the increase is the same for lane closure crashes (0.7 percent daytime vs. 3.8 percent nighttime) and for all work zone crashes (0.7 percent daytime vs. 3.8 percent nighttime). However, the absolute frequency of these crashes was very low; totally only 12 crashes during daytime periods and 11 crashes during nighttime periods over the 6-year period of analysis.

Intrusion crashes involving construction equipment and those involving construction debris or materials are also higher at night but to a lesser degree. Intrusion crashes still make up only a small proportion of all types of traffic crashes in either daytime or nighttime work zones. The percentages shown in Table 4 are consistent with previously reported trends in work zone intrusion crashes (*47*, *48*). As stated previously, it

Table 4. NYSDOT traffic crash types.

Key Crash Types	All Work Zone Traffic Control Types		Lane Closure Traffic Control Work Zones Only	
	Daytime Work Operations, Daytime Crashes (n = 1762)	Nighttime Work Operations, Nighttime Crashes (n = 315)	Daytime Work Operations, Daytime Crashes (n = 886)	Nighttime Work Operations, Nighttime Crashes (n = 182)
Rear End	49.0%	35.6%	59.1%	45.6%
Other Multi-Vehicle	16.8%	14.3%	14.8%	13.2%
Single Vehicle Run-Off-Road	9.4%	9.8%	5.3%	7.1%
Intrusion Impacts:	0.7%	3.8%	0.7%	3.8%
with Workers	3.7%	4.8%	4.7%	6.0%
with Equipment	3.1%	3.8%	4.3%	4.4%
with Debris/Other				
Non-intrusion Impacts:	0.4%	0.3%	0.2%	0.5%
with Workers	3.6%	6.7%	2.5%	4.4%
with Equipment	6.8%	8.6%	4.9%	7.7%
with Debris/Other				
	2.7%	9.8%	2.5%	4.9%
Impact with TMA	3.8%	2.5%	1.0%	2.4%
Other Miscellaneous Types				
Chi-Square Test Results	Daytime and nighttime distributions are significantly different[a]		Daytime and nighttime distributions are significantly different[b]	

[a] $X^2 = 118.360 > X^2_{Crit\ (7,\ 0.025)} = 16.013$

[b] $X^2 = 21.828 > X^2_{Crit\ (7,\ 0.025)} = 16.013$

Table 5. Severity of NYSDOT work zone rear-end crashes.

Injury Severity	All Work Zone Traffic Control Types		Lane Closure Traffic Control Work Zones Only	
	Daytime Work Operations, Daytime Crashes (n = 863)	Nighttime Work Operations, Nighttime Crashes (n = 112)	Daytime Work Operations, Daytime Crashes (n = 524)	Nighttime Work Operations, Nighttime Crashes (n = 83)
Fatal	0.3%	2.7%	0.6%	2.4%
Injuries	35.2%	42.9%	31.1%	34.9%
PDO	61.9%	54.4%	68.5%	62.7%
Chi-Square Test Results	Daytime and nighttime distributions are not significantly different[a]		Daytime and nighttime distributions are not significantly different[b]	

[a] $X^2 = 3.307 < X^2_{Crit\ (1,\ 0.025)} = 5.024$
[b] $X^2 = 1.622 < X^2_{Crit\ (1,\ 0.025)} = 5.024$

is not possible to determine from the analysis whether the actual risk of such crashes increases at night, or whether the shift in the relative frequencies between daytime and nighttime work conditions is instead the result of a lower relative frequency of rear-end crashes associated with nighttime operations. Still, the fact that intrusion crashes involving workers are a greater proportion of nighttime work zone traffic crashes in general may partially explain why the highway worker perceives night work to be more hazardous.

Although night work is associated with a lower percentage of rear-end crashes relative to daytime work activities, the question still exists as to whether the rear-end crashes that do occur at night are more severe because of generally higher traffic speeds. The comparison of day and night operations in Table 5 indicates that a slightly greater percentage of rear-end crashes in night work operations involves fatalities and injuries, both for all work zones and for those at lane closures. However, the differences are not statistically significant. A similar comparison of the severity of workspace intrusion crashes between daytime and nighttime conditions is shown in Table 6. Similar trends are evident when all work zone types combined are considered, specifically for lane closures. The percentage of fatalities and injuries associated with intrusion crashes is greater at night than during the day. However, whereas the difference in percentages between nighttime and daytime is statistically significant for all work zone types combined, it is not when only lane closure intrusion crashes are considered.

Work Zone Construction Accident Analysis

Types of Construction Worker Accidents

Table 7 presents the relative frequency of different types of construction worker accidents reported at NYSDOT work zones on freeway and expressway facilities during daytime and nighttime work activities. Overall, the percentages are similar between daytime and nighttime conditions, with no statistically significant differences detected. Accidents involving tools or construction materials are the largest category, followed by strains caused by slipping or tripping and accidental contacts with utilities. The percentage of accidents that involve workers being hit by construction vehicles or equipment in the work zone is nearly identical for daytime and

Table 6. Severity of NYSDOT workspace intrusion crashes.

Injury Severity	All Work Zone Traffic Control Types		Lane Closure Traffic Control Work Zones Only	
	Daytime Work Operations, Daytime Crashes (n = 133)	Nighttime Work Operations, Nighttime Crashes (n = 39)	Daytime Work Operations, Daytime Crashes (n = 86)	Nighttime Work Operations, Nighttime Crashes (n = 26)
Fatal	2.3%	7.7%	2.2%	0.0%
Injuries	36.8%	53.8%	36.3%	56.4%
PDO	60.9%	38.5%[a]	61.5%	43.6%[b]
Chi-Square Test Results	Daytime and nighttime distributions are significantly different[a]		Daytime and nighttime distributions are not significantly different[b]	

[a] $X^2 = 7.419 > X^2_{Crit\ (1,\ 0.025)} = 5.024$
[b] $X^2 = 2.728 < X^2_{Crit\ (1,\ 0.025)} = 5.024$

Table 7. NYSDOT construction worker accident types.

Accident Type	Daytime Accidents (n = 931)	Nighttime Accidents (n = 114)
Falls – Elevated	4.1%	6.2%
Slip/Trip Strain	17.6%	18.6%
Accident with Tool or Material	30.4%	27.4%
Worker Hit by Equipment or Construction Vehicle	6.3%	7.1%
Other Equipment or Vehicle Accident	8.5%	13.3%
Utility Contact	26.4%	17.7%
Other Accident	6.7%	9.7%
Chi-Square Test Results	Daytime and nighttime distributions are not significantly different[a]	

[a] $X^2 = 4.523 < X^2_{Crit\ (6,\ 0.025)} = 12.592$

nighttime work activities and account for 6 to 7 percent of all construction worker accidents.

Severity of Construction Worker Accidents

The severity of construction accidents occurring during daytime and nighttime work operations is compared in Table 8. During night work, a slightly greater percentage of construction accidents resulted in injuries than during daytime work, although this small difference is not statistically significant. It is particularly noteworthy that only three worker fatalities resulted from construction accidents over a 6-year period (0.3 percent of 931 reported accidents), and they all occurred in daytime operations.

Summary of Findings

The following key findings are drawn from the NYSDOT work zone accident database regarding work zones on freeway and expressway facilities, which are most often targeted for night work operations. These findings pertain to both traffic crashes and construction accidents.

- About half of daytime work zone traffic crashes and 60 percent of nighttime work zone crashes on NYSDOT freeways and expressways occur during traffic lane closures. This statistically significant increase in lane closure crashes at night is probably the result of the higher relative frequency of lane closure operations at night, rather than a higher crash risk.
- Overall, there appears to be little difference in traffic crash severity between daytime and nighttime work operations on freeway and expressway facilities. However, worker-involved traffic crashes at nighttime work zones were significantly more severe than in daytime. It should be noted that worker "involvement" did not necessarily imply that the worker was struck by the vehicle; the higher percentage of severe crashes at night was often drivers or passengers in the vehicle rather than the worker. If a worker was struck, it usually resulted in an injury regardless of whether it occurred during the day or at night.
- Rear-end collisions comprise a smaller proportion of work zone traffic crashes at night work zone operations than during daytime operations. This result is consistent with expectations that moving work activities to nighttime hours reduces congestion and queuing that can lead to higher rear-end crash frequencies. Also, working at night does not appear to result in more serious rear-end crashes (when they do occur) than during daytime work operations.
- Crashes involving workers, construction vehicles or equipment, and construction materials and debris (both intrusion and non-intrusion crashes) comprise a greater percentage of crashes at night than during the day. Intrusion crashes involving workers (those of most concern to agencies and highway contractors) are a higher percentage of crashes at night than during daytime hours. However, they are only a small proportion of the total work zone crash experience in either time period.
- Intrusion crashes at nighttime work operations for all types of traffic control combined are significantly more severe than at daytime work operations. A similar trend is evident for lane closure crashes, although the differences between nighttime and daytime conditions are not statistically significant.
- The types of construction worker accidents occurring at NYSDOT freeway and expressway work zones do not differ significantly between daytime and nighttime operations.
- The severity of construction worker accidents does not differ significantly between daytime and nighttime operations.

Table 8. NYSDOT construction worker accident severity.

Injury Severity	Daytime Accidents (n = 931)	Nighttime Accidents (n = 114)
Fatal	0.3%	0.0%
Injury	65.2%	73.5%
None/PDO	34.5%	26.5%
Chi-Square Test Results	Daytime and nighttime distributions are not significantly different[a]	

[a] $X^2 = 2.846 < X^2_{Crit\ (1,\ 0.025)} = 3.841$

CHAPTER 3

Analysis of Traffic Crashes during Nighttime and Daytime Work Zone Operations

Study Methodology

Researchers designed the experimental plan for this component of the research study to best answer the previously identified question, "How does doing a project task at night affect traffic safety relative to doing this same task during the day?" Implied in this question is the recognition that the comparison should be based on the same work task being performed (at least from a traffic control perspective) and on doing the work at the same location. Also, implied in this question is the assumption that the comparison is being made on the basis of total additional crash costs being incurred over the duration of the project task that needs to be completed (since the severity of the additional crashes occurring during the day and at night may be different).

Because directly comparing traffic crash experiences for similar temporary traffic control setups used during nighttime and daytime work operations at a given location would be too limited to allow proper statistical analyses, researchers developed an experimental plan to make use of a large number of projects on freeway facilities that involved frequent or intermittent temporary lane closures during either daytime or nighttime work hours. Researchers expected that daytime temporary lane closures would exist at project sites on lower-volume facilities where the closure of travel lanes would not generate significant congestion and delay. Similarly, researchers anticipated that projects where temporary lane closures are done at night would occur predominantly on higher-volume facilities because of desires to avoid creating significant congestion and delays during daytime hours. There would be some overlap of these ranges, depending on the specific criteria used by the highway agency having jurisdiction over each project, roadway and work task characteristics, etc. From this dataset, statistical techniques would be used to establish separate relationships of the additional crash costs per period of work activity involving temporary lane closures during daytime work periods and during nighttime work periods. For the daytime work periods, the effect of working during the day at higher-volume locations would have to be extrapolated beyond the limits of the data; for nighttime work periods, an extrapolation to lower-volume freeway types would be required. This analysis approach is depicted graphically in Figure 1. The relationships are depicted as nonlinear, reflecting expectations that the effects of congestion and queues significantly add to the crash risk as volumes increase. The potential for the increased crash costs at night work operations to exceed those at daytime work operations is also implied at very high traffic volume levels since temporary lane closures on very high-volume facilities can still create traffic and congestion even at night.

Similar relationships could likewise be developed for other comparable work conditions. For example, daytime versus nighttime crash cost increase comparisons during periods of work activity without temporary lane closures would be of interest to assess the relative effects of work distractions, vehicle and equipment access impacts, and other non-lane closure influences on traffic safety. In addition, daytime versus nighttime comparisons of crash cost increases during periods of work inactivity could provide an indication of the relative effects of work zone design features (reduced lane and shoulder widths, lane shifts, etc.) on traffic safety.

Researchers initially contemplated stratifying the data on the basis of roadway type. One would expect the decision of whether or not to work at night to be influenced by different reasons for an urban arterial work zone versus a work zone on a freeway or expressway segment, for example. Differences in driver demographics, traffic volumes and speeds, and crash rate increases between daytime and nighttime conditions are likely not the same for different roadway types. Unfortunately, the sample sizes required to properly evaluate nighttime and daytime work operations on multiple roadway types were beyond the budget limitations of this study. Consequently, researchers focused their efforts in this study on freeway and expressway facilities. Although the results of the study do

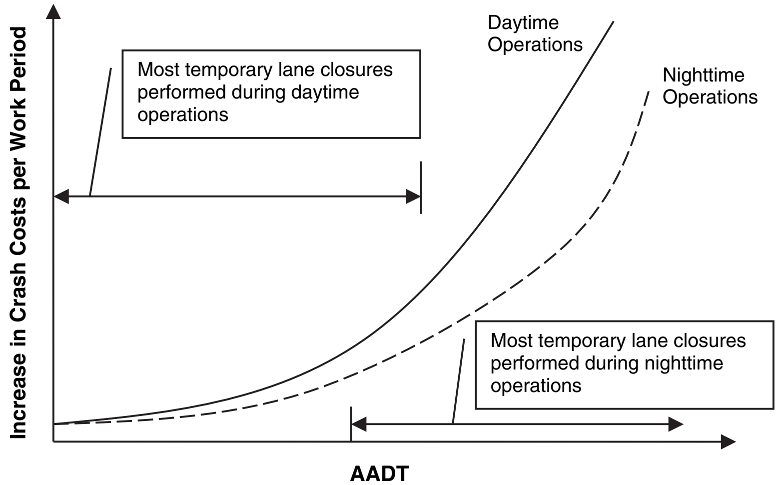


Figure 1. Theorized relationships between increased traffic crash risk and roadway traffic demand at nighttime and daytime work operations that require temporary lane closures.

provide important insights into this issue, it should be remembered that the findings may not represent all possible types of work zones where a decision of whether to work at night must be made.

Data Collection

The experimental plan for this portion of the study called for the collection of crash and project activity data across a range of geographically dispersed highway work zones nationally, each of which involved occasional to frequent temporary lane closures to complete the work. For some of the projects, these temporary lane closures occur primarily during daytime hours; for the other projects, these temporary lane closures occur almost exclusively at night. Researchers targeted states that participate in the FHWA HSIS so that multiple years of crash data, annual average daily traffic (AADT), and roadway characteristic data would be more easily accessible. Ultimately, projects were identified from four HSIS states:

- California,
- North Carolina,
- Ohio, and
- Washington.

Originally, the intent was to obtain data from several projects in Texas as well. However, the lack of available crash data prompted researchers to drop that state from the analysis. Researchers contacted department of transportation (DOT) officials in each of the other states to request assistance in identifying suitable candidate projects to use in this study. An initial list of 92 projects was generated through this effort.

In order to accomplish the analysis approach described in the previous section, researchers required details about the daily (and nightly) work activity performed by the highway contractor at each project such as: hours of work, hours and locations of temporary lane closures set up and removed, and the number of travel lanes closed each work period. Project details such as these must be extracted manually from the daily diaries of the project inspectors who were onsite each day or night. A few states have construction management databases (such as the Trns•port SiteManager software available through the American Association of State Highway and Transportation Officials [AASHTO]) where this information may be entered electronically (*49*). Even so, it was necessary for research staff to sit down with either the diaries or the SiteManager program itself to extract the pertinent information for each work period on each project of interest. In addition to work activity information, researchers also required information about the traffic control plan used, construction phasing, etc., for each project.

Two- to three-person data collection teams traveled to each state, except Ohio, to gather the necessary project data for analysis. Ohio uses a construction management database that they were willing to download and send electronically, negating the need to travel to that state. In the other three instances, the state DOT staff in each state provided key assistance in gaining the data collection access to the necessary project records. In most cases, the projects themselves had been closed out and the records archived, and so the DOT staff had to request that the files be pulled and transported to a location where the research team could use them. Once the records were in hand, the data collection team had to verify that all of the necessary information was available and that the project was useable. In a few cases, project diary information or traffic control plans were misplaced and not with the rest of the project documents. For those situations, no project data could be collected. From the initial list, data were located and retrieved by research staff for 84 of the projects.

Once the data collection team returned to the office, researchers requested crash and roadway inventory data for each project segment length for the duration that the project itself was active and for several years preceding. Additional details regarding the before periods for each project can be found in Appendix A. Researchers actually requested data for an additional upstream distance around each project to permit a check for indicators that traffic queues or other work-zone-related effects were contributing to crashes occurring in those adjacent segments. A high percentage of crashes coded as "work zone involved" in adjacent segments over the duration of the project was the key indicator that the effects of the work zone were extending beyond the limits of the project. In these cases, the limits of the project were then expanded to incorporate those segments. When the project limits were expanded, the added segment generally totaled less than 0.5 mi per direction.

The number of usable projects was further reduced due to the following issues that unfortunately were not discovered until after the data collection effort:

- Based on the roadway inventory data, three projects contained sections of roadway that were not limited access facilities (i.e., freeway). This occurs when the work activity is conducted in the area where a roadway changes to or from a limited access facility. Researchers decided not to include these projects in the dataset since the accident trends on these roadways may differ from the rest of the dataset.
- Ten of the Ohio projects could not be used since the electronic diary data did not include the exact work times (e.g., midnight to 5 am), information concerning lane closures, or both. Researchers contacted the Ohio DOT to obtain more detailed hard-copy diaries but found that the hard-copy diaries did not contain any additional information.
- During the data collection and reduction stages, it was anticipated that the 2005 Ohio crash data would become available; however, this did not come to fruition. Thus, two Ohio projects conducted during this time period could not be used.
- One of the Ohio projects could not be used since the mile points where the project occurred were missing from the HSIS.
- Washington did not provide 1997 and 1998 crash data to FHWA for inclusion in the HSIS. Thus, four Washington projects conducted during this time period could not be used.

This reduced the final dataset to a total of 64 projects. Even though somewhat smaller than the initial list of projects targeted, this dataset is substantial. An overall summary of project characteristics and crash statistics is presented in Table 9. Overall, the projects encompass approximately

Table 9. Summary of project characteristics and crash statistics.

Statistic	State				
	California	North Carolina	Ohio	Washington	Overall
Duration of Projects, Days:					
Total of All Projects in Sample	6,719	11,329	5,710	6,048	29,806
Average per Project	419.9	566.5	571.0	336.0	466.0
Standard Deviation	215.6	549.6	363.5	321.3	399.0
Minimum per Project	74	44	81	40	40
Maximum per Project	862	2,114	1,033	1,236	2,114
Lengths of Projects, Miles:					
Total of All Projects in Sample	110.9	155.9	44.0	154.0	464.8
Average per Project	6.9	7.8	4.4	8.6	7.3
Standard Deviation	4.4	7.2	2.8	18.2	10.6
Minimum per Project	1.4	2.0	0.3	0.7	0.3
Maximum per Project	17.0	30.2	9.4	80.5	80.5
Traffic Exposure of Projects, mvm:					
Total of All Projects in Sample	4,369.5	4,742.0	1,371.7	2,430.4	12,913.6
Average per Project	273.1	237.1	137.2	135.0	201.8
Standard Deviation	359.6	315.0	159.1	193.4	279.4
Minimum per Project	27.6	3.4	25.7	0.7	0.7
Maximum per Project	1,425.8	1,234.5	544.1	716.1	1,425.8
Traffic Crashes Occurring during Projects:					
Total of All Projects in Sample	6,613	4,831	2,776	3,008	17,228
Average per Project	413.3	241.6	277.6	167.1	269.2
Standard Deviation	607.3	325.0	412.1	272.6	415.3
Minimum per Project	27	0	12	0	0
Maximum per Project	2,292	1,294	1,382	1,105	2,292
Average per Mile per Year	289.0	106.96	200.8	139.6	245.9

465 centerline-mi of roadway and over 82 years of work, for which researchers had to manually determine days and hours of work activity and whether temporary lane closures were present. Both project length and duration were highly variable, with an average length of slightly more than 7 mi and an average duration of about 16 months. Actual lengths ranged from 0.3 to 80.5 mi, and durations ranged from 40 days to 5.8 years. Also summarized in Table 9 are the work zone crashes occurring on these projects. More than 17,000 crashes were reported during the performance of these 64 projects. Additional project details and crash statistics can be found in Appendix A.

Next, Table 10 summarizes the daytime and nighttime crash rates per 100 mvm that would normally be expected for the sample project locations in each state if a work zone were not present. As shown, these non-work zone crash rates tended to be higher at night than during the day. Furthermore, the difference between the nighttime and daytime rates tended to be greater for the severe crashes. These numbers indicate that, even in the absence of a work zone, driving at night is normally more risky for drivers than driving during the day on a per-vehicle-mile traveled basis. Although the per-mvm rates are usually higher on roadway facilities nationally at night than during the day, the much lower traffic volumes using the facilities at night means that the actual number of crashes occurring on a per-night, per-mile basis is still usually less than for a per-day, per-mile basis on the same facility.

Researchers developed exposure estimates and stratified the crashes occurring during each project in the database into one of six categories:

- Daytime and nighttime periods when the project was inactive and no temporary lane closures were in place in the work zone;
- Daytime and nighttime periods when work activity was occurring somewhere within the project but temporary lane closures were not in place (i.e., no work was occurring in the way of travel); and
- Daytime and nighttime periods when work activity was occurring somewhere within the project and temporary lane closures were in place that reduced the available capacity of the roadway.

Table 10. Expected (non-work zone) average crash rates in the project dataset.

Crash Severity	State	Crashes per 100 mvm	
		Nighttime	Daytime
Severe (Injury or Fatality)	California	97.1	78.7
	North Carolina	91.6	72.1
	Ohio	92.7	77.1
	Washington	87.5	89.7
	Overall	92.8	78.1
PDO	California	150.7	151.8
	North Carolina	153.5	121.4
	Ohio	248.4	231.2
	Washington	112.6	108.9
	Overall	155.8	140.5

A fourth possible category, daytime and nighttime periods when the project was inactive and temporary lane closures were in place, was very limited in the dataset and so was not considered in this analysis.

Researchers attempted to ensure that the projects obtained from each state were somewhat balanced between those that had work activity and temporary lane closures during the day, and those that had work activity and temporary lane closures at night. Ultimately, however, very few projects with daytime work activities and temporary lane closures were available from California and Ohio. Therefore, this category is overrepresented by North Carolina and Washington projects. Also, the projects obtained from California and Ohio tended to be on higher AADT facilities than those from North Carolina and Washington.

Researchers hypothesized that increases in crash risk during the inactive periods of the project (relative to the crash risk normally expected on that roadway segment) reflected the influences that temporary geometric changes and other work zone design decisions had upon safety. Similarly, crash risk increases during periods of work activity but with no temporary lane closures was assumed to reflect the combined effects of the geometric changes/work zone design decisions and distractions and turbulence caused by work activities adjacent to the travel lanes. Finally, the increase in crash risk during periods of work activity with temporary lane closures represented the combined effect of geometric changes/work zone design decisions, work activity distractions and turbulence, and additional traffic turbulence caused by the temporary roadway capacity restrictions. Table 11 illustrates this concept.

The projects used in this study varied widely in terms of the relative amount of work activity performed during the day and night, as well as the frequency with which these active work periods required one or more travel lanes to be temporarily closed. This is illustrated in Table 12. Averaged across each state and over the entire study sample, the projects tended to be active more often during the day than at night in North Carolina, Ohio, and Washington (the California projects were approximately equally active day or night). However, much of the activity during the day at these projects occurred outside the roadway, whereas most of the work activity at night involved temporary lane closures. Specifically, when work occurred at night on the sample projects, 88 percent of the time it involved a temporary lane closure. In contrast, temporary lane closures were utilized only 26 percent of the time that work activity occurred during the day. Of course, these statistics may not be indicative of all freeway projects in these states because projects involving temporary lane closures were specifically targeted in this analysis.

Table 11. Relationship between work zone analysis periods and influences on work zone safety.

Work Zone Analysis Period	Effect of Temporary Geometric and Work Zone Design Influences on Safety	Effect of Off-Travel Lane Work Activity Distractions and Disruptions on Safety	Effect of Traffic Disruptions due to Temporary Roadway Capacity Reductions on Safety
When Work Zone Inactive and No Temporary Lane Closures	X		
When Work Zone Active and No Temporary Lane Closures	X	X	
When Work Zone Active and Temporary Lane Closures Present	X	X	X

As expected, the majority of projects where temporary lane closures were performed during the day occurred at locations where AADTs were relatively low, and those performed where AADTs were relatively high involved predominantly nighttime temporary lane closures. This is illustrated graphically in Figure 2, which shows the percentage of hours involving a temporary lane closure at each project that was performed during nighttime hours (nighttime was defined as beginning at 7:00 pm, after the evening peak period, and ending at 6:00 am, prior to the start of the morning peak period). As shown, temporary lane closures at projects on roadways with AADTs less than about 40,000 vehicles per day (vpd) were mostly performed during daytime hours, whereas those on freeways with AADTs in excess of 100,000 vpd were almost all performed at night. Between these ranges, the results were mixed. Night work was used extensively on some projects as low as 35,000 vpd, while a few projects on freeways with AADTs of up to 75,000 vpd still had about 60 percent or more of temporary lane closures occur during daytime hours.

Data Analysis

For each of the work zone analysis periods of interest, researchers used empirical Bayesian (EB) statistical techniques to estimate the incremental increase in crash risk that occurred relative to what would have been expected to have occurred if the work zone were not present at that location. EB techniques increase the precision of estimation and correct regression-to-the-mean bias (*50*). Often, the limited duration of a particular work zone project means that the sample size of crashes available for use in the analysis is quite small. Regression-to-the-mean biases may also exist at some work zone locations if the selection of roadway segments being targeted for repair and improvement is based partially on the recent crash experiences of that roadway segment. Consequently, EB techniques provide better estimates of the safety impacts of highway work zones than traditional before-during crash comparisons.

The EB procedure required researchers to develop safety performance functions (SPFs), using data from a reference group, of freeway facilities under daytime and nighttime conditions in each of the states where work zone projects were taken. The estimates from the SPFs were then combined with crash data occurring within the project limits for several years preceding the work at that location. The combination of the SPF and pre-work zone crash data provided a more precise estimate of the crashes that would be expected to occur over a given period of time at that location if the work zone had not been present. The ratio of the actual number of crashes occurring during the operation of the work zone to the EB estimate is then used to estimate the incremental effect of the

Table 12. Amount of work activity and temporary lane closures during daytime and nighttime periods in sample projects.

Statistic	State				
	California	North Carolina	Ohio	Washington	Overall
% of Time Active, Daytime	20.9	33.5	40.2	26.9	30.6
% of Time Active, Nighttime	20.8	13.6	15.2	15.7	16.0
% of Active Time with Temporary Lane Closures, Daytime	21.6	37.0	5.2	34.4	26.2
% of Active Time with Temporary Lane Closures, Nighttime	89.8	84.9	88.3	88.9	87.8

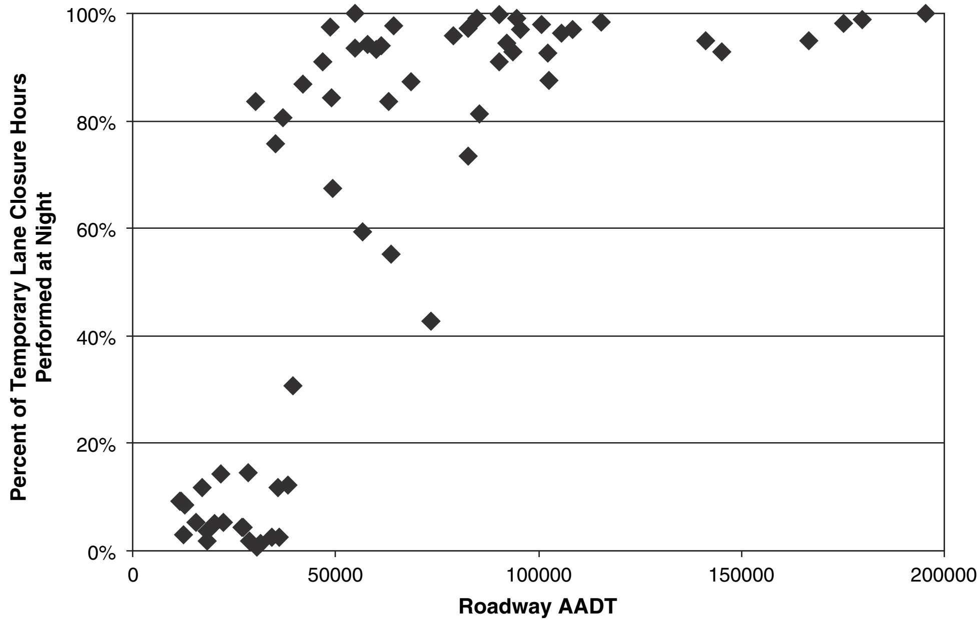


Figure 2. Percentage of temporary lane closures performed at night at each project.

work zone upon safety and is referred to herein as the "index of change" observed. Researchers analyzed fatal and injury crashes separate from PDO so that possible daytime and nighttime differences in crash severity could be estimated as well (reference to "injury" crashes herein implies the combination of both fatal and injury crashes). Additional details of the EB procedure employed for this study can be found in Appendix A.

