Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-05/0-4747-2		

4. Title and Subtitle	5. Report Date
EVALUATING THE SAFETY RISK OF ACTIVE NIGHT WORK ZONES	April 2005
	6. Performing Organization Code
7. Author(s) Gerald L. Ullman, Brooke R. Ullman, and Melisa D. Finley	8. Performing Organization Report No. Report 0-4747-2
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-4747
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Technical Report: March 2003-Febuary 2005 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Assessing the Impacts of Active Nighttime Work Zones upon Motorist and Worker Safety

16. Abstract

In this report, researchers present an assessment framework for evaluating the expected crash consequences of performing a particular work activity on a given highway at night versus doing that same activity during the day. Researchers predicate the framework on the availability of normal crash rates (crashes per 100 million-vehicle-miles), differentiated by daytime and nighttime conditions, on the particular roadway segment of interest. These normal rates are then adjusted on a percentage basis to account for the incremental increase in crashes expected under both the daytime and nighttime work conditions. An analyst would multiply the adjusted crash rates, representing the additional crash risk due to work activities, by traffic volumes expected to encounter the work zone in either the daytime or the nighttime period and the length of the work zone to determine the number of additional crashes that would be expected to occur due to the work zone in either period.

Also included in this report is a review of several potential countermeasures identified by the research team to reduce crashes resulting from active night work zone. Researchers provide a critique of each one with regard to potential adoption consideration by the Texas Department of Transportation. Overall, researchers could not justify widespread or blanket adoption of any of the countermeasures.

17. Key Words	18. Distribution Statement
Work Zone Safety, Vehicle Crashes	No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	60	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

EVALUATING THE SAFETY RISKS OF ACTIVE NIGHT WORK ZONES

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Project Number 0-4747
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Texas Department of Transportation
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Federal Highway Administration

April 2005

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DISCLAIMER

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors would like to thank several TxDOT staff members for their insights and guidance in this research: Tammy Sims (Maintenance Division), project director; William Garbade (Austin District-retired) and Tom Beeman (Design Division), program coordinators; Paul Frerich (Yoakum District), Terry Sams (Dallas District), Tom Beeman (Construction Division), and Sally Wegmann (Houston District), Project Monitoring Committee; and Wade Odell, Research and Technology Implementation (RTI) office liaison. The project team was also assisted by an external advisory committee. The contributions of Jeff Lewis (Occupational Safety and Health Administration [OSHA] Region VI), Randy Rogers (Williams Brothers Construction, Houston), and Lee Taylor (Associated General Contractors [AGC] Texas) are also gratefully acknowledged. Finally, the contributions of Lane Roberts, Marshall Cheeks, and Alicia Licon-Alonzo, all of whom provided significant input into various components of this project through their participation in the Southwest Region University Transportation Center Undergraduate Summers Fellow Program, are also greatly appreciated.

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INTRODUCTION

STATEMENT OF THE PROBLEM

In Texas and across the United States, highway agencies and contractors are frequently turning to night work when activities necessitate closure of one or more travel lanes on a high-volume roadway. Making the decision to do highway work at night requires 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 (material supply logistics, additional traffic control, noise, safety and health, etc.). Several methodologies have been proposed in recent years to systematically assess the feasibility of doing highway work at night (*1*-*3*). Generally speaking, most of these methodologies have similar formats. As an example, Tables 1 and 2 present the assessment matrices provided in the recently published National Cooperative Highway Research Program (NCHRP) document *A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance* (*3*). In Table 1, the authors of that report identify and combine the various costs associated with each traffic control option being considered.

Table 1. Sample Cost Identification Worksheet (*3*).

Objective	Factor	Cost		
		Option 1	Option 2	Option 3
Traffic Control	Setup/Takedown			
	Device Rental			
	Maintenance			
	Pedestrian Accommodation			
	Enforcement			
	Detour/Upgrade			
Lighting	Planning			
	Hardware Rental			
	Maintenance			
Constructability	Labor			
	Labor Premiums			
	Incentive Clauses			
	Materials			
	Equipment			
User	Traffic Delay Costs			
	Vehicle Operating Costs			

Table 2, from that same report, uses a three-point ranking system of the effect of the traffic control option on other factors. An analyst using this process then identifies and applies an overall weighting scheme of these various factors to the ratings, and computes a single cost-effectiveness rating for each option.

Table 2. Sample Effectiveness Rating Worksheet (3).

Objective	Factor	Rating		
		Option 1	Option 2	Option 3
Community/Traffic Impact	Business Impact			
	Pedestrian/Bicycle Impact			
	Environmental Concerns			
	Public Transit			
	Emergency Services			
	Noise Effects			
	Effects of Lighting and Glare			
	Off-site Traffic in Local Neighborhood			
	Impact to Off-Site Traffic			
	OVERALL RATING			
Safety	Traffic Accidents			
	Construction Accidents			
	Maintenance			
	OVERALL RATING			
Constructability	Experience of Contractor			
	Suitability of Temperatures			
	Supervision			
	Worker Efficiency at Night			
	Quality of Lighting Plan			
	Materials and Equipment Availability			
	OVERALL RATING			

As currently presented, the process addresses both traffic crashes (accidents) and construction accidents only through the relative rating scheme in Table 2. The authors of the process have done this out of necessity because of the overall lack of safety data regarding night work activities (3):

"…these guidelines do not account for accidents in the total cost estimate, but do allow any judgment of accident potential to affect the safety component of effectiveness. Should data become available that would allow one to estimate accident costs for different traffic control schemes, accident costs would be included in the same way as user costs. The only exception would be that some accident costs would be incurred by the agency and some by the user."

Obviously, better guidance on how to properly assess the safety consequences (or relative risk) of night work activity would be extremely valuable in bringing objectivity and balance into the overall assessment procedure. This type of information would also be useful in determining how to best incorporate recommendations in a companion NCHRP document regarding traffic control procedures and devices for use in night work zones (*4*). In this report, researchers describe analysis and results of a two-year project conducted for the Texas Department of Transportation to develop such guidance.

PROJECT OBJECTIVES

The objectives of this research project were 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.

A previous interim report (*5*) presented the results of analyses 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 night work activity does significantly increase the likelihood of crashes on a facility, sometimes quite dramatically. In addition, observational studies of traffic behavior approaching recurrent congestion queue locations showed that erratic maneuvers occurred at a higher rate during nighttime driving conditions than during daytime (at the same location). Researchers believe this incrementally higher erratic maneuver rate represents the consequences of the lower overall visibility that is generally available to drivers at night.

Although the findings presented in that report provide useful insights into the consequences of night work activities on roadway crashes, the numbers by themselves are insufficient for direct application in an overall assessment process such as that previously outlined from NCHRP *(3)*. In particular, the estimated increases in crash likelihood that occur during night work activity reflect the increased risk to a driver using that roadway facility when work activity occurs. In other words, a motorist using the roadway at night during the time that work activity is present does have a proportionally greater likelihood of being involved in a crash. However, although the implications of night work upon the risk to individual motorists is important, the more critical question that must be answered is whether this increased risk, when considered collectively among all those who travel on the facility over all of the periods of night activity required to complete the work, is greater than the overall risk had the work been performed during daytime periods. This shift in focus requires additional information and analysis not included in the interim report and is one of the subjects addressed in this report.

CONTENTS OF THIS REPORT

In this report, researchers describe development of an assessment framework to evaluate the safety consequences of performing highway work at night versus doing the same work during daytime periods. Researcher predicate the assessment on the calculation of total crash expectancy over the duration of a particular highway project to be performed, in contrast to evaluating the effects of night work upon individual driver crash risk as has previously been performed. In this report, researchers describe the various data requirements, analysis assumptions, and eventual evaluation results achieved. Researchers also present a step-by-step procedure to perform this type of analysis, which is also included as an appendix in the report.

In addition to the assessment framework, this report also describes an analysis of several countermeasures identified in the literature to potentially reduce higher nighttime crash risks caused by night work activities. Most of these countermeasures have not been evaluated in terms of their anticipated crash risk reduction benefits when deployed at active night work zone locations. Using the results of the assessment framework, researchers examined these countermeasures in terms of the crash reduction benefit (i.e., percent reduction in risk) that would be required to offset the additional costs of countermeasure implementation. This breakeven risk reduction percentage provides a “reasonableness” check of whether to adopt a particular countermeasure.

DEVELOPMENT OF THE NIGHT WORK RISK ASSESSMENT FRAMEWORK

OVERVIEW

Consideration of additional road user costs that would result under a particular traffic control strategy for a particular work zone activity has become a common component to highway agency decision making (*6*). Traditionally, road user cost calculations focused on driver delays and vehicle operating costs, largely ignoring the additional driver crash costs that may be attributable to the work zone (*7, 8*). Decision-makers often justified this exclusion because the period of work (day or night) being considered was the same for each of the alternatives. Therefore, the additional crash costs under each strategy scenario would be quite similar and need not be considered in the final analysis.

When considering the implications of working at night versus during the day, however, the differences in excess crash costs between strategies might actually be quite significant. Furthermore, it is not immediately clear whether the additional crash costs are greater during the daytime or at night. It is fairly well-known, for example, that normal (non-work zone) crash rates themselves are significantly higher at night than during the day (*9*). However, other studies have shown a relationship between higher traffic volumes (which typically exist during daylight hours) and higher crash rates (*10, 11*). In addition, traffic volume exposure is much higher during daylight hours than at night. With regard to work zone effects, the data reported in the interim report suggested that crash risk increased quite significantly at night when work activities were present and that erratic maneuvers at locations of traffic queuing were greater at night than at the same location during daytime conditions (*5*). Others have also suggested that lower traffic volumes, as are usually present at night, allow speeds to be higher and cause those crashes that do occur to be more severe.

In this chapter, researchers describe an overall assessment process that allows practitioners to objectively compare the safety consequences of performing a particular work activity either during daytime hours or as night work. Specifically, the process focuses on calculating the expected crash costs over the entire period of time required to complete the work activity under either scenario. By focusing on the total time required to complete a particular work activity, analysts can account for the differences in the duration of each work zone set-up during the day or at night. Obviously, longer work durations each night allows a project to be completed over fewer nights. The process relies on the availability of normal daytime and nighttime roadway crash rates for a particular facility, which the analyst then modifies by a percent increase to account for the additional crashes expected to occur as a result of having the work zone in place on that facility. The percentage increases used in the analysis are based on the previously-documented results of crash studies at several work zones where night work occurred, as well as observational studies of erratic maneuvers under daytime and nighttime queuing conditions (5).

THE CRASH ASSESSMENT MODEL

Mathematically, calculation of the additional crash risk expected due to the work activity that must be performed is as follows:

$$\#\ \text{Additional Crashes}_i = (\text{Rate}_i \times \Delta\text{Rate}_i \times L_i \times \text{Vol}_i \times N_i\ )\ /\ 10^{10} \quad (1)$$

where,

i = doing the work either during the daytime or at nighttime

Rate_i = normal (non-work zone) crash rate on the facility corresponding to when the work will be done, day or night (crashes per 100 million-vehicle-miles, or 100 mvm)

ΔRate_i = expected increase in crash rate due to the work activities being done during the day or at night (%)

L_i = length of a work zone set-up expected each day or night that work occurs (miles)

Vol_i = sum of the traffic volume expected to pass the work zone during each set-up for a daytime or nighttime work period (vehicles per set-up)

N_i = number of work zone set-ups that will be required to complete the work activity during the day or at night

Overall, the goal is to compute the additional number of crashes expected to result from doing work activities in either of the two candidate time periods. The two time periods differ significantly in terms of the amount of traffic that will utilize the roadway segment, the normal crash rates (or likelihood) that are expected on the roadway segment, and the effect that work activities during either time period are expected to have on crash likelihood. In the following paragraphs, researchers briefly discuss the estimation of each of these parameters.

Normal Daytime and Nighttime Crash Rates

Normal crash rates computed separately for daytime or nighttime work periods serve as the basis from which to estimate changes due to work activity. Crash rates per 100 million-vehicle-miles of exposure are a very common parameter used by highway agencies to evaluate the overall safety levels of roadway segments. Normal crash rates are fairly easy to calculate once information on number of crashes over a given road segment and the amount of traffic using that roadway segment over the time duration of interest (such as a year) are known. Some agencies regularly calculate the crash rates of the various facilities in their jurisdictions, but these are often full 24-hour rates and do not differentiate between daytime and nighttime periods, as is needed for this analysis.

Ideally, the practitioner will have site-specific crash data from which daytime and nighttime crash rates for a particular roadway segment can be calculated. The Crash Records Information System (CRIS) currently being implemented by TxDOT will provide much easier access to crash data and allow such calculations to be made. In lieu of site-specific data, however, researchers developed some default crash rate tables based on state-wide crash data from the years 1999 through 2001 (the latest years for which data were available at the time of analysis) and assumed potential time periods of work during the day or at night. Researchers computed default crash rate values on the basis of roadway type, time period, and roadway average daily traffic (ADT) ranges per lane. Researchers believe each of these factors is systematically correlated with crash risk, based on the available research literature *(10, 11)*. The results, shown in Tables 3 and 4, verify the systematic variations in crash rates for each of these factors.

Comparing across the annual ADT (AADT)/lane categories in Table 3, the crash rate increases by nearly a factor of four (from 39.0 to 128.9 crashes/100 mvm) during the day and by a factor of about three at night (from 61.8 to 186.1 crashes/100 mvm). In addition, the night crash rate at each AADT/lane level is about 40 to 60 percent higher than the corresponding crash rate for that level during the day.

Table 3. Typical Crash Rates on Texas Interstate Facilities, 1999-2001 (crashes per 100 million-vehicle-miles).

	AADT/Lane				
	0-4999	5000-9999	10000-14999	15000-19999	20000+
Day	39.0	50.3	78.2	84.3	128.9
Night	61.8	73.7	107.5	128.4	186.1

AADT = annual average daily traffic
Day = 9 am to 4 pm
Night = 7 pm to 6 am

Table 4. Typical Crash Rates on Texas US Highways, 1999-2001 (crashes per 100 million-vehicle-miles).

	AADT/Lane				
	0-4999	5000-9999	10000-14999	15000-19999	20000+
Divided-Day	56.3	77.3	77.4	103.5	94.7
Divided-Night	88.1	119.4	126.3	205.1	168.4
Undivided-Day	83.6	180.4	131.0	---	---
Undivided-Night	112.0	184.8	120.0	---	---

AADT = annual average daily traffic
Day = 9 am to 4 pm
Night = 7 pm to 6 am
--- = not enough data for an estimate

Similar results are evident for both divided and undivided US highways, as shown in Table 4. It is interesting to note that the crash rates at the highest AADT/lane levels are actually slightly lower than those for the next highest level. Researchers hypothesize that more of the highway segments at the highest volume level are actually facilities in urban areas that have been upgraded to near interstate roadway geometric conditions (i.e., US 290 in Houston, US 281 in San Antonio, etc.). Consequently, researchers expected the crash rates on the highest-volume facilities to be more in line with those in Table 3, which indeed they are.

One would expect that use of different beginning and ending times for each day or night period would yield slightly different crash rate values. Similarly, separation of the data between weekdays and weekends would also yield slightly different rates. Therefore, the values presented in Tables 3 and 4 should be considered approximations only. Local data based on actual expected alternative work times day and night should be used whenever possible for a more accurate estimate.

Expected Increase in Crash Rates Due to Work Activity in Each Time Period

In a previous report, researchers reported on the percent change in crash likelihood during nights of actual work activity at a sample of work zones in Texas (*5*). Researchers calculated this change via a before-during comparison of crashes on nights of actual work activity, using a comparison section close to each work zone to estimate the expected change in crash likelihood (*12*). Since the comparison sites were on the same roadways as the work zones (just a short distance away), researchers believed these percentage changes were equivalent to the changes in crash rates that would have been observed at each site had actual traffic volume data been available both before and during the conduct of the work. Researchers re-recreated the results of that analysis in Table 5.

Table 5. Change in Total Crash Frequencies at Project Locations (5).

Project	Daytime		Nighttime		Overall Change During Project
	WZ Active	WZ Inactive	WZ Active	WZ Inactive	
H1	+35.3%*	+5.9%	-22.8%	+60.4%*	+28.8%**
H2	+40.6%	-11.7%	+496.8%	+48.7%	+32.9%*
H3	+32.1%	-30.2%*	+49.2%	+57.3%	-0.7%
H4	+87.5%**	+29.0%	+22.3%	-0.3%	+29.9%**
H5	+28.9%**	+38.0%**	+262.8%**	+63.2%**	+42.3%**
H1-H5 Combined	+36.5%**	+14.0%	+102.2%**	+48.7%**	+31.5%**
R1			+117.1%	+18.8%	+48.7%
R2			+15.9%	-2.8%	+1.1%
R1-R2 Combined			+55.4%	+2.1%	+13.4%

* Changes in crash frequencies are significantly different (α = 0.10)
** Changes in crash frequencies are significantly different (α = 0.05)
WZ = work zone
H1-H5 = hybrid projects, work activity both day and night (work in travel lanes limited to night)
R1-R2 = resurfacing projects, work activity only at night

The results of that analysis implied that night work activity does indeed have a fairly significant effect on the likelihood of a crash occurring relative to the likelihood that exists under normal nighttime conditions. Considering all hybrid projects together, researchers estimated a 102 percent increase in crash likelihood when work activities were performed at night. However, researchers noted that these same projects also experienced a 49 percent increase in crash likelihood during construction on those nights when work activity was not occurring. Researchers speculate that this latter increase is due primarily to temporary geometric restrictions required during the project, and is not indicative of the influence of actual night work activity. Therefore, researchers estimate that the true impact of night work activity at those projects is actually the difference between those two increases (102.2 percent – 48.7 percent), or a 53.5 percent increase in crash likelihood due to the work activity. Interestingly, this value was very close to the increases computed for the two resurfacing projects examined (55.4 percent). At the resurfacing projects, roadway geometrics were not altered when work was not occurring. Therefore, the researchers believe that the increases at those two sites are indicative of the influence of work activity at night. The fact that the crash increase at night when work was not occurring at those projects was negligible (2.1 percent) lends further support to this belief. Based on these (albeit limited) results, researchers decided not to differentiate between hybrid projects commonly associated with major roadway reconstruction, and resurfacing or rehabilitation projects that are completed using only temporary lane closures on nights of activity. Although the total number of additional crashes that occur during night work activity on these two types of projects may be substantially different, the amount attributable to the presence of work crews in the travel lanes on certain nights of activity appears to be quite similar.

Researchers did note a wide range in crash likelihood change from project to project. A plot of these changes in crash likelihood during night work versus the AADT/lane at each project suggests that crash rate increases during night work activity were greater at the sites with the higher levels of AADT/lane (see Figure 1). This may signify that traffic congestion and queues created at night during all or part of the night work periods may have been partially responsible for these crash rate increases. Unfortunately, the project diary information for these projects was not detailed enough to determine whether queuing at night during work activities was prevalent at these locations and subsequently led to the larger increases in crashes. Regardless of the data limitations, it is evident that night work activities on high-volume roadway segments may warrant even more special attention than is normally given (i.e., extra enforcement, additional warnings to traffic farther upstream, etc.) to combat the proportionally greater increases in crashes at these types of sites.

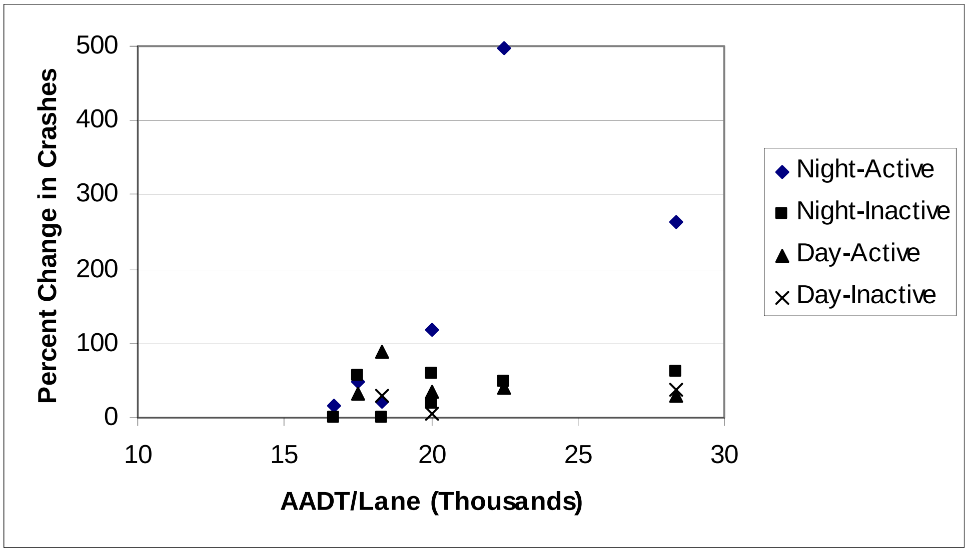


Figure 1. Changes in Crash Likelihood versus AADT/Lane for Hybrid Projects.

Another key piece of data needed for this analysis is an estimate of the effects of doing work in the travel lanes at each of these project locations during the daytime upon crash likelihood, as was done for the night work. Unfortunately, such a direct comparison is not possible, as the main reason for doing the work at night at these projects was to avoid creating the congestion and delays due to lane closures during the day. The crash increases shown in Table 5 for daytime activity are strictly the result of the restrictive geometrics present at each site and possibly some distraction effects of work activities occurring out of the travel lanes.

Without actual daytime crash data from these projects during times of work activities in the travel lanes, researchers relied on other means to estimate the potential impact of daytime work activities in travel lanes (similar to the work that was done at night) upon crash likelihood. Ultimately, researchers relied on the results of the observational studies of night work zones and other data for this estimate. The results of the observational studies, again reported in the interim report, indicated the following (5):

- Erratic maneuvers at the upstream end of a traffic queue due to a recurrent bottleneck occurred 26 percent more frequently under nighttime conditions than under daytime conditions at the same location. Presumably, this higher rate reflects the fact that drivers at night have more difficulty judging vehicle speeds in front of them or recognizing when traffic has queued and/or are not as mentally prepared for the presence of a traffic queue than under daytime conditions.
- Unexpected traffic queues such as those that occur at temporary work zone lane closures and at incidents may result in four times more erratic maneuvers as traffic queues that occur regularly at bottleneck sites and thus are generally expected by the motoring public. Researchers based this statement upon a comparison of data collected at daytime work zone and recurrent bottleneck sites, but believe that similar results would occur under nighttime conditions as well.
- Even when nighttime work zone lane closures do not create significant traffic queues at a location, the unexpected nature and characteristics of the work can result in erratic maneuver rates that approach rates observed at locations where traffic queues develop at recurrent bottleneck sites at night.
- Comparing daytime work zone lane closures with traffic queues to nighttime work zone lane closures without traffic queues, researchers estimate that the erratic maneuver rate (and by inference, crash potential) is six times lower at night without queues than during the day with queues.

Of these results, the 26 percent increase in erratic maneuver rates between nighttime and daytime conditions is the most conservative for use in this assessment process. The other findings, while important, are based on very limited data and so will require additional validation before it is appropriate to use them in any type of analysis. Therefore, researchers suggest using the following values for $\Delta Rate_i$ in the assessment process at this time:

- $\Delta Rate_{Night}$ = +53.5%
- $\Delta Rate_{Day}$ = +42.2%

Certainly, it is possible that the above estimates of increased crashes expected during work activities in the travel lanes under daytime conditions would be much higher than those at night if the daytime conditions generated a sizeable traffic queue that would not also form at night. Obviously, such a scenario is not reflected in the suggested rate adjustments above. However, until additional data become available, the values recommended above provide at least a conservative basis of comparison between the two potential work periods. As researchers will demonstrate later in this chapter, these conservative estimates of crash risk changes are still overshadowed by much different vehicle exposure characteristics between the daytime and nighttime work periods.

Length and Number of Work Zone Set-ups Required to Complete the Work Activity

One of the keys to properly understanding and interpreting the results obtained through this assessment is to utilize equivalent bases of comparison between doing work during the day versus doing the same work at night. Basing the calculations on the total completion time of the specific work activity of interest accomplishes this most easily. In essence, this approach is equivalent to utilizing a life-cycle cost analysis for determining which roadway investment alternative is more appropriate. Engineers utilize life-cycle cost analysis to account for differences in not only initial costs of alternatives but in corresponding service lives, rehabilitation costs, etc. over an entire analysis horizon of interest (*6*). A life-cycle type of approach is needed for this assessment because it may take different numbers of days or nights to fully complete the work, depending on how long during each day or night period the contractor is allowed to be in the travel lanes. One of the key advantages of working at night (other than in avoiding daytime traffic volumes) is the potential to utilize longer work periods (*13*). Longer work periods reduce the total number of traffic control set-ups and take-downs required and can slightly reduce the overall duration of the work activity required. Even disregarding the differences in the number of traffic control set-ups, the fact that longer periods of work are available each night relative to what is typically available during a single day implies that it will take more day periods than night periods to complete a particular work activity. Production rates, properly adjusted for the slightly more difficult working conditions at night, can be used to estimate the number of day or night periods that will be required to complete a particular work activity.

The process also requires an average or approximate length of work activity per each day or night period to calculate the vehicle-miles of exposure to the work zone. For spot locations, this might be the same during the day or at night and may simply represent the amount of roadway required for channelizing devices for the lane closure(s) and work zone. For activities that move longitudinally along the roadway such as overlays, the entire length of the project may be the more appropriate length to use. Some evidence does suggest that crashes in work zones are not necessarily distributed evenly over the entire work zone length, but may instead be consolidated around those specific areas where work is actually occurring (*11*). However, the connection between how these crash "clusters" relate to crash rates on a facility or the increases caused by a work zone has not been established at this time. Furthermore, work zone activity has a distracting or "rubber-necking" effect upon drivers traveling in both directions of travel, and so could adversely affect crash rates in locations even some distance away. Therefore, researchers recommend that the entire length of a work zone set-up on a given day or night be used in this assessment process. The units of length are in miles so as to maintain compatibility with the normal crash rate values used in these calculations.

Traffic Volumes Traveling Past the Work Zone

The final component needed to complete the assessment is an estimate of the amount of traffic that approaches and passes by the work zone each time it is set up (day or night). This traffic volume, when multiplied by the length of the work zone and the number of set-ups required to complete the work activity, yields an estimate of total vehicle miles of exposure for the work activity. As depicted in Equation 1, vehicle exposure multiplied by the assumed crash rate per 100 mvm on the facility multiplied by the percentage increase in the normal crash rate assumed to result from the presence of the work zone results in the number of additional crashes attributable to the work zone activity itself.

As with the normal crash rates under daytime and nighttime conditions for a particular roadway segment, actual traffic volume data over the periods of time each day or night of interest would be preferable in this analysis. Unfortunately, such data are generally not available. Certain high-volume facilities in the major urban areas in Texas do have or will eventually have instrumentation in place on the roadway to count and record hourly (or even more finely disaggregated) traffic volume data over the course of a 24-hour period. For other roadway segments, however, an analyst must approximate the volumes in some manner for use in the assessment.

Although hour-by-hour traffic counts are not available for much of the roadways state-wide, estimates of AADT do exist. These estimates, developed by the Transportation Planning and Programming (TPP) division at TxDOT, represent a statistical approximation based on assumed trends, spot sampling of counts on selected roadways, and a limited number of permanent automatic traffic recorder (ATR) stations. The ATR information is generally available in annual summary reports or in electronic files from the division. Meanwhile, the combination of these data sources provides a general estimate of the AADT on each roadway segment that can be accessed from the state-wide roadway inventory (RI) file, also maintained by TxDOT. It is fairly common knowledge that these AADT estimates in the RI file can deviate significantly from actual volumes on the facility. Furthermore, the estimates are provided in fairly broad 10,000 vehicle-per-day (vpd) increments. Nevertheless, they offer at least a general indication of traffic demands on a particular roadway segment that can be employed in this type of assessment.

If only an AADT estimate is available, an analyst must adjust that value to reflect the amount of traffic that actually passes by the work zone during the hours that the work zone is present. The simplest approach to accomplishing this is to rely on the ATR data from nearby count stations for hourly volume distribution percentages as a function of the AADT value. Researchers present an example of such a distribution for interstate highways in Table 6. These values, based on a sample of 10 interstate highway ATR stations state-wide, describe the hourly percentages of AADT that typically utilize a particular interstate highway segment. The analyst can estimate volumes during specific day/nights and time periods, depending on the desired level of detail. Hourly percentages of AADT are fairly consistent Monday through Friday, but are somewhat different on the weekend (as expected). If only a general estimate of the volumes is needed, the analyst should use an overall hourly distribution such as shown in the far right column of Table 6. Researchers provide a similar table for US highways as Table 7.

Table 6. Percent of ADT That Occurs Each Hour of the Day (Interstates). [a]

Hour	SUN	MON	TUE	WED	THU	FRI	SAT	M-F	ALL
12-AM	2.3%	1.3%	1.1%	1.1%	1.2%	1.2%	2.0%	1.1%	1.4%
01-02	1.6%	0.8%	1.2%	0.8%	0.8%	0.8%	1.4%	0.9%	1.0%
02-03	1.4%	0.7%	0.7%	0.7%	0.8%	0.8%	1.2%	0.7%	0.9%
03-04	0.9%	0.6%	0.6%	0.6%	0.6%	0.6%	0.8%	0.6%	0.7%
04-05	0.8%	0.9%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
05-06	1.0%	2.1%	2.1%	2.0%	1.9%	1.7%	1.3%	2.0%	1.7%
06-07	1.4%	4.7%	4.9%	4.7%	8.1%	3.8%	2.2%	5.3%	4.3%
07-08	1.9%	6.7%	7.0%	6.8%	6.4%	5.6%	3.2%	6.5%	5.4%
08-09	2.7%	5.7%	5.9%	5.8%	5.5%	5.0%	4.2%	5.6%	5.0%
09-10	4.0%	5.1%	5.1%	5.0%	4.8%	4.7%	5.1%	4.9%	4.8%
10-11	5.1%	5.2%	5.1%	4.9%	4.8%	4.9%	5.9%	5.0%	5.1%
11-12	5.9%	5.6%	5.3%	5.2%	5.1%	5.3%	6.4%	5.3%	5.5%
12-PM	6.8%	5.8%	5.5%	5.4%	5.3%	5.6%	6.6%	5.5%	5.8%
01-02	7.3%	5.9%	5.6%	5.6%	5.4%	5.8%	6.6%	5.7%	6.0%
02-03	7.5%	6.2%	5.9%	5.9%	5.7%	6.2%	6.7%	6.0%	6.3%
03-04	7.6%	6.6%	6.5%	6.4%	6.3%	6.7%	6.7%	6.5%	6.7%
04-05	7.7%	7.3%	7.2%	7.1%	6.9%	7.1%	6.6%	7.1%	7.1%
05-06	7.6%	7.7%	7.8%	7.7%	7.4%	7.3%	6.5%	7.6%	7.4%
06-07	6.9%	6.1%	6.2%	6.2%	6.0%	6.5%	6.1%	6.2%	6.3%
07-08	5.8%	4.5%	4.5%	4.6%	4.6%	5.4%	5.3%	4.7%	4.9%
08-09	4.7%	3.5%	3.6%	3.7%	3.7%	4.4%	4.4%	3.8%	4.0%
09-10	3.9%	3.0%	3.2%	4.8%	3.3%	3.8%	4.0%	3.6%	3.7%
10-11	3.1%	2.3%	2.4%	2.5%	2.6%	3.3%	3.5%	2.7%	2.8%
11-12	2.1%	1.6%	1.6%	1.8%	1.8%	2.5%	2.7%	1.9%	2.0%

[a] Average from the following ATR stations: S004, S040, S125, S145, S149, S171, S186, S204, S215, and S224

Table 7. Percent of ADT That Occurs Each Hour of the Day (US Highways). [a]

Hour	SUN	MON	TUE	WED	THU	FRI	SAT	M-F	ALL
12-AM	1.5%	1.2%	1.1%	1.1%	1.1%	1.1%	1.8%	1.1%	1.3%
01-02	1.0%	0.9%	0.9%	0.9%	0.9%	0.8%	1.3%	0.9%	0.9%
02-03	0.8%	0.7%	0.7%	0.7%	0.8%	0.7%	1.0%	0.7%	0.8%
03-04	0.6%	0.7%	0.7%	0.7%	0.7%	0.7%	0.9%	0.7%	0.7%
04-05	0.7%	1.1%	1.0%	1.0%	1.0%	0.9%	1.0%	1.0%	0.9%
05-06	0.8%	1.9%	1.8%	1.8%	1.7%	1.4%	1.4%	1.7%	1.5%
06-07	1.3%	3.4%	3.4%	3.4%	3.2%	2.6%	2.3%	3.2%	2.8%
07-08	2.0%	5.2%	5.5%	5.5%	5.2%	4.2%	3.6%	5.1%	4.4%
08-09	3.0%	5.3%	5.6%	5.5%	5.3%	4.5%	4.9%	5.2%	4.9%
09-10	4.5%	5.8%	5.9%	5.8%	5.7%	5.1%	6.1%	5.6%	5.6%
10-11	5.6%	6.2%	6.2%	6.1%	6.0%	5.5%	6.9%	6.0%	6.1%
11-12	6.5%	6.5%	6.2%	6.2%	6.1%	5.8%	7.1%	6.2%	6.3%
12-PM	7.2%	6.5%	6.1%	6.1%	6.1%	5.9%	7.0%	6.2%	6.4%
01-02	7.7%	6.8%	6.5%	6.4%	6.3%	6.3%	6.8%	6.5%	6.7%
02-03	7.9%	6.9%	6.7%	6.6%	6.6%	6.7%	6.7%	6.7%	6.9%
03-04	8.0%	7.1%	6.9%	6.9%	6.9%	7.0%	6.6%	7.0%	7.0%
04-05	7.9%	7.2%	7.2%	7.2%	7.3%	7.4%	6.4%	7.3%	7.2%
05-06	7.7%	7.1%	7.2%	7.3%	7.2%	7.6%	6.0%	7.3%	7.2%
06-07	6.9%	5.6%	5.7%	5.8%	5.9%	6.8%	5.5%	6.0%	6.0%
07-08	5.9%	4.3%	4.3%	4.4%	4.6%	5.5%	4.7%	4.6%	4.8%
08-09	4.7%	3.4%	3.5%	3.6%	3.8%	4.4%	3.9%	3.8%	3.9%
09-10	3.5%	2.8%	2.9%	3.0%	3.2%	3.6%	3.3%	3.1%	3.2%
10-11	2.6%	2.2%	2.3%	2.3%	2.5%	3.1%	2.7%	2.5%	2.5%
11-12	1.7%	1.6%	1.6%	1.7%	1.8%	2.3%	2.0%	1.8%	1.8%

[a] Average from the following ATR stations: S015, S016, S025, S029, S033, S043, S072, S074, S102, and A328

Comparison of the hourly percentages between daytime and nighttime periods emphasizes the substantial reduction in vehicle exposure to the work zone that occurs at night. For example, summing the average M-F hourly percentages between the hours of 9 am and 3 pm (a common period of work activity) indicates that 32.4 percent of the AADT on a facility will use the facility during this 6 hour period of time. Conversely, the summation of percentages between 7 pm and 6 am (a common period of work activity at night on a higher volume facility) indicates that only 22.8 percent of the AADT will use the facility during this much longer 10 hour period of time. In other words, during a 67 percent longer period of time, the work zone is exposed to 30 percent less traffic. If both periods of comparison are the same (6 hours) and work is started either at 9 am or at 10 pm, the amount of traffic passing by the work zone at night will be 74 percent less than it would have been during the daytime hours.

APPLICATION EXAMPLES OF THE ASSESSMENT PROCESS

Perhaps the easiest way to understand the application of the assessment process is through a series of sample applications. In this section, researchers describe and analyze two hypothetical scenarios using the process and data previously listed.

Example 1

Scenario

In the first example, researchers assume that a 3-mile resurfacing project planned on a six-lane interstate facility that serves approximately 140,000 vehicles per day. Researchers further assume that this job requires 300 work-hours to complete. If the crew works during the day between 9 am and 3 pm (6 hours), they will require 50 day periods to complete the work. Conversely, the crew will need only 28 nights to complete the work if they begin at 7 pm and work until 6 am each night (11 hours). Finally, if the crew waits until 10 pm at night to begin and works until 6 am (8 hours), they will need 38 nights to complete the work. Each of these estimates ignores the differences in total work time resulting from additional installation and removal times for traffic control in the daytime work option as compared to the night work options. How are traffic crashes likely to be affected by each option?

Normal Crash Rates

Researchers estimate the normal crash rate on facility using the default values in Table 3 for an interstate highway with ADT/lane = 140,000/6 =23,333 vehicles per day per lane. From Table 3, the normal crash rates on the facility are:

- 128.9 crashes per 100 mvm during daylight hours, and
- 186.1 crashes per 100 mvm during nighttime hours.

Increase in Crash Rate Due to Work Zone

During the daytime work period, researchers estimate that the normal crash rate will increase by 42.2 percent when work occurs during the day or by 53.5 percent when work occurs at night. Researchers multiply these factors by the normal crash rates and determine the following expected increases in crash rates during work activity:

- 54.4 additional crashes per 100 mvm during daylight hours, and
- 99.5 crashes per 100 mvm during nighttime hours.

Amount of Traffic Encountering the Work Zone

From Table 6, researchers estimate that the following traffic volumes pass by the work zone during each period in the daytime or the nighttime:

- between 9 am and 3 pm, 32.4 percent of the AADT passes the work zone, equivalent to 45,360 vehicles per daytime period;
- between 7 pm and 6 am, 22.8 percent of the AADT passes the work zone, equal to 33,040 vehicles per nighttime period; and
- between 10 pm and 6 am, only 10.7 percent of the AADT, or 14,980 vehicles, passes the work zone during this shorter nighttime period.

Calculations

Using these estimates and the other values as noted at the beginning of the example, researchers calculate the following crash consequences for each work zone option.

- Working during the day: (54.4 crashes/100,000,000 vehicle miles) × 45360 vehicles × 3 miles × 50 day periods = **3.7 additional crashes while work occurs.**
- Working at night (7 pm to 6 am): (99.5 crashes/100,000,000 vehicle miles) × 33040 vehicles × 3 miles × 28 day periods = **2.7 additional crashes while work occurs.**
- Working at night (10 pm to 6 am): (99.5 crashes/100,000,000 vehicle miles) × 14980 vehicles × 3 miles × 38 day periods = **1.6 additional crashes while work occurs.**

Therefore, researchers conservatively estimate that working at night yields fewer additional crashes than doing the work during the day in this example. This benefit is realized even though the actual crash rates are more affected at night than in the daytime. Furthermore, the analysis implies that delaying the start of work each night until 10 pm would result in still fewer crashes than starting at 7 pm, even though this will require more nights to complete the work.

Example 2

Scenario

In the next example, researchers assume that a concrete patching job involves 10 locations where it will be necessary to close a lane for 6 hours at a time (the amount of time needed is the same for both day and night). The traffic control for each set-up is approximately 1 mile. It is a four-lane divided US highway facility that serves approximately 70,000 vehicles per day. Researchers assume it is possible to perform the work during the day between 9 am and 3 pm or at night beginning at 7 pm and ending at 1 am. How are traffic crashes affected by each option?

Normal Crash Rates

Researchers estimate the normal crash rate on the facility using the default values in Table 4 for US highways with ADT/lane = 70,000/4 =17,500 vehicles per day per lane. The corresponding normal crash rates on this type of facility are:

- 103.5 crashes per 100 mvm during daytime hours, and
- 205.1 crashes per 100 mvm during nighttime hours.

Increase in Crash Rate Due to Work Zone

Data are not available regarding the crash consequences of night work on US highways. Therefore, researchers used the changes observed at the interstate facility sites. During the daytime work period, researchers estimated that the normal crash rate increases by 42.2 percent when the work crew is present. Similarly, researchers estimate that crashes increased by 53.5 percent when the work crew is present at night. Researchers then multiplied these factors by the normal crash rates to determine the following estimates of the additional crash rates expected during work activity:

- 43.5 additional crashes per 100 mvm during daylight hours, and
- 109.7 crashes per 100 mvm during nighttime hours.

Amount of Traffic Encountering the Work Zone

From Table 7, researchers estimate the following traffic volumes pass by the work zone during each period in the daytime or the nighttime (Monday through Friday averages are assumed to be appropriate for this situation):

- between 9 am and 3 pm, 37.1 percent of the AADT passes the work zone (25,970 vehicles) per daytime period; and
- between 7 pm and 1 am, 17.1 percent of the AADT passes the work zone (11,970 vehicles) per nighttime period.

Calculations

Using these estimates and the other values as noted at the beginning of the example, researchers estimate the following crash consequences for each work zone option.

- Working during the day (9 am to 3 pm): (43.5 crashes/100,000,000 vehicle miles) × 25,970 vehicle × 1 mile × 10 day periods = **0.1 additional crashes while work occurs.**
- Working at night (7 pm to 1 am): (109.7 crashes/100,000,000 vehicle miles) × 11,970 vehicle × 1 mile × 10 night periods = **0.1 additional crashes while work occurs.**

In this example, these conservative results indicate that there is no difference in terms of the safety consequences of doing the work during the day or at night. The decision whether to do the work during the day or at night needs to be based on other factors such as mobility concerns, characteristics of the work to be accomplished, neighborhood and business concerns, etc.

GENERAL TRENDS IN ADDITIONAL WORK ZONE CRASHES FOR DAY VERSUS NIGHT WORK

In both of the previous examples, the assumption of a greater increase in crash rates during night work relative to day work did not translate to a greater number of additional crashes expected during work activities at night compared to daytime work activities. Instead, the much lower traffic volumes exposed to work activities during nighttime hours more than compensated for the assumed higher crash rates due to work activities. As indicated by the graph presented in Figure 2, such results are expected to almost always occur for interstate facilities. In this figure, researchers assumed periods of work activity (9 am to 4 pm for daytime work, 7 pm to 6 am for nighttime work) and calculated additional expected crashes due to work activity, normalized to a per-100-work-hours-per-lane basis. As the graph illustrates, additional crashes due to work zones will almost always be higher (and substantially so) if the work is done during the daytime as compared to doing the work at night. At low AADT per lane levels, estimated differences in the additional crashes that would occur during the day versus at night are extremely small. As the AADT/lane increases, the differences in crash rates become more evident. However, in all cases, the additional crashes expected on a per 100 work hours/lane/mile basis are higher for daytime conditions than at night.

The picture is less clear when considering US highways (divided). Using the same assumed increases in crash rates during work as in Figure 2 and the default crash rates for divided US highways from Table 4, one sees that the calculated normalized additional crashes due to work activity are higher at night than during daytime conditions for the higher AADT/lane levels. This is primarily due to much higher normal crash rates on these facilities at night. The magnitude of the difference is small at each AADT/lane level and would likely not be significant for all but the most lengthy of projects. However, it does imply that the decision whether to do the work at night might need to consider the implications on traffic safety more carefully.

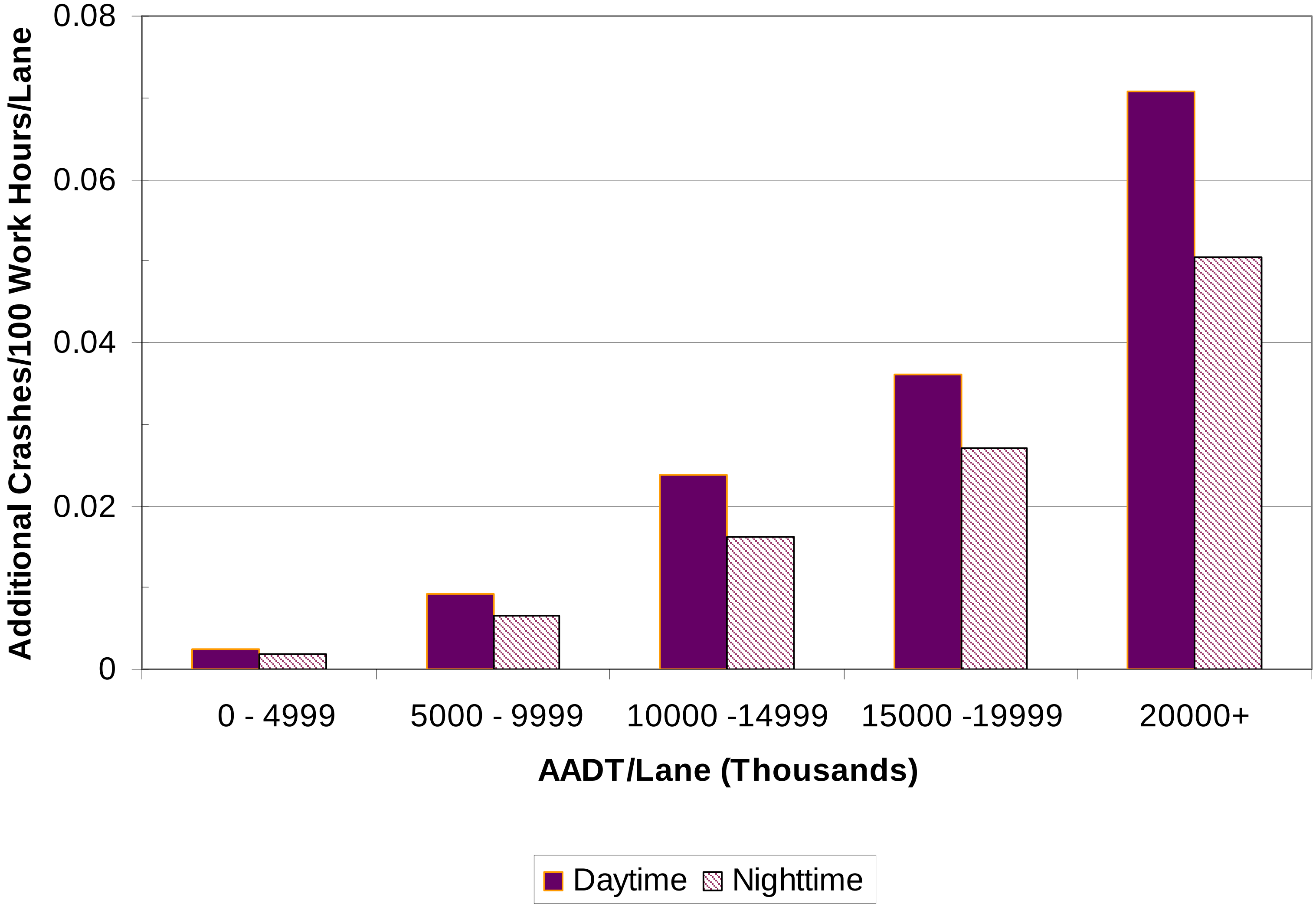


Figure 2. Additional Crashes Due to Work Zones, Normalized by Work Duration, Interstates.

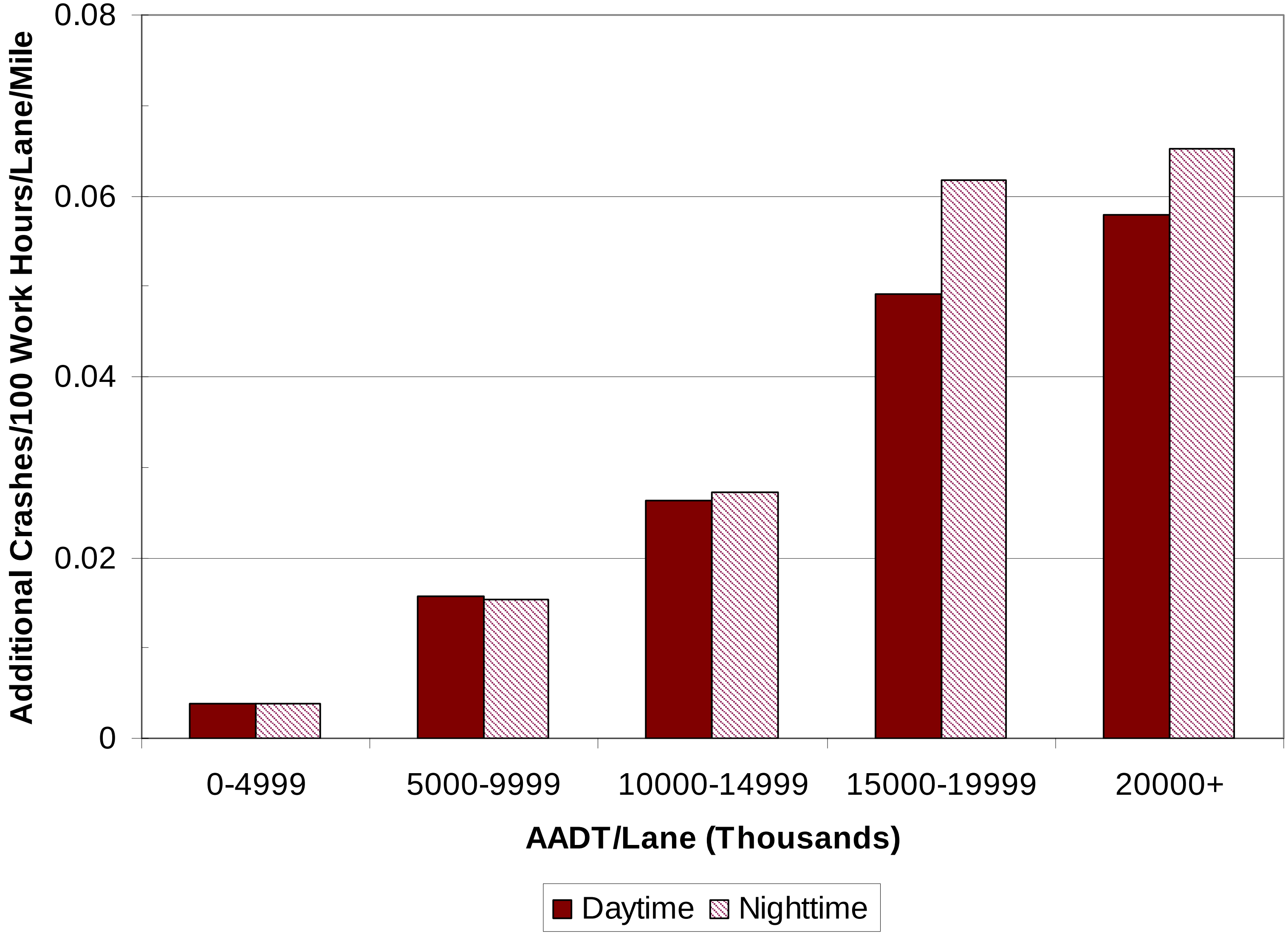


Figure 3. Additional Crashes Due to Work Zones, Normalized by Work Duration, Divided US Highways.

To reiterate, these analyses are based on very conservative estimates of how daytime crash rates might be affected by performing work activities during the day on high-volume roadways. The assumption used here is that the increase in crash rate due to the work activity would be greater at night than during the day. In reality, it might indeed be the opposite, with the presence of a traffic queue during the day leading to a much greater percentage increase in crashes than at night. Unfortunately, it was not possible to estimate what impact a daytime work zone that creates a traffic queue would have on crashes within the time and budget limitations of this project. Fortunately, an ongoing NCHRP project is underway that will hopefully provide data on this issue (*14*). If that project is successful, the assessment process outlined in this chapter would still be valid. The increase in crash rate, ΔRate for daytime conditions, would simply need to be changed to better reflect the conditions expected during work activity.

IDENTIFICATION AND EVALUATION OF POTENTIAL SAFETY COUNTERMEASURES FOR NIGHT WORK ACTIVITY

Although the findings described in the previous chapter indicate that performing work at night (as compared to daylight hours) may not result in dramatically higher numbers of additional crashes compared to daytime crashes, TxDOT has an ongoing desire to improve safety in all types of work zones, including those performed at night. As part of the research activities for this project, researchers identified a number of potential countermeasures proposed to reduce crash risks in nighttime work zones. The list of potential countermeasures, developed based on the observational studies discussed in the interim report (*5*) and on a review of the recent NCHRP guidelines pertaining to night work activities (*4*) consist of the following:

- additional signs and channelizing devices in the work zone to ensure adequate guidance and warning to motorists at night,
- specification of additional enforcement upstream of the work zone,
- highly-mobile worker protection devices,
- active queue presence warning systems,
- vehicle arrestor nets at total freeway closures or ramp closures, and
- formal lighting plans for active night work zones.

In this chapter, researchers discuss each of these countermeasure categories in terms of expected costs and necessary crash reduction benefits required to make their implementation worthwhile at night work zones in Texas.

USE OF ADDITIONAL TRAFFIC CONTROL IN THE WORK ZONE

The authors of NCHRP Report 476 present a lengthy discussion of the potential difficulties that motorists can face in safely negotiating a highway work zone at night. They mention issues pertaining to reduced overall visibility, lower expectancy of a work zone at night, higher speeds, and greater incidences of impaired driving. The authors addressed some of these concerns by recommending additional signs in the advance warning area to provide greater warning distances, reduced channelizing device spacing to provide a stronger visual indication of proper temporary travel paths, and channelizing devices installed transversely across closed travel lanes as warnings for drivers who inadvertently enter into a closed lane (*4*). In essentially all cases, the authors base their recommendations on engineering judgment and years of field experience rather than on any type of controlled study of countermeasure effects upon driver behavior or safety. Adoption of these recommendations appears to be lagging, which researchers believe is due in large part to the fact that practitioners have not been able to objectively assess whether the recommended devices and their associated costs are likely to yield improvements in behavior and safety that are at least comparable to their implementation costs.

Among the various recommendations included in the NCHRP 476 guidance, two were considered by project researchers to initially have merit for possible consideration by TxDOT. These are as follows:

- reduced channelizing device spacing on lane closure tapers and tangents in the work zone, and
- transverse channelizing devices or barricades positioned laterally across the closed lane approximately every 750 feet.

Other recommendations, such as ensuring that advance warning signs begin one mile upstream of a closure and that portable changeable message signs be considered for use, are already part of TxDOT standards (at least for high-speed freeway facilities).

Typical drum spacing in work zones, as recommended in the *Manual on Uniform Traffic Control Devices* (MUTCD), is the speed limit multiplied by two (*15*). In NCHRP 476, the authors recommend that this spacing be reduced to equal the actual operating speed, with a maximum spacing of 40 feet. This spacing would be applicable to both the taper and tangent areas of the lane closure. For a "typical" 1-mile work zone that includes a 4500-foot tangent section and a 780-foot taper corresponding to a 65 mph operating speed on an interstate facility, adopting a shorter barrel spacing requires more than double the normal number of drums (from 47 in the MUTCD approach to 133 drums following the NCHRP 476 approach). Using a daily rental and set-up cost of $2.50 per day (as quoted by a local traffic control device rental agency), the additional drums would increase the traffic control costs of a lane closure set up by $215 per night.

NCHRP 476 authors also recommend the use of mid-lane transverse barricades to be placed at regular intervals along a closed lane in a nighttime work zone. These devices provide visual cues and physical obstacles to alert motorists that have inadvertently entered a closed lane to move back out of the work area. The NCHRP authors recommend placement of either two channelizing devices (e.g. drums) in the lane or one larger type III barricade every 750 feet. At this spacing, a 4500-foot work zone tangent would potentially have five transverse barricade locations. Again using the daily rental cost quote of $2.50 per night per drum, this enhancement would require an additional $25 per night. Therefore, the combined estimated additional cost of these two changes for a lane closure of this length would be $240 per night. Obviously, longer lane closures would involve proportionately higher additional costs. Current TxDOT unit bid prices for lane closures (including signs, channelizing devices, arrow panels, and installation) are about $547 per day (*16*). Therefore, the calculations of these additional costs to reduce barrel spacing and add transverse barrels periodically in the closed lane appear to be reasonable.

Without available performance data to judge the expected crash reduction benefits that could be achieved by adopting these recommendations, the next best option is to compare these costs against the additional increases in night work crashes calculated in the previous chapter. Specifically, it is possible to determine the extent to which the additional devices would need to reduce the additional work zone crashes expected in order to offset the costs of implementation. The results of such an analysis are presented in Table 8. For purposes of this analysis, researchers assumed a standard crash cost of $63,800. This value reflects the FHWA-recommended crash cost values (*17*) updated to 2004 dollars and adjusted for the distribution of fatal-injury-property damage only (PDO) crashes observed at the work zones investigated in the interim report (*5*).

The results shown in Table 8 are somewhat surprising. Researchers expected that the small additional costs associated with installation of additional devices into a traffic control set-up would be easily recouped with even a minor improvement in estimated safety. However, the results show that the additional crash costs estimated to be attributable to a night work zone (based on the assessment process in the previous chapter) at the lower AADT/lane levels do not even cover the additional costs of these devices. At the higher AADT/lane levels, expected additional crash costs due to the night work are higher than the additional costs of the devices, but not tremendously so. In fact, as the last column of Table 8 shows, the additional devices would have to be able to reduce the additional crashes expected in the night work zone by almost one-third in order to justify them on the basis of crash cost savings.

Table 8. Comparison of Additional Crash Costs at Night Work Zones to Costs of Adding More Drums in the Traffic Control Plan (Interstates)

AADT/Lane (Thousands)	Additional Crashes Expected Due to Work Zone Per Night	Additional Crash Costs Expected Due to Work Zone Per Night	Reduction in Additional Crash Costs Needed to Offset Costs of Devices
2,500	0.000205	$26.12	NA
7,500	0.000732	$93.38	NA
12,500	0.001780	$227.08	NA
17,500	0.002976	$379.76	63%
22,500	0.005546	$707.72	34%
27,500	0.013558	$864.98	28%
32,500	0.016023	$1,022.26	24%

NA = results not applicable. Additional crash costs do not exceed cost of device implementation.

Researchers believe that the estimates with regards to the additional crash costs created by the presence of a night work zone are somewhat conservative in Table 8. Even so, the likelihood that closer drum spacing and the addition of transverse drums in the closed lane would be able to reduce crash costs by enough to justify their use economically appears small. Therefore, TxDOT should consider the use of these additional devices only on a case-by-case basis at this time if engineering judgment deems it warranted for a particular application.

SPECIFICATION OF ADDITIONAL ENFORCEMENT

Enforcement can play many roles at a nighttime work zone. Two specific roles outlined in the NCHRP 476 report pertain to lane closure enforcement and speed management. In the role of lane closure enforcement, the presence of a police cruiser in areas near a closure ensures that no unauthorized vehicles enter the work area. The officer should be in communication with other police and with the construction crew to provide information either of vehicle intrusions or other erratic motorist behaviors. Placement of this vehicle must be considered with extreme caution.

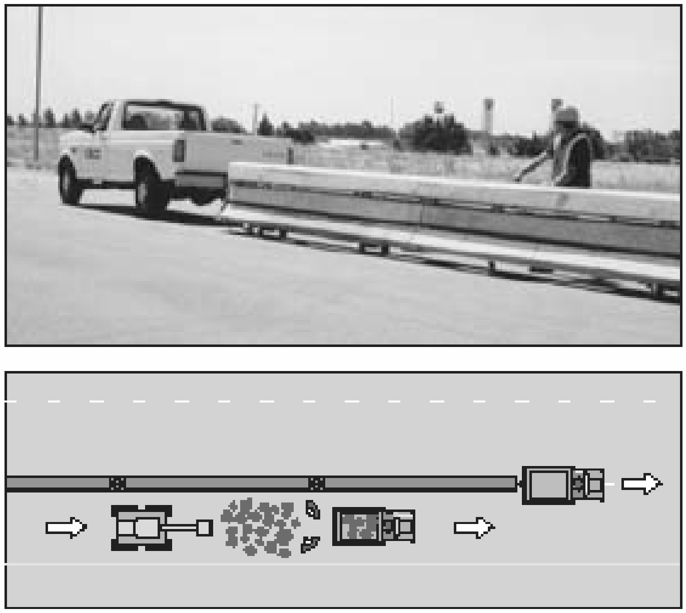
At no time should the vehicle be situated in buffer areas that are intended for clear zone to accommodate actions such as attenuator vehicle roll ahead or arrestor net deflection. Improper enforcement vehicle placement was the primary cause of a recent law enforcement officer fatality in a work zone and has led to efforts to develop improved training about proper law enforcement activities and positions in work zones (*18*). Typically, this type of enforcement is paid for as a specific traffic control cost item on the construction project. Current bid prices of enforcement support for work zone traffic control are about $50 per hour (*16*).

With respect to speed management, enforcement is one of the most effective means of reducing vehicles speeds in work zones and, by association, in promoting work zone safety (*19*). To date, however, few studies have been able to accurately correlate enforcement efforts with improved safety benefits such as fewer or less severe crashes (*20*). Furthermore, it is not immediately clear whether the use of law enforcement for lane closure management or speed management at nighttime work zones is more critical. Most TxDOT districts already rely heavily on off-duty enforcement personnel at active night work zones, primarily for lane closure management. It is likely that such use will continue in the foreseeable future.

HIGHLY MOBILE WORKER PROTECTION DEVICES

The authors of the NCHRP 476 report note that vehicle intrusions into the work area are a special concern at active night work zones. The higher incidence of impaired or drowsy drivers coupled with higher operating speeds, which reduce available reaction times for workers in the path of an errant vehicle, are two reasons why the authors of that report emphasize increasing the attention-getting ability of the work zone set-up through brighter and more frequent devices, longer advance warning distances, etc. In addition to such efforts to reduce the probability of such an intrusion in the first place, several vendors are currently developing and marketing systems designed to protect a work crew from an intruding vehicle. Figures 4 and 5 illustrate examples of such systems. This is currently an emerging technology, so cost information is not available for comparison to likely benefits. Again, though, if one considers the conservative estimates of additional crash costs presented in Table 8, it is evident that such systems will either need to be useful over a very long service life or eventually become quite commonplace and moderately priced in order for them to be economically viable.

Figure 4. Example of the Balsi Beam Worker Protection System (*21*).



Easy to Tow: The SafeGuard Link System can be towed longitudinally to create moveable work zones.

Figure 5. Example of the SafeGuard Link Worker Protection System (22).

ACTIVE QUEUE DETECTION AND WARNING SYSTEMS

Field observations reported on in the interim report indicated that the presence of traffic queues at nighttime work zones is a significant safety concern. While the presence of unexpected queues on high-speed facilities is a concern at all times, it is especially problematic at night when visibility is degraded and expectancies of such slowdowns are lower. For those night work zones where traffic queuing is expected to exist, researchers hypothesized that the use of an active real-time warning of queue presence could be an effective crash countermeasure. With this type of system, the components would need to be able to monitor traffic to identify when queuing is occurring and then warn approaching motorists through the use of portable changeable message signs (CMSs).

Researchers contacted multiple vendors and obtained detailed information (including cost estimates) for two of these types of systems. Both of these systems are marketed by the same vendor but are representative of different levels of traffic surveillance. The Smartzone® system is an extensive portable traffic management system. It includes a tower that extends to a maximum of 33 feet and can hold a variety of sensor technologies, a closed-circuit television (CCTV) camera, and a communications antenna that can send real-time information to a regional traffic management center. The system also includes a CMS that can convey real-time driving conditions to motorists. This system costs $84,900.

As an alternative, the vendor also distributes a system known as a portable equipment platform. The tower on this system is 20 feet high and has traffic sensors attached to the mast. In contrast to the previous system, this platform does not include video surveillance or communication that can be fed to a traffic management center. The cost for this system is $18,350. The CMS required to communicate real-time information to motorists would be an additional cost, approximately $3,000 per sign, if an agency chooses to retrofit an existing CMS to communicate with the platform.

Although several of these types of systems have been sold, specific evaluations to determine their potential for reducing crashes at and within a traffic queue are not yet available. While the use of these types of systems would not be appropriate for all types of night work activities, there may be particular locations and conditions where traffic queuing concerns at night are sufficient to warrant the specification of this type of device in the traffic control plan.

VEHICLE ARRESTOR NETS AT TOTAL FREEWAY CLOSURES AND RAMP CLOSURES AT NIGHT

NCHRP 476 authors discuss vehicle arrestor nets as an option to be considered for full roadway or ramp closures at night. Arrestor nets are designed to safely stop errant vehicles entering the closed area prior to a vehicle reaching the active work area, and so would be another countermeasure to address vehicle intrusion crashes into the work zone. Arrestor net systems typically consist of a chain link fence (the net) attached to energy-absorbing anchors.

Researchers contacted multiple vendors of arrestor net systems and were able to obtain a price quote for one such system. The DRAGNET is a reusable system specially made for each customer to their specifications. The lengths of the nets can be adjusted somewhat, and so can be used on different roadways by a transportation agency if needed. The manufacturer estimates that the price for a full-roadway arrestor net is approximately $9,000 plus the cost of anchorages, which are another $1,500-$2,000 installed.

The New York State Department of Transportation (NYSDOT) has used vehicle arrestor nets extensively across the state. NYSDOT reports positive experiences with the ability of the arrestor nets to stop work zone intrusion during roadway closures (NYSDOT stops approximately four errant vehicles per year with their installed systems) (*23, 24*). The systems require installation of anchors at each end of the net, and so are appropriate for use only at long night work projects. The nets make work zone access by the contractor a little more difficult. Furthermore, the nets require supplemental delineation or other advance warning devices in front of them (drums, barricades) to warn drivers that the nets are there. Based on the experiences of the NYSDOT, researchers would encourage TxDOT to consider this type of technology only for very specific applications where the benefits of stopping an errant vehicle in this manner are very apparent.

REQUIREMENTS OF A FORMAL LIGHTING PLAN FOR ACTIVE NIGHT WORK ZONES

A few states, notably New York, New Jersey, and Louisiana, have formal policies that require provision of a lighting plan for active night work zones. These policies address such things as the furnishing, installation, operation, maintenance, moving, and removal of portable light towers and/or equipment-mounted fixtures for nighttime construction operations. In general, the policies include equipment requirements, illumination requirements, glare control, and operational requirements. A few of the more notable requirements from the Louisiana Department of Transportation and Development (DOTD) are listed below (*25*):

- Thirty days prior to the start of nighttime operations, the contractor shall submit a lighting plan to the project engineer for approval.
- The contractor shall furnish to the project engineer two light meters capable of measuring illuminance.
- Prior to the first night of operation, the project engineer shall check the adequacy of the installed lighting using a light meter. Operational checks shall be made when construction phasing changes. Agencies also commonly require periodic checks throughout the duration of nighttime operations.

- The work area is defined as a minimum of 50 feet ahead and behind an employee (where work is performed).
- A minimum of 5 foot-candles shall be maintained throughout the work area during the nighttime operations and during setup and removal of lane or roadway closures. Three lighting levels are included (level I – 5 foot-candles; level II – 10 foot-candles; and level II – 20 foot-candles). Equipment mounted systems shall be attached to construction equipment and provide level II and level III illumination.
- The use of strobe lights on vehicles and equipment is prohibited. To prevent motorist distraction, the use of flashing lights should be kept to a minimum. Flashing lights cannot be used behind barrier protection systems.

These specific lighting requirements are consistent with recently published guidelines by NCHRP (*26*). Whereas the goal of policy development such as this is obviously to ensure safety of both the contractor and the motoring public, the costs and difficulty of implementing such a policy and the specific crash risk reductions that could be expected by its adoption are not immediately known. One of the issues raised by the Project Monitoring Committee for this research effort is that it would be difficult at the present time to verify compliance with a formal policy such as this, as the department does not currently have individuals well-versed and trained in highway lighting. As with the other potential countermeasures, TxDOT should consider this approach only on a case-by-case basis after careful engineering judgment as to the merits of adopting it.

SUMMARY AND CONCLUSIONS

In this report, researchers presented an assessment framework for evaluating the expected crash consequences of performing a particular work activity on a given highway at night versus doing that same activity during the day. The framework is predicated on the availability of normal crash rates (crashes per 100 million-vehicle-miles), differentiated by daytime and nighttime conditions, on the particular roadway segment of interest. These normal rates are then adjusted on a percentage basis to account for the incremental increase in crashes expected under both daytime and nighttime work conditions. The adjusted crash rates, representing the additional crash risk due to work activities, are multiplied by traffic volumes expected to encounter the work zone in either the daytime or the nighttime period and the length of the work zone to determine the number of additional crashes that would be expected to occur in either period.

To aid in the assessment process, researchers developed default values of normal crash rates by roadway type and AADT/lane ranges. Researchers then used the results of both the before-during crash studies at various night work zone projects in Texas and observational studies of daytime and nighttime recurrent congestion bottlenecks and work zone lane closures to estimate the expected increases in crashes due to work zone activity during the day or at night. Researchers also developed tables of traffic volume distributions by time-of-day and day of week to aid in the estimation of traffic volume exposure to the work zones as a function of AADT, which is often all that is available for analysis purposes. Researchers presented examples on how the framework would be applied. In addition, researchers also presented the additional crashes expected in a given work zone during the day or at night normalized to a standard duration of work activity. On interstate facilities, the results of that normalization indicate that even though nighttime crash rates are generally much higher on roadways than daytime rates, and that work zones are assumed to increase the crash rate percentage-wise more dramatically at night than during the day (an assumption that should be evaluated further with additional data), the dramatically lower volumes at night more than offset the higher rates and yield slightly lower crash expectancies for a work activity of a given duration. Calculations were less conclusive for US highways, however. US highways at high AADT/lane levels were calculated to have slightly higher crash expectancies at night than during the day for a given work activity duration.

The framework itself has been packaged as a product for potential implementation by TxDOT and is included as an appendix to this report. However, given the trends observed with regards to lower crash expectancies for night work zones relative to day work zones at a given interstate location, it is unlikely that TxDOT will need to perform an assessment for most of the roadways where night work is being done or is being considered in the future.

Also included in this report is a review of several potential countermeasures identified by the research team to reduce crashes resulting from active night work zones. Researchers provided a critique of each one with regard to potential adoption consideration by TxDOT. Overall, researchers could not justify widespread or blanket adoption of any of the countermeasures by TxDOT. Even a recommendation to reduce drum spacing in the lane closure taper and in the tangent section at night is not expected to be able to reduce the additional crash costs expected in the work zone by an amount that could justify the cost of implementation. However, given the rather conservative estimates of the increased crash risk attributable to daytime and nighttime work activity, it is recommended that TxDOT personnel continue to rely on engineering judgement and consider potential use of one or more of the countermeasures on a case-by-case basis.

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APPENDIX: RISK EVALUATION GUIDE FOR NIGHTTIME WORK

TRAFFIC CRASH RISK EVALUATION: NIGHTTIME VERSUS DAYTIME WORK ZONES

This evaluation of the risk of doing a particular work zone activity at night is based on the comparison of the additional traffic crashes expected to occur during the hours when work is performed at night versus the additional crashes expected to occur if the same work was to be performed during daylight hours. The evaluation consists of five main steps:

Step 1: **Determine the hours of work activity each night or day that are to be compared, and estimate the number of periods that would be required to accomplish the work activity under the nightwork and the daywork alternatives;**

Step 2: **Determine the normal daytime and nighttime roadway crash rates per 100 million vehicle miles on the roadway segment of interest;**

Step 3: **Determine the estimated percentage increase in crashes expected to occur during work activities in each alternative work period (day or night);**

Step 4: **Determine the amount of traffic expected to pass through the work zone during each nighttime or daytime work period;**

Step 5: **Multiply the normal crash rate for each period by the expected percentage increase due to a work zone. Multiply this product by the amount of traffic that will pass the work zone each day or nigh, the expected length of the work zone each night, and the number of days or nights required to complete the work.**

The form on the next page can be used to aid in the calculations. Default values for normal daytime and nighttime crash rates, as well as time-of-day distributions of traffic volumes, are provided on the following pages for both interstate highways and US divided highways in Texas.

Step	Sources of Data	Night	Day
1: Define starting and ending hours of work daytime or nighttime and number of days or nights required to complete work activity	Starting and ending hours	A	A
	Number of days or nights needed to complete work	B	B
2: Estimate normal crash rates for daytime and nighttime periods	From local data or use default values from Tables A-1 and A-2 (crashes per 100 million-vehicle-miles)	C	C
3: Estimate expected percentage increase in crashes during work activity	Use 0.535 for night activity and 0.422 for day activity unless more accurate data are available	D	D
4: Estimate amount of traffic to pass through work zone each night or day work period	From local data or estimate using AADT of roadway and summation of hourly percentages from Tables A-3 and A-4	E	E
4: Multiply factors by length of work zone each day or night to determine number of additional crashes expected during work activity	For each column, multiply B x C x D x E x Length	F	F

Table A-1. Typical Crash Rates on Texas Interstate Facilities, 1999-2001 (crashes per 100 million-vehicle-miles).

	AADT/Lane (Thousands)				
	0-4999	5000-9999	10000-14999	15000-19999	20000+
Day	39.0	50.3	78.2	84.3	128.9
Night	61.8	73.7	107.5	128.4	186.1

AADT = annual average daily traffic
Day = 9 am to 4 pm
Night = 7 pm to 6 am

Table A-2. Typical Crash Rates on Texas US Highways, 1999-2001 (crashes per 100 million-vehicle-miles).

	AADT/Lane (Thousands)				
	0-4999	5000-9999	10000-14999	15000-19999	20000+
Divided-Day	56.3	77.3	77.4	103.5	94.7
Divided-Night	88.1	119.4	126.3	205.1	168.4
Undivided-Day	83.6	180.4	131.0	---	---
Undivided-Night	112.0	184.8	120.0	---	---

AADT = annual average daily traffic
Day = 9 am to 4 pm
Night =7 pm to 6 am
--- = not enough data for an estimate

Table A-3. Percent of ADT That Occurs Each Hour of the Day (Interstates)[a].

Hour	SUN	MON	TUE	WED	THU	FRI	SAT	M-F	ALL
12-AM	2.3%	1.3%	1.1%	1.1%	1.2%	1.2%	2.0%	1.1%	1.4%
01-02	1.6%	0.8%	1.2%	0.8%	0.8%	0.8%	1.4%	0.9%	1.0%
02-03	1.4%	0.7%	0.7%	0.7%	0.8%	0.8%	1.2%	0.7%	0.9%
03-04	0.9%	0.6%	0.6%	0.6%	0.6%	0.6%	0.8%	0.6%	0.7%
04-05	0.8%	0.9%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
05-06	1.0%	2.1%	2.1%	2.0%	1.9%	1.7%	1.3%	2.0%	1.7%
06-07	1.4%	4.7%	4.9%	4.7%	8.1%	3.8%	2.2%	5.3%	4.3%
07-08	1.9%	6.7%	7.0%	6.8%	6.4%	5.6%	3.2%	6.5%	5.4%
08-09	2.7%	5.7%	5.9%	5.8%	5.5%	5.0%	4.2%	5.6%	5.0%
09-10	4.0%	5.1%	5.1%	5.0%	4.8%	4.7%	5.1%	4.9%	4.8%
10-11	5.1%	5.2%	5.1%	4.9%	4.8%	4.9%	5.9%	5.0%	5.1%
11-12	5.9%	5.6%	5.3%	5.2%	5.1%	5.3%	6.4%	5.3%	5.5%
12-PM	6.8%	5.8%	5.5%	5.4%	5.3%	5.6%	6.6%	5.5%	5.8%
01-02	7.3%	5.9%	5.6%	5.6%	5.4%	5.8%	6.6%	5.7%	6.0%
02-03	7.5%	6.2%	5.9%	5.9%	5.7%	6.2%	6.7%	6.0%	6.3%
03-04	7.6%	6.6%	6.5%	6.4%	6.3%	6.7%	6.7%	6.5%	6.7%
04-05	7.7%	7.3%	7.2%	7.1%	6.9%	7.1%	6.6%	7.1%	7.1%
05-06	7.6%	7.7%	7.8%	7.7%	7.4%	7.3%	6.5%	7.6%	7.4%
06-07	6.9%	6.1%	6.2%	6.2%	6.0%	6.5%	6.1%	6.2%	6.3%
07-08	5.8%	4.5%	4.5%	4.6%	4.6%	5.4%	5.3%	4.7%	4.9%
08-09	4.7%	3.5%	3.6%	3.7%	3.7%	4.4%	4.4%	3.8%	4.0%
09-10	3.9%	3.0%	3.2%	4.8%	3.3%	3.8%	4.0%	3.6%	3.7%
10-11	3.1%	2.3%	2.4%	2.5%	2.6%	3.3%	3.5%	2.7%	2.8%
11-12	2.1%	1.6%	1.6%	1.8%	1.8%	2.5%	2.7%	1.9%	2.0%

[a] Average from the following ATR stations: S004, S040, S125, S145, S149, S171, S186, S204, S215, and S224

Table A-4. Percent of ADT That Occurs Each Hour of the Day (US Highways)[a].

Hour	SUN	MON	TUE	WED	THU	FRI	SAT	M-F	ALL
12-AM	1.5%	1.2%	1.1%	1.1%	1.1%	1.1%	1.8%	1.1%	1.3%
01-02	1.0%	0.9%	0.9%	0.9%	0.9%	0.8%	1.3%	0.9%	0.9%
02-03	0.8%	0.7%	0.7%	0.7%	0.8%	0.7%	1.0%	0.7%	0.8%
03-04	0.6%	0.7%	0.7%	0.7%	0.7%	0.7%	0.9%	0.7%	0.7%
04-05	0.7%	1.1%	1.0%	1.0%	1.0%	0.9%	1.0%	1.0%	0.9%
05-06	0.8%	1.9%	1.8%	1.8%	1.7%	1.4%	1.4%	1.7%	1.5%
06-07	1.3%	3.4%	3.4%	3.4%	3.2%	2.6%	2.3%	3.2%	2.8%
07-08	2.0%	5.2%	5.5%	5.5%	5.2%	4.2%	3.6%	5.1%	4.4%
08-09	3.0%	5.3%	5.6%	5.5%	5.3%	4.5%	4.9%	5.2%	4.9%
09-10	4.5%	5.8%	5.9%	5.8%	5.7%	5.1%	6.1%	5.6%	5.6%
10-11	5.6%	6.2%	6.2%	6.1%	6.0%	5.5%	6.9%	6.0%	6.1%
11-12	6.5%	6.5%	6.2%	6.2%	6.1%	5.8%	7.1%	6.2%	6.3%
12-PM	7.2%	6.5%	6.1%	6.1%	6.1%	5.9%	7.0%	6.2%	6.4%
01-02	7.7%	6.8%	6.5%	6.4%	6.3%	6.3%	6.8%	6.5%	6.7%
02-03	7.9%	6.9%	6.7%	6.6%	6.6%	6.7%	6.7%	6.7%	6.9%
03-04	8.0%	7.1%	6.9%	6.9%	6.9%	7.0%	6.6%	7.0%	7.0%
04-05	7.9%	7.2%	7.2%	7.2%	7.3%	7.4%	6.4%	7.3%	7.2%
05-06	7.7%	7.1%	7.2%	7.3%	7.2%	7.6%	6.0%	7.3%	7.2%
06-07	6.9%	5.6%	5.7%	5.8%	5.9%	6.8%	5.5%	6.0%	6.0%
07-08	5.9%	4.3%	4.3%	4.4%	4.6%	5.5%	4.7%	4.6%	4.8%
08-09	4.7%	3.4%	3.5%	3.6%	3.8%	4.4%	3.9%	3.8%	3.9%
09-10	3.5%	2.8%	2.9%	3.0%	3.2%	3.6%	3.3%	3.1%	3.2%
10-11	2.6%	2.2%	2.3%	2.3%	2.5%	3.1%	2.7%	2.5%	2.5%
11-12	1.7%	1.6%	1.6%	1.7%	1.8%	2.3%	2.0%	1.8%	1.8%

[a] Average from the following ATR stations: S015, S016, S025, S029, S033, S043, S072, S074, S102, and A328