Variables Affected by Nighttime Construction Projects

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An increasing number of roadway rehabilitation projects are using nighttime construction schedules. Factors involved in the decisions to employ nighttime construction schedules were examined in a study of state highway agencies. The study consisted of a survey concerning the various parameters that were considered when nighttime construction schedules were required in construction contracts. State personnel familiar with nighttime construction projects were asked to describe particular aspects of projects that were different as a result of the night schedule. In addition, a survey was conducted with construction contractors who had experience with nighttime construction projects. Results show that the overriding factor for a nighttime schedule that is contractually required is the unacceptably high traffic congestion that would result from daytime roadway work. On nighttime projects, of particular concern is safety and traffic control. Although worker scheduling is made more difficult at night, several contractors indicated that they elected to use nighttime schedules even when not contractually required to do so. These contractors noted that task scheduling is easier at night and that material deliveries are more readily made at night. However, for all parties involved in the process, safety tends to be the overriding concern.

Because roadway surfaces in this country are deteriorating, traffic congestion in metropolitan areas is becoming a greater problem. A paradox is presented because the congestion will increase as a direct result of the efforts taken to rehabilitate the roadways. The added congestion caused by the rehabilitation efforts is often so severe as to preclude work from being performed during regular working hours, particularly during times that coincide with the local rush hour or peak traffic periods. As a result, more work on roadways is taking place at night when the impact on the traveling public is minimized.

Undoubtedly, numerous factors exist that are affected by nighttime construction projects. Reduction in daytime traffic congestion that would result from a conventional construction schedule is one obvious benefit derived from nighttime construction work. However, various negative aspects are introduced as well. For example, construction workers are accustomed to working during the daylight hours. To what extent is labor scheduling a problem on nighttime construction projects? Is worker morale and productivity reduced on nighttime construction projects? Is worker absenteeism increased when work is performed at night? To what extent is supervision impaired by night work? Similar questions could be asked about:

- Availability of materials after hours and any associated premiums that must be paid,
- Impact of noise from nighttime construction projects on residential communities,
- Added risks to drivers imposed by nighttime construction work,
- Added risks for construction workers,
- Inconvenience imposed by nontypical working hours for inspectors and other representatives of the owner,
- Relative quality of nighttime construction caused by reduced visibility,
- Response time of answers to questions when few individuals with authority are available, and
- Impact of the change in relative humidity and temperature on material quality.

Many of these questions go unanswered. However, these are important issues to consider because nighttime construction schedules for rehabilitation of major metropolitan roadways is likely to increase in the coming years in an effort to resolve the problem of deteriorating roadways. For this reason, a research study was conducted to investigate, in greater detail, the decision-making process concerning nighttime construction. The primary objective was to determine which factors are considered most important when construction work needs to be done at night. The study was also designed to examine some of the principal variables that are of particular concern after a nighttime construction schedule has been established. Input was received from state highway agencies and from contractors experienced in nighttime work.

REVIEW OF RELATED LITERATURE

The literature review consisted of an examination of a variety of published materials on road rehabilitation and on road maintenance activities. Examination of these materials was further restricted to activities on major metropolitan highways or arterials that were performed, at least in part, at night. This search of the literature was conducted to identify the primary factors that are considered when a decision is made to use a nighttime construction schedule. A secondary objective was to identify unique aspects of nighttime construction.

From the literature, decisions regarding the use of a nighttime schedule are based on information similar to that used when making determinations of traffic capacity. Texas has devised a means of determining traffic capacity for various roadway configurations when varying numbers of lanes are closed (*1*). Although this technique may be valuable in forecasting traffic levels, this planning tool does not specifically address nighttime lane closures. Another method is the *Highway Capacity Manual*'s (*2*) empirical formula used to estimate

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roadway capacity. Some suggest that this formula be modified to reflect also the influence of the duration of the lane closure (*3*). Thus, various methods exist whereby predictions of traffic capacity can be made. Because actual traffic volume varies with the time of day, it is possible to determine those time periods during which lane closures would cause the roadway capacity to be exceeded. The next step would be to determine if the queue formed and the resulting delay are acceptable. When daytime traffic delays are unacceptable, nighttime work schedules are justified. A general consensus exists that backups can be expected when traffic congestion is around 1,500 vehicles per hour per lane (vphpl) (*4*). These approaches are relatively objective because they do not consider subjective variables such as the needs of the work site, the duration of construction, the effect on motorists, or the reaction of the public. Mathematical models have been developed to describe the characteristics of the vehicle queue (*5*).