After the differences in crashes were estimated at each project location for each time period of interest, the crash costs associated with these differences were computed. Recent cost values for freeway crashes (*51*) were used:

- Injury crash (fatality or injury)—$206,015, and
- PDO crash—$7,800.

The differential crash costs per unit duration of work activity or inactivity (with and without temporary lane closures) per mile of work zone were computed and modeled as a function of AADT.

Consideration was given to developing incremental crash increase models for selected collision types (rear-end, sideswipe, run-off-road, etc.), but this level of dissection of the data was determined to be too fine to permit statistically significant conclusions to be drawn from the data. Therefore, a simple comparison of the percentage involvement of these factors in the crashes before and during construction, aggregated across each state, was used to determine whether significant differences existed between the before project conditions and each of the work activity periods of interest in this study.

Results

Increases in Traffic Crashes Occurring during Nighttime and Daytime Work Activities

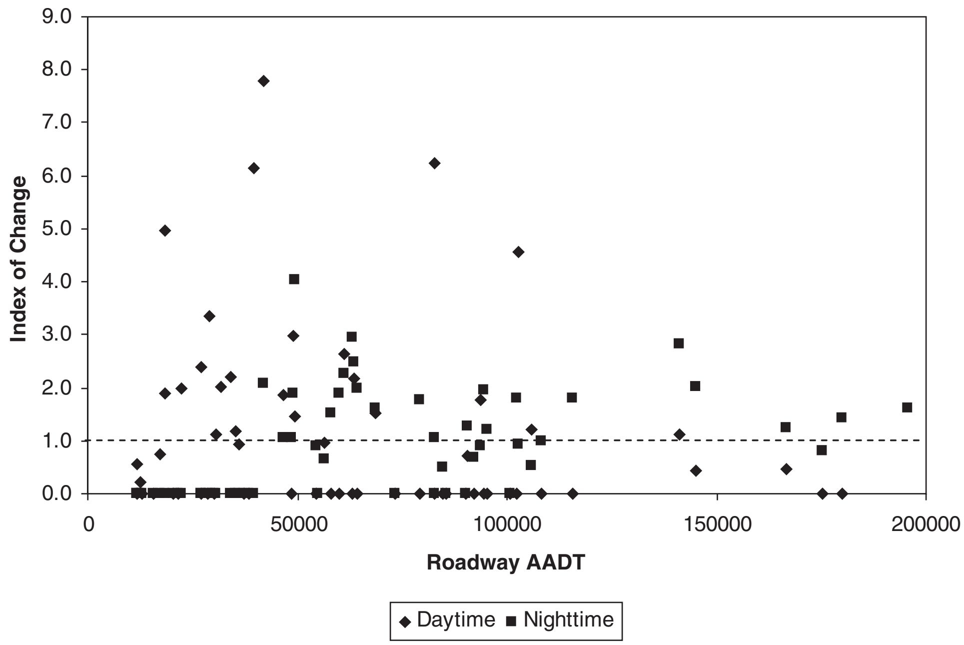
Increases in Crash Risk

Appendix B provides the number of injury and PDO crashes occurring at each project during each nighttime and daytime work period type (work activity or no work activity, with or without lane closures) and those expected to have occurred during those same periods if the work zone were not present.

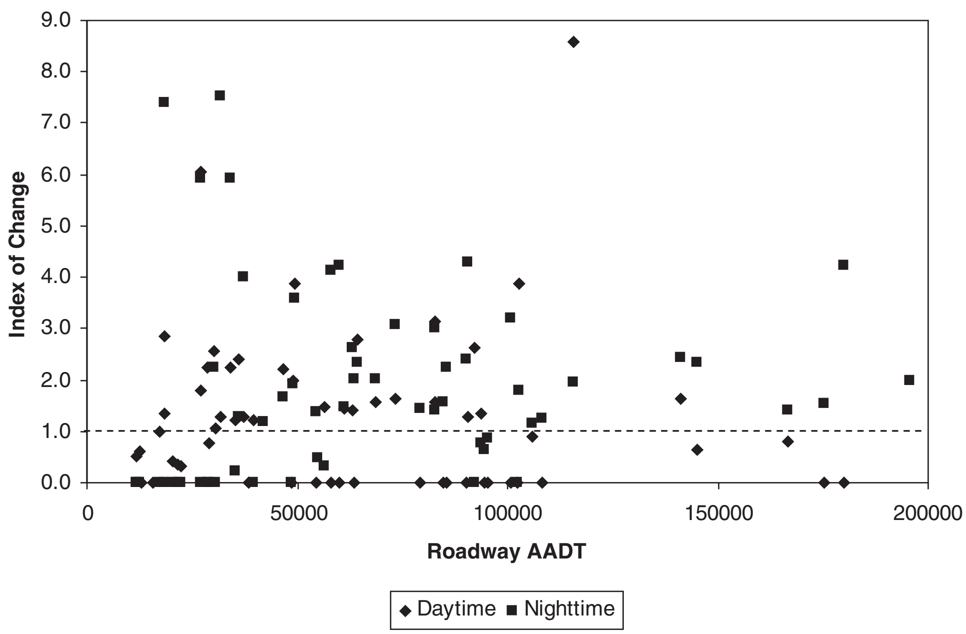
In Figures 3 through 5, the index of change estimated by the EB procedure is plotted against AADT for each project for each of the following scenarios:

- Project work was occurring (the work area was active), and temporary lane closures were in place (Figure 3);
- Project work was occurring, but no temporary lane closures were in place (Figure 4); and
- The project was inactive, and no temporary lane closures were in place (Figure 5).

An index of change of 1.0 indicates that the number of crashes actually occurring is equal to the number of crashes that were expected to have occurred based on the EB analysis. Values greater than 1.0 reflect an increase in actual crashes during construction relative to the number of crashes that would be expected if the work zone was not



(a) Injury Crashes



(b) PDO Crashes

Figure 3. Index of change for injury and PDO crashes during periods of work activity with temporary lane closures in place.

present. A higher ratio indicates a greater increase in actual crashes.

Across the three figures, considerable variability is evident from project to project. The index of change is as high as eight for some projects (i.e., the actual number of crashes that occurred is eight times greater than the crashes expected at that project location based on the EB analysis). In other instances, the actual number of crashes was less than the expected number (i.e., index of change is less than one). In still other cases, no crashes occurred during the project work period of interest, so the index of change is zero.

Although it was initially hypothesized that the effects of work activity and temporary lane closures would be higher (i.e., the index of change would be higher) at higher AADT levels, the analysis results did not bear this out. The projects were stratified into three AADT regions (less than 50,000 vpd;

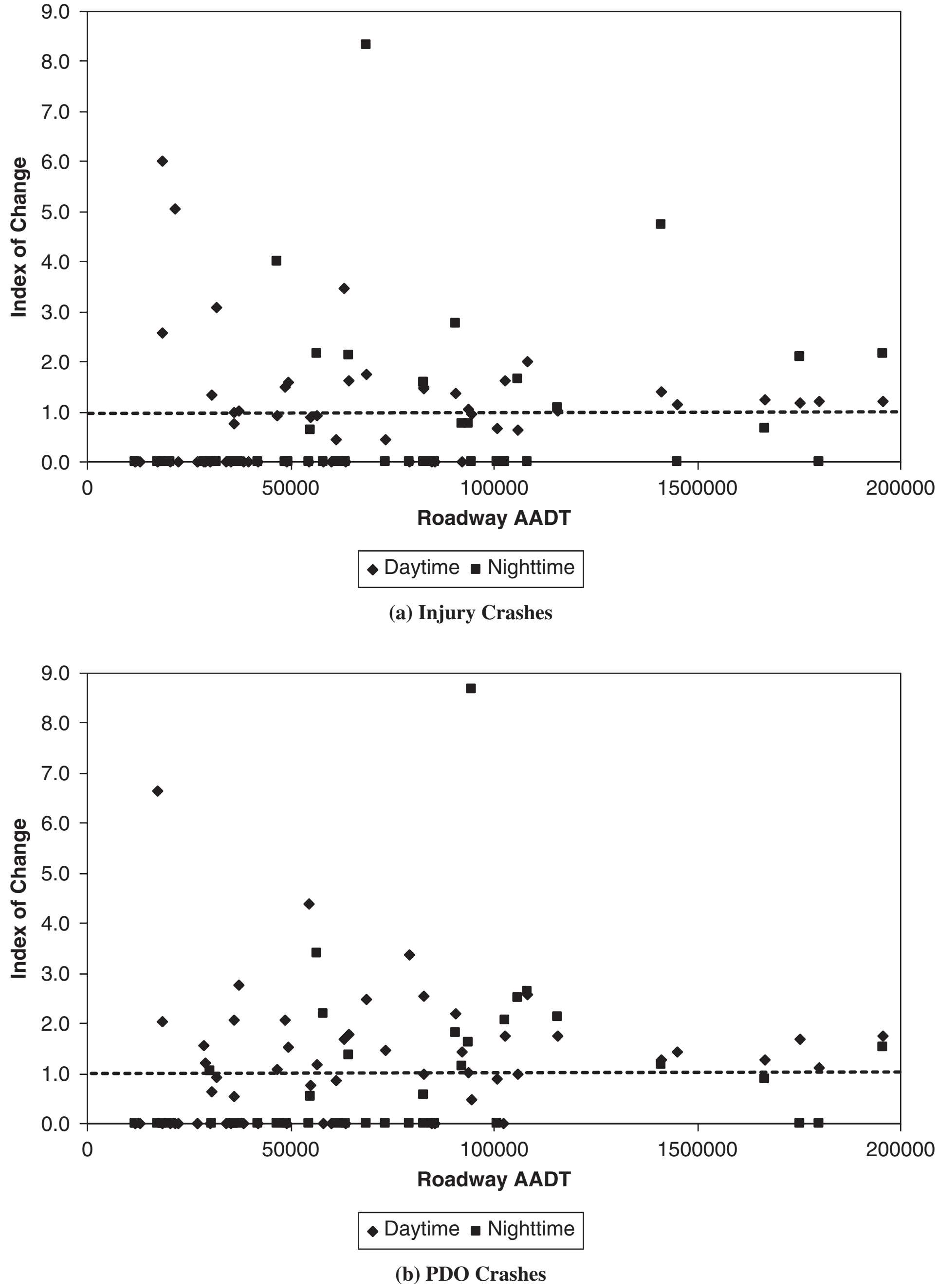
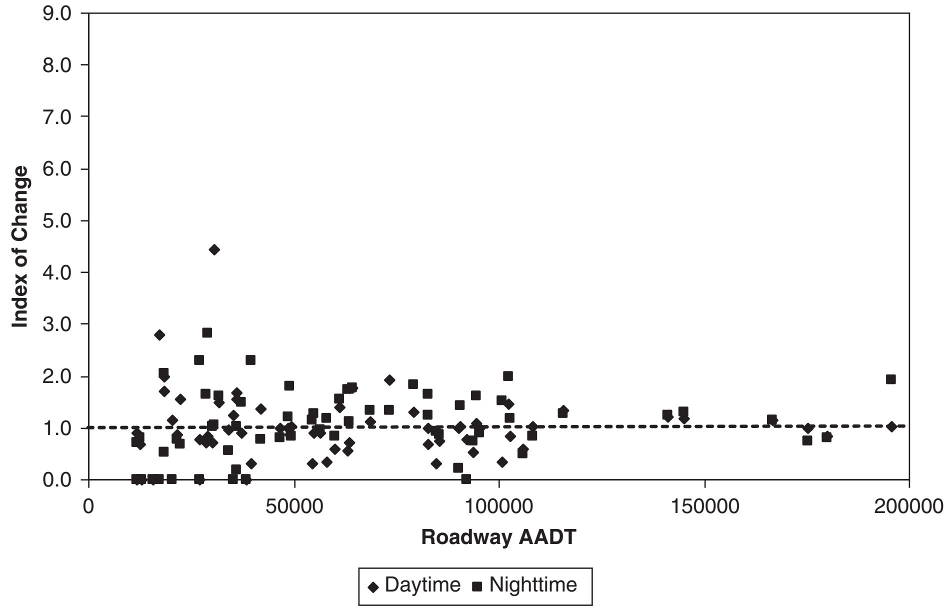
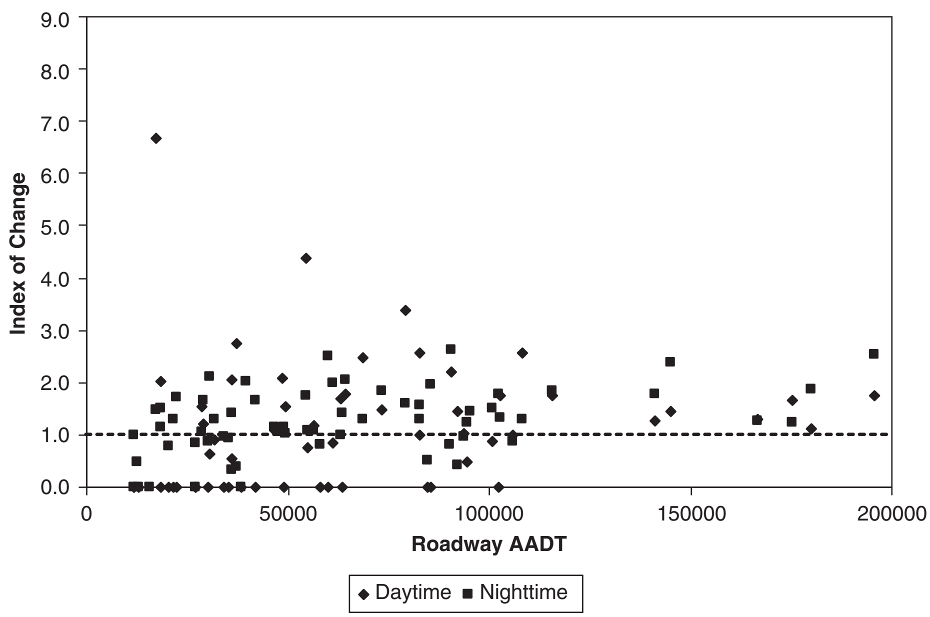


Figure 4. Index of change for injury and PDO crashes during periods of work activity but no temporary lane closures in place.

50,000–100,000 vpd; and greater than 100,000 vpd) and analyzed to determine the average index of change across the projects in each region. Table 13 presents the results of the analysis for periods when the work area was active and temporary lane closures were present. A weak trend of increasing ratios at higher AADT levels is evident for the nighttime work periods, but this is not replicated for daytime work periods. Furthermore, the fairly sizeable standard errors of these estimates indicates that there are no statistically significant differences in the crash ratios between any of the AADT regions for either injury or PDO crashes during either nighttime or daytime work periods. Consolidated across the entire AADT range, the index of change was essentially the same for both nighttime and daytime periods. Subtracting one from the index of change, expressed as a percent, defines the percent increase in crashes that occurred overall across the projects for the work condition and time period of interest. Injury crashes increased by 42.3 percent at night and by 45.5 percent during the day. For PDO crashes, the increase was 74.8 percent at night and 80.8 percent during the day. Researchers



(a) Injury Crashes



(b) PDO Crashes

Figure 5. Index of change for injury and PDO crashes when work area was inactive (no temporary lane closures in place).

also combined all crash severities together and computed an index of change. Total crashes increased 60.9 percent during daytime work activity with temporary lane closures and 66.3 percent at comparable work operations at night.

In Table 14, analysis results are presented for periods when work activity was occurring but no temporary lane closures were in place. Overall, this was a fairly infrequent event during night operations. Consequently, the crash ratio estimates obtained were not extremely reliable (as indicated by the large standard errors associated with the estimates). Again, no statistically significant differences were detected across the different AADT levels during either nighttime or daytime periods for either the injury crash or PDO crash indices of change. Although the overall injury index of change for the nighttime period appears to be higher than it is for the daytime period (indicating a 41.4 percent increase at night versus 17.4 percent increase during the day), they are, in fact, not statistically different from each other. Similarly, the index of change of PDO crashes in the nighttime period (indicating a 66.6 percent increase) is not statistically different than it is

Table 13. Index of change for injury and PDO crashes by AADT range during periods of work activity and temporary lane closures.

Crash Level	AADT Range	Index of Change (S.E.)	
		Nighttime	Daytime
Injury	<50k	*1.318* (0.227)	1.596 (0.149)
	50-100k	1.335 (0.151)	*1.166* (0.244)
	>100k	1.491 (0.116)	*1.261* (0.224)
	Overall	1.423 (0.085)	1.455 (0.112)
PDO	<50k	1.630 (0.188)	1.899 (0.126)
	50-100k	1.712 (0.137)	*1.338* (0.213)
	>100k	1.798 (0.103)	1.870 (0.199)
	Overall	1.748 (0.076)	1.808 (0.096)
All Crash Types Combined	<50k	1.527 (0.147)	1.770 (0.096)
	50-100k	1.569 (0.103)	*1.262* (0.161)
	>100k	1.649 (0.076)	1.645 (0.150)
	Overall	1.609 (0.057)	1.663 (0.073)

S.E. = Standard Error
Indices in italics are not significantly different than 1.

Table 14. Index of change for injury and PDO crashes by AADT range during periods of work activity but no temporary lane closures.

Crash Level	AADT Range	Index of Change (S.E.)	
		Nighttime	Daytime
Injury	<50k	*2.256* (1.302)	1.452 (0.216)
	50-100k	*1.341* (0.338)	1.189 (0.062)
	>100k	*1.395* (0.318)	1.132 (0.057)
	Overall	*1.414* (0.229)	1.174 (0.042)
PDO	<50k	*1.359* (0.680)	1.371 (0.147)
	50-100k	*1.227* (0.253)	1.410 (0.056)
	>100k	2.037 (0.293)	1.388 (0.044)
	Overall	1.666 (0.191)	1.398 (0.034)
All Crash Types Combined	<50k	*1.642* (0.622)	1.386 (0.121)
	50-100k	*1.285* (0.205)	1.323 (0.042)
	>100k	1.797 (0.215)	1.299 (0.035)
	Overall	1.577 (0.148)	1.314 (0.027)

Indices in italics are not significantly different than 1.

for the daytime period (indicating a 39.8 percent increase). Finally, total crashes during this condition increased 57.7 percent during daytime periods and 31.4 percent during nighttime periods.

Interestingly, the only category in which statistically significant differences were found between nighttime and daytime conditions was when the work area was inactive and no temporary lane closures were present. In Table 15, the differences in nighttime and daytime injury and PDO crash ratios across the AADT regions are not statistically significant. Overall, a slightly higher increase in injury crashes is seen for nighttime conditions (11.4 percent increase) than for daytime conditions (2.0 percent increase), but these are not statistically different from each other. For PDO crashes, the average increase at night (33.0 percent) was actually significantly higher than during the day (19.6 percent). For total crashes, the average increases were 23.7 percent and 12.7 percent during nighttime and daytime periods, respectively. The greater increases at night presumably reflect degraded geometric conditions in the work zone (relative to a no-work zone condition) that—coupled with nighttime-specific issues such as limited visibility, less attentive drivers, and so forth—raise nighttime crash risk more substantially than during inactive times in daytime periods.

It is important to note that the indices of change in each work condition category are higher for the PDO crashes than for the injury crashes, indicating that the additional crashes that do occur while the work zone is present tend to be less severe in nature. This trend exists regardless of whether the work is performed during the day or at night and is consistent with previous studies that indicated that crash rates may increase in work zones but that crash severity often decreases.

The magnitude of the change indices when work activity was occurring but no travel lanes were closed was a rather surprising finding from this analysis, especially for the nighttime period. These indices and those from when work was occurring and lanes were closed are compared directly in Table 16. Theoretically, the lack of temporary lane closures when work is occurring means that motorists do not have an obstacle (the lane closure) in their travel path that requires a driving reaction, and they do not have to deal with significant reductions in speed because of traffic congestion upstream of the closure. This would imply that the increase in crash risk when the work zone is active but lane closures are not present should be lower than when work activity is occurring and temporary lane closures are present. Although the crash ratios for daytime operations with and without temporary lane closures are consistent with this hypothesis, the results of this analysis indicate that working at night outside the travel lanes may have more substantial impacts on motorist safety than was known previously. Unfortunately, it is not clear from the data whether the increase in nighttime

Table 15. Index of change for injury and PDO crashes by AADT range during periods of no work activity and no temporary lane closures.

Crash Level	AADT Range	Index of Change (S.E.)	
		Nighttime	Daytime
Injury	<50k	*1.054* (0.087)	*1.106* (0.061)
	50-100k	*1.141* (0.071)	*0.936* (0.038)
	>100k	*1.106* (0.063)	*1.051* (0.030)
	Overall	1.114 (0.042)	*1.020* (0.022)
PDO	<50k	*1.133* (0.068)	1.271 (0.050)
	50-100k	1.309 (0.067)	1.102 (0.033)
	>100k	1.455 (0.059)	1.234 (0.025)
	Overall	1.330 (0.039)	1.196 (0.018)
All Crash Types Combined	<50k	*1.094* (0.054)	1.208 (0.039)
	50-100k	1.240 (0.051)	*1.042* (0.025)
	>100k	1.303 (0.043)	1.159 (0.019)
	Overall	1.237 (0.029)	1.127 (0.014)

Indices in italics are not significantly different than 1.

crash risk during these work conditions is the result of the following factors:

- Work area lighting glare that work crews do not mitigate well when they are not located in travel lanes;
- More frequent construction equipment and material deliveries into and out of the work area at night that create large speed differentials and subsequent crashes; or
- Other differences between daytime and nighttime work activity behaviors when travel lanes are not closed, such as higher speeds, reduced driver expectancy of encountering a work zone, and more impaired and drowsy drivers.

Table 16. Index of change comparisons with and without temporary lane closures during periods of work activity.

Crash Severity	AADT Range	Index of Change (S.E.)	
		Nighttime	Daytime
Injury	With lane closures	1.423 (0.085)	1.455 (0.112)
	Without lane closures	*1.414* (0.229)	1.174 (0.042)
PDO	With lane closures	1.748 (0.076)	1.808 (0.096)
	Without lane closures	1.666 (0.191)	1.398 (0.034)
All Crash Types Combined	With lane closures	1.609 (0.057)	1.663 (0.073)
	Without lane closures	1.577 (0.148)	1.314 (0.027)

Comparison of Daytime and Nighttime Work Based on Increased Crash Costs Associated with Work Zone

Figures 3 through 5 and Tables 13 through 16 provide estimates of the increased crash risk resulting from the presence of a work zone under each of the different work period categories examined. The ratios (reflecting a percentage increase in actual crashes from what would have been expected had the work zone not been present) identify how the crash risk of individual drivers encountering these work zones is affected. As noted above, drivers approaching a work operation at night where travel lanes are closed have a 42.3 percent greater risk (on average) of being in an injury crash and a 74.8 percent greater risk of being in a PDO crash than they would if the work zone were not there. Similarly, those same drivers traveling through that location at night when work is not occurring and no temporary lane closures are present have an 11.4 percent greater risk of being in an injury crash and a 33.0 percent greater risk of being in a PDO crash. In both instances, the increase in risk to individual drivers does not appear to depend upon the amount of traffic that the roadway handles on a daily basis. From the perspective of the practitioner who has to decide whether or not to work at night, though, the issue is not simply of the effects upon individual drivers, but on the entire driving population as a whole. Specifically, the question is whether completing a particular project or project task at night results in more or less additional crash consequences to motorists in total than doing the same project or task during the day. Given that the severity of crashes normally differs between nighttime and daytime conditions, calculation of the effects of a standardized project task duration and length under a nighttime and daytime work scenario at a given location is the appropriate basis of comparison.

Theoretically, computation of the additional crash costs expected for a particular project task duration and length could be accomplished uniquely for any project location, as long as the analyst had the following data:

- AADT of the roadway segment and how that AADT is distributed between the nighttime and daytime work periods of interest,
- Estimated duration of the project task to be completed,
- Length of the work zone or work area, and
- Normal or typical crash rates for the nighttime and daytime periods being analyzed (or models that allow the analyst to estimate the number of crashes normally expected on the facility).

If the more traditional (but less accurate) crash rate per mvm of the roadway segment is available, the analyst estimates the total vehicular exposure that would be experienced if the work were done during the day (number of days of work required multiplied by the amount of traffic passing through the work area each day period multiplied by the length of the work zone) versus what it would be if the work were performed at night. The appropriate percentage increases in crashes from Table 13 through Table 15 are then applied to the crash rate and multiplied by the estimated vehicle exposure for each period to estimate the additional crashes anticipated to occur because of the work task during that time period. Finally, multiplying these crashes by the appropriate unit crash costs and summing across all severity levels (if severe and PDO crashes are estimated separately) would allow an equivalent comparison of increased costs between the two time periods.

To illustrate the differences in daytime and nighttime work activity crash costs, SPF models for six-lane urban freeways in California (see Appendix A) were used to demonstrate how crash costs would be expected to increase for daytime and nighttime work zones as a function of the AADT level of the roadway segment. Similar trends would be obtained if the SPF models from the other states were used, although the absolute numbers would be different. The SPF model for freeway segments within large interchanges (where crashes tend to be somewhat higher) was averaged with those segments between interchange areas. A comparison of the estimated increased crash costs for a project task that requires a temporary lane closure to be used when work activity is occurring is provided in Figure 6. The values are computed assuming that a project task requires 100 work hours to be completed regardless of whether it is done at night or during the day. The data are also normalized to a per-work-zone-mile basis.

Computed in terms of additional crash costs, it is apparent from Figure 6 that working at night when work activities require travel lanes to be temporarily closed results in lower crash costs than the same work performed during the day over the entire range of AADT levels shown. On higher AADT roadways, there is actually a very sizeable overall economic benefit to the motoring public of doing this work at night from a safety standpoint; on lower AADT roadways, the benefit may not be particularly large but still exists. For example, the reduction in crash costs for 100 hours of work per mile of work zone at night versus doing the work during the day exceeds $40,000 at a roadway AADT of 250,000 vpd.

The differences between working at night versus working during the day on a project task that does not require temporary lane closures are less clear. Using the same California SPFs as before, researchers applied the appropriate percentage crash rate increases for this condition from Table 14 to estimate the total increased crash costs on a per 100 work hours per mile of work zone basis. Figure 7 provides the results of that analysis. Overall, the increased crash costs per 100 hours of work activity per mile at night are very close to what they were in Figure 6. However, the increased crash costs for this particular work condition are much lower for the daytime condition than they were in Figure 6. Ultimately, there is little or no benefit for working at night when a lane closure is not present. While there is a small advantage for day work at lower AADTs and a slight advantage for night work at higher AADTs, these differences are too small to significantly impact a decision of whether or not to work at night.

Finally, Figure 8 presents the estimate of increased crash costs during the day and at night when the work zone is inactive and no temporary lane closures are required. For this particular case, the increased crash costs at night are slightly higher than during the day across the entire range of AADTs

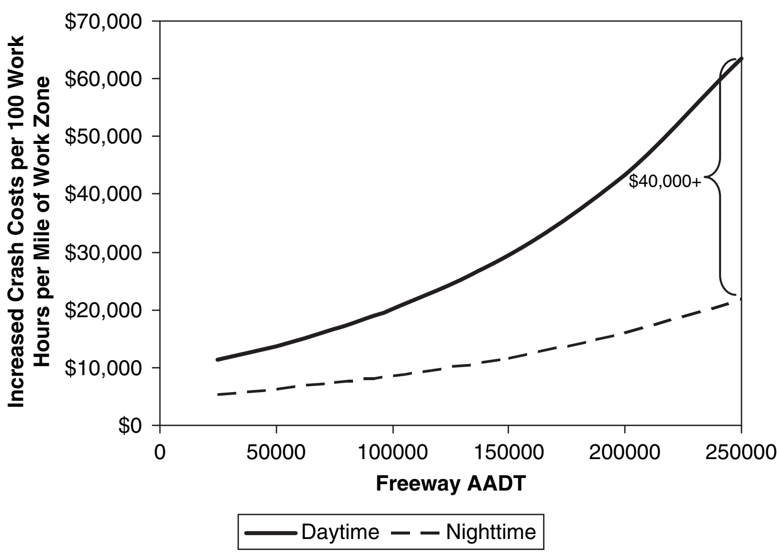


Figure 6. Increased crash costs with active work and lane closure present.

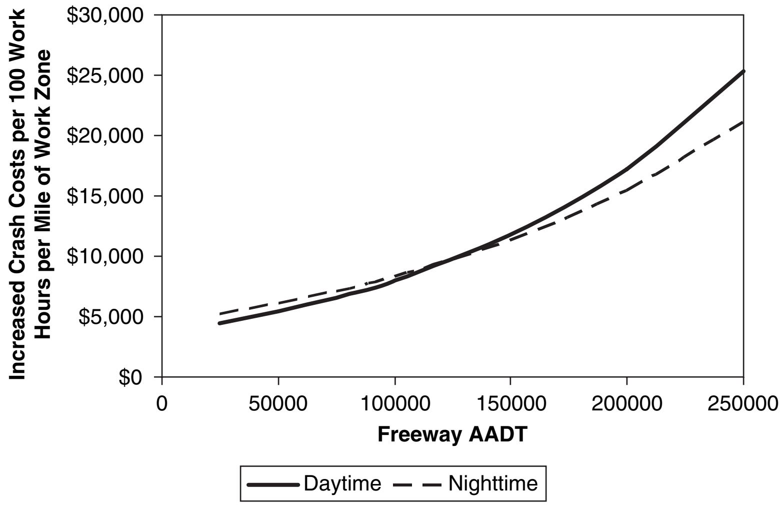


Figure 7. Increased crash costs with active work and no lane closure present.

examined. Of course, the increased crash costs are much lower across the entire range of AADTs for both daytime and nighttime conditions when compared to the previous figures when work is occurring (either with or without lane closures present).

Types of Crashes Occurring during Nighttime and Daytime Work

The preceding section examined the differences in work zone crash risk and crash costs between daytime and nighttime work for comparable periods of work activity and inactivity with and without lane closures present. The analysis considered both individual drivers and the driving population as a whole by including differences in traffic volume during night and day periods. Another relevant question is whether the types of work zone crashes differ significantly between nighttime and daytime periods. If so, such differences could lend insight into improved work zone safety policies, procedures, and practices that may produce an overall reduction in work zone crash risk.

In this section, an analysis of the distribution of different crash types/manners of collision is presented. Specifically, crashes were subdivided into one of four collision types:

- Rear-end collisions,
- Sideswipe collisions,

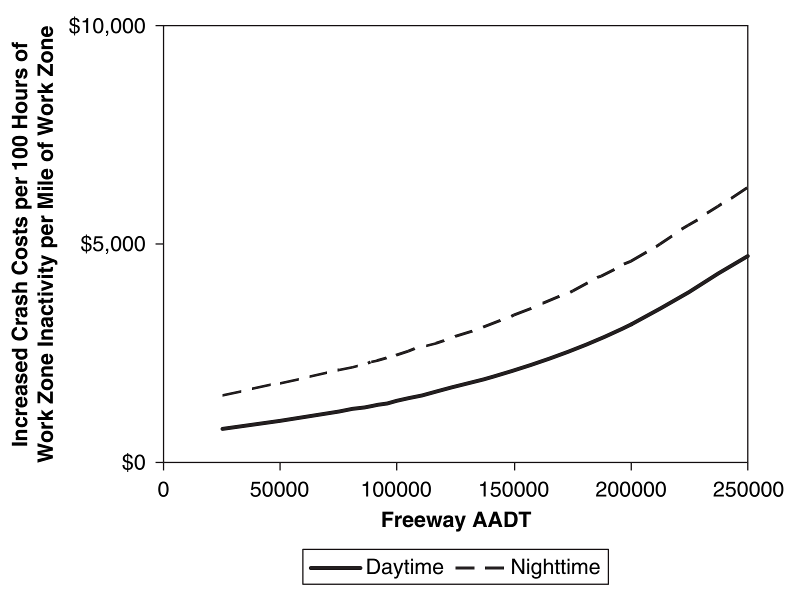


Figure 8. Increased crash costs with inactive work zone and no temporary lane closures present.

- Fixed-object (generally single-vehicle) collisions, and
- other remaining crash types.

The results of the analysis of collision types are provided in the following section.

Rear-End Collisions

As noted in the background section, several studies have indicated that rear-end crashes tend to be overrepresented in work zones. This was previously confirmed in the NYSDOT crash data analysis in Chapter 2, especially when lane closures are present in the work zone. Typically, it is hypothesized that the overrepresentation of such crashes occurs because of increased traffic congestion and queues associated with the reduction in roadway capacity in the work zone. The HSIS data collected in this project allow for a more thorough investigation of this hypothesis.

Table 17 presents the percentage of crashes that involved a rear-end collision by work condition and time of day across the entire range of projects contained in the four-state dataset. The second column (active work with lane closures) represents the greatest work zone capacity reduction and thus the highest potential for congestion and queuing. It would be expected to have the highest percentage of rear-end crashes associated with it. The third column (active work with no lane closures) represents the next most significant capacity reduction, due to driver rubber-necking, work vehicle interference, and lesser geometric restrictions. The fourth column (no work activity and no lane closures) would be expected to produce the least capacity reduction and thus the lowest percentage of rear-end crashes. Finally, the percentage of rear-end crashes across all project locations prior to the start of work is presented in the fifth column as an indication of non-work conditions for comparison purposes.

The above expectations are generally confirmed in Table 17 for night work crashes. Active night work with lane closures resulted in 38.4 percent rear-end crashes, compared to 33.6 percent during active work without lane closures and 26.0 percent with no active work or lane closures. The percentage of rear-end crashes during periods of no active work at night was identical to the corresponding pre-construction percentage.

However, this trend is not exhibited by crashes during daytime periods. Instead, the percentage of rear-end crashes is nearly consistent and is actually lowest when active work activity and lane closures are present. In other words, there does not appear to be a strong association between the capacity reductions associated with lane closures and the likelihood of a rear-end crash. In fact, the percentage of rear-end crashes in the work zone is actually a little lower than in the before work zone condition at these sites.

The effects of work zone conditions on rear-end crashes were further examined by stratifying the crash data by AADT. In Figure 9, rear-end crash percentages are provided by AADT level before the work zone was present and in the work zone during periods of inactive work with no lane closures. For these conditions, rear-end crashes typically increase as a function of AADT in both daytime and nighttime periods and are lower at night than during the day across the entire range of AADTs. Also, the difference between daytime and nighttime rear-end crash percentages increases with AADT. Furthermore, for both day and night, the percentage of rear-end crashes in the work zone is very similar to the before-construction condition. At higher AADTs, a small increase (approximately 5 percent) in rear-end crashes is seen when the work zone is present.

The rear-end crash percentages during periods of active work with and without temporary lane closures are provided in Figure 10 and Figure 11 for daytime and nighttime, respectively. During the day, a significant increase in rear-end crashes is evident at AADT levels below 100,000 vpd when the work zone is active regardless of whether or not a lane closure is present. At higher AADTs, however, rear-end crashes when the work zone is active are about the same or even lower than when work is inactive. This may be partly attributable to small sample sizes at higher AADTs for the active work with lane closure condition.

These results may indicate that there is an upper limit in terms of how much of the total crash experience at a location will be rear-end crashes. These high-volume locations may already experience so much congestion and stop-and-go traffic (which lead to rear-end crashes) that further degradation in operating conditions associated with the work zone simply results in the same distribution of crash types that normally exist on that facility. At lower AADT levels, rear-end collisions do not normally comprise the majority of crashes that occur, and so the introduction of capacity reductions and other turbulence on the roadway leads to more congestion

Table 17. Percent of rear-end crashes.

Time of Day	Active Work with Lane Closures	Active Work without Lane Closures	No Active Work, No Lane Closures	No Work Zone Present
Daytime Periods	46.9%	54.4%	48.7%	52.8%
Nighttime Periods	38.4%	33.6%	26.0%	26.0%

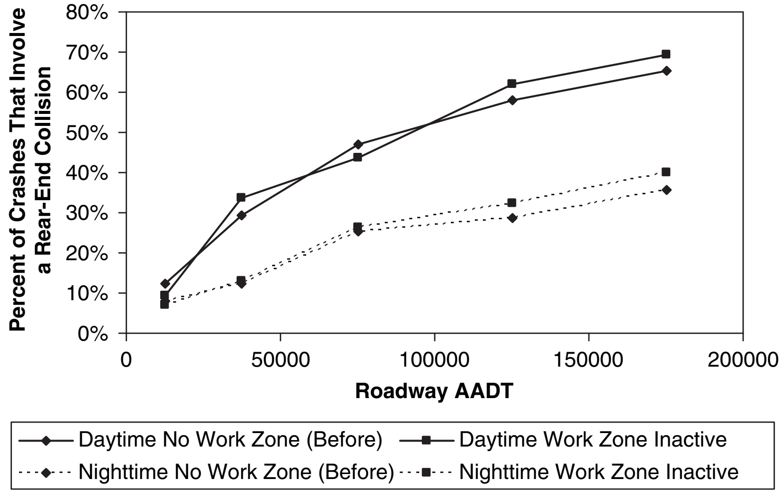


Figure 9. Comparison of roadway AADT to rear-end collision percentages, no work zone versus inactive work zone conditions.

and unexpected traffic, resulting in a greater proportion of rear-end collisions.

Authors of past studies have commonly assumed that the increase in rear-end crashes in work zones is primarily associated with unexpected congestion and traffic queues created by lane closures. As was shown in Figure 10, however, rear-end crash percentages during work activities without lane closures are almost identical to when a temporary lane closure is present. While it is possible that there are a few instances in which the project diaries failed to note a temporary lane closure, resulting in incorrectly coding the work zone as having no lane closure present, these instances are not believed to be frequent enough to explain the close agreement between the lane closure and no lane closure conditions. Rather, this close similarity in rear-end crashes between lane closure and no lane closure conditions appears to indicate that other work zone features and conditions also affect traffic flow during periods of work activity. These features and conditions may include construction traffic entering or exiting the workspace, actions by workers or equipment near the travel lanes that cause nearby motorists to brake unexpectedly, overall changes to roadway geometry, etc. These conditions and work zone features appear to contribute as much to the increased crash risk of the work zone as a temporary lane closure.

The rear-end crash trends by AADT for nighttime work are more consistent with expectations. Active work lane closures result in more rear-end crashes than during periods of inactive

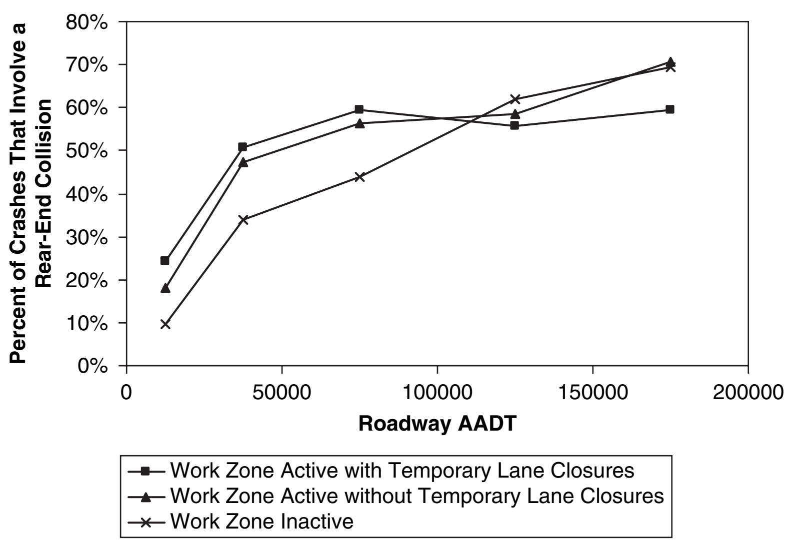


Figure 10. Comparison of work activity and roadway AADT to rear-end collision percentages, daytime work periods.

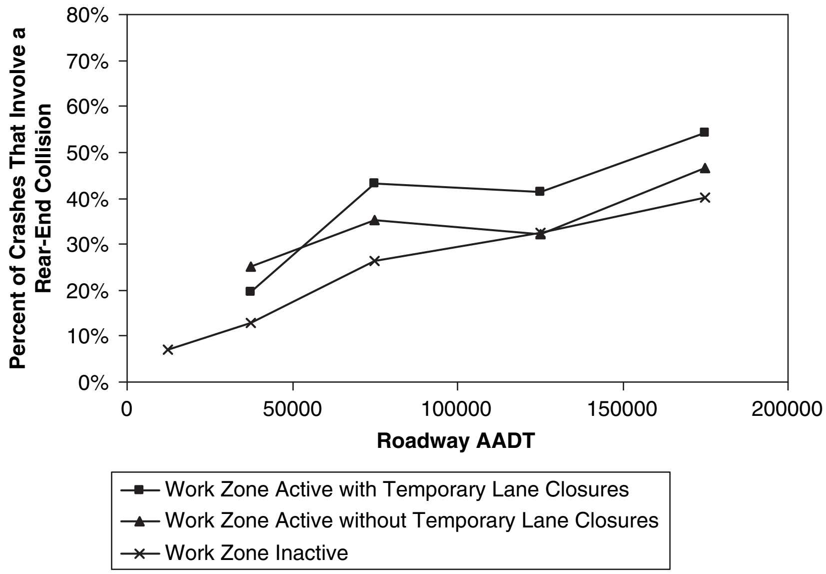


Figure 11. Comparison of work activity and roadway AADT to rear-end collision percentages, nighttime work periods.

work over the entire AADT range. Further, the percentage of rear-end crashes during active work but without a lane closure is also somewhat higher than during periods of work inactivity over the same AADT range. Finally, rear-end crashes during active work without lane closures are less than active work with lane closures, except at the lower range of AADT. Similar to the discussion for daytime conditions, there appear to be many sources of traffic disruptions during periods of work activity with and without temporary lane closures at night that contribute to an increase in rear-end crashes. While other effects—such as construction vehicle and equipment access and egress, distractions due to workers or equipment near the travel lanes, and so forth—cannot be determined with the current dataset, it is reasonable to expect that driver inattention, which is believed to be a greater concern at night, also is a factor. Overall, it seems reasonable to believe that capacity reductions associated with lane closures contribute some to the increase in rear-end crashes in active nighttime work zones, but other factors may also reasonably be believed to contribute. All of these contributing factors should be considered when work zone designers look for opportunities to improve work zone traffic safety.

Sideswipe Collisions

Sideswipe crashes are summarized in Table 18, which shows that daytime versus nighttime work, work activity, and lane closure presence did not dramatically influence the percentage of sideswipe crashes, especially during daytime. Sideswipe collisions comprised between 13 and 16 percent of crashes at the project locations under all conditions except for nighttime active work without lane closures. For that group, sideswipe crashes comprised 21 percent of the total. However, none of these differences are statistically significant.

Fixed-Object Collisions

Table 19 illustrates that fixed-object collisions consistently comprise a greater proportion of nighttime crashes than daytime crashes. Also, fixed-object crashes were almost identical for the no work zone present (before) condition and the inactive work zone condition both during the day and at night. Figure 12 presents fixed-object crashes compared to AADT, and it is apparent that fixed-object crashes for both the before and inactive periods decrease markedly

Table 18. Percent of total crashes that involve sideswipe collisions.

Time of Day	Active Work with Lane Closures	Active Work without Lane Closures	No Active Work, No Lane Closures	No Work Zone Present
Daytime Periods	13.6%	14.8%	14.8%	14.1%
Nighttime Periods	15.8%	21.0%	15.0%	13.3%

Table 19. Percent of total crashes that involve fixed-object collisions.

Time of Day	Active Work with Lane Closures	Active Work without Lane Closures	No Active Work, No Lane Closures	No Work Zone Present
Daytime Periods	20.3%	10.3%	15.9%	15.3%
Nighttime Periods	22.8%	21.0%	31.9%	32.4%

as a function of roadway AADT in daytime, and to a lesser degree at nighttime.

The change in fixed-object crashes with work activity is examined in Figure 13 for daytime conditions and Figure 14 for nighttime conditions. Generally speaking, no clear trends are evident with regards to the percentage of fixed-object crashes that occurred at different AADT levels. As Figure 13 indicates, the percentage of such collisions during periods of daytime work activity ranged between 10 and 25 percent across most of the AADT levels shown, with no clear trend evident. At night, the percentage of fixed-object collisions and AADT levels during work activity also did not demonstrate any clear trends (see Figure 14).

Other Vehicle Collision Types

The remaining crashes not previously categorized were consolidated into an "other crashes" category and examined for trends across the same time periods and work conditions as previously performed for the other categories. The results of this examination are shown in Table 20. Overall, the percentage of crashes that fall into this remaining category is slightly less during daytime conditions than during nighttime conditions. However, no clear trends exist in the percentages across the work conditions examined in either time period. During the day, the percentages range between 14 and 21 percent; at night, the percentages range between 23 and 28 percent. Neither of these ranges includes a statistically significant difference on the basis of work condition.

Summary

The following is a summary of key findings from the analysis of traffic crashes from 64 work zone projects across four states:

- Overall, when work activity is occurring and travel lanes are temporarily closed, the risk of a crash to a motorist traveling through the work zone increased by about 66 percent during daytime conditions and by 61 percent during nighttime conditions, compared to the expected crash risk that would normally exist at a particular location.
- The actual change in crash risk in these work zones varied substantially from project to project, even when stratified on the basis of time period (daytime or nighttime) and work condition (no work activity, active work without lane

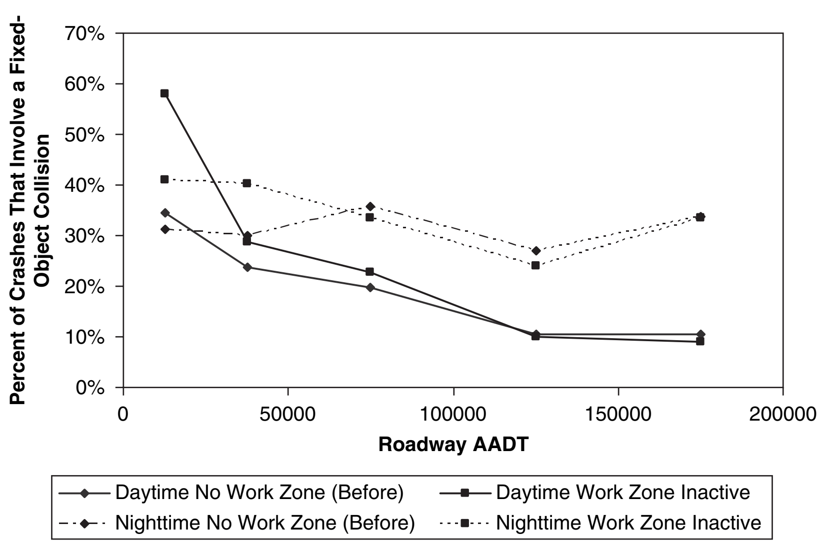


Figure 12. Comparison of roadway AADT to fixed-object collision percentages, no work zone versus inactive work zone conditions.

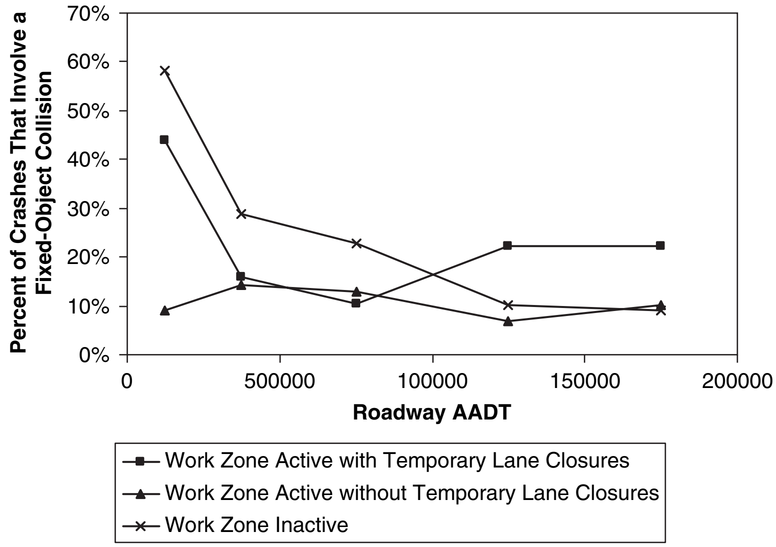


Figure 13. Comparison of work activity and roadway AADT to fixed-object collision percentages, daytime work periods.

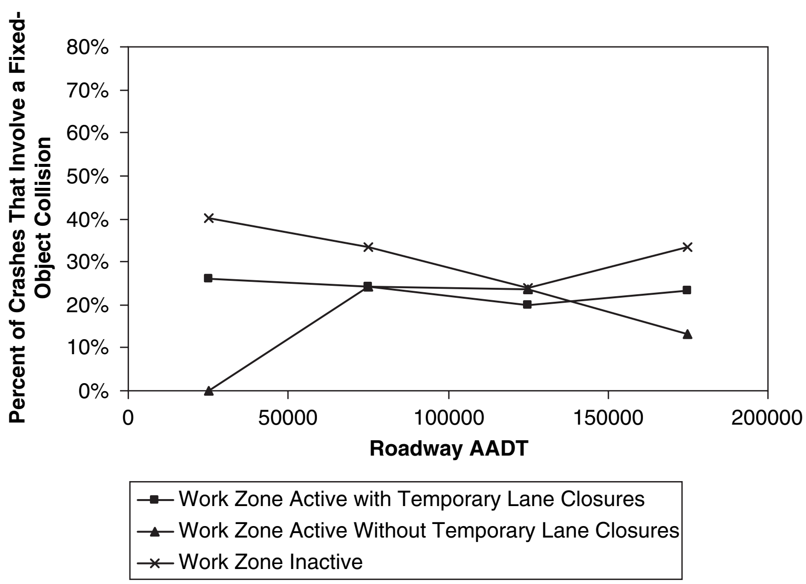


Figure 14. Comparison of work activity and roadway AADT to fixed-object collision percentages, nighttime work periods.

Table 20. Percent of total crashes that involve all other collision types combined.

Time of Day	Active Work with Lane Closures	Active Work without Lane Closures	No Active Work, No Lane Closures	No Work Zone Present
Daytime Periods	19.2%	20.6%	14.1%	17.7%
Nighttime Periods	23.1%	24.4%	25.2%	28.3%

closures, or active work with lane closures). Crash risks increased on some projects and decreased on others, compared to the expected values. Furthermore, no relationship appears to exist between the change in crash risk and roadway AADT.

- When work was active and lane closures were in place, severe crashes increased by 42.3 percent when the work was done at night and by 45.5 percent during the day. For PDO crashes, the increase was 74.8 percent at night and 80.8 percent during the day.
- When work activity was occurring but no temporary lane closures were used, the increase in severe crashes computed at night was higher (41.4 percent) than during the day (17.4 percent). Similarly, the increase computed in PDO crashes during work activity at night (66.6 percent) is greater than that during the day (39.8 percent increase). However, neither of these differences was found to be statistically significant due to the high project-to-project variability in the results. Still, it appears that working at night with no lane closures in place may be affecting crash risks more than was previously known. It is not clear from the data whether the greater nighttime crash risk during these work conditions is the result of the following factors:
  – Work area lighting glare that work crews might not be mitigating well when they are not located in travel lanes;
  – More frequent construction equipment and material deliveries into and out of the work area at night that create large speed differentials and subsequent crashes; or
  – Issues that continue to plague drivers encountering a work zone at night (lack of expectancy, poorer visibility, increased levels of impairment, etc.) regardless of whether or not a travel lane is closed.
- When the work was inactive and no lane closures were present, the increase in injury crashes was slightly higher for nighttime conditions (11.4 percent) than for daytime conditions (2.0 percent), but this difference is not statistically significant. For PDO crashes, the increase at night (33.0 percent) was significantly higher than that during the day (19.6 percent). The slightly greater increases at night presumably reflect somewhat degraded geometric conditions in the work zone relative to a pre-work zone condition that—coupled with nighttime-specific issues such as limited visibility, less attentive drivers and so forth—raise nighttime crash risk more than daytime conditions do when work is inactive.
- For each of the work conditions examined, the increases in crash risk are higher for the PDO crashes than for the injury crashes, indicating that the additional crashes that do occur due to the work zone tend to be less severe in nature. This trend exists regardless of whether the work is performed during the day or at night. This is consistent with previous studies that found similar results.
- The increased costs of work zone crashes, compared to expected crash costs based on the pre-construction crash history, were consistently lower for nighttime work than daytime work when the work was active and a lane closure was in place. This is true for the entire range of AADTs examined, and the difference between day and night was substantial for higher AADTs. This means that the overall safety impacts to the motoring public of work activities that involve temporary lane closures tend to always be less at night, and the benefit of working at night increases as AADTs increase.
- For work activities that do not involve a temporary lane closure, there appears to be little difference in working during the day or at night in terms of increased crash costs generated. The increased crash costs at night are actually slightly higher than during the day at lower AADT levels but slightly lower at higher AADT levels.
- The increase in crash costs when the work is inactive and no temporary lane closures are required is slightly higher at night than during the day across the range of AADTs examined, although these differences are not statistically significant. For both daytime and nighttime periods, the increased crash costs when work zones are present but with no work activity are much less, at any AADT, than when work is active, whether or not a lane closure is present.
- In terms of work zone crash characteristics, the percent of crashes involving rear-end collisions typically increases as a function of AADT in both daytime and nighttime periods, although the percentages remain substantially lower in the nighttime periods for the higher AADT regions. Furthermore, for both time periods, the percentage is very similar between the before (no work zone) and work zone inactive conditions.
- The effect of active work during the day with or without lane closures on rear-end collisions is not consistent across all AADT ranges. Rear-end collisions increase markedly during work activity on low- to moderate-volume roadways, but not on higher-volume roadways. There may exist an upper limit in terms of how much of the total crash experience at a location will be the result of rear-end collisions.
- At night, work activity resulted in an increase in the percentage of crashes that are the result of rear-end collisions across all roadway AADTs. The effect is somewhat greater when temporary lane closures are in place than when they are not, consistent with expectations.
- Overall, the percent of sideswipe collisions was not affected by time period, work activity, or lane closure presence. Sideswipe collisions accounted for between 13 and 21 percent of crashes occurring in the work zone.
- Fixed-object collisions consistently comprise a greater proportion of nighttime crashes than daytime crashes. Also,

fixed-object collisions comprise an almost identical percentage of crashes between the before (no work zone) condition and the work zone inactive condition. Fixed-object collision involvement in crashes for both of those conditions decreases significantly as a function of roadway AADT in the daytime period and to a lesser degree in the nighttime period.

- Overall, the percentage of all remaining crash types is slightly less during daytime conditions than during nighttime conditions. No clear trends exist in the percentages across the work conditions examined in either time period. During the day, the percentages range between 14 and 21 percent; at night, the percentages range between 23 and 28 percent.

CHAPTER 4

Recommended Management Policies, Procedures, and Practices to Improve Nighttime and Daytime Work Zone Safety

FHWA and every state and local highway agency share a desire to improve safety in highway work zones. The findings presented in the previous chapters of this report, as well as past studies, indicate that work zones have significant negative safety consequences. Agencies strive to minimize these adverse safety consequences as much as possible while maintaining traffic mobility and accomplishing the tasks that necessitate the need for the work zone in the first place. Simply put, work zones present competing objectives of maintaining a high level of safety for workers and the public, minimizing adverse traffic impacts, and accomplishing the work task on time, within budget, and of appropriate quality standards. Agencies attempt to address work zone safety concerns through the development and adoption of various strategies. Typically, such strategies are implemented as work zone policies, procedures, and/or practices to be followed during work zone planning, design, and implementation.

A recent comprehensive NCHRP publication recommended a systematic process intended to reduce the frequency and severity of traffic crashes during roadway work zone operations (*52*). The process was developed around the AASHTO Strategic Highway Safety Plan, and utilizes a traditional problem-solving framework of problem identification, goal and objective setting, identification and selection of alternatives, implementation, and evaluation (*53*). The NCHRP document also summarizes and critiques a comprehensive list of strategies, organized under six main objectives, intended to reduce work zone crashes. The specific strategies are organized under the following objectives:

- Reduce the number, duration, and impact of work zones,
- Improve work zone traffic control devices,
- Improve work zone design practices,
- Improve driver compliance with work zone traffic controls,
- Increase knowledge and awareness of work zones, and
- Develop procedures to effectively manage work zones.

The critique in that report included an assessment of the following considerations for each strategy under those objectives:

- Types of work zone crashes targeted;
- Expected effectiveness;
- Keys to success;
- Potential difficulties;
- Appropriate measures and data and associated needs;
- Organizational, institutional, and policy issues;
- Implementation time considerations;
- Costs;
- Training and other personnel needs;
- Legislative needs; and
- Compatibility with other strategies.

In general, the expected effectiveness of these various strategies to reduce work zone crash risks was described in qualitative terms (*52*). Few, if any, of the strategies have been formally evaluated in terms of their ability to mitigate increased work zone crash potential. The crash data collected as part of this research were seen as an opportunity to further assess the potential effectiveness of these strategies.

Given that this study relied on projects that had already been implemented in the field, the opportunity to systematically evaluate the effects of any particular strategy or group of strategies was extremely limited. In many cases, it was not clear from the available project documentation which strategy or strategies were in fact utilized for a particular project or the extent to which those that were in effect were properly and thoroughly applied. In other cases, data necessary to estimate how the lack of a particular strategy would have impacted crashes were also not available. For example, an analysis of the crash reduction potential of accelerated construction techniques would require information on the expected project duration without the techniques applied as well as the actual duration that was achieved with the techniques used. It would also require information on any changes in the traffic control strategies used to achieve the accelerated construction because any such changes could potentially have offsetting effects on the number of crashes experienced. Typically, such information was not included in the project documentation that was available to the researchers.

Although it is not possible to compute the crash reduction potential of the various strategies with the data collected and analyzed in this study, the opportunity does exist to use the data to more thoroughly define the frequency and costs of the crashes that some of the strategies are designed to target. Some of the strategies come with significant added costs to the agency or the highway contractor, while others do not. If the increased crash costs targeted for reduction at a particular project are equal to or less than the costs of implementing the strategy, the extent to which the strategy can be justified based on safety improvements alone is questionable.

Given that the economic consequences of increased crash risk in work zones depend on the amount of vehicle exposure, these data can also be useful to agencies in determining minimum AADT thresholds at which certain strategies may become worthwhile to implement. A discussion of these types of considerations for each of the major categories of strategies is presented in the sections that follow.

Strategies to Reduce the Number, Duration, and Impact of Work Zones

As the NCHRP guidance document (*52*) correctly points out:

> The fewer times motorists encounter work zones, the fewer chances there are for work-zone-related crashes to occur. Reducing the number of work zones, the length of time during which work zones are set up, and the adverse impact that work zones have on traffic will reduce the exposure of road users and workers to crashes.

Several strategies were identified to accomplish this particular objective:

- Improve maintenance and construction practices to reduce work zone duration and to reduce the number of work zones that are required,
- Utilize full-time roadway closure for construction operations,
- Utilize time-related contract provisions to reduce construction duration,
- Use nighttime road work,
- Use demand management programs to reduce volumes through work zones, and
- Design future work zone capacity into new or reconstructed highways.

Improvements in Maintenance and Construction Practices

Techniques that accelerate construction progress can be viewed as a type of safety benefit, even though such techniques are not typically implemented as a way to improve safety. Most often, these techniques are implemented in order to reduce the adverse impacts that a project may have on the mobility of the traveling public. However, to the extent that they also reduce exposure to the work zone, they can ultimately lead to fewer crashes and reduced crash costs, as long as the techniques do not somehow compromise the integrity of the work zone setup. Similarly, techniques that prolong the life of a roadway and reduce the frequency of work zones that are required also fall under this strategy. Either way, if the total duration of work zones on a facility is reduced over time, then vehicle exposure to the work zone (and resulting additional crash costs due to the work zone) will undoubtedly be lower, assuming that comparable levels of safety are provided in the work zones that are being used. Efforts to reduce work zone duration or frequency will most likely have some additional costs associated with them.

In addition to the work duration that is being reduced or eliminated through these strategies, the amount of crash cost reduction also depends both on roadway volume and the actual work condition being avoided. Figure 15 presents the results of the estimated additional crash costs per 100 hours of daytime work zone per work-zone-mile for the three work conditions previously documented in this report for six-lane freeways in California (work zone activity with temporary lane closures, work zone active without temporary lane closures, and work zone inactive). Based on the computations illustrated in the figure, techniques that reduce the number of inactive work zone hours may typically have only a minor safety benefit. Even on roadways with AADTs as high as 250,000 vpd, a savings of 100 hours of work zone inactivity results in only about $5,000 in expected crash cost savings. However, it should be noted that certain work zone features (significantly narrower lanes, other substantial geometric changes, etc.) could yield increased crash costs much higher than the averages estimated through this research. In those situations, more substantial benefits from this strategy even when the work zone is inactive may be possible.

In contrast, techniques that reduce the frequency and duration of work activity have a greater potential to reduce crash costs. At work zones on very low-volume roadways, a technique that reduces 100 hours of work activity without temporary lane closures would yield a crash cost reduction of about $5,000 ($600 per daytime period) that increases to more than $25,000 per 100 hours ($3,300 per daytime period) when the roadway AADT is 250,000 vpd. For active work zones when temporary lane closures are required, the crash

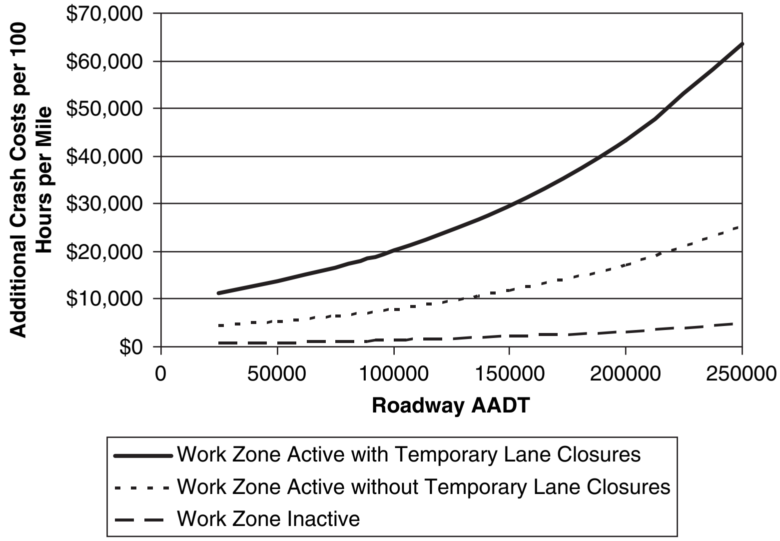


Figure 15. Effect of strategies to reduce work zone frequency and duration: daytime conditions.

reduction benefits range from $11,000 ($1,400 per daytime period) to almost $64,000 ($8,000 per daytime period) over the same AADT range. Of course, as has been previously shown in this report, most agencies rarely close lanes for work zone purposes if the AADT of the roadway exceeds approximately 75,000 vpd, so the likelihood of achieving these larger safety benefits is fairly low.

The ramifications of reducing the nighttime hours upon crash costs are shown in Figure 16. During periods when the work zone is inactive, the reduction in crash costs at night is actually very comparable to those during the day on a per 100 hours duration basis. At the upper end of the AADT range (250,000 vpd), reducing the inactive work duration by 100 night hours would yield an expected crash cost reduction of $6,300. If the per-day and per-night savings at this upper end of the AADT range are used together to compute a 24-hour period of work activity added together, the total expected reduction achieved by eliminating one calendar day of work inactivity on a project is approximately $1,290 in crash costs. Lower savings are achieved at lower AADT levels.

If work is being performed at night, strategies that reduce the frequency and duration of those work activities performed at night can provide some crash cost reduction potential. However, the potential crash cost reduction will be less than if the work is performed during the day. At roadway AADTs of about 25,000 vpd, the reduction of 100 hours of nighttime

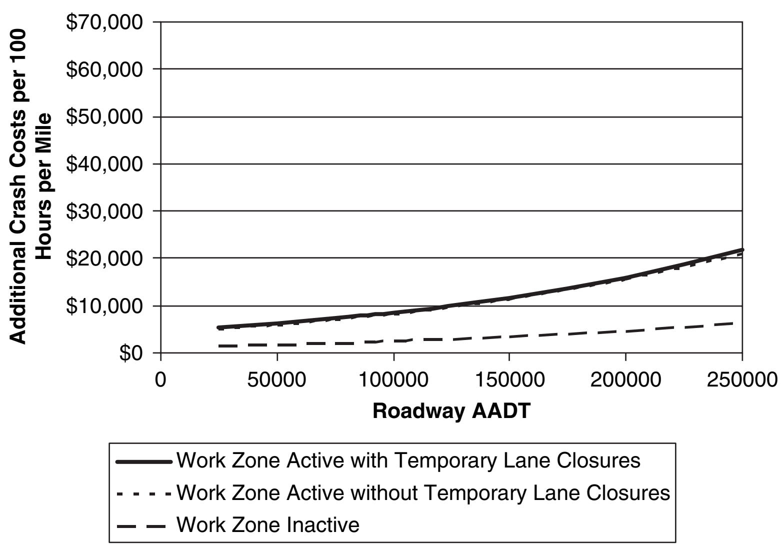


Figure 16. Effect of strategies to reduce work zone frequency and duration: nighttime conditions.

work activity with or without temporary lane closures is approximately $5,000. Conversely, the reduction of 100 hours of work activity on a roadway with an AADT of 250,000 vpd would yield a $21,000 reduction in crash costs, based on the values shown in Figure 16.

Full-Time Roadway Closures

When and where it is possible to do so, completely closing a roadway section to allow construction or maintenance work to be performed eliminates the potential for traffic crashes to occur in the activity area (*52*). In addition, the elimination of interactions between construction vehicles/equipment and traffic often allows for larger workspaces and increased worker productivity, thus reducing the total duration of the work activity. It is possible that work quality can be improved as well. Closing one direction of a freeway and putting both directions of traffic on the other directional roadway via median crossovers is one example of this strategy. Likewise, closing one direction and moving traffic onto the adjacent frontage road around the work zone is another example. However, this strategy can entail the complete closure of both travel directions and detouring of traffic onto completely different roadways in the region.

The various factors that need to be considered before implementing a full-roadway closure (i.e., availability and acceptability of detour routes; provision of adequate advance notification to residents, businesses, and regular users of the facility; etc.) are documented elsewhere (*52*). From a safety assessment perspective, the amount by which traffic crashes in the work zone is reduced can be significant since both the additional crash costs due to the work zone and the crashes normally occurring on that roadway segment are eliminated. However, these reductions in crash costs may be offset to some degree by an increase in crash costs on the detour route(s) due to the additional traffic exposure that is placed on each route. Whereas this is not likely to be a significant concern when median crossovers or frontage road detours are employed, it may be more important if traffic is being completely detoured off of a freeway-type facility onto arterials and other surface streets. Normally, crashes occur more frequently on arterial streets than on freeways but are less severe. Consequently, a detailed analysis of a particular site and the feasible alternative routes would be required to assess whether there is a net crash cost benefit to a full roadway closure. Estimating the additional crash costs on these detour routes requires information on how much additional traffic is being carried on each route, the normal traffic volumes on those routes, and the SPF(s) for each route (recognizing that the SPF for each route may vary depending on the number and type of intersections, frequency and use of driveways, etc.). These were not available for any of the projects used in this database.

Accelerated Contract Provisions

Previously, it was noted that efforts to reduce work zone duration through accelerated construction techniques typically increase project costs to some degree. The savings in crash costs associated with these techniques can partially offset those project cost increases. However, it is typically up to the contractor to determine the magnitude of the additional costs and how to best adjust the bid price to account for those costs. Another approach that agencies can take to accelerate the work is to include time-related contract provisions that provide incentives for completing the work faster (or disincentives if the work is not completed fast enough) and encourage the use of non-peak times for any temporary lane closures that are required. Specific techniques that fall under this particular strategy include the following:

- Cost-plus-time (also known as A+B) bidding,
- Lane rentals,
- Incentive/disincentive clauses, and
- Liquidated damages clauses.

A number of resources are available that discuss these techniques in detail, which have been identified in the NCHRP guidance (*54*).

Traditionally, justification of these techniques and the values assigned to them have been made on the basis of potential travel time delays, which alone can result in large additional road user costs. From the perspective of safety, however, the ramifications of accelerating construction through the use of time-related contract provisions do provide some additional benefit, identical to those described previously in the "Improvements in Maintenance and Construction Practices" section. These values could be added to other costs (i.e., delay or deferred usage costs) typically considered in the overall determination of the values assigned to these techniques in a construction or maintenance contract.

Nighttime Work

The decision whether work must be performed at night should involve a comprehensive cost-effectiveness evaluation that should consider the implications of each alternative (including active night work) with respect to three key impact factors:

- Impact to the community and traffic (business operations, pedestrians and bicyclists, emissions, public transit, emergency services, noise effects, lighting and glare effects, traffic diversion impacts, etc.);
- Impact on safety (construction safety, traffic safety, and safety during maintenance efforts); and

- Impact on constructability (contractor experience, temperatures, supervision capabilities, worker efficiency, lighting plan quality, and materials/equipment availability).

The impacts of working during the day versus working at night are compared against the cost of performing the work during each time period. In most cases, the alternative that achieves the highest score (effectiveness/cost) would be the preferred choice (*35*). In the majority of cases, however, avoidance of adverse traffic impacts drives the decision of whether or not to work at night. Various criteria are used to determine when the threshold of maximum acceptable impacts is exceeded. Some agencies simply identify a maximum per-day or per-hour traffic volume per open lane that can exist if a lane closure is to be allowed. If the traffic volume during all or part of the time that the lane closure is being anticipated is higher than that threshold, it must be scheduled during a time when traffic volumes are lower. Other agencies use predicted estimates of delay or queue lengths to decide if work must be performed at night.

The prior chapters of this report present the safety implications and trade-offs associated with working at night. Whereas the decision to work at night is typically made predominantly for the purpose of avoiding the creation of long traffic queues and large delays for motorists when travel lanes must be temporarily closed, the results of this analysis demonstrate that there can be some crash cost savings as well. The amount of savings depends on the AADT of the roadway. The extent of the expected savings when lanes are closed is illustrated graphically in Figure 17 (again based on California data). Also shown in Figure 17 are the expected savings of working at night when travel lanes do not need to be temporarily closed. For the former, the crash cost savings are substantial and increase exponentially at higher AADT levels. Although still considerably smaller than the savings in travel time delays that are typically achieved by working at night, these numbers can be used as further justification and incentive for requiring night work. Based on the data collected, avoiding the creation of traffic queues (implied by the much greater increase in expected crash costs during daytime lane closures at higher AADT levels) should be emphasized by agencies whenever possible.

In contrast to the situation where travel lanes need to be temporarily closed, there is little incentive from a safety standpoint to working at night if travel lanes do not need to be closed. As also shown in Figure 17, the difference in crash costs for this type of work condition is very small for most of the AADT range.

Transportation Demand Management Programs to Reduce Traffic Volumes Through Work Zones

Transportation demand management (TDM) programs are one part of a comprehensive traffic management approach to improve safety and reduce delays in work zones (*52*). The goal of TDM is to reduce the total amount of traffic attempting to use the work zone and other routes in the corridor by encouraging various trip reduction techniques (carpooling/vanpooling, increased use of transit, increased bicycling/walking, etc.). A reduction in vehicle trips reduces the magnitude and duration of delays experienced throughout the corridor. In addition, vehicle exposure in the work zone is also reduced, which improves safety. The efforts required to implement TDM techniques can be fairly extensive, and they are most typically applied to significant construction projects that involve major capacity reduction in urban areas.

Based on the data from this study, fairly significant reductions in crash costs can be achieved through fairly moderate reductions in trips in a work zone corridor due to TDM

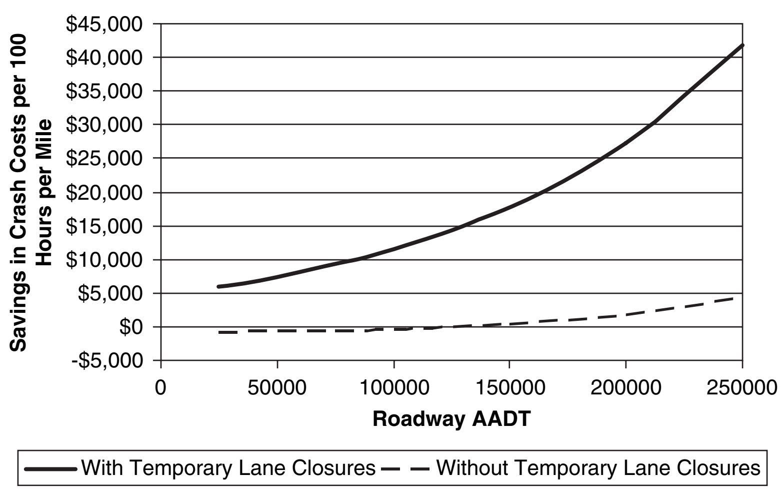


Figure 17. Example of reduction in crash costs achieved by working at night.

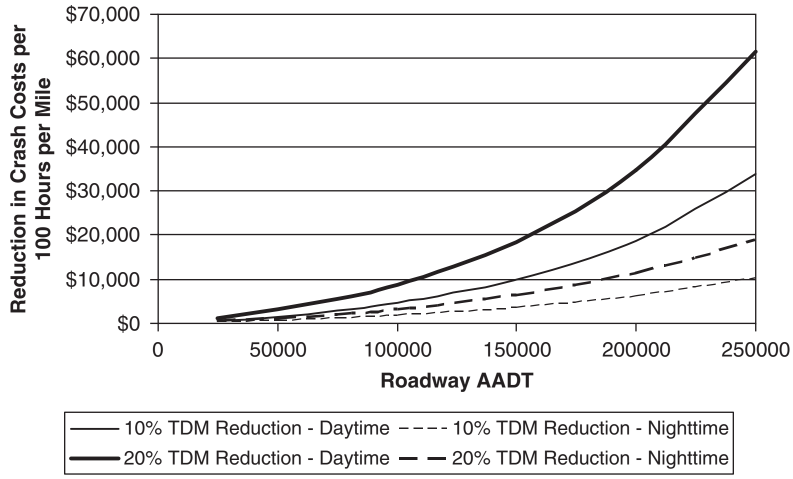


Figure 18. Example of reduction in crash costs by travel demand management strategies during work activity with temporary lane closures.

efforts. Again using the California SPF models for six-lane freeways as an example, the potential safety benefit of 10 and 20 percent trip reductions due to TDM techniques during times when work is active and lanes are temporarily closed is illustrated in Figure 18. During daytime conditions, crash cost reductions range from nearly zero at lower volumes to over $60,000 per 100 hours of work per mile of work zone at the highest AADTs (recognizing, of course, that the likelihood of a daytime lane closure at these higher AADT levels is very low). At night, the potential crash cost reductions range from zero to slightly less than $20,000.

The potential benefits of TDM techniques that yield 10 to 20 percent trip reductions during times when work is active but travel lanes are not closed are illustrated in Figure 19. Potential crash cost reductions during daytime conditions range from zero to nearly $50,000 per 100 hours of work per mile and from zero to nearly $20,000 per 100 hours per mile during nighttime hours. The values in Figure 19 are only slightly smaller than in Figure 18 because of the fact that the TDM techniques work to reduce all crash costs on a facility, not only those additional costs that are attributable to the presence of the work zone. Consequently, even during times when the work zone is inactive (Figure 20), potential crash cost savings are more than $40,000 per 100 hours per mile during daytime conditions and nearly $20,000 during nighttime conditions. It must be kept in mind that these crash cost savings are achieved if the number of trips being made is reduced, not simply moved to other routes in the corridor. If the latter

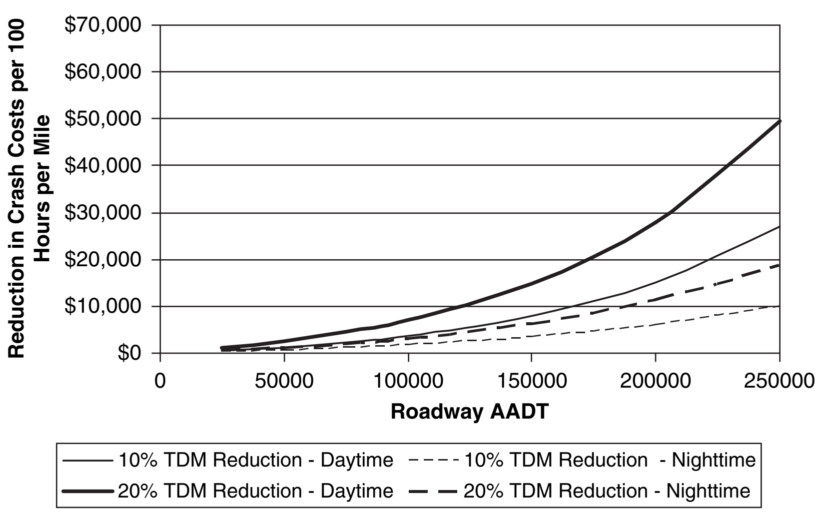


Figure 19. Example of reduction in crash costs by travel demand management strategies during work activity without temporary lane closures.

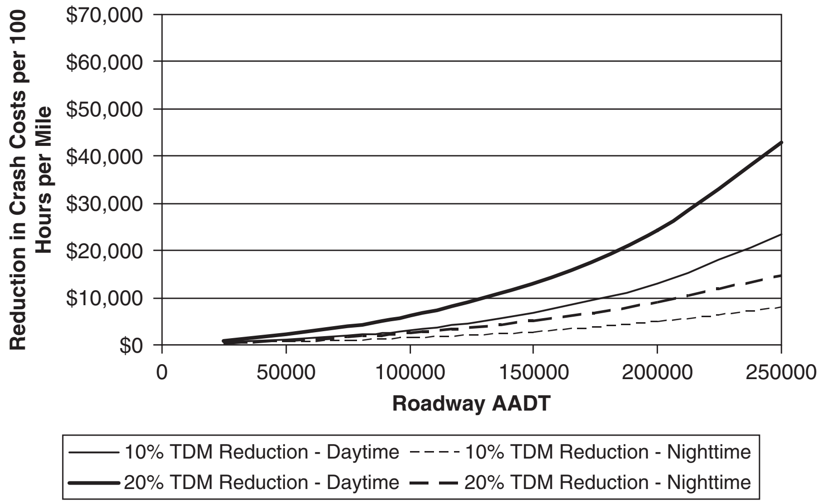


Figure 20. Example of reduction in crash costs by travel demand management strategies during work activity without temporary lane closures.

occurs, the situation is more complex, as was described earlier regarding the impacts of the full roadway closure strategy.

Designing Future Work Zone Capacity into New or Reconstructed Highways

Another technique to reduce the impact of work zones is to consider future work zone space needs in the design of new or reconstructed highways (*52*). Analyses that consider the potential impacts of work zone operations at various points in the future can be incorporated into trade-off analyses of alternative designs during the highway planning process. In some instances, it may be better to acquire greater right-of-way widths and design a wider sub-base than is initially planned for a roadway segment in order to allow for future widening that will be faster and less challenging to accomplish than if the sub-base had not already been established.

Unfortunately, these types of design decisions and their ramifications upon work zone safety are highly site specific. No data are available upon which to base estimates of how these types of decisions affect work zone duration or the frequency of future work zones. If such estimates were available, it would theoretically be a simple process to assess the impacts of such strategies using the roadway AADT and additional work zone crash costs graphs that are illustrated in Figure 6 through Figure 8.

Whereas certain design decisions could ultimately reduce the frequency and duration of work zones, others could allow those work zones that are still required to be accomplished with fewer lane closures (i.e., a roadway with full shoulders could allow traffic to be shifted during pavement rehabilitation work and still maintain the same number of lanes). Roadway designs that reduce the number of hours of work zone activity when lane closures are required can yield fairly substantial savings in excess crash costs during daytime hours but only minimal reductions for nighttime hours. Of course, the likelihood of an agency actually performing work activity that requires lane closures during the day on higher-volume roadways is fairly small. Consequently, it is probably more realistic to compare costs when work activity during the day does not require temporary lane closures (because the roadway design allows it) to the costs when work activity is done at night with temporary lane closures (because the roadway design did not allow the work to be done without closing a lane). This comparison is also illustrated in Figure 21 for the California data as an example. As the graph indicates, if an agency is willing to do work at night that requires temporary lane closures, the safety benefits associated with roadway designs that reduce the number of lane closures that are required will be fairly negligible, regardless of the AADT of the roadway segment. In other words, an emphasis on design enhancements that reduce the frequency and duration of work zones has more of a potential safety benefit than enhancements that reduce the number of work hours that travel lanes need to be closed.

Strategies to Improve Work Zone Traffic Control Devices

Traffic control devices are used to communicate with motorists in advance of and through work zones. Devices that are used to inform the driver of desired actions and correct travel paths through the work zone are especially important. Traffic control devices, especially those that are used to convey real-time information, can also significantly affect driver route choice decisions. Taken together, these devices are believed to have a substantial impact on work zone safety.

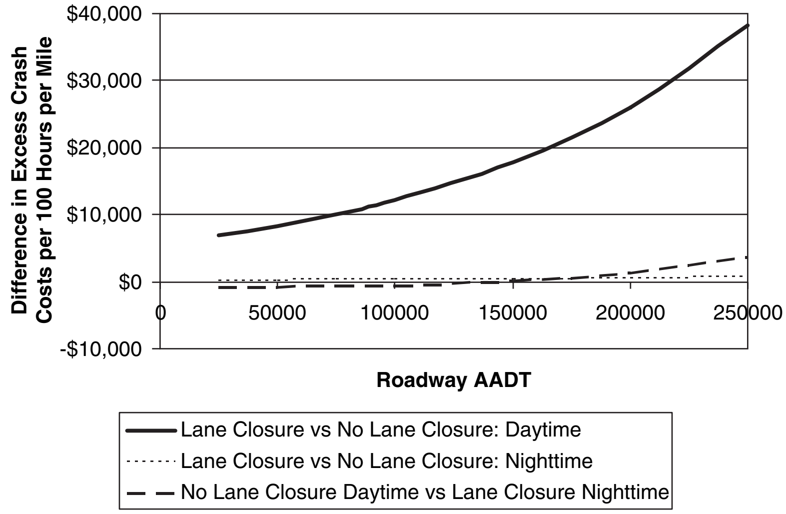


Figure 21. Reduction in crash costs by avoiding daytime lane closures through roadway design enhancements versus closing lanes at night.

