FINAL REPORT

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IMPROVING NIGHT WORK ZONE TRAFFIC CONTROL

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Senior Research Scientist

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

The objective of this study was to examine traffic control for night work zones from the perspective of both agencies and motorists. This was accomplished by investigating practices of state departments of transportation, identifying the problems associated with traffic control for night work zones, and identifying potential strategies to resolve them.

Reduced visibility, driver impairment or inattention, inadequate lighting, and difficulty in maintaining traffic control devices are common problems identified with night work zones based on surveys of state departments of transportation and residencies within the Virginia Department of Transportation. Having police present, making workers more visible, using drums in the taper, maintaining traffic control devices, and providing adequate lighting were common solutions.

Based on the review of work zones, traffic control for night work zones is generally adequate. Common problem areas were properly establishing work zones based in accordance with the *Virginia Work Area Protection Manual,* maintaining the traffic control devices, and properly aiming and aligning lighting to avoid glare.

Although there is a perception that night work zones are less safe than daytime work zones, evidence to substantiate this perception, such as higher accident rates, was not available because of a lack of accurate traffic exposure data. Based on a limited amount of data, there was no evidence of the perceived higher speeds at night.

Changes to the *Virginia Work Area Protection Manual* were recommended.

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16. Abstract

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Reduced visibility, driver impairment or inattention, inadequate lighting, and difficulty maintaining traffic control devices are common problems identified with night work zones based on surveys of state DOTs and VDOT residencies. Having police officers present, making workers more visible, using drums in the taper, maintaining traffic control devices, and providing adequate lighting were common solutions.

Based on the review of work zones, traffic control for night work zones is adequate in general. Common problem areas were properly establishing work zones based on the requirements of the *Virginia Work Area Protection Manual*, maintaining the traffic control devices, and properly aiming and aligning lighting to avoid glare.

Although there is a perception that night work zones are less safe than daytime work zones, this perception could not be verified or discounted because of a lack of accurate traffic exposure data. Based on a limited amount of data, there was no evidence of higher speeds at night. Changes to the *Virginia Work Area Protection Manual* were recommended.

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INTRODUCTION

State departments of transportation (DOTs) are focusing on maintaining and improving existing facilities instead of building new ones. Consequently, much of the necessary road work is performed with exposure to traffic. Additionally, an increasing amount of highway maintenance and construction work is being performed at night instead of during the day. Initially, night road work performed by the Virginia Department of Transportation (VDOT) was concentrated in the urbanized areas of the Northern Virginia, Suffolk, and Richmond districts. The purpose of conducting work at night was to avoid the traffic congestion and related problems that are often encountered on high-volume roadways during many of the daylight hours. Because traffic volumes have increased in nonurbanized areas, rural districts are now also performing road work at night. In some cases, nighttime work is completed in fewer days than daylight work because there are more hours in a work shift during the night and less interference from traffic.

As more road work is performed at night, VDOT staff and contractors have expressed much concern about the hazardous conditions associated with night construction and maintenance work zones. This concern has prompted some contractors to express a reluctance to bid on night work. At night, visibility is substantially reduced. Moreover, it is believed that some drivers are less attentive and travel at higher speeds at night, and more impaired drivers (alcohol or drug impaired) are reported to be involved in work site incidents and accidents.[1] Because of this driver behavior and the decreased visibility, many suspect that nighttime work zone accidents tend to be more severe and that lane closures are not as safe as they are during daytime operations.[1]

The traffic control used for night work is basically the same as that used for typical work zones despite the potential adverse conditions that may be encountered. There is a need to examine methods to improve traffic control and safety for night work zones. New technologies (such as intrusion alarms), traffic control plans that are different from the typical plans, and methods to monitor traffic can potentially provide improvements.

In response to the increasing amount of construction and maintenance operations being shifted from day to night, the VDOT Night Operations Task Force was created to (1) review night and non-regular business hours (weekends, holidays, etc.) operations, and (2) provide information designed to maximize the effectiveness of these activities.[2] In a survey of VDOT district and division administrators, work zone safety during night operations was identified as the number one issue with regard to VDOT night operations.[2] The task force recommended that

VDOT develop and implement an operational plan to ensure that all night activities maximize the safety of contractors, VDOT workers, and the traveling public. The plan is also to include the review and enhancement of traffic control measures to maximize public and worker safety. Independent of this task force's activity, the Virginia Transportation Research Council's Traffic Research Advisory Committee rated this research topic as its highest research priority in 1994.

PURPOSE AND SCOPE

The purpose of this study was to examine traffic control for night work zones from the perspective of both transportation agencies and motorists. This was accomplished by investigating practices of other transportation agencies, identifying the problems associated with traffic control for night work zones, and identifying potential strategies to resolve them. Because most night work is performed on high-volume, multilane roads such as the interstate and primary arterials, this effort focused on these types of roads.

METHODS

Literature Review

Literature related to traffic control for work zones and for nighttime work zones was reviewed.

Identification of Problems with Traffic Control for Night Work Zones for Transportation Agencies

Information on traffic control for night work zones used by other transportation agencies was obtained by questionnaire survey with follow-up data requested by telephone. A questionnaire was mailed to all 50 state DOTs. The survey is provided in the Appendix.

To provide statewide coverage, a questionnaire was sent to all VDOT residencies and the results were analyzed.

In addition, the researcher conducted onsite visits of seven night work zones to observe and identify specific problems that are being encountered with traffic control for night work zones. The inspections included interviews with the inspector, when possible, and VDOT and contractor personnel. The visits were conducted during the 1996 and 1998 construction seasons. (Other research activities were a priority during 1997.) Contractors performed the work at all sites reviewed.