From the previous discussion, objective means exist by which to measure the impact of roadway constrictions imposed by construction work. In specific instances, nighttime work provided cost savings as a result of reduced costs of traffic control and increased efficiency of operations (*4*). Methods for calculating user costs have been developed (*1,6,7*) although user costs are not directly paid by the owner agency and, as a result, may not be dominant factors in traffic decisions.

Although several studies have examined the effectiveness of different traffic control strategies, little has been concluded in terms of night work. Nighttime traffic control is made more complex because of reduced visibility and the possible presence of a greater number of intoxicated or inattentive drivers. Traffic control studies have evaluated the effectiveness of changeable message signs (*8*), appropriate wording on signs (*9*), effectiveness of flags and flashing warning lights (*4*), use of sequential arrow boards and reflectorized cones (*8*), value of using drums and barricades (*4*), merits of employing a uniformed traffic officer (*10*), usefulness of flaggers (*8*), need for a traffic control plan, and use of total road closures (*4*).

Reduced visibility on nighttime projects increases the inherent hazards of construction. Safety has also been addressed by various studies. One study disclosed an increased number of accidents on highway projects, but did not develop any conclusions regarding night work (*11*). Other studies have shown a marked increase in accident frequency on night projects (*12,13*).

Nighttime construction requires the use of artificial lighting in the work place. The lighting must be sufficient to permit clear visibility without creating glare. Some operations are best performed with the use of supplementary hand-held lights (*8*), portable floodlights (*4*), or spot lighting (*12*).

Poor visibility associated with night construction must be addressed to maintain an acceptable level of work quality. Acceptable surface finishes have been achieved through nighttime operations (*10*). Cooler nighttime temperatures offer the best opportunity for placing some types of portland cement concrete during the summer months. For similar reasons, a nighttime schedule is commonly used when using latex-modified concrete on bridge decks.

Noise from a nighttime construction project may be of particular concern if noise ordinances are more stringent at night. A contract may include an incentive provision for the contractor to reduce the noise level (*14*). In addition, various measures can be taken to reduce equipment noise (*15*).

Most construction workers are accustomed to working during the day. A nighttime project may be new to many workers. Nighttime projects incur a larger turnover of workers on the night shift, in spite of the pay differential that compensates the workers for the nighttime inconvenience (*4*).

Productivity is also affected by a nighttime schedule. This effect can generally be minimized with good planning and by staffing the project with a person who has the authority to make decisions for the company (*4*).

Various factors have been identified in the literature as being affected, either favorably or unfavorably, by a nighttime schedule. However, no study was identified that incorporated all of these variables and enumerated the relative importance of each in the decision-making process concerning nighttime construction.

RESEARCH METHODOLOGY

A two-part questionnaire was distributed to state highway agencies. Part I was designed to be completed by someone familiar with the decision-making process when a nighttime construction schedule was contractually required, such as a state transportation planner or a district construction engineer. This portion of the survey included questions on the amount of nighttime construction that is contractually required on state roadway projects, future projections of the amount of nighttime construction to be used in the state, a ranking of the most important variables to be considered when deciding on nighttime construction, the nature of the analysis to assess the merits of a nighttime construction schedule, and the cost impact of a nighttime construction schedule.

Part II did not address the decision-making process regarding nighttime construction but rather the various factors that are involved once a nighttime construction schedule is used on a project. Ideally, Part II was assumed to be completed by individuals with field experience involving nighttime construction, such as project engineers and resident engineers. These individuals have direct experience with planning and monitoring construction activities. This portion of the survey included questions on the ranking of the most important factors affected by nighttime construction schedules, including such variables as traffic control, safety, noise, productivity, project costs, and community impacts. Information was also requested on the most effective means to ensure safety for workers and nighttime drivers. Additional questions addressed unique problems encountered by nighttime construction schedules, the presence of any advantages of nighttime work, the relative quality of paving work performed at night, and specific cost differentials for performing certain tasks at night. The last question of the survey asked for the name of a contractor known to have experience with nighttime construction work.

The survey was sent to the 50 state highway agencies. In total, 30 responses from 21 states were received for Part I and 36 responses from 19 states were received for Part II. Twenty-three states were represented by the survey respondents because some states only responded to one portion of the survey. Multiple responses were received from three states.

Before compiling the responses, an examination was made to determine if multiple responses from states should be treated differently from single ones. This analysis revealed that multiple responses from states were not different from the single responses received from the state agencies. For this reason, the final analysis did not consider the differences between states, but treated all responses as being unique responses, regardless of respondent location.

Another survey was prepared to obtain information from contractors about nighttime construction. The contractors included in this study were those who were identified as being experienced with nighttime construction by respondents to Part II. Because no known study on nighttime construction had included contractors, a less formal format was seen as being most effective. Thus, the contractor portion of the study was conducted on the telephone. Questions were asked about contractor rationale for electing to perform nighttime construction work, types of projects best suited for nighttime scheduling, most effective traffic control devices, cost differential for various types of work performed at night, and particular problems encountered with night work. Eighteen contractors from 11 different states were interviewed.

DECISION TO REQUIRE NIGHTTIME WORK

Responses to Part I reflect the experience of 30 respondents each of whom award, on the average, more than 150 contracts per year. Each respondent awards about three contracts per year requiring work to be performed at night. The nighttime construction contracts, totaling 173 for the respondents, were valued at more than $1.5 billion, with the average per-contract value being just under $9 million. An additional three night projects per respondent were performed each year, although the nighttime schedule was not contractually required. Over the past 5 years, 408 projects, valued at nearly $3 billion, were awarded in which nighttime construction was contractually required and another 364 projects were completed in which the contractors elected to use a nighttime schedule. The total number of nighttime construction projects has remained relatively constant over the past 5 years. However, the respondents projected that approximately 195 nighttime construction contracts would be awarded in the next 2 years, indicating an increase in the use of contractually required nighttime construction work (see Table 1).

Several respondents pointed out that the distinction between contractually required nighttime projects and projects in which the contractors elected to perform the work at night may be subtle. For example, a contract may not specifically state that nighttime work must be performed, but instead may stipulate that lane closures cannot occur during certain peak traffic hours. The result is that the contractor is essentially bound to perform the work at night in response to the lane closure limitations. The completion date, coupled with the unique traffic handling requirements, can be construed to dictate a nighttime work schedule.

Because nighttime construction work was contractually required by most (approximately 70 percent) of the respondents, questions were asked to ascertain the relative importance of the different factors considered during the decision-making process. Twelve factors meriting consideration were identified through the literature review and personal interviews. These factors were then rated on a scale of 7 by each of the respondents. A rating value of 1 indicated a low importance for the factor, whereas a value of 7 represented the highest level of importance that could be assigned. The summary of this factor rating is presented in Table 2.

TABLE 1 GENERAL DESCRIPTION OF THE RESPONDENTS TO PART I OF THE STATE HIGHWAY AGENCY SURVEY

Total Number of Respondents	30
Number of States Represented by the Respondents	21
Number of Construction Contracts Awarded per Respondent	161 Contracts/Year
Number of Construction Contracts Requiring Nighttime Work Awarded in the Past Two Years per Respondent	3.1 Contracts/Year
Average Value per Nighttime Contract	$8.9 Million
Number of Construction Projects on Which the Contractor Elected to Work at Night in the Past 2 Years	3.0 Projects/Year
Number of Construction Contracts Requiring Nighttime Work Awarded in the Past 5 Years per Respondent	3.1 Contracts/Year
Average Value per Nighttime Contract Awarded in the Past 5 Years	$7.1 Million
Number of Construction Projects on Which the Contractor Elected to Work at Night in the Past 5 Years	3.3 Projects/Year
Number of Construction Contracts Requiring Nighttime Work Expected to be Awarded in the Next 2 Years per Respondent	4.2 Contracts/Year
Average Value per Nighttime Contract to be Awarded in the Next 2 Years	$6.5 Million

From the rating values provided, traffic congestion receives the most important consideration. Safety is also considered to be important, whereas the cost of the nighttime project to the owner is of relatively low importance in the decision-making process. One respondent indicated that safety was a serious concern because reduced traffic congestion associated with a nighttime project caused driver speeds to be higher. This condition is aggravated by the presence of greater numbers of intoxicated or inattentive drivers.

Because the importance of congestion to the decision-making process was anticipated, questions were asked about the type of analyses conducted when the decision is made on whether nighttime construction work will be required. An objective analysis, similar to that described earlier, is employed by four of the respondents. When compared with other respondents, these four gave higher ratings to the importance of safety, productivity, and noise. However, the importance of user costs was rated lower by those performing a detailed analysis.

Empirical formulas and agency experience are two means of estimating roadway capacity. Fourteen of the respondents use both approaches, eight make exclusive use of the *Highway Capacity Manual* (2) equation, and five indicated that they relied solely on experience (three provided no response). One

TABLE 2 RATINGS OF THE IMPORTANCE OF FACTORS TO CONSIDER WHEN DECIDING ON NIGHTTIME CONSTRUCTION CONTRACTS

Factor	Average Rating
Congestion	6.72
Safety	5.93
Noise	5.31
Work Time Available	5.21
User Cost	5.14
Quality	4.93
Light Glare	4.66
Productivity	4.29
Agency Experience	3.79
Contractor Experience	3.43
Temperature	3.38
Owner Cost	3.07

respondent also mentioned that actual counts by time of day were useful for determining highway capacity.

Level of congestion can be quantified objectively or subjectively. Objective analysis includes use of either current traffic volume counts or queuing theory. Use of past experience or judgment is a subjective approach. The 27 respondents to this question indicate using volume counts is the most common, with 23 (85 percent) using volume counts and 5 (18 percent) of the respondents making exclusive use of this method. Queuing theory is used by 9 (33 percent) of the respondents, whereas 20 (74 percent) use past experience. All three approaches are used by 32 percent of the respondents (see Table 3). Multiple responses from some states were not the same for all respondents within each state, implying that differences exist between the districts within the states.

Regardless of the means used to predict level of congestion, several respondents were reasonably consistent in considering nighttime construction to be appropriate when congestion approached 1,500 vphpl. Consistent with the literature, 10 of the respondents consider night work to be justified when congestion is in the range of 1,200 to 1,600 vphpl. The actual range of this value for all respondents was from 800 to 1,900 vphpl. Experience is also used in this determination without specifying the actual level of congestion.

A question was asked about determining whether construction should be done with total or partial road closure. Factors generally considered include anticipated level of traffic congestion, duration of the project, existence of a feasible detour route, cost of the project to the owner, and cost impact on road users. Respondents were asked to rate the relative importance of these factors on a 7-point scale. As presented in Table 4, level of congestion and availability of a detour are the most important considerations. For respondents conducting detailed analysis, importance of the level of congestion is rated even higher. In fact, respondents performing detailed analyses rated all of these factors as being more important.

TABLE 3 TYPES OF INFORMATION USED TO QUANTIFY TRAFFIC CONGESTION

Type of Information	Number of Respondents[1]
Current Traffic Volume Counts	23[2]
Past Experience	20
Queue Theory	9[3]

[1]A total of 27 responses were received to this question
[2]Five respondents use this method exclusively
[3]Traffic counts and past experience are also used.

TABLE 4 RATING OF CONCERNS WHEN DECIDING ON PARTIAL VERSUS TOTAL ROAD CLOSURES

Factor	Average Rating
Congestion	6.79
Detour Routes Available	6.24
Duration of Project	5.69
User Cost	4.55
Owner Cost	4.38

One question concerned the cost of nighttime construction projects. In order to quantify costs, identifying specific cost items affected by the nighttime schedule would be necessary. When asked if any specific pay items for nighttime work existed in the pay schedules, only three respondents gave affirmative answers. Thus, costs of specific items of work required by a night schedule cannot be readily retrieved by most state highway agencies because the costs of nighttime construction are generally absorbed in other pay items. The lack of this type of information is consistent with the low level of importance placed on owner costs.

Safety of roadway construction depends to some extent on the public information system used to notify motorists, police, fire, and ambulance services about upcoming road and lane closures. This information permits users to identify alternate routes, reschedule their travel accordingly, or expect delays. The notification system varies by state. The most common means of disseminating information is through newspapers, radio, and television. Many agencies have a public information division or press office that is responsible for notifying the media concerning construction that will affect the public. In some cases, contractors are required to notify the public information office or the media directly. A time frame of from 24 to 72 hr before a road or street closure is usually specified. In some cases, notification 1 to 2 weeks before closure of a street or lane may be necessary. In several states, personnel with emergency units are invited to a preconstruction meeting in which they are fully apprised of the impact of the anticipated work. One state agency writes a weekly newspaper column, which publicizes information about road and lane closures. Information is also spread with the use of changeable message signs, billboards, or special road signs.

FACTORS AFFECTED BY A NIGHTTIME CONSTRUCTION SCHEDULE

Part II of the state highway agency survey focused on primary concerns of using a nighttime construction schedule. A wide variety of projects were selected on which the experience of the respondents was based, including new construction with asphalt and portland cement concretes, bridge deck overlays or replacements, asphalt concrete overlays, portland cement concrete removal and replacement, roadway maintenance activities, and various combinations. Paving with an asphalt concrete overlay was the most common activity performed at night.

Respondents were asked to provide answers to a variety of questions pertaining to projects with which they were personally familiar. Respondents were asked to rate the relative importance of a number of planning concerns when nighttime road closure projects were being scheduled (see Table 5). Traffic control was given the highest rating, followed by concern for worker and driver safety. With partial closure, the same three factors were seen as dominant concerns. However, concern for driver safety was rated the most important. Other concerns about night work specifically mentioned included amount of work, time frame of road or lane closure, public notification, quality of workmanship, and weather.

Road closures, whether total or partial, require that careful attention be paid to the means used to control the traffic. Various types of traffic control devices and methods of providing for worker safety are available. Respondents were asked to provide their perception of the relative effectiveness of various selected methods on a 7-point scale (see Table 6). For total and partial road closures, lighting was considered to be the most effective means of providing for the safety of workers and drivers. Signs and sequential arrow boards were also given high ratings for total and partial road closures. Use of safety vests and physical barriers was rated as having greater importance on partial road closure projects. Other suggested methods include the use of reflective channel devices, reflectorized barrels, and flashing lights. Some respondents mentioned that the effectiveness of some methods may be considerably enhanced when one of the other approaches is also used, presenting difficulties in judging a single approach.

In situations where changeable message signs were used, respondents were asked to indicate the most effective wording they had observed. Approximately two-thirds of the respondents preferred wording such as Right (Left) Lane Closed, Merge Left (Right) over less specific wording such as Night Work Ahead and Construction Ahead. Speed reduction signs and specific instructions for drivers such as Exit Available to Avoid Construction were mentioned as helpful in controlling traffic.

TABLE 5 RATING OF VARIABLES TO CONSIDER WHEN PLANNING NIGHTTIME WORK

PLANNING CONCERN	TOTAL ROAD CLOSURE	PARTIAL ROAD CLOSURE
Traffic Control	6.76	6.61
Safety of Workers	6.53	6.57
Safety of Drivers	6.47	6.66
Community Impact	5.79	5.33
Productivity	4.94	4.89
Project Cost	4.44	4.33
Noise Level	3.85	3.89

TABLE 6 RATING OF TRAFFIC CONTROL DEVICES ON NIGHTTIME CONSTRUCTION PROJECTS

Traffic Control Device	Total Road Closure	Partial Road Closure
Lighting	6.39	6.59
Signs	6.24	6.41
Sequential Arrow Board	6.06	6.41
Physical Barriers	5.94	6.09
Changing Message Sign	5.76	5.91
Safety Vests	5.48	6.32
Reflectorized Cones	5.31	5.91
Police Patrol	5.06	5.65
Flaggers	3.94	4.91

Aside from traffic control, nighttime construction projects present new challenges for these projects. Several questions were asked to determine the extent that nighttime construction altered or affected the quality of the work performed. One question concerned the quality of asphalt concrete paving when performed at night. Seventy-six percent of the respondents felt that the quality of asphalt concrete paving work performed at night was lower than the quality of similar work performed during the day. Only one respondent felt that the quality of night work was better. A typical response was that "it is very hard to control the placing and finishing of asphalt and get a good job." Two respondents indicated that, in their respective states, the wearing course was never placed at night.

When asked about the principal problems encountered with the nighttime placement of asphalt concrete (AC) paving, "unevenness of the paving surface" was the dominant (79 percent) response. Inconsistency in the mix, poor compaction, and cold joints were mentioned as problems by about 20 percent of the respondents. Most of these problems stem from the difficulty in providing sufficient lighting for the site. Inspection of the work is a problem for a similar reason. Other difficulties mentioned include shadows, less control of tack spread, a longer waiting period for the tack to break, asphalt dropping from trucks onto the pavement that cannot be readily seen at night, alignment, repairing roller marks, and scheduling work forces.

Similar questions were asked about the night placement of portland cement concrete (PCC). Most respondents (63 percent) indicated that the quality of PCC placed at night was below that of materials placed during the day. The overriding problem, noted by 85 percent of the respondents, was the difficulty of obtaining a good finish. Problems of cold joints and mix inconsistencies were noted by only two respondents. The root source of the problems with placing PCC at night is the issue of insufficient lighting. In addition, cooler nighttime temperatures limit PCC placement time in some areas. How-

ever, during summer months nighttime work offers more comfortable working temperatures, better workability and curing of concrete, and easier material delivery with the absence of daytime traffic congestion.

Other typical road work activities were identified and the respondents were asked to rate, on the 7-point scale, the relative quality that could be expected on those work items if performed at night (see Table 7). The best quality was apparently achieved in the compaction of the subgrade (rated 4.88), whereas the lowest quality attained occurred with crack sealing on AC pavement (rated 4.10) and crack sealing on PCC pavement (rated 4.19).

Apparently, nighttime construction is different principally because of the absence of natural lighting by which to observe the work activities being performed. Because some artificial lighting must be provided in order for night work to proceed the survey asked whether lighting intensity to be provided was stipulated in the contract documents. Eighty-two percent of the respondents did not specify a minimum level of lighting intensity. Respondents who did have specifications for minimum acceptable lighting intensity also rated lighting as being a particularly important safety measure. Although lighting intensity was specified by some respondents, foot-candle intensities specified were too varied to provide any meaningful guidance. These respondents also rated barriers as effective safety devices on road closures. Incidentally, these were the same respondents who indicated that better quality performance was realized with subgrade compaction, asphalt concrete surface compaction, AC pavement crack seals, and PCC pavement crack seals.

Various disadvantages of performing construction work at night have been presented. Respondents were also asked to identify tasks for which performance was improved at night (Table 8). Although no single task was agreed on by a majority of the respondents, some tasks were mentioned more frequently than others, notably AC paving, bridge deck rehabilitation, pavement marking, and PCC paving. In most cases, the advantage of a night project tends to be associated with cooler temperatures and more efficient delivery of materials because of reduced traffic.

Regardless of the quality of work achieved, cost differentials exist for work performed at night. Respondents were asked to estimate cost differentials for a selected number of items (see Table 9). Although Table 9 is interesting, the information must be recognized as being variable. Most respondents gave estimates for various cost differentials; however, each estimate was based on a specific project. Accurate estimates are difficult to ascertain when portions of a project are performed during the day and when added costs of night construction are buried in other pay items. Cost values provided should be useful to provide an order of magnitude estimate of the added costs of night construction, recognizing that the costs may vary considerably with the type of project and the locality. The overall cost differential for total project costs is 9 percent. This increase may be attributed, in large part, to the other cost items noted in the table. One respondent stated that night construction was more costly because night work increased project duration, which contributed to a 30 percent cost increase in administration costs.

TABLE 7 RATING OF QUALITY ACHIEVED IN SPECIFIED OPERATIONS PERFORMED AT NIGHT

Operation Performed at Night	Quality Rating
Compaction of Subgrade	4.88
Surface Compaction of Asphalt Concrete	4.77
Installing Guard Rails	4.73
Placing PCC Pavement	4.54
Pavement Marking	4.36
Crack Sealing on PCC Pavement	4.19
Crack Sealing on AC Pavement	4.10

TABLE 8 HIGHWAY CONSTRUCTION TASKS PERFORMED BETTER AT NIGHT

Construction Task	Number of Respondents Naming the Task
Asphalt Concrete Paving	6
Bridge Deck Rehabilitation	5
Pavement Marking	5
PCC Paving	4
Demolition	3
Setting Girders	2
Concrete Joint Repairs	2
PCC Pavement Spall Repair	2
PCC Pavement Slab Repair	2
Latex Modified Concrete	2
Grooving PCC Pavement	1
Large Concrete Pours	1
Asphalt Concrete Removal	1
Loading and Hauling Dirt	1
Preparing for Structural Pours	1
Backfilling Structures	1
Shifting Traffic	1
Installing Guardrails	1
Signals	1
Street Lighting	1
Grading/Crushing Aggregate	1

TABLE 9 ESTIMATED INCREASE IN THE COST DIFFERENTIAL OF PERFORMING WORK AT NIGHT

Project Cost Item	Increase in Cost
Lighting	63%
Traffic Control	28%
Engineering Inspection	22%
Labor (Shift Premiums)	18%
Overtime (Agency Personnel)	16%
Material Costs	5%
Total Contract Amount	9%

RESULTS OF CONTRACTOR INTERVIEWS

Information obtained from the contractors was less extensive than that received through the state highway agency surveys. However, some interesting comments were given. The focus of the interviews was on issues of safety, innovations, and problems associated with nighttime construction.

The contractors represented a diverse group, ranging from firms involved solely with projects performed at night to those who performed only 5 percent of their work at night. For the sample, the average contractor performed about 50 percent of the work at night. From these statistics and supported by their comments, some contractors prefer nighttime construction projects, whereas others prefer daytime projects.

Nighttime projects ranged in duration from 2 months to as long as 3 years. Longer projects reported about 25 percent nighttime work, whereas shorter projects had a much greater extent, about 80 percent. Contract values ranged from $300,000 to more than $200 million. On these projects, about 40 percent of the contractors made the decision to work at night, about 40 percent were contractually obligated to perform the work at night, and the remainder made a joint decision with the state highway agency on the nighttime schedules. Some key factors in deciding on a nighttime schedule included less traffic, better production, more work-time available, early completion incentives, and greater ease of getting materials delivered.

Contractors were asked to describe the types of work performed at night (see Table 10). The most frequently mentioned projects involved AC paving, PCC paving, and bridge decks. Contractors indicated that on about 70 percent of the projects the traffic control plan used was specified by the state highway agency. On 20 percent of the projects, contractors worked with the state agency to develop an acceptable traffic control plan. For the remaining projects, development of the traffic control plan was the sole responsibility of the contractor. In establishing a traffic control plan, contractors indicated that the most effective traffic control devices were arrow boards (see Table 11). Other effective means less frequently mentioned included lighting, police patrol cars, and changeable message signs. Contractors mentioned problems with some of the devices. Some stated that arrow boards were generally not placed for the best effect and become visible only after the driver was in the work zone. Others stated that drivers often failed to read the messages regarding traffic control.

TABLE 10 TYPES OF WORK PERFORMED AT NIGHT AS REPORTED BY CONTRACTORS

Type of Work	Number of Responses
AC Paving	8
Bridge Decks	7
PCC Paving	6
Hauling	3
Structures	3
PCC Pavement Repair	2
Pile Driving	2
Milling	2
Grading	1
Drainage	1
Excavation	1
Utilities	1

TABLE 11 EFFECTIVE TRAFFIC CONTROL DEVICES AS REPORTED BY CONTRACTORS

Traffic Control Device	Number of Responses
Arrow Boards	12
Lighting	7
Police Patrol Cars	6
Changeable Message Signs	5
Physical Barriers	3
Reflectorized Barrels and Drums	3
A-Frame Barricades	2

Most contractors stated that nighttime work was dangerous. In order to counteract the dangers, workers must wear reflective clothing and the site must be well lighted. For worker safety, the workers should be separated from traffic by physical barriers. Several contractors stated that contract provisions may limit lane closures to the one lane on which work is being performed. For improved safety, these contractors would like to be permitted to close an additional lane. Another common problem is that drivers fail to adequately reduce their speeds consistent with the needs of the project. More than 75 percent of the contractors stated that worker morale is not a problem. One contractor stated that wage premiums, more time off, short-duration projects, and a regular night schedule were important means by which worker morale and productivity could be maintained. This comment implies that worker morale might become a problem if specific measures are not taken.

Contractors were asked to estimate the cost differential for performing construction work at night. Average overall added cost for nighttime construction projects was estimated to be about 10 percent, a value consistent with the estimate provided by the state agency respondents. Most of the added costs were attributed to the premium wages paid for shift work. Materials were an added cost only for those few contractors who did not have their own batch plants. Material costs could rise significantly if more expensive materials, such as a fast-setting patching product, were required as a result of a night schedule. Traffic control was not generally mentioned as being more expensive at night. One contractor stated that lighting (an expenditure not encountered on daytime projects) could constitute a 1 percent cost increase on the total contract.

Contractors were also asked to comment on any problems that were specific to nighttime construction. Typical comments listed quality control problems stemming from poor visibility, shadows, material mix inconsistencies, and cold temperatures. The danger posed by intoxicated or inattentive drivers was a cause of common concern for most contractors. Lane closure schedules pose unique problems because workers can only access the site after the closure and because the work site must be vacated when the roadway or lane is reopened to traffic.

CONCLUSION

Information has been added to the existing literature on nighttime construction. Some of the results support various findings of past research studies, whereas other results are unique. The literature describes several types of detailed analyses that can be used to evaluate nighttime construction alternatives; however, the findings show that these approaches are used by only a small number of state agencies. Decision making tends to focus on traffic congestion as the most important factor, but the anticipated level of congestion is largely based on experience and judgment. Little use is made of objective analysis, which indicates that state agencies assume that a good intuitive understanding of congestion exists.

Consistent with the literature, congestion and safety were found to be the primary factors for deciding on a nighttime construction project. When the impact is considerable, either factor may dictate that nighttime construction is appropriate. Cost of the project to the owner is regarded as being of little importance, whereas user costs, which are directly related to congestion, are given careful consideration. Noise was also found to be a relatively important factor in the decision-making process. In fact, where specific nighttime noise levels are prescribed by local governments, nighttime construction may be precluded unless remedial actions to reduce the noise levels are undertaken.

When contractors elect to perform work at night, their decision is based primarily on production and scheduling. As noted in the literature, no detailed methods exist by which scheduling problems can be mitigated. Difficulties in scheduling are presented by the time required to set up traffic control devices and to remove them before reopening the traffic lanes. Scheduling becomes more severe when the rush hour or peak levels of traffic develop early in the day and extend into the night hours. Night hours must also be coordinated with state personnel, for example, inspectors and project engineers.

Costs associated with nighttime construction were examined. State agency estimates indicated that total project costs could be expected to increase by about 10 percent when nighttime construction is performed. Interestingly, contractors provided a similar estimate of the cost of nighttime construction. This cost is lower than most cost estimates of nighttime construction noted in the literature. Perhaps these values are reasonably accurate and indicate why owners do not regard owner cost as being important.

The sources of the added costs of construction were examined. One cost that tends to be unique to nighttime construction is the need for artificial lighting. In order to meet lighting requirements, contractors can add lights to their equipment or obtain a variety of other types of lights that can be placed on the job near the primary work activity. Equipment modified with lights provides the added benefit that the setup cost is incurred only one time. Unfortunately, little information is available in the literature regarding cost-efficient, safe, and effective means of equipping paving machinery with special lighting.

State agency personnel estimated that material costs were increased by 5 percent when nighttime construction took place. Contractors, on the other hand, did not give estimates that were consistent with these values. Most contractors stated that material prices did not increase when work was performed at night. Cost of materials are not increased because most contractors have their own batch plants and thereby establish greater control over the material. Because streets are less congested at night, the actual cost of material delivery may be reduced on night projects.

The literature suggests that more traffic control should be used for nighttime road construction than for daytime work. State personnel and some contractors estimated that the added costs of traffic control on a nighttime project were about 25 percent higher. However, many contractors indicated that they emphasized traffic to an equal extent for daytime and nighttime construction. Traffic control is important regardless of the time of day. Reduced speeds through the construction work zone and a well-lighted site can add considerably to the safety of construction workers and drivers. The issue on which there is disagreement between state personnel and the contractors is whether costs are increased by day or by night to get drivers to observe precautions.

The literature indicates that changeable message signs are effective for traffic control in a nighttime construction work zone. Respondents do not fully agree. The state agency respondents indicated a preference for changeable message signs with simple messages, such as Night Work Ahead. Use of such signs by the contractors is relatively low. Perhaps the information about these signs is not well disseminated among the firms that could benefit from them.

Flashing warning lights are another traffic control mechanism to get the attention of drivers. Survey respondents and the literature agree on the value of flashing warning lights. One particular type of warning light, found on police patrol cars, was noted in the literature as being effective for traffic control. However, survey respondents did not evaluate this as an effective means. Perhaps the respondents had little experience with the use of police patrols on construction sites.

The majority of the state highway agencies agree that the difficulty of providing adequate lighting has an adverse impact on quality. Although the quality may meet established standards, defects in the finished surface for both asphalt and PCC pavement are apparent. Defects appear to be a tradeoff that agencies are willing to accept in exchange for reduced congestion.

From the literature, public information seems to be an important means of reducing problems of nighttime construction. Respondents also agreed that public information is helpful. Various means of disseminating information such as newspapers, radio, and signs may all be used to reach different audiences.

REFERENCES

1. C. L. Dudek, S. H. Richards, and R. C. Wunderlich. *Handling Traffic in Work Zones*. FHWA, U.S. Department of Transportation, 1985.
2. *Special Report 209: Highway Capacity Manual*. TRB, National Research Council, Washington, D.C., 1985.
3. J. J. Wang and C. M. Abrams. *Planning and Scheduling Work Zone Traffic Control Technical Report*. FHWA, U.S. Department of Transportation, 1981.
4. F. D. Shepard and B. H. Cottrell, Jr. *Benefits and Safety Impact of Night Work Zone Activities*. FHWA, U.S. Department of Transportation, 1985.

5. F. L. Mannering and W. Kilareski. *Principles of Highway Engineering and Traffic Analysis*. John Wiley, New York, 1988.
6. *A Manual on User Benefit Analysis of Highway and Bus Transit Improvements*. AASHTO, Washington, D.C., 1977.
7. R. L. Lytton, W. F. McFarland, and D. L. Schafer. *NCHRP Report 160: Flexible Pavement Design and Management: Systems Approach Implementation*. TRB, National Research Council, Washington, D.C., 1975.
8. D. A. Price. *Nighttime Paving*. FHWA, U.S. Department of Transportation, 1985.
9. R. S. Hostetter, K. W. Crowley, G. W. Dauher, L. E. Pollack, and S. Levine. *Determination of Driver Needs in Work Zones*. FHWA, U.S. Department of Transportation, 1982.
10. D. A. Price. *Nighttime Paving*. FHWA, U.S. Department of Transportation, 1986.
11. J. L. Graham, R. J. Paulsen, and J. C. Glennan. *Accident and Speed Studies in Construction Zones*. FHWA, U.S. Department of Transportation, 1978.
12. H. S. Lum. Economic Feasibility of Using Artificial Lighting in Construction Zones. *Public Roads*, Dec. 1980, pp. 118–122.
13. Z. A. Nemeth and A. Rathi. Freeway Work Zone Accident Characteristics. *Transportation Quarterly*, Vol. 37, No. 1, Jan. 1983, pp. 145–159.

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