The NCHRP guidance document identifies the following four main strategies under this particular safety improvement objective (*52*):

- Improvements in visibility of work zone traffic control devices,
- Improvements in visibility of work zone personnel and vehicles,
- Reductions in flaggers' exposure to traffic, and
- Implementation of ITS strategies to improve safety.

The extent to which improvements in traffic control device visibility and work zone personnel and vehicle visibility can result in reduced crash costs for a particular work zone depends both on the highway agency's current traffic control device standards (required grade of sheeting, whether fluorescent sheeting is used, types of pavement markings used, etc.) and work zone inspection practices (frequency, level of diligence applied, etc.) to ensure that the devices are adequately maintained. A work zone that has high-quality devices that are positioned properly and maintained during the project may not experience any safety benefits through the installation of additional devices (in fact, too many devices or even brighter devices may have a detrimental effect if an information overload situation is created). On the other hand, work zones where the traffic control devices are worn, have poor retroreflectivity at night, are misaligned or otherwise out of position, etc., may experience substantial improvements in safety by improving those devices. Devices in poorer condition at night, confounded with higher percentages of impaired drivers, a lack of other visual cues, etc., could result in higher crash costs, making efforts to improve those devices economically worthwhile. Unfortunately, it is not possible to realistically assess the potential crash cost reduction or safety benefit associated with this particular strategy at this time.

Similarly, inadequately delineated work zone personnel and vehicles are believed to be at a higher crash risk than those that have been adequately delineated, although the extent of any changes in crash risk that are achieved by visibility improvements has not been quantified. Because of these constraints, it is not feasible to use the crash data from this study to assess the potential safety benefits of this strategy.

Techniques that improve the visibility of flagger stations or replace the flaggers entirely (i.e., temporary traffic signals or automated flagger technologies) are another identified strategy that is believed to have the potential for improving safety. Flaggers are not typically used at work zone operations on freeway or expressway facilities during the day or at night, and so the potential effects of this strategy upon safety cannot be assessed with the data collected and analyzed for this study.

The final strategy listed is the use of ITS which allows for improved real-time information about conditions in and around a work zone to be collected, collated, analyzed, and then disseminated to drivers. This information can improve safety by alerting drivers to the presence of the work zone as well as providing information that can be used to make realtime decisions regarding speed or travel route choices. Consequently, these systems allow agencies to better target those work zone crashes that are congestion related or are the result of other violations of driver expectancy, namely rear-end collisions and sideswipes (*52*).

From the data illustrated in Figure 9 and Table 18, the percentage of crashes that involve rear-end collisions increases as roadway AADT increases to a point, whereas sideswipe

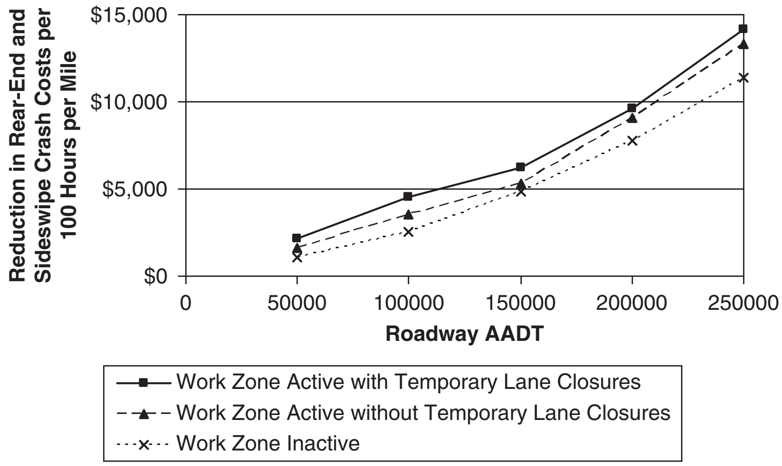


Figure 22. Estimated reduction in crash costs due to a 10 percent reduction in rear-end and sideswipe collisions: daytime conditions.

collisions tend to comprise a fairly constant percentage of work zone crashes across a wide range of AADTs. Therefore, the crash costs that are expected to occur because of rear-end and sideswipe collisions combined also increase as a function of AADT. Although the actual crash reduction potential of a work zone ITS deployment is currently not known, it is possible to assess what crash cost savings could be achieved if the system were able to reduce these types of crashes by some amount. Again using California data as an example, Figure 22 illustrates the estimated reductions in crash costs that would be achieved if the system were able to reduce rear-end and sideswipe collisions by 10 percent during daytime conditions (the crash costs during nighttime conditions are shown in Figure 23). All rear-end and collision crashes, not just the additional crashes due to work zone presence, are included in the numbers since an ITS deployment could potentially reduce some of those crashes that would have occurred even if the work zone were not present. As a result, the effects of work activity (with or without lane closures) are not as substantial upon crash costs as they are for other strategies. In fact, the expected reduction that would be achieved during times of work inactivity could serve as a conservative estimate of the potential crash cost savings during the work zone, regardless of whether or not work activity and lane closures were present. The reduction in crash costs when the work zone is inactive ranges from about $1,000 per 100 hours per mile during the day on 5,000 vpd roadways to about $11,000 per 100 hours per mile on 250,000 vpd roadways.

At night, the values range from as little as $500 per 100 hours per mile at 5,000 vpd up to approximately $3,000 per 100 hours

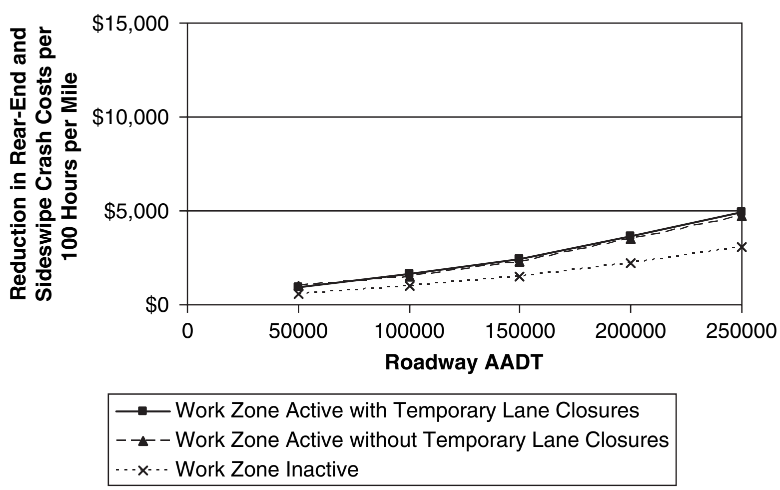


Figure 23. Estimated reduction in crash costs due to a 10 percent reduction in rear-end and sideswipe collisions: nighttime conditions.

per mile on 250,000 vpd roadways. Different assumptions regarding the reductions in these types of crashes would yield simple proportional changes in these crash cost reduction estimates. From these figures, it is apparent that work zone ITS technologies offer somewhat less potential to reduce crash costs than do those strategies that emphasize reduced exposure through fewer and shorter duration work zones, demand management strategies to reduce vehicle trips through the work zone, etc. For example, a comparison of Figure 22 to Figure 18 indicates that TDM strategies that yield a 10 percent reduction in trips at lower AADT levels could potentially achieve crash cost savings that are similar to what would be expected if a work zone ITS deployment reduced rear-end and sideswipe collisions by 10 percent. However, at an AADT of 250,000 vpd, the crash cost savings via the TDM strategies would be more than twice the crash cost savings of a work zone ITS deployment that reduced rear-end and sideswipe crashes by 10 percent. Although the potential benefit of TDM strategies is obvious, the ability to achieve even modest reductions in demand is much more difficult. Consequently, ITS applications may ultimately offer a more feasible crash reduction potential overall.

Of course, a work zone ITS deployment may also result in some traffic diverting to other routes, which would further reduce crash costs in the work zone. As previously stated, though, the implication of these diverted trips on the crash costs of the other routes in the corridor would be highly site specific and cannot be effectively assessed using the data presented in this report.

Strategies to Improve Work Zone Design Practices

The third category of strategies identified in the NCHRP guidance document pertains to establishing improved work zone design practices as a way to improve work zone safety and ultimately reduce work zone crash costs. Every work zone is different and presents a unique challenge to designers. Often, space is extremely limited, and the work zone designer must balance the space needs of the work crew to accomplish the tasks needed to maintain or improve the condition of the roadway with the needs of motorists to travel through the work zone while it is being repaired or upgraded.

The strategies listed under this category include the following:

- Improvements in work zone design guidance;
- Improvements in work zone safety for pedestrians, bicyclists, motorcyclists, and heavy-truck drivers; and
- Implementation of measures to reduce workspace intrusions and limit consequences of intrusions.

The crash data in this study do not offer an opportunity to assess the ramifications of the first two strategies since there was not sufficient detail in the project data reviewed to allow for a comprehensive and systematic analysis of design features and how they may have influenced crash experiences across the projects. A recent NCHRP publication does provide some guidance regarding the design of construction work zones on high-speed roadways (*54*). A number of design elements are considered; recommended ranges of values are provided for several of them. However, most of the recommendations reflect current and/or accepted practices by agencies rather than safety-based research results.

With respect to the third strategy, measures to reduce workspace intrusions and limit the consequences of intrusions that occur, the results of this study are useful in estimating the economic consequences of these events. In turn, these crash cost estimates can be compared to the costs of implementing various countermeasures to determine which are economically feasible and under what conditions (primarily traffic volume levels) they are feasible.

As was noted from the NYSDOT crash data analysis reported in Table 4, intrusion crashes comprise a relatively small subset of freeway work zone crashes during temporary lane closures (9.8 percent of those occurring during the day and 14.4 percent of those occurring at night). Worker-involved intrusion crashes are even more rare events, comprising only 0.7 percent of crashes during the day and 3.9 percent of crashes at night. The intrusion crashes in the NYSDOT database did tend to be fairly severe, however. During the day, 41.0 percent of the intrusion crashes involved injuries or fatalities; at night, 53.2 percent of intrusion crashes involved an injury or a fatality. If these percentages are combined with the SPF data from California that is being used for illustrative purposes throughout this chapter (assuming the intrusion crash percentages in New York are applicable to California work zones), one can gain a sense of the magnitude of the work zone intrusion issue in monetary terms. Figure 24 illustrates the estimated crash costs attributable to vehicle intrusions during the day, whereas Figure 25 illustrates the estimated costs at night. Overall, the crash costs attributable to vehicle intrusions into the work zone are relatively small compared to the other crash cost figures in this chapter. Although values as high as $13,000 per 100 hours per mile are evident in Figure 24, these represent estimated costs that would occur if temporary lane closures were used, something that rarely happens anymore during daytime conditions at that AADT level. Excluding those numbers, the majority of the graph lines fall around or below $5,000 for both daytime and nighttime conditions.

The implication of these rather low numbers is that countermeasures intended to mitigate these intrusions must be fairly low cost and highly effective in reducing intrusions in order to make their application economically worthwhile. For instance, a countermeasure used at a nighttime work

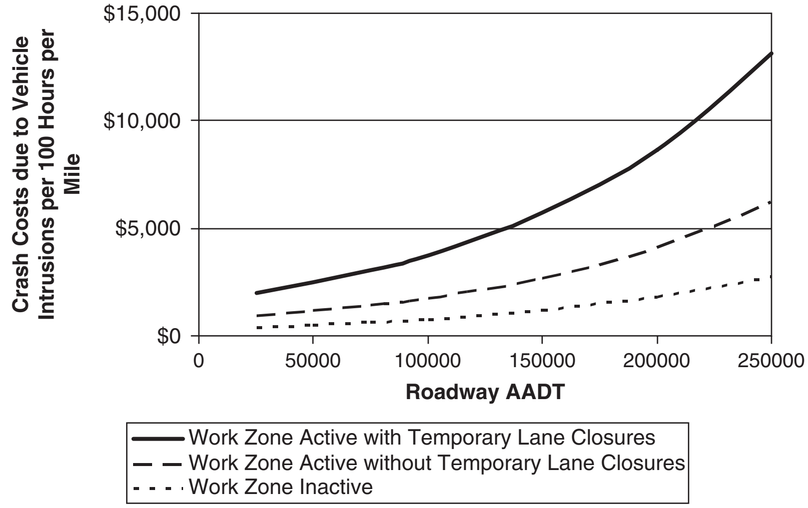


Figure 24. Estimated crash costs due to vehicle intrusions: daytime conditions.

zone on a 200,000 vpd facility that reduces the chance of an intrusion by 10 percent would generate a crash cost savings of only $500 ($5,000 × 0.10) per 100 hours per mile, or about $5 an hour per mile while it is in place. Stated in terms of another example, a countermeasure that costs $25 per hour per mile to implement would need to achieve a 50 percent reduction in vehicle intrusions in order to offset the costs of implementation. From a practical standpoint, portable concrete barriers provide a high degree of intrusion crash reduction at a fairly low cost, as long as the duration of the work zone is sufficiently long and/or traffic demands are fairly high (*54*).

If only worker-involved vehicle intrusion crashes are considered, the numbers are even smaller. Figure 26 illustrates the estimated crash costs attributable to worker-involved vehicle intrusion crashes during work activities involving temporary lane closures at night and during the day. It is interesting to note that it is the nighttime conditions for which the costs are higher; they are approximately twice those of daytime conditions. However, those "higher" crash costs equate to only about $1,000 per 100 hours per mile ($10 per hour per mile) when the AADT of the roadway is approximately 150,000 vpd. This number is reduced even further when one considers that the typical workspace where workers are present is only a fraction of a mile. Obviously, a countermeasure to reduce the likelihood of a worker-involved intrusion crash must be both highly effective and very low cost to be economically viable from a strictly crash cost savings perspective. Further research is needed to determine the costs of some of these intrusion

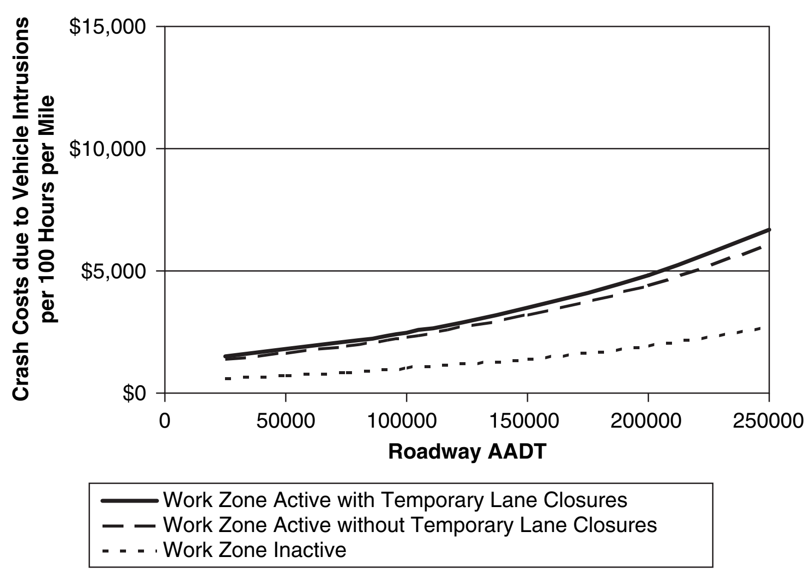


Figure 25. Estimated crash costs due to vehicle intrusions: nighttime conditions.

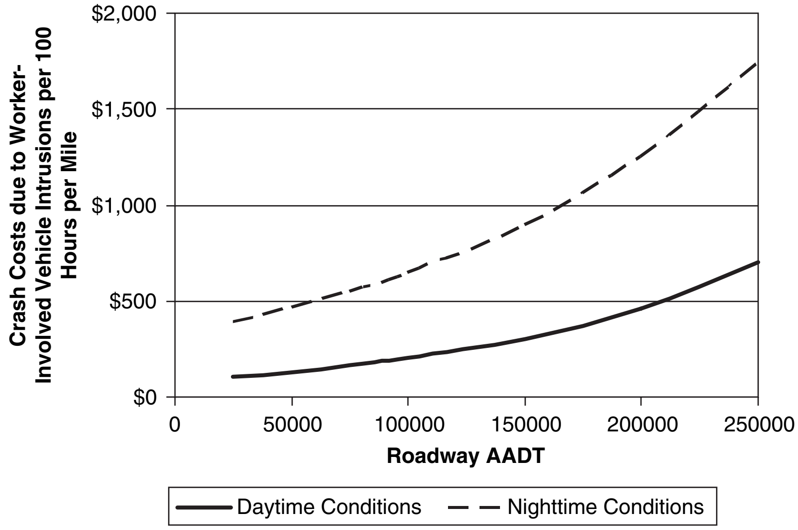


Figure 26. Estimated costs of worker-involved vehicle intrusion crashes during work activities involving temporary lane closures.

countermeasure ideas, as well as to estimate the expected crash reductions that may be achieved by the countermeasures.

Strategies to Improve Driver Compliance with Work Zone Traffic Controls

Good compliance with traffic laws and regulations in work zones is critical to obtaining and maintaining a high level of safety and orderly, efficient traffic flow. The NCHRP guidance document lists the following three specific strategies under this category that are believed to positively influence work zone safety:

- Improved credibility of signs,
- Enhanced enforcement of traffic laws in work zones, and
- Improved application of increased driver penalties in work zones.

The first strategy, improving the credibility of signs, emphasizes the importance of ensuring that the posted signing in work zones meets current federal and state standards and reflects actual conditions in the work zone. Efforts to ensure that the information presented via static and dynamic signing is as accurate and as current as possible at all times is also believed to result in improved driver compliance and, ultimately, work zone safety (*52*). Although this statement is intuitively obvious, the extent to which these efforts can be quantified in terms of potential work zone crash reductions or improvements is limited. Theoretically, agencies with good policies and standards in place as well as effective procedures to monitor and quickly correct deficiencies in the field would have limited opportunity to further improve conditions or safety through this strategy. In contrast, agencies whose policies, standards, and procedures are lacking would have the potential to improve conditions and achieve measurable safety benefits. In reality, differences between agencies may be much more subtle, with examples of both good and not-so-good work zone implementations evident in either jurisdiction. One could hypothesize that the higher rear-end crash percentages cited in the previous chapter are one way in which a lack of sign credibility manifests itself, leading to higher levels of inattentive or unsuspecting drivers who disregard the advance warning signs of a work zone.

The remaining two strategies in this category both relate to the effectiveness of law enforcement to ensure driver compliance with traffic laws and regulations in the work zone. Essentially all states utilize law enforcement personnel in some fashion in their work zones (*55*). However, the manner in which enforcement personnel are used varies. Some agencies emphasize the use of enforcement for active identification of violators and issuance of citations in the work zone, whereas others emphasize the use of enforcement presence for visibility and attention-getting purposes during times when workers are out in travel lanes at high risk next to moving traffic (*55*). Currently, there is little objective evidence to suggest which approach is more effective in promoting safety, although an ongoing NCHRP project is examining this issue in more detail (*56*).

Overall, there is some evidence to suggest that additional enforcement presence in both work zones and non-work zone locations can improve safety (*57, 58, 59, 60*). However, the amount of the improvement from a crash reduction perspective varies due to differences in enforcement strategies used, the amount of additional enforcement used, and the

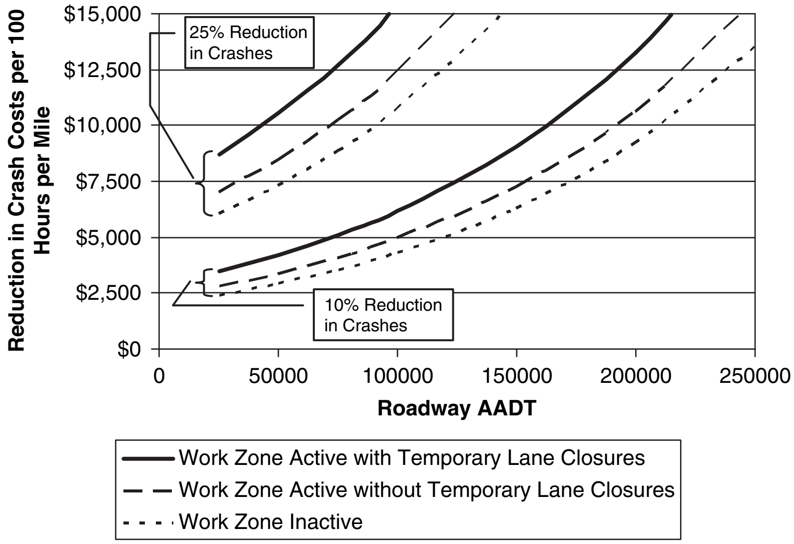


Figure 27. Possible reductions in crash costs due to enforcement presence: daytime conditions.

type of crash analysis used, making comparisons across studies difficult. Conservatively, crash reductions of up to 25 percent in the vicinity of enforcement may be possible. If reductions of this magnitude are achieved, the question becomes whether the costs of providing that enforcement are outweighed by the reduction in crash costs that occur. Depending on the characteristics of the work zone, the answer appears to be yes. Using the California crash models again for illustrative purposes, Figure 27 and Figure 28 present the crash cost savings that would be achieved under the various work conditions during daytime and nighttime periods. Total crash costs, not just the additional crash costs due to work zone presence, are used in the analysis because enforcement presence would be expected to influence the potential of all crashes to occur. Both a 25 percent reduction and an even more conservative 10 percent crash cost reduction are shown.

A review of some recent memorandums of understanding (MOUs) between highway and enforcement agencies to provide work zone enforcement support indicates hourly costs of between $25 and $60 per hour per officer (between $2,500 and $6,000 per 100 hours). The costs may be higher in other states. These costs can be compared to the crash cost savings estimated in the figures to determine the AADT level at which the savings begin to exceed these costs (for a work zone 1 mile in length). At the lower end of the pay scale, it appears that enforcement can be economically justified under all work

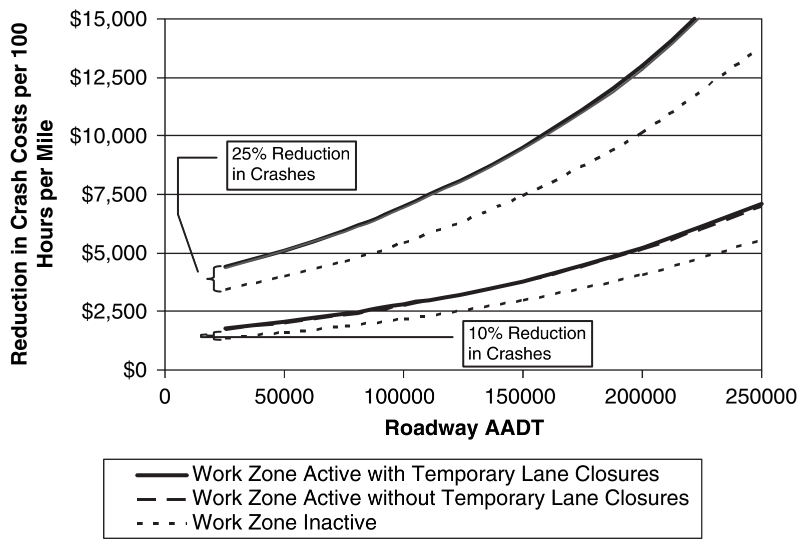


Figure 28. Possible reductions in crash costs due to enforcement presence: nighttime conditions.

conditions during the day or at night at all AADT levels if the reduction in crash costs exceeds at least 10 percent. If the cost of enforcement is higher than this amount, their use is only justified if greater reductions in crash costs are achieved or their use is restricted to higher-volume roadways. For example, if enforcement costs for a 1-mile work zone are $50 per hour ($5,000 per 100 hours), their use can be economically justified during periods of work zone activity with temporary lane closures during the day on roadways with an AADT of 75,000 vpd if a 10 percent reduction in crash costs can be achieved and at nighttime once the roadway AADT approaches 200,000 vpd. Conversely, if crash cost reductions of 25 percent are achieved, use of enforcement at this cost level is justifiable at all AADT levels during the day and once AADT levels exceed about 50,000 vpd, if the work activity and temporary lane closures are done at night.

The third strategy in this category, improved application of increased driver penalties in work zones, is predicated on the notion that higher penalties consistently applied to violators of traffic laws in work zones will change driving behavior and yield a reduction in work zone crash costs. Most states already have laws in place to increase the penalties for work zone traffic violations. Some of the increases are fairly extensive. However, it appears that these increased penalty laws are not always fully supported in the courts (*61*). Although it may be possible to improve the extent and consistency with which these penalties are applied, it is not clear whether such improvements will yield measurable safety benefits. Deterrence theory indicates that it is the likelihood of apprehension, rather than the penalty received by being apprehended, that has the major influence on behavior (*62*). This theory is supported by several European studies of automated speed enforcement systems (albeit in non-work zone locations), which have shown a 25 to 35 percent reduction in crashes associated with the implementation of these systems even though the penalties associated with the violations are not extreme (*63*, *64*). Emphasis on increasing the likelihood of apprehension through additional enforcement officer presence or automated enforcement technologies would appear to offer a greater potential benefit to work zone safety at this time.

Strategies to Increase Knowledge and Awareness of Work Zones

The NCHRP guidance document suggests the following two strategies that increase knowledge and awareness of work zones as a way of improving safety (*52*):

- Disseminate work zone safety information to road users, and
- Provide work zone training programs and manuals for designers and field staff.

Efforts to inform and raise motorist awareness of the hazards of driving through work zones are already fairly prevalent across the United States. Most states have work zone safety tips and other information posted on their websites, and they make brochures and pamphlets available to motorists at driver licensing stations and other locations (*65*). In addition, a number of public safety announcements have been developed and are periodically run on local television and radio outlets. Nationally, Work Zone Awareness Week is held each April to further raise driver consciousness about this particular safety concern (*66*). Finally, a training program has recently been developed to educate new drivers about work zones and how to better navigate them safely (*67*).

Training of work zone designers and field staff has been an area of emphasis for FHWA, highway agencies, labor unions, etc., for many years. An abundance of training courses, manuals, videos, web-based modules, and other techniques exist. Most of these can be found, organized by topic, at the National Work Zone Safety Information Clearinghouse (*68*). Recently, the FHWA Work Zone Safety Grant program was established to provide assistance for highway work zone safety training and guideline development toward the improvement of highway work zone safety. A number of consortiums are developing guidance on a number of work zone safety-related topics and conducting various types of training to disseminate this guidance to users (*69*).

Although these efforts are generally accepted as beneficial in promoting safer work zones, measuring the effects of these types of activities upon safety is generally not possible. Although indicators of the quantity of outreach to motorists and training of designers and field personnel can be identified, the ability of agencies to assess the quality of those efforts in terms of changes in either driving behavior or in worker-related activities does not exist. Consequently, it is not possible to apply any type of economic assessment to these strategies as has been done elsewhere in this chapter.

Strategies to Develop Procedures to Effectively Manage Work Zones

The emphasis of the strategies identified in the NCHRP guidance document for this category is on programs and procedures that an agency can implement to bring about an institutional change in how work zone safety is incorporated into the agency's way of doing business (*52*). Four specific strategies were identified that were believed to offer high-leverage opportunities for safety improvements to occur:

- Develop or enhance agency-level work zone crash data systems;

- Improve coordination, planning, and scheduling of work activities;
- Use incentives to create and operate safer work zones; and
- Implement work zone quality assurance procedures (i.e., safety inspections or audits).

Work zone crash data systems are addressed in detail in the next chapter. The improvement of coordination, planning, and scheduling of work activity strategy refers to efforts to coordinate multiple agencies that may be affected by a particular project as well as to coordinate multiple projects in a region that may interact with each other from a traffic perspective (*52*). This type of coordination is believed to reduce the frequency and significance of traffic congestion that may be created by work zones and thus, has a potential safety benefit. However, the NCHRP document does recognize that attempting to quantify the relationship between this type of strategy and actual safety benefits would not be feasible. Similarly, incentives to create and operate safer work zones are also viewed as a way of raising awareness of safety issues and ensuring that safety is constantly considered by agency and contractor personnel; however, data do not exist to allow assessment of the strategy upon work zone crash costs.

The final strategy, implement work zone quality assurance procedures, refers to the use of periodic inspections of work zone traffic control and other features to ensure that they are installed and operating as intended throughout the duration of each project (*52*). Several states conduct regular inspections of their work zones, both by personnel assigned to the project (i.e., inspectors) as well as those not affiliated with the day-to-day operations of the work zone (i.e., a district or division quality review team). In order for this technique to be effective, it must consider how the temporary traffic control is functioning as a system from the user's perspective (i.e., is it providing clear and unambiguous path guidance, etc.), not just whether the devices are present as called for in the traffic control plan (*52*). This strategy also refers to the use of work zone safety audits, similar to road safety audits, as a way to identify potential contributors to work zone crashes and ways to modify the work zone so as to mitigate those crashes as much as possible. The idea of work zone safety audits being performed before and during a work zone project is fairly new. Guidance is currently being developed as part of the previously mentioned FHWA Work Zone Safety Grant program (*70*). As with the other strategies in this category, the ability to directly link efforts of either inspections or audits to actual crash cost reductions is quite limited. Anecdotal information implies a correlation between a systematic and regular application of these types of activities and reduced crash frequencies, but a direct cause-effect analysis of crash cost reductions is not possible.

Summary

The information presented in this chapter provides some insight into the magnitude of benefits possible by implementing some of the strategies listed in the NCHRP guidance document. Table 21 summarizes the results of this assessment. Overall, strategies that reduce overall work zone frequency and duration either indirectly or through accelerated contracting mechanisms appear capable of yielding substantial safety benefits. Likewise, efforts to reduce overall traffic demands through work zones by way of trip reductions and mode choice changes have the potential to provide substantial safety benefits (although achieving even small reductions may be difficult in some locations). Decisions to work at night now being made by many agencies, although primarily a congestion mitigation strategy, can also be shown to yield crash cost reductions when compared to doing the same work during daytime hours. Finally, the provision of law enforcement in work zones appears to be capable of yielding crash cost reduction benefits that offset the cost of providing such enforcement in most situations.

In addition to these high-return strategies, there also appear to be a number of strategies that provide moderate crash cost reductions when applied. These include full roadway closures (this strategy may be particularly effective if median crossovers and detours onto adjacent frontage roads are included), the design of future work zone capacity into highways, and possibly the application of ITS strategies at work zones that are likely to experience frequent but unexpected bouts of congestion created by work zone activities. For work zones of significant duration on high-volume roadways, methods that protect against vehicle intrusions into the workspace (i.e., portable concrete barrier) may fall into this category as well.

Relative to those strategies already listed, there are several strategies in the guidance document for which the potential impact on crash costs is more limited. In many instances, the frequency of crashes that the strategy is intended to target is relatively small. Intrusion crashes on relatively short-duration projects would be one such example. Whereas intrusion protection on long-term projects on high-volume roadways may ultimately be justifiable using portable concrete barriers (as the per-hour cost of the countermeasure decreases over time), other strategies to address more short-duration situations have the potential to impact only a small portion of crash costs overall. Still, such strategies may be justified in certain situations where risks are extremely high (such as

Table 21. Potential effectiveness of agency strategies to improve work zone safety.

Strategies	Work Zone Conditions Influenced	Potential Impact on Crash Costs	Key Considerations
Practices to Reduce Work Zone Duration and Number of Work Zones Required	All work zone conditions	High	One of the most effective strategies available to reduce work zone crash costs.
Full Roadway Closures	All work zone conditions	Moderate-high	Crash cost reductions in work zone may be offset by crash cost increases on alternative routes if crash rates on alternative routes are substantially higher than that on the work zone route.
Time-Related Contract Provisions to Reduce Construction Duration	All work zone conditions	High	Similar in effectiveness to first strategy listed in this table.
Moving Work Activities to Nighttime Hours	Active work zones with temporary lane closures	High	The effectiveness of this strategy in reducing work zone crash costs increases exponentially at higher AADTs.
Demand Management Programs to Reduce Volumes through Work Zones	All work zone conditions	High	Crash cost reductions in a work zone can be high if trips are reduced or eliminated. If trips are simply diverted, crash cost reductions may be offset by higher crash rates on diversion routes.
Designing Adequate Future Work Zone Capacity into Highways	All work zone conditions	Moderate	Similar crash cost reductions can be achieved by shifting work to nighttime hours if lanes need to be temporarily closed.
Improvement of Work Zone Traffic Control Device Visibility	All work zone conditions	Low-moderate	Crash cost reductions achieved only if current agency policies and processes for ensuring quality devices are lacking.
Improvement of Work Zone Personnel and Vehicle Visibility	Active work zones	Low	Low frequency of these types of crashes.
Reductions in Flaggers' Exposure to Traffic	Active work zones	Low-moderate	Low frequency of these types of crashes.
ITS Strategies to Improve Safety	Active work zones	Moderate	Effectiveness depends on frequency of unexpected congestion that is created in work zone.
Improvements in Work Zone Design Guidance	All work zone conditions	Unknown	Dependent upon design features to be improved.
Improvements for Pedestrians, Bicyclists, Motorcyclists, and Heavy-Truck Drivers	All work zone conditions	Unknown	Data not available regarding effects of strategies on these user groups.
Measures to Reduce Workspace Intrusions and Limit Consequences	All work zone conditions	Low-moderate	Low frequency of these types of events limits the amount of crash cost reduction that can be achieved. Those that result in a worker being hit will be very severe and costly, however.
Improved Credibility of Signs	All work zone conditions	Unknown	Data not available regarding effects of strategies on crash costs.
Enhanced Traffic Law Enforcement	All work zone conditions	High	Effectiveness dependent upon amount of enforcement presence applied.
Improved application of increased driver penalties in work zones	All Work Zone Conditions	Low	Higher penalties have not been shown to dramatically affect driver behavior.
Dissemination of work zone safety information to road users	All Work Zone Conditions	Unknown	Effectiveness likely depends on extent of work zone safety information already being disseminated by agency.
Work zone training programs and manuals for designers and field staff	All Work Zone Conditions	Unknown	Effectiveness likely depends heavily on whether current agency training programs and tools are already of high quality and available.
Develop/enhance agency-level work zone crash data systems	All Work Zone Conditions	Unknown	Effectiveness depends on whether analysis of the crash data leads to changes in policies, procedures, and/or design criteria.
Improved coordination, planning, and scheduling of work activities	Primarily Active Work Zones	Unknown	Reductions in total frequency and duration of work zones would yield crash cost reductions similar to those listed in first and third strategies in this table.
Incentives to create and operate safer work zones	All Work Zone Conditions	Unknown	Data not available regarding effects of strategies on crash costs.
Work zone quality assurance procedures (i.e., safety inspections or audits)	All Work Zone Conditions	Unknown	Effectiveness depends heavily on whether current agency policies and procedures result in high-quality work zones already.

during a bridge rail repair activity where workers have no reasonable escape route in the unlikely event that a vehicle intrusion occurs). In those situations, though, the agency and contractor are generally paying a premium to provide protection in excess of the likely reduction in crash costs to be achieved.

Finally, the likely impacts of some strategies on crash costs cannot be assessed at this time. In most cases, the relation between these types of strategies and crash cost reductions is likely to be indirect. Consequently, the adoption of one or more of these strategies is likely to be based on factors other than crash cost potential at individual work zones.

CHAPTER 5

Recommended Work Zone Crash Data Elements, Collection Techniques, and Analysis Methods

Introduction

Highway agencies are beginning to recognize the value of having access to comprehensive crash and other supporting (i.e., exposure) data for work zones. These data can be used to develop work zone crash rates and to assess work zone operating characteristics such as traffic, delays, and travel speeds/times. These crash rates and operating characteristics could be used by the agencies to determine statewide work zone safety and mobility trends and/or the need to modify or enhance work zone traffic control plans.

FHWA rulemaking finalized in 2004 increases the importance of this issue. Specifically, it requires highway agencies to collect and analyze work zone data, including crash data (*71*):

> (c) Work zone data. States shall use field observations, available work zone crash data, and operational information to manage work zone impacts for specific projects during implementation. States shall continually pursue improvement of work zone safety and mobility by analyzing work zone crash and operational data from multiple projects to improve State processes and procedures. States should maintain elements of the data and information resources that are necessary to support these activities.

Previously, highway agencies and others have indicated a significant concern that police accident reports frequently do not accurately or consistently indicate work zone involvement in traffic crashes, which can significantly impact the results of any analyses performed on that data (*72, 73*). The majority of police crash report forms used by states now include some explicit field or code to identify whether a crash occurs within the limits of a highway work zone. However, although some improvements in crash reporting for work zones are evident, more is still needed.

Highway agencies have expressed a number of concerns regarding work zone crash data, which can generally be grouped into the following categories:

- Lack of consistency and accuracy of police crash databases,
- Lack of interoperability between databases,
- Lack of timely data,
- Lack of work zone information,
- Lack of identification of work zone limits,
- Lack of ability to know whether or not the work activity had any effect on the crash, and
- Lack of identification and assessment capabilities of worker injuries/fatalities.

Categories of Critical Data Elements

While a number of state crash reporting forms include a way to identify work zone crashes—and a few do include some additional fields to capture work zone characteristics—most do not obtain sufficient information to fully assess the relationship of a crash to common work zone features. A number of suggestions have been made by state highway agencies as to the types of safety performance measures that would be useful in assessing and comparing work zone crash experiences and improvement initiatives (*74*):

- Crashes per day of work activity per hours of work;
- Crashes per day the work zone traffic control is in place;
- Crashes per work zone mile;
- Crashes per type of work zone or work zone activity;
- Crashes per vehicle-miles traveled;
- Crashes per million entering vehicles; and
- Number of crashes per location in work zone (e.g., number of crashes in queues, number of crashes in the advance warning area, etc.).

However, the ability to perform a meaningful analysis is based on the availability of sufficient data that adequately describe the crash and the characteristics of the work zone where it occurred, as well as other information about the project and traffic characteristics. Some of the types of data considered desirable include:

- Description of the traffic control devices in the area of the crash;

- Type of work activity (e.g., construction or maintenance, permanent or temporary, specific activity, etc.);
- Location of the crash in the work zone (e.g., advance warning area, transition, etc.);
- Money spent on construction/maintenance projects;
- Duration of work zone;
- Total number of miles of work zone;
- Number of work zones per type of roadway;
- Volume of traffic through the work zone;
- Hours of work zone activity without positive protection;
- Queue lengths per type of roadway;
- Running speed or other traffic operational measures about the work zone;
- Frequency of motorists exceeding the posted speed limit; and
- Number of erratic/conflict maneuvers in work zones.

A detailed list of data elements for work zone crashes is discussed at the end of this chapter. The most basic data components needed to address these objectives can be grouped into the following categories.

1. *Basic crash characteristics*—Information such as the basic nature of the crash, location, time and date, vehicles and persons involved, resulting injuries, and basic roadway characteristics is included in sufficient detail in most state crash report forms. All of this information is critical in assessing crash causation and severity and is equally important for work zone crashes.
2. *Work-zone-specific crash characteristics*—The involvement of workers, work vehicles and equipment, and other work zone features is important to address various work zone objectives.
3. *Work zone characteristics*—Information describing work zone characteristics is critical to assess the effectiveness of work zone procedures and to identify needed improvements. Desirable information includes work zone type (lane closure, crossovers, etc.), devices and safety features present, location of devices and safety features, presence of work operations/equipment/workers, when work activity was occurring (day, night, weekends, etc.), whether lanes were being closed, and other information to fully describe the work zone at the location and time of the crash.
4. *Basic project characteristics*—This includes the project type (pavement overlay, reconstruction, widening, bridge repairs, etc.), length and duration of the project, project limits (mainline and intersecting roads), project budget, etc.
5. *Traffic operating characteristics*—Several data elements are needed to develop exposure rates and assess traffic operations. These include traffic volumes, operating speeds, speed limits, queues, delays, and travel times. These data elements are needed to establish crash rates and to stratify crashes during certain operating conditions of the work zone (such as crashes during periods of queuing).
6. *Other work zone non-crash accidents*—While work zone crashes involving traffic are a major safety concern for the traveling public, workers are at risk both from traffic crashes and from industrial accidents that occur in work zones. These include falls, electrical contacts, struck by work vehicles/equipment, etc. Data elements needed for such accidents are similar to those needed for work zone crashes but involve industrial accidents rather than traffic crashes. Worker injury data from industrial accidents may be a major cost factor in highway programs, and its availability can be useful in the overall safety management of highway programs.

Review of Work Zone Crash Data Sources and Systems

The discussion above clearly establishes the importance of access to detailed work zone crash data, and this importance is recognized by state highway agencies. It also establishes that there is little consistency among the systems used to compile work zone data and that the systems in use entail a range of shortcomings. There are a number of systems and approaches currently in use to record and compile work zone crash data on a statewide or national basis. The three most basic systems currently in use are described as follows.

State Crash Reports

In most states, crash reporting is coordinated by a centralized state agency, with the crash reports generated and submitted by police agencies and in some cases by the motorists involved in the crash. This system typically includes the use of a state standard reporting form. Many state crash reporting forms and procedures currently in use do provide a way to identify crashes occurring in work zones. However, in most cases, only very limited data elements are compiled concerning the work zone and its involvement. Furthermore, there is little consistency in the forms and procedures used between states, and even within states in some cases.

Crash reports are used by a number of states to summarize work zone crashes within the state. However, in most cases, the level of detail captured is limited, and in most cases it does not permit the examination of specific work zone parameters. Because of the state-to-state differences, it is difficult to combine data on a nationwide basis to address issues of national concern beyond very simple measures such as total work zone crash fatalities.

MMUCC Guideline-Based Enhancements to State Crash Reports

The Model Minimum Uniform Crash Criteria (MMUCC) guideline defines a dataset for describing crashes of motor vehicles that will generate the information necessary to improve highway safety within each state and nationally and provides recommendations of data elements to be included on state crash report forms (*75*). The MMUCC provides for recording more extensive work zone data than what is now obtained in most existing state crash reporting forms. With some relatively minor revisions to the present MMUCC, states that adopt these elements into their state crash report form could be successful in capturing a great deal of the work zone crash information considered important. The biggest drawback to the guideline is that it has not been widely implemented to its fullest extent nationally, and it does not appear that it will be in place in more than a handful of states in the foreseeable future. For those states that do adopt the work-zone-related data elements recommended in the MMUCC, it would be possible to combine data from multiple states to assess work zone issues of national significance, and it would also permit the comparison of certain work zone safety performance measures between states.

State DOT Agency-Based Work Zone Crash Data Reporting

Some state DOTs have established an internal crash reporting mechanism in place to capture work zone crash data above and beyond data available from the statewide crash reporting system. A state can have a system in place to capture crash data on selected types of projects, or in some cases on all projects for fatal crashes or other limited categories of crashes. These procedures rely on data collection and report preparation by highway agency personnel, typically at the project level. These project-initiated reports are typically supplemented by standard state-level crash reports and may be linked to other agency data such as traffic volumes, project characteristics, etc. This system may include industrial accidents in addition to work zone crashes. However, it may be less successful in capturing crashes and industrial accidents that occur on nights and weekends and at other times when project staff are not present.

Comparison of Crash Data Sources

Table 22 below summarizes the comparative advantages and disadvantages of these three sources of data.

Selecting a Work Zone Crash Data Source

As shown in Table 22, each of the three approaches to collecting work zone crash data offers distinct advantages and disadvantages. The adoption of a single uniform system nationwide, based on the MMUCC guideline or a revised version of it, would offer a distinct advantage in that it would permit pooling of work zone crash data on a national basis and would provide more detailed work zone crash data characteristics for analysis purposes than the data that are now available in most states. However, even if national implementation of the MMUCC recommendations is achieved, which seems highly unlikely in the foreseeable future, there will still be some shortcomings relative to all of the ideal objectives of a work zone crash reporting system.

Ultimately, the selection of which crash reporting system to use will be made at the agency level, as is appropriate. In most cases, it is reasonable to expect that this decision will be made by the state highway agency, in conjunction with input from other state agencies involved in the crash reporting system including police agencies responsible for traffic law enforcement and crash investigation on highway projects. It is also reasonable to expect that each state's FHWA Division Office will provide input in the decision of how to obtain crash data. Specific considerations for the adoption of each of the three available systems are discussed below.

Use of Existing State Crash Reports

Use of existing statewide crash report forms to track and evaluate work zone safety programs is likely the least costly option for most states. Unfortunately, unless the state has incorporated additional data elements concerning work zones into the form (such as is recommended in the MMUCC guideline), the manner and extent to which these data can be used is fairly limited. Going forward, a number of terms and conditions can be stated that should be present to allow these data to be considered an acceptable option for purposes of meeting the intent of the FHWA safety and mobility rule regarding the collection and review of work zone safety data. These terms and conditions are as follows:

- The statewide crash reporting form must allow identification of crashes that occur within a work zone or that are likely related to work zone activities (i.e., at the end of a work zone queue).
- The statewide crash reporting form must also contain basic crash characteristics (severity, manner of collision, etc.).
- The report form should include at least the most essential work zone characteristics, as is discussed in the section that follows.
- The ability should exist for work zone crash reports to be forwarded to the highway agency in a timely manner as requested. Such critical reports would typically include fatal crashes within a work zone and serious crashes directly involving the work operation or personnel.
- A good level of cooperation must exist between the highway agency, the agency that compiles the reports, and the police agencies that investigate the crashes and prepare the

Table 22. Advantages and disadvantages of available work zone crash data sources.

State Crash Reports	MMUCC Guideline Enhancements to State Crash Reports	Highway Agency-Generated Work Zone Crash Reports
Advantages		
Already in place in all states	Would help make forms uniform across states	Can provide best work zone detail
Most states provide basic field to identify a crash as occurring in a work zone	Includes other good work zone details	Can capture non-crash accidents
Captures most non-minor crashes	Supported by key national agencies – FHWA, NHTSA, etc.	Can help improve timely reporting to DOT
Includes good basic crash characteristics	Identifies additional crash data elements that may be useful in work zone analyses	High level of DOT control
Can be revised at state level to add elements as needed	May be improved at state level to add elements	Can be customized to meet specific needs
May be linked to roadway, project, and traffic data	May be linked to roadway, project, and traffic data	May be linked to roadway, project, and traffic data
		May provide better information that is useful in defense of legal claims
Disadvantages		
Not uniform between states	No AASHTO involvement	Not uniform between states
Requires ongoing enforcement training	Requires more training for enforcement personnel	Requires development of state procedures
Omits industrial accidents	Overlooks most minor crashes	May miss some events—nights, weekends
Most contain few, if any, work zone characteristics	Omits industrial accidents	Requires DOT staff training
Overlooks most minor crashes	Work zone terminology needs "tweaking"	Requires DOT management commitment
Access to data by DOT is often delayed	Access to data by DOT is often delayed	Added cost to DOT
May lack uniformity within state		Should be supplemented by state crash report

individual reports. This would assume that revisions to the reporting form and procedures can be considered from time to time to meet specific needs of the highway agency.

- The crash reporting procedure should include a reasonably low reporting threshold so that most work zone crashes are captured.
- The highway agency should consider developing a supplemental reporting system to capture serious non-crash worker industrial accidents occurring on project sites. These would include serious injuries to workers (hospital treatment may be a useable threshold), accidents resulting in substantial property damage or environmental damage, and "near-miss" accidents that did not result in serious consequences but clearly had the potential to be much more severe. A typical example would be the overturning of a large crane that missed workers and vehicles traveling through the project, or the rupture of a large natural gas transmission line.
- Adequate training must be provided to law enforcement personnel that respond to crashes to ensure that the work zone and other data entered into the forms are correct and consistent.
- The highway agency should develop clear-cut procedures as to how the crash report form data are to be extracted, analyzed, and used to guide decisions and changes to work zone policies, procedures, and practices. If data concerning non-crash worker industrial accidents are to be collected, efforts should be made to ensure that the requirements are understood by all agency staff that have responsibility for its implementation.
- Buy-in to this system is obtained from the state division office of FHWA.

Adoption of MMUCC Work Zone and Related Data Elements on the State Crash Report Form

The MMUCC guideline identifies several work zone data elements recommended for inclusion on state crash report forms. Overall, the recommendations represent a substantial improvement over the crash reporting forms used in many states and offer the potential to provide good uniformity of reporting among the states where it is used. However, it appears that only a handful of states have implemented the

1998 version of the MMUCC relative to the work zone data elements, and it is not known at this time if any have adopted the latest 2003 version. For state highway agencies that rely on the state crash reporting system to collect work zone crash data, implementation of the MMUCC at the state level will provide essentially all of the advantages those states now realize in terms of obtaining work zone crash data through their state crash reporting system, but with the significant added advantage of capturing more detailed and more consistent work zone characteristics in the reports.

For the data elements to be available, the state agency responsible for the statewide crash data form must first implement the MMUCC. Once this is in place, the MMUCC will provide the specific major advantage of collecting much more detailed work zone crash data than most of the non-uniform state systems now in place. While the MMUCC will provide a greatly improved level of data in most cases, the other necessary terms and conditions listed above for the existing state report forms are also applicable to use the MMUCC data.

State Highway Agency-Based Crash Data Collection and Reporting

Currently, some states have internal systems in place for collecting work zone crash data elements using their own personnel or contractor personnel at the project sites. In at least one case, non-crash worker industrial accidents are collected as well. Development of a work zone crash data collection and archival system within an agency does appear to provide the most effective means to compile complete data on work zone crashes. When combined with the availability of police crash reports based on the MMUCC guideline and the ability to link crashes to project, program, and traffic characteristics, such a system can provide the complete range of information needed for an agency to determine statewide work zone crash trends, and/or the need to modify or enhance work zone policies, procedures, temporary traffic control plans, etc. When non-crash worker industrial accidents are included in the system, it also provides the ability to assess the overall safety of the agencies' construction and maintenance programs.

While this approach offers the opportunity to obtain the most detailed work zone crash and characteristics data, tailored to the specific needs of an agency, it is not without a few disadvantages, mostly related to increased costs and efforts by the highway agency to implement and continuously manage. Furthermore, if this type of approach is to be successful in allowing comparisons across states, it will be necessary for AASHTO or a follow-up NCHRP effort to promote the use of a uniform set of work zone data elements (as described in the next section) by highway agencies (an approach that is similar in concept to the MMUCC effort).

As was the case for the state crash report form approach, there are a number of terms and conditions that can be stated that are essential for this approach to be considered an effective option:

- The highway agency must develop comprehensive reporting forms for reporting crashes and accidents occurring on agency projects. These forms can standardize the coding and entry of data elements needed about the crash or accident not captured on the standard state crash report form.
- As part of the collection process, a mechanism is needed to match the highway agency's collected data on its report form with the data collected on the state crash report form (relevant for all traffic crashes investigated).
- Agency management must commit to providing the resources needed to collect the work zone crash and accident data, to analyze it in a timely manner, and to utilize it effectively to manage work zone safety and mobility.
- Mechanisms are needed to ensure that the agency-collected work zone crash reports are forwarded to the highway agency in a timely manner, and individual crash reports should be available to the highway agency personnel on a near-immediate basis for critical crashes when requested. Such critical reports would typically include fatal crashes within a work zone and serious crashes directly involving the work operation or personnel.
- The crash reporting procedure should include a reasonably low reporting threshold such that most work zone crashes are captured in the police crash reports.
- The reporting system should include provisions to capture serious non-crash accidents occurring on project sites. These would include serious injuries to workers (hospital treatment may be a useable threshold), accidents resulting in substantial property damage or environmental damage, and "near-miss" accidents that did not result in serious consequences but clearly had the potential to be much more severe. A typical example would be the overturning of a large crane that missed workers and vehicles traveling through the project, or the rupture of a large natural gas transmission line.
- The highway agency must develop clear-cut procedures to ensure the collection and dissemination requirements of the work zone crash report data are known and correctly followed by all agency staff having responsibilities for its implementation. Typically, this includes training of the involved staff as needed and ensuring that adequate quality control procedures are established.
- A critical quality control component needed is the establishment of back-up procedures to alert project staff to crashes and work accidents that occur on nights and weekends and at other times when agency staff are not present. A close working relationship with law enforcement personnel at

the project level can be critical to capture such crashes. Contract provisions can be included to require contractors to report non-crash accidents and incidents directly to agency staff to permit the agency to follow up with its reporting procedures.
- Buy-in to this approach will need to be obtained from the state division office of FHWA.
- Finally, a periodic agency summary of the work zone crashes and accidents should be prepared and circulated throughout the agency as a way to distribute lessons learned and to gain a consensus on needed changes in agency-level work zone policies and procedures.

Recommended Model Work Zone Crash Report Data Elements, Attributes, and Definitions

MMUCC Guideline Data Elements and Attributes—2003 Edition

The 2003 MMUCC criteria include much of the information that is considered desirable to document work zone crashes in a manner that makes it feasible to manage traffic safety and some aspects of mobility in work zones. A full list of all 111 MMUCC data elements appears in Appendix C; those thought to be most directly critical to work zone management are identified in the column "Work Zone Critical." Several of the 111 elements actually include several subfields, such that the total number of data elements is considerably more than 111. Each of the 111 data elements and associated subfields includes a range of specific data attributes that are fully described in the MMUCC guideline. Several data elements relate directly to work zones, and several others address various work zone attributes in a less direct manner. These elements and attributes are discussed in this section.

Only one of the 111 data elements in the MMUCC is used solely to describe work zone attributes. Data element C19 is defined as follows:

> C19. Work Zone-Related (Construction/Maintenance/Utility): Definition: A crash that occurs in or related to a construction, maintenance, or utility work zone, whether or not workers were actually present at the time of the crash. 'Work zone-related' crashes may also include those involving motor vehicles slowed or stopped because of the work zone, even if the first harmful event occurred before the first warning sign.

Combined with definitions of work zone and work zone crash also provided in the MMUCC, this definition of "work zone related" describes what would typically be regarded as work zone crash events. To further clarify this definition, Figure 6C-1 of the *Manual on Uniform Traffic Control Devices* (MUTCD), "Component Parts of a Temporary Traffic Control Zone," is reprinted as an MMUCC appendix. Minor revisions to these definitions are discussed in the next section.

Four sets of attributes are provided with this data element C19 to provide specific detailed information relating the crash to the work zone and its specific characteristics.

Subfield #1 indicates whether or not the crash occurred in or near a work zone, given the choices of "yes," "no," and "unknown." When the attribute is "yes," three additional subfields are used to enter additional information.

Subfield #2 defines the location of the crash, with the choices of:

- Before the First Work Zone Warning Sign,
- Advance Warning Area,
- Transition Area,
- Activity Area, and
- Termination Area.

Subfield #3 identifies the type of work zone, given the following choices:

- Lane Closure,
- Lane Shift/Crossover,
- Work on Shoulder or Median,
- Intermittent or Moving Work, and
- Other.

Subfield #4 addresses the presence of workers, providing the choices of "yes," "no," and "unknown."

Several other data elements can also be used to provide data addressing work zone conditions, although all of them apply to crashes in general and are not limited to use in work zone crashes. These other elements and the attributes that may be applicable are presented in Table 23.

In addition to those discussed in the table, the MMUCC guideline includes numerous other data elements that are useful in describing the characteristics of work zone crashes. These include such elements as C8—Manner of Crash/Collision Impact, C12 – Light Conditions, and several elements describing injuries resulting from a crash, characteristics of persons and vehicles involved, and others that are potentially valuable in addressing work zone safety concerns. Overall, this guideline provides a very detailed and comprehensive description of highway crashes that includes much of the information considered important to effectively manage work zone safety and, to some extent, mobility. Even so, there are a number of specific revisions that can be suggested to enhance its usefulness for managing work zone safety. With consideration of the revisions discussed in the next section, this guideline can become even more effective as a system for recording work zone crash data.

Table 23. MMUCC data elements relevant to describing work zone traffic crashes.

Element Number	Element Name	Attribute Discussion
C6	First Harmful Event	This element includes attributes to describe various collision and non-collision events. The attribute "*thrown or falling object*" could be used to describe the involvement of construction debris falling from a bridge or from construction vehicles or equipment. The attribute "*collision with work zone/maintenance equipment*" and the attribute "*collision with a pedestrian*" could apply to highway workers, including flaggers. Also included are "*collision with impact attenuator/crash cushion*" and "*collision with other traffic barrier.*"
C13	Roadway Surface Condition	One of the available attributes is "*mud, dirt, gravel,*" which can be used to describe conditions sometimes encountered in work zones.
C15	Contributing Circumstances, Road	One of the available attributes is "*work zone (construction/maintenance/utility),*" which can be used to identify possible contribution of a work zone to the occurrence or outcome of a crash.
V2	Motor Vehicle Type and Number	This element contains a choice of attributes to identify vehicle type, including "*working vehicle/equipment.*" This attribute can be used to identify vehicles and equipment involved in the work zone operation.
V17	Traffic Control Device Type	One of the available attributes is "*person (including flagger, law enforcement, crossing guard, etc.),*" which can be used to identify work zones where flagger traffic control was present at the crash location.
V20	Sequence of Events	This data element includes several attributes that can be used to identify safety features commonly found in work zones. These attributes include "*traffic sign support, impact attenuator/crash cushion, concrete traffic barrier, and work zone/maintenance equipment.*"
V21	Most Harmful Event for This Motor Vehicle	This data element includes the same attributes as V20.
P3	Person Type	This element includes several attributes that can be used to characterize highway workers involved in crashes, including "*motor vehicle driver and passenger, and non-motorist categories including pedestrian and occupant of motor vehicle not in transport (parked, etc.).*"
P22	Non-motorist Action Prior to Crash	Attributes include "*working, approaching or leaving motor vehicle, and playing or working on motor vehicle.*" Several other attributes may also be used to describe worker actions prior to a crash.
P23	Non-motorist Action at Time of Crash	Attributes include "*in roadway (standing, on knees, lying, etc.)*" and several others that may be useful to describe worker actions at the time of a crash.
P25	Non-motorist Location at Time of Crash	The list of attributes for this element can be used to describe the location of a worker at the time of a crash, in terms of standard highway terminology. Available choices include "*in roadway (not in crosswalk or intersection), shoulder, sidewalk, roadside, and outside trafficway,*" as well as several others.
P26	Non-motorist Safety Equipment	Attributes include "*helmet and reflective clothing (jacket, backpack, etc.),*" which can be used to identify worker use of hardhats and high-visibility apparel.
RL2-9 and 11-18	Roadway Elements	These data elements all describe common highway design elements, safety features, and operating characteristics and highway classifications that may be of considerable interest in managing work zone safety and mobility. Included are such attributes as lane and shoulder widths, intersection characteristics, access control, roadway lighting and pavement markings, and traffic volumes.

Suggested Revisions to MMUCC Guideline Definitions

The first category of suggested revisions to the MMUCC addresses a number of definitions that are not consistent with commonly used highway terminology, and in some cases are inconsistent with the MUTCD and other highway guidelines and standards. The first of these is the basic definition of the work zone itself. The guideline definition of "work zone," which very closely parallels the definition in the MUTCD, is given as:

> Work Zone—An area of a highway with highway construction, maintenance, or utility work activities. A work zone is typically marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign or flashing lights on a vehicle to the END ROAD WORK sign or the last traffic control device. A work zone may exist for short or long durations and may include stationary or moving activities.

This definition is very consistent with the MUTCD, although shortened slightly. A slight revision to "flashing lights on a work vehicle" would clarify this definition and make it even more consistent with the MUTCD definition.

A second critical definition is that of "work zone crash," stated in the guideline as:

> Work Zone Crash – A Work Zone Crash is a traffic crash in which the first harmful event occurs within the boundaries of a

work zone or on an approach to or exit from a work zone, resulting from an activity, behavior or control related to the movement of the traffic units through the work zone. Includes collision and non-collision crashes occurring within the signs or markings indicating a work zone or occurring on approach to, exiting from or adjacent to work zones that are related to the work zone. For example: 1) An automobile on the roadway loses control within a work zone due to a shift or reduction in the travel lanes and crashes into another vehicle in the work zone, 2) A van in an open travel lane strikes a highway worker in the work zone, 3) A highway construction vehicle working on the edge of the roadway is struck by a motor vehicle in transport in a construction zone, 4) A rear-end collision crash occurs before the signs or markings indicating a work zone due to vehicles slowing or stopped on the roadway because of the work zone activity, 5) A pickup in transport loses control in an open travel lane within a work zone due to a shift or reduction in the travel lanes and crashes into another vehicle which exited the work zone, 6) A tractor-trailer approaching an intersection where the other roadway has a work zone strikes a pedestrian outside the work zone because of lack of visibility caused by the work zone equipment. Excludes single-vehicle crashes involving working vehicles not located in trafficway. For example: 1) A highway maintenance truck strikes a highway worker inside the work site, 2) A utility worker repairing the electrical lines over the trafficway falls from the bucket of a cherry picker.

This definition is very comprehensive and includes all types of crashes involving vehicles either within a work zone or upstream of the advance warning area if the crash was influenced by traffic backups and queues or other activity within the work zone. However, this definition could be further clarified by adding a sentence stating: "This definition includes all crashes that occur within a work zone, whether or not workers are present and work is actively underway."

While all of the examples included in the definition are clearly work zone crashes, all of them involve motor vehicles, and it is not clear if accidents involving a pedestrian, bicyclist, or other non-motor vehicles would be considered a work zone crash unless a motor vehicle is also involved. It is desirable that this issue be clarified to include any events involving a pedestrian, bicyclists, or other non-motor vehicle traveling through a work zone as a work zone crash, regardless of whether or not a motor vehicle is involved. Managing such events is an important aspect of work zone safety management, especially in urban areas where pedestrians and bicycles are common, and data concerning these accidents are an important part of a crash data system.

It is expected that this definition can be easily revised to address this issue. However, whereas police response to vehicle crashes is typically expected, this may not always be the case for accidents involving pedestrians and bicycles unless a more serious injury with a motor vehicle is involved. While revising this definition may result in capturing some of these events, it is likely that the MMUCC guideline will be less sensitive to pedestrian and bicycle accidents than to crashes involving motor vehicles, and a highway-agency-based reporting system may be better able to capture such events.

A third critical definition is that of "work zone related crashes," which is stated as:

> Work Zone-Related Crash—A crash that occurs in or related to a construction, maintenance, or utility work zone, whether workers were actually present at the time of the crash or not. Work zone-related crashes may also include those involving motor vehicles slowed or stopped because of the work zone, even if the first harmful event was before the first warning sign.

This definition is consistent with the definition typically applied by most highway agencies and does not require revision.

In addition to these three basic definitions, 18 other definitions were identified that involve work zone features. Some of these are not inconsistent with standard terminology in the MUTCD and other highway-related standards, and others need to be expanded or clarified to clearly describe common work zone features. These additional definitions are discussed in Appendix D.

Suggested Revisions to MMUCC Data Elements and Attributes

In addition to the suggested revisions to guideline definitions, there are also a number of data elements and attributes that would benefit from minor revisions such that they can more adequately describe work zone features and characteristics. These revisions are summarized in Table 24.

Inherent Limitations in the MMUCC Guideline

In addition to the suggested revisions to the 2003 edition of the MMUCC guideline, three inherent limitations were identified that impact its usefulness for managing some aspects of work zone safety, and these limitations may be difficult to overcome within the existing framework of the MMUCC guideline.

The most critical limitation is that this guideline focuses entirely on work zone crashes and does not address non-crash events. Non-crash events that are routinely of interest to highway agencies in managing the overall safety and impacts of highway work include:

- Industrial accidents occurring in a work zone (falls, workers struck by equipment, trench collapse, etc.);
- Near-miss accidents resulting in only minimal injuries or property damage but with clear potential for more severe consequences;
- Worker exposure to toxic materials;
- Contacts with utilities (electrical transmission lines, gas mains, etc.) with the potential to cause injuries or property damage or disrupt service; and
- Harmful environmental events such as release of hazardous waste or debris into the environment.

Table 24. Recommended enhancements and revisions to MMUCC data elements and attributes.

Element Number	Element Name	Suggested Attribute Revisions
C6	First Harmful Event	• While the attribute "*thrown or falling object*" can be used to describe construction debris, it would be helpful to add an additional new attribute "*construction debris/material*" for this purpose. • Likewise, the attribute "*pedestrian*" would presumably include highway workers and flaggers. However, it would be helpful to include this as a separate attribute "*construction/maintenance worker/flagger.*" • The existing attribute "*work zone/maintenance equipment*" should be revised to read "*work zone/maintenance equipment or vehicle.*" It is suggested that an additional attribute "*work vehicle with portable crash cushion attached*" be added to permit tracking crashes involving shadow vehicles equipped with truck-mounted attenuators. • The definition associated with the attribute "*impact attenuator/crash cushion*" does not distinguish between permanent and work zone devices. It would be helpful to revise this attribute to "*impact attenuator/crash —permanent"* and to add a new attribute "*impact attenuator/crash cushion—work zone."* • The attribute "*other traffic barrier*" as currently defined can be used to include a wide range of work zone safety devices but is not consistent with standard highway terminology. A revised definition of this attribute is provided in Appendix D. In addition, it is suggested that two additional attributes be added to identify commonly used work zone barriers. These are "*temporary work zone concrete barrier—non-moveable*" and "*temporary work zone concrete barrier—moveable.*" • It is suggested to add a new attribute under fixed objects: "*construction features—excavation/trench/material stockpile, etc."*
C19	Work Zone-Related (Construction/ Maintenance/ Utility)	• Under Subfield 2, location of crash includes attributes for each of the work zone areas, as well as for before the first work zone sign. It would be helpful to revise the current attribute for "*activity area*" to three new attributes including "*activity area—traffic space,*" "*activity area—workspace,*" and "*activity area—buffer space.*" Definitions for each of these attributes should be added to the definitions, using the current definitions in MUTCD Figure 6C-1. • Under Subfield 3, the attribute "*lane shift/crossover*" should be separated into two distinct attributes because these are not similar work zone types. • A new Subfield 5 is recommended for "*workspace intrusion,*" with three attributes provided as "*yes,*" "*no,*" and "*unknown.*" • A definition for work zone intrusion should be added, as noted in Appendix D.
V20	Sequence of Events	• The attribute "*work zone/maintenance equipment*" under "*collision with person, motor vehicle, or non-fixed object*" should be expanded to "*work zone/maintenance vehicle or equipment.*"
V21	Most Harmful Event for This Motor Vehicle	• The attribute "*work zone/maintenance equipment*" under "*collision with person, motor vehicle, or non-fixed object*" should be expanded to "*work zone/maintenance vehicle or equipment.*"
P26	Non-motorist Safety Equipment	• Under Subfield 1, revise the attribute "*helmet*" to "*helmet or hardhat.*"

The MMUCC does not currently address any of these types of events, unless they are related to a traffic crash, and even then, detailed information about the event is not included as attributes that would be collected via the MMUCCC guideline. Given the goals and objectives of the current guideline and its existing format and structure, a major revision would be required to address such events. It is considered more practical to address such needs through agency-based reporting systems and other sources of event reporting that are already in place to address such events through such venues as the Occupational Safety and Health Administration (OSHA) reporting requirements, insurance company and construction company records, and reporting requirements of various other state and federal agencies.

A second limitation, which may be problematic for some work zone events, is the focus on events involving motor vehicles, while not clearly including non-vehicle events involving pedestrians or bicycles. This limitation may be addressed to some extent by revising the existing guideline, but even with the suggested revisions, it appears that these non-vehicle events may not be addressed as completely as would be desired. This limitation is discussed above under the suggested revisions to the definition of "work zone crash."

The third significant limitation is that most of the linked roadway data elements RL1–RL18 provide information on roadway features that are also of interest in work zone crashes. However, because these data elements are obtained by linkage to roadway inventory files, it is expected that the attributes recorded will be those normally present when no work zone is present. However, some or all of these attributes may be changed during some or all of the time the work zone is present. Reliance on this linked data thus has a high likelihood of providing incorrect data for work zone crashes. A major revision would be required to the guideline to address this limitation, and it does not appear likely that it can be addressed within the existing framework.

Considering these limitations, reliance exclusively upon the MMUCC data elements and state crash report forms may not generate all work zone crash and accident data elements deemed essential to managing work zone safety. Even if all the MMUCC data elements and attributes are adopted by a state and all enhancements suggested in this report to better capture work zone crash data are also adopted, a highway-agency-based reporting system may still be desirable to better capture the full range of data elements considered important.

Data Element Considerations of Highway-Agency-Based Crash Reporting Systems

Some states have implemented work zone crash and accident reporting within the highway agency. Examples of reporting forms for three such states (Florida, Maryland, and Louisiana) are provided as examples in Appendix E. These data are supplemented by police accident reports.

NYSDOT has implemented a much more comprehensive system for reporting work zone crashes and other accidents that occur on its construction projects. Termed the "Construction Accident Reporting Program," this system was initiated in the mid-1980s and has been expanded and refined several times to increase the information compiled and improve timeliness of reporting and analysis of the data for use in agency-wide management of work zone safety and mobility. This system requires a major commitment of resources by the agency and is believed to represent the most comprehensive database of this nature now available nationally. While it addresses many of the crash and accident data needs discussed in the preceding sections, a potential major drawback of this system is that it is unique to this agency and does not utilize the MMUCC guideline or any other standardized reporting format. This will make it difficult to combine and compare data between states. Such a capability would be extremely helpful to projects such as this one and other efforts to examine work zone safety and mobility questions and issues on a national basis. It is noted that this system is applicable to crashes and construction accidents that occur on department-administered construction projects, whether on the state highway system or local highways, and also any crashes or accidents involving Construction Division employees, regardless of the location. It also includes crashes and accidents on highway permit work sites administered by the Construction Division. A separate, less detailed system not directly linked to this one is used to report crashes and accidents in maintenance work zones staffed by agency maintenance employees. This system is not applicable to work zones administered by toll roads or by local highway agencies in New York State.

The basic requirements for the latest iteration of this system, implemented in 2004, are set forth in that agency's construction procedures manual (*5*). It defines the purpose of this reporting system as "to keep executive management informed of developing situations, to define the scope of safety related problems, and to identify corrective action." This system provides for electronic reporting directly by project field office staff of crashes and accidents meeting the criteria in the referenced procedure. Individual reports are maintained in project files, regional office files, and the central office where they are used to generate various reports for use in managing work zone and construction safety, including the preparation of annual reports to summarize safety-related issues.

Reporting requirements for this system address nearly all crashes and accidents that occur on an agency construction contract, as well as all accidents involving Construction Division employees, regardless of where they occur. The following describes event types that are covered by this reporting system:

Immediate Notification Required

- Any injuries to NYSDOT construction employees,
- All accidents involving state-owned vehicles and private vehicles used on state business,
- Any fatal or hospital transportation to consultant or contractor employee directly related to construction activity,
- Traffic accidents resulting in fatal or multiple (three or more) personal injuries, if directly related to construction activity or the maintenance and protection of traffic,
- Any utility incidents, and
- Any accident resulting in media attention.

Notification Required as Soon as Possible

- Any traffic accident involving maintenance and protection of traffic, but not resulting in fatal or multiple (three or more) personal injuries,
- Any traffic accident within the project limits resulting in a fatality or personal injury, but not related to construction activity or within limits of active M&PT,
- Any construction-related accident resulting in minor worker injury or damage to private property, and
- Any near miss accident.

A user manual defines the procedure for entering crash and accident data into the electronic Construction Accident

Reporting Program, written in Visual Basic/Crystal Reports. It also details how reports are to be transmitted and stored within the agency, and periodic management reports generated by the system track the completion and follow-up of individual accident reports. This manual provides a partial list of the data elements and attributes included in the program, but it does not provide an overall comprehensive list. Appendix D provides a list of the NYSDOT data elements and attributes compiled from the user manual and the database itself.

The NYSDOT Construction Accident Reporting Program, in its current form, offers a number of specific advantages for the management of work zone safety and mobility:

- It is based on management's commitment to the reporting of all crashes, accidents, and other incidents related to the agency's construction program, and use of the data to manage and improve safety in the construction program.
- Procedural guides and user manuals have been developed to assist in the uniform implementation of the program.
- The program provides for immediate or rapid reporting of all such incidents up through the agency chain of command.
- An electronic reporting program provides for data entry at the field office. The overall system provides for distribution of reports throughout the agency as appropriate and generation of various management reports on a systematic basis.
- Other reports, such as police accident reports, are appended to these reports.
- An extensive "accident file" is assembled for serious accidents to assist in defense of any claims, to develop corrective measures, and for various other purposes.
- This system provides for statewide data availability and analysis for the preparation of agency-wide summary reports.
- In addition to traffic crashes involving vehicle collision, this system captures virtually all harmful or potentially harmful events that occur on construction or permit projects, or involving Construction Division employees. This includes construction accidents; accidents or crashes involving pedestrians, bicycles, and motorcycles; incidents involving damage to or contacts with utility infrastructure; and off-site accidents involving Construction Division employees.
- The reporting program includes detailed data elements and attributes designed to provide specific information considered necessary to the management of the agency's construction program.
- These reports can be linked to other data available within the agency such as traffic volumes, roadway inventory, construction program attributes, and others as deemed necessary.

In spite of the significant strengths of this program, it appears that it also entails a number of potential weaknesses, especially in terms of the development and implementation of the electronic reporting system:

- The user manual provided for the reporting system appears to omit specific instructions for some portions of the system. Based on a review of the reports submitted since the current reporting system was implemented, there are clearly inconsistencies in how some of the elements are reported.
- The methodology of using true/false attributes for a number of data elements is cumbersome and confusing. For example, rather than providing a single data element for "manner of crash," followed by a list of several allowable attributes defining the various manners of crash, the current program includes several elements that use a true/false attribute. Adding further to the confusion, these elements are not grouped together within the system.
- The data elements in the system do not provide a comprehensive list of all possible manners of crash, consistent with those in the MMUCC guideline.
- A number of closely associated data elements are not located together in the form, increasing the risk of incorrect or inconsistent reporting.
- The data element for work zone intrusion is inconsistent in that it appears to classify both workspace intrusions and certain other crashes involving workers and work vehicles/equipment as intrusions even when they do not occur in the workspace.
- The records do not clearly indicate the involvement of most work zone traffic control devices and safety features in a crash, except as noted in the narratives. This may preclude automated sorting of the records to identify all such crashes and may even fail to identify some of these crashes.
- The unique and cumbersome coding system included in the current program makes it extremely difficult to combine the New York data with data available from other states and other work zone crash data sources.
- The coding system also makes it extremely cumbersome to query the database to identify specific crash and accident types and characteristics, other than those specific data elements and attribute factors now included in the reporting program.
- There are no specific data elements and lists of attributes to describe construction accidents involving workers. While this information can be obtained from the narrative descriptions, a specific data element to identify construction accident attributes would be a very helpful feature.
- A number of other potential concerns are mentioned in the discussion of the individual data elements and attributes provided in Appendix F.

Data Element Considerations of Work Zone Exposure Information

The previous discussion notes the importance of capturing roadway and certain work zone characteristic information present at the time of a crash; this information is typically not captured in agency roadway inventory databases because of the temporary nature of the work zone. In addition to these types of event-based data elements, there is a need for agencies to begin to establish mechanisms to gather and organize data pertaining to work zone exposure information. These exposure data elements are needed to properly normalize crashes into appropriate rate-based measures so that they can be consolidated across multiple work zones and compared in various ways.

The data elements needed or desired for exposure estimation purposes include those pertaining to traffic and to specific characteristics of the work zone itself. Suggested elements and attributes include the following:

- Traffic volumes and characteristics (ADTs, hourly volumes, and vehicle mix);
- Work zone length (overall and by sections with similar geometric features);
- Work zone duration (duration of phases, hours of work activity, and times and durations of capacity restrictions); and
- Highway worker and equipment exposure (number of workers and equipment present, and location of workers/equipment within the work zone).

Currently, few agencies actively collect work zone traffic data, although the increased use of work zone ITS technologies now provides an opportunity to do so with greater frequency. On the other hand, much of the proposed data pertaining to work zone exposure are already within the potential grasp of many highway agencies. Daily project diaries already provide spaces to document times of work activity, equipment and workers present, locations of work activities, etc. As agencies move toward electronic storage of daily project information (using the AASHTO Trns•port SiteManager or other construction management software), the opportunity does exist to more easily extract this type of data for use in exposure estimation. The challenge will be in ensuring adequate documentation levels of these data elements. As part of this research, thousands of pages of such diaries were reviewed. The extent to which those elements were consistently reported in the diaries varied widely.

Other data elements, most notably lane closures that temporarily restrict the capacity of the roadway, do not have a specific field in the inspector diary but are typically documented in the narrative portion of the diary. Capturing these data at the present time is thus extremely time consuming. Modification to project diary pages to specifically request lane closure information, and the inclusion of this item in construction management software where project diary data are kept, would be an important first step.

Recommended Work Zone Crash Data Analysis Methods

In the most general terms, work zone crash data can be used for ongoing monitoring functions or for detailed after-the-fact (post-hoc) investigations to quantify and/or test the statistical significance of various crash-related hypotheses. The monitoring function can be for a particular project, or it can be for a particular crash type across a district, region, or even state. For example, project engineers often maintain an informal awareness of the crashes occurring in their particular project (either informally by discussions with local law enforcement or by regularly obtaining actual hard copies of crash reports occurring in the work zone) as a way of checking for any obvious safety problems that need immediate attention in the work zone. Likewise, some states maintain a running total of the number of fatalities or the number of certain types of crashes occurring in work zones throughout the year to compare against similar year-to-date totals in previous years. Meanwhile, post-hoc investigations are typically carried out to determine the amount of crash increase occurring in work zones overall or of a particular type, to evaluate the effect of a particular design feature or operating strategy upon crashes, or to evaluate the effectiveness of a particular countermeasure implemented to address a particular crash issue. The analyses performed as part of this research are examples of these post-hoc investigations.

The Ohio Department of Transportation is one agency that has formalized its efforts to monitor crashes in its significant work zones (*76*). For those work zones selected for monitoring, the agency divides the projects into 0.5-mi segments and compares crashes occurring in each segment with the average rate of crashes that had occurred in those segments in the previous 3-year time period. Those segments where crashes appear abnormally high are targeted for further assessments of the possible underlying factors that may be contributing to the higher-than-normal crash frequencies. An example of the type of analysis generated through this effort is provided in Figure 29. Crashes are examined both by location and by time to identify unusual trends. A key component of this process is the commitment of personnel resources by the Ohio DOT to manually collect hard-copy crash reports from the law enforcement office at each project every 2 weeks and to enter that data into the spreadsheets used for analysis.

A comparison of some of the opportunities and challenges associated with monitoring and post-hoc investigations of work zone crashes is provided in Table 25. Review of the

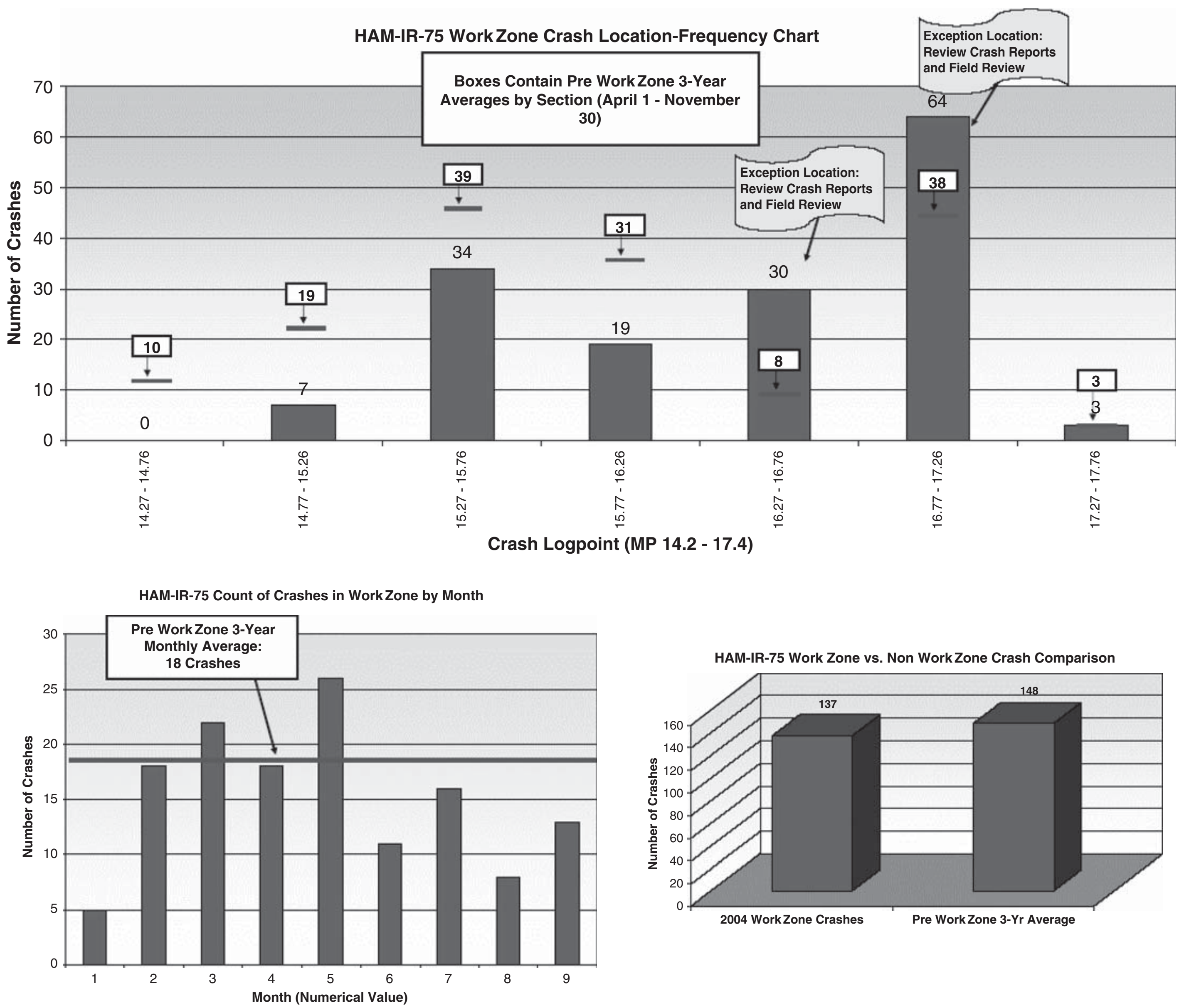


Figure 29. Example of work zone crash analysis performed by Ohio DOT (76).

points presented in the table illustrates that both approaches have a significant role within highway agencies as they strive to improve safety within the work zones under their jurisdiction. Perhaps more importantly, there is a degree of synergy between the two main analysis approaches. Monitoring efforts are best suited to identify possible safety issues at the project level that may be quickly mitigated by the agency or the contractor. Monitoring efforts can be an effective method of identifying possible work zone design features, operating strategies, etc. that may be unduly contributing to crashes occurring in work zones and so need to be modified. Post-hoc investigations are more suited to actually quantifying the extent to which those features and operating strategies are contributing to work zone crashes and to quantifying the extent that any modifications made to them are actually reducing crash risk.

Summary

Although no work zone crash data system currently in use fully addresses the needs of effective work zone safety management, it appears that such a system can be developed by combining the desirable features of the MMUCC with an agency construction accident reporting program similar in concept to the one now in use at NYSDOT. However, revisions and improvements to both of these are considered essential to achieve the goal of providing comprehensive, timely, and consistent data for crashes, construction accidents, and other

Table 25. Comparison of monitoring and post-hoc crash analysis approaches.

Crash Monitoring	Post-Hoc Investigations
Opportunities	
• Allows for near real-time identification of possible safety problems (features, strategies, etc.) • Demonstrates a culture of diligence about work zone safety by the agency (potentially useful for litigation purposes)	• Allows for quantification of influence of work zone feature(s), operating strategies, and safety countermeasures implemented • Allows experiences from multiple work zones to be properly consolidated and interpreted (useful for periodic assessment of agency policies and processes)
Challenges	
• Requires commitment by the agency to collect and process data in a timely manner • Difficult to determine relative contributions of multiple features or strategies to a possible safety problem	• Difficult to know what feature(s) or operating strategies are the highest priority to investigate • Typically requires more data to perform correctly • Often a significant time lag exists between when a crash occurs and the time it is available for analysis

harmful events in and related to highway work zones. Specifically, the following actions would be needed:

- The MMUCC guideline needs to be implemented by more states to permit sharing of data between states.
- Minor modifications to the MMUCC guideline should be made to address the weaknesses and inconsistencies discussed in the preceding sections.
- Some roadway data elements in the MMUCC guideline are recorded in the field, while others are obtained through linkage to other roadway databases. Because roadway characteristics are frequently temporarily changed in work zones, the linked roadway data included in the MMUCC may be invalid for work zone crashes. Therefore, it appears necessary to verify these linked roadway elements in the field at the time of a work zone crash, or to establish procedures that would allow work zone roadway element features present at the time of the crash to be determined via construction plans, project diary documentation, or other mechanisms.
- While the NYSDOT system is conceptually sound, there are inherent weaknesses in it that need to be corrected. These involve revising some data elements and attributes and adding others. The reliance on true/false attributes should be replaced by standard attributes associated with specific data elements to facilitate use of the database.
- A nationally supported research effort either by FHWA or through the NCHRP program appears to be the most practical means to develop a model state system, using the NYSDOT program as a starting point, and revising and expanding it to address its weaknesses.

The proposed list of data elements and attributes for work zone crashes addresses specific characteristics of work zone crashes and accidents using attributes based on generally accepted terminology. The MMUCC data elements are classified into four major groups – crash, motor vehicle, person, and roadway data. With the corrections and revisions discussed in the previous sections, the MMUCC data elements would be sufficient to provide much of the information needed for vehicle-involved crashes. However, it includes no data elements to address work zone accidents by pedestrians and bicycles but not involving a vehicle, and no elements for construction accidents. In addition, there are insufficient elements to identify all of the specific types of work zone traffic control devices and safety features present or involved in the crash, other than a few included in other data elements such as "Traffic Control Device Type." In addition, there are no elements to describe work vehicles, equipment, and work operations.

These lacking data elements can best be addressed by developing a comprehensive list of data elements and attributes to be incorporated into a work zone crash/accident reporting program to be implemented by highway agencies as a supplement to MMUCC or similar crash reports. Such a comprehensive list should have a strong consensus of support from highway agencies in this country. These data elements would include the following four groups:

- *Project and crash identification elements*—A series of elements would identify the date, time, and location of the event and the contract or permit where the event occurs. An element could be included to identify agency region or district as well as project type (reconstruction, bridge rehabilitation, safety improvement project, etc.). Involved contractors, subcontractors, and consultants would also be identified. A tracking number would be included for each event.
- *Work zone elements*—These elements would identify commonly used work zone traffic control devices, traffic safety

features, and construction safety features and devices. Also included would be elements to describe work vehicles and equipment involved and the related work operations.

- *Supplemental person elements*—These elements would provide information about workers involved, including job title, employer, etc.
- *Report tracking elements*—These elements would identify persons involved in preparing and reviewing the report, report dates, etc. They would be used for internal agency management purposes and are not directly associated with crash or accident safety management.

In addition to these data elements to be addressed solely in the work zone crash/accident reporting program, the proposed system will also rely on numerous data elements included in the MMUCC. To the extent that the MMUCC or equivalent accident reports are available in a timely manner to supplement the agency internal report, this information could be available as needed. In reality, however, some delay will be encountered in obtaining MMUCC or other similar reports prepared by police agencies, and more critically not all crashes and events will generate a police report. Therefore, it is important to duplicate certain data elements from the MMUCC into the work zone crash/accident reporting program to ensure that the necessary information is available in a timely manner for all events. These elements are identified in the column "Work Zone Related" in Appendix C.

While the above categories of elements are thought to include those most relevant to work zone safety management, individual highway agencies could have the option to add any additional elements considered important for internal purposes.

CHAPTER 6

Findings and Recommendations

This research was performed to determine: how nighttime and daytime work zones affect crash risk and rates; to determine similarities and differences in the characteristics between traffic crashes at nighttime and daytime work zones; to identify and evaluate various management practices to promote safety and mobility in nighttime and daytime work zones; and to identify and develop recommendations to improve the data collected, archived, and analyzed regarding work zone traffic crashes. Based on analysis of data from five states (New York, California, North Carolina, Ohio, and Washington), the key findings from this research are summarized in the section that follows.

Findings

Nighttime and Daytime Work Zone Effects on Crashes and Worker Accidents

Overall, working at night does not result in significantly greater crash risk for an individual motorist traveling through the work zone than does working during the day. When work activity is occurring and travel lanes are temporarily closed, the risk of a crash for an individual motorist traveling through the work zone increased by about 66 percent during the day and by 61 percent at night, compared to the expected crash risk that would normally exist at a particular location. The actual change in crash risk varied substantially between projects examined in this research, even when stratified on the basis of time period (daytime or nighttime) and work condition (no work activity, active work without lane closures, or active work with lane closures). Crash risks increased on some projects and decreased on others, compared to the expected values. Furthermore, no relationship existed between the change in individual motorist crash risk and roadway AADT.

Crashes that occur in nighttime work zones are not necessarily more severe than those that occur in similar daytime work zones. For each of the work conditions examined, the increases in crash risk are higher for the PDO crashes than for injury and fatal crashes, indicating that the additional crashes that occur in work zones tend to be less severe in nature. This trend exists regardless of whether the work is performed during the day or at night. The only exception to this finding was for intrusion crashes extracted from the NYSDOT database. In that particular subset of the data, intrusion crashes during nighttime work operations involved a higher percentage of injury and fatal crashes than did intrusion crashes during daytime work operations. Not all injuries or fatalities in either time period involved highway workers; many were drivers and passengers of the intruding vehicles.

Although the increased risk of a crash is similar, differences do exist in the types of crashes that occur at nighttime and daytime work zones. For example, based on the NYSDOT work zone traffic crash and worker accident database, those traffic crashes involving workers, construction vehicles or equipment, and construction materials and debris (both intrusion and non-intrusion crashes) comprise a greater percentage of crashes at night than during the day. Furthermore, intrusion crashes involving workers are also a higher percentage of crashes at night than during the day. However, they are only a small proportion of the total work zone crash experience in either time period.

Nighttime and daytime work zones also affect rear-end traffic crash percentages differently. Although the percent of crashes involving rear-end collisions typically increases as a function of AADT in both daytime and nighttime periods, the percentages are substantially lower in the nighttime periods. Furthermore, the percentage of rear-end collisions increases noticeably during daytime work activity on low- to moderate-volume roadways, but this is not so on higher-volume roadways. At night, rear-end collision percentages increased during work activity across the entire range of roadway AADTs. The effect is somewhat greater when temporary lane closures are in place than when they are not, consistent with expectations.

For work activities that require temporary lane closures, the total safety impacts to the motoring public are less if the work is done at night. Active work zones result in additional crash costs regardless of whether the work is performed during the day or at night. However, the amount of the increase is less if the work is done at night. This benefit of working at night, compared to doing the work during the day, extends across all AADTs, but it becomes much larger at higher AADTs.

The severity of worker construction accidents is the same when working at night or during the day. The available data regarding worker accidents did not allow a determination to be made as to whether such accidents are more frequent at night. However, the data do show that the accidents that do occur are no more severe at night than they are when they occur during the day.

Management Policies, Procedures, and Practices to Improve Nighttime and Daytime Work Zone Safety

Several strategies have the potential to substantially lower the increased crash costs resulting from work zones. Strategies that appear to offer the greatest potential for crash cost reduction include the following:

- Practices to reduce the number and duration of work zones required;
- Use of full directional roadway closures via median crossovers or detours onto adjacent frontage roads;
- Use of time-related contract provisions to reduce construction duration;
- Moving appropriate work activities (i.e., those that require temporary lane closures) to nighttime hours;
- Use of demand management programs to reduce volumes through work zones; and
- Use of enhanced traffic law enforcement.

Other strategies may offer moderate reductions in crash costs due to work zones, depending on conditions. Strategies that have been grouped into this category include the following:

- Designing adequate future work zone capacity into highways;
- Use of full roadway closures that require traffic detours onto adjacent surface streets;
- Use of ITS strategies to reduce congestion and improve safety;
- Improvement of work zone traffic control device visibility;
- Efforts to reduce flaggers' exposure to traffic; and
- Efforts to reduce workspace intrusions and their consequences—primarily at long-term, high-volume work zones.

Work Zone Crash Data Elements, Collection and Storage Techniques, and Analysis Methods

A need exists for both a state crash report form that includes the recommended MMUCC data elements and highway-agency-collected data elements for work zone crash analysis. Both approaches to obtaining work zone crash information have their advantages and disadvantages. The large amount of data that police officers investigating a crash must collect on the state crash reporting form limits how much specific detail about work zones can be included. In addition, certain types of technical data (type of devices in use, work zone design features in place, etc.) cannot be effectively judged by police personnel who do not have this level of engineering expertise. Collection of this type of data by highway agency personnel is more appropriate. In addition, details about industrial accidents in the work area, something that is not typically investigated via police crash reporting, can be better collected directly by the highway agency. The main drawback to highway agency collection of crash data is that it may miss those crashes and accidents that occur when project staff are not onsite when the event occurs (weekends, rain days, periods of work inactivity, etc.).

The crash report form data elements currently recommended in the MMUCC guideline provide a good starting point for establishing quality data on work zone crashes. Many of the recommended data elements provide information that can be useful in assessing how work zones are affecting safety at both a project and process (regional or agency-wide) level. Some minor adjustments in several of the MMUCC data elements (changes to specific code descriptions and introduction of an additional work-zone-specific code) could further enhance the quality and quantity of crash data available to assess work zone impacts on traffic safety.

Exposure data at work zones are particularly needed to improve process-level work zone crash analysis. Hours of activity (with and without lane closures or other capacity restrictions), traffic volumes, etc. are needed to allow consolidation across multiple work zones, to facilitate the computation of current benchmarks, to track safety performance against those benchmarks over time, and to allow possible comparison across regions and states.

Work zone crash analysis procedures should include both monitoring and post-hoc analysis components. Monitoring procedures require quick access to crash data (the Ohio DOT manually collects hard-copy crash reports from law enforcement offices on a regular basis during a significant project) and a simple method of determining whether certain roadway segments or time periods in the project timeline are resulting in exceptionally more crashes than would be expected. These assessments serve as flags that the agency may need to evaluate certain aspects of the work zone more closely. However, the more subtle effects of particular work zone design decisions or operating strategies can only be assessed through a more rigorous analysis across multiple projects and longer exposure periods, typically after the projects have been completed.

Recommendations

The results of this research have led to a number of recommendations that agencies should consider as they strive to improve work zone safety in their jurisdictions. In addition, a number of questions raised in this report have generated recommendations for future research that should be considered as well. These are enumerated below:

- At a minimum, agencies should evaluate their current policies and procedures to encourage consideration of the following strategies during design and implementation of work zones in their jurisdiction:
  - Practices to reduce work zone duration and number of work zones required;
  - Use of full directional roadway closures via median crossovers or detours onto adjacent frontage roads;
  - Use of time-related contract provisions to reduce construction duration;
  - Moving appropriate work activities (i.e., those that require temporary lane closures) to nighttime hours, especially on high-volume roadways;
  - Use of demand management programs to reduce volumes through work zones;
  - Use of enhanced traffic law enforcement;
  - Consideration of incorporating future work zone capacity into highway designs;
  - Use of full roadway closures that require traffic detours onto adjacent surface streets, where adequate capacity is available on alternative routes;
  - Use of ITS strategies to reduce congestion and improve safety;
  - Improvement of work zone traffic control device visibility;
  - Efforts to reduce flaggers' exposure to traffic; and
  - Efforts to reduce workspace intrusions and limit their consequences at long-term, high-volume work zones.
- Agencies should consider establishing their own data collection, archival, and analysis procedures for work zone crashes. The specific data elements to collect and the methods used to collect those data will depend on what other data elements are already being collected through the state crash report form. Crash report forms that have most or all of the MMUCC data elements that were recommended for work zones in Chapter 5 may require agencies to collect only a few additional items in the event of a work zone crash. Crash report forms that do not include most of the key data elements identified will necessitate the collection of more of the data by the highway agency. In either case, it is important that both sources of data be accessible on a crash-by-crash basis to facilitate subsequent analysis.
- For significant projects, agencies should consider establishing procedures to monitor crashes occurring during construction in a way that allows agency personnel to quickly ascertain whether an excessive number of crashes are occurring at specific locations or during certain times within the project.
- This research suggests that intrusion crashes, especially those that involve highway workers, are a relatively small subset of work zone crashes. However, when they do occur, they are more likely to result in injuries and fatalities to motorists, passengers, and/or highway workers. Additional research is recommended to further define the significance of the work zone intrusion crash problem and to conduct studies to determine the extent to which various proposed countermeasures reduce such intrusions.
- Finally, this research has yielded a rich multi-state database of work zone, roadway, and crash data. Although extensive analyses of that dataset were performed as part of this research, there are likely many other questions about work zone crash safety that could be examined using these data. It is recommended that steps be taken to make these data available to other researchers or students looking for research topics related to work zone safety issues.

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Appendixes A, B, C, and F

Unpublished Material

Appendixes A, B, C, and F contained in the research agency's final report are not published herein. Copies are available on the TRB website. The appendices are titled as follows:

Appendix A: Data Collection, Reduction, and Analysis in California, North Carolina, Ohio, and Washington
Appendix B: EB Crash Analysis
Appendix C: MMUCC Guideline Data Elements
Appendix F: NYSDOT Accident Reporting Program – Data Elements and Attributes

APPENDIX D

Suggested Revisions to MMUCC Guideline Definitions

Revisions to Existing Definitions

Activity Area—currently defined as "Located adjacent to actual work area, whether workers and equipment were present or not." This definition is inconsistent with the definition in the MUTCD and with the Diagram in appendix L of the Guideline. This definition should be made consistent with the MUTCD by changing it to "the part of the work zone where the work takes place. It includes the traffic space, work space, and buffer spaces."

Advance Warning Area—currently defined as "Located after the first warning sign but before the work area." This definition is also with the MUTCD and appendix L, and should be revised to "From the first warning sign to the start of the transition area."

Concrete Traffic Barrier—currently defined as "A type of permanent median made of concrete that is usually fixed but sometimes can be moved by special equipment to shift lane direction." This definition is inconsistent with highway terminology, and is incorrect in that this feature is a traffic barrier, not a median. The suggested revised definition would read "a type of permanent traffic barrier made of concrete that is located in a highway median or on the roadside. Although usually fixed in place, some versions on this barrier can be quickly moved from side-to-side by a special machine to open and close lanes." It is suggested that the term itself be revised to "Concrete Traffic Barrier—Permanent" to distinguish from the two new terms "***temporary work zone concrete barrier-non-moveable***" and "***temporary work zone concrete barrier-moveable***" defined below.

Crossover—the current definition "Area where motor vehicles are permitted to travel across the opposing lanes of traffic or do a U-turn" is potentially confusing, especially in work zones, because it seems to include intersections. The term crossover has a very specific meaning in WZs, and this term should be revised to read "Area in the median of a divided trafficway provided to enable vehicles to do a U-turn, or a work zone type with a connection between the two roadways of a divided highway where vehicles are diverted from one roadway onto the other, such that both directions of travel use a single roadway."

Flagger—the current definition "Traffic control person controlling traffic with a flag applicable to the motor vehicle at the crash location" is incomplete in that the required device is now a stop-slow paddle, with a flag used for only limited situations. The definition should be revised to read "Traffic control person controlling traffic with a stop-slow paddle or flag applicable to the motor vehicle at the crash location."

Helmet—the current definition "Safety helmet worn by non-motorist (bicyclist) or driver (motorcyclist)" should be expanded to read "Safety helmet worn by non-motorist (bicyclist) or driver (motorcyclist) or a protective hardhat worn by a worker." The term itself should be changed to "Helmet or Hardhat."

Impact Attenuator/Crash Cushion—the current definition is "A barrier at a spot location, less than 25 ft. (7.6 m) away, designed to prevent an errant motor vehicle from impacting a fixed object/hazard by gradually decelerating the motor vehicle to a safe stop or by redirecting the motor vehicle away from the hazard." This term should be revised to "Impact Attenuator/Crash Cushion – Permanent" and its definition changed to "A barrier permanently fixed at a spot location, less than 25 ft. (7.6 m) away, designed to prevent an errant motor vehicle from impacting a fixed object/hazard by gradually decelerating the motor vehicle to a safe stop or by redirecting the motor vehicle away from the hazard." A new term for "**Impact Attenuator/Crash Cushion—Work Zone**" is defined below.

Intermittent or Moving Work—currently defined as "Type of work zone." This definition is too brief, and in incomplete. A suggested revised definition is "Type of work zone that moves intermittently or continuous along a highway, and remains in one location for no more than a few minutes."

Lane Closure—the current definition "Type of work zone" should be expanded to read "Type of work zone in which one or more travel lanes are closed to traffic, with traffic moved into the remaining open lanes, thus resulting in a reduction in the total number of lanes available for travel."

Lane Shift/Crossover—the current definition of "Type of work zone" is incomplete, and is inconsistent with the suggested revised definition for crossover provided above. It is recommended that this term be shortened to "lane shift" and that the definition be revised to "a traffic lane is moved laterally in either direction, but the total number of lanes is not reduced.

Non-Highway Work—the existing definition "Maintenance or other types of work occurring near or in the trafficway but not related to the trafficway" does not clearly explain what should be included under this category. It appears it is intended to identify work on utility infrastructure such as overhead transmission lines. It could also include work on property adjacent to a highway, such as building repair or demolition, which requires closing or shifting a sidewalk, shoulder, or even a travel lane. It is not clear whether an excavation or similar work within the roadway to install or repair an underground facility would be categorized as Non-Highway Work. A related major concern is that the law enforcement officer that enters this information may not be able to determine whether the activity necessitating a work zone is Highway Work or Non-Highway Work. This attribute is included in data element C15. "Contributing Circumstances, Road," but its purpose is unclear. It is recommended that definition should be re-examined in the planned next edition of the guideline.

Stop Signs—the current definition reads "A six-sided red sign with "STOP" on it, requiring motor vehicles to come to a full stop and look for on-coming traffic before proceeding with caution." Stop signs are required by the MUTCD to include eight sides, and this definition should be revised accordingly.

Transition Area—the current definition "Where lanes are shifted or tapered for lane closure" is incorrect in that the transition area includes any change in the normal traffic pattern, not just lane closures or shifts." It should be revised to read "That part of a work zone located prior to the Activity Area where traffic is moved out of its normal path, such as at a lane closure, lane shift, lane width reduction or median crossover."

Work on Shoulder or Median—the current definition "Type of work zone" should be redefined for clarity to read "Type of work zone in which the activity takes place on a shoulder or median, but not in a travel lane, and no travel lanes are disrupted."

Work Zone/Maintenance Equipment—It was suggested in the discussion of attribute revisions that this term be revised to include equipment and vehicles. Accordingly, the current definition "Equipment related to the work zone or roadway maintenance" should be revised to read "Equipment or vehicles related to the work zone or roadway construction, maintenance, or utility work."

Suggested Additional Definitions

Activity area—the part of the work zone where the work takes place. It includes the work space as well as the traffic space and any buffer spaces.

Buffer Space—Area within the activity area provided for the protection of traffic and workers by providing room for an errant vehicle to stop or to return to the traffic space.

Impact Attenuator/Crash Cushion—Work Zone—A barrier temporarily placed at a spot location in a work zone, less than 25 ft. (7.6 m) away, designed to prevent an errant motor vehicle from impacting a fixed object/hazard by gradually decelerating the motor vehicle to a safe stop or by redirecting the motor vehicle away from the hazard."

Temporary Work Zone Concrete Barrier—Moveable—similar to **Temporary Work Zone Concrete Barrier—Non-Moveable, except** it can be quickly moved from side-to-side by a special machine to open and close lanes.

Temporary Work Zone Concrete Barrier—Non-Moveable—a type of traffic barrier made of concrete that is located in a highway median or roadside in a work zone. This barrier consists of individual sections that are set in place and pinned together. This barrier can be relocated within the work zone, and is removed at the completion of the work.

Traffic Space—the part of the activity area available for the use of traffic (vehicles, pedestrian, bicycles) to pass through the activity area.

Work Space—the part of the activity area set aside for workers, equipment, and material storage. The work space is typically marked by traffic cones, drums or similar devices or by the presence of work vehicles.

Work Space Intrusion—A vehicle traveling through a work zone enters the work space and collides with a worker, work zone/maintenance equipment or vehicle, or another work zone feature such as an excavation of material stockpile.

APPENDIX E

Florida, Louisiana, and Maryland Agency Work Zone Crash Reporting Forms

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

**ENGINEER'S MAINTENANCE OF TRAFFIC (MOT)
EVALUATION AT CRASH SITE**

700-010-64
CONSTRUCTION
08/04
Page 1 of 3

Date/Time of Occurrence: ____________ Report Date: ____________

FIN Project No.: ____________ State Road No.: ____________ District: ____________

Federal Project No.: ____________ County: ____________

Contract No.: ____________ WPI No.: ____________

MOT Evaluation at Crash Site:

Have there been other crashes in the same vicinity of the work zone?

○ YES ○ NO

If yes, give dates. ____________

Police Investigated? ○ YES ○ NO

If available, attach police report.

Work Zone Location of Crash:
(Approach, transition, work area) ____________

Is the immediate area at the crash site in accordance with State Standards, MUTCD and TCP? ○ YES ○ NO

Are there any recommended enhancements to the MOT at the crash site?

○ YES ○ NO

List enhancements to be made to the work site. ____________

____

____

____

____

Distribution: Original to Project Administrator
Copies to: District Safety Engineer
Contractor
State Construction Office (MS 31)
State Safety Office (MS 53)

Florida DOT Crash Report Form.

700-010-64
CONSTRUCTION
08/04
Page 2 of 3

DIAGRAM:

Crash Diagram including all traffic control devices present at the time of crash, vehicles involved, etc.

In addition to the above diagram, if the traffic control plan in effect follows guidelines of MUTCD, Part VI, indicate figure number, standard index sheet number, or plan sheet.

+ INDICATE NORTH

∀	Sign with flag & light
V	Sign on Portable or Permanent Support
[	Vertical Panel
I	Barricade
©	Cone
●	Drum
▶	Flagger

ANALYSIS OF CONDITIONS: if known

Pavement:	Visibility:	Routing:
☐ Wet	☐ Clear	☐ Existing Pavement
☐ Dry	☐ Limited	☐ Detour
☐ Asphalt	☐ Night (darkness)	☐ Approach to Construction
☐ Concrete	☐ Day (daylight)	
☐ Other		

Type of Project:

- ☐ Resurfacing Undivided Median
- ☐ Resurfacing Divided Median
- ☐ Widening Undivided Median
- ☐ Reconstruction Undivided Median, Rural
- ☐ Reconstruction Divided Median, Rural
- ☐ Widening Undivided to Divided
- ☐ Reconstruction Undivided Median, Urban
- ☐ Reconstruction Divided Median, Urban
- ☐ New Construction, Undivided Median
- ☐ New Construction, Divided Median
- ☐ Intersection
- ☐ Other (Describe) ____________________

______________________________ Telephone Number (daytime)

______________________________ Signature of Project Administrator

Florida DOT Crash Report Form, continued.

DOTD BUILDS THE WAY

WORK ZONE CRASH/FATALITY SHEET

PROJECT NUMBER:____________________DATE OF CRASH/FATALITY:_________________

PROJECT NAME:____

PARISH: ______________________________ ROUTE:_________________

LOG MILE OF COLLISION:_________________ LENGTH OF PROJECT:_________________

NUMBER OF INJURIES: ___ Ô const. worker Ô driver/passenger Ô pedestrian Ô bicyclist Ô other
NUMBER OF FATALITIES: ___ Ô const. worker Ô driver/passenger Ô pedestrian Ô bicyclist Ô other

NUMBER OF VEHICLES INVOLVED: ______ Pictures: Ô yes Ô no
(non-digital only)

NARRATIVE: (Please list all Work Zone devices 1 mile in each direction)

Investigating Agency:____

P.E. Name:________________________ **P.E. Signature:**______________________________

Project Engineer
Original

Highway Safety Section 82
Fax Copy: 225-242-4552

Louisiana DOTD Crash Report Form.

SHA Maryland SHA Work Zone Accident/Incident Report

A. Accident Report ☐

Incident Report: ☐

(An event that results in damage to traffic control devices or barrier, crash cushion, pavement, etc. {ex.: tire marks on barrier, skid marks on pavement, broken headlights/taillights, etc.})

MAARS Report Number (Preprinted on Police Report)

Contract Number

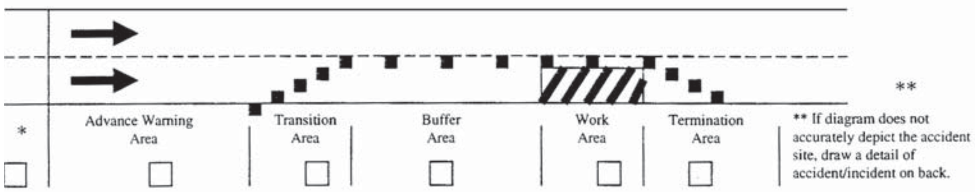
Acct/Incid Date

B. ________ County ________ Route ________ Location (Intersecting Road etc.)

Acct/Incid Time ________ ☐ Non Work Hours ________ Weather

C. Accident/Incident Severity ☐ Fatal ☐ Injury ☐ Property Damage ☐ Unknown

D. Location of Accident/Incident Check all that apply: ☐ Non-Intersection ☐ Intersection ☐ Accel/Decel Lane ☐ Ramp



E. Traffic Control in Use
- ☐ Right Lane Closure
- ☐ Left Lane Closure
- ☐ Center Lane Closure
- ☐ Shoulder Work/Closure
- ☐ Lane or Roadway Shift
- ☐ Lanes Divide
- ☐ Flagging Operation
  - ☐ Intersection
- ☐ Detour/Road Closure
- ☐ Exit/Entrance Ramp
- ☐ Traffic Markings in Use
  - ☐ Lane Lines ☐ Edge Lines
  - ☐ Centerline
- ☐ Mobile
  - ☐ Less than 15 min/slow
  - ☐ Moving normal
  - ☐ Mowing
  - ☐ Marking
- ☐ Other ________

F. Type of Accident/Incident
- ☐ Rear End
- ☐ Sideswipe
- ☐ Turning
- ☐ Head-on
- ☐ Run-off-Road/Drop-off
- ☐ Fixed Object
  - ☐ Barrier Tangent
  - ☐ Barrier Flare
  - ☐ Barrier End Treatment (crash cushion)
  - ☐ Channelizing Devices
  - ☐ Sign/Sign Support
  - ☐ Arrow Panel/VMS
  - ☐ Work Vehicle/Equipment
- ☐ Other ________

G. Road Geometrics
- ☐ Straight & Level
- ☐ Horizontal Curve
- ☐ Vertical Curve
- ☐ Combination of Above Curves

H. Speed Limit MPH
- ___ Prior to Work
- ___ During Work

Mail to:
1) Office of Traffic & Safety
TDSD RM 150
Hanover Complex
2) Asst. District Engineer-Traffic

Name (Person Completing Report) ________ Date ________

Title ________ Phone Number ________

* An accident/incident which may occur **before** the advance warning area should be noted.

SHA 52.4 Revised 9/29/99

Maryland SHA Crash Report Form.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation