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Nighttime Construction: Evaluation of Construction Operations

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16. Abstract

The different aspects that should be considered in making decisions on nighttime construction operations are identified and investigated in light of the current state of knowledge and practice. A state-of-the-art review was conducted of the current practices in nighttime operations by highway agencies, the main advantages and disadvantages, and the effect of nighttime shifts on factors such as traffic, construction, society, and the environment. Surveys were sent to state Departments of Transportation, Illinois Department of Transportation (IDOT) districts and IDOT contractors. The surveys involved questions about nighttime construction operations in practice and the factors affected by scheduling work during nighttime. An Excel software package that can be used by personnel to make an informed comparison between day shifts and night shifts was developed. This software is to complement other important information available to decision makers in making decisions on nighttime construction operations.

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NIGHTTIME CONSTRUCTION: EVALUATION OF CONSTRUCTION OPERATIONS

FINAL REPORT

May 2004

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EXECUTIVE SUMMARY

Funded under the Illinois Transportation Research Center (ITRC) contract IVA-H2, FY00-01, the research teams from Bradley University and the University of Illinois at Urbana-Champaign undertook the research project to evaluate nighttime construction operations in the State of Illinois. The project is mainly concerned with maintenance, reconstruction, or new construction projects where nighttime shifts are employed.

The objective of this research project is two fold. First, the different aspects that should be considered in making decisions on nighttime construction operations need to be identified and investigated in light of the current state of knowledge and practice. Second, the research should assist decision makers and other Illinois Department of Transportation (IDOT) personnel in making informed decisions on using nighttime construction operations in highway projects.

The research approach consisted of three major phases. In the first phase, a comprehensive state-of-the-art review was conducted of the current practice in using nighttime operations by highway agencies, the main advantages and disadvantages, and the effect of nighttime shifts on factors such as traffic, construction, society, and the environment. The results of the state-of-the-art review were included in Interim Report #1.

The second phase of the research project involved conducting three questionnaire surveys that were sent to state Departments of Transportation (DOTs), IDOT districts, and IDOT highway contractors. Those surveys involved questions about nighttime construction operations in practice and the many factors that are affected by scheduling work during nighttime. The surveys were analyzed and results were included in Technical Memoranda #1 and #2.

The last phase of the project involved the development of a software package that can be used by agency personnel in making an informed comparison between day shifts and night shifts. This is to be used to complement other important information available to decision makers in making decisions on nighttime construction operations.

The spreadsheet software and its documentation were included in Interim Report #2. This software is available from the Illinois Department of Transportation, Bureau of Materials and Physical Research.

The decision making assisting tool EVALUNITE, the main outcome of the current research, is applicable to all situations when night shifts are thought of as an alternative to conventional daytime shifts. The software utilizes cost-effectiveness analysis which is a tool to evaluate complex multi-faceted problems such as transportation problems. It requires the full installation of Excel on a PC (it is not compatible with a Macintosh). Since it uses VisualBasic macros, they must be enabled when questioned. The program is very transparent by using the commands that are in the new “Nighttime” pulldown menu at the top of the screen that appears along with the other pulldown menus. A set of default values are available that also allow for the user to change the input. Besides this practical tool, many important findings that have practical implications were drawn from the investigations conducted by this research.

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1 INTRODUCTION

In the last two decades, the shift from building new highway facilities to maintaining and upgrading existing ones has been on the rise. This shift has mainly been induced by the ever-increasing traffic demand on the already-congested highway systems and the simultaneous decline in funding new highway projects. While this shift is being viewed as inevitable to meet the new social and economic realities, road maintenance and reconstruction usually cause serious disruptions to traffic, resulting in significant delays, increased fuel consumption, and negative impacts on air quality and traffic safety.

Scheduling construction activities during nighttime, when traffic demand is typically at its lowest levels, is being viewed by many transportation agencies as an effective strategy to alleviate the negative impacts of work zones on the traveling public. However, this argument addresses only one aspect of road construction related to traffic congestion and delay. Many other aspects are also affected by nighttime operations and therefore need to be considered in making decisions on the use of nighttime operations. Some of these aspects are construction-related such as work productivity, work quality, worker’s safety, and construction costs. Others are traffic-related that involve not only congestion and delays, but also traffic safety and traffic control plans. Also, there are other aspects that are related to society and environment such as impacts on neighboring communities and businesses, air quality, and energy conservation. Therefore, an informed decision on nighttime construction should take into consideration all these important aspects for the specific situation at hand.

This report is mainly organized in three major parts. In the first part, the results of the state-of-the-art-review are summarized and presented. The second part, which is mainly concerned with the questionnaire surveys conducted by this research project, includes description of these surveys and summary of results. Finally, the third part is concerned with the decision-making assisting tool EVALUNITE. It describes model structure, methodologies implemented, and the software user interface.

2 STATE-OF-THE-ART REVIEW

2.1 Nighttime Construction: Advantages and Disadvantages

Nighttime has an effect on many aspects of highway maintenance and reconstruction activities, both favorable and unfavorable. While some of these effects are well known, others haven't been sufficiently investigated. This section provides a general overview of both positive and negative effects as observed in practice, reported in studies, or as perceived by highway agencies and the traveling public.

Advantages: The most important advantages of nighttime operations for highway reconstruction and maintenance can be summarized in the following:

- Reduction in delay and congestion: There is a consensus in the literature that the most important advantage of nighttime operations is significant reduction in work-related delay and congestion (Elrahman and Perry 1998, Price 1986a and 1986 b, OECD 1989, Hinze and Carlisle 1990a and 1990b). This is mainly due to the fact that lane closures at work zones have minimal impacts during the night when traffic is at its lowest levels. As such, this advantage is considered a decisive (overriding) factor in selecting night shifts over day work (Hinze and Carlisle 1990a, Elrahman and Perry 1998).
- Less air pollution: It is believed that nighttime operations contribute to a better air quality by reducing amount of tailpipe emissions. This effect is a direct byproduct of lower levels of delay and congestion at work zones during nighttime.
- Energy conservation: The reduction in delay and congestion at sites of lane closures will lead to lower fuel consumption and energy conservation.
- Minimizing inconvenience to the traveling public: Nighttime operations are advocated for minimizing inconvenience (irritation) to the traveling public caused by lane closures at work zones. Therefore, nighttime reconstruction and maintenance projects are always well received by the traveling public.

- Longer work periods: Nighttime operations are also advocated for providing longer period for lane closures (with low traffic levels) as compared with daytime weekdays off-peak periods.
- Less impact on surrounding businesses: The economic impact on surrounding businesses is less when work is performed during the night, after normal working hours.

Nonetheless, as visibility significantly deteriorates during nighttime and due to other human factors as related to construction workers and drivers (fatigue, sleepiness, impaired driving, etc), nighttime construction is also viewed as having several negative aspects such as:

- Traffic safety: Nighttime conditions tend to create legitimate safety concerns such as inadequate lighting, inferior visibility, glare, and reduced levels of alertness for workers and drivers (due to fatigue, sleepiness, alcohol). Therefore, it is logical to expect that the risk of being involved in a traffic accident in work zones is higher at night. However, the total number of accidents, which is an important safety measure, is normally lower during nighttime because of the lower traffic exposure.
- Work quality: There is a common perception that work quality is compromised during nighttime as a result of light conditions and reduced visibility.
- Work productivity: Workers' morale, sleep deprivation, and fatigue are thought to negatively affect productivity rate during the night.
- Workers safety: Light conditions, reduced visibility and workers alertness all create concerns about higher risk for construction-related accidents during nighttime operations.
- Material availability and equipment maintenance: Materials procurement is not always possible during the night or may involve higher costs. Also, equipment maintenance normally requires more time during night shifts (parts may not be available until next day).
- Higher construction costs: The provision of adequate lighting at the job site and nighttime traffic control plans are two major elements that involve extra cost for

nighttime projects. Other important elements involving extra costs during night shifts are labor premiums and material acquisition.

- Scheduling: Difficulties in scheduling may be encountered if work is performed during night shifts. The time needed to set up traffic control devices and remove them before the morning rush hour, delaying too long before lane closure, and scheduling work hours for agency inspectors and project engineers to coincide with night activities make scheduling a night shift problematic (Elrahman and Perry 1994).
- Noise disturbance to surrounding communities: Construction-related activities create noise that could cause disturbance to noise-sensitive land uses, for example residential areas and hospitals that are located close to the job site.

2.2 Decision on Nighttime Construction: Current Practice

Nighttime construction is being used increasingly by state DOTs and other highway agencies to conduct highway maintenance and reconstruction projects. However, the literature search showed that no uniform guidelines or procedures currently exist at the national level that can be used to assist in making decisions on when to employ nighttime operations for highway maintenance and reconstruction projects. This is mainly because many State DOTs and highway agencies have only limited experience with nighttime construction operations and its use by their projects is fairly a new practice. It is important to study the effects of nighttime construction and establish guidelines for construction and contract decisions.

Decisions to conduct maintenance operations at night vary from state to state and largely depend on how much traffic can be allowed to back up, what the public will tolerate, and the characteristics of the system in question (Ellis et al. 1992).

A Study by the Kentucky Transportation Cabinet (KyTC) conducted a survey on nighttime construction practices that involved State DOTs, contractors, and the KyTC resident engineers (Hancher and Taylor 2000). The study identified the issues that contributed the most to the decision to work at night. These issues are presented in Table 1 for the three groups involved in this survey. It is clear from survey results that high daytime traffic level is the main consideration in selecting nighttime operations for highway projects.

Table 1. Top 5 Issues Contributing to the Decision to Work at Night (Hancher and Taylor 2000)

Dept. of Transportation	**Highway Contractor**	**KyTC Resident Engineer**
1. High Daytime Traffic	*1. High Daytime Traffic*	*1. High Daytime Traffic*
2. Traffic Control	*2. Contract Incentives*	*2. Temperature Concerns*
3. Road User Cost	*3. Schedule Issues*	*3. Traffic Control*
4. Longer Work Periods	*4. Traffic Control*	*4. Schedule Issues*
5. Schedule Issues	*5. Safety*	*5. Longer Work Periods*

Another survey on nighttime construction practices investigated the relative importance of different factors that are considered by State highway agencies in making decision on nighttime operations (Hinze and Carlisle 1990a, 1990b). This study was conducted by the University of Washington and surveyed highway agencies in 21 different states. The results of the survey as related to the most determinant factors in the selection of nighttime operations are presented in Table 2. Traffic congestion was also found to be the most important decision-making factor considered by state highway agencies.

Some States, such as New York, have used their experience in nighttime construction operations to develop statewide policies and guidelines concerning the use of night shifts in highway projects. A report prepared by New York State Department of Transportation (NYSDOT 1999) states that a policy was set in 1996 for the statewide selection of projects for nighttime construction. According to this policy, consideration of nighttime operations was compulsory for many projects in two regions (New York and Long Island) but optional for projects in other parts of the state. Apparently, this policy was developed based on the favorable experience of nighttime highway construction operations that was summarized in two reports of N.Y.DOT (NYSDOT 1997, 1999).

Table 2. Importance of Decision-Making Factors as Reported by State Highway Agencies (Hinze and Carlisle 1990a)

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

Another report by N.Y.DOT proposed a detailed approach (framework) for comparative analysis between nighttime and daytime construction operations to be part of the selection process (Elrahman and Perry 1994). This approach consists of sequential steps as summarized below:

I. Evaluate the proposed project
II. Assess roadway occupancy
III. Identify traffic control alternatives
IV. Analyze volume/capacity relationships
V. Identify capacity-improving techniques
VI. Quantify impacts
VII. Assess feasibility of a night schedule
VIII. Select preferred alternative

2.3 Nighttime Construction Operations: Main Variables

2.3.1 Traffic-Related Variables

Closure of highway lanes at work zones causes a drop in capacity at the affected area and often results in extra congestion and delay to traffic, particularly on well-traveled urban highways. Delays normally involve an increase in fuel consumption and tailpipe emissions, loss of valuable time, and inconvenience to the traveling public. Also, unexpected temporary traffic plans at work zones, distractions caused by work activity, and the potential impact of work activity on visibility all raise concerns about traffic safety at the affected areas.

These traffic-related impacts at work zones typically exist regardless of work shift. However, these impacts have different scales and magnitudes for daytime and nighttime construction operations. It is well known that nighttime construction, in essence, exploits the diurnal fluctuation in traffic demand to alleviate the impact of lane closures on the traveling public. While this contributes, in general, to less congestion and delay, traffic safety and traffic control plans are other factors that need to be considered in evaluating nighttime operations. The following sections discuss these important aspects of nighttime operations for highway maintenance and reconstruction projects.

2.3.1.1 Delay and Congestion

This is the most important factor that is considered by State highway agencies in making decisions regarding the use of nighttime operations for highway maintenance and reconstruction projects (Ellis et al. 1993, Hinze and Carlisle 1990a and 1990b, Elrahman and Perry 1994). Two reasons are behind this fact:

1. Public opinion (and concerns) is a priority for most highway agencies. Nighttime operations largely minimize the inconvenience to the traveling public since it causes less delay and congestion.

2. Delay costs are typically more significant than other cost differentials between day and night shifts, particularly in heavily traveled urban highways.

Delay at construction zones occurs from three main sources:

1. Time spent in queue (congestion)
2. Extra time due to slower speed of travel at the affected area
3. Extra time spent in work zone detours

2.3.1.1.1 ***Impact Assessment:***

Assessing the level of delay and congestion at work zones is essential to develop traffic control and lane closure plans. The literature shows several approaches that have been used in quantifying delay at work zones. Jiang (1999) suggested a procedure to estimate work zone delay by adding up four different delay components; deceleration delay, reduced speed delay, acceleration delay and queue delay. Another study (Carl 2000a) used different delay calculations as it assumed delay to consist of two components only; backup delay (while in queue) and speed delay due to lower travel speed at the work zone. Other studies such as Ellis (1993) mainly focus on queue delay as the main component of delay while overlooking other less significant components.

Congestion Assessment at Work Zones

Congestion is typically viewed as the most important contributor to traffic delay at work zones. It usually occurs when approach traffic volumes exceed work zone capacity. In large urban areas, traffic levels during daytime (especially during AM and PM peak periods) often approach and exceed highway capacities under normal conditions. Therefore, lane closures due to maintenance and reconstruction typically create levels of delay and congestion that are considered intolerable by the traveling public.

Assessing the congestion and queuing at work zones is typically done using one of the following techniques:

a. Deterministic queuing analysis (cumulative demand-capacity analysis)

b. Shockwave analysis
c. Traffic simulation

Deterministic queuing analysis (cumulative demand- capacity analysis)

One of the most powerful tools to quantify the level of congestion on highways is the simple plot of cumulative demand and cumulative capacity (also referred to as deterministic queuing analysis). This analysis starts by plotting the actual (or anticipated) demand and work zone capacity as a function of time or providing this information in a tabulated format. The cumulative plot is then constructed based on the previous plot for the time duration of interest, which is typically the time when congestion is anticipated. Figure 1 shows a typical cumulative demand-capacity plot of a congested facility for time duration from t_1 to t_2.

This conventional technique allows the analyst to estimate the level of congestion in terms of the number of vehicles in queue at any point in time. Also, it can be used to provide an approximate estimate of queue length using the number of vehicles in queue and the estimated jam density as inputs. The times of the start and end of congestion are readily available from the visual inspection of the cumulative plot. Strategies to influence traffic demand (such as route diversion strategies) or to influence the work zone capacity (as related to traffic control plans) can easily be tested using this technique.

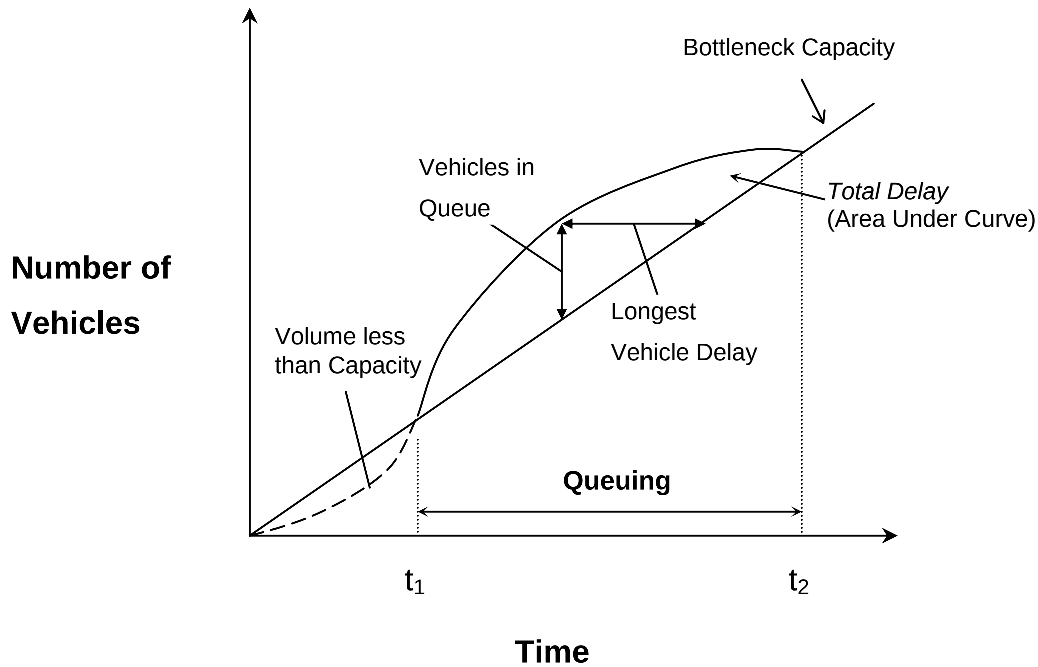


Figure 1. Cumulative Demand-Capacity Curve for a Queuing Scenario

For its simplicity and versatility, this analysis has been the most widely used technique to quantify congestion at work zones. The main limitation of this technique is that it underestimates the length of queue upstream of the work zone as well as the number of vehicles in queue. It is worthy to mention here that the well-known stochastic queuing analyses can only be utilized when traffic demand does not exceed work zone capacity and therefore, in most situations, they are not suitable to investigate congestion and delays at work zones.

Shockwave Analysis

Another technique that is used to assess queuing at bottlenecks in general is called shockwave analysis. This technique is well known in traffic engineering, yet it is less frequently used in practice to analyze queuing and congestion. It usually provides comparable estimates of the amount of congestion and average delay to those obtained from the cumulative demand-capacity technique. However, this technique yields more accurate estimates of the queue size (number of vehicles in a queue) and queue length upstream of work zone as it includes the "extra" vehicles caught up in the growing queue. Further, the analysis requires additional inputs besides demand and capacity, which are the densities within and upstream of the queue. The analysis is based on the following shockwave speed formula:

$$S = \frac{D - C}{d_q - d_u}$$

Where S = speed of shockwave (rate of queue growth); D = traffic demand at work zone; C = capacity at work zone; d_q = traffic density within the queue; and d_u = traffic density upstream of the queue.

To find the congestion-related parameters (total delay, average delay, queue size, etc.), the analyst needs to construct the distance-time diagram, which visually shows queue size as well as growth and dissipation of queue as related to time and space. More details about this analysis are found in most traffic engineering books (May 1990, Roess et al. 1998).

Traffic Simulation

Traffic simulation is another technique that can be utilized to investigate congestion and delay at highway maintenance and reconstruction zones. It has been increasingly used in many traffic engineering applications such as planning special events and testing alternative traffic control strategies. However, the literature search suggests that the current practice does not involve the use of this robust tool in estimating queues and delays at highway work zones.

To estimate congestion and delay using any of the previous techniques, two important inputs are needed; the first is the anticipated traffic level at the affected area (demand) and the second is the capacity of work zone. While traffic demand and its daily variation can be estimated based on historical traffic data, the estimation of work zone capacity is more difficult as suggested by the current practice.

Estimating Work Zone Capacity

Work zones on freeways are typically classified into short-term maintenance sites and long-term reconstruction sites. While many similarities exist between the two types of work zones, capacity of long-term freeway reconstruction zones is typically higher than that of short-term maintenance zones. Two factors are believed to contribute to this difference in capacity. First, the use of portable concrete barriers at reconstruction sites provides a better physical separation between work activity area and the traveled lanes when compared to plastic barrels and cones commonly used at maintenance sites. The second factor is that regular drivers gain familiarity over time with long-term reconstruction sites, a matter that is quite unlikely at short-term maintenance sites.

The Highway Capacity Manual (HCM) procedures (TRB 2000a) provide a simplistic model to estimate the capacity of short-term maintenance work zones and only limited estimates of long-term reconstruction zones on freeways and multilane highways. This model is shown below:

$$c_a = (1600 + I - R) * f_{HV} * N$$

Where c_a = Adjusted mainline capacity; I = Adjustment factor for intensity and location of work activity; R = Adjustment for ramps; f_{HV} = Adjustment for heavy vehicles (same as that for normal freeways); and N = Number of lanes open through the short-term work zone.

As shown in the model above, factors that are accounted for in estimating work zone capacity involve the presence of heavy vehicles, intensity and location of work activity and presence of ramps within the work activity area.

The HCM estimates for long-term reconstruction zones are severely limited as they apply only to two lane closure configurations as shown in Table 3. The HCM provides no guidance on how these estimates are affected by traffic, geometric and environmental conditions. These estimates, first introduced in the 1985 HCM (TRB 1985), are based on empirical data collected more than two decades ago in the State of Texas at a limited number of sites and range of circumstances (Dudek and Richards 1981).

Table 3. Average Capacity at Long-Term Reconstruction Sites (TRB 2000a)

No. of Normal Lanes	Lanes Open	Number of Studies	Range of Values (veh/h/l)	Average per lane (veh/h/l)
3	2	7	1780-2060	1860
2	1	3	----	1550

Besides the HCM procedures, several studies reported capacity estimates from field observations at specific work sites (Kermode and Myyra 1970, Dudek and Richards 1981, Dixon et al. 1996, Bryden 1986, OECD 1989, Al-Kaisy et al. 2000, Al-Kaisy and Hall 2000 and 2001). Examples of these capacity estimates for long-term reconstruction zones are provided in Table 4.

Table 4. Observed Capacities at Long-Term Maintenance Work Zones (Dudek and Richards 1981)

Number of Lanes		Number of Studies	Average Capacity	
Normal	Open		vph	vphpl
3	1	7	1170	1170
2	1	8	1340	1340
5	2	8	2740	1370
4	2	4	2960	1480
3	2	9	2980	1490
4	3	4	4560	1520

Also, fewer studies suggested mathematical models to estimate work zone capacities (Memmott and Dudek 1984, Abrams and Wang 1981, Krammes and Lopez 1992 and 1994, Kim et al. 2001). However, most of these capacity models are based on limited field data and do not consider the influence of the numerous factors that affect work zone capacity. Using relatively extensive field data, one recent study proposed what seems to be a more comprehensive model for work zone capacity at long-term reconstruction sites incorporating the effect of several important variables such as; heavy vehicles, driver population, work activity at site, rain, light condition (day versus night), and side of lane closure (Al-Kaisy and Hall, 2002).

It is important to mention here that the HCM procedures for normal highway facilities are not applicable to highway work zones, as they differ in many aspects resulting in different lane capacities. In the course of literature search, it was noticed that some previous studies (Ellis and Herbsman 1993, Elrahman and Perry 1994) utilized this erroneous approach in estimating work zone capacity.

Another important implication of nighttime work zones is the effect of darkness on work zone capacity. A recent study (Al-Kaisy and Hall 2000) suggested that work zone capacity during nighttime is significantly lower than that during daytime based on empirical observations. According to this study, an average reduction of 5% in work zone capacity is expected to take place during nighttime on well-lit facilities. A higher decline in work zone capacity is expected on unlit facilities especially in rural areas.

Finally, some States highway agencies have developed their own estimates of lane capacities for different lane closure configurations at work zones and different types of work activity (Bryden 1986).

2.3.1.1.2 <u>Cost Valuation</u>

One of the most important benefits of nighttime construction is the substantial reduction in road user costs. In general, road user costs consist of three components:

a. The value of travel time spent by drivers (and passengers)

b. Vehicle operating costs
c. Accident costs

The value of time (delay costs) represents the most significant component of road user costs. Also, it represents the major component of nighttime savings of user costs.

The impact of delay at work zones on road user cost is investigated by several previous studies (Carl 2000, Elrahman and Perry 1994, Jiang 1999 and 2001, Daniels 1999 and 2000). While those studies utilized different approaches to quantify traffic delay as discussed earlier, they all used one simple approach to estimate delay costs. This approach utilizes the following inputs to calculate user costs as related to work zone delay:

a. Amount of delay in vehicle-time units
b. Percentage of trucks
c. Average auto occupancy
d. Value of time

The proportion of trucks in the traffic mix is an important factor in estimating delay costs, as value of time for trucks is different from that for automobiles. Average auto occupancy is used to convert delay measured in vehicle-time units into that measured in person-time units. Trucks are always considered as having single occupancy and therefore no conversion is made. The generic formula of delay cost is:

$$DC = [TD \times VOCC \times VOT_A \times (1-P_T)] + \{TD \times VOT_T \times P_T]$$

Where:

DC = Delay cost
TD = Total delay measured in vehicle-time units
VOCC = Average vehicle occupancy (autos)
VOT_A = Value of time for auto occupants (drivers and passengers)
VOT_T = Value of time for trucks (drivers)
P_T = Proportion of trucks

Different approaches used to estimate delay and congestion at work zones were discussed in the previous section. Average auto occupancy and the proportion of trucks in the traffic stream are obtained from traffic studies and historical data.

As for the value of time, there are several studies in the literature that investigated this important component of road user costs.

Value of time is mainly a function of an hourly wage rate, most often multiplied by an average occupancy (ridership) as shown in the following formula (Daniels 1999):

$$VOT = f\ [\ (AWR) \times (Occupancy)\ ]$$

Where VOT is the value of time and AWR is the average wage rate. The average wage is used as a surrogate variable to indicate the driver's "willingness to pay" for savings in travel time.

The monetary value of time can be found in the AASHTO Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (1977). These values should be adjusted to the present time using simple economic parameters. A recent study by Texas DOT (Daniels 1999) conducted telephone interviews with several State DOT's to compare the value of time utilized by different states in estimating user costs. Table 5 shows the values of time that are being used by those states for automobiles and trucks.

Table 5. Value of Time Used by Selected States (Daniels 1999)

State	Value of Time ($) Autos	Value of Time ($) Trucks
North Carolina	8.70	------
New York	9.00	21.14
Florida	11.12	22.36
Georgia	11.65	--------
Texas	11.97	21.87
Virginia	11.97	21.87
California	12.10	30.00
Pennsylvania	12.21	24.18
Washington	12.51	50.00
Ohio	12.60	26.40
Median	**$11.97**	**$23.61**
Mean	**$11.38**	**$27.23**

Table 6. VOT Used in Derivation of Road User Costs (Daniels 2000)

Vehicle Type	Value of Time from MBC (1990 Dollars)
Small passenger car	$9.75
Medium/large passenger car	$9.75
Pickup / van	$9.75
Bus	$10.64
2-axle single-unit truck	$13.64
3-axle single unit truck	$16.28
2-S2 semi truck	$20.30
3-S2 semi truck	$22.53
2-S1-2 semi truck	$22.53
3-S2-2 semi truck	$22.53
3-S2-4 semi truck	$22.53

As shown in this table, the average value of time for auto occupants was only around 41.6% of the average value assigned for truck drivers.

Another study (Daniels 2000) provided a more detailed set of VOT for different types of vehicles as shown in Table 6. These values are used in a highway economic analysis software called MicroBENCOST or MBC.

2.3.1.1.3 Current Practice

Several models have been developed to quantify delay and its associated user cost (Memmot and Dudek 1984, Carl 2000a, Harding 2000, Jiang 1999). The most known among these models is the model QUEWZ developed by Texas Transportation Institute in early 1980's. This computer simulation model is mainly intended for estimating queue length and associated user costs for lane closures at freeway work zones (Krammes et al. 1993). The original version of this model was later revised and improved using additional field data from the state of Texas. This software package has been used by several state transportation agencies to plan maintenance and reconstruction work on freeways. The software utilizes capacity estimates that are available in the Highway Capacity Manual (HCM) to quantify queues and delay. These estimates, however, are very approximate especially for long-term reconstruction zones.

Another model that involves quantifying traffic delay at construction zones and its associated user cost is called the Construction Congestion Cost System (CO^3). This model, developed by the University of Michigan, is an integrated set of tools to estimate impact of traffic maintenance contract provisions on congestion, road user cost, and construction cost (Carl 2000a). It is intended to provide an acceptable balance between construction cost and congestion. However, the model outputs are only approximate and therefore it is mainly applied at the first stages of project consideration when a project is still ill defined (Carl 2000b).

A research project sponsored by the FHWA and Indiana DOT suggested a model for estimating work zone delay and its associated user cost. Besides work zone capacity and the anticipated traffic demand, the model accounts for the fluctuation in traffic demand as related to work zone delay when demand is less than capacity. Also, besides queue-related delays, the model considers the delay incurred by motorists during the deceleration upstream of the queue and acceleration back to normal speeds beyond the work zone.

Another software program to estimate road user costs and to conduct highway user benefit-cost analysis at the project level is called MicroBENCOST. This software program was developed by Texas A&M University and is being used by some state DOTs such as Tennessee DOT (Wegmann et al. 1996).

It is worthy to mention that, besides the value of time wasted in congestion or delay, some view inconvenience to motorists as another consequence of congestion and delay. In this regard, the Michigan Department of Transportation placed a value on the inconvenience to all motorists caused by reconstruction of the Lodge Freeway at $50,000 per day. This amount was budgeted into the cost of construction and was reflected into incentives for early completion of the project (TRB 1999).

2.3.1.2 Safety

2.3.1.2.1 <u>Impact Assessment</u>

Safety at work zones is a major concern for the traveling public, the transportation agencies, and the construction industry. Establishing work zones for construction and maintenance activities through lane closures poses inherent hazards for road users approaching and traveling through the work zone (TRB 2000b). Available national statistics show that there were 772 people killed and 39,000 injured in motor vehicle accidents in construction work zones in 1998 (Krizan 2000, Villanova 2001).

Empirical evidences suggest that traffic accident rates in work zones are generally higher than that experienced during normal operations at the same sites when work zones are not present. Restriction imposed by work zone activity area delineation (using plastic cones/barrels or portable concrete barriers), distraction and/or deterioration in visibility due to ongoing work activities, and lack of familiarity with the work zone (mostly by non-commuter drivers) are believed to be the main causes for the high accident rates at work zones.

A recent study (Migletz et al. 1999) analyzed accident data at 66 work zone sites before and during construction. The study involved 444.9 miles of roadway and a total of 12,150 traffic accidents including 5,017 accidents in the period before construction and 7, 133 accidents in the period during construction. Table 7 shows the results of this comparative study.

Table 7. Summary of Accident Experience at Study Sites (Migletz et al. 1999)

	Before Period	During Period	Percent Increase
Total length of study sites (km)	716.0	716.0	
Total exposure (MVKT)[a]	4964.2	6617.4	
Total number of accidents in period	5,017	7,133	
Total number of fatal and injury accidents	1,743	2,488	
Total accident rate	1.01	1.08	6.7
Fatal and injury accident rate	0.35	0.38	6.9

[a] MVKT – million vehicle-kilometers of travel

As shown in this table, the total accident rate at study sites was, on average, 6.7% higher during construction than before construction, while the fatal and injury accident rate was, on average, 6.9% higher during construction than before construction. However, this same study showed that on rural freeways (29 sites), there was an increase of 41.3% in total accident rate and 30.7% in fatal and injury accident rate during the construction period. A study of a single project in Virginia (Younes 1994) indicated that the overall frequency of accidents increased 119%, with fatalities going up by 320%. Another study (FHWA 1998) investigated 79 projects and 20,000 accidents in Colorado, Georgia, Michigan, Minnesota, New York, Ohio and Washington. The study revealed that higher accident rates occurred in 69% of the projects. Also, in 24% of the projects, increase in accident rate of 50% or more was experienced.

There is a general belief that nighttime construction is associated with higher risk and severity of work zone accidents. Poor visibility, inadequate lighting, worker fatigue, driver's drowsiness, and substance abuse are all factors that are believed to increase accident risks during the night. Moreover, less congestion encourages driving at faster speeds thus resulting in higher risk and severity of accidents. A study by Sullivan (1989) examined historical data on the relationship between accident rates and nighttime reconstruction along several urban freeways in California. The study concluded that nighttime construction was associated with 87% increase in the accident rate. In addition, the accident rate when work activity was underway was 75% higher than the rate when no work activity was present at the construction site. The same study investigated accident severity and the influence of alcohol on work zone accidents during day and night. The results are summarized in Table 8.

Table 8. Principal Differences Between Day and Night Accidents At Three Southern California Locations (Sullivan 1989)

Accident Type	Day Accidents		Night Accidents	
	Number	Percent	Number	Percent
Total Accidents	800	100	273	100
Single-Vehicle Accidents	104	13	71	26
"Hit Object" Accidents	119	15	73	27
Fatal & Injury Accidents	241	30	124	45
Influence of Alcohol	19	2	54	20

This table shows that the percentage of fatal and injury accidents was 50% higher during nighttime when compared with daytime accidents. Also, 20% of nighttime accidents involved alcohol as a contributing factor versus 2% of daytime accidents.

2.3.1.2.2 <u>Cost Valuation</u>

It is generally difficult to assess traffic accidents in dollar values with reasonable certainty. This is mainly due to the many factors of cost that are involved in traffic accidents. The valuation of accident costs is believed to be the same within or outside highway work zones.

A study on the economic cost of motor vehicle crashes (Blincoe, 1996) considered the following cost components for vehicle crashes:

1. Productivity losses
2. Property damage
3. Medical costs
4. Rehabilitation costs
5. Travel delay
6. Legal and court costs
7. Emergency service costs
8. Insurance administration costs
9. Premature funeral costs
10. Costs to employers

According to this study, the total cost of motor vehicle crashes in the U.S. that occurred in 1994 was $150.5 billion. Each fatality resulted in lifetime economic costs to society of over $830,000 in 1994. Over 85% of this cost is due to lost workplace and household productivity. The average cost for each critically injured survivor was $706,000. Medical costs and lost productivity accounted for 84% of the cost. Also, while the average property damage associated with all crashes (fatal, injury, & PDO) was slightly higher than $3,000, property damage cost accounted for 35% of all costs ($52.1 billion in 1994). The report also showed that, in 1994, around 9% of all motor vehicle crash costs were paid from public revenues.

A report by the National Highway Traffic Safety Administration of the U.S. Department of Transportation estimated the cost of traffic accidents due to impaired driving nationwide and by state (NHTSA 2001). The report suggests that the average alcohol-related fatality in the United States in 1996 cost $3.2 million; $1.2 million in monetary costs and $2 million in quality of life losses. The estimated cost per injured survivor of an alcohol-related crash in the same year averaged $79,000; $36,000 in monetary costs and $43,000 in quality of life losses. According to this report, Illinois figures were very close to the national averages.

2.3.1.3 Traffic Control

*2.3.1.3.1 **Planning Traffic Control at Work Zones***

Temporary traffic control at work zones is essential to provide for safe and expeditious movement of traffic while maintaining safe, rapid, and efficient construction operations. This is because work zones often impose abnormal disruptions to normal traffic operation, and thus raises concerns about higher accident risks and the safety of road users and construction workers alike. While traffic control is an essential element for safe and efficient work zone operations, it becomes more critical during nighttime due to several important factors such as poor visibility, higher speeds, and impaired driving.

Traffic control at work zones mainly involves two elements: 1) a temporary traffic control plan that describes temporary traffic control measures to be used for facilitating road users through a work zone, and 2) traffic control zone (work zone) and traffic diversion strategies through detours or alternative routes (FHWA 2000). Ramp control plans should be addressed when preparing work zone traffic control as well. The component parts of a traffic control zone (work zone) are shown in Figure 2.

Traffic control plans at work zones should alert drivers in advance to hazards created by work activities and lane closures, direct and guide them safely through and out of the work zone. They typically involve work zone layout throughout the duration of work activities and the use of different traffic control devices to warn, direct, and guide traffic through work zones.

There are no universally applicable procedures in developing traffic control at work zones as each specific case has a unique solution. Therefore, regulations should be considered as guidelines instead of standard procedures (OECD 1989). The formulation of traffic control strategies (plans) at work zones is usually affected by many factors such as (OECD 1989):

a. Environment (urban, suburban, and rural)
b. Type of highway (number of lanes in each direction, divided or not divided)
c. Traffic volume and speed

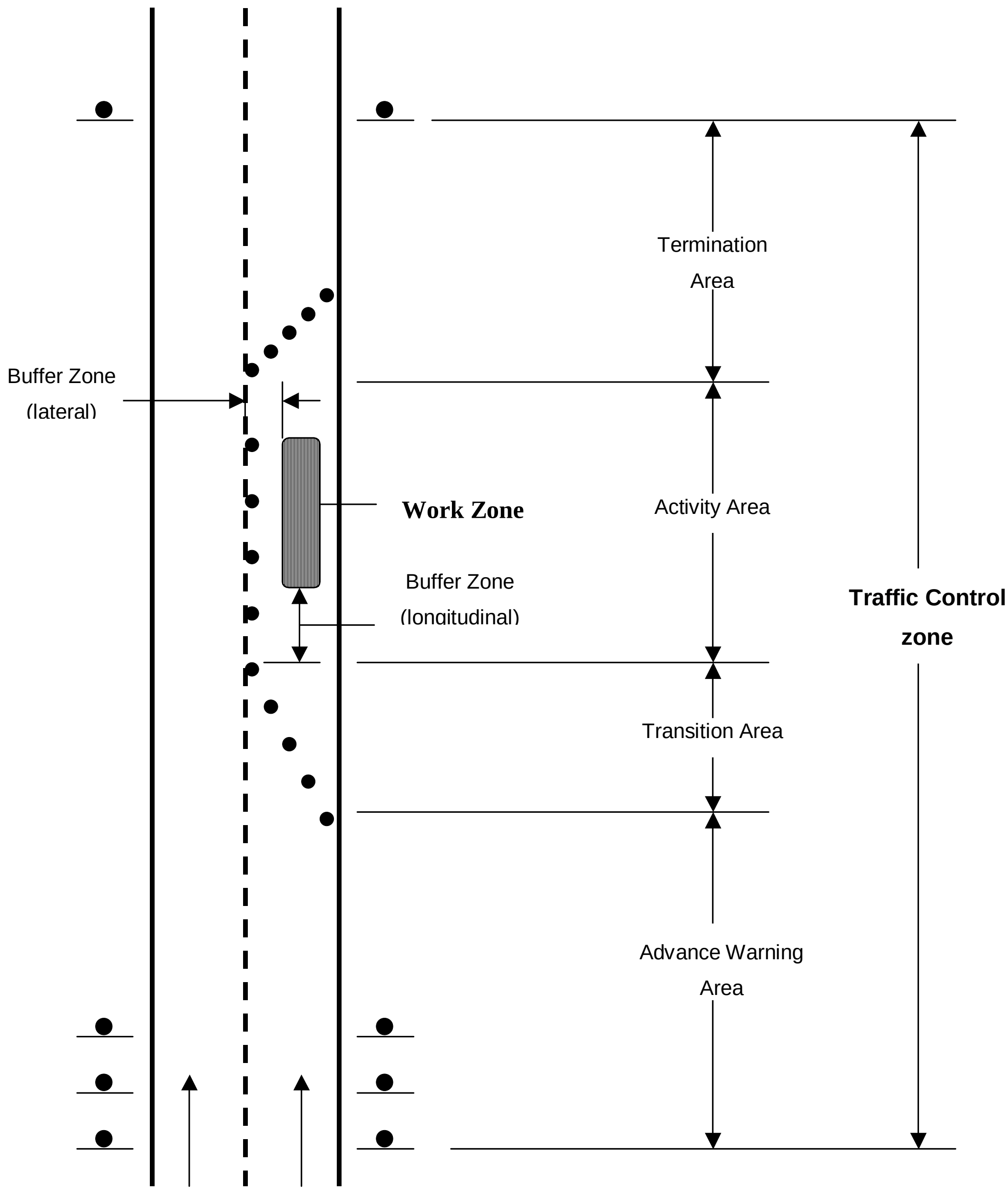


Figure 2. Traffic Control Zone (Work Zone) Components

d. Traffic composition (autos, heavy vehicles, etc.)
e. Sight distance upstream and at the work zone
f. Mobility of work zone (if not stationary)
g. Duration of work
h. Transversal encroachment of work zone

In the United States, most highway agencies have procedures to ensure that a traffic control plan is developed for highway construction works in conformance with the MUTCD (Manual on Uniform Traffic Control Devices) guidelines and the requirements requested by state policies. They also require the designation of a qualified person at the project level to be responsible for assuring the effective administration of the traffic control plan (Ellis et al. 1992). A survey of state highway agencies, project engineers, and contractors (Hinze and Carlisle 1990b) conducted by the University of Washington revealed that in 70% of projects surveyed, a temporary traffic control plan was specified by the state highway agency, in 20% of cases contractors worked with the agency or were allowed to modify the traffic control plan, and in 10% of cases contractors set up the temporary traffic control plan at work zones. Some state highway agencies utilize quality assurance program for work zone traffic control such as that developed and implemented by the NYSDOT (Bryden and Andrew 2001). The purpose of the program is to gather information to evaluate the overall quality and effectiveness of work zone traffic control to identify areas where improvement is needed.

Construction and major maintenance activities can be classified into two types from the point of view of nighttime traffic control planning and implementation (Homburger 1989);

1. Long-duration stationary (fixed-location) projects where the location of the construction activity can be predicted fairly accurately for each night
2. Short-duration mobile (moving) projects where each night's program depends on the work accomplished the preceding night and, therefore, the exact location and extent of activity for each night cannot be predicted accurately.

In general, traffic control plans are easier to implement and administer at fixed-location long-duration projects than at mobile projects. In mobile projects, decisions are made on a daily basis regarding the exact use of traffic control devices, and therefore, they are more difficult to control from the design office and more reliance must be placed on the resident engineer, the contractor, and their staffs to adjust controls each night to the work in progress. Also, the type of project as classified above is expected to affect the selection of the appropriate traffic control devices and type of installation (movable versus semi-permanent).

2.3.1.3.2 ***Traffic Control Devices***

A brief description of the most common traffic control devices that are used in work zone traffic control plans are (FHWA 2000):

1. Warning, regulatory and guide signs

   Temporary work zone signs convey both general and specific messages by means of words and symbols. Warning signs are extensively used to alert drivers in advance of highway construction. For nighttime construction, the MUTCD requires that all signs are reflectorized or illuminated.

2. Changeable message signs (CMS)

   These are portable signs with the flexibility to display a variety of messages. These signs are most often used on high-density urban freeways. While CMS vary in size, they should be visible from 0.8 km (0.5 mi) under both day and night conditions. It is important to mention here that the portable CMS should be used as a supplement to and not as a substitute for conventional signs and pavement markings.

3. Channelizing devices

   They mainly include cones, vertical panels, drums, tubular markers, barricades, and temporary raised islands. They are intended to warn road users of conditions created by work activities in or near the roadway and to guide road users through a bypass or detour, or into a narrower traveled way. They are also used to separate motor vehicle traffic from the workspace or from the opposing traffic.

4. Arrow Panels

   An arrow panel is a sign with a matrix of elements capable of either flashing or sequential displays. Usually used in combination with other traffic control devices, this sign is intended to provide additional warning and directional information to assist in merging and controlling road users through or around the work zone.

5. Temporary Traffic Barriers

   Temporary traffic barriers have two main functions a) to channelize road users, and b) to protect the workspace. Usually supplemented by delineators, these traffic control devices should not be used for a merging taper except in low-speed urban areas.

6. Pavement Markings

   Pavement markings are often used in long- and intermediate-term stationary work zones. They are not used for mobile work zones and short-term maintenance zones. All pavement markings and devices used to delineate road user paths should be carefully reviewed during daytime and nighttime periods.

Numerous studies have examined the effects of various innovative traffic control devices at work zones. Most of these innovative devices aim at reducing the average speed or controlling merging of vehicles upstream of lane closure thus improving safety for the traveling public and construction workers.

A recent study conducted on an interstate highway work zone in Missouri reported that the use of white lane drop arrows and rumble strips can be expected to promote some decreases in mean speeds of vehicles approaching work zones (Bernhardt 2001). Another recent study tested the effect of radar speed display and rumble strips on the speed of traffic approaching a work zone on a rural highway in Texas (Fontaine 2001). Speed displays are radar-activated signs that dynamically display oncoming vehicle speeds in large numerals. The study found that the radar speed displays were generally more effective than the rumble strips at reducing vehicle speed in the advance warning area. Another study in Texas examined the effect of a system of interconnected, synchronized flashing warning light that produce the illusion of motion to encourage drivers to change lanes and leave the closed lane well in advance of the lane drop (Finley 2001). The study found 23% and 63% reduction in the number of passenger cars and trucks respectively in the closed lane 305 m (1000 ft) upstream of lane closure.

2.3.1.4 Vehicle Operating Costs

Vehicle operating costs include costs associated with fuel consumption, tires, engine oil, maintenance and depreciation. They represent the last typical component of road user costs besides the cost of delay and traffic accidents.

Vehicle operating costs typically increase at highway construction zones where disruptions to traffic cause queuing, significant deterioration in travel speeds, and cycles of speed changes. The most perceived component of these costs by road users is fuel consumption that is dependent on average speed, change in speed, and travel time. As nighttime construction significantly reduces disruption to traffic caused by construction activities, the amount of fuel consumption and other vehicle operating costs at work zone decrease.

Jiang (1999) investigated the extra vehicle operating costs as related to highway work zones due to reduced speeds and increased cycles of speed changes. The study utilized the tabulated values for extra vehicle operating costs that are found in the AASHTO Red Book (AASHTO 1977) as a reference. Currently, software programs can estimate vehicle operating costs as part of estimating road user costs. Examples of these programs are MicroBENCOST and QUEWZ that were developed by Texas Transportation Institute at Texas A&M University (Wegmann et al. 1996, Krammes et al. 1993). The former is used to perform highway user cost-benefit analysis at the project level while the latter is used to estimate delays and road user costs associated with work zones.

Vehicle-operating costs tend to be quite small in comparison with motorists delay costs and, as a result, are generally not a major concern in user cost analysis (TRB 2000b).

2.3.2 Construction-Related Variables

The main construction-related variables that are affected by nighttime construction are quality, cost, productivity and safety. Although nighttime construction of transportation projects is being used increasingly, there is no consensus in practice regarding the actual effect of nighttime operations on any of the above-mentioned variables. In general, literature search showed that previous research related to the impact of nighttime operations on each of these variables is limited. In the next four sections, the findings of the previous research will be summarized. Finally, issues that are related to nighttime construction but yet unexplored will be discussed.

2.3.2.1 Quality

Although there is no single definition of construction quality for transportation projects, several quality performance measures have been established. In the next sections, some aspects of nighttime construction quality are discussed. First, the effect of nighttime paving on surface smoothness (ride ability) will be discussed. Then, a discussion of how the compaction is affected by nighttime work will be presented. Also, other factors and measures of nighttime construction will be introduced. Finally, operations whose quality can be affected by nighttime construction will be presented.

2.3.2.1.1 Rideability or Surface Smoothness

Perhaps the most notable quality aspect affected by nighttime construction is surface smoothness or ride ability, which is affected due to the change in illumination and the use of artificial lighting, which in turn affect workers' visibility. Surface smoothness is often measured by the profile index (PRI in in/mi). The PRI is often computed using the California-type computerized proiligraph. In an early research carried out in Colorado (Price 1986a, 1986b) a mile and half section on I-25 north of Denver was chosen to compare PRIs before and after nighttime paving. The reduction in roughness was compared to that usually achieved by daytime paving. It was found that an overall project roughness average of 8.8 in/mi. before paving was reduced to 3.5 in/mi after paving. While in many similar asphalt overlay jobs a final roughness of 2 in/mi can be achieved, (Collins et al 1996, Fernando 1997, Hossain and Parcells, 1995) the surface achieved during nighttime is still considerably smooth. In this study, the conclusion was that the quality of the finished product only suffered in appearance. Price (1986a, 1986b) reported that roller marks are difficult to eliminate when working at night.

In another related research (Dunston et al. 2000), the Washington State Department of Transportation implemented a pilot project to evaluate the option of a full weekend closure; closure of all lanes in a single direction throughout designated weekend hours- as an alternative to nighttime construction. Surface smoothness (rideability), among other quality measures, was compared between daytime and nighttime mainline paving for this project. The surface smoothness test results are shown in Table 9.

Table 9. Profile Index (PRI) Results (Dunston et al. 2000)

Lane	Wheel Path	Prelevel PRI [mm/km (in/mi.)]	Overlay PRI [mm/km (in./mi)]	Improvement in PRI [mm/km (in./mi)]	When Paved
			Southbound		
1	Inside	68 (4.3)	47 (3.4)	+ 14 (0.9)	Night
2	Outside	106 (6.7)	28 (1.8)	+ 77 (4.9)	Day
2	Inside	28 (1.8)	27 (1.7)	+ 2 (0.1)	Day
2	Outside	79 (5.0)	22 (1.4)	+ 57 (3.6)	Day
1	Inside	66 (4.2)	79 (5.0)	- 13 (0.8)	Day
			Northbound		
1	Inside	182 (11.5)	20 (1.3)	+ 161 (10.2)	Night
3	Outside	123 (7.8)	38 (2.4)	+ 85 (5.4)	Day
2	Inside	98 (6.2)	20 (1.3)	+ 77 (4.9)	Day

As far as surface smoothness, the statistical analysis of the PRIs (profile index measured in mm/km or in/mi.) revealed no differences between daytime and nighttime paving shifts. Note however that the number of samples utilized in this research was small and they mostly involved daytime shifts. A larger sample from several projects is desirable in order to draw relatively firm, statistically supported conclusions. The results of the smoothness tests can be compared to specification usually requiring the contractor to produce a riding surface with a profile index of about 80 mm/km (5in/mi) (Ksaibati et al. 1995, Smith et al. 1997). This specification is representative of a customary acceptable surface smoothness for flexible pavements.

According to these research efforts and other studies and reports (Hinze and Carlisle 1990a and 1990b, Ellis1993), although surface smoothness of nighttime paving is usually within specifications, it is usually less than that of daytime. In addition, achieving reasonable surface smoothness may require additional care and quality control by the contractor.

2.3.2.1.2 Compaction

Compaction is another construction activity where quality can be affected during nighttime. The effect of nighttime on compaction however is less significant than that on surface smoothness. Compaction test results from a daytime paving project, I-70, were compared to that of a similar construction job done during nighttime hours on I-25 (Price 1986a, 1986b). It was felt initially that compaction performance might suffer due to cooler nighttime temperatures. However compaction of night paving was just as high as that of day jobs, and in some tests was even higher. It was found that the overall quality of the work done on the nighttime project was very similar to a well-done day job.

Table 10. Compaction, Asphalt Content and Specific Gravity Data (Price 1986a)

	Mean Night Paving	Mean Day Paving	High Night Paving	High Day Paving	Low Night Paving	Low Day Paving	Std. Dev. Night Paving	Std. Dev. Day Paving	Spec on Night Job	Spec on Day Job
Compaction (N = 62)	96.1	95.6	98.7	97.9	95.2	95	0.81	0.735	95	95
Asphalt Content (N=47)	5.49	5.81	6.46	6.29	5.12	5.26	0.267	0.222	5 to 6	5.3 to 6.3
Field Specific Gravity (N=62)	2.22	2.23	2.28	2.28	2.2	2.21	0.019	0.018	2.31	2.33

The summary of the data collected in this study (Price 1986a) is shown in Table 10. As no statistical tests were reported in this study, some tests were performed to further analyze the data. Specifically, a t-test was performed to compare the average compaction of daytime versus nighttime work, with the hypothesis that mean compaction of work performed during nighttime construction was not significantly different from that during daytime. The test confirmed that the mean compaction of nighttime was significantly different (higher) than that of daytime at 95% confidence level. Also, there were no significant differences in the asphalt content and the field specific gravity between daytime and nighttime at 95% confidence level.

In the research by Dunston (2000), statistical analysis revealed no significant differences in pavement densities between lots paved in the daytime and those paved in the nighttime. Table 11 shows the conclusions of both studies.

Table 11. Conclusions of Quality Studies (adapted from Dunston 2000, Price 1986a)

Study	Densities	Ride Ability
Price	It was found that the mean compaction of nighttime was statistically different (higher) than that of daytime, at a 95% confidence level.	Roughness average of 8.8 in/mi. before paving was reduced to 3.5 in/mi after
Dunston	Statistical analysis revealed no significant differences in pavement densities between lots paved in the daytime and those paved in the nighttime.	Statistical analysis of the PRIs revealed no differences between daytime and nighttime paving shifts (with limited data)

2.3.2.1.3 Factors Affecting Nighttime Construction Quality

Factors that are believed to adversely affect the quality of nighttime construction include: poor visibility, inadequate lighting, lack of supervision and inspection, and poor workers' morale. Factors that are believed to have positive impact include less disruption due to lower traffic volumes, and cooler temperatures in some locations (Abd Elrahman and Perry 1994, 1998). The common perception among contractors, owners, and state officials is that the quality of nighttime repairs and overlays obtained by using proper procedures, adequate inspection and testing and with strict grade control can compare favorably with the quality of the overlays constructed during daytime. Some of the factors that are believed to affect the quality of nighttime construction include:

1. Inspection and testing: Inspection personnel should be familiar with the fact that during nighttime, lighting reflects on asphalt pavement and greatly magnifies ridges and depressions.
2. Construction period: The most critical areas in the surface course of an overlay occurs at the transverse joints at the end of each night's overlay. These joints are always difficult to construct and could cause rough areas in the pavement unless extreme care is taken during construction. The construction should be planned so that approximately 800 feet of overlay or more is placed each night (Wills 1982). This means that the contractor should schedule work to start no later than 10 pm and to end at 7 am. In general construction operations should

start no later than 11 pm. In residential areas this is consistent with restrictions on when nighttime construction is allowed to start and end as will be discussed later.

3. Lighting: Matching the joint is an important spot to tackle strategically when paving at night (Ball 2001). Usually, the workers could see the head of material, but couldn't quite see how it came out from underneath the screed. To mitigate this problem, the contractor can have another magnetic light mounted to the edger plate. Results of a past study on nighttime overlay operations at various airports indicated that although it is entirely feasible to repair and overlay existing runways at night, the completed overlays were somewhat less than satisfactory (Wills 1982). Failure to construct the proper transition at the end of nighttime paving operations has been the complaint of pilots upon landing on the newly placed hot mix asphaltic concrete overlay (Wills 1982).

   Another area that is critical is illuminating the operator's pedal on the paver. The operator must be able to see his instrument panels. The pedestals for the back of the paver must also be well lit so the screed operator can see the controls to be used.

4. Human Factors: The most often identified factors having the greatest impact on worker’s performance include, sleep, human circadian rhythms, and social/domestic issues (Monk 1989, Khayat 1999).

   Workers on night shifts have complained about poor quality or insufficient sleep which results from trouble falling asleep, waking during sleep, and waking up early (Delisle 1990). A survey indicated that 20% of night shift workers in the U.S. suffer from sleep-related problems, which can be termed “night worker neurosis”. An individual who finds it difficult to adapt to night work is not able to remain mentally alert, and as a result, becomes an added safety risk (Ellis et al. 1992). Therefore, it is imperative that night shift workers obtain an adequate amount of uninterrupted sleep.

   The circadian rhythms or biological clock of worker can be altered over time to cope effectively with night shift, however there is disagreement on the length of time that is required for the human body to adapt to changes in the circadian rhythms. The most widely accepted method for reversing the biological clock is for the person to perform the same type of activities on the reversed schedule as would normally be done on the standard schedule. Management should find a night shift crew who would retain their altered sleep cycle whether or not they were working (Ellis 1993).

Shift workers complain that they are not able to spend enough time with their family and children. It has been found however that in places where nearly all workers are shift workers, problems of socialization and friendships are not significant.

2.3.2.1.4 __Perception of state officials and contractors of nighttime construction quality__

In a previous study (Hinze and Carlisle 1990a, 1990b), a two-part survey was sent to state officials and contractors from 23 states. Seventy six percent of the respondents felt that 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 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.

The principal problem encountered with nighttime placement of asphalt concrete paving was the "unevenness of paving surface." Inconsistency in the mix, poor compaction, inspection of the work and cold joints were mentioned as problems by about 20% of the respondents due to inadequate lighting. On the other hand, the principal problem with Portland Cement Concrete (PCC) paving, as indicated by 85% of the respondents, was in obtaining a good finish. 63% of the respondents indicated that the quality of nighttime PCC is below that of the daytime PCC. Figure 3 shows the results of a survey on the quality of operations performed. Table 12 shows the results of a survey on the respondents' opinion about operations whose performance may be enhanced when performed at night.

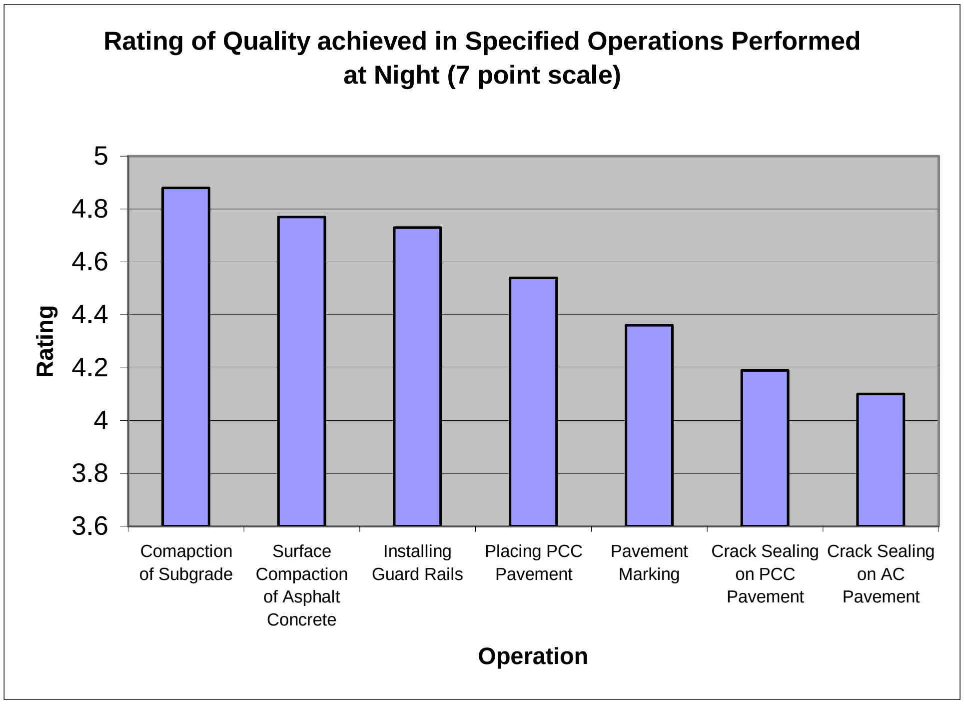


Figure 3. Rating of Quality Achieved in Specific Operations (adapted from Hinze and Carlisle 1990)

Similarly, in a research by Dunston (2000), state respondents were asked to indicate any quality trends associated with nighttime construction. The respondents indicated that nighttime paving tends to result in higher variability in densities, a rougher ride, more instances of cyclic segregation, and lower quality longitudinal joints.

In addition to the above studies, a few reports and technical memos addressed the issue of quality of nighttime operations. Some resident engineers find better quality control in certain jobs requiring cooler temperatures for material and equipment. (Price 1986a). Regional officials in New York state (NYSDOT 1999) indicated that based on their experience, the quality of work performed at night is the same as that performed on daytime construction projects.

Generally, it can be concluded that even though some operations might lose quality during nighttime construction, the work performed is usually in compliance with specifications and no serious problems arise (Shepard and Corttel 1985). The literature is insufficient to conclude that night operations result in poorer quality. In comparing daytime and nighttime paving quality, it is important to note that most of the studies in the literature failed to consider other measures of pavement performance like gradation, longitudinal joints and, cyclic segregation.

Table 12. Results from Question about Operations Whose Performance can be Enhanced at Night (from Hinze and Carlisle 1990)

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 Repairs	2
PCC Pavement Slab Repair	2
Latex Modified Concrete	2
Grooving PCC Concrete	1
Large Concrete Pours	1
Asphalt Concrete Removal	1
Loading and Hauling Dirt	1
Repairing for structural Pours	1
Backfilling Structures	1
Shifting Traffic	1
Installing Guard Rails	1
Signals	1
Street Lighting	1
Grading/Crushing Aggregate	1

Table 13. Comparison of Activities Whose Quality is Affected by Nighttime Construction

Hancher *(Hancher and Taylor, 2000)*		**Hinze** *(Hinze and Carlisle 1990a)*		**Price** *(Price 1986b)*		**Summary of Matching Activities**		
Quality Does Suffer	***Quality Does not Suffer***	***Quality Does Suffer***	***Quality Does not Suffer***	***Quality Does Suffer***	***Quality Does not Suffer***	***Quality Does Suffer***	***Disagreement***	***Quality Does not Suffer***
Earthwork	***Bridge Deck Pour***	Crack Sealing on PCC Pavement	**Asphalt Concrete Paving**	Guardrail installation		Crack Sealing on PCC Pavement	**Asphalt Concrete Paving**	***Bridge Deck Overlay***
Concrete Pavement	***Bridge Deck Overlay***	Crack Sealing on AC Pavement	***Bridge Deck Rehabilitation***	Crack Filling		Crack Sealing on AC Pavement		***Bridge Deck Rehabilitation***
Asphalt Pavement	Structural Work	Grooving PCC Concrete	Pavement Marking	Rolling		Traffic Control Systems		
Blasting	Drainage/ Utilities	Large Concrete Pours				Guardrail installation		
Striping	Rock Excavation	Asphalt Concrete Removal						
Sign Placement		Loading and Hauling Dirt						
Traffic Control Systems		Repairing for structural Pours						
		Backfilling Structures						
		Shifting Traffic						
		Guard Rails Signals						
		Street Lighting						

2.3.2.1.5 <u>Jobs Whose Quality Is Affected By Nighttime Construction</u>

Certain jobs are more suited for nighttime construction than others in respect to the achieved quality. A recent study by Hancher and Taylor (2000), surveyed State Departments of Transportation, selected Kentucky highway contractors, and the Kentucky Transportation Cabinet Resident Engineers. Questions were asked about the effect of performing a construction job at night versus daytime. On a scale of 1 to 5 (1-Negative effect, 3-No effect, 5-Positive Effect) it was found that, in general, nighttime construction has no effect on the quality of work performed (score = 3). It was also found that the quality of nighttime construction is dependent on the type of job considered. Similar results from other studies are summarized in Table 13.

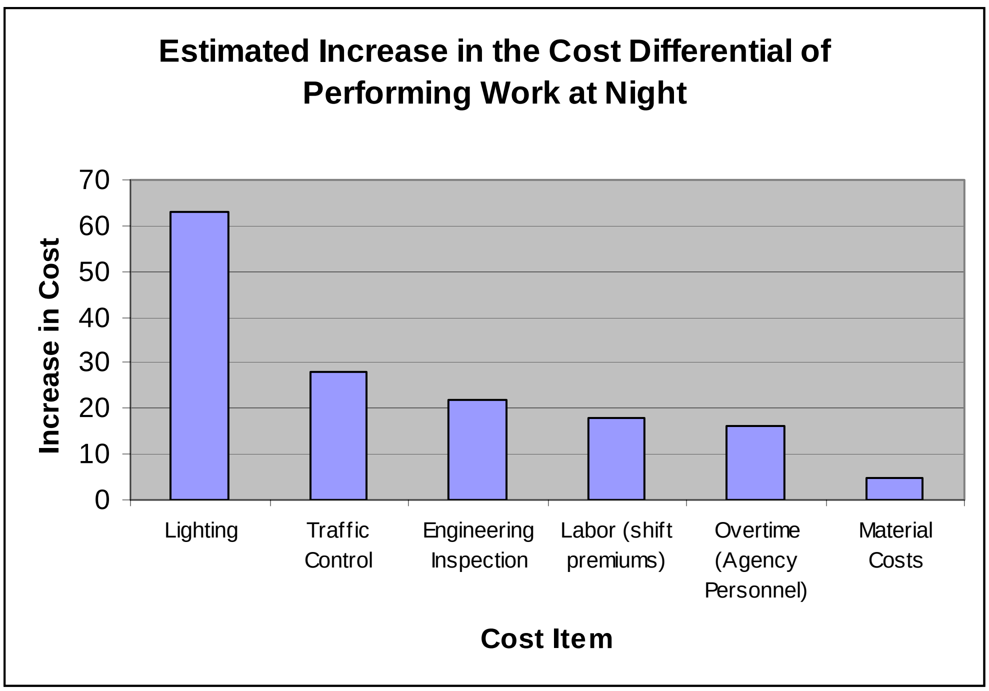
Guardrail installation, for example, is a job that should not be considered at night. The ability to aesthetically place guardrail was found to be difficult under nighttime conditions. Also operations such as crack filling and rolling were identified to be more difficult due to shadows produced by improper lighting (Price 1986b). It is difficult to see cracks in the old asphalt even with hand held lights and spotlights.

2.3.2.2 Construction Costs

Most studies in the literature suggest that nighttime construction results in higher costs than daytime construction. However, there is disagreement in the literature as to the extent that construction costs increase during nighttime. Most estimates range from 0% to 40%.

2.3.2.2.1 <u>Cost comparisons between daytime and nighttime construction</u>

In New York State (NYSDOT 1997), 20 project components from six nighttime construction projects were used to compare daytime and nighttime costs. The average price for each item from all bidders was computed rather than from low bidders for each component). Expectedly, including the high bids tended to increase the cost of each component for nighttime construction. The study found that costs of nighttime construction ranges from a negligible amount to as much as 20 percent higher than the costs of similar daytime operations. However, in this study the comparison was based on the arithmetic average cost for each component to a weighted average cost of these same components. Therefore a follow up audit was conducted on the data by comparing weighted averages for each component and compared these with the weighted average for all projects. The analysis found that costs associated with nighttime construction were generally not as high as indicated in the previous study. As an example, the cost of asphalt was found to increase by only 3 percent versus 16 percent from the previous report. It is also argued that innovative incentive provisions, which are included in most contracts that require nighttime construction work, could offset increases in specific contract items related to nighttime construction.



Total Contract Amount Increase = 9%

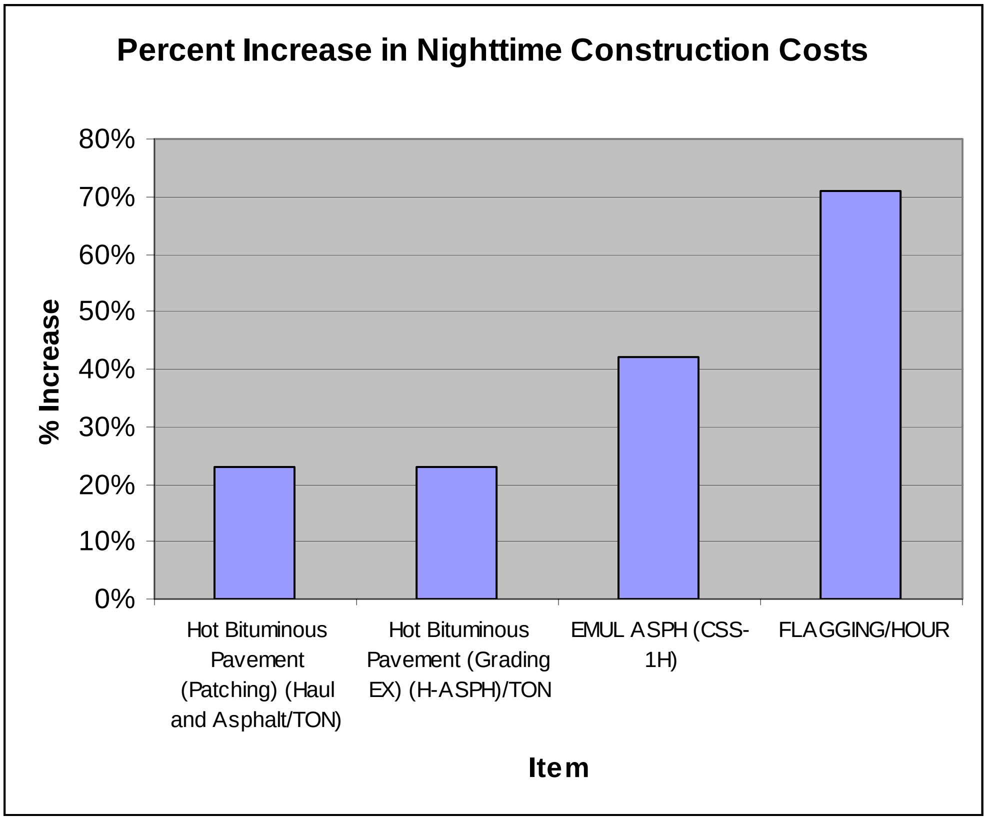
Figure 4. Estimated Increase in Cost for Various Operations (adapted from Hinze and Carlisle 1990a)

In a study by Hinze and Carlisle (1990a and 1990b), state officials estimated that material costs were increased by 5 percent when nighttime construction took place. Contractors, on the other hand, did not give estimates consistent with these values.

Most contractors stated that material prices did not increase when work was performed at night. In this study, it was found that the costs of materials did not increase at night because most contractors have their own batch plants and thereby establish greater control over the material. In fact the cost might be reduced because of less congested streets at night (although, the labor rates may be higher, and offset this finding).

Another study by Ellis and Kumar (1993) looked at a set of typical highway construction work items based upon their presence in a typical day as well as night shifts, their significant contribution to project costs, and their large quantities. The study looked at eight cost items in nine different projects. It was found that nighttime item rates are significantly different from daytime rates, although such rates are significantly high for some items and significantly low for others. The cumulative cost for each of the eight items considered was consistently lower for nighttime construction for all the nine projects. However, the results of statistical cost comparisons do not suggest a project cost may increase or decrease due to nighttime construction. It is important to note that there was high variations in cost items between the different projects (measured by standard deviation), which shows that unit costs in this study are dependent more on project-related conditions than on changes in nighttime and daytime.

In an earlier study by Wills (1982), two similar overlay projects were used to conduct a cost comparison between daytime and nighttime. Cost items compared are shown in Figure 5 and Figure 6. Costs of nighttime construction were found to be higher due to shift differentials, overtime, special signing, and lighting. Asphalt prices increased due to hiring employees at the batch plant with wage differential and overtime (note some contractors own their plants). Costs for fitting traffic control devices for nighttime situation were found to be fairly higher.



Total Costs = 159% Higher at Night
Average/Item = 40% Higher at Night

Figure 5. Percent Increase in Nighttime Construction Costs for Various Operations (adapted from Wills 1982)

One of the specific items required by a night schedule is artificial lighting. In order to meet the 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 primary work activity. Equipment modified with lights provided the added benefit that the setup cost is incurred one time. However, little information is available in the literature on lighting-equipped paving machinery that is safe and cost effective.

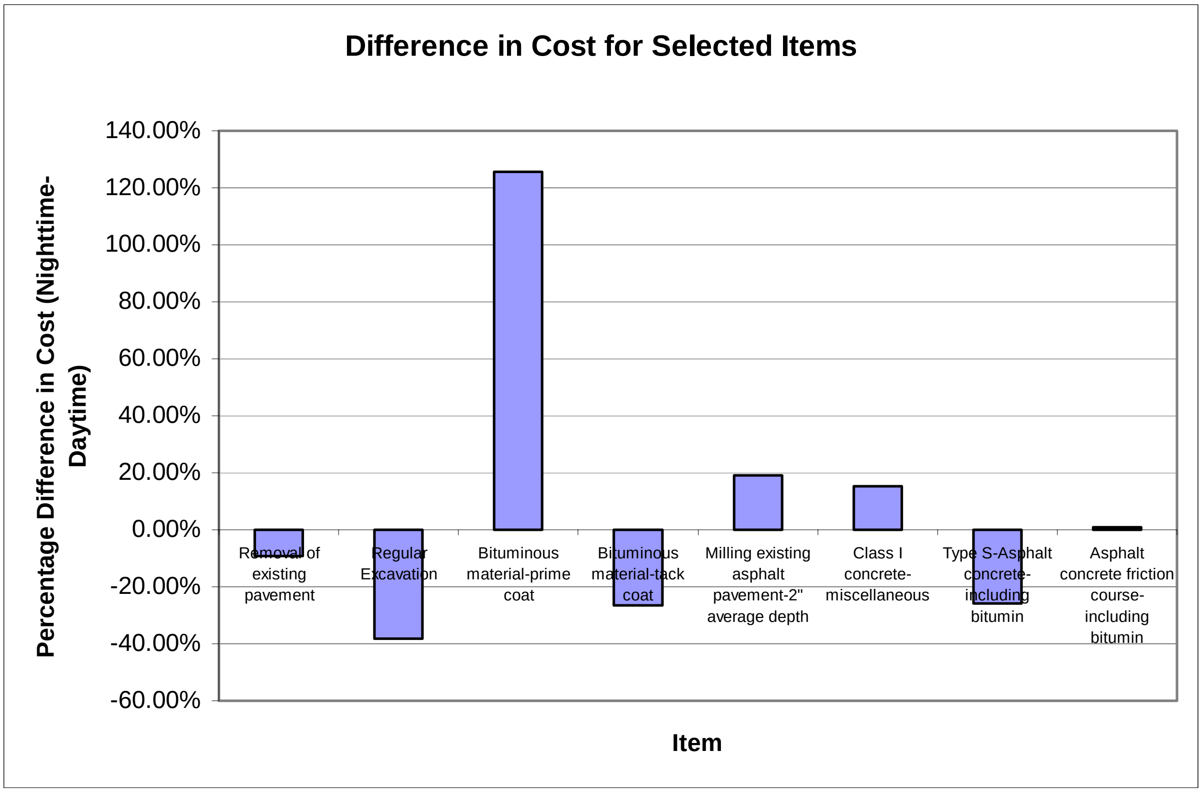


Figure 6. Difference in Costs for Selected Items (adapted from Wills 1982)

Another study (Falin 1990) found that shift premiums accounted for an increase of about 18% in direct labor costs during nighttime. Also, additional agency personnel costs due to nighttime construction were as high as 16%. Comparisons by FDOT indicate increases in material costs for asphalt work during nighttime by about 2-3% (Layfield 1988). In the same report, it was noted that labor costs can also increase and this was supported by an example where a Florida contractor agreed to pay $0.50/hr for all personnel working at nighttime operations.

Finally, it is important to note that the costs of specific work items required by a night schedule cannot be readily retrieved by most state highway agencies because the costs of nighttime construction are generally absorbed by other pay items.

2.3.2.2.2 ***Estimating premium costs***

One of the suggested practices for estimating premium costs associated with nighttime construction is to question the contractors in the area. It is expected that the estimates of extra costs among contractors varies to a great extent. It is probable that some of the contractors will report a rather high premium cost to the engineer for nighttime construction if queried when the preliminary project estimate is being prepared. That should be discounted since when the project is actually advertised and bids received, the contractors normally reflect the premium cost in their bids. These are typically 10% to 20% higher than daytime costs but will be substantially lower than the cost quoted to the Engineer at the time of the preparation of the plans and specifications.

2.3.2.3 Productivity

Several factors including difference in temperature, workers morale, lighting conditions, and traffic loads affect the productivity of nighttime construction. In urban areas under normal daytime construction operations, there are two peak traffic loads which actually cut the work day to 5 1/2 hr per day, while at night the working period and actual daily work hours are extended (Layfield 1988).

Ellis and Kummar (1993) carried out a statistical test on the significant difference between daytime and nighttime productivity. In their study, two types of operations were tested, structural course of plant mixed surfaces and milling existing pavements. The data for the two operation types were collected from projects carried out on I-95. The test for the structural course operation did not confirm a difference between the production rate of plant mixed surface for day and nighttime jobs, although the mean production for nighttime projects appears to be slightly less than that on daytime limited access projects. For milling existing pavement, statistical tests did not confirm a difference between day and nighttime production rates. The study concluded that night shift does not significantly affect productivity. According to this study, there can be project by project variations attributed to several factors which include: long working hours, less traffic interferences, total road closures, inadequate lighting, worker's morale and equipment breakdown and repair.

It is important to note that two limitations exist in this study. The first limitation is the very small sample size (4 nighttime construction projects), which taints the accuracy of the statistical tests. The second limitation is that the study compared production measured in tons/day and square yards/day—not productivity that is normally defined using tons or square yards/man-hour or man-day.

In a survey by Dunston (2000), hourly production rates were noted to be different in the form of either greater variability or higher production rates. Only one of 6 respondents surveyed cited lower production. In this study, Florida DOT noted higher production rates during nighttime. However, an earlier study for Florida DOT (Ellis and Kummar 1993) concluded that nighttime paving productivity (tons/h) could be as high as that for daytime paving, although the total shift production may not be as high.

In a project by Columbia metropolitan airport in west Columbia, South Carolina, data was secured from South Carolina asphalt pavement association and from the contractor (Wills 1982). The contractor on the job already had extensive experience in nighttime construction and was noted to have excellent production with a total production of 67,410 tons of hot mix asphalt (HMA) placed during a period of 5 day and night periods, with the asphalt being delivered from different plants. The reported production during the 5-day period is shown in Table 14. The total production for the five days was calculated although day 5 had only day work (no night shift), which influenced the overall production comparison. In order to have an unbiased comparison, the fifth day was excluded since no paired data at night existed (and also not to offset the results by considering the learning effect during the first 4 days). The average was calculated for the first 4 days only to compare nighttime and daytime production. The results are shown in Figure 7. Although the results are only from one project during a 4-day period, one can see that, in general, the production at nighttime is somewhat less than that of daytime. However, no generalizations can be made regarding the productivity of nighttime versus daytime construction since the literature on this topic is limited.

Table 14. Production Comparison Between Daytime and Nighttime Work

		Asphalt Plant #4 (tons)	Asphalt Plant #7 (tons)	Asphalt Plant #8 (tons)
Day 1	Day	**3053**	2188	2700
	Night	740	2530	1508
Day 2	Day	2527	2594	2803
	Night	3149	2524	2238
Day 3	Day	2522	2753	**1372**
	Night	2236	2161	1944
Day 4	Day	2620	2467	2487
	Night	1803	*1266*	2238
Day 5	Day	1177	2094	2008
Totals	Day	11899	12096	11370
	Night	7928	8481	7928
Day (1 to 4) Totals only	Day	10722	10002	9362
	Night	7928	8481	7928

Average nighttime temperature 57°-68°
Average daytime temperature 80°-85°
Mix Temperature 285°

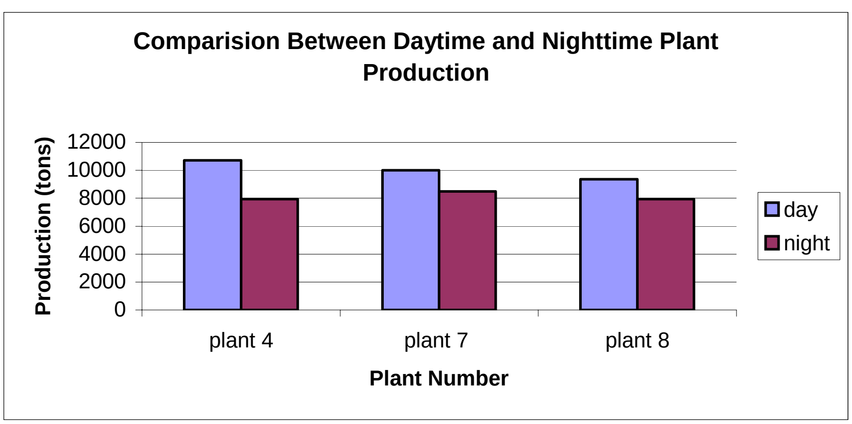
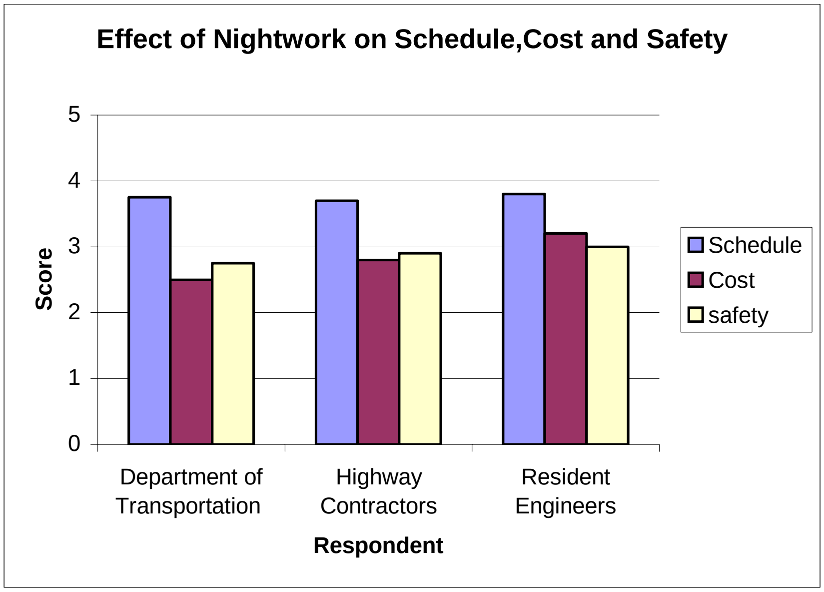


Figure 7. Comparison Between Daytime and Nighttime Productivity

2.3.2.4 Workers' Safety

Nighttime construction poses unique risks for workers safety due to the lower visibility for drivers and equipment operators during nighttime as well as the high proportion of drivers under the effect of fatigue, drugs, or alcohol. One suggestion is not to allow nighttime construction in weekends when the probability of intoxicated drivers is higher (Ellis et al 1992). On the other hand, the lower traffic volume at night may mean fewer accidents. Unfortunately, the majority of construction accidents investigation techniques and reporting systems do not properly address why accidents occur by identifying possible root causes (Abdelhamid and Everett 2000). A recent survey (Hancher and Taylor 2000) showed that state officials, highway contractors and resident engineers almost agree that nighttime construction has little effect on safety as shown in Figure 8. According to many states, community awareness is one of the most important measures for reducing workers' accidents, in addition to appropriate traffic control, sufficient lighting and added caution.



5 indicates positive effect, 3 no effect and 1 negative effect

Figure 8. Night Work's Effect on Schedule, Cost and Safety (adapted from Hancher and Taylor 2000)

In the State of Ohio, of the 32 construction projects scheduled for one recent year in Franklin County (the Columbus metropolitan area), 13 involve nighttime construction (Ohio DOT 2000). Work zone accidents in central Ohio have risen substantially over the past six years. Since 1993, the number of work zone accidents rose 71 percent from 661 in 1993 to 1,135 in 1999. About 60 percent of all work zone fatalities occur at night, according to national statistics (Ohio DOT 2000).

In the State of Maine, of the 601 accidents in construction areas on Maine highways in 2000, only 93 (about 15 percent) occurred during nighttime hours. Peak accident time for construction zones is noontime (Maine Today 2001).

Police coverage is also another important measure that can positively impact safety, since drivers are more likely to slow down. Massachusetts and other states, require state troopers to be present at every highway construction site.

2.3.3 Environmental and Social Variables

The literature on environmental and social impacts of nighttime construction is restricted to studies on mitigating the negative effects of nighttime construction on local and neighboring communities. Specifically, main environmental impacts are related to the effect of noise, vibration and dust, while social impacts are related to community awareness and educating the public on nighttime construction impacts on surrounding areas.

2.3.3.1 Noise

In a recent study (Schexnayder and Ernzen 1999) a telephone survey of State DOTs identified the critical nighttime construction noise generators. Results of this survey are provided in Table 15. Backup alarms and slamming tailgates were the most frequent answers. When queried on the types of activities that cause nighttime construction noise problems, respondents indicated that pavement breaking and paving/resurfacing were the most problematic (see Table 16).

Table 15. Critical Nighttime Construction Noise Generators (Schexnader and Ernzen 1999)

Noise Generator	Percent Identifying Activity as Cause of Problems
Back-up Alarms	41
Slamming Tailgates	27
Hoe Rams	24
Milling/Grinding Machines	16
Earthmoving Equipment	14
Crushers	6

Table 16. Types of Activities that Cause Nighttime Construction Noise Problems (Schexnayder and Ernzen 1999)

Activity Type	Percent Identifying Activity as Cause of Problems
Pavement Breaking	27
Paving/Resurfacing	25
Pile Driving	24
Bridge Deck Removal	24
Rehab	20
Patching	12
Earthmoving	2
Crushing	2

In order to understand noise regulations and mitigation techniques a review of sound basics is presented next.

2.3.3.1.1 ***Noise Measurement: Background***

Noise fluctuates from one moment to another, so some mean of temporal averaging is necessary by amalgamating all sound information into one number called equivalent sound level (L_{eq}) (Haling and Cohen 1996). L_{eq} is the equivalent noise energy level of a steady unvarying tone measured in decibels (dBA). A decibel (db) is the basic unit of sound. Since humans only hear frequencies ranging from 202Hz up to 20KHz, an A-weighted decibel (dbA) was developed based on a scale adjusted to accentuate the frequencies heard by man. Sound can also be presented using percentile sound levels, L_n, which refers to sound level exceeded "n" percent of the time. An L_{10} for example is an A-weighted sound level exceeded 10 percent of the time. In construction activity the L_{10} has been found to be about 3dBA higher than L_{eq} and correlated well with construction activity. In order to study the consequences of nighttime construction noise, the noise generated from various machines must first be determined and then compared to noise regulations.

In order to predict the effect of machine noise, Miller (1995) offered the following equation:

$$L_{eq}(equip) = E.L. + 10\log(U.F.) - 20\log\left(\frac{D}{50}\right) - 10G\log\left(\frac{D}{50}\right)$$

L_{eq}(equip) = L_{eq} at the receiver resulting from the operation of a single piece of equipment over a specified time. It reflects in a single number the sound energy experienced.

E.L. = noise emission level of the particular equipment at the reference distance of 50ft. The range of E.L. for various construction machines is from 82 dBA (at 50 ft) for a compactor to 90 dBA (at 50 ft) for a compressor (SAE).

U.F. = usage factor that accounts for the fraction of time that the equipment is in use over the specified time period. In nighttime, U.F. should be increased to a factor of 10 to account for noise sensitivity.

D = distance from the receiver to the equipment, and

G = constant that accounts for topography and ground effects

*2.3.3.1.2 **Nighttime Construction Noise Regulations***

The above equation is used to estimate the noise level that can then be compared with established limits. Table 17 shows some nighttime construction noise regulations in terms of maximum dBA allowable.

*2.3.3.1.3 **Mitigating the effects of noise***

Mitigating the effects of noise in nighttime construction can be accomplished by three main controls: source control, path control and receptor control (Schexnayder and Ernzen 1999). Source control can be accomplished by construction operations planning, ensuring proper maintenance, restrictions on type of equipment to be used, operating at minimum power, controlling non-construction traffic, using quieter alternate methods (e.g. use top-down or tunneling rather than cut-and-cover techniques), and using quieter alternate equipment.

Path control can be accomplished by moving equipment farther away from the receiver, enclosing especially noisy activities or stationary equipment, erecting noise barriers or curtains, using landscaping and, using active noise control. On the other hand, receptor control can be accomplished by community relations, community participation, window treatment program, and temporary relocation.

Table 17. Nighttime Construction Noise Limit Regulations (Schexnayder and Ernzen 1999)

Location	dBA at 25 ft	dBA at 50 ft	dBA	Time
Ancorage Alaska			80 at 100ft	
San Francisco			80 at 100ft	
Colorado	75			7 p.m.-7a.m.
District of Columbia	55 (residential) 60 commercial			7 p.m.-7a.m.
Hawaii	45 to 70 depending on land use			10 p.m.-7a.m.
Chicago Illinois		70 to 80 depending on land use		
Maryland	55 to 75 depending on land use			10 p.m.-7a.m.
Billings, Montana		75		8 p.m.-8a.m.
New Jersey	50 (residential0 65 (commercial)			10 p.m.-7a.m.
New York			64 to 74 at 400ft depending land use	
Houston Texas	58 (residential)			10 p.m.-7a.m.
Alexandria, Virginia		85		
Washington	45 or 50 (residential)			10 p.m.-7a.m.

2.3.3.2 Dust

The dust problem is accentuated in nighttime construction by lighting of the site, which makes particulate matter more visible. In most cases however the dust problem is not limited to nighttime and therefore mitigation techniques are regularly specified in the contracts. Techniques include watering and dust suppressants, barriers, screens, and covers. Spray on dust suppressants like fiber-reinforced, cement-based products that are sprayed over the ground and form a protective shell reduce the dust nuisance. A machine similar to a hydro-seeder is used to apply these suppressants. Stockpiles protected by plastic tarp covers that are secured with sandbags is another good technique (Schexnayder and Ernzen 1999).

2.3.3.3 Vibration

The unpredictability and the unusual nature of a vibration source rather than the vibration level itself is more likely to cause complaints. Mitigation techniques include careful project layout and access design, sequencing of operations and alternative construction methods. Operating equipments should be placed as far as possible from the receptors. Demolition, earthmoving and ground-impacting operations should be phased so as not to occur in the same time period. Demolition methods not involving impact should be selected like sawing bridge decks into sections for removal.

2.3.3.4 Nighttime Construction and the Environment

A number of States like Texas approved a rule package banning heavy construction during morning hours due to ozone concerns. Texas officials approved a pollution-reduction plan for Houston that will ban morning use of heavy construction equipment seven months of the year and require early purchase of tier 2 and 3 machinery. Specifically, construction operations time shift bans use of non-road diesel construction equipment >50 hp from 6 a.m. to 10 a.m. during ozone season (June through October). The ban raises several issues that impact the public as well as the local construction industry. It will shift the workday later, affecting evening rush-hour traffic. To get a full day in, contractors will have to perform night operations. Although there is still debate about the real environmental effects of such variables, such regulations will drive an increase in nighttime construction.

2.3.3.5 Economic Impacts on Surrounding Businesses

Very limited research has been carried out on the impact of nighttime construction on neighboring communities and its influence on the businesses in the area. The Arizona Department of Transportation operates an effective community relations program to actively partner with the community it seeks to serve. The program involves holding town meetings, and soliciting input from area commercial and residential communities for ways to minimize the effect on their businesses. The program is noted as a success because it gets the community to “buy-in” to the project (Schexnayder and Ernzen 1999). In California (Ellis et al 1992) Caltrans hired a public relations agency to create public awareness of recirculation routes. From the previous literature, it is imperative for local DOTs to engage the public in such campaigns and programs to minimize not only the effect on the nearby businesses and residences but also to enhance traffic flow.

2.3.3.6 Community Awareness and impact on surrounding communities

A variety of methods are available to agencies to disseminate information about project duration, type of work, and benefits of the work. Table 18 shows the results of a survey that involved 211 state, city and county agencies about different techniques used for public awareness (Shepard and Cortell 1985). Results show that the common medium used was the newspaper, followed by radio and television.

Table 18. Community Awareness Techniques and Their Effectiveness (Shepard and Cortell 1985)

Technique	Effectiveness (1=most effective)
Special signs	1
Personal Contact	
Door-to-door	2
Special gathering	5
Special Mailings	
Personalized Letter	3
Occupant form/memo	7
Registered notice	9
Press Release	
Radio	4
Newspaper	6
Television	8

2.3.4 Issues Needing Further Exploration

Several questions remain to be addressed by research. They include:

- To what extent is labor scheduling a problem in nighttime construction projects? Nighttime construction usually involves employing shift workers. In some seasons and in some locations this can be problem. It is important to identify any trends and periods where availability of shift workers is limited.
- Is worker absenteeism increased when work is performed at night? Due to the harsher conditions that work sometimes has to be carried out during nighttime construction, absenteeism might become a problem to the contractor and hinder its ability to meet schedules.
- To what extent is supervision impaired by night work? A number of studies mentioned the importance of adequate supervision during nighttime construction. It would be important to understand any operational problems or procedures that have to be followed during nighttime supervision that differ from those of daytime.

- The availability of materials after regular working hours and associated premiums that must be paid if any? Material costs, along with labor wage premiums, have been noted to be some of the factors driving up the cost of nighttime construction. Some contractors own their plants and material costs in those cases are usually not increased. However, it is important to understand the true cost in these situations and how does this impact the cost of the overall job.
- Contractual effects on the cost, productivity, and quality of nighttime construction. It was mentioned in several previous studies that nighttime construction could be contracted using some of the untraditional contracting methods like A+B, incentive contracting, or job-order contracting. An important question is whether any specific contracting method is better suited for nighttime construction than others.
- Response time of answers to design questions. Since most questions regarding design will most likely be at night, it is interesting to know if this affects the flow of work during nighttime construction.
- The accurate estimate of work zone capacity is a very important input to quantify traffic-related impacts of lane closures (essential to compare daytime and nighttime construction activities). Procedures available in current practice to estimate work zone capacity are severely limited and estimates typically involve a large degree of approximation.
- There is very little information about the effect of nighttime construction on traffic accident risks, rates, and severity in order to provide a realistic assessment of traffic safety at nighttime work zones. Safety is a major criterion that is used by most highway agencies in making the decision on nighttime operations.

3 QUESTIONNAIRE SURVEYS

3.1 State DOTs & IDOT Districts Survey: Introduction

Questionnaires to the state DOT's and IDOT districts were prepared in coordination with the ITRC Technical Review Panel (TRP), sent out to the participants, and returned surveys were processed and analyzed. The surveys solicit important information on issues identified during the previous stage, state-of-the-art review, and from discussions with the project TRP. This information is mainly concerned with nighttime construction experience and practices in Illinois as well as in other states and the important factors involved in nighttime construction operations as perceived by state DOT's and IDOT districts. Responses were received from 15 state DOTs and all the nine IDOT districts. The corresponding response rates are 30% and 100% respectively. The questionnaire surveys for state DOTs and IDOT districts are provided in Appendix A and B.

3.1.1 Nighttime Construction Practice

3.1.1.1 Magnitude of Nighttime Construction

Participants from state DOT's were asked to provide a breakdown of highway construction projects during the past five years by work shift based on the dollar value of the projects. This information is useful to have an idea about the nighttime construction practice in different states. The responses from state DOT's are summarized in Table 19.

As shown in this table, most highway construction projects involved daytime shift only. Nighttime shift and dual shifts account for a small percentage of highway construction projects though figures in this table suggest that dual shifts are more common in highway construction. The only exception in practice was found in the states of California and Michigan. In California, the vast majority of highway construction projects were conducted using dual shifts and only a small percentage of projects were conducted using daytime shift only. Apparently, shortening the construction period must have been a priority in most highway projects in California. In Michigan, both daytime shift only and dual shifts roughly involved the same percentage of highway construction

Table 19. Percentage of Nighttime Construction Projects by State

	State	Daytime Shift Only	Nighttime Shift Only	Dual Shifts
1	**Arkansas**	80%-100%	0%-20%	0%-20%
2	**California**	0%-20%	None	80%-100%
3	**Georgia**	60%-80%	0%-20%	20%-40%
4	**Indiana**	80%-100%	0%-20%	0%-20%
5	**Iowa**	60%-80%	0%-20%	0%-20%
6	**Main**	80%-100%	0%-20%	0%-20%
7	**Maryland**	60%-80%	20%-40%	20%-40%
8	**Michigan**	40%-60%	None	40%-60%
9	**Minnesota**	80%-100%	0%-20%	0%-20%
10	**Nebraska**	80%-100%	0%-20%	None
11	**Nevada**	40%-60%	0%-20%	0%-20%
12	**Ohio**	60%-80%	0%-20%	0%-20%
13	**Texas**	80%-100%	0%-20%	0%-20%
14	**Washington**	40%-60%	20%-40%	20%-40%
15	**Wisconsin**	80%-100%	0%-20%	0%-20%

projects. In these two states, no projects were reported with nighttime shift only. This means that the use of nighttime construction is not intended to avoid interrupting traffic during daytime hours, but rather to speed up the construction work. Also, in the state of Nebraska, no project was reported to involve dual shifts.

To have an overall idea about the breakdown of the projects by the three types of work shift, the previous results are summarized in Figure 9.

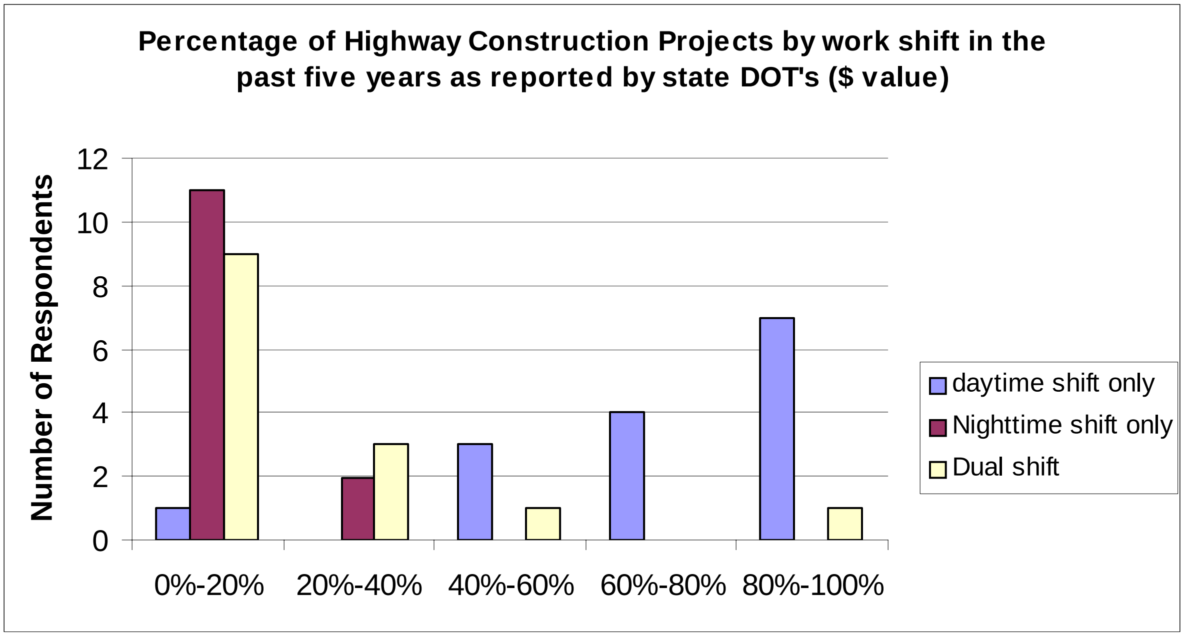


Figure 9. Percentage of Highway Construction Projects by Work Shift in the Past Five Years as Reported by State Districts ($ value)

This figure clearly confirms that daytime-shift-only projects constitute the majority of highway construction projects. Also, the projects with dual shifts are relatively more common in practice than the nighttime-shift-only projects.

The breakdown of highway construction projects by shift type in the state of Illinois as reported by the nine IDOT districts is illustrated in Figure 10. While this figure generally confirms the findings from Figure 9, it clearly shows a greater difference in the percentage of projects that were conducted during daytime shift only versus nighttime shift only. It also shows that projects with dual work shifts are relatively less common in Illinois when compared with the national trends.

However, it should be clear that the amount of highway construction differs from state to state, and as such, it is hard to infer with reasonable certainty from the last two figures the aggregate amount of construction projects by shift type measured in $ value.

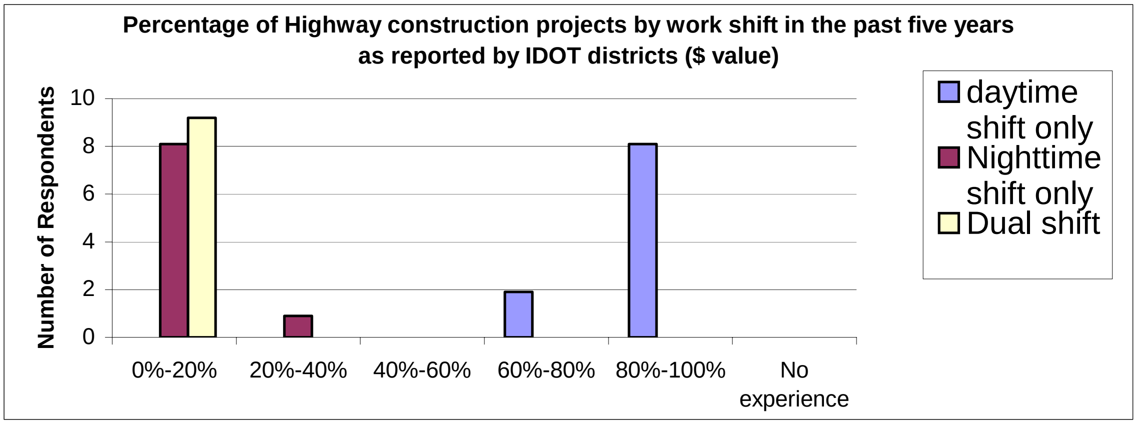


Figure 10. Percentage of Highway Construction Projects by Work Shift in the Past Five Years as Reported by IDOT Districts ($ value)

3.1.1.2 Projects by Facility Type

One important aspect of highway construction projects is facility type. In general, it is expected that nighttime construction is most beneficial on highways that have significant traffic volumes during daytime. Those mostly involve multi-lane highways including in urban areas and to some extent suburban areas. This is particularly true when nighttime construction is used as an alternative to conventional daytime shifts.

The participants of state DOT's and IDOT districts were asked to estimate the percentage of nighttime construction projects on 2-lane rural roads versus multi-lane highways in urban and suburban areas. The results are presented in Figure 11. This figure is consistent with expectation as it shows that 93% of the states surveyed reported 0%-20% of nighttime construction projects on two-lane rural roads. The remaining 7% reported no experience. A very similar experience was reported by IDOT districts. Specifically, 89% of the districts (8 out of 9) reported 0%-20% nighttime construction projects on two-lane rural roads and 11% reported no experience (one district).

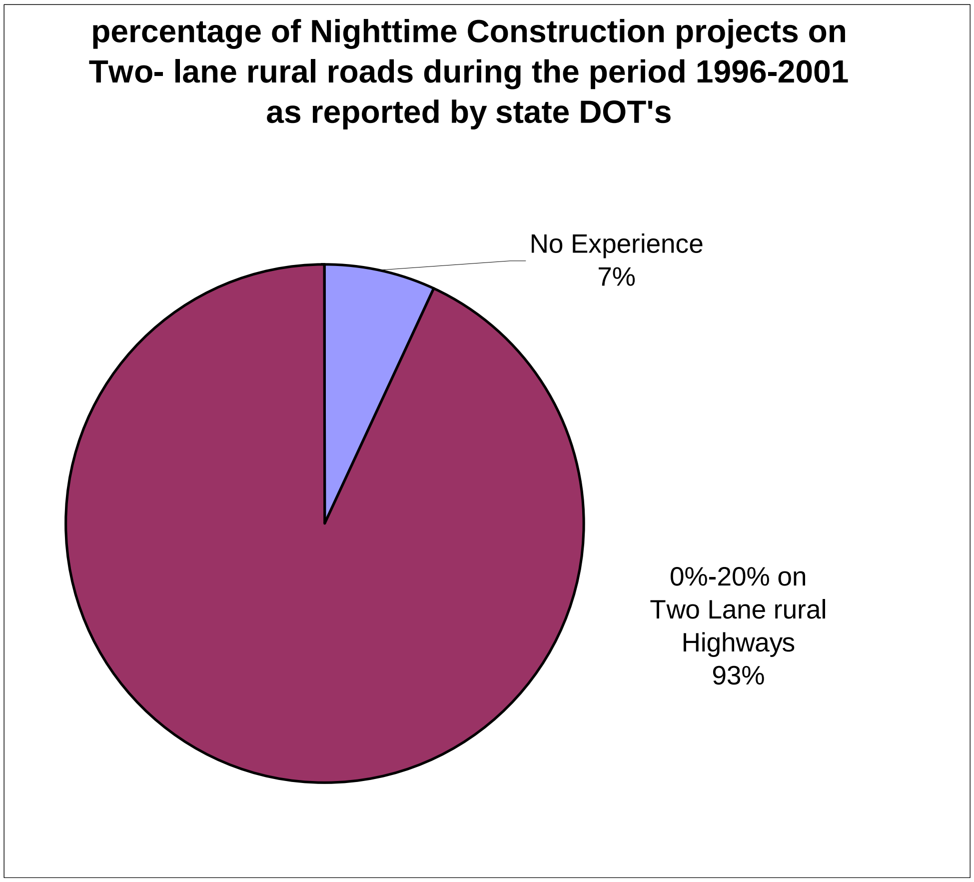


Figure 11. Percentage of Nighttime Construction Projects on Two-Lane Rural Roads During the Period 1996-2001 as Reported by State DOT's

3.1.1.3 Decision on Nighttime Construction

When asked about following specific procedures in deciding to use nighttime construction, eight of the respondent states (53.33%) reported the existence of such procedures. Other respondent states (46.67%) follow no formal procedures in making nighttime construction decisions. Further, only five of the eight states that follow such procedures stated that those procedures involve the estimation of road user costs. Those results are shown in Figure 12.

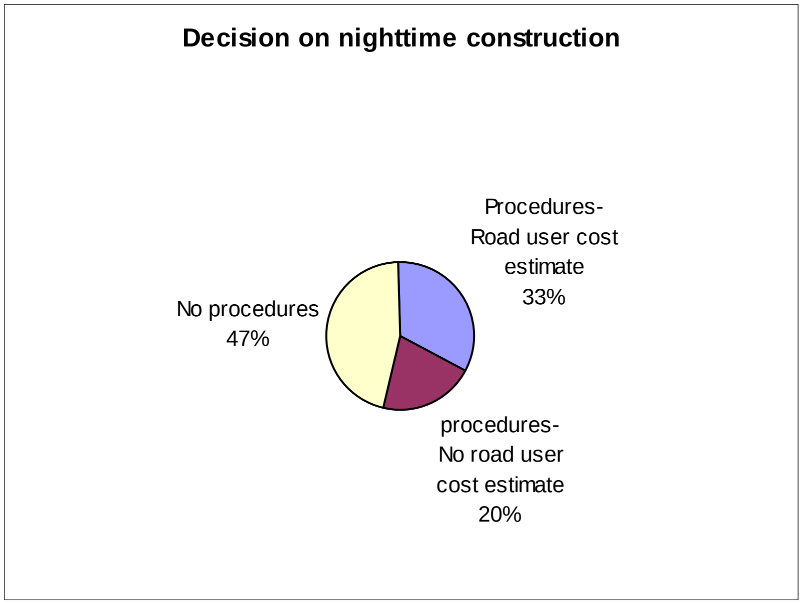


Figure 12. Decision on Nighttime Construction

The survey also asked State DOT's and IDOT Districts about the importance of the various factors that are believed to have a role in making the decision on nighttime construction. The results from state DOT's and IDOT districts surveys are shown in Figure 13 and Table 20.

The most important factor in making nighttime construction decisions as found by the two surveys is the significant daytime traffic that is avoided if work is performed during nighttime. The two surveys are also consistent concerning the importance of both traffic safety and workers safety (scored 4+ in the two surveys). Factors that are found less important (scored less than 3) mainly involve productivity, work quality, temperature, lighting issues, scheduling issues, and longer work hours. Most of these factors are concerned with the construction work at the site. Traffic control was found to have moderate importance in the two surveys (scored 3.8 by State DOT's and 3.55 by IDOT districts). Also, freedom in planning lane closures was found more important by the state DOT's survey as compared with IDOT districts survey.

Despite the relative consistency in the two surveys regarding nighttime decision factors, the ranking of factors by its importance was noticeably different.

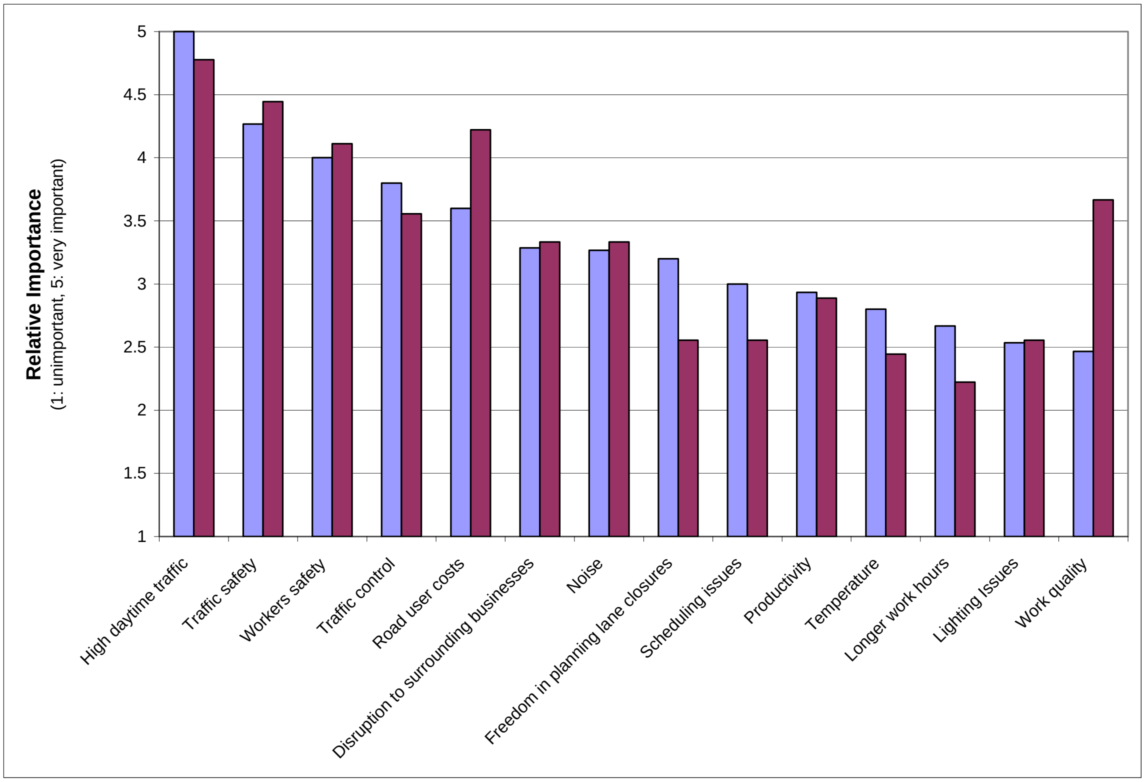


Figure 13. The Relative Importance of the Different Factors that Affect the Decision on Nighttime Construction as Reported by State DOT's and IDOT Districts

Table 20. The Relative Importance of the Different Factors that Affect the Decision on Nighttime Construction as Reported by IDOT Districts

Decision Factor	Rank by State DOT's	Score by State DOT's	Rank by IDOT Districts	Score by IDOT Districts
High daytime traffic	1	5	1	4.777
Traffic safety	2	4.267	2	4.444
Workers safety	3	4	4	4.111
Traffic control	4	3.8	6	3.555
Road user costs	5	3.6	3	4.222
Disruption to surrounding businesses	6	3.285	7	3.333
Noise	7	3.267	8	3.333
Freedom in planning lane closures	8	3.2	10	2.555
Scheduling issues	9	3	11	2.555
Productivity	10	2.933	9	2.888
Temperature	11	2.8	13	2.444
Longer work hours	12	2.667	14	2.222
Lighting Issues	13	2.533	12	2.555
Work quality	14	2.466	5	3.666
Average				

3.1.1.4 Advantages of Nighttime Construction

The relative significance of nighttime construction advantages as perceived by state DOT's and IDOT districts is illustrated in Figure 14. It is interesting to see the high degree of consistency in the perception of nighttime construction advantages as reported by state DOT's and IDOT districts. Specifically, the ratings of relative significance in the two surveys are very close for all the advantages with the exception of freedom to plan lane closures that was found more important by state DOT's.

The figure clearly shows that the most important advantage of nighttime construction is the significant reduction in congestion and delay for the traveling public that would otherwise incurred during daytime (scored 4.8 and 4.88 respectively). Minimizing impact on surrounding businesses was found to have moderate significance by the two groups of respondents (scored 3.53 and 3.44 respectively). As stated above, the greatest difference in the perceptions of the two groups was found in providing more freedom to plan lane closures. This advantage was found to have moderate significance by state DOT’s (scored 3.53) and much less significance by IDOT districts (scored 2.66). Finally, allowing longer work hours and reducing air pollution were perceived to have less significance than other nighttime construction advantages.

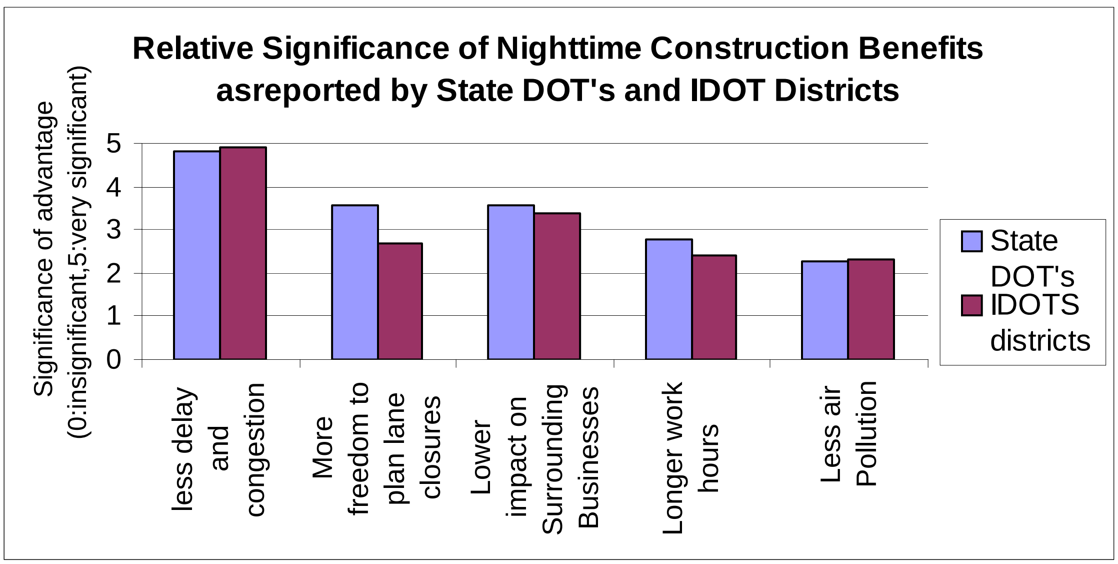


Figure 14. Relative Significance of Nighttime Construction Benefits as Reported by State DOT’s and IDOT Districts

3.1.1.5 Disadvantages of Nighttime Construction

The significance of the different concerns / disadvantages of nighttime construction as perceived by state DOT’s and IDOT districts is illustrated in Figure 15. Apparently, the impact of nighttime on visibility at work zones was found to be the most important concern by the two groups of respondents. Concerns that were found to have moderate significance by the two surveys involved traffic safety, workers safety, and higher construction costs (scores generally more than 3) while those that were found less significant by the two surveys involved materials variability, equipment maintenance, and scheduling problems. The figure also shows a smaller degree of consistency between the perceptions of the two groups when compared with nighttime construction advantages (presented in Figure 14). This is clearly evident from the significantly different rankings of the concerns perceived by the two groups as shown in Table 21.

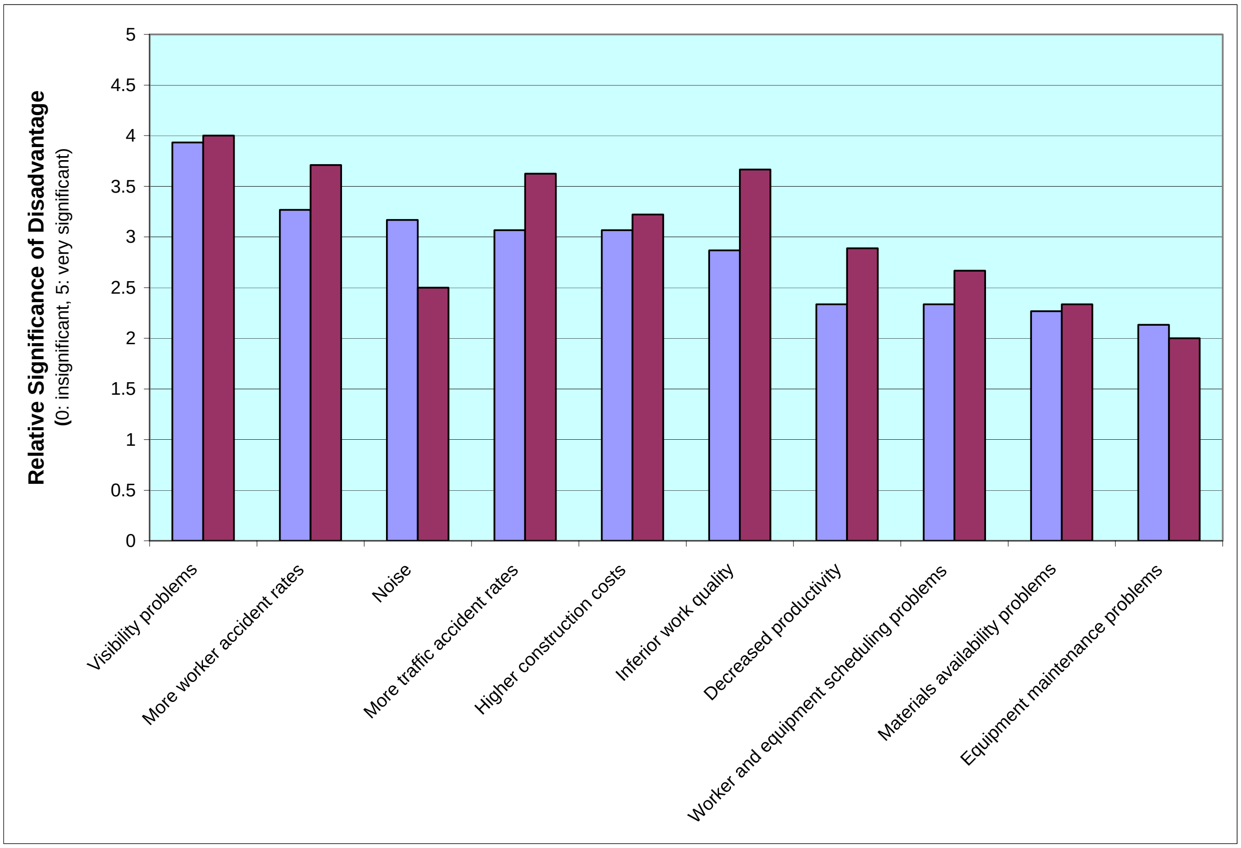


Figure 15. Relative Significance of Nighttime Construction Disadvantages as Reported by State DOT's and IDOT Districts

Table 21. Ranking of Nighttime Construction Disadvantages as Perceived by State DOT's and IDOT Districts

Concern / Disadvantage	Rank by State DOT's	Score by State DOT's	Rank by IDOT Districts	Score by IDOT Districts
Visibility problems	1	3.9333	1	4
More worker accident rates	2	3.2666	2	3.7142
Noise	3	3.1666	8	2.5
More traffic accident rates	4	3.0666	4	3.625
Higher construction costs	5	3.0666	5	3.2222
Inferior work quality	6	2.8666	3	3.6666
Decreased productivity	7	2.3333	6	2.8888
Worker and equipment scheduling problems	8	2.3333	7	2.6666
Materials availability problems	9	2.2666	9	2.3333
Equipment maintenance problems	10	2.1333	10	2
Average		2.84328		3.06167

One important observation here is that state DOT's view construction-related factors (concerns) as less important than other factors such as traffic and workers safety and the impact of noise on residential areas. On the other hand, IDOT districts placed more weight on construction-related factors and did not perceive the impact of noise as an important concern. To some extent, this observation sounds both expected and logical due to the different nature of work for people who work in state DOT's headquarters and those who work at the districts of a state DOT. Generally speaking, the first group is more involved in policies and planning while the second group is more involved in construction-related details. Finally, in comparing the relative ratings between the two groups, one should take into account the difference in the average relative weights as reported by the two groups.

3.1.2 Construction Related Issues

A number of construction-related questions were included in the survey. These questions addressed issues like cost associated with nighttime construction, suitability of certain construction and maintenance operations for nighttime work, quality and production rates of nighttime construction. The findings of these questions are summarized below.

3.1.2.1 Costs Associated with Nighttime Construction

There seems to be a high degree of agreement among Illinois DOT districts about the extra cost associated with nighttime construction. IDOT districts and state DOTs were asked about how the cost of nighttime jobs compare to similar daytime jobs. Most of the districts that responded to this question (78%) agreed that nighttime construction costs are zero to twenty five percent more than similar daytime jobs. There also seems to be a general agreement between all the surveyed state DOTs regarding the cost increase of nighttime jobs. All the state DOTs that responded (14 of 16) also indicated a zero to twenty five percent increase in construction costs (with the exception of Iowa, which indicated costs as being the same for daytime and nighttime jobs). Figure 16 shows the combined (states and IDOT districts) results. The figure exhibits a uniform agreement among the IDOT districts and other state DOTs about the amount of cost increase in nighttime construction.

It was clear from the literature review that two of the main reasons for the increase in costs of nighttime jobs are the extra lighting requirements and the increase in administrative costs (due partially to extra compensation for working during nighttime). There also seemed to be an agreement between the IDOT districts and the surveyed state DOTs regarding the increase in administrative costs as well. Half of the respondents indicated an increase of zero to twenty five percent in administrative costs due to nighttime construction (Figure 17). Furthermore, although 33% of the respondents showed no cost differential in administrative costs between daytime and nighttime, Minnesota indicated a larger increase in administrative costs that is between 25% and 50%. One of the reasons for increase in administrative costs is extra compensation for nighttime supervision personnel.

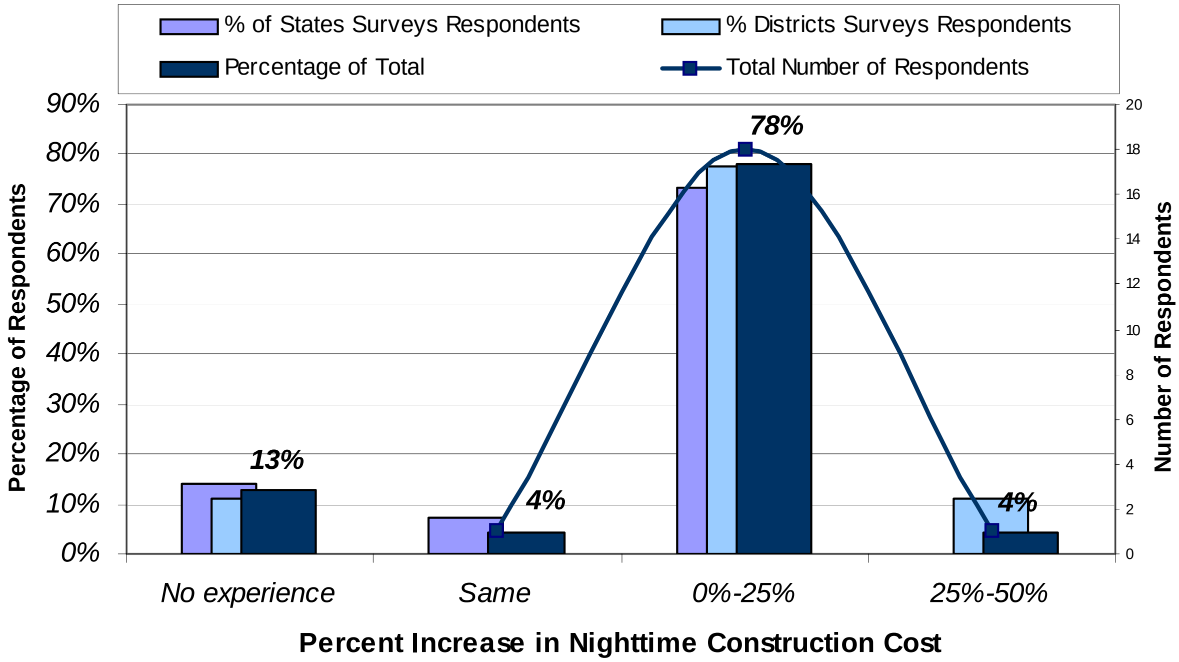


Figure 16. Increase in Construction Cost of Nighttime Construction

The survey also showed that half of the IDOT districts and the survey states do provide extra compensation for nighttime construction supervision personnel (Figure 18). The majority (78%) of the states surveyed do not provide this extra compensation. In Illinois, however, most of the districts survey indicated that they do provide extra compensation for nighttime supervision personnel.

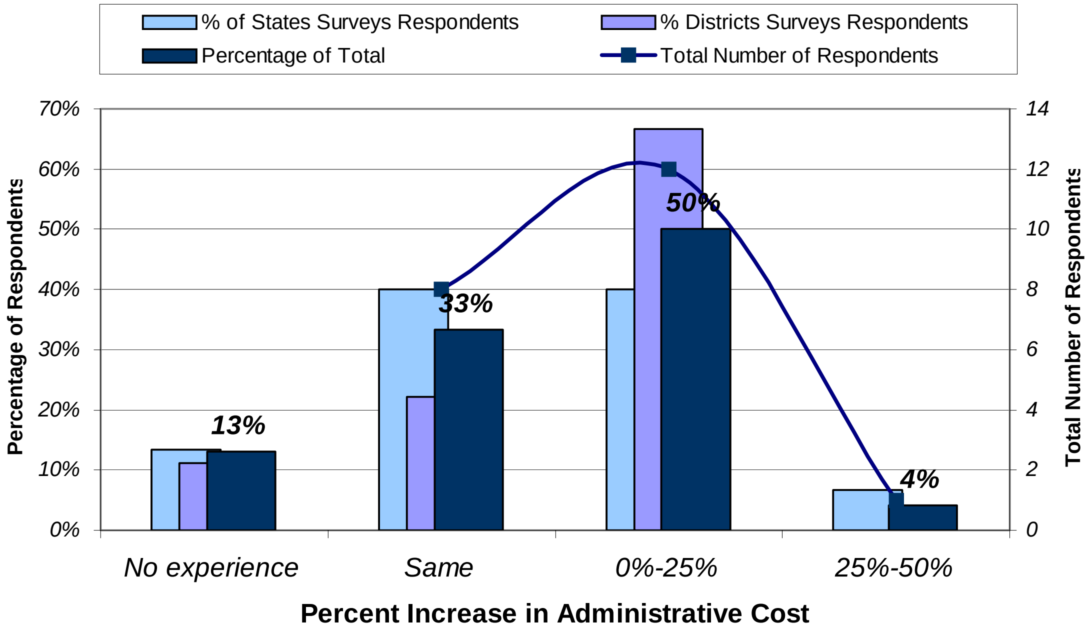


Figure 17. Increase in Administrative Costs of Nighttime Construction

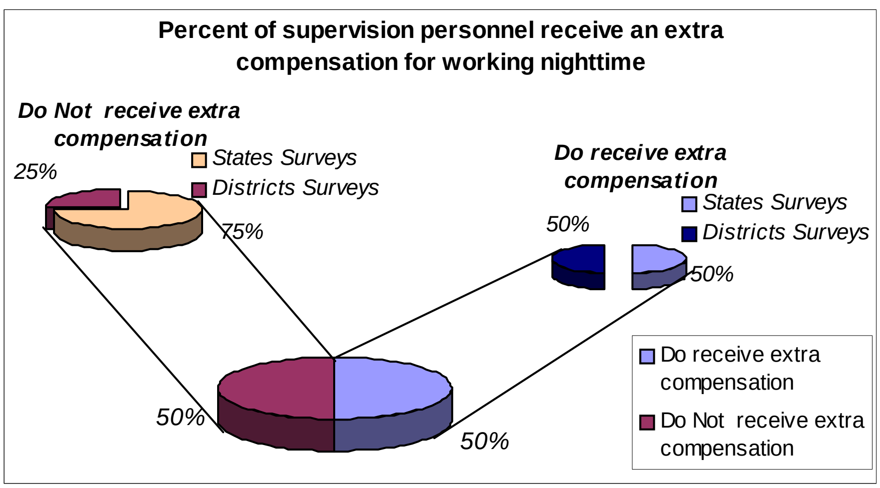


Figure 18. Extra Compensation for Nighttime Supervision Personnel

A suggestion by one of the respondents that pertains to cost, is that nighttime pay items should be bid separately. Nighttime pay items may include things like lighting equipment and additional traffic control. Bidding nighttime line items separately might result in more accurate (and possibly lower) bids. In addition it would also provide a more efficient way of tracking extra costs associated with nighttime construction.

3.1.2.2 Contracting Method

State DOTs and IDOT districts were also asked to rate a number of contracting methods in terms of suitability for nighttime construction (1 = Completely unsuited to 5 = Perfectly suited). The results are shown in Table 22 and Figure 19. The top three choices were the traditional contracting method, the lane rental method and A+B contracting. IDOT district engineers chose Lane rental contracting as the most suitable method by the scoring 4.29 (out of 5.00), while the surveyed state DOTs chose the traditional method as the most suited. The lane rental method is an innovative contracting technique by which a contractor is charged a fee for occupying lanes or shoulders to do the work. The A+B is essentially a cost plus time bidding procedure that selects the low bidder based on a monetary combination of the contract bid items (A) and the time (B) needed to complete the critical portion of the project. It is important to take note of the percentage of respondents who indicated no experience while examining the suitability score given for each contracting method. The percentage provides additional insight to the data. For example, while Job Order contracting was given a high score by state DOTs, a high percentage of the respondents (71%) indicated no experience with this contracting method. This shows that although this contracting method had not been used very often, it was perceived as being successful in the few instances in which it was actually used.

Table 22. Building Delivery Methods for Nighttime Construction

Rank	*Contracting Method*	States Average	States No experience	Districts Average	Districts No experience	Totals Total Weighted Average	Totals Percent "No Experience"
1	Traditional	4.33	0.00	4.11	0.00	4.25	0%
2	Lane Rental	4.13	7.00	4.29	2.00	4.19	38%
3	A+B	4.31	2.00	3.75	5.00	4.10	29%
4	Warranty Contracting	4.33	9.00	3.00	5.00	3.83	58%
5	Job Order Contracting	4.33	12.00	2.25	5.00	3.55	71%
6	Design Build	4.00	6.00	0.00	9.00	2.50	63%

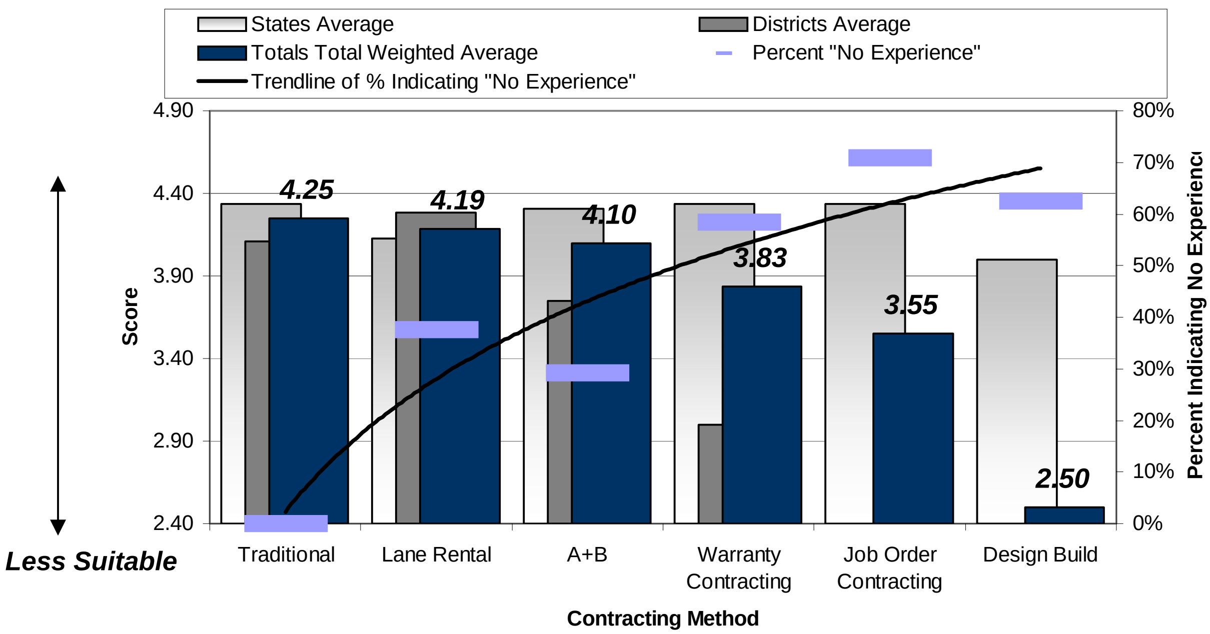


Figure 19. Suitability of The Different Contracting Methods For Nighttime Construction

3.1.2.3 Quality of Nighttime Construction Compared to Daytime

From the literature review it was clear that the majority of the previous research indicated that the quality of nighttime construction projects is comparable to that of daytime project, a finding verified by the survey. The respondents were asked to rate the quality of nighttime construction projects they worked on in comparison to similar projects that were performed during daytime. Figure 20 shows the results of this question. More than half of the respondents (54%) found the quality of nighttime construction projects to be similar to that of the daytime projects. The other half, on the other hand, were almost split with 17% indicating a loss in quality in nighttime projects and 13% indicating an improvement. The results again are fairly uniform indicating that generally the quality of nighttime projects is similar to that of daytime.

One of the main reasons for this finding is that both daytime and nighttime projects still have to meet the same quality specifications regardless of when the work was done. This fact was emphasized in the literature and was mentioned by some respondents.

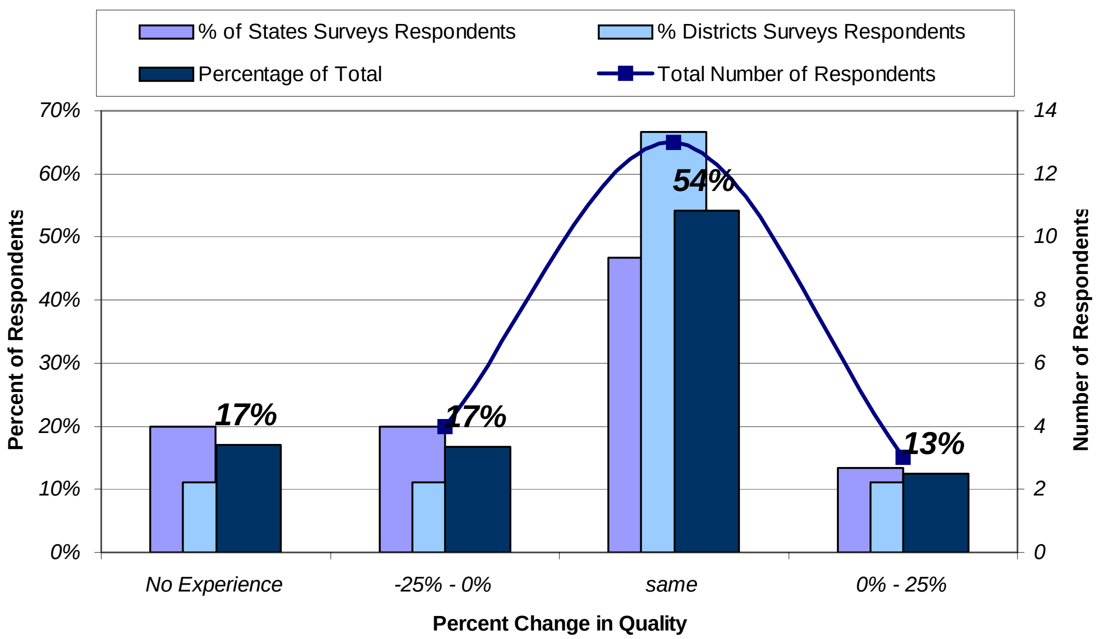


Figure 20. Nighttime Construction Quality

3.1.2.4 Production Rates of Nighttime Construction Compared to Daytime

A question in the survey asked the respondents to compare the production rates of nighttime jobs to similar daytime jobs. The results are shown in Figure 21. The results show that the opinion on the effect of nighttime construction on the production rates among the respondents varies widely. The production rates of nighttime construction were found to be anywhere between 50% more than that of similar daytime jobs to 25% less than that of daytime jobs. This may be due to the fact the every job has a unique set of constraints and characteristics that significantly impact the production rates. If the same daytime job were to be done at night, a number of factors would affect the production rates. The amount of nighttime traffic, the availability and closeness of the plant, the amount of lighting, the bio-rhythmic cycles of the crew, are all factors that affect the production rates of nighttime jobs.

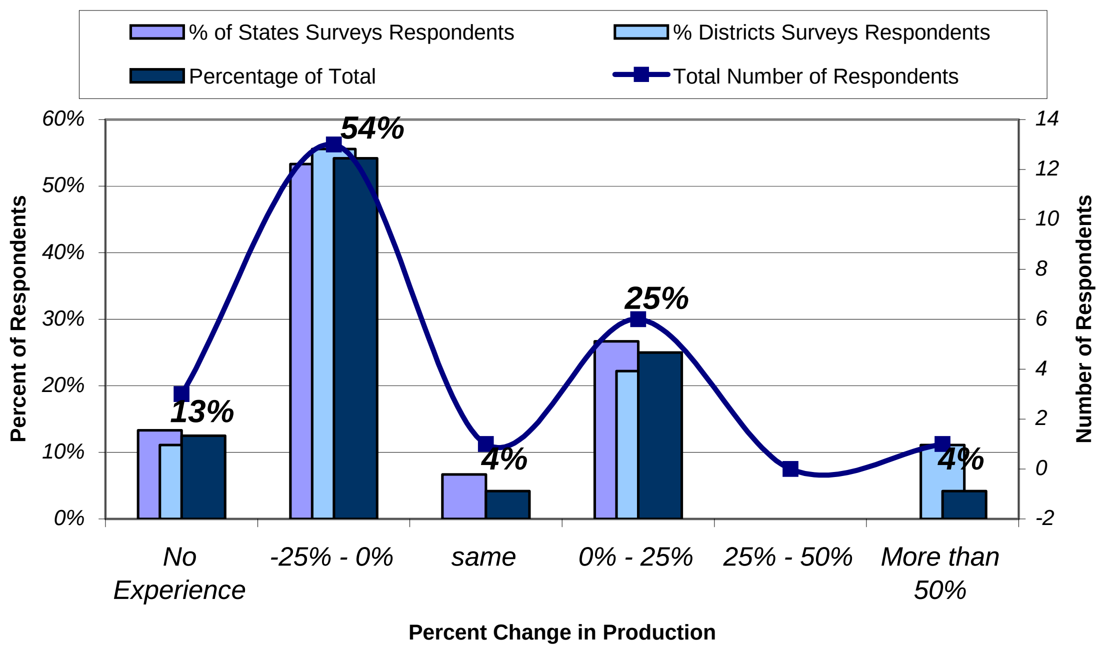


Figure 21. Production Rates of Nighttime Construction

3.1.2.5 Suitability of Specific Operations

Some construction activities are more suitable to be performed at night than others, due to many factors including visibility requirements, e.g. impact of traffic on the activity and availability of material delivery. A list of 18 construction activities and 16 maintenance activities were identified and the respondents were asked to rate accordingly. Construction of bituminous surfaces, concrete sawing and shoulder work were rated the top three most suitable construction activities. Repair of concrete pavement, milling and removal, and resurfacing were the top three most suitable maintenance activities. The results are shown in the following tables and figures.

Table 23. Suitability of Nighttime Construction Activities

		States		Districts		Totals	
Rank	***Construction Activities***	Average	Number with No experience	Average	Number with No experience	Weighted Average	% with No experience
1	Construction of bituminous surfaces and pavements	4.00	0	4.00	1	4.00	4%
2	Concrete sawing	4.13	0	3.63	1	3.94	4%
3	Shoulders: bituminous and Portland cement concrete	3.80	0	3.75	1	3.78	4%
4	Work traffic control	3.80	0	3.38	1	3.64	4%
5	Bridge Construction	3.86	1	3.14	2	3.59	13%
6	Sub-base and Base course	3.38	2	3.50	1	3.43	13%
7	Pavement marking: striping and markers	3.47	0	3.00	1	3.29	4%
8	Highway signing	3.57	1	2.67	3	3.23	17%
9	Electrical poles and posts: lighting/traffic signals	3.21	1	3.25	1	3.23	8%
10	Concrete pavement and sidewalks	3.21	1	3.17	3	3.20	17%
11	Electrical wiring and cables	3.46	2	2.63	1	3.15	13%
12	Sub-grade	3.23	2	2.88	1	3.10	13%
13	Earthwork: excavation/embankment/backfill	3.14	1	2.75	1	3.00	8%
14	Drainage structures	3.15	2	2.17	3	2.78	21%
15	Guardrail and fences	2.92	2	2.50	3	2.76	21%
16	Culverts and sewers	3.15	2	2.00	3	2.72	21%
17	Erosion control: riprap/ditch lining	2.27	4	2.00	3	2.17	29%
18	Landscaping: seeding/mulch/sodding/planting	1.82	4	2.00	3	1.89	29%
	OVERALL AVERAGE	***3.31***		***2.91***		***3.16***	

Table 24. Suitability of Nighttime Maintenance Activities

		States		Districts		Totals	
Rank	***Maintenance Activities***	Average	Number with No Experience	Average	Number with No Experience	Weighted Average	% with No Experience
1	Repair of concrete pavement	4.27	4	4.38	1	4.31	21%
2	Milling and Removal	4.36	4	3.88	1	4.18	21%
3	Resurfacing	4.27	4	3.75	1	4.08	21%
4	Pot Hole Filling	4.27	4	3.29	2	3.90	25%
5	Bridge Decks Rehabilitation and Maintenance	4.20	5	3.29	2	3.86	29%
6	Crack Filling	3.89	6	2.57	2	3.39	33%
7	Waterproofing/Sealing	4.13	7	2.00	5	3.33	50%
8	Sweeping and cleanup	3.20	5	3.14	1	3.18	25%
9	Surface Treatment	3.38	7	2.50	5	3.05	50%
10	Reworking Shoulders	3.00	6	2.83	3	2.94	38%
11	Drainage structures maintenance & rehabilitation	2.30	5	2.67	3	2.44	33%
12	Maintenance of Earthwork/Embankment	2.67	6	1.20	4	2.12	42%
13	Sidewalks repair & Maintenance	2.22	6	1.00	5	1.76	46%
	OVERALL AVERAGE	***3.55***		***2.81***		***3.27***	

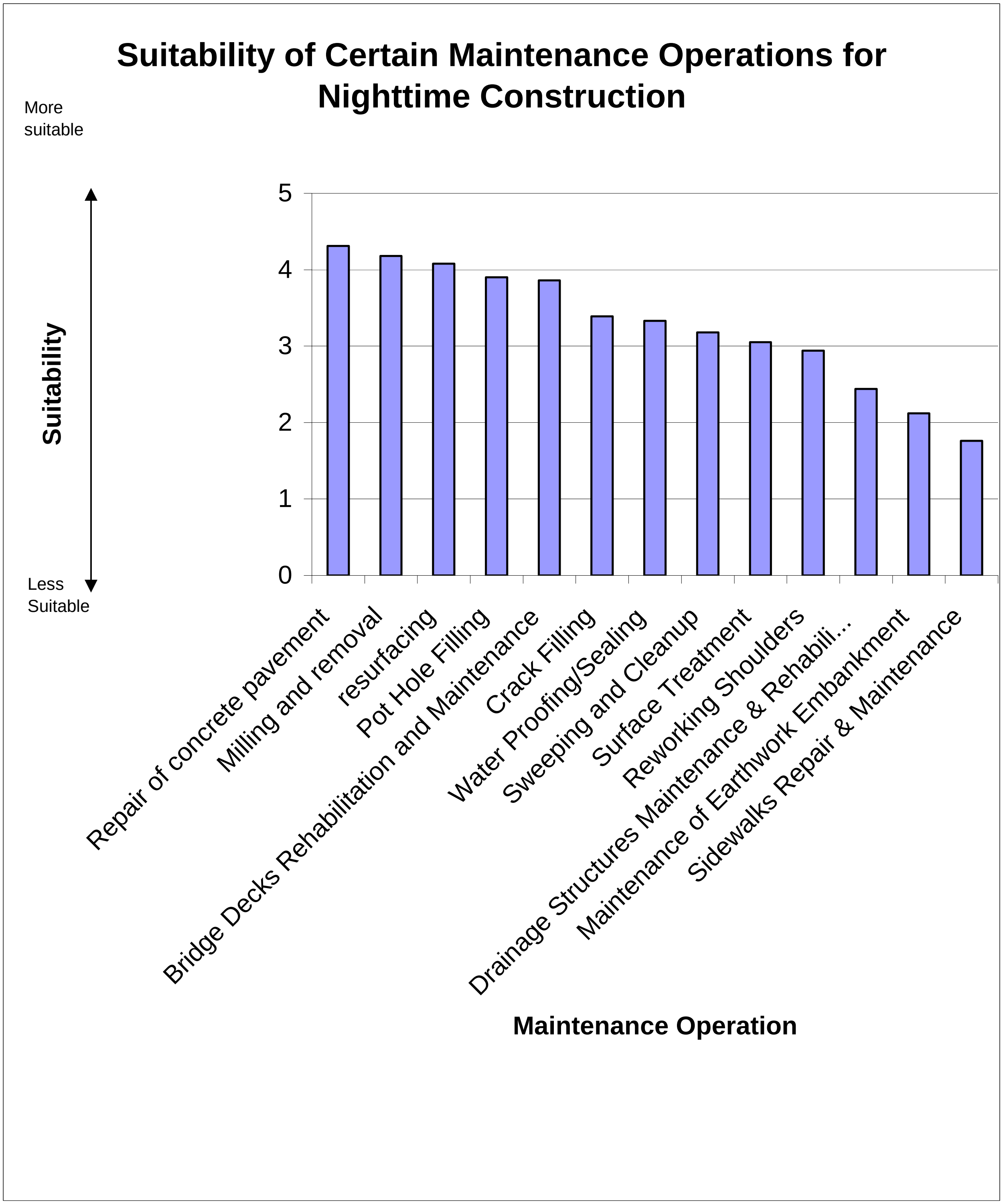


Figure 22. Suitability of Certain Maintenance Operations for Nighttime Construction

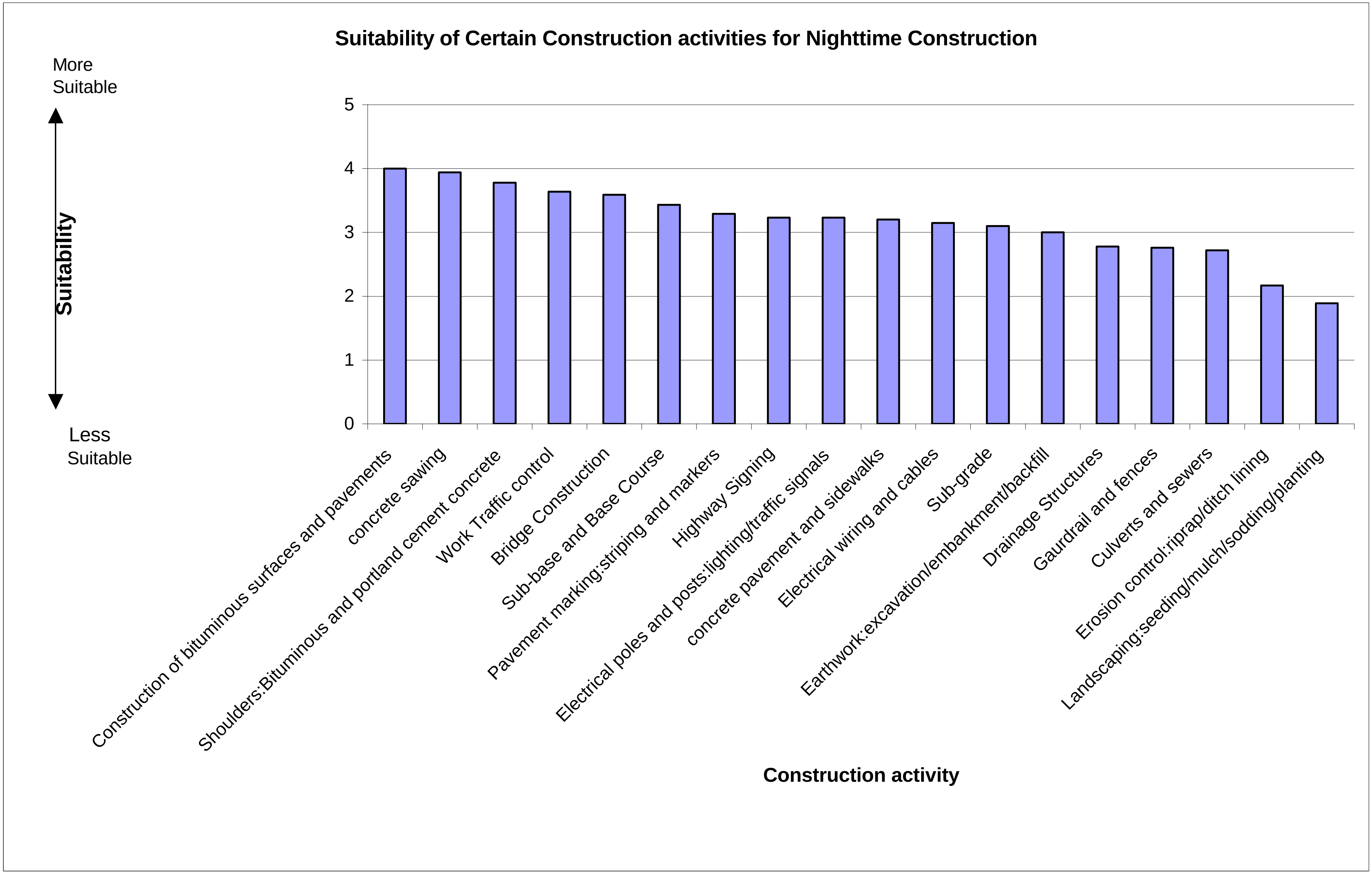


Figure 23. Suitability of Certain Construction Activities for Nighttime Construction

3.1.3 Traffic-Related Issues

3.1.3.1 Estimating Delay and Congestion at Work Zones

An important consideration in conducting highway construction during nighttime is the significant delay incurred by the traveling public if work is conducted during daytime hours. Also, delay represents a main component of road user costs and therefore has an important role in determining the feasibility of nighttime construction. Figure 24 shows the different techniques used by state DOT's in estimating delay and congestion at work zones. Eleven out of the fifteen respondent states (73.33%) reported that they normally estimate delay and congestion in making the decision on nighttime construction while the other four states (26.67%) do not perform this estimate. Five of the 11 states that perform this estimate (33.33% of respondents) use manual simple queuing analysis while the other six states (40% of respondents) use software to perform this analysis. This figure also shows the percentage of respondent states that utilize QUEWZ (20% - 3 states), QuickZone (13.33% - two states) or other software (6.67% - 1 state).

Two important observations can be drawn from this figure. The first is the relatively significant number of states that do not estimate delay to the traveling public as part of their decisions on nighttime construction. The second observation is that almost half the states that perform this estimate still use manual analyses which normally tend to be less accurate and more time consuming.

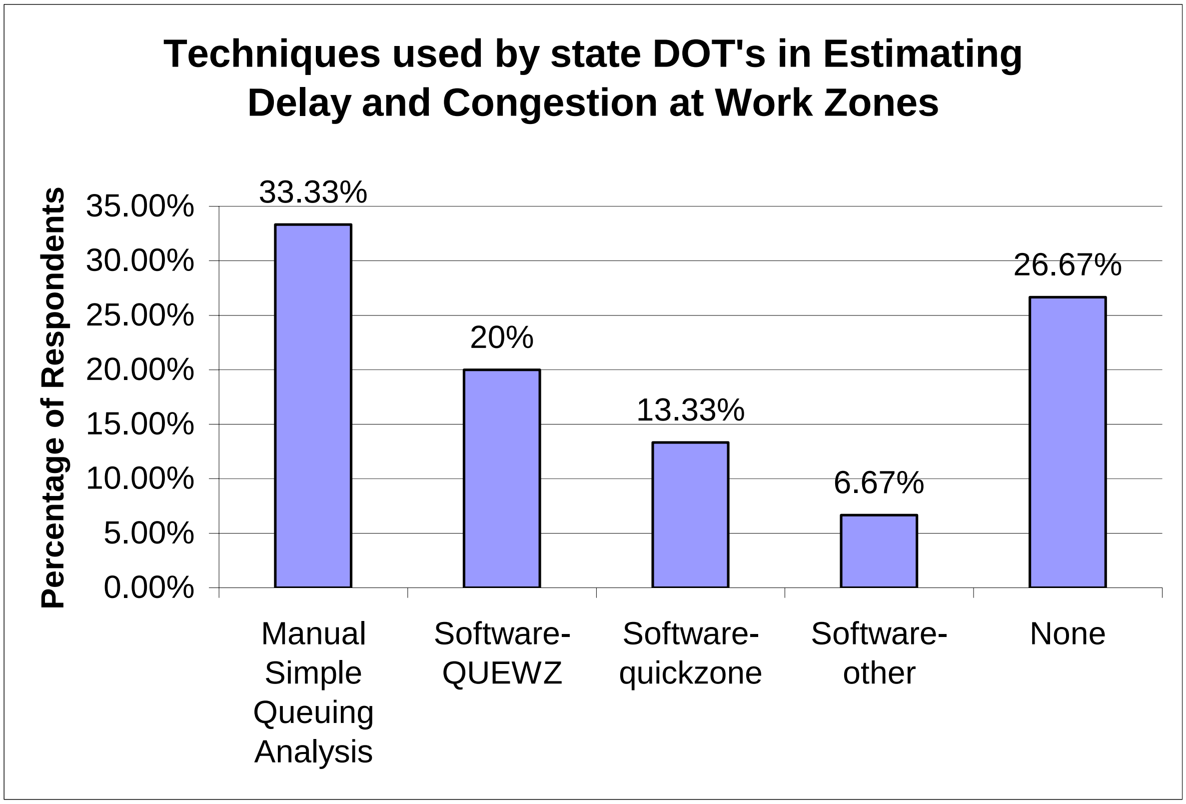


Figure 24. Techniques Used by State DOT's in Estimating Delay and Congestion at Work Zones

When asked about the accuracy of estimating delay and congestion, only three states reported that the estimate is inaccurate while the other twelve states reported otherwise. Specifically, only three states (20% of responding states) find delay estimates accurate and the remaining nine states (59% of responding states) find it somewhat accurate. This indicates the general satisfaction of state DOT's with the existing delay estimate techniques. However, a few states answered this question though they reported that they do not normally estimate delay and congestion in making decisions on nighttime construction. Figure 25 shows the breakdown of the state DOT's responses.

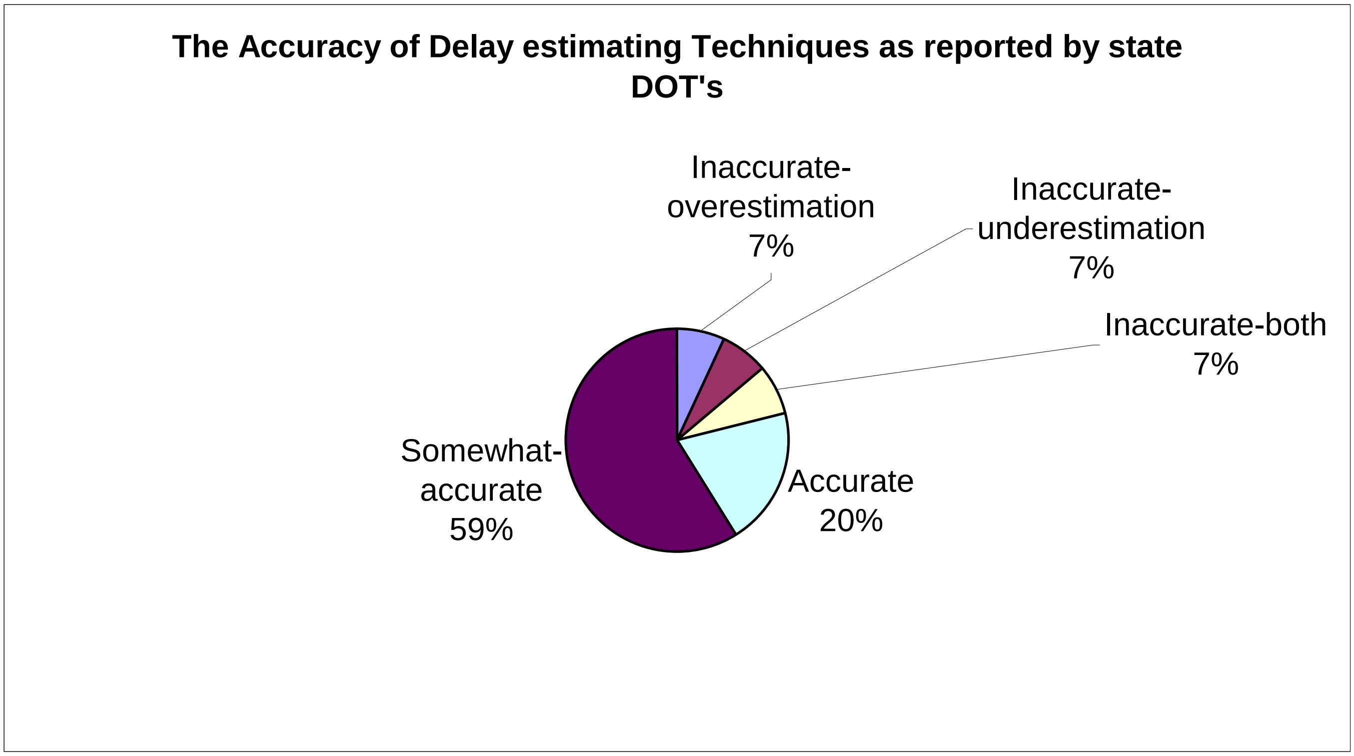


Figure 25. The Accuracy of Delay Estimating Techniques as Reported by State DOT's

3.1.3.2 Traffic Control at Work Zones

One of the nighttime construction challenges is to devise traffic control plans at work zones that maintain safety for the traveling public and construction crews despite the deterioration in visibility levels during nighttime. Therefore, extra provisions to compensate for inferior visibility are expected to be part of nighttime construction traffic control plans, and as such, traffic control plans during nighttime are very likely to involve extra cost as compared with daytime plans.

Most of the states that responded to the survey (13 out of 15) reported that nighttime traffic control plans at work zones involve extra cost when compared with daytime plans. Also, the majority of these states (73.3%) estimated the extra cost to be in the range of 0% to 20%. The responses to this question by state DOT's are provided in Figure 26.

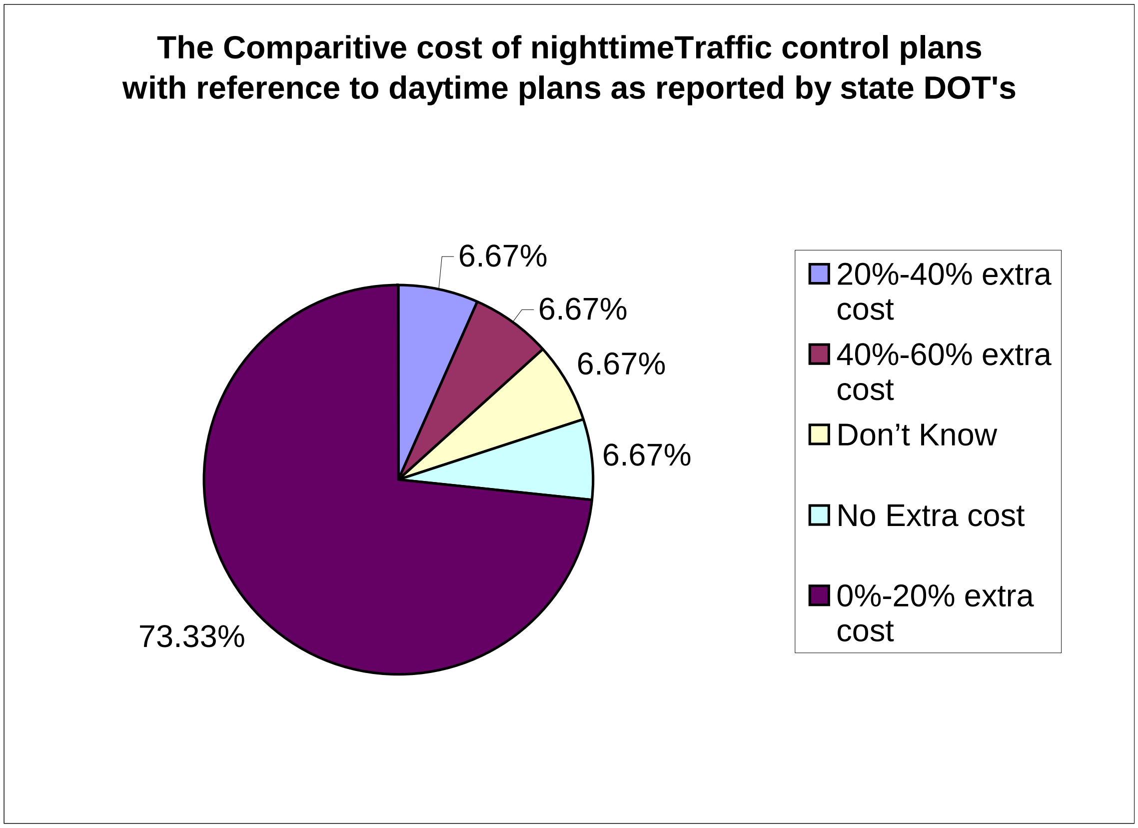


Figure 26. The Comparative Cost of Nighttime Traffic Control Plans with Reference to Daytime Plans as Reported by State DOT’s

As for preparing temporary traffic control plans at work zones, state DOT’s were asked whether these plans are prepared by the agency, the contractor, or jointly between agency and contractors. The responses are summarized in Figure 27. As shown in this figure, more than half of the respondents (53.3% - 8 states) reported that traffic control plans are prepared by their agencies. A much lower percentage (26.67% - 4 states) reported that traffic control plans are prepared jointly between the contractor and the agency. The remaining three states provided different answers as shown in this figure.

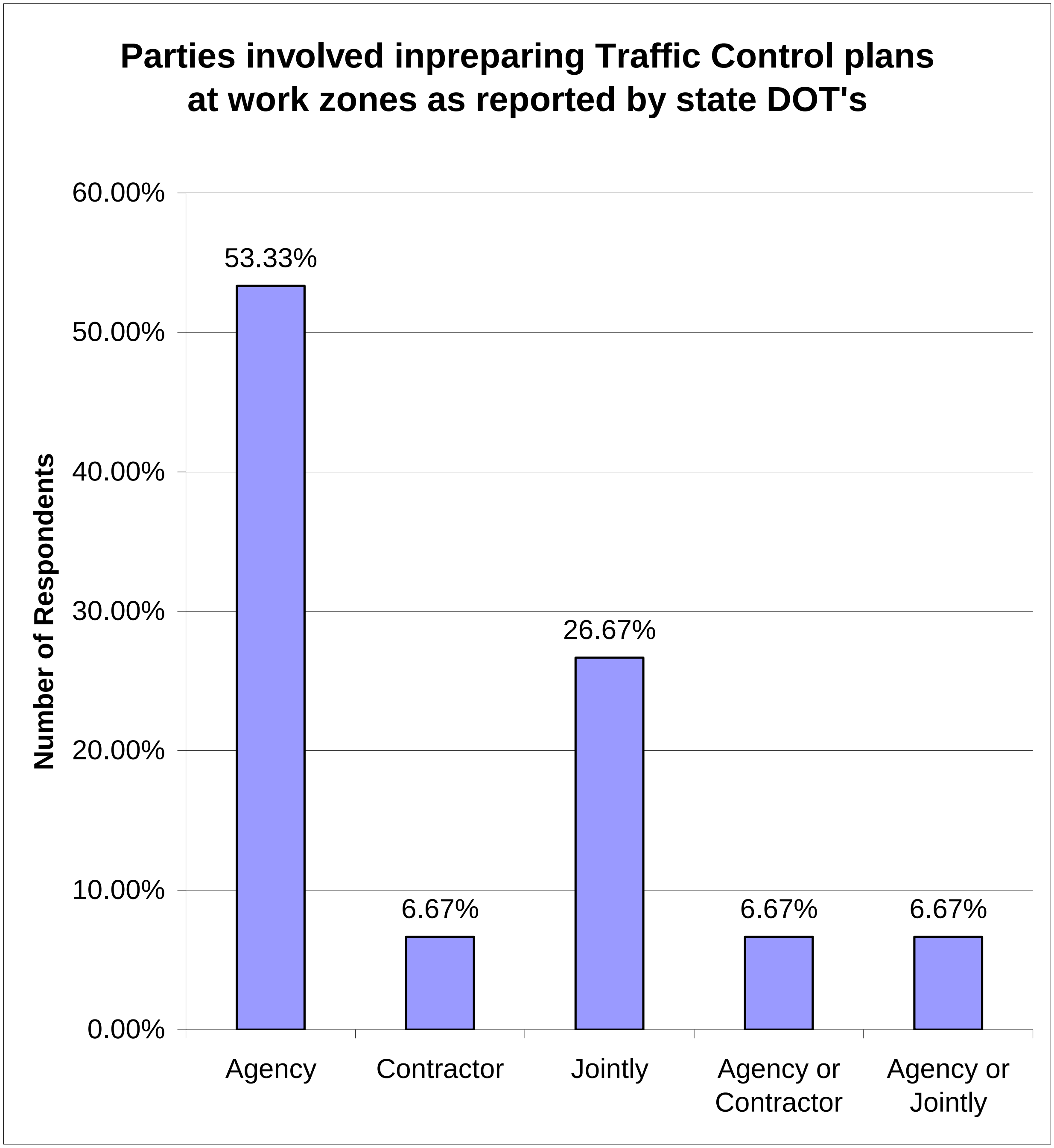


Figure 27. Parties Involved in Preparing Traffic Control Plans at Work Zones as Reported by State DOT's

3.1.4 Social, Economic, and Environmental Issues

The two surveys for state DOT's and IDOT districts asked one question about the social, economic, and environmental impacts. Specifically, the question asked survey participants whether their agencies assess the impact of noise on surrounding residential areas, the impact on surrounding businesses, air pollution / energy conservation, and light trespassing. Figure 13 shows these impacts as reported by state DOT's. As clearly shown in this figure, impacts on surrounding communities and businesses are perceived to have more importance by state DOT's than environmental impacts such as air pollution and energy conservation. Though state DOT's are more qualified to answer such questions as they are more involved in the general policies of those agencies, very similar trends were obtained from IDOT districts as shown in Figure 28.

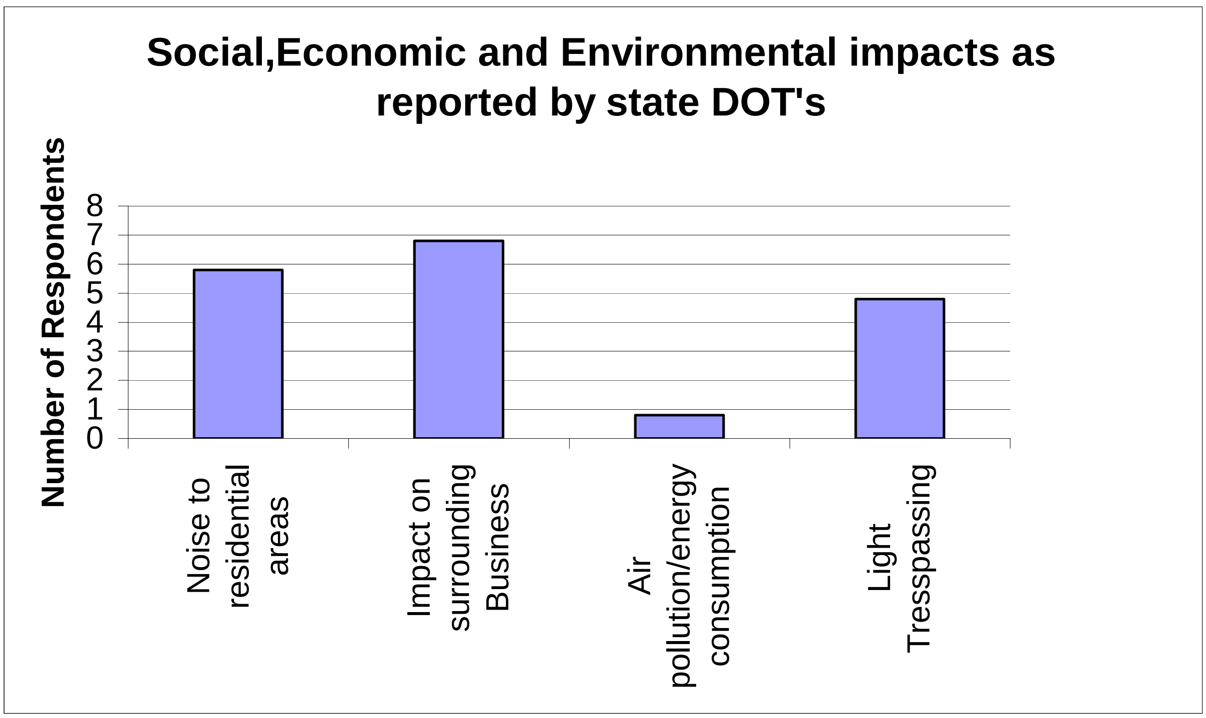


Figure 28. Social, Economic, and Environmental Impacts as Reported by State DOT's

3.1.5 State DOTs & IDOT Districts Surveys: Summary of Findings

The most important findings are summarized below:

- Nighttime construction operations still constitute a small percentage of highway construction projects. Also, the use of dual shifts in highway projects is relatively more common than nighttime shifts alone. Further, it was found that nighttime construction projects are less common on two-lane rural roads (0%-20% of nighttime projects).
- Half of the respondent states do not follow any formal procedures in making nighttime construction decisions. The most important factor in making these decisions by state DOT's is avoiding daytime traffic, followed by traffic safety and workers safety. The results suggest that construction-related factors such as work quality and productivity have less importance in making these decisions.
- Consistent with the previous finding, the most important advantage as perceived by state DOT's is reducing delay and congestion. On the other hand, deterioration in visibility during nighttime was found to be the most important concern of nighttime operations.
- The traditional contracting and lane rental methods were found most suitable for nighttime construction projects.
- Construction costs and administrative costs are generally higher during nighttime. The extra cost is in the range 0% to 25%.
- Research results suggest that production rates are slightly impacted during nighttime. However, while this may apply to most construction and maintenance activities, it seems that it does not apply to some other activities. Also, these results suggest that work quality in nighttime jobs is comparable to that of daytime jobs.
- Some construction and maintenance activities were found more suitable for nighttime operations than others. Construction of bituminous surfaces and pavements, concrete sawing and the shoulder work were the top three

construction activities. On the other hand, repair of concrete pavement, milling and removal, and resurfacing were the top three maintenance activities.

- Only 50% of the responding states reported that they normally estimate delay and congestion in making decisions on nighttime construction. The use of manual queuing analysis was reported by 33% of the responding states while the use of software was reported by 28% of the responding states.
- Traffic control plans during nighttime were found to involve extra cost in comparison with daytime plans (most states reported 0%-20% extra cost). These plans are prepared by highway agencies in most of highway construction projects. However, some states may cooperate with the contractor in preparing these plans or require contractors to prepare the plans, depending on the circumstances.
- Among the social, economic, and environmental factors, impacts on surrounding communities and businesses are perceived to have more importance than environmental impacts such as air pollution and energy conservation.

3.2 IDOT Contractors Survey: Introduction

This survey involved a questionnaire to IDOT contractors that included many of the nighttime construction issues that are most related to contractors such as; construction cost, productivity, quality, social and physical impacts, etc. These issues were identified from the state-of-the-art review, the previous two surveys (State DOTs & IDOT resident engineers), or from discussions with the TRP review panel. The questionnaire was prepared in coordination with the ITRC Technical Review Panel (TRP), sent out to participants, and returned surveys were processed and analyzed.

3.2.1 Study Sample

The research team obtained a list of contractors from the IDOT TRP panel. This list involved 89 construction companies who worked for IDOT and are located in the state of Illinois. Multiple copies were sent to each contractor to get input from people at different projects. The total number of contractors who responded to the questionnaire was 27 while the total number of surveys received was 31. This indicates a return rate of 30.4%, which is considered within our expectation. It is important to mention that five of the contractors who responded to this questionnaire provided no information, as they have not been involved in nighttime construction projects.

3.2.2 Survey Description

As mentioned earlier, this survey questionnaire involved many issues that were identified from the literature search, results from the previous two surveys, or from discussions with the project TRP. The issues were organized in four different sections. The first section involved questions about the nighttime construction practice from the contractors' perspective. Specifically, three questions were included in this section soliciting information about contractors' preference of work shift by time, their experience and perception of nighttime construction advantages and disadvantages, and the suitability of different contracting methods for nighttime projects.

The second section involved questions related to a very important construction variable; that is construction cost. The extra line items for nighttime projects and cost differential between nighttime and daytime projects were investigated in this section. The differential costs were split into those associated with equipment and materials cost, and those related to labor, personnel and supervision. Also, these cost differentials are provided for different highway maintenance activities.

Issues related to construction quality and productivity were addressed in the third section of the questionnaire. This section involved questions about the contractors experience and perception of quality and productivity in nighttime projects. Similar to cost differential, the comparative answer to each question is provided for different work activities.

Finally, the last section of the questionnaire involved questions about some social and physical aspects of nighttime work. A copy of the survey questionnaire is provided in appendix C.

3.2.3 Survey Results

Survey results are discussed for each individual section and presented in the same sequence it appears in the questionnaire. These results are included in the following sections.

3.2.3.1 Nighttime Construction Practice

3.2.3.1.1 <u>Preference by Shift Type</u>

The contractors were asked about their preference of shift type by time in conducting highway maintenance and construction projects. The results of this question are shown in Table 25.

Table 25. Contractors Preference by Type of Work Shift

Shift Type	Preference (1=least preferred, 5=most preferred)					No Experience	No Answer
	1	2	3	4	5		
Day Shift	0	0	0	4	24	0	3
Night Shift	13	8	4	0	0	3	3
Dual Shift	8	5	8	0	0	5	5

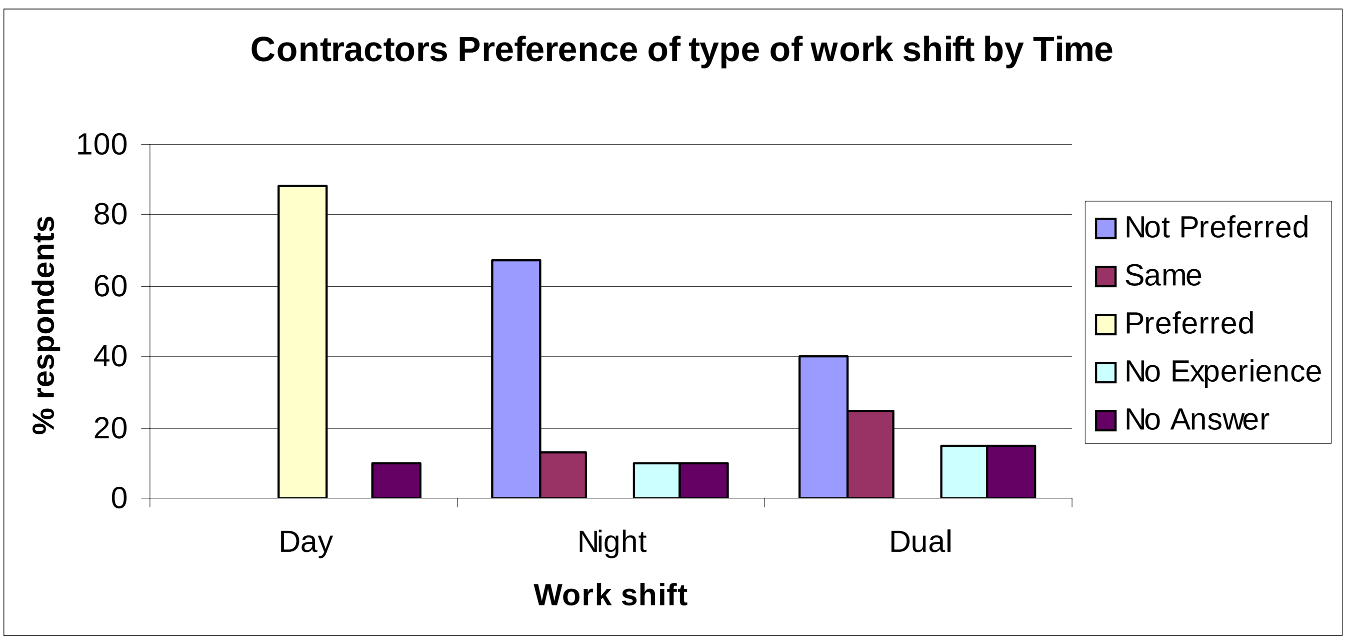


Figure 29. Contractors' Preference of Type of Work Shift by Time

Results from Table 25 were rearranged into three categories; preferred (4 and 5), same (3), and not preferred (1 and 2) and plotted as shown in Figure 29.

It is clear that all contractors surveyed prefer daytime work shift over other shifts. Also, Table 25 and Figure 29 both show that no contractor prefers night or dual shifts (scores 4 & 5 in the table). Further, night shift was found to be the least preferred shift by contractors (as compared with day and dual shifts). Results also show that only a small number of contractors are indifferent about performing work during night or dual shifts. Specifically, four out of thirty one respondents reported that they view no merit of day shifts over night shifts or vice versa while a larger number (eight respondents) reported the same in comparing dual shifts with day shifts. One other observation is that while no contractor reported having no experience in daytime shifts, three contractors reported no experience with nighttime shifts versus five contractors with dual shifts. These responses may reflect, to a large extent, the contractors' perception of the merits and demerits of nighttime projects that are discussed in the following section.

3.2.3.1.2 Advantages & Disadvantages of Nighttime Construction

The contractors surveyed were asked about their perceptions of the advantages/ disadvantages of nighttime work as related to the various aspects of highway construction work. The results of this investigation are provided in Table 26. These score results are rearranged using three qualitative categories (advantageous, disadvantages, and same) and plotted as illustrated in Figure 30.

Table 26. The Merit / Demerit of Nighttime Work for Different Work Aspect

Nighttime Work Aspect	Merit (1=Very Disadvantageous, 5=Very Advantageous)					No Experience	No Answer
	1	2	3	4	5		
Length of work hours	7	6	15	0	0	0	3
Impact on surrounding businesses	2	0	8	12	6	0	3
Personnel Scheduling issues	10	13	5	0	0	0	3
Equipment Scheduling issues	4	7	16	0	1	0	3
Difficulty of Traffic control	7	10	6	4	2	0	2
Temperature and environmental working conditions	4	9	6	7	1	1	3
Noise	2	8	15	3	0	0	3
Traffic accident rates	8	10	7	3	1	0	2
Worker accident rates	9	12	6	1	1	0	2
Materials availability problems	8	10	7	0	2	0	4
Equipment maintenance problems	7	10	10	1	0	0	3

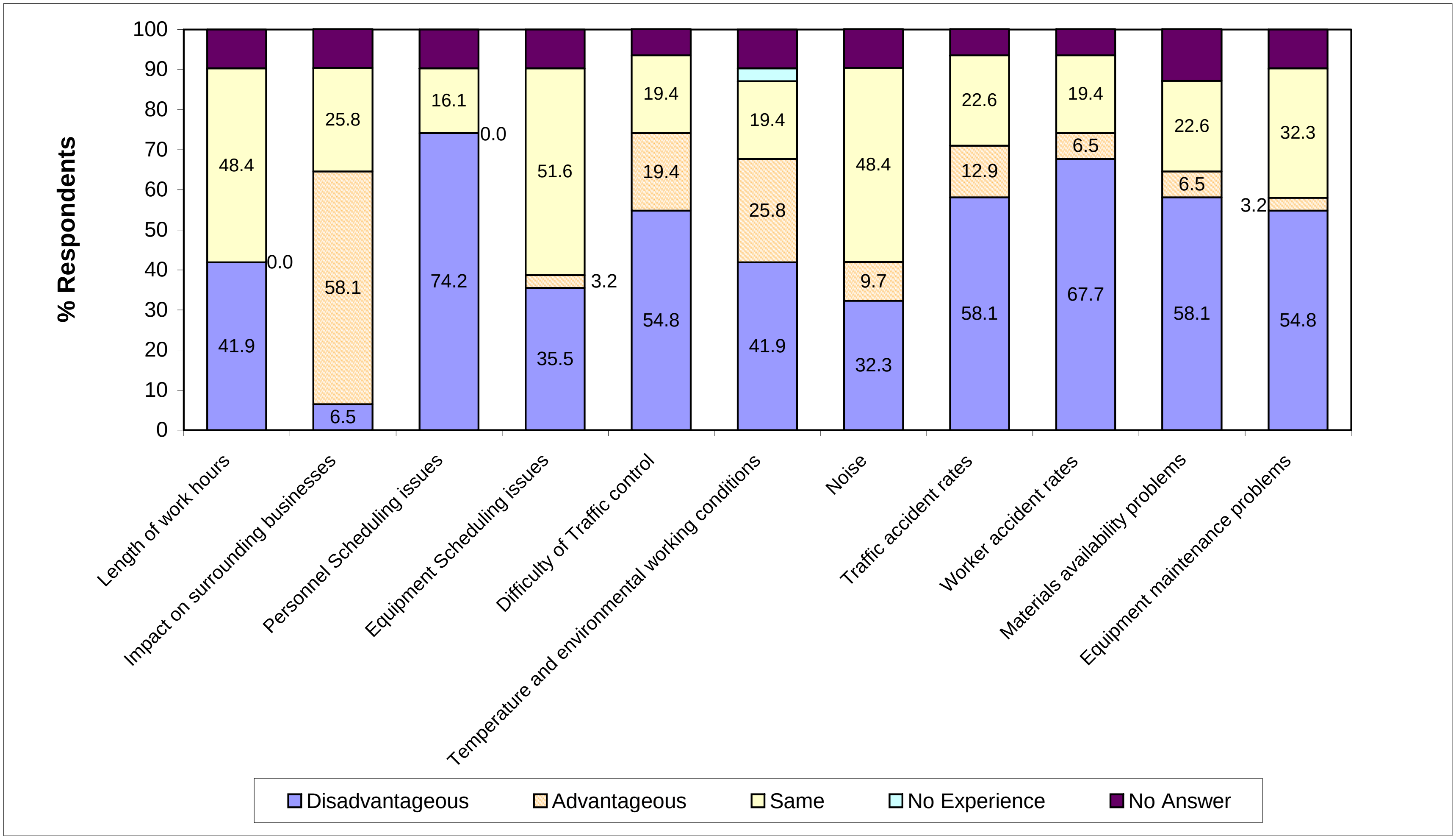


Figure 30. **The Merit / Demerit of Various Aspects of Nighttime Construction Work**

It is evident that the majority of contractors perceive nighttime construction work as disadvantageous in general, or in other words, the disadvantages of night shifts outweigh the advantages. Specifically, more than 50 % of the total number of respondents reported that night shifts are disadvantageous concerning the following work aspects:

1. Personnel scheduling issues
2. Difficulty of traffic control
3. Traffic safety
4. Workers safety
5. Materials availability
6. Equipment maintenance

Nighttime construction was found advantageous for only a single work aspect as reported by more than 50% of the respondents. This aspect is the impact of construction work on surrounding businesses. In effect, this finding is expected and consistent with logic and intuition. Other than this aspect, only a few contractors perceive advantages in conducting work during nighttime while a significantly larger number of contractors view neither advantage nor disadvantage by conducting construction work during nighttime.

To have a better idea about the overall contractors' perception, the results were aggregated over different construction work aspects and plotted as illustrated in Figure 31. This figure shows that around 48% of the respondents perceive nighttime as disadvantageous versus only 13% as advantageous. 30% of the respondents perceive neither advantages nor disadvantages from using night shifts.

3.2.3.1.3 <u>Contracting Method</u>

Six contracting methods were evaluated in this survey for their suitability for nighttime construction projects. The contractors were asked to grade each contracting method using a scale of 1 to 5, with 1 being the most unsuited and 5 the best suited. The results are provided in Table 27. Also, score results were

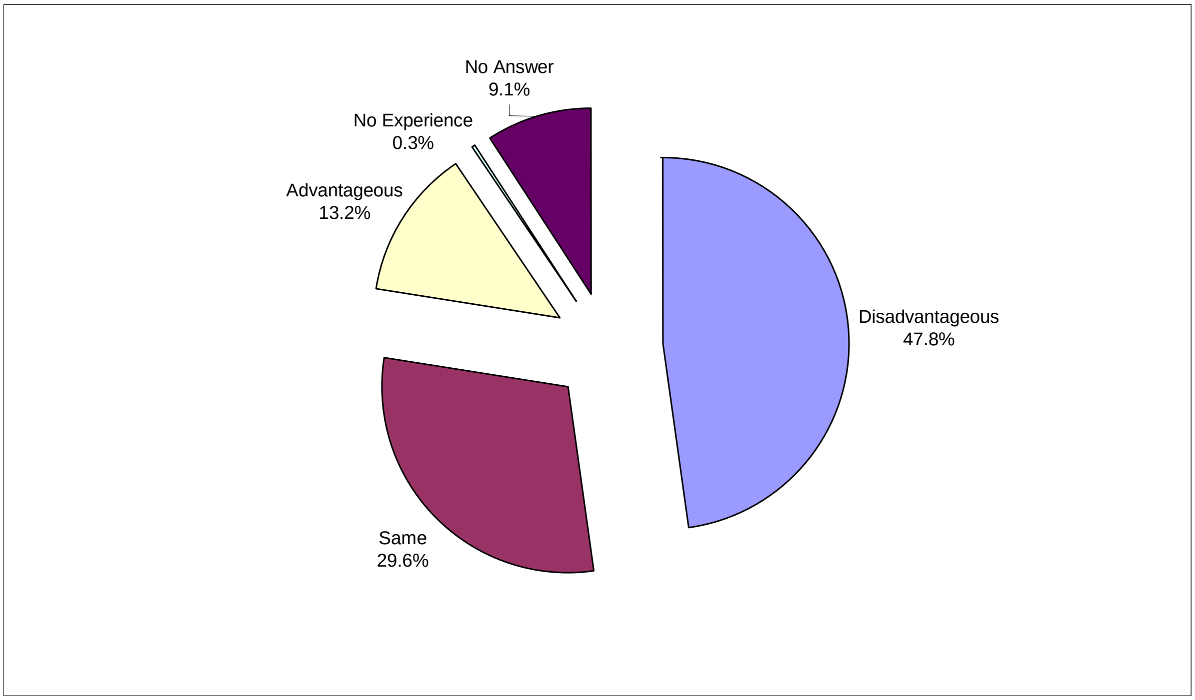


Figure 31. Aggregate Results of Contractors' Perception of Nighttime Construction Advantages and Disadvantages

rearranged into three qualitative categories (suitable, unsuitable, and same) and plotted as illustrated in Figure 32.

A very important observation here is that most contractors were indifferent concerning the suitability of various contracting methods for nighttime construction projects. In other words, those respondents do not view any advantage of using a specific contracting method for nighttime projects.

Consequently, this finding simply suggests that contractors do not perceive contracting method as an important factor in nighttime construction projects. Despite this evident trend in the results, the conventional contracting method was found relatively more appropriate than other methods (ten out of thirty one respondents reported the suitability of this method). Also, consistent with expectation, the number of contractors who have no experience in the innovative contracting methods is much higher that those who have no experience with the conventional contracting method. This is evident in the fact that more than 50% of respondents, on average, reported no experience in using innovative contracting methods for nighttime projects. However, these results should be interpreted with caution as respondents have different levels of familiarity with different contracting methods. This resulted in having different numbers for respondents who gave scores for different contracting methods. This is evident in the fact that the ratio of the number of respondents who favor any contracting method to the total number of respondents who gave a score for that method is pretty much comparable across the six contracting methods.

Table 27. Suitability of Contracting Methods for Nighttime Construction Projects

Contracting Method	Suitability (1=least suitable, 5=most suitable)					No Experience	No Answer
	1	2	3	4	5		
Traditional	1	4	12	4	6	3	1
Design Build	1	1	4	4	0	16	5
A+B	1	0	5	2	1	17	5
Lane Rental	2	1	4	2	1	16	5
Warranty Contracting	1	4	6	1	2	14	3
Job Order Contracting	1	1	7	0	1	17	4

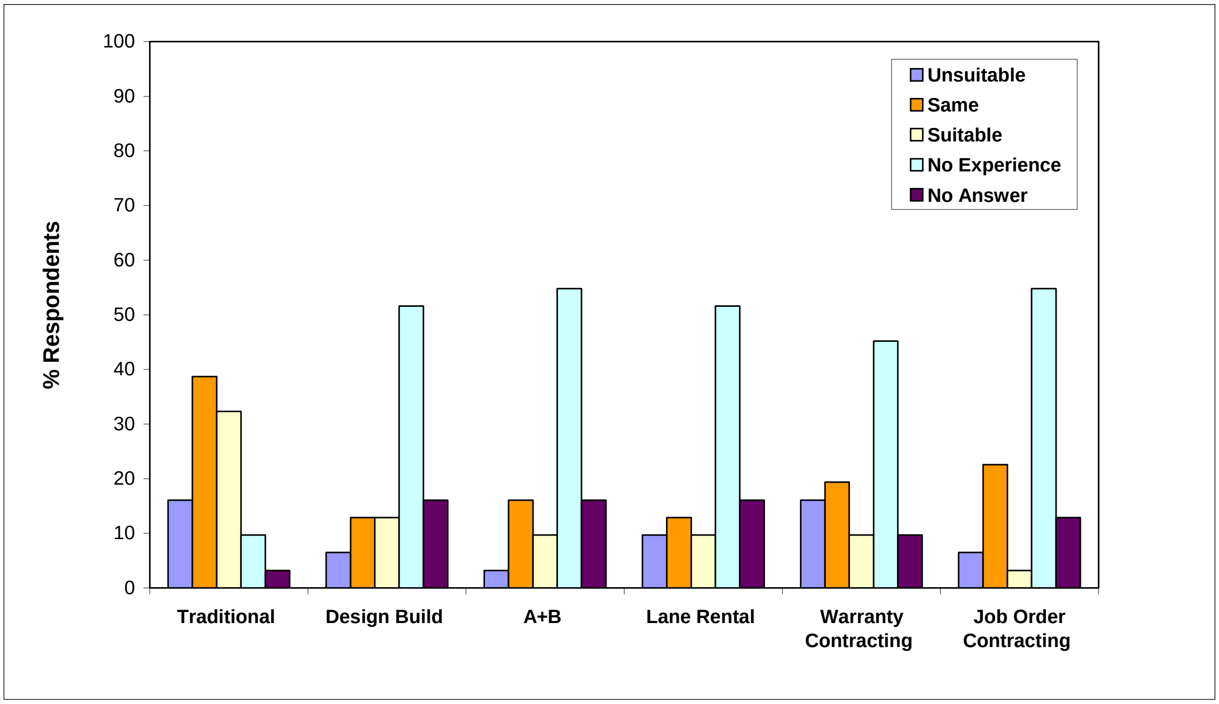


Figure 32. Suitability of Various Contracting Methods for Nighttime Projects

3.2.3.2 Construction Related Issues

3.2.3.2.1 <u>Construction Cost</u>

One of the most important aspects to consider when making decisions on nighttime construction is the cost of construction operations. Previous studies have shown that construction costs of nighttime projects generally tend to be higher than daytime projects. Often however, there are also cost savings when construction operations are performed at night. The most significant cost saving from performing construction operations at nighttime is due to the reduced traffic volumes during nighttime on some freeways and the resulting decrease in road user costs (RUC). This is why, in practice, most State Transportation Agencies (STAs) use nighttime construction in projects that are located on major urban freeways where they perceive the most road user benefits. In making decisions on nighttime construction, these savings in RUC need to be weighed against the increase in construction costs if the project were to be performed at nighttime.

In some cases incentives/disincentives may be needed. As stated in the Illinois Department of Transportation (IDOT) Bureau of Design and Environment Manual BDE: “Incentive/Disincentive clauses are intended for those projects where early completion would greatly benefit both the road user and the Department and where ramifications of not meeting the completion date are extreme.” In fact, one of the special situations where the use of incentives/disincentives is allowed by IDOT is on nighttime construction projects.

To perform a tradeoff between savings in RUC and construction costs (and also to calculate the amount of incentives/disincentives to be used), the agency needs to estimate two main factors: the increase/decrease in construction costs and the impact of lane closure on traffic.

The agency needs to estimate the impact of traffic when nighttime construction is required. Indeed IDOT mandates that the Traffic Management Analysis (TMA) should consider limiting construction to non-peak or nighttime hours on high volume roadways. Specifically, all TMAs prepared for roadways with greater than 25,000 Average Daily Traffic (ADT) shall include a traffic capacity analysis and a queuing analysis. Nighttime construction is mandated when the one-way volume measured in vph (vehicles per hour) exceeds 1700 or when the Level Of Service (LOS), which is a qualitative measure of traffic performance used by the Highway Capacity Manual, drops to E or F.

The agency also needs to estimate the effect of nighttime construction on construction costs. From the agency’s perspective, the increase or decrease in construction cost is reflected in the minimum and average bids submitted by the contractors for jobs where nighttime work is specified. However the decision to require nighttime construction on highway projects is often made before the bidding time, which limits the amount of information the agency has in making these decisions. Thus, it is important to be able to make good decisions on when to require nighttime construction and to be able to calculate the incentive/disincentive when it is used. In order to assess these factors, questions were designed to gain a better understanding of current cost practices.

Extra Cost Items For Nighttime Projects

It was concluded from the State DOTs survey that performing construction work during nighttime involves extra cost to the contractor in most cases. Therefore, the contractors were asked to identify the main extra line items for nighttime work in addition to lighting and additional traffic control required during nighttime. After analyzing the results of this question, it was clear that the extra cost items for nighttime construction identified by the different contractors tend to fall into six main categories:

Overtime shift pay scale: One of the most frequently identified responses was the extra cost associated with the extra labor cost due to overtime shift expenses. Most workers on nighttime projects are compensated for this according to an overtime shift pay scale. This can be premium pay for owner-operators or craft shift differential. The union rules specify that the workers be paid for 8 hrs of work even though the workers would only get in seven or seven and a half hours of actual work during the nighttime shift. One contractor identified the ratio:

$$\frac{\textit{Total hours of actual work performed}}{\text{Total hours paid}}$$

The contractors stated that this could result in losses up to twenty percent.

Lighting: An obvious nighttime cost item identified by the contractors is lighting. This extra cost involves the traffic lighting devices, additional lighting on the equipment, illumination of traffic control devices, and lighting at production sites off the project. One contractor indicated that the cost increase due to lighting could be as high as 20%.

Nighttime Apparel: A large number of contractors who responded to this question also identified the additional safety apparel for workers and personal safety equipment as an extra cost item associated with nighttime work. ANSI-class 2-class 3 worker apparel is required on nighttime construction jobs, which can be very expensive compared to daytime apparel. Also retro-reflective safety equipment, and clothing can further add to the cost of nighttime construction jobs.

Extra material costs: Some respondents identified additional material cost for night delivery due to the added costs of material suppliers and vendors (such as ready-mix concrete). According to one of the respondents, there is also an extra material cost during nighttime construction due to the fact that asphalt plants use more fuel in production thus increasing the cost of asphalt mixes.

Extra equipment costs: One of the most significant indirect costs of nighttime construction is the added cost of equipment during nighttime work. This is mainly due to the cost of standby machines, parts, tires, etc. Also equipment downtime costs are increased during nighttime construction due to the unavailability of parts and some rental equipment during nighttime. One respondent also identified trucking, shop, and mechanic utilization as added indirect cost items.

Others Indirect Costs: There are also other indirect cost items and intangibles associated with nighttime construction. For example one of the respondents cited additional insurance cost for nighttime work. Other respondents cited management difficulties along with loss of labor productivity due to poor visibility, biological clock, and fatigue inherent to night.

Extra Costs of Nighttime Construction & Bidding Practice

All the cost items identified above are extra costs specific to nighttime construction work. However, often there is no specific pay item for the extra costs associated with nighttime work. In the previous survey of IDOT districts, one district identified this point as an important issue in nighttime construction contracts. Therefore a question was included in the contractors' survey about how these pay items are currently being charged on different nighttime construction jobs. According to the contractors' surveys, these extra cost items are currently being charged using one of four main different methods:

1. Charged to traffic control

2. Charged to mobilization
3. Charged to the pay items being performed during night work, such as bituminous or concrete.
4. Spread over all applicable pay items.

One respondent mentioned that the extra nighttime construction cost items are currently being charged either directly to the pay item or if not applicable, to mobilization. Another respondent noted that equipment and material availability must be factored into production rates of the affected items.

Bidding Lighting Costs as a Separate Pay Item

In order to make an informed decision on requiring nighttime work and the appropriate tradeoff between the savings in road user costs and construction costs, transportation agencies need a reliable estimate of the extra construction costs during nighttime. Ideally, the increase or decrease in construction cost is reflected in the minimum and average bids submitted by the contractors for jobs where nighttime work is specified. However because decisions on the use of nighttime construction is often made before the bids are submitted by the contractors, the transportation agencies usually do not have an exact idea about the increase/decrease in construction costs. There are two methods suggested to address this problem. One method is to bid nighttime construction as an alternate. The other is to bid extra costs associated with nighttime construction as a separate pay item. In this survey, the contractors were asked if they would prefer to bid lighting costs as a separate pay item. The responses to this question are summarized in Figure 33.

It is clear that the majority of the contractors surveyed (fifty seven percent) would prefer to bid extra costs as a separate pay item, whereas a third of the contractors would not. In addition to giving the agency an accurate figure on costs, a district engineer stated that the bidding of nighttime construction costs items separately would quantify and spell out the increase in construction costs of nighttime projects.

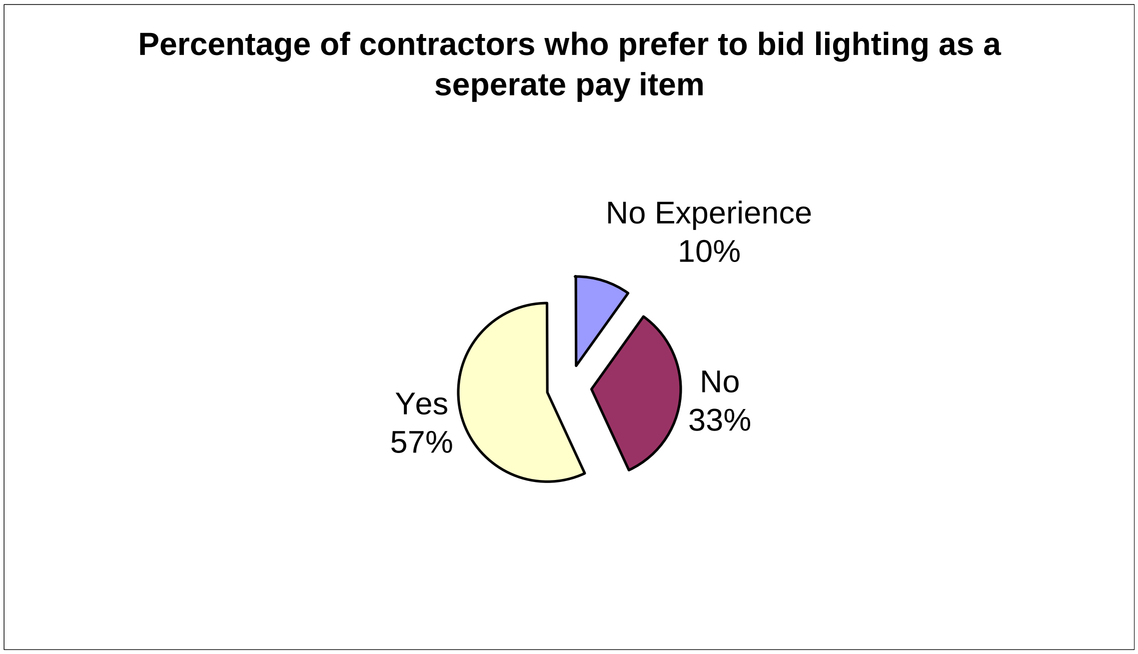


Figure 33. **Percentage of Contractors Who Prefer to Bid Lighting as a Separate Pay Item**

Cost of Nighttime Versus Daytime Operations

From the results of the previous survey, it was found that nighttime construction operations generally cost between 0 to 25 percent more than daytime operations. Not all projects, however, incur a higher construction cost when performed at nighttime as compared with daytime. Indeed some projects may have the same cost and in other situations the cost of nighttime construction may even be less that that of daytime. These projects would therefore be a perfect candidate for nighttime construction. In order to identify which operations would be more suited for nighttime construction and to provide an idea on the costs of different nighttime construction operations in the absence of hard cost data from the contractors' bids, a number of questions were included in the survey to assess the change in construction costs of certain nighttime construction operations. The list of operations used here was compiled based on the responses of the different DOTs and the IDOT districts from the previous surveys. The operations include construction as well as maintenance operations.

Two main cost factors were analyzed: first labor, personnel and supervision costs, and second equipment and material costs.

Labor, Personnel and Supervision Costs

The contractors were asked how the labor, personnel and supervision costs of certain nighttime jobs compare to similar daytime jobs (1 = over 25% higher, 2 = 0 to 25% higher, 3 approximately the same, 4 = 0 to 25% lower, 5 = over 25% lower). Figure 34 shows the summary of the average responses for the different construction operations. From the responses one can see that all the operations listed tend to cost more if performed at night. Specifically, pavement marking (striping and markers) and work traffic control are the worst two operations in terms of the increase in labor, personnel and supervision cost. On the other hand, milling and removal, waterproofing and sealing, and highway signing will have the least labor, personnel and supervision cost increase if performed at night. All other construction operations have cost increase that falls between the two ends described above.

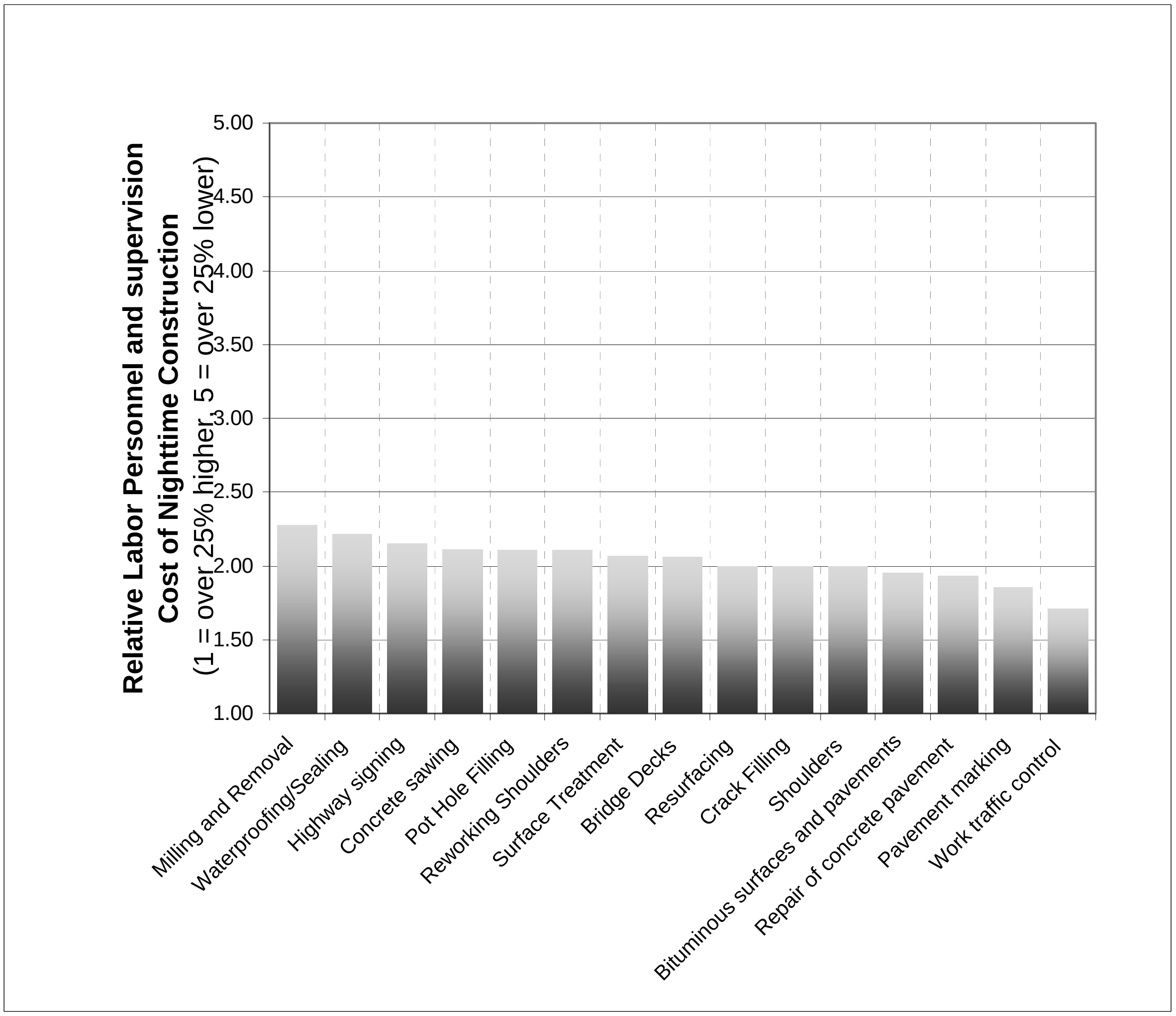


Figure 34. Relative Labor, Personnel and Supervision Cost of Nighttime Construction

Table 28.

3.2.3.2.1.1 <u>Equipment and Material Costs</u>

Contractors were also asked how the equipment (rental, operation and maintenance) and material costs (delivery cost and price) of certain nighttime jobs compare to similar daytime jobs (1 = over 25% higher, 2 = 0 to 25% higher, 3 approximately the same, 4 = 0 to 25% lower, 5 = over 25% lower). The answers to this question are summarized in Figure 35.

Again waterproofing and sealing and highway signing were identified as operations that will have the least equipment and material cost increase if performed at night. Reworking shoulders was also identified among the top three operations with the least cost increase. On the other hand bridge deck rehabilitation and maintenance, work traffic control, and shoulder construction (bituminous and Portland cement concrete) were identified as the worst operations in terms of the increase in equipment and material costs.

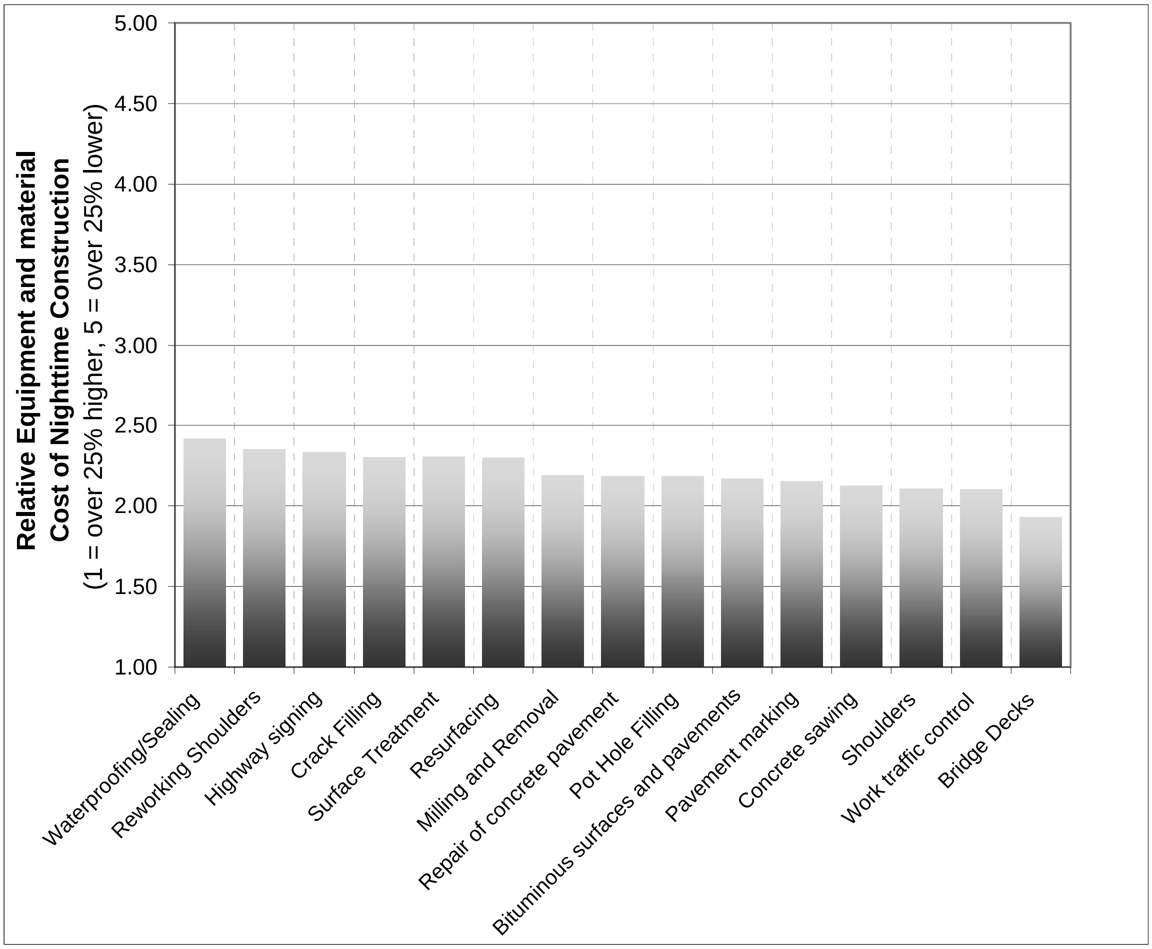


Figure 35. Relative Equipment and Material Cost of Nighttime Construction

The results from the questions on labor, personnel and supervision costs as well as those on equipment and material costs were averaged to get an idea of the total cost increase of nighttime construction projects. Figure 36 shows that milling and removal, highway signage and surface treatment have the least amount of overall cost increase when performed at night. On the other hand

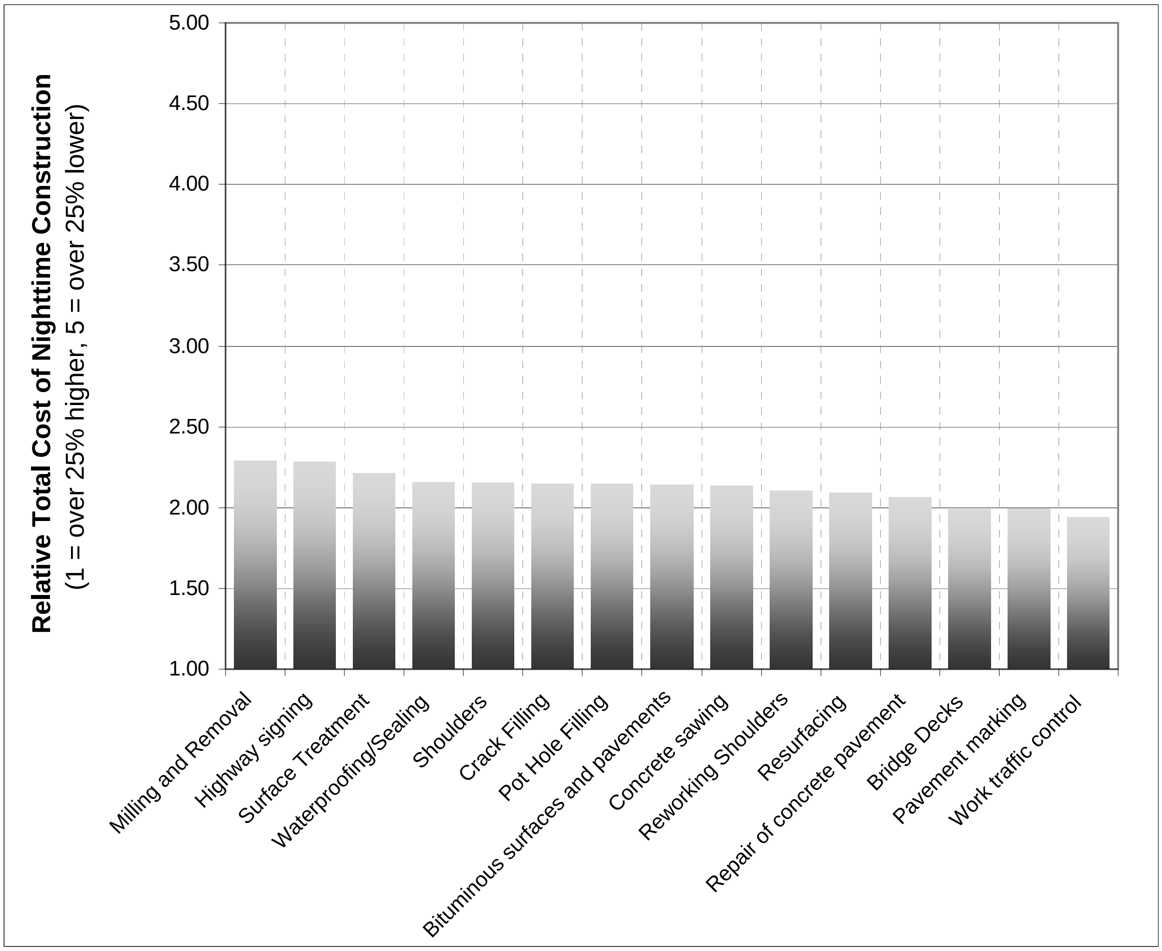


Figure 36. Relative Total Cost of Nighttime Construction

bridge decks, pavement marking, and work traffic control exhibit the most cost increase when performed at night.

However, it is important to note that because every construction project is different, these values need to be used with caution.

3.2.3.2.2 Construction Quality

Contractors were also asked to evaluate how the quality of certain nighttime activities compared to that of similar daytime activities measured by problems or percent of callback work not meeting specifications (scale from 1 to 5 where 1 =

over 25% higher, 2 = 0 to 25% higher, 3 approximately the same, 4 = 0 to 25% lower, 5 = over 25% lower). The results are summarized in Table 28 and Figure 37.

Table 29. Relative Quality of Nighttime Construction

	Total	Average	Number of No Experience	Standard Deviation	Coefficient of Variation
Pavement marking	38	2.92	17	0.86	30%
Reworking Shoulders	48	2.82	13	0.81	29%
Highway signing	31	2.82	19	0.87	31%
Concrete sawing	47	2.76	13	0.75	27%
Pot Hole Filling	43	2.69	14	0.48	18%
Shoulders	48	2.67	12	0.59	22%
Waterproofing/Sealing	29	2.64	19	0.67	26%
Crack Filling	34	2.62	17	0.51	19%
Repair of concrete pavement	39	2.60	15	0.74	28%
Milling and Removal	54	2.57	9	0.68	26%
Bridge Decks	36	2.57	16	0.85	33%
Bituminous surfaces and pavements	48	2.53	11	0.84	33%
Work traffic control	45	2.50	12	0.79	31%
Surface Treatment	32	2.46	17	0.66	27%
Resurfacing	49	2.45	10	0.76	31%

Table 28 shows clearly that, in general, work quality is negatively impacted if work is performed during nighttime. Consistent with the results from the IDOT districts and state DOTs surveys, resurfacing and surface treatment were identified as having the worst quality when compared to daytime jobs. Nighttime pavement marking, reworking shoulders and highway signing operations were identified as having the closest quality to that of daytime operations. The variability of the responses of the questions was measured using the coefficient of variation. The majority of the responses had coefficient of variations ranging around 30 percent.

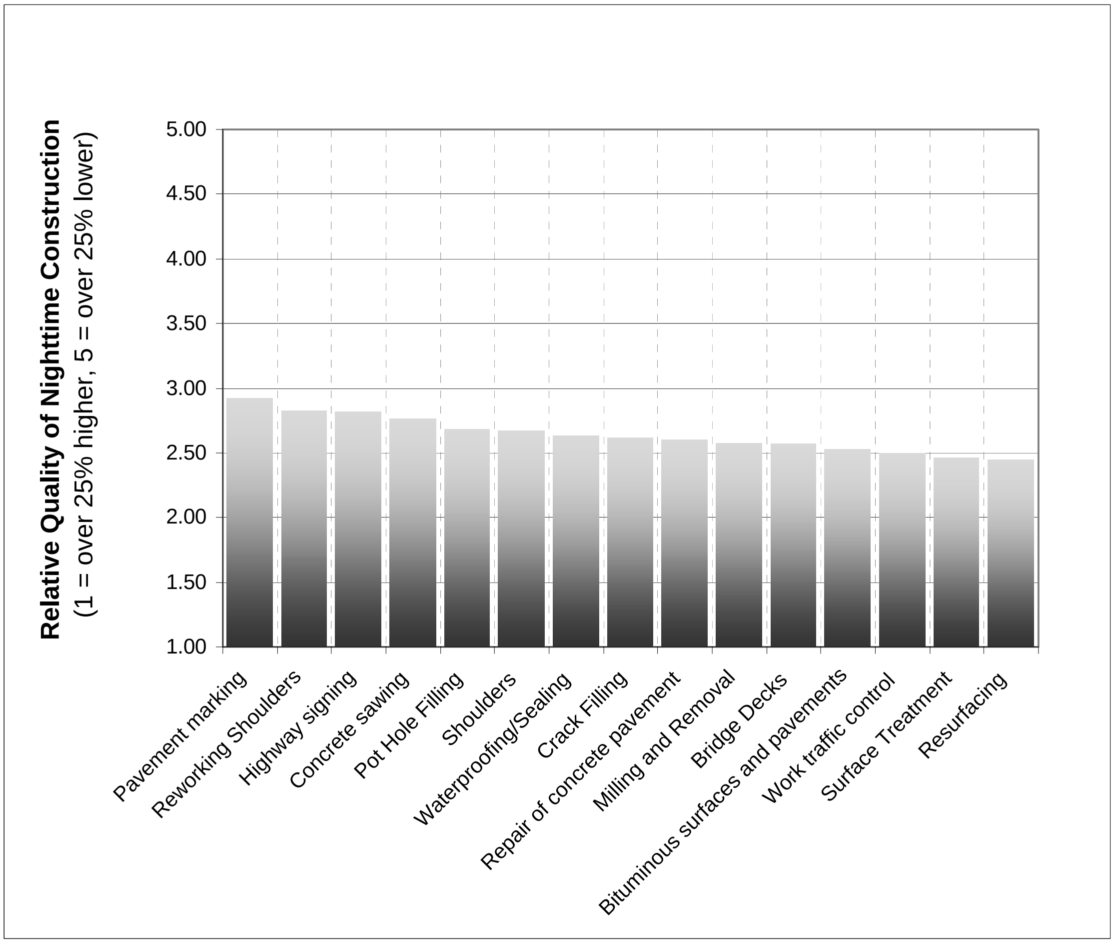


Figure 37. Relative Quality of Nighttime Construction

3.2.3.2.3 __Construction Productivity__

Identifying the change in productivity during nighttime construction projects is very important, especially in completion day contracts. This is because in when nighttime work is scheduled in completion day contracts the production rates have to be revised to reflect the differing rates for nighttime work. Therefore, contractors were asked how the production rates of certain nighttime jobs compare to similar daytime jobs (1 = over 25% higher, 2 = 0 to 25% higher, 3 approximately the same, 4 = 0 to 25% lower, 5 = over 25% lower). The responses to this question are summarized in Table 29 and Figure 38 below.

The productivity of nighttime jobs, in general, was found to be slightly lower than that of daytime jobs. Specifically, the productivity of milling and removal, repair of concrete surfaces, and pavement marking during nighttime operations were found to be very close to that of similar daytime operations. On the other hand bridge deck, waterproofing and sealing, and reworking shoulders were the worst three operations in terms of lost productivity during nighttime (though not significantly worse).

Table 30. **Relative Productivity of Nighttime Construction**

	Total	Average	Number of No Experience	Standard Deviation	Coefficient of Variation
Milling and Removal	64	3.05	9	0.97	32%
Repair of concrete pavement	41	2.93	16	0.92	31%
Pavement marking	35	2.92	18	0.90	31%
Resurfacing	58	2.90	10	1.02	35%
Bituminous surfaces and pavements	54	2.84	11	0.90	32%
Pot Hole Filling	45	2.81	14	0.98	35%
Work traffic control	50	2.78	12	0.88	32%
Concrete sawing	44	2.75	14	0.86	31%
Highway signing	33	2.75	18	0.87	31%
Shoulders	49	2.72	12	0.89	33%
Crack Filling	35	2.69	17	0.95	35%
Surface Treatment	35	2.69	17	0.85	32%
Reworking Shoulders	48	2.67	12	0.84	32%
Waterproofing/Sealing	29	2.64	19	0.92	35%
Bridge Decks	35	2.50	16	0.85	34%

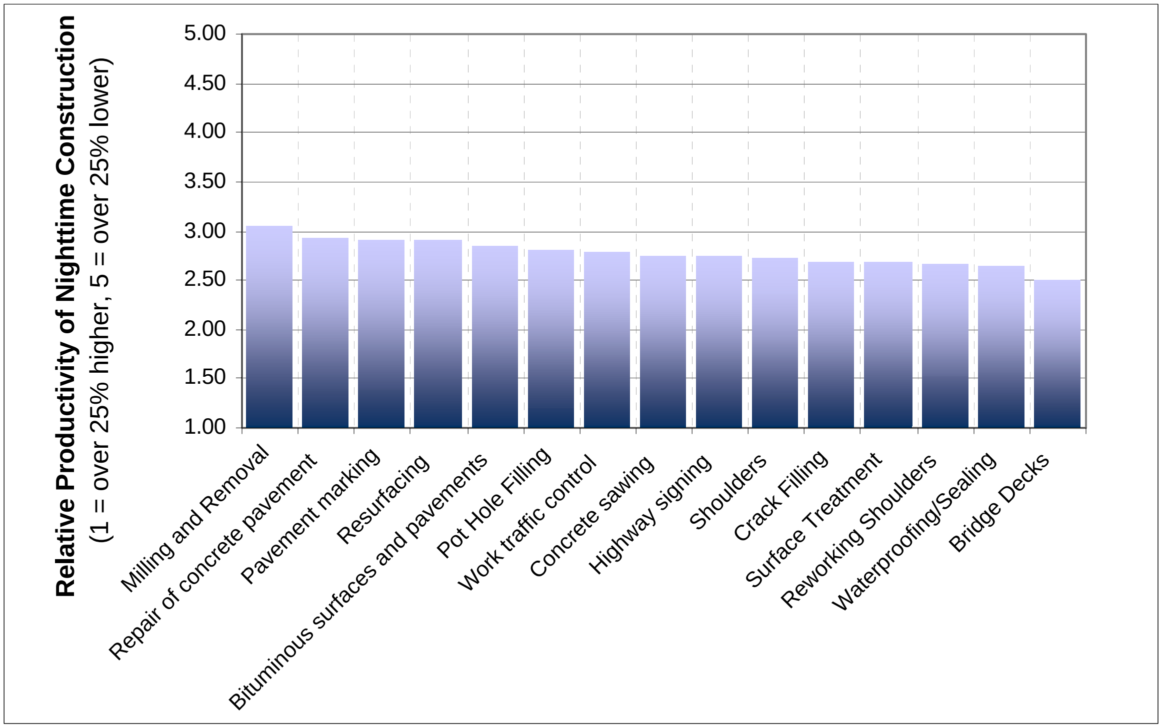


Figure 38. Relative Productivity of Nighttime Construction

3.2.3.2.4 Summary Of Construction Issues

Figure 39 and Table 30 show the summary of the results concerning cost, quality and productivity of nighttime construction projects. It is clear that working during nighttime negatively impacts all these aspects. The cost is the most significantly impacted factor with an average increase between o% and 25%. According to the survey, the productivity is the least factor impacted by nighttime construction, with an average nighttime productivity very close to that of daytime.

Table 31. Summary of Construction Issues

	Average	Average # of No Experience	Standard Deviation	Coefficient of Variation
Cost	2.12	13.23	0.62	29%
Labor Personnel and supervision costs	2.04	12.40	0.63	31%
Equipment and material costs	2.21	14.07	0.61	28%
Quality	2.64	14.27	0.72	27%
Productivity	2.78	14.33	0.91	33%

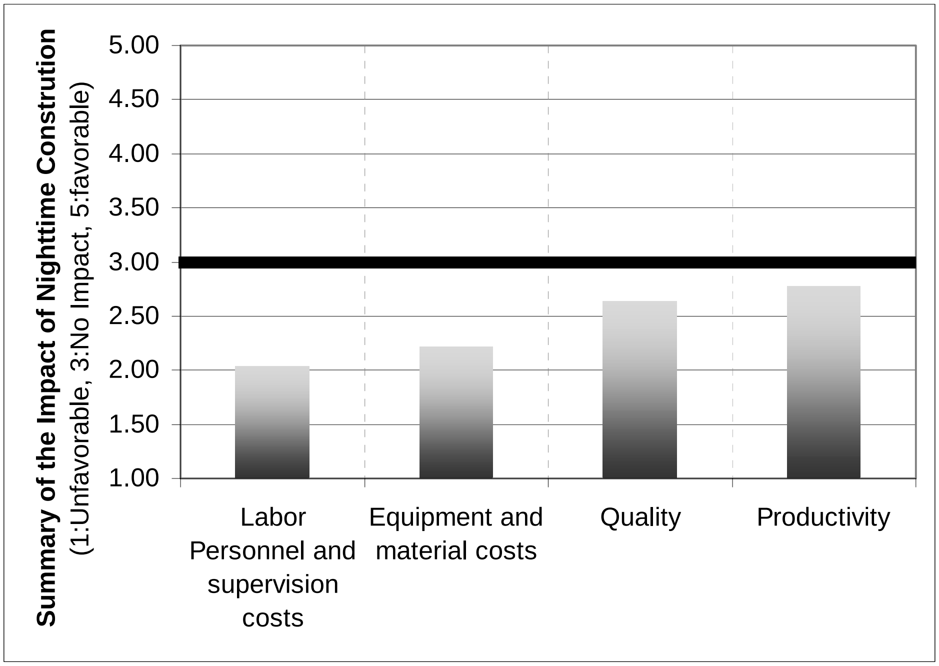


Figure 39. Summary of Construction Issues

3.2.3.3 Social And Physical Issues

In this section of the questionnaire, the contractors were asked about the effect of nighttime work on average hours of sleep, average hours of work, impact on social life, and about the extra compensation that would make it worthwhile for them to perform work during nighttime. The results regarding each of these questions are presented next.

3.2.3.3.1 Hours of Sleep

Out of the 31 subjects who responded to the questionnaire, only 22 (71%) provided an estimate for the hours of sleep in nighttime projects. Most estimates (18 out of 22) reported an average sleep of less than 7 hours per night with some estimates as low as 2.5 hours per night. These results are illustrated in Figure 40.

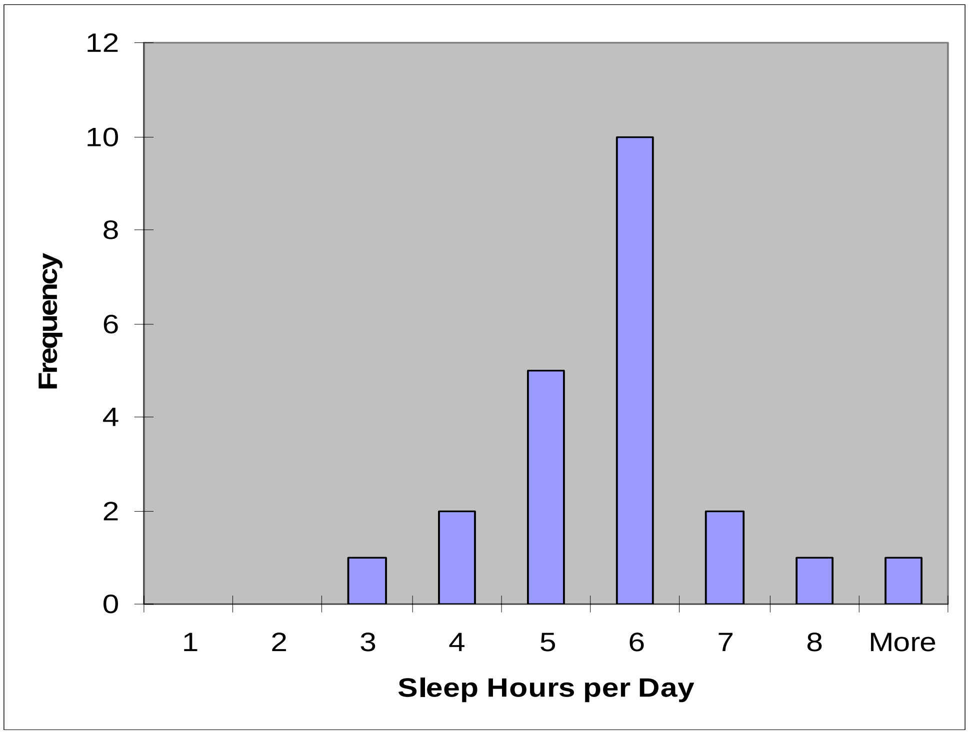


Figure 40. Frequency Diagram of Average Sleep Hours per Day

The aggregate average is 5.5 hours per day, which is much less than the typical average sleep hours per day a normal person would need to function properly. This figure is a source of great concern as the insufficient hours of sleep per day may suggest an effect on workers' vigilance on site, thus affecting their safety at work. Also, another possible implication is an adverse impact on quality of work performed during the night. While the results from this survey confirm the latter concern, there is no sufficient evidence in the literature supporting this finding.

3.2.3.3.2 Work Hours

The contractors surveyed were asked to estimate the average number of work hours per day in nighttime projects. Out of 31 respondents, 24 provided such an estimate and the results are illustrated in Figure 41.

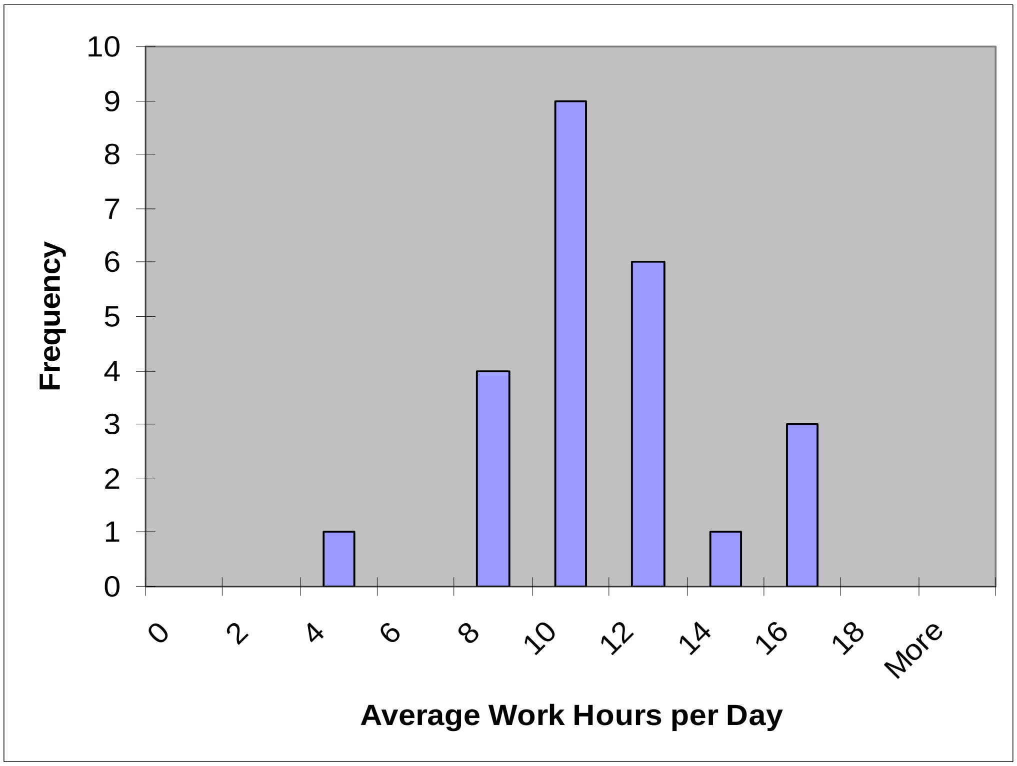


Figure 41. Frequency Diagram of Average Work Hours per Day

As shown in this figure, most estimates exceed the typical range for daily work hours (7-9 hours). The aggregate average is 10.32 hours, which is relatively high. While some of the extreme values may not be very reliable (such as the estimated average of 3 hours and 16 hours), most of the other estimates are above the normal range for a daily work shift. When work hours per day exceed this average, it is logical to expect that some of the nighttime workers may suffer from fatigue thus affecting their safety, productivity, and work quality. This is a logical consequence especially since the average hours of sleep are generally insufficient. Results from this survey confirm this logical hypothesis concerning productivity and quality. Further, in their additional comments, two respondents reported that fatigue is to be blamed for decreasing workers safety. Other comments referred to the effect of fatigue on work quality and productivity during nighttime. The state-of-the-art review conducted in the course of this research project suggests that, while the quality of nighttime work may be within specifications, it is usually less than that of daytime. In addition, achieving reasonable surface smoothness may require additional care and quality control by the contractor. These observations from the literature are consistent with the previous results.

3.2.3.3.3 <u>Impact on Social Life</u>

The survey involved a question about the effect of nighttime work on the social life of people who are involved in nighttime projects. Only 25 out of 31 respondents answered this question and the results are shown in Figure 42.

According to this figure, 62% of the respondents (19 out of 31) suggest that nighttime work has an impact on workers' social life, while only 13% (4 out of 31 respondents) reported no effect. This result is consistent with expectations as switching the time for sleep and work will logically affect the social life of people involved in nighttime projects. This is also evident in the discussions concerning survey results presented in the following section.

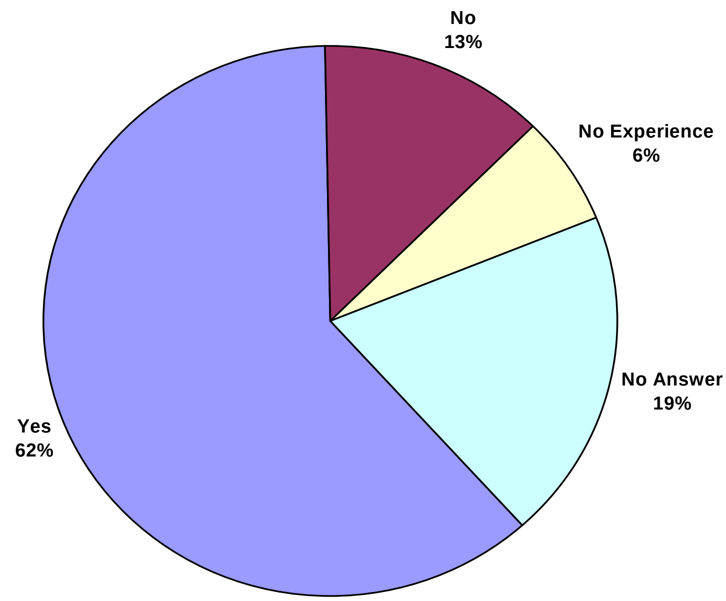


Figure 42. Effect of Nighttime Work on Workers' Social Life

3.2.3.3.4 __Appeal of Night Shifts to Construction Workers__

The appeal of night shifts to construction workers was investigated indirectly by asking the contractors or their personnel about what extra pay they see sufficient to make it worthwhile for them to work during the night. Twenty out of thirty-one respondents provided a valid response to this question. According to these respondents, the average extra pay that would make night work worthwhile is around 38%. This is a very important finding as it shows that, in general, contractors do not prefer night shifts.

Another important implication is that contractors' personnel who responded to this questionnaire perceive inherent disadvantages to nighttime work (such as the effect on safety or social life) that can only be compensated by this significant extra pay. This finding is largely consistent with the previous findings of this survey.

3.2.4 Contractors' Survey: Summary of Findings

The most important findings are summarized below:

- The vast majority of contractors surveyed prefer the conventional daytime shift. Only a small number of contractors are indifferent about performing work during night or dual shifts.
- It is evident that the majority of contractors perceive nighttime construction work as disadvantageous in general, or in other words, the disadvantages of night shifts outweigh the advantages.
- Results suggest that contractors do not perceive contracting method as an important factor in nighttime construction projects.
- A slight majority of the contractors surveyed would prefer to bid extra costs as a separate pay item.
- Nighttime construction is associated with 0-25% increase in labor, personnel, and supervision costs.
- Nighttime construction is associated with 0-25% increase in materials and equipment costs.
- In general, work quality is negatively impacted if work is performed during nighttime. Resurfacing and surface treatment were identified as having the worst quality when compared to daytime jobs. Nighttime pavement marking, reworking shoulders and highway signing operations were identified as having the closest quality to that of daytime jobs.
- The productivity of nighttime jobs, in general, was found to be slightly lower than that of daytime jobs. Bridge deck, waterproofing and sealing, and reworking shoulders were found the worst three operations in terms of lost productivity during nighttime.
- Results suggest that workers during night shifts get less-than-average hours of sleep (average 5.5 hrs) and more-than-average hours at work (average 10.32 hrs).
- Survey results suggest that night shifts have a negative impact on worker's social life.

4 EVALUNITE: A DECISION-MAKING ASSISTING TOOL FOR NIGHTTIME PROJECTS

4.1 Introduction

While nighttime construction is viewed as an effective means that could dramatically minimize congestion and delay to the traveling public, night shifts are also associated with negative effects on one or more of construction work aspects such as construction costs, work quality, workers and traffic safety, and noise.

Highway agencies need to make informed decisions on the situations where the use of night shifts is more appropriate than the conventional day shifts. However, this is a relatively difficult task due to the many factors that are affected by nighttime work and the lack of quantitative tools to assess these factors. This assessment is essential in making any meaningful comparison between daytime and nighttime work for different scenarios of traffic control plans at the work zone.

Most previous studies in the literature dealt with identifying the factors that should be considered in making this comparison and a few of them went further to suggest a decision framework for nighttime projects without providing means to quantify these effects. The proposed decision-making tool, EVALUNITE, builds on those studies in the literature and added many quantitative analyses based on the findings and results obtained by this research project.

This part of the report involves a description of the proposed decision-making tool that is essential for the effective and accurate use of the software.

4.2 Model Description

EVALUNITE is a simple software package that may be used for the evaluation of the suitability of nighttime work for highway projects. It is mainly used whenever night shift is thought of as an alternative to the conventional daytime shift. The software was developed using Microsoft Excel spreadsheet and Visual

Basic for Applications (VBA). The software has a user-friendly interface that leads the user through the process of data input and running the model in a simple and clear manner. The researchers fully realize that input data is project sensitive and may largely differ from one project to another. Therefore, most input variables are user-specified. However, default values were set for these variables in case the required information is not available to the user. This feature is very useful as it is quite likely for the users not to have all the input data especially at the planning stage of the project. In determining these default values, the researchers attempted to reach realistic estimates for many parameters based on what is available from previous studies and the results from questionnaire surveys that were conducted as part of this research project.

4.3 Model Structure

The proposed model utilizes the cost-effectiveness analysis as a basis for the comparison between daytime and nighttime projects. This technique is well known for its effectiveness in evaluating different transportation alternatives. Variables related to decisions on nighttime construction are of two types. The first type involves variables that can be assessed using cost units ($ values) while the second type involves other variables that cannot be assessed but qualitatively. Therefore, an explicit economic cost model was not appropriate for the nature of the analysis implemented in the proposed model.

The model consists mainly of two main modules; the cost module and the effectiveness module. The cost module assesses all the variables that can be quantified using dollar values while the effectiveness module evaluates other important variables that cannot be expressed in cost units. Using the priorities and objectives set by the highway agency, the model comes up with a recommendation concerning the use of night shifts in highway projects.

A schematic diagram showing model structure is provided in Figure 43.

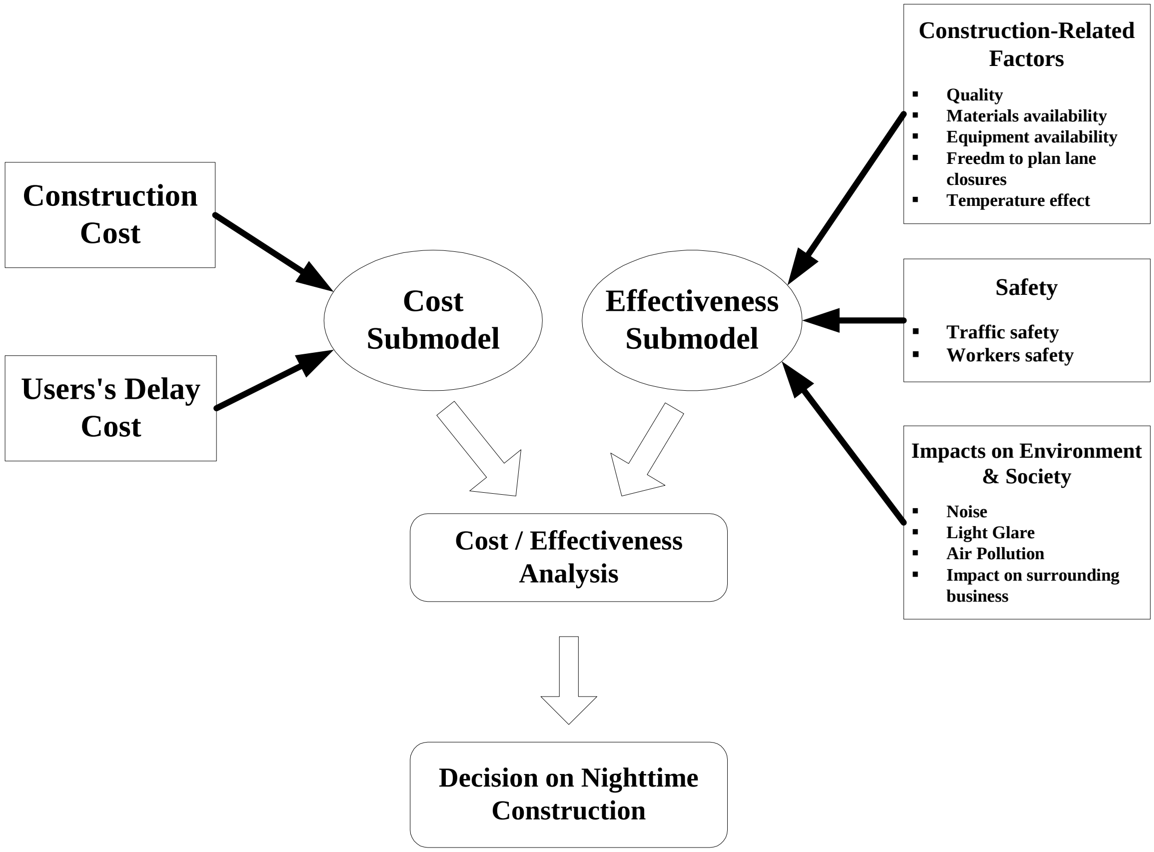


Figure 43. Schematic Diagram of the Proposed Decision-Making Tool

4.3.1 COST MODULE

The cost module consists of three different cost models; users' delay model, accident cost model, and construction cost model. A detailed description of each of these models is provided in the following sections.

4.3.1.1 Users' Delay Model

Delay in this model refers to the time spent while vehicles are in queue waiting to pass the work zone. Delays due to slow down, acceleration, and traveling at less than the desirable speed are not accounted for by this model. However, it should be mentioned that delay due to queuing is typically the most important delay component at work zones.

In order to assess the delay cost of a specific alternative, the delay model utilizes what is called the "demand and discharge method" which is a tabulated form of the cumulative demand / capacity analysis. In this method, the model divides the total duration of analysis time into small increments (intervals). For each interval, the estimated demand is compared with the capacity to check if there is a delay incurred by road users while in queue during that interval. If demand is found less than capacity and there was no queue from the previous time interval, then no delay is incurred by users. However, there will be delay incurred by users in the following two situations:

1. If demand is less than capacity during the specific time interval but there was a queue from the previous time interval (dissipating queue at the lane closure).

2. If demand is greater than capacity during the time interval, then there will be a growing queue at the lane closure.

The time interval used by the delay model is 5 minutes. In each time interval, the model updates the status of queue at the lane closure and the number of vehicles in queue. The model then finds the total amount of delay in veh-hr for the total duration of lane closure.

The user is required to enter traffic demand anticipated at the particular location of interest along with other information about lane closure and traffic conditions for daytime and nighttime closures. Below is the main information that is needed to run the delay model:

- Number of normal lanes
- Number of open lanes
- Start time of lane closure
- End time of lane closure
- Hourly volumes of traffic demand for a typical weekday or weekend
- Percentage of heavy vehicles
- Expected traffic diversion to other alternative routes
- Estimated delay cost per hour
- Type of work zone (sort-term maintenance versus long-term reconstruction)
- For short-term maintenance
    - Presence of ramp within 150 m of start of activity area
    - Intensity of work activity
- For long-term reconstruction zones
    - Side of lane closure (left or right)
    - Weekend or weekday

Figure 44 shows the delay model user interface.

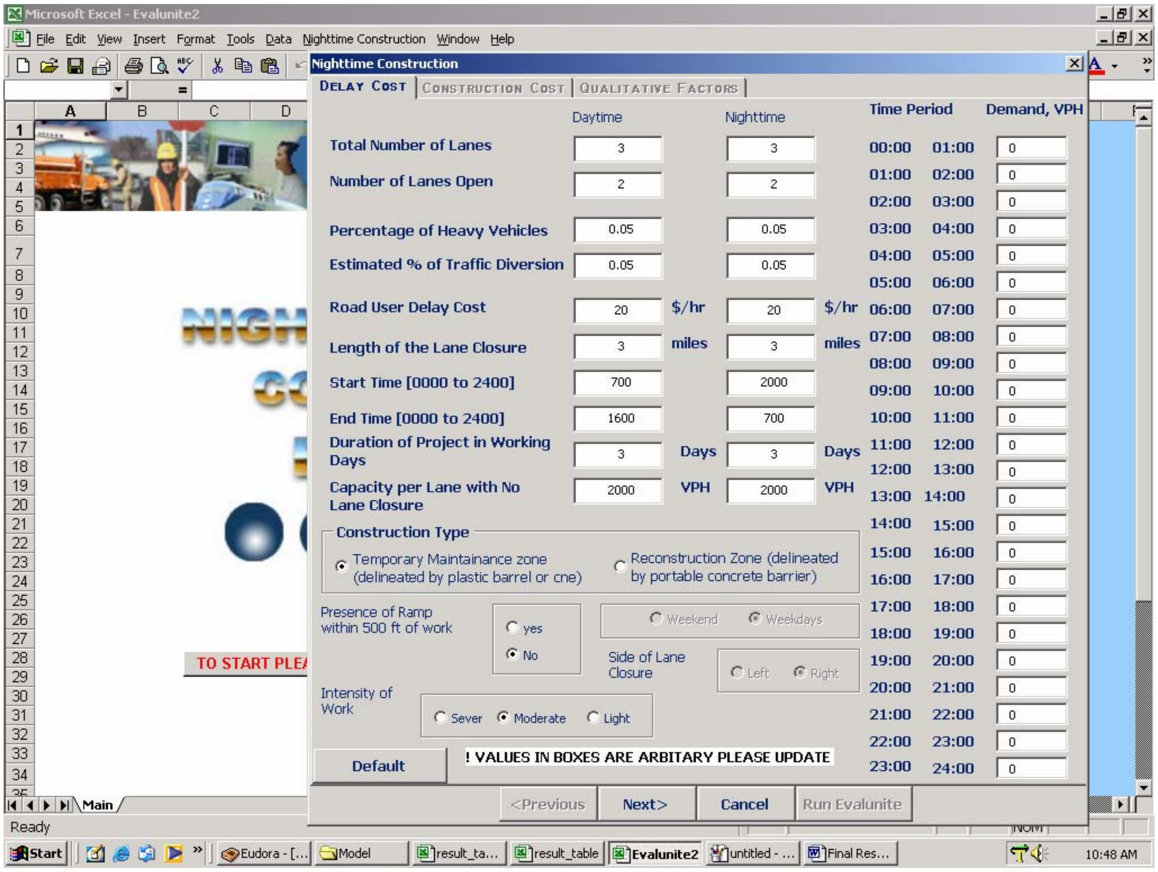


Figure 44. Delay Model User Interface

4.3.1.1.1 Estimating Traffic Demand:

Traffic patterns at any highway facility may be estimated with reasonable accuracy from historical traffic volume records. This data is available to most highway agencies from permanent detector stations at certain locations on the highway network. Also, traffic volumes by time of day could easily be measured by the agency using portable traffic counters when it is difficult to obtain accurate data from permanents detector stations. These traffic patterns may be affected after the onset of construction work due to change in travel time and the effect of work on driver’s convenience. Most highway agencies devise route diversion plans as part of planning work zones on major highway facilities especially when construction work is performed during daytime. This traffic diversion is intended to alleviate the congestion at the affected area by encouraging the users to use other alternative routes. The delay model presented here recognizes this fact and therefore the user is prompted to enter the estimated percentage of traffic that is expected to use the alternative routes. This will be used along with the typical weekday or weekend hourly volumes for the 24-hour period.

4.3.1.1.2 Estimating Work Zone Capacity

Short-term maintenance work zones refer to those work zones that are delineated using temporary plastic barrels and cones. Long-term reconstruction zones refer to work zones that are delineated using portable concrete barriers.

To estimate users’ delay, the model roughly estimates traffic demand at the affected area as well as the capacity of work zone before and after lane closure. Traffic demand can be estimated relatively straightforward from the hourly volumes of the day of interest as well as the percentage of traffic diversion. However, estimating work zone capacity is much more complicated. The capacity for the two types of work zones is significantly different. While many similarities exist between the two types of work zones, capacity of long-term reconstruction zones on multi-lane highways is typically higher than that of short-term maintenance zones. Two factors are believed to contribute to this difference in capacity. First, the use of portable concrete barriers at reconstruction sites provides a better physical separation between work activity area and the traveled lanes when compared to plastic barrels and cones commonly used at maintenance sites. The second factor is that regular drivers gain familiarity over time with long-term reconstruction sites, a matter that is quite unlikely at short-term maintenance sites.

While the Highway Capacity Manual (HCM) provides limited procedures for estimating capacity at maintenance zones on multi-lane highways, no formal procedures are provided to estimate the capacity at long-term reconstruction zones.

The proposed model utilizes two different procedures to estimate work zone capacity based on the type of work zone as discussed next.

<u>Estimating capacity at short-term maintenance zones:</u> The methodology used to estimate capacity at maintenance work zones was developed by Krammes et al. (1994) and was included later in the Highway Capacity Manual (HCM 2000). The model used is shown below:

$$c_a = (1,600 + I - R) * f_{HV} * N$$

Where:

c_a = Adjusted mainline capacity

I = Adjustment factor for intensity and location of work activity

R = Adjustment for ramps

f_{HV} = Adjustment for heavy vehicles (same as that for normal freeways)

N = Number of lanes open through the short-term work zone

The adjustment factor for heavy vehicles was computed using the same formula provided by the HCM *(2000)*:

$$f_{HV} = \frac{1}{1 + P_{HV}(E_{HV} - 1)}$$

Where:

P_{HV} = Proportion of heavy vehicles in the traffic stream

E_{HV} = Passenger Car Equivalency factor used for heavy vehicles

Estimating capacity at long-term reconstruction zones: The HCM does not provide any analytical procedure to estimate work zone capacity at long-term reconstruction zones. Instead, it provided two capacity observations for two different lane closures. These estimates, first introduced in the 1985 HCM (TRB 1985), are based on empirical data collected more than two decades ago in the State of Texas at a limited number of sites and range of circumstances (Dudek and Richards 1981). Also, the HCM provides no guidance as to how these estimates are affected by traffic, geometric and environmental conditions.

The proposed model utilizes a recent procedure to estimate long-term reconstruction zones that was developed by Al-Kaisy and Hall (2002). This procedure is based on empirical data that was collected at several reconstruction sites in Ontario, Canada. The model proposed by this methodology is shown below:

$$C = C_b * f_{HV} * f_d * f_w * f_s * f_r * f_l * f_i$$

Where:

C = Work zone capacity under prevailing conditions (vphpl)

C_b = Base work zone capacity (pcphpl), for freeways use 2000 pcphpl

f_{HV} = Adjustment factor for heavy vehicles

f_d = Adjustment factor for driver population

f_w = Adjustment factor for work activity

f_s = Adjustment factor for side of lane closure

f_r = Adjustment factor for rain

f_l = Adjustment factor for light condition

f_i = Adjustment factor for non-additive interactive effects

The adjustment factors for prevailing conditions are provided in Table 31. The model utilizes a base capacity estimate for freeway reconstruction zones of 2000 pcphpl (as estimated from empirical data) and adjusts this value based on prevailing conditions using adjustment factors.

The adjustment factor for heavy vehicles was computed using the same formula provided by the HCM *(2000)* and presented previously in the previous section.

Some of these input conditions may not be available to the users of the proposed tool. Therefore, default values were assigned to these conditions and the user is prompted to enter the project-specific information if available.

Table 31. Recommended Adjustment Factors for the Proposed Capacity Model

Adjustment Factor	Recommended Values
Heavy Vehicles (f_{HV})	Model utilizes the same HCM formula for heavy vehicles adjustment factor. However, the recommended equivalency factors for trucks and buses at freeway reconstruction sites are: E_{HV} = *2.4* *level terrain* E_{HV} = *3.0* *3% 1-km upgrade* *For other grades with similar length (around 1-km), linear interpolation may provide a reasonable approximation.* *For specific grades with different lengths, the values for 1-km length may be adjusted in the same proportions calculated using the HCM 2000 equivalency factors for trucks and buses.*
Driver Population (f_d)	f_d = 1.00 peak hours – weekdays f_d = 0.93 off-peak - weekdays f_d = 0.84 weekends
Work Activity (f_w)	f_w = 1.00 no work activity at site f_w = 0.93 work activity at site
Side of Lane Closure (f_s)	f_s = 1.00 closure of right lanes f_s = *0.94* *closure of left lanes*
Rain (f_r)	f_r = 1.00 no rain f_r = 0.95 light to moderate rain f_r = *0.90* *heavy rain*
Light Condition (f_l)	f_l = 1.00 daytime f_l = *0.96* *nighttime with illumination*
Non-Additive Interactive Effect (f_i)	f_i = 1.03 for left-lane closures during weekdays-off peak f_i = 1.08 for weekends when work activity is present f_i = 1.02 for left-lane closures during weekends f_i = *1.05* *for rain during weekends* f_i = *1.00* *for all other conditions*

Construction Cost Model

It was concluded from the State surveys that performing the work during nighttime will involve extra cost to the contractor in most cases. Therefore, a second survey was sent out to the contractors and they were asked to identify the main extra line items for nighttime work in addition to lighting (lights, generators) and additional traffic control (extra traffic cones, etc.) as well as the percent increase/decrease in construction cost.

The construction cost model considers the increase (or decrease) in total construction cost due to nighttime operations. The construction cost increase considered here includes all the following cost items:

- Decreased/Increased productivity cost
- Traffic control costs
- Overtime shift pay scale
- Extra Lighting cost
- Nighttime Apparel
- Extra material costs
- Extra equipment costs
- Other Indirect Costs (e.g. additional insurance cost for nighttime work)

In the developed software tool, EVALUNITE, there are two options for calculating the construction cost increase. First, users can directly enter the costs of daytime construction option. The cost increase can be determined from the alternate bid amounts as suggested in the previous technical memorandum. In absence of exact figures about the percentage increase/decrease in construction cost, the results of the surveys can be utilized. Therefore the second approach to estimate the percentage change in construction cost is determined statistically from the results of the surveys.

After analyzing the results of the previous surveys and specifically the questions about the increase in construction cost, it was found that the percentage cost increase follows a normal distribution (the traditional bell-shaped curve). Goodness of fit tests were also carried out for further verification. An illustration of the statistical approach used is shown in Figure 45.

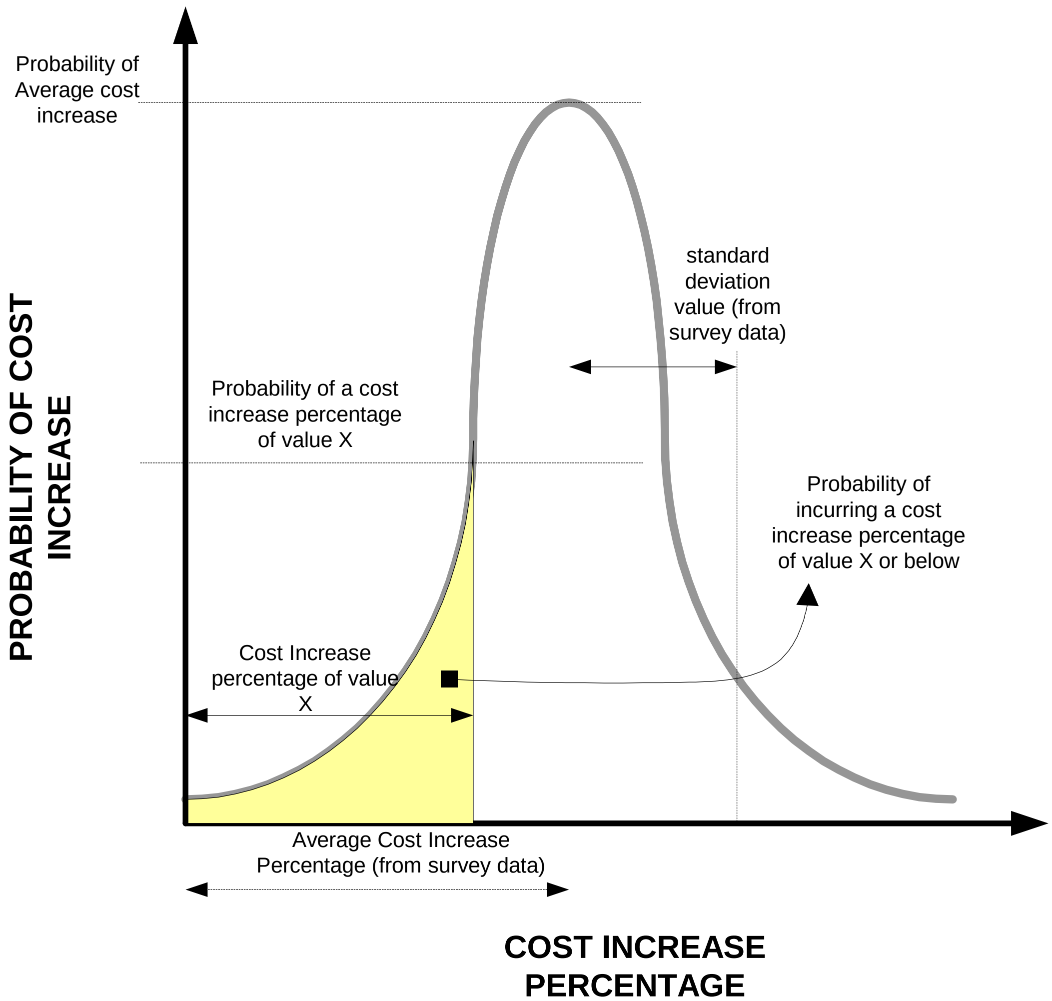


Figure 45. Normal Distribution Used for Cost Increase Percentage

Since the cost increase follows a normal distribution, a probabilistic approach was used to obtain an average percent increase as well as a confidence interval. Given a certain degree of certainty (which is input by the user), EVALUNITE in turn calculate the maximum expected cost increase percentage. This is done by utilizing the normal distribution function:

$$f(y) = \frac{e^{-(y-\mu)^2 / 2\sigma^2}}{\sigma\sqrt{2\pi}} \cdots \sigma > 0, \quad -\infty < \mu < \infty, \quad -\infty < y < \infty$$

where,

f(y) = The probability corresponding to the normal distribution.

Y = cost increase percentage

μ = the arithmetic mean of the distribution.

σ = the standard deviation of the distribution.

Given these values, the inverse of the normal cumulative distribution for the specified mean and standard deviation is calculated. This is calculated using an iterative technique. Given a probability value, a number or successive iterations are carried out until the result is accurate to within ± 3x10^-7.

The average cost increase was found to be about eleven percent with a standard deviation of about 3.6. Therefore, in order to determine the maximum expected cost increase in EVALUNITE, the users need to enter the probability of incurring that maximum cost increase.

For example, given a probability of 80 percent, the maximum expected cost increase is 14 % (using the data from the surveys, i.e. an average of 11 % and a standard deviation of 3.6). This means that there is an eighty percent chance of incurring a cost increase of 14 percent or less. Generally, the higher the probability the higher the expected maximum cost increase.

Alternatively, users can directly enter the expected percent cost increase, if it is known beforehand for a specific construction operation. Users can also edit and save the average and standard deviation values if more data becomes available, to be used to make decisions about future projects. The construction cost user interface is shown in Figure 46.

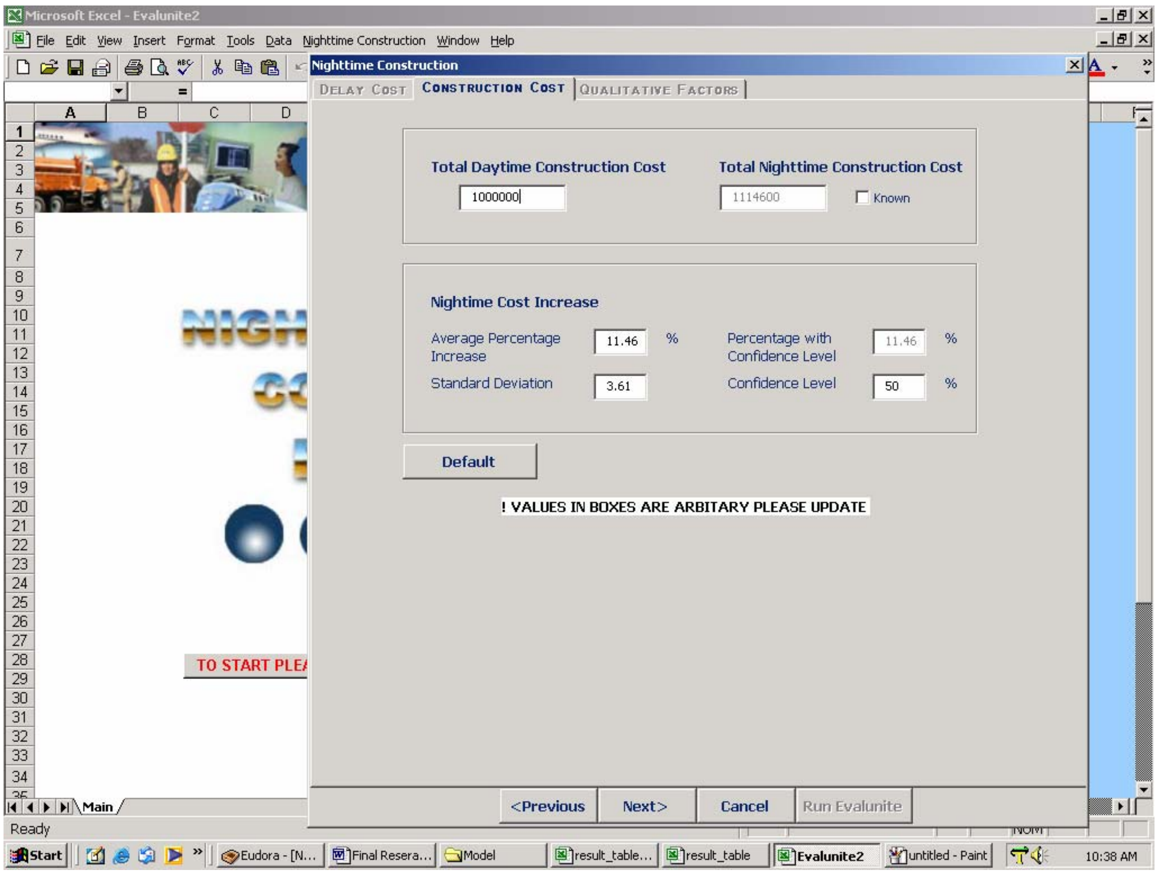


Figure 46. EVALUNITE Interface for the Construction Cost Model

4.3.2 EFFECTIVENESS MODULE

A number of qualitative aspects were also considered in the model. The qualitative aspects considered were related to 3 main aspects: environmental and social related factors, safety factors and construction related factors. A number of factors were identified in relation to each of these three different aspects. The environmental aspects include factors like noise disturbance, economic impacts on surrounding business, light glare to motorists and air pollution. The safety aspects considered here involve traffic safety and workers safety. Finally, construction related factors involve materials/equipment availability, freedom to plan lane closures, work quality and temperature.

Since these are qualitative aspects, the performance of the different construction alternatives will vary for each project according to the particular circumstances of the project. They have to be evaluated by the district or IDOT for each specific project individually. Each aspect is to be evaluated and then given a score out of 5. A score of 5 indicates a high degree of effectiveness and vice versa. In addition weights are assigned to the three different aspects to indicate the degree of importance for each specific situation. Table 32 shows a tabulated format of the effectiveness model with hypothetical weighs and ratings.

In order to simplify the process however, EVALUNITE utilizes a more intuitive users' interface as shown in Figure 47. The user first assigns a relative importance weight for each of the three aspects using the slider control. Next the user assigns the score for each factor in a similar manner. EVALUNITE converts the textual assessments (e.g. high risk, severe glare) to numerical values and calculates a total effectiveness that will be used in evaluating the suitability of night shifts as described in the following section.

Table 32. Sample Weights and Effectiveness Measures

Aspects/ Objectives	Factor	Weight	Rating		Subtotal	
			Daytime	Nighttime	Daytime	Nighttime
Environmental and Social Factors	Noise Disturbance	1	1	1		
	Economic Impacts on Surroundings Business		1	1		
	Light Glare to Motorist		1	1		
	Air Pollution		1	1		
	Overall Rating		**4**	**4**	**4**	**4**
	Traffic Safety	1	1	1	1	1
Safety Factor	Worker's Safety		1	1	1	1
	Overall Rating		**2**	**2**	**2**	**2**
Construction related Factors	Materials/Equipment Availability	1	1	1		
	Freedom to Plan Lane Closures		1	1		
	Work Quality		1	1		
	Temperature		1	1		
	Overall Rating		**4**	**4**	**4**	**4**
	TOTAL				**10**	**10**

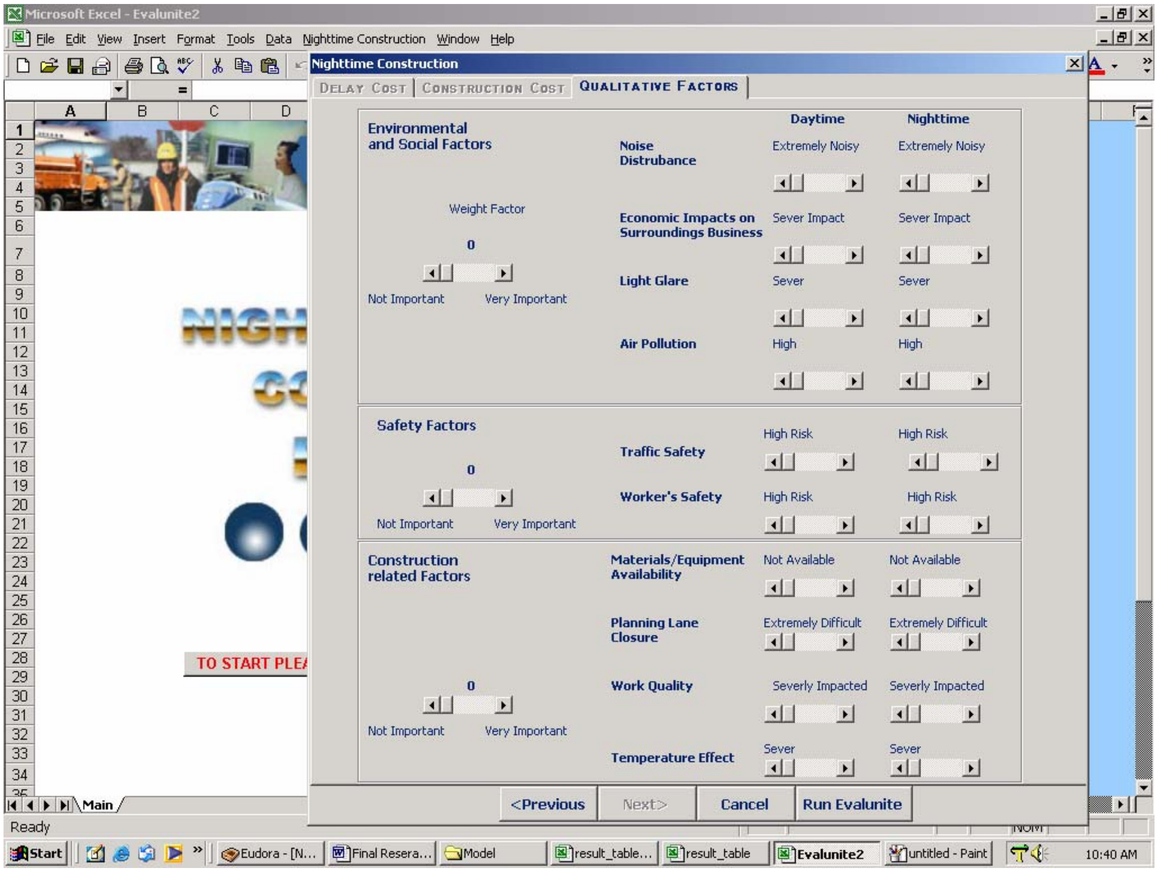


Figure 47. EVALUNITE User Interface for the Effectiveness Module

4.4 EVALUATION AND CHOICE

The total expected cost (which includes users delay and construction costs) and the effectiveness of each alternative are used in making the decision on nighttime construction. Therefore it is important to determine a total score for the effectiveness of each alternative (daytime and nighttime) and use that score in conjunction with the total cost to make the decision. Combining the score of each factor and its relative importance weight to form a combined score can be done using different methods, depending on the decision maker’s preference and the particular situation.

One method to determine the total score of the qualitative aspects is to multiply the aspect relative importance weight W_i by the sum of scores for that particular factor $S_{j,i}$, i.e.,

$$\sum_{i=1}^{3}\left[\sum_{j=1}^{m} S_{j,i}\right] \times W_i$$

Where,

i	represents the three effectiveness aspects being considered
j	represents the factors for any aspect I
$S_{j,i}$	the score given for factor j of aspect i
W_i	weight of aspect I

However, the summation method is good only when one aspect has a dominating effect over the other (Hopgood 1993). This is demonstrated when one alternative yields a completely inappropriate score with respect to a particular aspect that has a low relative importance weight. This alternative can still be placed in a higher order and may still be selected if it performs well with respect to an aspect with a higher relative weight.

Another method is to combine the scores and weights of the various criteria by multiplication, instead of addition, i.e.,

$$\prod_{i=1}^{3}\left[\sum_{j=1}^{m} S_{j,i}\right] \times W_i$$

Using this method an alternative, that has good all-round performances with respect to all aspects, is more likely to be recommended.

Both the summation and multiplication methods will over emphasize the weight of the aspect over the value of the aspect score, i.e. the sum of the factor scores (Hopgood 1993). In situations when differences between the aspect scores for the different alternatives is relatively small, any of these two methods would be useful, as it allows the designer to emphasize the relative importance weight of the aspect.

However, a third method was developed to address the issue of over emphasizing the weight of the aspect over the aspect score (Reid 1980). Using this third method the least appropriate alternative is actually the one that has the lowest score for the aspect with the highest relative importance. The combined score is still calculated by multiplication but two new terms are added so that the combined score becomes,

$$\prod_{i=1}^{3} W_i \times \left[\left[\left(\sum_{j=1}^{m_i} S_{j,\,i} \right) - \text{offset}_i \right] + \text{scale\_shift}_i \right]$$

In this method the *scale_shift* term is the smallest number that will ensure that the combined score of the weight and score, remains a positive value. The *offset* term is used to indicate degrees of undesirability. Scores lower that the *offset* value indicates the degree of undesirability of the alternative with respect to the particular criterion.

The decision maker can select which method to use to evaluate the combined score based on the particular situation. The software developed currently incorporates the first method. However in the future it will allow for the user to select the appropriate method depending on the specific situation. This gives increased flexibility in the selection procedure.

Once the combined effectiveness score is calculated, the decision on nighttime versus daytime can be easily made. The decision maker (or user of the model) can evaluate the total expected cost (which as mentioned above includes users' delay and construction costs) of both alternatives as well as the effectiveness scores and make an informed decision on which alternative to use.

In the case where more than one construction alternative can be utilized, (i.e. in cases when the DOT has the option to close a single lane or two lanes), a cost effectiveness chart such as that in figure 9 can be used. In this chart, limits on the acceptable effectiveness scores and total costs can be set, and in return any alternative not meeting these minimum requirements would not be considered feasible. On the other hand alternatives in the feasible area of the chart can be evaluated based on their total cost and effectiveness scores.

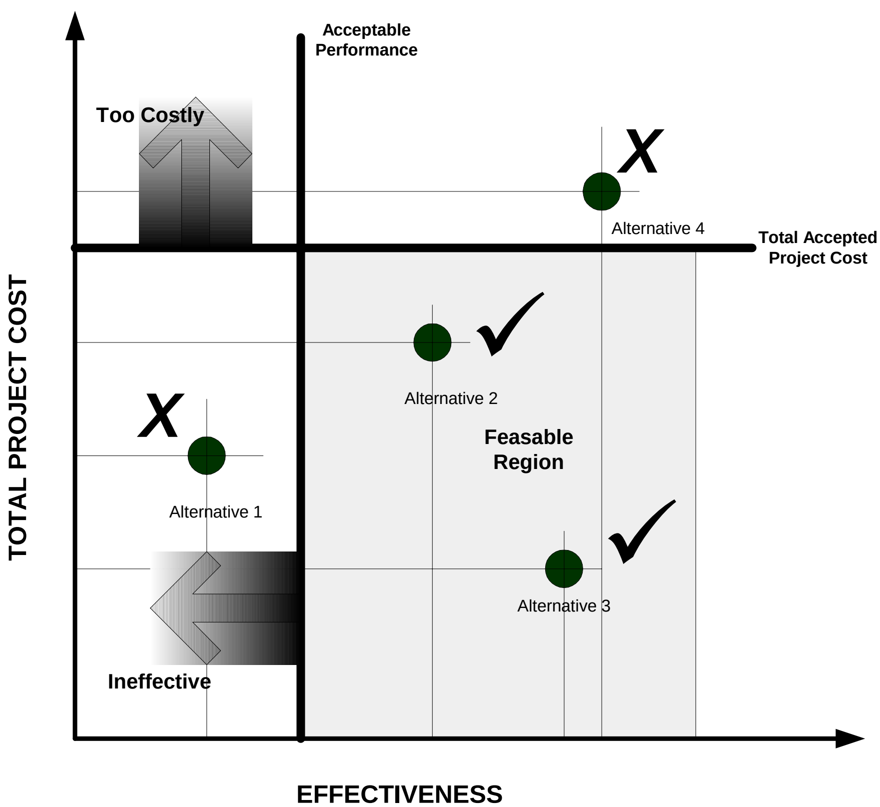


Figure 48. Effectiveness versus Cost for Multiple Alternatives

5 SUMMARY

In the last two decades, the shift from building new highway facilities to maintaining and upgrading existing ones has been on the rise. This shift has mainly been induced by the ever-increasing traffic demand on the already-congested highway systems and the simultaneous decline in funding new highway projects. Road maintenance and reconstruction usually cause serious disruptions to traffic, resulting in significant delays, increased fuel consumption, and negative impacts on air quality and traffic safety.

Scheduling construction activities during nighttime, when traffic demand is typically at its lowest levels, is being viewed by many transportation agencies as an effective strategy to alleviate the negative impacts of work zones on the traveling public. Many other aspects are also affected by nighttime operations and therefore need to be considered in making decisions on the use of nighttime operations. Some of these aspects are construction-related, traffic-related, or related to society and environment.

Nighttime Construction: Advantages and Disadvantages

A comprehensive state-of-the-art review was conducted to determine the advantages and disadvantages of nighttime construction.

Advantages:

- Reduction in delay and congestion
- Less air pollution
- Energy conservation
- Minimizing inconvenience to the traveling public
- Longer work periods
- Less impact on surrounding businesses

Disadvantages:

- Traffic safety

- Work quality
- Work productivity
- Workers safety
- Material availability and equipment maintenance
- Higher construction costs
- Difficulties in scheduling
- Noise disturbance to surrounding communities

For details on these items, see also section 2.1.

Current Practice

Studies have identified the issues that contributed the most to the decision to work at night. As might be expected, high daytime traffic and congestion were the leading issues as stated in Tables 1 and 2 of section 2.2 which also state other contributing issues.

Main Variables

Traffic-related variables are discussed in section 2.3.1 and include several items. First of all, delay and congestion items (section 2.3.1.1) need to be considered:

- Quantifying delay and impact assessment using deterministic queuing analysis, shockwave analysis, and Traffic simulation.
- Components of cost valuation including the value of travel time spent by drivers, vehicle operating costs, and accident costs.
- Use of current models such as QUEWZ, CO^3, and MicroBENCOST.

Safety (Section 2.3.1.2) is a serious concern and the following items should be considered:

- Impact assessment considering higher risk and severity of work zone accidents.

- Cost valuation including productivity losses, property damage, medical and rehabilitation, travel delay, legal and court costs, emergency service, and costs to employers.

Traffic control (section 2.3.1.3) is another important variable with following items to be considered:

- Temporary traffic control at work zones should include 1) a temporary traffic control plan that describes temporary traffic control measures to be used for facilitating road users through a work zone, and 2) traffic control zone (work zone) and traffic diversion strategies through detours or alternative routes
- Common traffic control devices include warning signs, changeable message signs (CMS), channelizing devices, arrow panels, temporary traffic barriers, and pavement markings

The last traffic related variable relates to the vehicle operating costs (section 2.3.1.4). Software programs are available to estimate vehicle operating costs as part of road user costs:

- MicroBENCOST is used to perform highway user cost-benefit analysis at the project level.
- QUEWZ is used to estimate delays and road user costs associated with work zones.

Construction-related variables need to be considered as well as the traffic-related variables above.

Quality issues (section 2.3.2.1) include several performance measures related to nighttime construction:

- Surface smoothness or ride ability, is affected due to the change in illumination and the use of artificial lighting, which in turn affect workers' visibility.

- Compaction is another construction activity where quality can be affected during nighttime construction, though it is less significant than that of surface smoothness.
- Other factors that are believed to adversely affect the quality of nighttime construction include: poor visibility, inadequate lighting, lack of supervision and inspection, and poor workers' morale.
- Certain jobs are more suited for nighttime construction than others in respect to the achieved quality. Results of contractor views on this subject are discussed in section 3.2.3.2.2.

Construction costs (section 2.3.2.2) are certainly another important construction-related variable. Important points include:

- Most studies in the literature suggest that nighttime construction results in higher costs than daytime construction. Several studies are examined where estimates of extra costs range from 0% to 40%.
- Productivity of nighttime construction is affected by several factors including difference in temperature, workers morale, lighting conditions, and traffic loads.
- Nighttime construction poses unique safety risks for workers due to the lower visibility for drivers and equipment operators during nighttime as well as the high proportion of drivers under the effect of fatigue, drugs, or alcohol.

Environmental and social impacts of nighttime construction (section 2.3.3) need to be considered as well as the traffic-related and construction-related variables previously mentioned. The main environmental impacts are related to the effect of the following items:

- Noise—where mitigating the effects of noise in nighttime construction can be accomplished by three main controls: source control, path control and receptor control.

- The dust problem is accentuated in nighttime construction by lighting of the site, which makes particulate matter more visible. However, mitigation techniques are the same as during the day.
- To prevent vibration problems, equipment should be placed as far away as possible or different methods selected.
- Environmental concerns are addressed in some localities by limiting the timing of operations due to ozone concerns.
- Economic impact can be addressed by engaging the public in campaigns and programs to minimize not only the effect on the nearby businesses and residences but also to enhance traffic flow.

Social impacts are further addressed by different techniques used for public awareness. Results show that the common medium used was the newspaper, followed by radio and television.

Questionnaire Surveys

The second phase of the research project involved conducting three questionnaire surveys that were sent to state Departments of Transportation (DOT's), IDOT districts, and IDOT highway contractors. The surveys solicited important information on issues concerned with nighttime construction experience and practices in Illinois as well as in other states.

DOT's Response

State DOT's reported (section 3.1) that most highway construction projects involved daytime shifts only, but that not only varied from state to state, but also locality to locality.

The most important findings are summarized below:

- Nighttime shift and dual shifts account for a small percentage of highway construction projects. The only exception in practice was found in the states of California and Michigan. In California, the vast majority of highway construction projects were conducted using dual shifts and only a small percentage of projects were conducted using daytime shift only. In Michigan, both daytime shift only and dual shifts roughly involved the same percentage of highway construction.

- Half of the respondent states do not follow any formal procedures in making nighttime construction decisions. The most important factor in making these decisions by state DOT's is avoiding daytime traffic, followed by traffic safety and workers safety. The results suggest that construction-related factors such as work quality and productivity have less importance in making these decisions.
- Consistent with the previous finding, the most important advantage as perceived by state DOT's is reducing delay and congestion. On the other hand, deterioration in visibility during nighttime was found to be the most important concern of nighttime operations.
- The traditional contracting and lane rental methods were found most suitable for nighttime construction projects.
- Construction costs and administrative costs are generally higher during nighttime. The extra cost is in the range 0% to 25%.
- Research results suggest that production rates are slightly impacted during nighttime. However, while this may apply to most construction and maintenance activities, it seems that it does not apply to some other activities. Also, these results suggest that work quality in nighttime jobs is comparable to that of daytime jobs.
- Some construction and maintenance activities were found more suitable for nighttime operations than others. Construction of bituminous surfaces and pavements, concrete sawing and the shoulder work were the top three construction activities. On the other hand, repair of concrete pavement, milling and removal, and resurfacing were the top three maintenance activities.

- Only 50% of the responding states reported that they normally estimate delay and congestion in making decisions on nighttime construction. The use of manual queuing analysis was reported by 33% of the responding states while the use of software was reported by 28% of the responding states.
- Traffic control plans during nighttime were found to involve extra cost in comparison with daytime plans (most states reported 0%-20% extra cost). These plans are prepared by highway agencies in most of highway construction projects. However, some states may cooperate with the contractor in preparing these plans or require contractors to prepare the plans, depending on the circumstances.
- Among the social, economic, and environmental factors, impacts on surrounding communities and businesses are perceived to have more importance than environmental impacts such as air pollution and energy conservation.

Contractor Response

This survey (section 3.2) involved a questionnaire that raised issues most related to contractors such as; construction cost, productivity, quality, social and physical impacts. This questionnaire went to 89 construction companies who worked for IDOT and were located in the state of Illinois. Multiple copies were sent to each contractor to get input from people at different projects.

The issues were organized in four different sections. The first section involved questions about the nighttime construction practice from the contractors' perspective.

The second section involved questions related to construction cost. The extra line items for nighttime projects and cost differential between nighttime and daytime projects were investigated in this section.

Issues related to construction quality and productivity were addressed in the third section of the questionnaire. This section involved questions about the contractors experience and perception of quality and productivity in nighttime projects.

Finally, the last section of the questionnaire involved questions about some social and physical aspects of nighttime work.

The most important findings are repeated below:

- The vast majority of contractors surveyed prefer the conventional daytime shift. Only a small number of contractors are indifferent about performing work during night or dual shifts.
- It is evident that the majority of contractors perceive nighttime construction work as disadvantageous in general, or in other words, the disadvantages of night shifts outweigh the advantages.
- Results suggest that contractors do not perceive contracting method as an important factor in nighttime construction projects.
- A slight majority of the contractors surveyed would prefer to bid extra costs as a separate pay item.
- Nighttime construction is associated with 0-25% increase in labor, personnel, and supervision costs.
- Nighttime construction is associated with 0-25% increase in materials and equipment costs.
- In general, work quality is negatively impacted if work is performed during nighttime. Resurfacing and surface treatment were identified as having the worst quality when compared to daytime jobs. Nighttime pavement marking, reworking shoulders and highway signing operations were identified as having the closest quality to that of daytime jobs.
- The productivity of nighttime jobs, in general, was found to be slightly lower than that of daytime jobs. Bridge deck, waterproofing and sealing, and reworking shoulders were found to be the worst three operations in terms of lost productivity during nighttime.

- Results suggest that workers during night shifts get less-than-average hours of sleep (average 5.5 hrs) and more-than-average hours at work (average 10.32 hrs).
- Survey results suggest that night shifts have a negative impact on worker's social life.

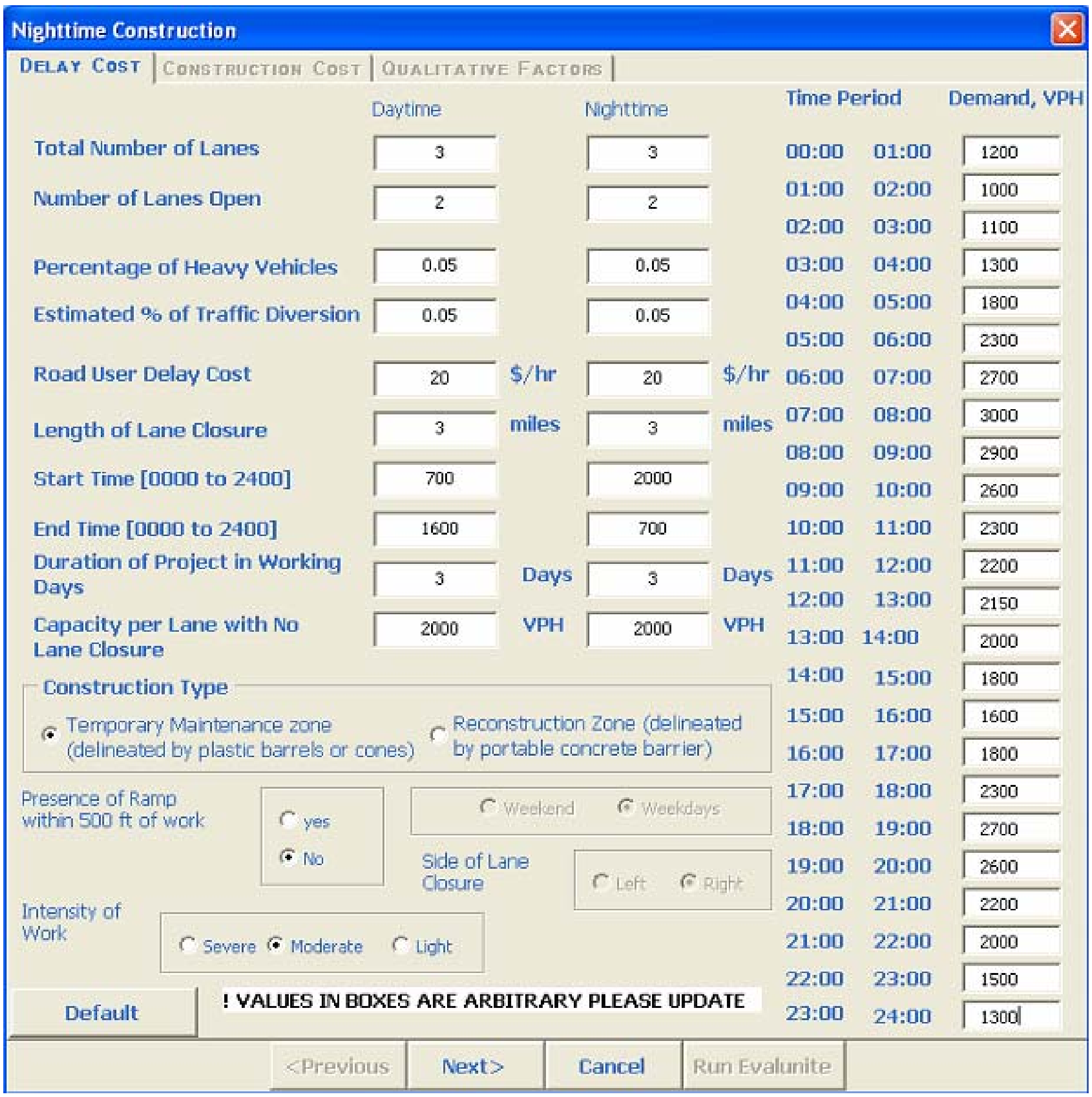
Computer Model

The last phase of the project involved the development of a software package to be used by agency personnel in making an informed comparison between day shifts and night shifts. This is to be used to complement other important information available to decision makers in making decisions on nighttime construction operations. Documentation is included in Section 4.

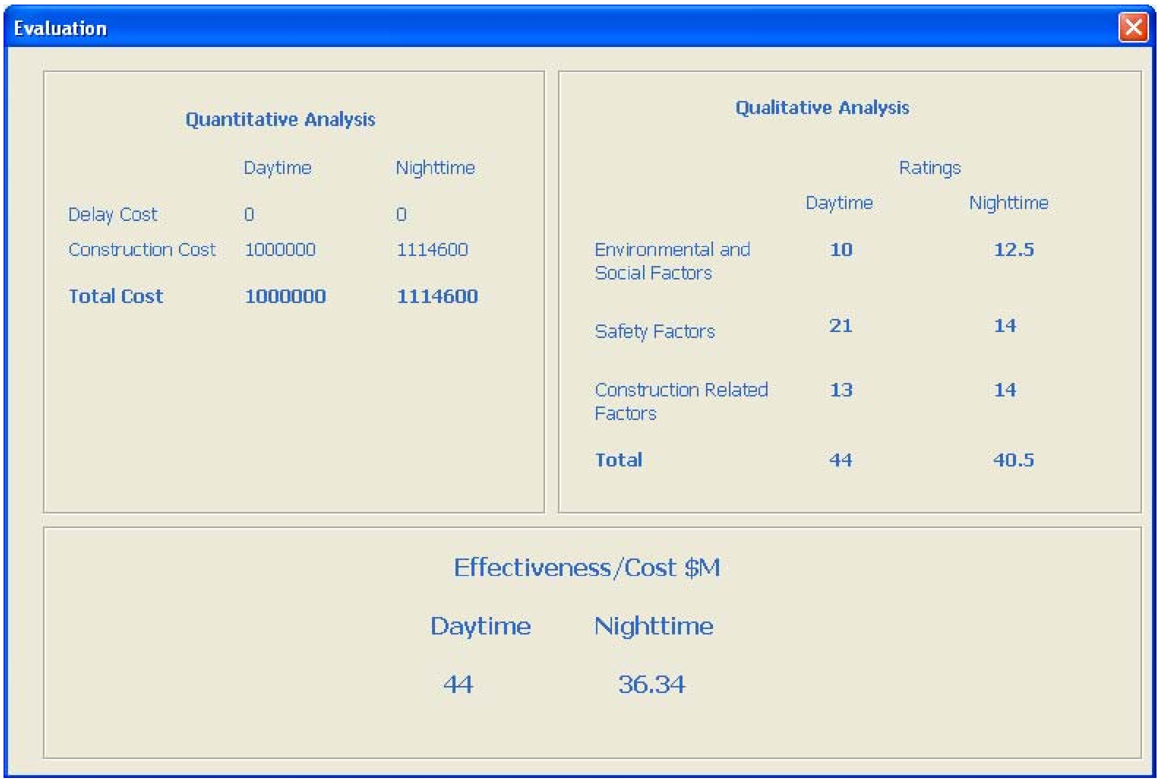
The decision making assisting tool EVALUNITE, is applicable to all situations when night shifts are thought of as an alternative to conventional daytime shifts. The software utilizes cost-effectiveness analysis as a tool to evaluate complex multi-faceted problems such as transportation problems.

It is to be used whenever night shift is thought of as an alternative to the conventional daytime shift. The software was developed using Microsoft Excel spreadsheets and Visual Basic for Applications (VBA). The software has a user-friendly interface that leads the user through the process of data input and running the model in a simple and clear manner. The researchers fully realize that input data is project sensitive and may largely differ from one project to another. Therefore, most input variables are user-specified. However, default values were set for these variables in case the required information is not available to the user. This feature is very useful as it is quite likely for the users not to have all the input data especially at the planning stage of the project. In determining these default values, the researchers attempted to reach realistic estimates for many parameters based on what is available from previous studies and the results from questionnaire surveys that were conducted as part of this research project.

The user must have the full version of Excel installed on a PC (it is not compatible with a Macintosh). Excel will notify the user that the software uses macros, which must be enabled when prompted at startup. The program is very transparent by using the commands that are in the new “Nighttime” pulldown menu at the top of the screen along with the other pulldown menus, and the program will prompt for input that varies from the default values as shown in the illustration that follows.



The model consists mainly of two main modules, the cost module and the effectiveness module. The cost module assesses all the variables that can be quantified using dollar values while the effectiveness module evaluates other important variables that cannot be expressed in cost units. Using the priorities and objectives set by the highway agency, the model comes up with a recommendation concerning the use of night shifts in highway projects as follows.



This software is available from the Illinois Department of Transportation, Bureau of Materials and Physical Research.

6 CONCLUSIONS AND RECOMMENDATIONS

Several conclusions and recommendations with regard to nighttime construction operation decisions can be reached as a result of this research project.

Conclusions:

- Currently, daytime-shift-only projects constitute the majority of highway construction projects. Projects with dual shifts are relatively more common in practice than the nighttime-shift-only projects.
- The most important advantage of nighttime construction is the significant reduction in congestion and delay for the traveling public that would otherwise incurred during daytime. Minimizing impact on surrounding businesses was found to have moderate significance.
- The quality of nighttime construction projects is comparable to that of daytime projects.
- Certain construction activities are better suited for nighttime construction than others. Waterproofing and sealing, and highway signing were identified as operations that will have the least equipment and material cost increase if performed at night. Reworking shoulders was also identified among the top three operations with the least cost increase.
- Costs may be more for nighttime construction when compared to construction during the daytime. Two of the main reasons for the increase in costs of nighttime jobs are the extra lighting requirements and the increase in administrative costs (due partially to extra compensation for working during nighttime).
- Computer software could be used to a greater extent to help plan projects. Traffic models such as QUEWZ, CO^3, QuickZone, and MicroBENCOST are proven packages.

Recommendations: Based on the work of the researchers, it is recommended that IDOT incorporate the following guidelines in the Bureau of Design and Environment Policy Manual:

- Scheduling construction activities during nighttime should be considered. This is when traffic demand is typically at its lowest levels, and proves to be an effective strategy to alleviate the negative impact of work zones on the traveling public.
- Bidding documents specific to nighttime construction in the bill of materials should be used to help identify costs that impact decisions. One method is to bid nighttime construction as an alternate. Another is to bid extra costs associated with nighttime construction as a separate pay item.
- The traditional contracting method, the lane rental method, and A+B contracting methods should be explored as possible methods for nighttime construction suitability. The lane rental method is an innovative contracting technique by which a contractor is charged a fee for occupying lanes or shoulders to do the work. The A+B is essentially a cost plus time bidding procedure that selects the low bidder based on a monetary combination of the contract bid items (A) and the time (B) needed to complete the critical portion of the project.
- The Excel spreadsheet EVALUNITE that was developed through this project should be utilized to help evaluate the considerations necessary in making a decision regarding nighttime construction. This software is available from the Illinois Department of Transportation, Bureau of Materials.

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APPENDIX A: STATE DOTS QUESTIONNAIRE SURVEY

BRADLEY
UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING AND CONSTRUCTION

QUESTIONNAIRE SURVEY
ITRC PROJECT IVA-H2, FY 00/01

NIGHTTIME CONSTRUCTION: EVALUATION OF CONSTRUCTION OPERATIONS

STATE DEPARTMENTS OF TRANSPORTATION

This survey is intended for the evaluation of nighttime construction operations in the State of Illinois. The objectives mainly involve surveying the amount of nighttime construction, its main advantages and disadvantages, and identifying the construction operations that are most suited to nighttime construction. Your cooperation in responding to this questionnaire is greatly appreciated.

Name: ______________________________

Position: ______________________________

Organization: ______________________________

Date: ______________________________

Section A: Nighttime Construction Practice

1. Over the past five years, estimate the approximate percentage of highway construction projects that are performed during the following shifts (based on $ value)

	0% to 20%	20% to 40%	40% to 60%	60% to 80%	80% to 100%	No experience
Daytime Shifts only	☐	☐	☐	☐	☐	☐
Nighttime Shifts only	☐	☐	☐	☐	☐	☐
Dual Shifts	☐	☐	☐	☐	☐	☐

2. Over the past five years, estimate the percentage of nighttime construction projects that are located on 2-lane roads (as opposed to multilane roads)

☐ 0%-20%
☐ 20%-40%
☐ 40%-60%
☐ 60%-80%
☐ 80%-100%
☐ No experience

3. Does your agency follow specific procedures in selecting nighttime construction operations?

☐Yes ☐No

If yes, do these procedures estimate road user costs?

☐Yes ☐No

4. Rate the following factors in terms of their importance in making decisions on nighttime construction by your agency (1:unimportant, 5:very important).

ITEM	**1**	**2**	**3**	**4**	**5**
High daytime *traffic*	☐	☐	☐	☐	☐
Longer work hours	☐	☐	☐	☐	☐
Road user costs	☐	☐	☐	☐	☐
Scheduling issues	☐	☐	☐	☐	☐
Traffic control	☐	☐	☐	☐	☐
Traffic safety	☐	☐	☐	☐	☐
Workers safety	☐	☐	☐	☐	☐
Temperature	☐	☐	☐	☐	☐
Disruption to surrounding businesses	☐	☐	☐	☐	☐
Noise	☐	☐	☐	☐	☐
Freedom in planning lane closures	☐	☐	☐	☐	☐
Work quality	☐	☐	☐	☐	☐
Lighting Issues	☐	☐	☐	☐	☐
Productivity	☐	☐	☐	☐	☐
Others: please specify					
1.	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐

5. Rate the following benefits (advantages) of nighttime construction in terms of their significance as perceived by your agency (1: insignificant, 5:very significant)

BENEFITS	1	2	3	4	5
Less delay *and* congestion	☐	☐	☐	☐	☐
Less air pollution	☐	☐	☐	☐	☐
Longer work hours	☐	☐	☐	☐	☐
More freedom to plan lane closures	☐	☐	☐	☐	☐
Lower impact on surrounding businesses	☐	☐	☐	☐	☐
Other: specify					
1.	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐

6. Rate the following concerns (disadvantages) of nighttime construction in terms of their significance as perceived by your agency (1: insignificant, 5:very significant).

CONCERNS	1	2	3	4	5
More traffic *accident* rates	☐	☐	☐	☐	☐
More worker accident rates	☐	☐	☐	☐	☐
Inferior work quality	☐	☐	☐	☐	☐
Decreased productivity	☐	☐	☐	☐	☐
Materials availability problems	☐	☐	☐	☐	☐
Equipment maintenance problems	☐	☐	☐	☐	☐
Visibility problems	☐	☐	☐	☐	☐
Higher construction costs	☐	☐	☐	☐	☐
Worker and equipment scheduling problems	☐	☐	☐	☐	☐
Noise	☐	☐	☐	☐	☐
Others: please specify					
1.	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐

7. Do state supervision personnel receive an extra compensation for working nighttime

   ☐Yes ☐No

   If yes, please specify:

8. Based on your experience, how do the administrative costs of nighttime jobs compare to similar daytime jobs

   ☐ Less than -50%
   ☐ -25 to -50%
   ☐ -25% to 0
   ☐ Same
   ☐ 0% to 25%
   ☐ 25% to 50%
   ☐ 50% and above
   ☐ No experience

Section B: Construction Related Issues

9. Based on your experience, how does the cost of nighttime jobs compare to similar daytime jobs

- ☐ Less than -50%
- ☐ -25 to -50%
- ☐ -25% to 0
- ☐ Same
- ☐ 0% to 25%
- ☐ 25% to 50%
- ☐ 50% and above
- ☐ No experience

10. Based on your experience rate the following contracting methods in terms of suitability for nighttime construction (1 = Completely unsuited to 5 = Perfectly suited)

CONTRACTING METHOD	**1**	**2**	**3**	**4**	**5**	**No experience**
Traditional1	☐	☐	☐	☐	☐	☐
Design Build2	☐	☐	☐	☐	☐	☐
A+B3	☐	☐	☐	☐	☐	☐
Lane Rental4	☐	☐	☐	☐	☐	☐
Warranty Contracting5	☐	☐	☐	☐	☐	☐
Job Order Contracting6	☐	☐	☐	☐	☐	☐
Others, Specify						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐

11. Based on your experience rate the following highway ***maintenance*** activities in terms of their suitability for nighttime construction (1 = Completely unsuited to 5 = Perfectly suited)

---

1 Traditional Definition: Traditionally highway projects are designed, bid, and built with the contract awarded to the lowest bidder.

2 Design Build Definition: When a single entity provides both the design and construction through a single contract between the owner and the Design-Build firm.

3 A+B Definition: A cost plus time bidding procedure that selects the low bidder based on a monetary combination of the contract bid items (A) and the time (B) needed to complete the critical portion of the project

4 Lane Rental Definition: An innovative contracting technique by which a contractor is charged a fee for occupying lanes or shoulders to do the work.

5 Warranty Contracting Definition: “A guarantee of the integrity of a product and of the makers responsibility for the replacement or repair of deficiencies.”

6 Job Order Contracting Definition: The combining of like projects into one contract that is administered by the owner/agency.

Maintenance Activity	1	2	3	4	5	No experience
Maintenance of Earthwork/Embankment	☐	☐	☐	☐	☐	☐
Reworking Shoulders	☐	☐	☐	☐	☐	☐
Milling and Removal	☐	☐	☐	☐	☐	☐
Resurfacing	☐	☐	☐	☐	☐	☐
Repair of concrete pavement	☐	☐	☐	☐	☐	☐
Crack Filling	☐	☐	☐	☐	☐	☐
Pot Hole Filling	☐	☐	☐	☐	☐	☐
Surface Treatment	☐	☐	☐	☐	☐	☐
Waterproofing/Sealing	☐	☐	☐	☐	☐	☐
Sidewalks repair & Maintenance	☐	☐	☐	☐	☐	☐
Bridge Decks Rehabilitation and Maintenance	☐	☐	☐	☐	☐	☐
Drainage structures maintenance & rehabilitation	☐	☐	☐	☐	☐	☐
Sweeping and cleanup	☐	☐	☐	☐	☐	☐
Please list any additional maintenance activities						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐

12. Based on your experience, in general how does the quality of nighttime jobs compare to similar daytime jobs (measured by problems or percent of redo work not meeting specs)

    ☐ Less than -50%
    ☐ -25 to -50%
    ☐ -25% to 0
    ☐ Same
    ☐ 0% to 25%
    ☐ 25% to 50%
    ☐ 50% and above
    ☐ No experience

13. Based on your experience, in general how do the production rates of nighttime jobs compare to similar daytime jobs in general

    ☐ Less than -50%
    ☐ -25 to -50%
    ☐ -25% to 0
    ☐ Same
    ☐ 0% to 25%
    ☐ 25% to 50%
    ☐ 50% and above
    ☐ No experience

14. Based on your experience rate the following highway ***construction*** activities in terms of their suitability for nighttime construction (1 = Completely unsuited to 5 = Perfectly suited)

CONSTRUCTION ACTIVITY	1	2	3	4	5	No experience
Earthwork: excavation/embankment/backfill	☐	☐	☐	☐	☐	☐
Landscaping: seeding/mulch/sodding/planting	☐	☐	☐	☐	☐	☐
Erosion control: riprap/ditch lining	☐	☐	☐	☐	☐	☐
Sub-grade	☐	☐	☐	☐	☐	☐
Sub-base and Base course	☐	☐	☐	☐	☐	☐
Construction of bituminous surfaces and pavements	☐	☐	☐	☐	☐	☐
Concrete pavement and sidewalks	☐	☐	☐	☐	☐	☐
Shoulders: bituminous and Portland cement concrete	☐	☐	☐	☐	☐	☐
Bridge Construction	☐	☐	☐	☐	☐	☐
Culverts and sewers	☐	☐	☐	☐	☐	☐
Drainage structures	☐	☐	☐	☐	☐	☐
Guardrail and fences	☐	☐	☐	☐	☐	☐
Work traffic control	☐	☐	☐	☐	☐	☐
Highway signing	☐	☐	☐	☐	☐	☐
Pavement marking: striping and markers	☐	☐	☐	☐	☐	☐
Electrical wiring and cables	☐	☐	☐	☐	☐	☐
Concrete sawing	☐	☐	☐	☐	☐	☐
Electrical poles and posts: lighting/traffic signals	☐	☐	☐	☐	☐	☐
Please list any additional construction activities						
1.	☐	☐	☐	☐	☐	
2.	☐	☐	☐	☐	☐	
3.	☐	☐	☐	☐	☐	

Section C: Traffic-Related Issues

15. If delay and congestion are one of the factors that are considered by your agency in selecting night shifts or in estimating road user costs, what are the tools / methods your agency use to estimate delay and congestion at work zones?
    - ☐Manual simple queuing analysis
    - ☐Software:
        - ☐QUEWZ
        - ☐QuickZone
        - ☐Other: please specify ______
    - ☐ None

16. In estimating road user costs, what is the value for delay cost used by your agency?

____

17. Does your agency use dollar values in estimating traffic accident costs?

☐Yes ☐No

If yes, what are these values?

____

18. In planning traffic control at work zones, temporary traffic control plans are prepared by:

☐Your agency
☐Contractor
☐Jointly by your agency & contractor

19. Does traffic control during nighttime construction involve extra cost as compared with daytime construction?

☐Yes ☐No

If yes, please select the range of extra cost from the following:

☐ 0%-20%
☐ 20%-40%
☐ 40%-60%
☐ 60%-100%
☐ Don't know

20. Based on your past experience, estimation of delay and congestion in planning daytime construction activities is:

☐ Accurate
☐ Somewhat accurate
☐ Inaccurate: check one of the boxes below
☐ Overestimation of delay & congestion
☐ Underestimation of delay & congestion
☐ Both (based on circumstances)

Section D: Social, Economic, & Environmental Issues

21. Does your agency estimate the following nighttime impacts? (Check the ones that apply)

☐ Noise to residential areas
☐ Impact on surrounding business
☐ Air pollution / Energy consumption
☐ Light Trespassing

22. If yes to any of boxes in 21 above, please briefly describe how these impacts are estimated.

____

23. During the past five years, please indicate:

The total number of nighttime construction projects that you worked on: ☐

The total number of all the projects that you worked on: ☐

24. Please provide any additional comments or explanations:

____
____
____
____
____
____
____

PLEASE ATTACH ANY WRITTEN POLICIES OR PROCEDURES REGARDING NIGHTTIME CONSTRUCTION YOU CAN SHARE.

We wish to express our gratitude for your valuable time and effort in responding to this questionnaire

Please complete this questionnaire and return to:

Prof. Ahmed Al-Kaisy
Department of Civil Engineering and Construction
Bradley University
1501 W. Bradley Avenue
Peoria IL, 61625

Email: alkasiy@bradley.edu
Phone: 1 309 677 2779
Fax: 1 309 677 2867

APPENDIX B: IDOT DISTRICTS QUESTIONNAIRE SURVEY

BRADLEY
UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING AND CONSTRUCTION

QUESTIONNAIRE SURVEY
ITRC PROJECT IVA-H2, FY 00/01

NIGHTTIME CONSTRUCTION: EVALUATION OF CONSTRUCTION OPERATIONS

ILLINOIS DEPARTMENT OF TRANSPORTATION DISTRICTS

This survey is intended for the evaluation of nighttime construction operations in the State of Illinois. The objectives mainly involve surveying the amount of nighttime construction, its main advantages and disadvantages, and identifying the construction operations that are most suited to nighttime construction. Your cooperation in responding to this questionnaire is greatly appreciated.

Name: ____

Position: ____

District: ____

Date: ____

Section A: Nighttime Construction Practice

1. Over the past five years, estimate the approximate percentage of highway construction projects that are performed during the following shifts (based on $ value)

	0% to 20%	20% to 40%	40% to 60%	60% to 80%	80% to 100%	No experience
Daytime Shifts only	☐	☐	☐	☐	☐	☐
Nighttime Shifts only	☐	☐	☐	☐	☐	☐
Dual Shifts	☐	☐	☐	☐	☐	☐

2. Over the past five years, estimate the percentage of nighttime construction projects that are located on 2-lane roads (as opposed to multilane roads)

   ☐ 0%-20%
   ☐ 20%-40%
   ☐ 40%-60%
   ☐ 60%-80%
   ☐ 80%-100%
   ☐ No experience

3. Does your agency follow specific procedures in selecting nighttime construction operations?
   ☐Yes ☐No
   If yes, do these procedures estimate road user costs?
   ☐Yes ☐No

4. Rate the following factors in terms of their importance in making decisions on nighttime construction by your agency (1:unimportant, 5:very important).

ITEM	**1**	**2**	**3**	**4**	**5**
High daytime *traffic*	☐	☐	☐	☐	☐
Longer work hours	☐	☐	☐	☐	☐
Road user costs	☐	☐	☐	☐	☐
Scheduling issues	☐	☐	☐	☐	☐
Traffic control	☐	☐	☐	☐	☐
Traffic safety	☐	☐	☐	☐	☐
Workers safety	☐	☐	☐	☐	☐
Temperature	☐	☐	☐	☐	☐
Disruption to surrounding businesses	☐	☐	☐	☐	☐
Noise	☐	☐	☐	☐	☐
Freedom in planning lane closures	☐	☐	☐	☐	☐
Work quality	☐	☐	☐	☐	☐
Lighting Issues	☐	☐	☐	☐	☐
Productivity	☐	☐	☐	☐	☐
Others: please specify					
3.	☐	☐	☐	☐	☐
4.	☐	☐	☐	☐	☐

5. Rate the following benefits (advantages) of nighttime construction in terms of their significance as perceived by your agency (1: insignificant, 5:very significant)

BENEFITS	**1**	**2**	**3**	**4**	**5**
Less delay and *congestion*	☐	☐	☐	☐	☐
Less air pollution	☐	☐	☐	☐	☐
Longer work hours	☐	☐	☐	☐	☐
More freedom to plan lane closures	☐	☐	☐	☐	☐
Lower impact on surrounding businesses	☐	☐	☐	☐	☐
Other: specify					
3.	☐	☐	☐	☐	☐
4.	☐	☐	☐	☐	☐

6. Rate the following concerns (disadvantages) of nighttime construction in terms of their significance as perceived by your agency (1: insignificant, 5:very significant).

CONCERNS	**1**	**2**	**3**	**4**	**5**
More traffic accident rates	☐	☐	☐	☐	☐
More worker accident rates	☐	☐	☐	☐	☐
Inferior work quality	☐	☐	☐	☐	☐
Decreased productivity	☐	☐	☐	☐	☐
Materials availability problems	☐	☐	☐	☐	☐
Equipment maintenance problems	☐	☐	☐	☐	☐
Visibility problems	☐	☐	☐	☐	☐
Higher construction costs	☐	☐	☐	☐	☐
Worker and equipment scheduling problems	☐	☐	☐	☐	☐
Noise	☐	☐	☐	☐	☐
Others: please specify					
3.	☐	☐	☐	☐	☐
4.	☐	☐	☐	☐	☐

7. Do state supervision personnel receive an extra compensation for working nighttime

   ☐Yes ☐No

   If yes, please specify:

8. Based on your experience, how do the administrative costs of nighttime jobs compare to similar daytime jobs

   ☐ Less than -50%
   ☐ -25 to -50%
   ☐ -25% to 0
   ☐ Same
   ☐ 0% to 25%
   ☐ 25% to 50%
   ☐ 50% and above
   ☐ No experience

Section B: Construction Related Issues

9. Based on your experience, how does the cost of nighttime jobs compare to similar daytime jobs

- ☐ Less than -50%
- ☐ -25 to -50%
- ☐ -25% to 0
- ☐ Same
- ☐ 0% to 25%
- ☐ 25% to 50%
- ☐ 50% and above
- ☐ No experience

10. Based on your experience rate the following contracting methods in terms of suitability for nighttime construction (1 = Completely unsuited to 5 = Perfectly suited)

CONTRACTING METHOD	1	2	3	4	5	No experience
Traditional[1]	☐	☐	☐	☐	☐	☐
Design Build[2]	☐	☐	☐	☐	☐	☐
A+B[3]	☐	☐	☐	☐	☐	☐
Lane Rental[4]	☐	☐	☐	☐	☐	☐
Warranty Contracting[5]	☐	☐	☐	☐	☐	☐
Job Order Contracting[6]	☐	☐	☐	☐	☐	☐
Others, Specify						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐

11. Based on your experience rate the following highway ***maintenance*** activities in terms of their suitability for nighttime construction (1 = Completely unsuited to 5 = Perfectly suited)

---

[1] Traditional Definition: Traditionally highway projects are designed, bid, and built with the contract awarded to the lowest bidder.

[2] Design Build Definition: When a single entity provides both the design and construction through a single contract between the owner and the Design-Build firm.

[3] A+B Definition: A cost plus time bidding procedure that selects the low bidder based on a monetary combination of the contract bid items (A) and the time (B) needed to complete the critical portion of the project

[4] Lane Rental Definition: An innovative contracting technique by which a contractor is charged a fee for occupying lanes or shoulders to do the work.

[5] Warranty Contracting Definition: “A guarantee of the integrity of a product and of the makers responsibility for the replacement or repair of deficiencies.”

[6] Job Order Contracting Definition: The combining of like projects into one contract that is administered by the owner/agency.

Maintenance Activity	1	2	3	4	5	No experience
Maintenance of Earthwork/*Embankment*	☐	☐	☐	☐	☐	☐
Reworking Shoulders	☐	☐	☐	☐	☐	☐
Milling and Removal	☐	☐	☐	☐	☐	☐
Resurfacing	☐	☐	☐	☐	☐	☐
Repair of concrete pavement	☐	☐	☐	☐	☐	☐
Crack Filling	☐	☐	☐	☐	☐	☐
Pot Hole Filling	☐	☐	☐	☐	☐	☐
Surface Treatment	☐	☐	☐	☐	☐	☐
Waterproofing/Sealing	☐	☐	☐	☐	☐	☐
Sidewalks repair & Maintenance	☐	☐	☐	☐	☐	☐
Bridge Decks Rehabilitation and Maintenance	☐	☐	☐	☐	☐	☐
Drainage structures maintenance & rehabilitation	☐	☐	☐	☐	☐	☐
Sweeping and cleanup	☐	☐	☐	☐	☐	☐
Please list any additional maintenance activities						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐

12. Based on your experience, in general how does the quality of nighttime jobs compare to similar daytime jobs (measured by problems or percent of redo work not meeting specs)

    ☐ Less than -50%
    ☐ -25 to -50%
    ☐ -25% to 0
    ☐ Same
    ☐ 0% to 25%
    ☐ 25% to 50%
    ☐ 50% and above
    ☐ No experience

13. Based on your experience, in general how do the production rates of nighttime jobs compare to similar daytime jobs in general

    ☐ Less than -50%
    ☐ -25 to -50%
    ☐ -25% to 0
    ☐ Same
    ☐ 0% to 25%
    ☐ 25% to 50%
    ☐ 50% and above
    ☐ No experience

14. Based on your experience rate the following highway ***construction*** activities in terms of their suitability for nighttime construction (1 = