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16. Abstract

Researchers present a summary of the extent and type of nighttime work zone activity that currently occurs in Texas; an analysis of Department of Public Safety (DPS) crash data to assess the ramifications of night work on crash experiences; and an assessment of differences in operational characteristics of traffic at nighttime and daytime work zones.

Researchers found that the amount of active night work occurring in the districts correlates well with the overall traffic demands (expressed as total vehicle-miles-traveled per lane-mile of responsibility) in the district. Once district-wide demands reach 2000 vehicle-miles-traveled per lane-mile, active night work begins to take on a greater role in the district. However, researchers did not find a significantly greater propensity for night work zone crashes or for more severe nighttime crashes in those districts with significant amounts of night work. Researchers did find that crashes on nights with work activity were slightly more frequent, in general, than those during nights of inactivity or during daytime periods. Projects that were believed to have experienced significant levels of traffic queuing at night when lane closures were instituted appeared to experience the greatest increase in crashes. Additional analysis and findings are also presented in the report.

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ASSESSING THE SAFETY IMPACTS OF ACTIVE NIGHT WORK ZONES IN TEXAS

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INTRODUCTION

STATEMENT OF THE PROBLEM

Nationally, the practice of performing some work zone activities at night has been around since at least the 1960s (*1*). As is the case today, early attempts at night work were initiated because officials considered it impractical to close traffic lanes on certain high-volume roadways during normal daylight hours. Early experiences indicated to practitioners that the concept did indeed reduce the impact of work on the traveling public. Furthermore, lower traffic volumes meant fewer conflicts between traffic and construction vehicles, making it easier to get materials to and from the work site (*1*).

One of the questions that commonly arises when the potential for night work is discussed is whether doing so adversely affects the quality and quantity of work performed. Studies of this particular issue have found that it is possible to achieve levels of work quality and productivity at night comparable to daytime conditions (*1-4*). In fact, increased production effectiveness may actually occur in some instances because of easier construction vehicle access to the work site with deliveries (as noted above). A few studies have mentioned that problems can occur with both productivity and quality at night work zones. However, these problems appear to be related to project-specific factors and are not necessarily a function of working at night (*5*).

Although it appears that night work productivity and quality can be comparable to daytime work, evidence is less supportive of night work in other areas. For example, one concern that commonly arises when discussing the appropriateness of doing highway work at night is the effect that the practice has on the workers themselves. Studies of shift workers in non-work zone environments strongly suggest that night work increases the amount of stress placed on the body, negatively affects the amount and quality of sleep that workers obtain, and can significantly alter physiological characteristics such as appetite (*6*). In addition to physiological impacts, night work also tends to adversely affect the social and domestic aspects of a worker's life (*4*). Perhaps more importantly, it has been shown that shift work in general can also impair overall worker alertness, reaction times, and even motor skills (*7*). This is not to say that all practitioners believe that night work is more dangerous for their personnel than daytime work. For example, perceptions of selected state department of transportation officials, highway contractors, and resident project engineers regarding night work were assessed through a rating process. Overall, those surveyed did not rate project safety as being significantly impacted by whether work is done at night (*5*).

Assessments of the implications of night work activity upon traffic safety are even more difficult to come by in the literature. In several studies, researchers investigated the effects of work zones on nighttime crashes. Some of these concluded that nighttime crashes increase substantially in work zones (*8-10*), whereas other studies concluded the opposite (*11-13*). This inconsistency is not unexpected, since information regarding whether a work zone is currently active at the time of a nighttime crash is not recorded on most crash report forms. Consequently, the effects of actual night work in existing crash databases confound with crashes that occur at work zones that are inactive during the nighttime hours.

One study, performed on several construction projects in California in the 1980s, concluded that the nighttime crash rate on those sections of roadway where work activity was being performed increased 87 percent over the normal nighttime crash rates at those locations (*14*). Also, the data suggested that the crash rate during nights when lane closures were required was 75 percent higher than during nights of activity when no lane closures were required. Another study of night work lane closures in Virginia replicated this finding (*15*). Even though the crash rates during night work increased substantially, the California researchers noted that the overall frequency of crashes at night might still have been lower than would have been expected if the work had been performed during the day, due to the much higher vehicle exposure levels present during the day (*14*).

Certainly, making the decision to perform highway work at night requires the consideration of a number of interrelated factors. In essence, the benefits of doing road work at night (reduced congestion, cooler temperatures, longer allowable work "windows," etc.) need to be balanced against the additional costs and consequences of doing so (more difficult material supply logistics, additional traffic control costs, noise, safety and health concerns, etc.). Researchers have proposed a few methodologies in recent years to systematically assess the feasibility of doing highway work at night (*5,16,17*).

One of the limitations of these analysis methodologies, however, is in accurately capturing the true safety consequences of doing work at night. Currently, these methodologies either ignore the safety differences between working at day and at night or address both traffic crashes (accidents) and construction accidents only through a relative rating scheme (*18*).

Consequently, practitioners must currently rely on personal perceptions and intuition to rate the safety implications of night work as well as to weight the relative importance of safety to the other factors that must be considered in the night work decision. As noted above, such perceptions can vary widely and may not reflect the actual effects that night work has on safety. Obviously, better guidance on how to properly assess the safety consequences (or relative risk) of night work activity would be extremely valuable in this or similar assessment procedures by bringing objectivity and balance into the overall assessment procedure.

PROJECT OBJECTIVES

The objectives of this research project are twofold:

- develop objective, quantified estimates of risk experienced by workers and the motoring public during various types of nighttime work activities in Texas; and
- develop cost-effectiveness estimates of countermeasures to address the major factors that contribute to increased safety risk in nighttime work zones.

This report documents the results of research efforts that address the first objective. Specifically, the report contains a summary of the extent and type of nighttime work zone activity that currently goes on in Texas; an analysis of Department of Public Safety (DPS) crash data to assess the ramifications of night work on crash experiences; and an assessment of differences in operational characteristics of traffic at nighttime and daytime work zones.

EXTENT OF NIGHT WORK ACTIVITY IN TEXAS

One of the first tasks undertaken by the Texas Transportation Institute (TTI) research team was to assess the amount and characteristics of night work activity that currently occurs in Texas. Contractors and TxDOT employees are doing significantly more night work in recent years due to increasing traffic congestion levels, to the point that it is quite commonplace (and necessary) in most of the larger urban districts. The practice is also becoming more common in medium-sized urban areas. This chapter describes the results of two assessment efforts:

- a survey of night work practices and procedures in each of the 25 Texas Department of Transportation (TxDOT) districts, and
- an analysis to quantify the amount and types of night work activities that occur in three of the districts that report regularly performing such night work.

The authors summarize the results of these efforts below.

DISTRICT SURVEYS

Purpose and Methodology

TTI researchers conducted a survey of the TxDOT districts to determine the following:

- the amount of night work that takes place in each district,
- policies and practices implemented by the districts that affect the amount of night work taking place,
- the types of work activities completed during night work, and
- difficulties encountered with respect to night work and methods currently used to address those difficulties.

Researchers spoke to construction, maintenance, and/or traffic engineers in all 25 TxDOT districts.

Results

Amount of Night Work

The amount of night work performed in the 25 TxDOT districts varies, with some districts utilizing night work more than once a week and others only using night work in emergency situations. Table 1 shows the amount of night work occurring in each district according to three categories: significant (28 percent of the districts), occasional (36 percent of the districts), and rare-to-never (36 percent of the districts). In general, the seven districts in major urban areas experience a significant amount of night work.

Because of the high traffic volumes, these districts have implemented guidelines that restrict the closure of active travel lanes during the day, which in turn encourages night work. A summary of these district guidelines is located in Table 2. In general, the Austin, Houston, and Waco Districts do not allow daytime lane closures on major roadways (e.g., interstates). In addition, the Houston District allows only one lane to be closed during the day on roadways with volumes that exceed approximately 1700 vehicles per lane per hour (vplph). The Dallas, El Paso, Fort Worth, and San Antonio Districts daytime lane closure restrictions are based on time of day. In general, these districts do not allow daytime lane closures on major roadways during peak times. Some of the differences in the time of day restrictions are as follows:

- Dallas, El Paso, and San Antonio Districts restrict the number of lanes that can be closed during the daytime off-peak times.
- Dallas and San Antonio Districts also restrict the number of the freeway lanes that can be closed at night.
- Fort Worth District uses lane rental fees during off-peak times.

In contrast to the districts that utilize a significant amount of night work, those districts that use night work only occasionally or rarely comprise smaller urban or rural areas that have roadways with lower traffic volumes. Generally speaking, most of these districts determine on a case-by-case basis whether night work will be needed on a project. In addition to TxDOT construction or maintenance activities, utility companies occasionally perform night work on state-maintained roadways. These companies usually coordinate activities with TxDOT on a case-by-case basis.

Table 1. Amount of Night Work by District.

District	Daily VMT/ Lane-Mile	Significant	Occasional	Rare/Never
Abilene	811		X	
Amarillo	944		X	
Atlanta	1606			X
Austin	3543	X		
Beaumont	2576		X	
Brownwood	687			X
Bryan	1844		X	
Childress	457			X
Corpus Christi	1872		X	
Dallas	6133	X		
El Paso	2258	X		
Fort Worth	4412	X		
Houston	8047	X		
Laredo	1063		X	
Lubbock	752			X
Lufkin	1306		X	
Odessa	853			X
Paris	1429			X
Pharr	3029		X	
San Angelo	629			X
San Antonio	3475	X		
Tyler	1857			X
Waco	2123	X		
Wichita Falls	1015		X	
Yoakum	1457			X

VMT = vehicle-miles-traveled.
Significant – more than once a week.
Occasional – less than once a week but more than twice a year.
Rare/Never – emergency only or less than twice a year.

Table 2. Summary of Lane Closure Guidelines Provided by Districts That Conduct a Significant Amount of Night Work.

District	Daytime Lane Closure Policy [a]	Nighttime Lane Closure Policy
Austin	No lane closures on interstates and some major arterials.	None.
Dallas [b]	No lane closures on freeways during peak times (6:00 am to 9:00 am, 3:30 pm to 7:00 pm, and event times). Restrictions on the number of freeway lanes that can be closed during off-peak times (9:00 am to 3:30 pm).	Restrictions on the number of freeway lanes that can be closed during off-peak times (7:00 pm to 10:30 pm) and lowest volume times (10:30 pm to 6:00 am).
El Paso	No lane closures within the city limits on interstates and major arterials with an ADT greater than 20,000 during peak times (6:00 am to 9:00 am and 3:00 pm to 6:00 pm). Allows for one lane to be closed on these roadways during off-peak times (9:00 am to 3:00 pm).	None.
Fort Worth	No lane closures on major interstates during peak times (6:00 am to 9:00 am and 3:30 pm to 6 pm). [c] Use lane rental fees during off-peak times. These fees are established on a project by project basis.	Use lane rental fees during off-peak times. These fees are established on a project by project basis.
Houston	No lane closures on major freeways. For other roadways, if the volumes exceed approximately 1700 vehicles per lane per hour (vplph) then only allow one lane to be closed.	None.
San Antonio [d]	Restrictions on the number of main lanes that can be closed on freeways inside Loop 1604 (times vary by roadway).	Restrictions on the number of main lanes that can be closed on freeways inside Loop 1604 (times vary by roadway).
Waco	No lane closures on I-35.	None.

ADT = Average Daily Traffic

a Generally applies to Monday through Friday.

b A copy of the Dallas District policy is located in the Appendix.

c Times may vary depending on the project.

d A section of the San Antonio District policy is located in the Appendix.

Types of Work Activities Completed during Night Work

Interstates and major urban arterials (e.g., state highways, U.S. highways, and farm-to-market [FM] roads) experience most of the night work, since these facilities have high traffic volumes. The majority of the work activities completed at night include:

- elevated structure repair or demolition,
- concrete pours,
- paving, and
- striping.

Demolishing elevated structures, such as bridges and overpasses, and diverting traffic onto another roadway typically requires night work when traffic volumes are lower. Repair to elevated structures is also a common night work activity, since it usually involves the work being completed over active traffic lanes. Concrete pours take place at night, especially during the summer, because the ambient temperature gets too hot during the day. Paving operations, such as milling, sealcoat, and overlay, typically require lane closures; thus, these operations are also done at night to reduce their impact on traffic. Similarly, striping operations take place at night in urban areas, since these slow-moving operations reduce the flow of traffic.

Difficulties Encountered during Night Work

District personnel reported the following difficulties encountered with respect to night work:

- quality of work,
- availability of manpower,
- access to materials, and
- safety issues.

The main concern expressed by the districts was a reduction in the quality of work at night because of the low-visibility conditions. The availability of TxDOT employees for night shifts was another concern. Reasons cited include a lack of personnel, a lack of funds to pay overtime, and not having an assigned night shift (i.e., employees must switch back and forth between day and night work). In addition, TxDOT inspectors that work at night do not have access to other personnel when problems arise and have a more difficult time getting lab work completed. Access to materials, such as concrete, asphalt, and equipment parts, is another difficulty associated with night work, since most plants and repair shops are not open at night. The districts also expressed their concern with the following safety issues: impaired drivers, higher speeds, and low driver expectancy of a nighttime work zone.

As a final area of assessment, researchers asked district personnel about the methods currently being used to address the difficulties discussed above. Responses included the following:

- adding more lighting or completing night work where there is permanent illumination,
- using the most experienced inspectors on night work so they can make decisions without assistance,
- utilizing a contractor that also owns a hot-mix plant, and
- utilizing police officers to alert drivers.

ASSESSMENT OF NIGHT WORK ACTIVITY IN DISTRICTS

Purpose and Methodology

The next part of the night work inventory effort undertaken by TTI researchers was to attempt to quantify night work activity levels in three selected TxDOT districts that reported performing a significant amount of night work activity. The purpose of obtaining detailed night work activity information was to develop a night work exposure estimate to use later in the research project in conjunction with crash and observational data in developing estimates of safety risk associated with night work activities. This effort was also useful in ascertaining relative differences in activity levels and other characteristics among the various "significant night work" districts. Researchers placed particular emphasis on assessing the implication of these activities on traffic operations and work crew exposure. The districts investigated were:

- Austin,
- Houston, and
- Waco.

Researchers contacted construction and maintenance personnel in each district to identify construction and maintenance contracts that had involved (or were currently involving) night work activities between June 2002 and May 2003. Researchers also determined the total number of contracts under way in each district during that time period as a way of assessing the percent that involved night work. For each contract involving night work activities, researchers inspected the daily project diaries, maintenance shop diaries, or the SiteManager™ project management software TxDOT has begun using, and determined which calendar dates involved night work. Other data obtained during the project diary reviews included the following:

- actual beginning and ending times of night work activity,
- number of travel lanes closed (and open, if available),
- length of lane closure,
- number of employees present,
- type of work being performed (generally), and
- number and type of equipment present.

Researchers divided the night work activities into five main categories:

- paving – milling, sealing, overlaying, concrete paving;
- traffic control – installation, switching traffic;
- bridge work – joints, bents, deck, demolition;
- striping – painting, rumble strips, raised pavement markers (RPM), sensors; and
- sign work – overhead sign bridges, lights.

Results

Extent of Nighttime Work

Overall, researchers identified and collected detailed diary data from 39 projects/ databases that involved some type of night work activity in the three districts during the June 2002 to May 2003 time period. During that same time, those three districts had a total of 280 projects with actual work activity occurring. Thus, approximately 16 percent of all projects in these districts involved night work. Approximately 23 percent of the projects in the Austin District, 12 percent of the projects in the Houston District, and 7 percent of the projects in the Waco District projects required night work.

Projects involving night work activity generally fall into one of two categories:

- projects that are performed almost exclusively at night (referred to herein as night-work-only projects), and
- projects that involve work activity off of the travel lanes during the day and on the travel lanes when necessary at night (referred to herein as hybrid projects).

As shown in Table 3, the projects split fairly evenly between these categories in the Waco and Austin Districts, whereas a greater percentage of hybrid projects occurred in the Houston District. Overall, researchers found 30 percent of night work projects to involve night work activity almost exclusively, with 70 percent of the night work projects being of the hybrid type.

Table 3. Distributions of Night-Work-Only and Hybrid Projects.

District	Percent of Night-Work-Only Projects	Percent of Hybrid Projects
Waco	50	50
Austin	50	50
Houston	19	81
Overall	30	70

Theoretically, hybrid projects could also involve some travel lane work during the daytime (i.e., a single lane closure during daylight hours and two or more lanes closed at night).

Although the researchers are aware that this type of hybrid does occur in other states and may also occur on occasion in Texas, none of the projects reviewed in this analysis were of that type.

Table 4 summarizes the total number of night work shifts that occurred in each district (for both night-work-only and hybrid projects) over the year-long time period of interest. As expected, the amount of night work activity in the Houston District far surpassed that of either the Waco or Austin Districts. Expressed another way, the Waco District experiences a night work zone approximately once every 4 or 5 days, whereas the Austin District experiences a night work zone nearly every day of the year. Meanwhile, the Houston District experiences, on average, about three night work zones each calendar day throughout the year.

Table 4. Extent of Night Work Activity.

District	Nights of Work Activity in One Year
Waco	78
Austin	281
Houston	1025

Researchers divided the number of nights of work activity by the total lane-miles in each district as a way to normalize the values. Then, researchers plotted these values against the vehicle-miles-traveled (VMT) in each district per lane-mile. Researchers found a generally increasing trend between these two variables, as shown in Figure 1. The values in Figure 1 imply that districts with less than an average of 2000 VMT per lane-mile of roadway responsibility typically do not require significant amounts of night work activity in their jurisdictions. Interestingly, this value correlates strongly with estimates of night work activity obtained during the district interviews, as illustrated in Table 1.

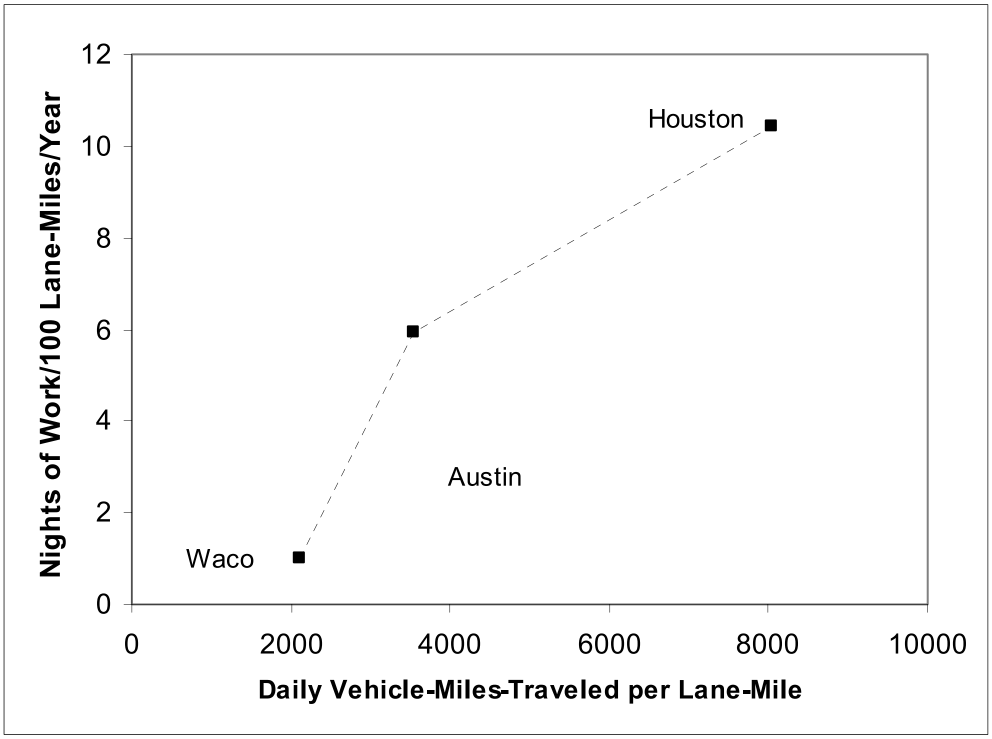

Figure 1. Night Work Activity as a Function of Average District Traffic Levels.

The relative distribution of night work among the various types of work activities is summarized in Table 5. Although some variability is evident, one sees general trends in the relative amount of work performed at night in each of the three districts investigated. Most of the projects and night work activity occurred in the Houston District. Consequently, the overall averages tend toward the Houston District values.

Table 5. Percent Distribution of Night Work Activities by Type of Work.

District	Traffic Control (%)	Sign Installation/ Maintenance (%)	Pavement Striping/ RPM Installation (%)	Paving (%)	Bridgework (%)
Waco	32	19	0	28	21
Austin	8	3	9	50	30
Houston	5	1	3	38	53
Overall	7	2	4	40	47

Physical Characteristics of Night Work Activity

TTI researchers collated information regarding both the number of lanes closed each night and the total length of lane closures installed for night activities for each project. Averages of both measures are presented by district in Tables 6 and 7. The Houston and Austin Districts involved a significantly greater percentage of multilane closures during night work activities than did the Waco District (see Table 6). Since both Houston and Austin contain a greater percentage of six-lane and wider roadway segments than does the Waco District, this finding was expected.

Table 6. Number of Travel Lanes Closed during Night Work by District.

District	Number of Lanes Closed		
	1	2	3+
Waco	72%	21%	7%
Austin	59%	39%	2%
Houston	39%	40%	29%

As further investigation into the implications of night work activities on roadway capacity, Table 7 presents the average number of lane-miles closed at each night work location by district and by type of work. The average lane-miles closed per night is fairly consistent between the Waco and Austin Districts but is about 25 percent greater (2.9 lane-miles versus 2.2 to 2.3 lane-miles) in the Houston District. Considering centerline-miles closed, however, indicates that the Houston District experienced slightly shorter closure lengths than the other two districts. Overall, pavement striping and RPM installation activities resulted in the greatest amount of lane-miles closed on average, whereas sign installation and maintenance activities required the least. However, one sees significant interaction between type of work, district, and the resulting average lane-miles closed per location for night work activities. For example, whereas bridgework activities in Waco and Austin involved fairly small lane closures (in terms of lane-miles), lane closures for this type of work in Houston were much greater. Houston has a significantly greater number of elevated freeway segments of greater lengths (as well as greater widths), and so any work activity (day or night) on those longer structures results in greater numbers of lane-miles closed during the work.

Table 7. Average Lane-Miles and Centerline-Miles Closed Per Night.

Type of Work	District			Overall
	Waco	Austin	Houston	
Traffic Control	3.1 L-mi 2.3 Cl-mi	2.5 L-mi 1.7 Cl-mi	3.1 L-mi 1.5 Cl-mi	3.0 L-mi 1.6 Cl-mi
Sign Work	1.9 L-mi 1.4 Cl-mi	1.9 L-mi 1.3 Cl-mi	0.8 L-mi 0.4 Cl-mi	1.7 L-mi 0.7 Cl-mi
Pavement Striping	---[a]	7.6 L-mi 5.3 Cl-mi	2.4 L-mi 1.2 Cl-mi	4.7 L-mi 2.1 Cl-mi
Paving	2.5 L-mi 1.9 Cl-mi	2.3 L-mi 1.6 Cl-mi	3.0 L-mi 1.5 Cl-mi	2.8 L-mi 1.5 Cl-mi
Bridgework	1.0 L-mi 0.7 Cl-mi	0.3 L-mi 0.2 Cl-mi	3.4 L-mi 1.7 Cl-mi	2.8 L-mi 1.3 Cl-mi
Overall	2.3 L-mi 1.7 Cl-mi	2.2 L-mi 1.5 Cl-mi	2.9 L-mi 1.4 Cl-mi	2.7 L-mi 1.4 Cl-mi

[a] none of the night work projects in this district involved this work activity.
L-mi = lane-miles.
Cl-mi = centerline-miles.

Workers and Equipment Used at Night Work Activities

TTI researchers also attempted to assess the level of worker and equipment activity associated with night work activities for use in assessing risk exposure levels in the later tasks of this project. Among the items of interest were average hours of work activity per night and density (number per lane-mile) of both workers and equipment utilized on night work projects.

Researchers found that the average duration of night work activities was fairly consistent across the districts and among the different types of work activities. On average, work activities lasted a typical 9 hours per night across the three districts, suggesting that worker shifts were normally of a standard duration. However, the distribution was highly skewed toward longer hours. In actuality, the lower traffic volumes associated with nighttime periods offered contractors the flexibility to extend work shifts if needed. For example, Table 8 summarizes the percent of night shifts in each district that lasted longer than 10 hours and those lasting longer than 12 hours per night.

Table 8. Percent of Extended Night Work Shifts by District.

District	Percent of Night Shifts Lasting:	
	10 hours or more	12 hours or more
Waco	34	19
Austin	46	3
Houston	56	9

A summary of the number of workers present on the various types of projects in each district is presented in Table 9. The units in Table 9 are both workers per lane-mile and workers per centerline-mile closed per night. In essence, these values serve both as a proxy for the level of work intensity occurring in those night work zones, as well as a proxy for the exposure levels of work personnel to the hazards of traffic moving nearby. In contrast to the Houston District, the lengths of bridgework projects in the Waco and Austin Districts were very short, resulting in much higher worker density values than those observed in Houston. The other types of work tended to be more consistent (in terms of worker density values) across the districts. Comparison of these values to those obtained in a recent national study of work zone exposure characteristics indicates that these exposure values are consistent with national trends (*18*).

Similar to Table 9, a summary of the density of work equipment deployed at each night work location by type of project and by district is shown in Table 10. Researchers observed moderate variations in equipment densities per lane-mile and per centerline-miles across the districts, and across the types of work activities performed. As researchers expected, some correlation is evident between the values in Tables 9 and 10, since each piece of equipment requires at least one worker to operate it.

Table 9. Average Number of Workers Present per Lane-Mile and Centerline-Mile Each Night.

Type of Work	Workers per Lane-Mile Closed			Overall
	Waco	Austin	Houston	
Traffic Control	6.0/L-mi 8.1/Cl-mi	6.9/L-mi 9.9/Cl-mi	5.3/L-mi 10.9/Cl-mi	5.8/L-mi 10.5/Cl-mi
Sign Work	0.5/L-mi 0.7/Cl-mi	4.2/L-mi 6.0/Cl-mi	12.1/L-mi 24.9/Cl-mi	4.1/L-mi 19.7/Cl-mi
Pavement Striping	---[a]	0.5/L-mi 0.7/Cl-mi	7.6/L-mi 15.7/Cl-mi	4.4/L-mi 12.4/Cl-mi
Paving	7.2/L-mi 9.7/Cl-mi	8.7/L-mi 12.4/Cl-mi	8.4/L-mi 17.3/Cl-mi	8.4/L-mi 15.9/Cl-mi
Bridgework	59.6/L-mi 80.5/Cl-mi	81.3/L-mi 116.3/Cl-mi	6.4/L-mi 13.2/Cl-mi	18.9/L-mi 37.9/Cl-mi
Overall	6.6/L-mi 8.9/Cl-mi	7.3/L-mi 10.4/Cl-mi	7.8/L-mi 16.1/Cl-mi	7.6/L-mi 14.5/Cl-mi

[a] no data were available for this type of work in this district.
L-mi = lane-miles.
Cl-mi = centerline-miles.

Table 10. Pieces of Equipment Present per Lane-Mile and Centerline-Mile Each Night.

Type of Work	Pieces of Equipment per Lane-Mile Closed			Overall
	Waco	Austin	Houston	
Traffic Control	5.2/L-mi 7.0/Cl-mi	4.8/L-mi 6.9/Cl-mi	6.5/L-mi 13.4/Cl-mi	5.8/L-mi 11.7/Cl-mi
Sign Work	3.1/L-mi 4.2/Cl-mi	3.9/L-mi 5.6/Cl-mi	12.1/L-mi 24.9/Cl-mi	5.8/L-mi 19.8/Cl-mi
Pavement Striping	---[a]	0.6/L-mi 0.9/Cl-mi	7.6/L-mi 15.7/Cl-mi	2.8/L-mi 12.5/Cl-mi
Paving	7.1/L-mi 9.6/Cl-mi	7.0/L-mi 10.0/Cl-mi	9.6/L-mi 19.8/Cl-mi	8.6/L-mi 17.2/Cl-mi
Bridgework	57.5/L-mi 77.6/Cl-mi	36.7/L-mi 52.5/Cl-mi	4.8/L-mi 9.9/Cl-mi	11.0/L-mi 22.4/Cl-mi
Overall	6.4/L-mi 8.6/Cl-mi	5.3/L-mi 7.6/Cl-mi	7.1/L-mi 14.6/Cl-mi	6.7/L-mi 12.8/Cl-mi

[a] no data were available for this type of work in this district.
L-mi = lane-miles.
Cl-mi = centerline-miles.

ASSESSMENT OF NIGHT WORK ACTIVITY UPON CRASHES

The previous chapter provides useful insights into night work activity occurring in TxDOT districts. Some districts experience relatively little, if any, night work activity, whereas others experience night work activities at several locations within their district every night. Given the wide range of activity levels, it would be of interest to know whether the work zone crash statistics provide any evidence of these differences in night work activity level. If so, such information would be valuable in developing useful estimates of the relative risk of night work compared to daytime work.

Unfortunately, standard crash records maintained by the Texas Department of Public Safety are rather information deficient with respect to supporting such an analysis. Current crash report forms include fields to indicate only whether the crash occurred in a work zone, not whether there was actual work activity present at the time of the crash. Furthermore, not all crashes that occur within work zone limits end up coded as such in the DPS database. Together, these issues provide a significant challenge to the estimation of the impact of night work activity on traffic safety in Texas. These challenges notwithstanding, TTI researchers conducted an exploratory analysis using Texas DPS crash data to try and assess what impacts that night work activity may have on crash risk. The results of that analysis are summarized in this chapter.

Parallel with the analysis of the DPS crash database, researchers also initiated an investigation of crash experiences at a number of construction projects where night work activities occurred. Researchers gathered project diary information to determine which nights (and days, in some cases) work took place at each location and performed a detailed before-during analysis of crashes. The goal of that analysis was to establish crash increase factors for night work projects and to determine if these factors differ systematically based on the type of work being performed. The results of that investigation are also documented in this chapter.

IMPACTS OF NIGHT WORK ON DISTRICT WORK ZONE CRASHES

Purpose and Methodology

The district interviews and project diary investigations of night work projects in the three districts provided a good indication of those districts where night work activity is fairly predominant and those where it is not. Furthermore, among those districts experiencing regular night work activity, daily VMT per lane-mile appears to be a good indicator of the relative amount of night activity in each of those districts. Armed with this information, the goal of the researchers was to determine whether it was possible to extract meaningful statistics from the DPS crash database that could suggest whether night work is more risky to motorists than working during the day.

Researchers first downloaded crash data from the DPS database for the most recent 3-year period available (1998-2000). At the time of the analysis, crash records were approximately 2 to 3 years behind, a fact that hindered analysis somewhat since night work activity has only recently become a significant part of operations in some districts. Because of the time difference between the crash data that were available and the dates for which researchers obtained information regarding night work frequency (2002-2003), researchers opted to consolidate data for those districts that appear to have none or only occasional night work activity and those districts that have significant amounts of night work activity occurring. The districts consolidated into the "significant night work" category were as follows:

- Austin,
- Beaumont,
- Dallas,
- El Paso,
- Fort Worth,
- Houston,
- Pharr,
- San Antonio, and
- Waco.

Each of these districts are experiencing traffic demands above 2000 vehicles-miles-traveled per lane-mile, suggested in Figure 1 as the level where night work becomes necessary. The remaining districts composed the "none or only occasional" night work category (referred to herein as "rare").

Because crash report forms do not include indications regarding whether the work zone had activity at the time of the crash, it is not possible to differentiate between those crashes that occur at inactive work zones at night and those that occur at active night work zones. If one assumes that the relationship of daytime-to-nighttime work zone crashes in the "none" night work districts is indicative of inactive night work zones exclusively, then the incremental differences between that group and those districts in the "significant" night work zone category should reflect the influence of night work. Unfortunately, it is also possible that differences in work zone exposure characteristics between the groups may be present, thereby influencing the relationship between the groups (e.g., there may be more work zone activity in general in the "significant" night work districts). Researchers hoped that this influence, if present, was minimal.

With the districts divided according to their expected level of night work activity, researchers focused on trying to answer the following questions:

- Relative to non-work zone crashes, does the relative frequency of work zone crashes at night in the "significant" night work category differ notably from those of the "rare" night work category?
- Relative to non-work zone crashes, does the severity of work zone crashes at night in the "significant" night work category differ notably from those of the "rare" night work category?

Results

Table 11 summarizes the number of daytime and nighttime work zone and non-work zone crashes recorded during the 3-year analysis period for the two night work categories as previously described. Researchers segregated these data according to level of severity, consolidating fatality, and all injury levels (incapacitating, non-incapacitating, and possible injury) as severe. Interestingly, those districts that have only rare instances of night work actually experience a slightly greater percentage of severe nighttime work zone crashes relative to work zone crashes during the day in those districts (64 percent severe crashes in work zones at night work zones versus 61 percent severe crashes in work zones during the day). Conversely, in those districts where night work activity is significant, a smaller percentage of work zone crashes at night are severe relative to work zone crashes during the daytime (62 percent versus 67 percent). Further review of the data in Table 11 indicates that the percentage of severe daytime work zone crashes in those districts with "rare" night work activity is substantially less than for non-work zone daytime crashes in those districts (the percentages of severe work zone and non-work zone crashes are fairly similar for the other categories). Researchers are unsure of the reasons for this anomaly.

Table 11. 1998-2000 Texas Crashes.

Night Work Category	Daytime Work Zone Crashes	Daytime Non-Work Zone Crashes	Nighttime Work Zone Crashes	Nighttime Non-Work Zone Crashes
Districts with "Rare" Night Work	4,903 total 2,987 (61%) severe	94,652 total 63,724 (67%) severe	1,545 total 984 (64%) severe	38,707 total 23,986 (62%) severe
Districts with "Significant" Night Work	15,806 total 10,530 (67%) severe	25,0811 total 169,756 (68%) severe	6,801 total 4,214 (62%) severe	100,310 total 63,131 (63%) severe

Examining the data in another way, Figure 2 illustrates the percent of all crashes occurring in work zones during daytime and nighttime hours by night work category. Overall, those districts which have significant amounts of night work have a greater percentage of crashes occurring in work zones during both daytime and nighttime periods than the districts with rare night work. Furthermore, whereas the rare night work districts have a larger percentage of crashes in work zones in the day as compared to the percent occurring at night, districts with significant night work see a greater percentage of crashes occur in work zones at night than happened during the day. However, researchers believe this result is due to differences in work zone exposure rather than relative differences in crash risk due to more active night work. In other words, more work zones simply occur during the day in the rare night work zone districts, and more work zones occur at night in the significant work zone districts.

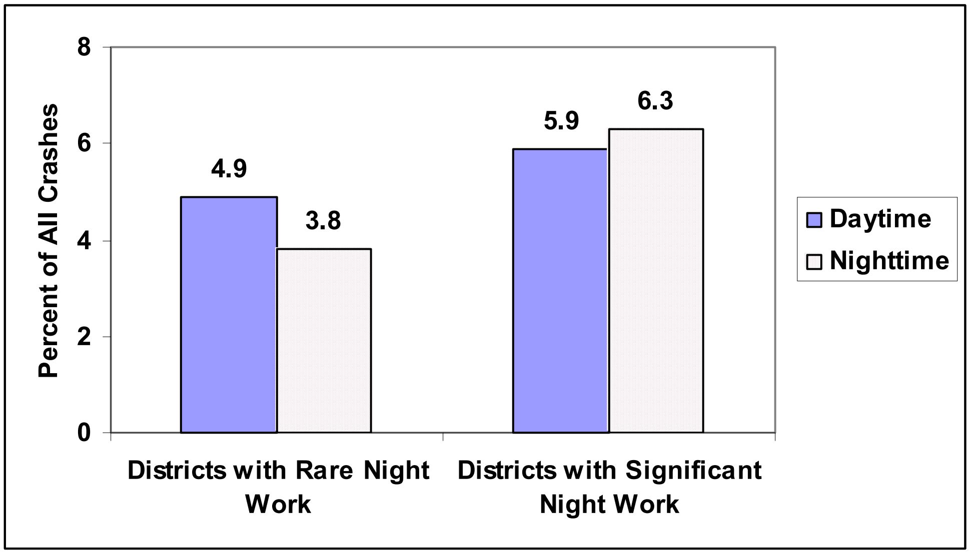

Figure 2. Percent of Crashes Occurring in Work Zones.

Table 12 presents the relative distribution of work zone and non-work zone daytime and nighttime crashes for both night work activity categories. For non-work zone crashes, the distribution between daytime and nighttime conditions is almost identical between the "rare" night work activity districts and the "significant" night work districts. For work zone crashes, however, the distribution for "rare" night work districts is skewed slightly toward daytime work zone crashes (76 percent of work zone crashes in daytime versus only 71 percent of non-work zone crashes during the daytime). The greater daytime percentage of work zone crashes again reflects that most work zone activity in the rare night work districts occurs during daytime hours. In comparison, the percentage of daytime work zone crashes in the significant night work zone districts is slightly less than in non-work zone daytime conditions. This implies that more of the work zone crashes occur at night in those districts that conduct a significant amount of night work. However, this again likely represents the increased level of work activity exposure during nighttime hours and a corresponding lesser amount of daytime work exposure in those districts.

It is interesting to note that the daytime/nighttime percentages of non-work zone crashes and work zone crashes are significantly different between the rare and significant night work categories (the extremely large number of non-work zone crashes in the data set allows one to detect even minute changes in percentages as statistically significant). However, whereas the daytime percentage of non-work zone crashes increases slightly between the rare and significant categories (from 71.0 to 71.4 percent), it decreases between these categories for the work zone crashes (from 76.0 percent down to 70.0 percent).

Table 12. Percent of All Crashes by Time of Day and Night Work Category.

Night Work Category	Nighttime Non-Work Zone Crashes (%)	Daytime/Nighttime Work Zone Crashes (%)
Rare	71.0/29.0	76.0/24.0
Significant	71.4/28.6[a]	70.0/30.0[b]

[a] significantly different (z = 2.743) than the rare active night work category.
[b] significantly different (z = 9.550) than the rare active night work category.

Researchers hypothesized that if all other factors remained constant, then the same types of trends in percentages observed in Table 12 should exist for severe crashes as well. The results of such a comparison of severe crashes only are shown in Table 13. Generally speaking, the trends compare to those in Table 12. A slightly greater percentage of work zone crashes occur in the daytime in those districts with "rare" night work activity (as compared to non-work zone crashes in those districts), whereas the trend reverses in those districts that have significant amounts of active night work. The magnitude of the differences between the two active night work categories is slightly smaller than in Table 12, but not enough to indicate whether the increased amount of night work has a substantial effect on work zone crash characteristics.

Table 13. Percent of Severe Crashes by Time of Day and Night Work Activity Category.

Night Work Category	Daytime/Nighttime Non-Work Zone Crashes (%)	Daytime/Nighttime Work Zone Crashes (%)
Rare	72.7/27.3	75.2/24.8
Significant	72.9/27.9	71.4/28.6[a]

[a] significantly different (z = 4.747) than the rare active night work category.

Another dimension along which to analyze these crashes is in terms of how many of all crashes are coded as severe in each category. Table 14 presents this comparison. Again, the analysis does not imply that those districts experiencing significant amounts of active night work have nighttime work zone crashes that are any more severe than those occurring in districts with only rare night work. In fact, the percent of nighttime work zone crashes that are severe in the significant night work zone districts is slightly less than that for the rare night work districts (62.0 percent versus 63.7 percent, respectively).

Table 14. Percent of Crashes That Are Severe.

Night Work Category	% of Non-Work Zone Crashes		% of Work Zone Crashes	
	Daytime	Nighttime	Daytime	Nighttime
Rare	67.3[a]	61.7	60.9	63.7
Significant	67.7[b]	62.9[c]	66.6[d]	62.0

[a] significantly different (z = 9.199) than daytime work zone crashes.
[b] significantly different (z = 2.007) than the rare active night work category.
[c] significantly different (z = 4.146) than the rare active night work category.
[d] significantly different (z = 7.322) than the rare active night work category.

In summary, the results of the DPS crash analysis did not provide any evidence to suggest that those districts with significant amounts of active night work experience proportionately greater numbers of severe nighttime work zone crashes than those with only rare active night work. The data do suggest a slightly greater percentage of total work zone crashes that occur at night in the significant active night work districts, but it is uncertain whether this increase is simply due to increased work zone exposure during nighttime hours or represents an incrementally higher rate of crashes than would have occurred if the work had been performed during the day. To better assess the possibility of the latter scenario, TTI researchers also conducted a series of before-during crash analysis at a number of work zones that involved active night work. That analysis is described in the next section.

BEFORE-DURING CRASH ANALYSIS AT ACTIVE NIGHT WORK ZONES

Purpose and Methodology

One of the difficulties in assessing crash risk at an aggregate level is that it is not possible to isolate the effects of differences in exposure levels (how many work zones occur during the day or at night, whether the work zones are comparable from one region to the next, etc.) from any effects that the work zones themselves have on crash potential or severity. Similarly, it is not possible to separate those crashes that occur at or near areas of work zone activity and those that occur in work zone areas that are inactive at the time of the crash. This latter limitation is particularly significant when assessing the crash risk of active night work, as crashes do occur occasionally at night in work zones that are active during daylight hours. Consequently, the authors initiated a more focused analysis approach to accomplish the following objectives:

- determine the change in crash likelihood during periods of active night work, active day work (if applicable), and for times of inactivity in a sample of construction projects in Texas;
- determine the level of consistency in crash likelihood for each category of work activity or inactivity; and
- to the extent possible, identify any increase in crash severity or rear-end collisions associated with active night work.

Through telephone and e-mail contacts with TxDOT personnel, TTI researchers identified a number of potential projects that involved nighttime activities. Some of these were resurfacing projects and other activities performed exclusively at night. Others were of the hybrid nature, where certain work activities occurred during the day off of the travel lanes, and active night work occurred whenever travel lanes needed to be closed. Researchers limited the analysis to projects located on interstates or controlled-access facilities, as that is where the vast majority of such projects occurred. Researchers considered potential project locations in Austin, Houston, Dallas, Fort Worth, San Antonio, and Waco. As previously noted, these districts conduct the largest amounts of nighttime work zone activity.

In order to obtain crash data, researchers pursued project locations that had work zone activity in the 1999 - 2001 calendar years. This limitation hampered project identification efforts somewhat, as many districts had already archived project information from that far in the past. Eventually, researchers identified eight projects for analysis. Two of these projects involved roadway resurfacing and so had only active night work occurring during the performance period of the project. The other six projects were major roadway rehabilitation or reconstruction projects that involved predominantly daytime work adjacent to the travel lanes, but with occasional periods of active night work when performing activities in the travel lanes. To maintain confidentiality of the crash data, researchers opted to avoid project descriptors that specifically identify these projects. Rather, researchers assigned each project a project code to use throughout this discussion. Table 15 summarizes the characteristics of each project.

Table 15. Night Work Zone Project Characteristics.

Project Code	Project Type	2000 AADT	Analysis Period
H1	Hybrid	~160,000	Sep '99 – Oct '01
H2	Hybrid	~180,000	Feb '00 – Aug '01
H3	Hybrid	~140,000	Oct '99 – Nov '00
H4	Hybrid	~110,000	Jan – Dec '00
H5	Hybrid	~170,000	Jan '99 – Jul '01
H6	Hybrid	~200,000	May '99 – Dec '01
R1	Resurfacing	~80,000	Feb – Apr '00
R2	Resurfacing	~100,000	May '00 – Mar '01

AADT = Annual Average Daily Traffic

Researchers identified the control-section and milepoint limits of each project analyzed. Researchers also identified a comparison segment on the same roadway or on a nearby facility. This comparison segment allowed the researchers to perform a before-during analysis with a control group at each site. Researchers also performed a check for comparability between the work zone and comparison segments to ensure that the analysis was appropriate (*19*, *20*). The result of the analysis is an estimated change in crash frequency in the project limits from what would have been expected if the project had not occurred during each particular time period of interest.

To conduct the analysis, researchers needed to be able to differentiate between days and nights when work activity took place and those days or nights when there was no activity. Researchers defined day conditions as between the hours of 6 am and 7 pm, and night conditions as between 7 pm and 6 am. Researchers traveled to each district with jurisdiction over one of the project study locations and reviewed project diary information to determine hours (days and nights) of activity or inactivity throughout the duration of the project. For the eight projects identified, researchers obtained data from 4300 days of diary entries. Researchers then reduced these data to a set of dates and times corresponding to one the following conditions:

- dates and times during the day when work occurred (available only for hybrid projects);
- dates and times during the day when the project was inactive;
- dates and times during the night when work occurred; and
- dates and times during the night when the project was inactive.

For each set of dates and times, researchers extracted all crashes occurring within the limits of that project as well as those in the limits of the comparison segment selected for that project. Researchers also obtained crash data for those segments for the 3 years prior to the start of work on that project. Researchers verified that crash trends in the comparison segment and in the project segment were indeed comparable before the start of work activities (*20*). For project R1, which lasted 7 months, researchers used only the months of actual project activity from the before analysis years to ensure proper comparability.

Results

Total Crashes

The change in total crash frequencies by time of day (daytime, nighttime) and work period (active, inactive) for each project is summarized in Table 16. Due to problems with the available data at project H6, only five of the hybrid projects are discussed. Researchers first computed overall changes in crashes for the entire project duration for comparison against previous work zone crash studies. Examined across all time periods, researchers found the overall increase in crash rates at four of the five hybrid projects to range between 30 and 40 percent, values which are generally consistent with past work zone crash studies (*8, 10, 11*). The overall combined estimate of crash increases at the hybrid projects was 31.5 percent, again very close to previous studies of work zone crash increases at freeway reconstruction projects in Texas (*8*). For the resurfacing projects, researchers opted to compare nights of work to nights without work exclusively (no daytime data or analyses were performed). Thus, the overall changes in crash rates calculated and reported for these projects in Table 16 reflect night periods only.

Next, researchers subdivided each project by day and night and work activity or inactivity and once again performed the crash comparisons. Significant variability in the percent changes was evident across the projects. However, when researchers condensed the projects for each time period of interest, a few important trends could be observed:

Table 16. Change in Total Crash Frequencies at Project Locations.

Project	Daytime		Nighttime		Overall Change During Project (Actual/Expected)
	WZ Active (Actual/Expected)	WZ Inactive (Actual/Expected)	WZ Active (Actual/Expected)	WZ Inactive (Actual/Expected)	
H1	+35.3%* (175/129.3)	+5.9% (67/63.3)	-22.8% (14/18.1)	+60.4%* (82/51.1)	+28.8%** (338/262.3)
H2	+40.6% (325/231.1)	-11.7% (167/189.1)	+496.8% (29/4.9)	+48.7% (318/213.8)	+32.9%* (839/631.5)
H3	+32.1% (169/127.9)	-30.2%* (274/392.2)	+49.2% (31/20.8)	+57.3% (196/124.6)	-0.7% (670/675.0)
H4	+87.5%** (47/25.1)	+29.0% (106/82.2)	+22.3% (17/13.9)	-0.3% (45/45.2)	+29.9%** (215/165.6)
H5	+28.9%** (528/409.5)	+38.0%** (226/163.8)	+262.8%** (38/10.5)	+63.2%** (226/138.5)	+42.3%** (1,018/715.2)
H1-H5 Combined	+36.5%**	+14.0%	+102.2%**	+48.7%**	+31.5%**
R1			+117.1% (4/1.8)	+18.8% (5/4.2)	+48.7% (9/6.1)
R2			+15.9% (6/5.2)	-2.8% (19/19.6)	+1.1% (25/24.7)
R1-R2 Combined			+55.4%	+2.1%	+13.4%

* Changes in crash frequencies are significantly different ($\alpha = 0.10$).
** Changes in crash frequencies are significantly different ($\alpha = 0.05$).

- Researchers found that crash frequencies during days when no work occurred at the hybrid projects were only slightly greater to what would have been expected at those locations if the work zone was not present (and was not statistically significant). Researchers hypothesize that this signifies that drivers had little difficulties accommodating the long-term work zone geometrics and traffic control that were installed at each project (lane shifts, ramp closures or temporary modifications, shoulder closures, etc.).
- When work activities did occur during the day at the hybrid projects, crashes tended to increase an average of 36.5 percent. Since the daytime work at these projects occurred in the median or freeway-frontage road separation and not the actual travel lanes

themselves, the increase is most likely attributable to work activity distractions (workers or equipment moving within the construction areas, dust or smoke clouds created in the construction area, etc.) or possibly due to temporary disruptions in traffic flow for construction equipment entering or exiting the work area.

- Although no increases in crashes occurred during the day when work was not occurring at the hybrid projects, the same could not be said for nighttime conditions when no work was present. Rather, at the five hybrid projects examined, researchers found that such crashes increased an average of 48.7 percent during periods of night inactivity. The increase suggests that the changes in geometrics and traffic control of the work zone, while not a problem for motorists during the daytime, created difficulties for motorists at night, even when there were no work activity distractions present.
- When work activity occurred in the hybrid projects at night (almost always because of the need to close one or more travel lanes), crashes increased by an average of over 102 percent. This value represents an additional 53.4 percent (102.2 – 48.7) above the increase observed at night when the work zone was inactive. Researchers hypothesize that the traffic disruptions caused by the introduction of channelizing devices, workers, and work equipment into the travel lanes on nights of activity confound with the effects of work zone geometrics and traffic control already established to generate the large increases. It should be noted that only two of the five hybrid projects actually experienced dramatic increases in crashes during work activity, whereas the increases during night work activity at the other three sites are much more similar to the changes observed at night when the work zone was inactive. The two locations where substantial crash increases occurred are believed to have resulted in significant traffic queuing during a portion of the night work operations. The fact that recovery areas are often reduced or eliminated in urban freeway reconstruction areas (i.e., shoulder closures, shorter or eliminated acceleration/deceleration lanes, etc.) may contribute substantially to crash increases when queuing occurs upstream of night work activities.
- At the resurfacing projects, researchers found that crashes at night when work was not occurring were almost identical to what would have been expected. Such a result was expected by researchers, since resurfacing projects do not generally involve the

establishment of temporary traffic control that remains in place when work is not occurring.

- On nights when work did occur at the resurfacing projects, crashes increased an average of 55.4 percent. The magnitude of this increase is very similar to the additional increase of crashes observed between the active and inactive night periods at the hybrid projects. It should be noted that the resurfacing projects, in general, were performed on roadways with lower traffic volumes than the hybrid projects (refer back to Table 15). However, researchers could not ascertain from the project diaries or other notes whether traffic queues were created during work activities at these locations.

It is important to recognize that these results, while informative, do not indicate that work should not be performed at night. Rather, they illustrate the extent to which such night work affects the typical crash rates present during the day and at night at the types of projects examined in this project. Given that traffic volumes are much lower at night as compared to daytime hours, a substantial increase in crash rates at night due to work activity could still yield a lower number of expected crashes over the duration of a project than would be expected had the work been done during the day. Furthermore, because of existing policy designed to minimize motorist impacts due to work activities, none of the lane closure activity was done during the day at these project locations. It is entirely possible that had such closures been done in daylight, the percentage increase in crashes observed during the daytime work activity periods would have been much higher. Such direct comparisons of lane closure impacts at a location are generally unavailable (the main reason for working at night is to avoid creating the tremendous congestion and motorist impacts during the day). Therefore, researchers were forced to examine the potential impact of daytime lane closures through indirect means (i.e., the observational studies described in the next chapter).

Severe Crashes

The small sample sizes available for some of the projects do not allow the same types of statistical comparisons to be performed on any subcategories of the crashes. Therefore, the next step taken by researchers was to consolidate the crash data for all projects and to compute the percent of crashes that were severe for this sample as a function of the different night and day categories. As shown in Table 17, the percent of crashes in the hybrid projects that were severe was slightly greater during the days of work activity as compared to the days of inactivity and to the before condition. At night, the percent of severe crashes was actually slightly less overall during the project on both nights of activity and nights without activity, as compared to the before condition. None of the differences are statistically significant. With regards to the resurfacing projects, the percentage of crashes that are severe was somewhat higher on nights of activity relative to the before condition, while the percentage of severe crashes on nights of inactivity during the project were actually lower than in the before condition. Researchers hypothesize that the nights of inactivity at these resurfacing projects may have correlated with nights of poorer driving conditions, as pavement overlays and other types of resurfacing activities would likely not be performed on nights when rain, wet pavement, etc., were present. Such conditions typically reduce travel speeds somewhat and may have attributed to the lower than normal level of severe crashes on those nights. Alternatively, adverse weather conditions may also increase the number of non-severe crashes that occur on those nights of inactivity, and thus dilute the proportion of severe crashes existing in the dataset (even if the number of severe crashes itself remained constant over time).

Table 17. Percent of Crashes That Are Severe at Project Locations.

Project	Daytime			Nighttime		
	Before	During-Active	During-Inactive	Before	During-Active	During-Inactive
Hybrid	68.1	71.6	68.3	65.7	59.3	59.8
Resurfacing				58.9	70.5	41.6
Overall	68.1	71.6	68.3	65.4	59.9	59.0

Rear-End Crashes

Finally, researchers assessed rear-end crashes for the seven work zone projects investigated. Several studies have consistently identified rear-end crashes as being overrepresented in work zones (*21, 22*). These disproportionate increases in rear-end crashes are usually explained in terms of temporary disruptions in traffic flow for construction equipment and materials access, as well as congestion created by the reduction in available roadway capacity. The statistical analysis of rear-end crashes at the seven project locations combined are presented in Table 18. At the project locations investigated, rear-end crashes as a percent of total crashes was only slightly higher during the day at the hybrid projects. Interestingly, it was during the days of inactivity that researchers saw the greater proportion of rear-end crashes. At night, the percentage of rear-end crashes was also only slightly higher for the hybrid projects (regardless of whether or not work activity was occurring). However, the resurfacing projects did show a more substantial increase on nights when work was occurring. These projects were much shorter in duration than the hybrid projects, so it is possible that these projects were more of a "surprise" to motorists encountering them at night, and this lack of expectancy contributed to the higher frequency of rear-end crashes.

Table 18. Comparison of Rear-End Crash Frequencies at Project Locations.

Project	Daytime			Nighttime		
	Before	During - Active	During-Inactive	Before	During-Active	During-Inactive
Hybrid	24.5	25.7	30.0	19.3	19.7	20.2
Resurfacing				10.6	31.5	8.5
Overall	24.5	25.7	30.0	18.9	20.2	19.6

Summary

As the results of this analysis show, isolating the effects of individual work zone attributes on traffic crashes is fairly difficult to accomplish. The wide variation in site conditions from work zone to work zone often compound with the factors of interest and make it difficult to obtain with much certainty an accurate measure of that factor's influence. Such was the case in assessing the relative safety effects of active night work. Although the analysis did find crashes at active night work zones to be higher (sometimes significantly) than expected at the location if the work zone was not present, researchers also found that crashes increased in some instances even when work activity was not present or during daytime work periods when travel lanes were not closed. For hybrid projects, researchers found the percentage of severe crashes to be slightly greater during times of work activity in the daytime, but not at night. For resurfacing projects, the percent of severe crashes was slightly higher than before on nights of activity, but slightly lower on nights of inactivity. Rear-end crashes did not change substantially at night within the hybrid projects both with and without work activity occurring, but did more substantially at the resurfacing projects when work was occurring. Researchers also saw small increases in rear-end crashes during the day at the hybrid projects, again both with and without work activity occurring.

Researchers believe that traffic queuing may have occurred upstream of some of the night work zone lane closures and that this may have contributed significantly to the higher crash frequencies at some of the sites. Although indirect evidence exists suggesting that active night work zones where traffic queues develop may be the biggest contributor to increases in crashes, it is not clear whether such queues created under nighttime conditions create safety deficiencies at a substantially higher rate than queues created under daytime conditions. Crash data, without detailed information about the operational conditions that existed at the time of the crash, cannot be used to evaluate this question directly. Therefore, in the next chapter, researchers present the results of a series of observational studies conducted at a sample of active work zones during daytime and nighttime periods. Of particular interest were locations where lane closures created traffic queues.

OBSERVATIONAL STUDIES OF ACTIVE NIGHT WORK ZONES

PURPOSE AND METHODOLOGY

The initial goal of the research team was to identify a series of active night work zones with and without traffic queues present. Research teams stationed upstream of the lane closure monitored the lane closure merge point, or where traffic queues are created, upstream end of the traffic queue as it moved upstream and downstream dependent on the approaching traffic demand levels over time. Researchers monitored and recorded three types of erratic maneuvers:

- a vehicle either changing lanes dramatically or going onto the shoulder to avoid running into a vehicle directly in front (usually at the upstream end of the queue, but not always),
- a vehicle pitching forward excessively or locking and squealing tires to avoid impacting a vehicle in front, and
- a vehicle involved in any type of crash that involves work vehicles or workers or between two vehicles at the upstream end of the queue (fortunately, researchers observed no such accidents during any of the studies).

Researchers contacted TxDOT personnel in several of the significant night work districts to identify potential study sites. Unfortunately, during the time period of interest, researchers identified very few active night work projects that created significant traffic queuing. Researchers finally selected one project in Dallas and one in San Antonio for study. Unfortunately, upon traveling to each site and setting up for data collection activities, the magnitude of traffic congestion that developed was less than what was expected. Researchers did collect erratic maneuver data at these locations (in the vicinity of the lane closure bottleneck) to assess nighttime driver behavior at lane closure locations without traffic queuing. Researchers eventually located a work zone with daytime lane closures and traffic queuing present, and so were able to collect erratic maneuver data under this type of configuration.

At the same time that the search was under way for active night work zones where traffic queues would develop, researchers became aware of another research project where TTI personnel had obtained videotape data of the upstream end of traffic queues in the Dallas region located at several geometric bottlenecks. Although not a true active night work zone, these videotape data offered researchers an opportunity to evaluate traffic behavior at the upstream end of traffic queues under both daytime and nighttime viewing conditions at the same sites. Researchers identified both a daytime and a nighttime bottleneck location for which videotape data were available. These sites were located relatively close to each other geographically (but on different freeways). Furthermore, the two sites had similar geometrics in terms of number of available travel lanes, available sight distance, etc., and so were believed to be fairly comparable. Researchers obtained approximately 4.5 hours of traffic queuing videotape during daytime conditions at one site and about 3.5 hours of videotape at the other site under nighttime conditions. In total, then, the researchers had a database of the following sites for use in analysis:

- nighttime active work zone lane closures with little or no traffic queuing present – two sites;
- daytime active work zone lane closures with significant traffic queuing present – one site;
- daytime recurrent congestion bottlenecks with significant traffic queuing present – one site; and
- nighttime recurrent congestion bottlenecks with significant traffic queuing present – one site.

Researchers summed the number of erratic maneuvers identified at each site and divided by the traffic volume approaching the upstream end of the queue (or passing through the lane closure bottleneck in the cases where traffic queues did not develop) to compute erratic maneuver rates for each site. Comparison of the erratic maneuver rates measured at the recurrent bottleneck location provided an indication of the relative increase in such maneuvers under nighttime conditions (relative to daytime conditions). Next, comparison of the erratic maneuver rate measured at the daytime work zone lane closure to the rate measured at the recurrent congestion bottleneck during daytime conditions provided an indication of the additional increase in risk generated when the traffic queue is unexpected instead of occurring at the same general location on a regular basis. Finally, comparison of the erratic maneuver rates of the nighttime work zone lane closures where traffic queuing did not occur to the erratic maneuver rates observed at the recurrent bottleneck locations allowed researchers to assess the relative implications of a non-queued versus a queued traffic condition on crash potential.

RESULTS

Table 19 summarizes the number of erratic maneuvers recorded, the vehicles observed, and resulting erratic maneuver rate calculated for each site. As illustrated in the table, the observed rates varied from as little as 0.5 erratic maneuvers per 1000 approaching vehicles to a high of 8.6 maneuvers per 1000 approaching vehicles.

Table 19. Erratic Maneuvers Observed at Study Sites.

Site	Erratic Maneuvers Observed		Total Vehicles Observed	Demand Volume per Open Lane (vph)	Total Erratic Maneuver Rate (No./1000 vehicles)
	Near Miss	Hard Braking			
Daytime Work Zone Lane Closure – Site A	8	13	2449	1547	8.6
Nighttime Work Zone Lane Closure – Site B	0	3	798	798	3.8
Nighttime Work Zone Lane Closure – Site C	0	1	2202	1100	0.5
Daytime Recurrent Bottleneck – Site D	36	33	36947	1944	1.9
Nighttime Recurrent Bottleneck – Site E	3	42	18896	1718	2.4

From the values in the table, researchers drew the following inferences:

- Erratic maneuvers at the upstream end of a recurrent traffic queue due to a geometric bottleneck occurred approximately 26 percent ([2.4-1.9]/1.9) more frequently under nighttime conditions than under daytime conditions.
- Comparison of the erratic maneuver rate from the daytime work zone lane closure site to the daytime recurrent congestion bottleneck site suggests that unexpected traffic queues (such as occur at temporary work zone lane closures and at incidents)

may result in four times as many erratic maneuvers as traffic queues that occur regularly at bottleneck sites and thus are generally expected by the motoring public.

- Comparison of the erratic maneuver rates at the nighttime work zone lane closure sites to the nighttime recurrent congestion bottleneck site suggests that even in the absence of a traffic queue, the unexpected nature and characteristics of the work can result in erratic maneuver rates approaching that observed at locations where traffic queues develop at recurrent bottleneck sites. However, it is also possible to achieve traffic control configurations that result in very small erratic maneuver rates.
- The decision to work at night in order to avoid the creation of traffic queues can reduce the erratic maneuver rate (and by interpolation, crash potential) by a factor of 6. Combining this with the fact that nighttime traffic volumes can be 50 percent lower (or more) than daytime off-peak periods, the impacts upon reduced crash risk are even more significant.

SUMMARY

In this report, researchers present a summary of the extent and type of nighttime work zone activity that currently occurs in Texas; an analysis of Department of Public Safety crash data to assess the ramifications of night work on crash experiences; and an assessment of differences in operational characteristics of traffic at nighttime and daytime work zones. Researchers identified the following key findings:

- Districts that currently experience significant amounts of active night work have widely varying policies in requiring night work, the criteria used to decide when night work must be done, and the number of travel lanes that can be closed to accommodate work activities.
- Analysis of work zone exposure data suggests that district-wide traffic demands of approximately 2000 vehicle-miles-traveled per lane-mile mark the onset of the need to begin conducting work activities at night. Most of the night work operations will be for paving and/or bridgework activities, as these typically require significant time periods when lanes can be closed.
- Of those districts conducting night work operations, most tend to take frequent advantage of the additional time between peak periods that are available to complete the work. This may have additional implications to work crew quality of life, already impacted by the disruption of circadian rhythms and social or family life. On average, night work activities involve approximately 2.7 lane-miles of closure, 7.6 workers per lane-mile, and 6.7 pieces of work equipment per lane-mile. Expressed in terms of centerline-miles of night work activity, these values equate to 1.4 centerline-miles of closure, 14.5 workers per centerline-mile, and 12.8 pieces of work equipment per centerline-mile. These latter values are comparable to those determined in a previous national study of work zone exposure characteristics (including both daytime and nighttime work zones).
- The crash data do not suggest that work zone crashes at night tend to be any more severe in districts with significant amounts of active night work than those districts where night work is never or only rarely performed. If anything, a small reduction

may exist in the relative number of severe work zone crashes that occur in those significant active night work zone districts. The fact that those districts with significant active night work are also those with the greatest traffic demands (and thus have significantly different operating characteristics and other factors which may also influence crash severity) prevents further assessment and interpretation of these results, however.

- Before-during crash analyses at seven work zone projects that involved active night work zones indicates that crash rates during activity may increase in most work zones, the magnitude of such increases may not be statistically significant. In fact, researchers found that temporary geometric constraints, coupled with the higher levels of traffic generally associated with daytime periods, may generate increases in daytime work zone crashes similar in scale to those observed during active night work periods. An exception to these trends occurred at two sites where it is believed that substantial traffic queues were created at night by the closure of active travel lanes. At these sites, the increase in crashes during active night work periods was much greater than during the other analysis periods.
- A series of observational studies at both daytime and nighttime work zone lane closures and recurrent congestion bottlenecks indicated that erratic maneuver rates are slightly higher at night and will be substantially greater at traffic queues that occur upstream of temporary lane closures and incidents, presumably because they are much less expected than traffic queues that regularly occur upstream of a recurrent congestion bottleneck.

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APPENDIX:

DISTRICT LANE CLOSURE POLICIES

Table A-1. Dallas District Freeway Lane Closure Guidelines.

Description of Operations		Permitted Lane Closures		
Category of Work	**Roadway Lanes (one direction)**	**Peak Times (6:00 am to 9:00 am) (3:30 pm to 7:00 pm) and Event Times**	**Off Peak Times (9:00 am to 3:30 pm) (7:00 pm to 10:30 pm)**	**Lowest Volume Times Weeknights (10:30 pm to 6:00 am) and as Determined by Engineer**
A. Placement of CTB or Placement of Pavement Markings or Full Depth Roadway Repair	5	None	2	3
	4	None	2	3
	3	None	1	2
	2	None	1	2
B. Adjacent Construction or Lanes for Construction Traffic	5	None	1	2
	4	None	1	2
	3	None	1	1
	2	None	0	1

<u>Additional Guidelines:</u>

1. The safety of workers and the traveling public will never be compromised and will be the first consideration when determining lane closures.
2. Off-Peak Times may be started earlier or be extended later in the Off-Peak direction if reasonable mobility can be maintained.
3. If reasonable mobility can be maintained, or exceptional circumstances exist, additional lanes may be closed during Off-Peak Times or Lowest Volume Times with written permission of the Engineer.
4. Any complete roadway closure will require a Traffic Control Plan to be submitted by the Contractor and approved by the Engineer.
5. Lane closures must be coordinated with adjacent projects. First closure submitted will have priority.
6. If at any time backups become unreasonable (> 20 min.), modifications to alleviate the congestion should be taken immediately.

Table A-2. San Antonio District Freeway Lane Closures for Construction and Maintenance.

Number	Location	Times Available for Closure	Volume (vph)	Lanes		
				Existing	Can Be Closed	Remain Open
1	10W @ North of La Cantera	12MID-6AM and 8PM-12MID	>1400	3	2	1
		Avoid AM and PM Peaks	>3400	3	1	2
	10E @ North of La Cantera	Avoid AM and PM Peaks	>3100	4	2	2
		Avoid AM and PM Peaks	>4800	4	1	3
2	1604W @ Lockehill-Selma	12MID-5AM and 9PM-12MID	>1450	2	1	1
	1604E @ Lockehill-Selma	12MID-5AM and 9PM-12MID	>1450	2	1	1
3	410W @ West Ave.	Under Construction	>1400	3	2	1
		Under Construction	>3400	3	1	2
	410E @ West Ave.	Under Construction	>1400	3	2	1
		Under Construction	>3400	3	1	2
4	Loop 1604W @ Huebner Rd.	12MID-5AM and 10PM-12MID	>1450	2	1	1
	Loop 1604E @ Huebner Rd.	12MID-5AM and 10PM-12MID	>1450	2	1	1
5	Loop 1604W @ Stone Oak	12MID-6AM and 8PM-12MID	>1450	2	1	1
	Loop 1604E @ Stone Oak	12MID-5AM and 10PM-12MID	>1450	2	1	1
6	US 281N @ Mud Creek	12MID-6AM and 9PM-12MID	>1400	3	2	1
		Avoid AM and PM Peaks	>3400	3	1	2
	US 281S @ Mud Creek	12MID-5AM and 8PM-12MID	>1400	3	2	1
		Avoid AM and PM Peaks	>3400	3	1	2
7	Loop 1604W between US 281 & Gold Canyon	12MID-5AM and 7PM-12MID	>1450	2	1	1
	Loop 1604E between US 281 & Gold Canyon	12MID-5AM and 10PM-12MID	>1450	2	1	1
8	Loop 410W @ McCullough	Under Construction	>1400	3	2	1
		Under Construction	>3400	3	1	2
	Loop 410E @ McCullough	Under Construction	>1400	3	2	1
		Under Construction	>3400	3	1	2