Identification of Problems with Traffic Control for Night Work Zones for Motorists

Feedback from motorists, an important element in identifying traffic control problems in night work zones, was obtained using a survey approach. A limited number of test subjects drove through a night work zone and completed a questionnaire survey. VDOT employees in the Transportation Planning and Location & Design divisions serving as test subjects drove through one or two of the four selected night work zones in the Richmond area. The subjects were asked for feedback as motorists, not VDOT staff. Staff from these divisions were selected because knowledge of work zone traffic control is not related to their work duties.

Identification of Potential Solutions

Strategies for improving traffic control for night work zones were developed using results from the literature review, survey responses, work zone observations by the researcher, and conversations with VDOT staff.

RESULTS AND DISCUSSION

Literature Review

In addition to the literature review presented here, several studies are cited later in this report.

Night Work Zones in General

In 1984, Shepard and Cottrell used information on the planning, safety, and traffic control aspects of night maintenance and construction activities to develop general guidelines on when and how maintenance and construction work should be done.[1] The report presents case studies illustrating the activities required in different types of night work situations.

The Transportation Research Center of the University of Florida developed procedures for night operations of transportation construction projects in 1993. Important factors such as cost, productivity, quality, safety, congestion, traffic control, noise, human factors, public information, and lighting that affect decisions concerning night operations were identified and evaluated.[3] Recommendations were made to assist in addressing the factors.

In 1994, Ossama and Perry assessed factors involved in night operations, provided guidance in establishing standard procedures to assist decision makers in reaching informed choices on construction scheduling, and outlined an advance planning process for night operations.[4] Flowcharts and a stepwise progression of the decision-making process was documented.

The objectives of NCHRP Project 17-17, Development of Guidelines for Nighttime Road Work to Improve Safety and Operations, are to (1) develop guidelines for nighttime road work to improve safety and operations, and (2) formulate procedures to facilitate decision making about undertaking nighttime work. The expected product of the research is a set of guidelines that will define appropriate provisions for the planning, design, implementation, and operation of nighttime road work and a procedure(s) that could be used to assess systematically day versus night work options. Traffic control for night work will be included in the guidelines. This comprehensive effort is scheduled for completion in December 1999.[5]

Accidents and Night Work

Sullivan examined historical data on the relationship between accident rates and nighttime reconstruction activities along seven sections of urban freeways in California in 1989.[6] A disaggregate analysis of accident rates was performed for the time periods when work activities were and were not underway. The accident rate was determined by estimating the vehicle-miles and lane-mile hours for the two time periods. It was concluded that the presence of nighttime construction was associated with an 87 percent increase in the accident rate. In addition, the accident rate for the period with lane closures (i.e., the period with work underway) was 75 percent higher than the rate for work without lane closures. Data limitations related to estimating exposure to traffic and sample size were noted.

A 1978 FHWA study analyzed data from seven states on accidents before and during construction.[7] The construction zones were in place continuously day and night, not only at night. The percentage of total night accidents to total accidents (day and night) remained constant at 30 percent for before and during construction. The implication is that the frequency of nighttime accidents is not increased by the presence of a work zone.

Traffic Control for Night Work

In 1989, Homburger reported on a field review of nighttime work activities of four construction projects in California.[8] The conclusion was that the traffic control, based on existing general guidelines for work zones, was at a high level of quality. The human factors involved in rerouting traffic and closing lanes or ramps necessitate a high level of expertise on the part of the field staff to make traffic control decisions (adjustments) based on site conditions. The use of portable changeable message signs (PCMSs) was strongly recommended. PCMSs were suggested for end-of-queue warnings in the early night hours when traffic volumes were likely to result in lower speeds and queues. Later at night when the speeds increased, these PCMSs could be relocated closer to the construction activity and used as special attention getters.

Problems Identified by Transportation Agencies

Survey of DOTs

Response Rate and Issues

Responses to the questionnaires were received from 28 DOTs, for a 56 percent response rate. Five DOTs, 18 percent of those responding, stated that they do not use night work zones. When asked if they use typical work zone traffic control for night work, 17 DOTS, 74 percent, answered yes. Three of the 17 indicated that there were exceptions to this in practice.

Table 1 presents the results of answers to questions to identify the major problems with night work zones and their possible solutions. Reduced visibility brought on by darkness was the

Table 1. Responses of DOTs Regarding Problems and Solutions for Night Work Zone Traffic Control

Problem	No. of Responses
Poor visibility	12
More impaired drivers	8
Higher speeds and lower volumes	6
Insufficient lighting for workers	6
Noise restrictions	3
Worker fatigue	2
Drivers who do not expect night work zones	1
Glare	1
Solution	
Improving visibility of workers	7
Using drums in taper	6
Having a detailed lighting plan	6
Using the police	5
Maintaining devices	5
Using PCMS with specific messages	4
Using fluorescent orange signs	3
Having higher fines for violations	2
Requiring noise variance and mitigation measures	2
Using flashing beacons on leading sign	1
Using flashing speed limits w/ lower speeds on trailer	1
Working where there is highway lighting	1
Arranging for delivery of materials	1
Illuminating flagger station	1
Providing buffer lane	1
Providing proper delineation	1
Evaluating each project for changes	1
Using a smaller spacing of channelizing devices	1
Using amber revolving lights and 4-way flashers on work vehicles	1
Requiring vehicle warning beacons and reflective tape	1
Taking care to avoid glare	1
Having spare lighting units on hand	1
Requiring Type A flashing light on first two channelizing devices	1
Requiring Type B flashing lights for isolated signs	1

most frequently cited problem. More impaired drivers was second, as recorded by 8 DOTs. Four specified drunk drivers or driving under the influence, and 4 specified impaired drivers, which included fatigued drivers. Six DOTs identified higher speeds and lower volumes, and 6 identified insufficient lighting for workers. Other problems were noise restrictions, worker fatigue, driver surprise, and glare.

Suggested Solutions

The most frequently cited solution to enhance night work zones was improving worker visibility, followed closely by using drums in the taper and having a detailed lighting plan. The use of high visibility clothing, noted by 4 DOTs, was the most frequently cited means to improve worker visibility. One DOT each noted using more reflective vests, illuminated apparel, and white clothing with reflective markings. Using drums in the taper improves visibility when compared to cones. Having police officers in the work zones to deter speeding and increase attention to the work zone was cited by 5 DOTs. Maintaining traffic control devices, using PCMSs with specific messages, and using fluorescent orange sign sheeting were also deemed to improve visibility. The Minnesota DOT stated that the PCMS message TROOPER ON SITE, SPEED LIMIT ENFORCED was very effective. Other solutions to improve visibility included using flashing beacons on the lead sign, flashing speed limits with lower speeds on a trailer, vehicle-warning beacons, and retroreflective tape on vehicles.

Survey of VDOT Residencies

To identify the magnitude of night work and practices of traffic control in night work zones throughout VDOT, a questionnaire survey was e-mailed to all 45 VDOT resident engineers. Responses were received from 18, for a 40 percent response rate. All residencies that maintain roads along the high-volume corridors where night work is conducted responded to the survey. Fifteen of the responding residencies, 83 percent, indicated that nighttime work is performed in their residency.

As shown in Table 2, visibility and higher average speeds were tied for the most frequently cited problem with night work zone activities (5 residencies). Motorist inattention and inadequate lighting were each noted by 4 residencies. *Motorist inattention* is a general or catch-all description that may address a broad group of concerns including in-vehicle distractions such as the radio, phone, or passengers; driver conditions such as fatigue, driving under the influence of alcohol or drugs, or stress; and distractions outside the vehicle. Maintaining traffic control devices and managing traffic control in complex, confusing areas were noted by at least 2 residencies.

The solution most frequently cited by the residencies as a means to enhance night work was the presence of police officers to control speed. Twelve of the 15 residencies use police officers in night work zones. The extent of use ranges from deployment in all night work zones

Table 2. Responses of VDOT Resident Engineers Concerning Problems and Solutions for Night Work ZoneTraffic Control

Problem	No. of Responses
Poor visibility	5
Higher average speed	5
Motorist inattention	4
Inadequate lighting	4
Maintenance of traffic control devices	3
Complex confusing area	2
Glare	2
Drivers less alert (fatigue)	1
Drunk drivers	1
Tractor-trailers	1
Motorists disobeying signs	1
Adequate placement of lighting and lighting dependability	1
Night work not expected	1
Setting up work zone safely	1
Lack of retroreflective safety clothes	1
Inadequate vehicle lighting	1
Contractor personnel tired	1
Replacement items hard to obtain at night	1
Limited resources available	1
Unreliable media releases	1
Solution	
Using state police vehicle near work zone to control speed	7
Specifying lighting requirements	3
Using drums	3
Using larger, heavier cones to avoid blowing over	1
Conducting periodic night inspections	1
Using flares at signs to alert motorists	1
Using an additional PCMS	1
Ensuring that contractor has adequate, rested, sober staff	1
Making contractor aware of night work issues	1

all of the time to deployment two times per week, deployment in work zones in critical areas only, and deployment when police officers are available. Two residencies suggested using drums to improve the visibility of the channelizing devices.

Review of Night Work Zones

The following are summaries of the reviews of the seven night work zones by the researcher.

I-81 Augusta County Paving Operation

The right lane was closed on this two-lane northbound section. The channelizing devices included drums in the taper and cones in the tangent section. Despite having weight at their base, many cones were either blown or knocked over. Some of the cones needed to be replaced because they were covered with asphalt materials. There were two flashing arrow boards: one 0.8 km (0.5 mi) in advance of the taper and one at the taper. The PCMS with the message PAVING WORK AHEAD, EXPECT DELAY was 6.4 km (4 mi) in advance of the lane closure. The speed limit was reduced from 104 km/h (65 mph) to 88 km/h (55 mph). The workers installing pavement markings were barely visible behind the cones. Their vests provided fair retroreflectivity, but when workers were bending over the marking machine that was being pushed, their vests were not visible. Traffic flowed without congestion.

I-64 Henrico County Paving Operation

The two right lanes were closed on this three-lane eastbound section. A state trooper's vehicle with flashing lights was placed at the beginning of the work zone. Some of the cones needed to be replaced because their retroreflective sleeves were covered with asphalt materials or worn out. The major problem observed at this site was the glare from the lights in the work area. The glare was too bright.

I-95 Spotsylvania County Paving Operation

The right lane was closed on this three-lane northbound section. Drums in the taper and cones in the tangent were in very good condition; they were new when the project began 5 weeks earlier. The advance warning signs were also in good condition. The visibility of the pavement marking crew was poor. Although two lanes were open, the traffic was using one lane. The center lane was narrowed with cones being placed to the left of the skip lines. The message on the PCMS located 4.8 km (3 mi) in advance was ROAD WORK AHEAD, RIGHT LANE CLOSED.

Route 3 Spotsylvania County Traffic Signal Pole Installation

The work vehicles were in the median, and cones were along the median shoulder. No lanes were closed. The visibility of the cones was poor because most did not have retroreflective sleeves.

Route 3 Spotsylvania County Mowing

The traffic control was for mobile operations with mowing in the median and to the right of the right shoulder. The signing was inadequate because nonretroreflective mesh signs were

used. The shadow vehicle for the tractor did not have an arrow board, just the flashing yellow strobe light.

I-95 Stafford County Bridge Washing

Two left lanes were closed on this three-lane northbound section. The drums were in good condition. The PCMS message was LEFT 2 LANES CLOSED, MERGE RIGHT. Flares were used at the beginning of the taper to bring attention to the lane opening process. A state police officer was observed ticketing a driver within the advance warning area.

Route 610 Stafford County Overhead Structure Inspection

The right lane was closed on this divided highway, with cones in good condition. The signs were in fair condition.

Problems Identified by Motorists' Survey of Night Work Zones

Site 1: I-64 Eastbound, Glenside to I-95

On this three-lane section, the two left lanes were closed for paving operations. A police vehicle was located on the left shoulder near the taper of cones.

The responses of the 11 study subjects are displayed in Table 3. The flashing arrow board and PCMS were the highest rated traffic control devices. The channelizing devices and warning signs could have been improved by cleaning or replacing them as needed. The presence of a horizontal curve limited the visibility of the police vehicle's flashing lights and the channelizing devices. The vehicle may have been more effective if it had been visible sooner. Glare from the

Table 3. Responses of Motorists at Site 1

Traffic Control	% Rated Excellent to Good (Number)
Changeable message sign	73 (8)
Warning signs	64 (7)
Flashing arrow boards	82 (9)
Channelizing devices	45 (5)
Police vehicle	55 (6)
Other (flares)	100 for two observers
Distractions or Problems	**% Rated No Problem (Number)**
Lighting	55 (6)
Work vehicles	82 (9)
Workers	73 (8)
Other eastbound vehicles	36 (4)
	% Responding Yes (Number)
Driving comfortably/ normal tension	55 (6)

lights illuminating the work area was a problem for 45 percent of the subjects. Other eastbound vehicles were a major source of problems. In the advance warning area, a queue had formed because of the reduction in lanes. Some drivers drove on the shoulder to avoid the queued traffic and to get ahead—this was a primary cause of driver tension. The stop-and-go traffic caused by the queue extended up to about 2.4 km (1 1/2 miles) at one point, and sudden stops in the traffic, and merging conflicts also created tension.

Suggestions were made to resolve two operational problems. An entry ramp was close to the lane closure taper, resulting in traffic merging from both the left and right at the end of the taper. It may have been helpful to move the taper several hundred meters in advance of the entry ramp to separate the merge points. This shift upstream would have also resolved a second problem—visibility of the flashing arrow board, the taper, and the police vehicle's flashing lights was limited because of a curve in the roadway. One subject suggested keeping the middle lane open longer to transition from three to two to one lanes (in accordance with the *Virginia Work Area Protection Manual* [10]) as opposed to three to one lanes. Another subject suggested adding speed limit and no passing signs to make merging easier. The researcher concurred with the suggestions to move the taper upstream to separate the merging point (it also improved the sight distance of the police vehicle, flashing arrow board, and taper) and to provide two transition sections in accordance with the established practices. Delaying the start of the night work should be the primary method to reduce traffic congestion.

Site 2: I-64 Westbound, I-95 to Glenside

On this three-lane section, the two left lanes were closed for paving operations. Each of the four study subjects rated the PCMS and flashing arrow board as good to excellent. Three of the four rated the effectiveness of the warning signs, channelizing devices, and police vehicle as good to excellent. Three subjects also rated the work vehicles and workers as distractions or problems. Other westbound vehicles were a distraction or problem to two subjects, and lighting was a problem for one. Three subjects drove comfortably with normal tension.

As with site 1, one subject suggested keeping the middle lane open longer to transition from three to two to one lanes as opposed to three to one lanes. Work zone lighting produced glare for most drivers. Other westbound drivers created problems by rubbernecking at the police and work area and slowing down, thus causing delays, or by using the shoulders to gain an unfair advantage. The glare may have also slowed drivers. One subject also stated that the police were stationed too close to the work area.

Site 3: I-64 Westbound, Airport Road to I-95, Stage 1

On this three-lane section, the traffic was rerouted to prevent vehicles from traveling under the Laburnum Avenue Bridge. The detour route channeled traffic onto the exit ramp to Laburnum Avenue, across Laburnum, and onto the entrance ramp to I-64 westbound from Laburnum Avenue. Work was being done on the Laburnum Avenue Bridge. Cones were used as

channelizing devices, and flares were placed near the entrance to the exit ramp to bring attention to the detour route.

All three subjects rated warning signs, flashing arrow boards, and channelizing devices as good to excellent. Both subjects who saw flares rated them good to excellent. The subject who saw the police vehicle rated it good to excellent. All subjects rated the work vehicles and workers as distractions or problems. Two subjects rated lighting as a problem. All three subjects drove comfortably with normal tension. For the most part, this site received an adequate rating. The flares were in the travel lane as opposed to on the shoulders. It is suspected that they rolled into the travel lane. The detour was unexpected, and detour signs posted at the bridge would have been helpful.

Site 4: I-64 Westbound, Airport Road to I-95, Stage 2

On this three-lane section, the two left lanes and right shoulder were closed. The two subjects rated channelizing devices good to excellent, and one rated the flashing arrow board at this level. Both subjects rated the lighting as a distraction or problem, and one rated other westbound vehicles as a problem. One subject drove comfortably with normal tension. Some of the warning signs should have been replaced. The lighting on the bridge over I-64 created intense glare. Traffic was slow at the merge point. The right shoulder closure made the open lane seem narrow; more warning signs would have been useful. There was a heavy backup during the early evening hours.

Summary

In general, the traffic control for the night work zones was adequate. Maintaining the traffic control devices, especially cones and signs, with adequate retroreflectivity was a concern, as was the visibility of the pavement marking crew. Poor visibility of traffic control devices and some workers and glare from work lights were identified as problems.

A Look at Two Issues Raised by Transportation Agencies and Motorists

Do More Accidents Occur at Night?

Accident records do not provide a distinction between day only, night only, or day and night work zones. Moreover, traffic data on the exposure or traffic volume through the work zones are not available. Therefore, statistics on night work zone accidents are not available. For 1997, 500 accidents were reported in work zones in Virginia, including 7 fatalities and 308 injuries.[9] Approximately 30 percent occurred between 6 p.m. and 6 a.m. (potential hours of darkness, depending on the season), and approximately 20 percent occurred from 9 p.m. to 6 a.m. For comparison, of the 129,980 total reported accidents in Virginia in 1997, 30 percent occurred

between 6 p.m. and 6 a.m., and 16 percent occurred between 9 p.m. and 6 a.m.[10] The 30 percent of accidents occurring between 6 p.m. and 6 a.m. is constant for work zone accidents and all accidents. This statistic of 30 percent was also cited in the literature. From 9 p.m. to 6 a.m., the percentage of accidents in work zones was slightly higher (20 percent) compared to all accidents (16 percent).

The New York DOT has extensive experience and information on night work. Their construction staff concurred on the absence of useful accident information because of a lack of traffic volume data to determine accident rates.

Do Drivers Drive Faster at Night?

As noted previously, survey responders from other DOTs and many from VDOT's residencies believe that speeds are higher when the volumes are lower at night. Speed data were collected at one night work zone on I-95 in Spotsylvania County. The right lane of this three-lane northbound section was closed for paving. Based on 39 vehicles, the mean speed, 85th percentile speed, and standard deviation were 91 km/h (57 mph), 107 km/h (67 mph), and 11 km/h (7 mph), respectively. The speed limit, 88 km/h (55 mph) was not reduced in the work zone. This sample at one site does not indicate a speeding problem at that location. This small sample of speeds at one site is intended only to provide an idea of what night work zone speeds are at this one site and is not intended for a statistical evaluation.

To obtain a larger sample of day versus night speeds in non-work zone areas, data were obtained from automated count stations at three interstate locations. Daytime speeds between 10 a.m. and 3 p.m. were compared with nighttime speeds between 11 p.m. and 4 a.m. Daytime off-peak hours were selected to compare the lower daytime volume period with the low nighttime volume. These six sets of speed data indicate that the daytime speeds are about equal to or slightly higher than the nighttime speeds (Table 4). Because the speed data were provided in 8-km/h (5-mph) bins (e.g., *x* number of vehicles traveled between 90 and 96 km/h [56 to 60 mph]),

Table 4. Daytime and Nighttime Speeds at Three Interstate Locations

Location	Parameter	Day	Night	Difference (Day-Night)
I-95 NB Henrico Co	Mean Speed km/h (mph)	105 (66)	99 (62)	+ 6 (4)
	Volume	12354	2467	
I-95 SB Henrico Co.	Mean Speed km/h (mph)	107 (67)	102 (64)	+ 5 (3)
	Volume	12538	2213	
I-81 NB Roanoke Co.	Mean Speed km/h (mph)	107 (67)	105 (66)	+2 (1)
	Volume	7322	1659	
I-81 SB Roanoke Co.	Mean Speed km/h (mph)	110 (69)	109 (68)	+1 (1)
	Volume	7514	1694	
I-495 NB Fairfax Co.	Mean Speed km/h (mph)	105 (66)	101 (63)	+4 (3)
	Volume	28537	3913	
I-495 SB Fairfax Co.	Mean Speed km/h mph)	105 (66)	104 (65)	+1 (1)
	Volume	31394	3636	

it was not possible to calculate the 85th percentile speeds and the standard deviation. Because of a system error, data were not available on speeds above 136 km/h (85 mph).

The researcher suggests an explanation for the perception of higher speeds at night: vehicles appear to be traveling faster than during the day because of the lower visibility and lower traffic volumes at night.

Potential Solutions for Improving Traffic Control at Night Work Zones

The researcher identified seven strategies for improving traffic control for night work zones:

1. Improve the visibility of traffic control devices.
2. Improve the visibility of workers.
3. Improve the visibility of work vehicles.
4. Reduce speeding and increase driver attention.
5. Reduce glare from work lighting.
6. Manage queuing and traffic flow.
7. Manage other safety risk factors.

Improving the Visibility of Traffic Control Devices

Several strategies will improve the visibility of traffic control devices, which will, in turn, provide motorists with the information needed to travel safely through night work zones:

- Use drums in the taper in place of cones. Cones are optional in the tangent section.
- Use two cones stacked together or weights on cones to keep them in place.
- Make certain that all signs and channelizing devices are maintained in good condition and in place. A person or crew designated as responsible for maintaining traffic control should do this maintenance and should regularly monitor the work zone by driving through it. This would require several drives through the work zone each night. A minimum frequency should be specified for clarification. The review should include all aspects of project visibility, including glare, and all traffic control devices. The condition assessment of these devices may be based on the American Traffic

Safety Services Association's guide.[11] VDOT inspectors should make sure that the contractor performs this task.

- The lane closure should be positioned to minimize the impact of curves in the roadway that limit sight distance.

When drums are used in the taper instead of cones, the white retroreflective surface area in the motorists' view goes from 325 cm^2 (50 in^2) to 1394 cm^2 (216 in^2), more than a 4-fold increase. When the orange retroreflective sheeting is added, the retroreflective surface area for a drum doubles, yielding more than an 8-fold increase. Several VDOT districts already use drums in the taper for night work—most began using them during this study. The daily cost increase incurred by using drums in the taper is estimated at under $25. Additional storage space for transporting drums may be required.

VDOT has, on occasion, included in the special provisions for major construction projects a requirement for a traffic operations coordinator whose primary responsibility is maintaining traffic control. An estimate of the cost for this activity could not be determined from the available data.

Improving the Visibility of Workers

In the *Virginia Work Area Protection Manual,* the description on work clothing states: "The retroreflective material shall be visible at a minimum distance of 1,000 feet. The retroreflective clothing shall be designed to identify clearly the wearer as a person and be visible through the full range of body motions."[12] In practice, a safety vest with retroreflective material is worn. To make the full range of body motions visible, the motion of a worker's arms and legs should be visible. In a study on safety service patrol uniforms, Brich concluded that the addition of circumferential retroreflective bands on the limbs and major hinge points (knees and elbows) provides for enhanced recognition of a person during nighttime.[13] This study recommended a safety service patrol uniform design that makes the full range of body motion visible at night. One way to accomplish this is to sew white retroreflective bands onto high-visibility clothing as proposed for the safety service patrol uniforms.[13] The Minnesota DOT uses highly visible vests, pants, and caps.[14] Other options include placing removable bands over clothing at a level slightly above the wrists, elbows, ankles, and knees or sewing the bands onto work clothing. The American Society of Testing Materials is considering developing specifications for nighttime visibility of workers.

Retroreflective hard hats should be required. The New York DOT requires a retroreflective strip 7.6 cm (3 in) long and 2.5 cm (1 in) high placed on each side of the hard hat.[15] About 15 years ago, VDOT removed retroreflective stripes from its standard issue hard hat because the chemicals in the glue attaching the stripe reacted with the plastic shell and compromised the shell's integrity. If this is not a problem today, then white retroreflective strips should be on hard hats worn by those working at night on VDOT roads. The hard hat should be visible from all sides.

Another item that can enhance recognition of a person at night is a flashing light either attached to a person or made into a vest. Although the light adds visibility to the worker, it does not make full body motion visible.

Improving the Visibility of Work Vehicles

Although the visibility of work vehicles was not identified as a problem in the night work zones reviewed, a VDOT employee commented that he was distracted by too many vehicles with lights flashing in a work zone. The New York DOT has the following considerations for work vehicle warning lights near open traffic lanes[16]:

- Inspectors' vehicles and other official vehicles must display an amber revolving light at all times in the work zone, except as noted below.

- In addition to amber revolving lights, all contractor and inspection vehicles should display four-way flashers when stopped or moving slowly in or adjacent to open traffic lanes.

- Warning lights and flashers should be turned off when vehicles are moving at normal speeds in traffic, or when out of traffic in a protected position, and turned on in advance of slowing, stopping, or exiting travel lanes. Unneeded warning lights in or adjacent to the traffic stream distract drivers' attention and reduce driver credibility for lights in general and should be avoided.

Reducing Speeding and Increasing Driver Attention

The use of police officers to control speed in night work zones was the solution most frequently cited by VDOT residencies. It was also cited by several DOTs. The flashing blue light grabs the attention of drivers, especially at night, and checking or reducing the vehicle speed is a natural reaction. A Minnesota DOT study concluded that the 85th percentile speed in work zones was reduced 13 to 18 km/h (8 to 11 mph) when police officers were present with vehicle lights and flashers activated.[17] In some cases and if resources are available, it may be beneficial to have a police vehicle stationed strategically as a warning device and a second police officer patrolling the work zone and ticketing speeders and violators.

In 1994, Garber and Patel conducted a study for the Virginia Transportation Research Council on the effectiveness of using PCMSs to reduce speeds in work zones.[18] When a vehicle's speed measured by the radar unit exceeded a specified value, the PCMS was activated. The message YOU ARE SPEEDING, SLOW DOWN was the most effective message for reducing speeds. The PCMS with a radar unit was an effective speed control device in work zones on interstate highways. In addition to reducing speeds, it reduced speed variance, which could result in safer conditions in the work zone. The study was performed in two phases: phase 1 focused on identifying the most effective message for short-term use and other guidelines, and

phase 2 examined the long-term effects of the PCMS with a radar unit. The Minnesota DOT used a radar-controlled PCMS on a night work zone project with the message YOU ARE SPEEDING.[19]

University of New Mexico researchers found that the Speed Monitoring Awareness Radar Tool (SMART) trailer was effective in reducing speeds by 6.4 to 8.0 km/h (4 to 5 mph) on urban arterials.[20] The SMART trailer is typically operated as an unstaffed trailer that uses radar to monitor speeds and a reader board to show drivers how fast they are going. A speed limit sign is typically displayed above the reader board. This supplemental treatment should be used with realistic (reasonable) work zone speed limits. This technique has been used in work zones in general but may be equally effective for night work zones.

Reducing Glare from Work Lighting

Glare from work zone lighting can be very discomforting and distracting to motorists. Positioning and aligning the lights to keep them aimed toward the work area should reduce glare. Glare may be caused by the failure to extend the light poles to the proper height or to aim the light downward to limit illumination to the work zone. Adding glare screens is also an option. NCHRP Project 5-13 and its sequel 5-13(2), *Illumination Guidelines for Nighttime Highway Work*, address glare and the appropriate level of illuminations needed.[21]

Managing Queuing and Traffic Flow

PCMSs are typically placed 3 to 5 km (2 to 3 mi) in advance of the lane closure in part to warn of a possible queue and delay ahead. Another strategy is to position a police vehicle with flashing lights on a shoulder near the back of the queue. The vehicle would move back and forth as needed to maintain this position—that is, near the back of the queue. A highway work vehicle may be used in place of a police vehicle.

A dynamic lane merge system (Figure 1) was developed to address safety problems of right-angle and rear-end collisions that may result from merging maneuvers associated with closing a travel lane.[22] The system is intended to encourage drivers to merge into the open lane early and to prohibit them from using the closed lane for passing. This system may, to some extent, also address the potential road rage by motorists who become enraged (and aggressive) after being passed by an impolite (and aggressive) motorist seeking to gain a small, unfair advantage. The system consists of dynamic and permanent no passing zones. The permanent no passing zone is designated by several (typically three) closely spaced DO NOT PASS static signs. These signs create a permanent no passing zone about 610 m (2,000 ft) long immediately upstream from the taper. The dynamic no passing zone is immediately upstream of the static zone. This zone consists of a series of three to six control stations with static signs and flashing beacons. The message on these signs is DO NOT PASS WHEN FLASHING. The control station is a solar-powered trailer system equipped with the static signs and strobe lights along

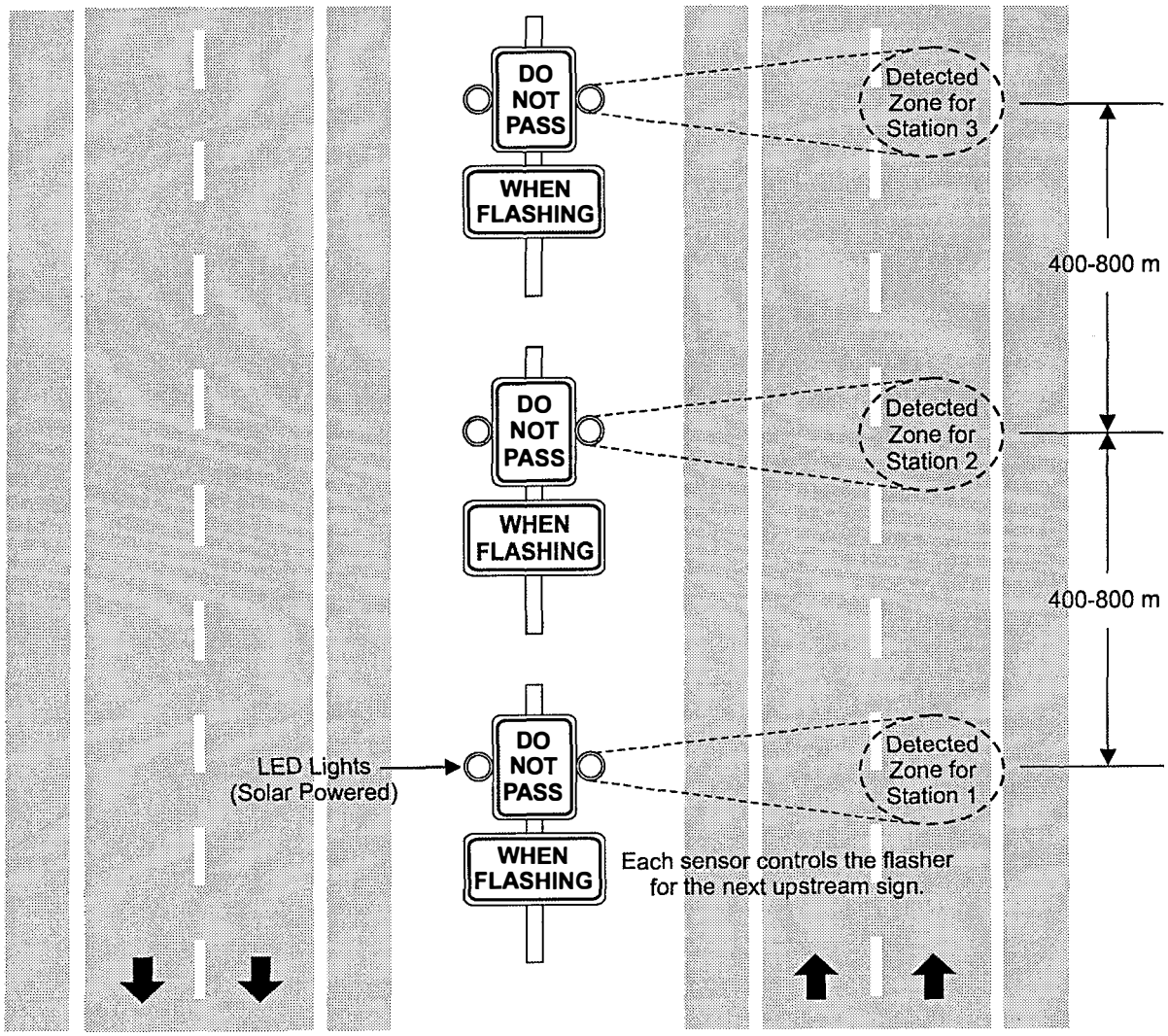

Figure 1. Dynamic No Passing Zones

with sonic detectors, radio transceivers, and remote processing units that control the strobe light of the next sign upstream. When stopped vehicles are detected in the open lane, a signal is transmitted to turn on the flashing strobe lights on the next upstream sign. When vehicles are moving again, the strobe lights are turned off. The length of the no passing zone is tailored to the congestion conditions present and ranges from 610 to 2590 km (2,000 to 8,500 ft). The standard lane closure signs are modified and positioned to accommodate the zone. Enforcement may be needed to improve the chances of success for this system.

Queue length detection systems have been designed for use in areas where traffic flow may change unexpectedly, such as in work zones.[23] The system warns drivers of slow-moving or stopped traffic ahead; thus, motorists can prepare to stop or slow. Although its primary benefit is to reduce rear-end accidents, the system can also encourage drivers to use alternate routes. The traffic monitoring component monitors the speed of traffic. Once the traffic has slowed to or

below a specified level, a PCMS or other device is activated to warn motorists of this condition. The message will remain for a specified period. These systems are especially useful where horizontal or vertical alignment changes may restrict sight distance of potential queues.

Managing Other Safety Risk Factors

Managing the risk factors of reduced visibility, impaired drivers, and high speeds is the prime approach for improving safety in the work zone. A relatively new technique that alerts workers when an errant vehicle enters the work area is an intrusion alarm. An intrusion alarm typically consists of two systems, a detection system such as a rubber tube or beam of light between two sensors across the roadway, and a horn whose sound signals an alarm. A truck-mounted impact attenuator is also used to reduce the severity of a collision with a shadow vehicle. A buffer lane between the open lane and the lane where the work is occurring should be considered if available.

LIMITATIONS OF THE STUDY

Many solutions identified through the surveys were based on experience, intuition, and anecdotes as opposed to investigative research. A limited number of sites were reviewed in the field. A small sample of motorists was surveyed as a gage for issues to examine. Initially, extensive data collection was planned to measure the effectiveness of potential traffic control improvements, but a practical method to obtain driver response to different channelizing devices or signs was not available.

CONCLUSIONS

- *Reduced visibility, driver impairment or inattention, inadequate lighting, and lack of maintenance of traffic control devices are common problems identified with night work zones.* These findings were consistent in the surveys of DOTs and VDOT residencies. Having police officers present, making workers more visible, using drums in the taper, keeping traffic control devices in good condition, and providing adequate lighting were common solutions offered by both sets of respondents.

- *Based on the motorists' survey conducted at selected sites and the onsite review of work zones, traffic control for night work zones, in general, is adequate.* Nevertheless, common problem areas identified were properly establishing work zones based on the *Virginia Work Area Protection Manual,* maintaining traffic control devices, and properly aiming and aligning lighting to avoid glare

- *Although there is a perception that night work zones are less safe than daytime work zones, a lack of accurate traffic exposure data does not allow this conclusion to be drawn.* Based on the limited amount of data gathered, there was no evidence of higher speeds at night. There is, however, a need to improve the visibility of workers.

RECOMMENDATIONS

VDOT's Traffic Engineering Division should revise the *Virginia Work Area Protection Manual* to include the following provisions for night work zones.

Improving Visibility of Traffic Control Devices

1. *Use drums in the transition area for lane closures.* Drums in the tangent section are optional.

2. *Consider requiring the contractor to have full-time traffic control staff to implement and maintain all traffic control operations when deemed appropriate.* This staff should also make sure that the work lights are not creating glare for the motorists and vehicle lights are not a distraction. This staff and VDOT staff should make sure that the traffic control complies with the *Virginia Work Area Protection Manual.*

3. *For all work zones under conditions of limited sight distance because of road alignment, shift the transition area upstream to improve the visibility of the flashing arrow board and the taper. Similarly, when a lane closure merge point is near an entry ramp, shift the transition area upstream to separate the two merge points.*

Improving Worker and Work Vehicle Visibility

4. *Require all workers to wear hard hats that have retroreflective material that is visible from all sides.* Ways to make retroreflective clothing visible through the full range of body motions should be considered.

5. *Use the New York DOT guidelines for use of work vehicle flashing and warning lights.*

Managing Traffic

6. *When a PCMS is used for night work zones, use messages appropriate for the existing road conditions.* A PCMS should be considered for end-of-queue warnings in the early hours when traffic volumes may cause queues and as special attention getters later at night when volumes are lower. When appropriate, the message TROOPER ON SITE, SPEED LIMIT

ENFORCED should be used. The use of a radar-controlled PCMS should be considered as a countermeasure for speeding.

7. *Position the police vehicle to maximize its visibility.*

IMPLEMENTATION PLAN

The VDOT Work Zone Safety Round Table Discussion Group consists of VDOT Traffic Engineering Division staff responsible for the *Virginia Work Area Protection Manual* and district work zone safety coordinators. This group is the forum for discussing and building consensus for changes in practices, guidelines, and policies regarding work zone traffic control. As the first step toward implementation, the recommendations should be presented to this group for review, revisions, and implementation. The researcher will provide assistance as needed through the implementation process.

VDOT's Employee Safety and Health Division should have the lead responsibility in the areas of worker safety clothing such as vests and hard hats. VDOT's Traffic Engineering Division and the Virginia Transportation Research Council should work with this division to implement these recommendations.

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APPENDIX

SURVEY ON TRAFFIC CONTROL IN NIGHT WORK ZONES

Name: _____
State: _____
Address: _____
_____
Phone Number: _____

(If additional space, is needed, please attach additional pages)

1. Do you use night work zones?

   ____ yes. Please continue with the survey.
   ____ no. Please stop and return the survey as noted below.

2. How do you determine when to perform night work? Please attach documents that answer or support this answer.

_____
_____
_____
_____
_____
_____

3. What are the major problems with night work zones? Also, identify any possible solutions to these problems.

   _____
   _____
   _____
   _____
   _____

4. Do you routinely use typical work zone traffic control for night work zones?

   ____yes ____ no. If no, please attach copies of the strategies or describe below. (Examples include longer tapers, smaller spacing of devices in the tapers, larger channelizing devices, more or larger signs, worker visibility or safety improvements, etc.). Supporting information explaining why you chose these strategies would be helpful. Please indicate whether the strategy is typical for all night work zones or its use is determined for each project.

4. (continued)

5. Please enclose copies of any reports or memos that document the effectiveness of the traffic control devices or strategies described in question 3.
____ documents enclosed. ____ no documents, explain below.

6. Comments or suggestions? Please identify any person, agency or report(s) that may provide information on night work zones.

Thank You.

Please return the completed surveys and enclosed materials by **Friday, April 4, 1997,** to:

Ben Cottrell
Virginia Transportation Research Council
530 Edgemont Road
Charlottesville, VA 22903-2454

Questions? Please call (804) 293-1932, e-mail at bhc2s@virginia.edu, or fax (804) 293-1990.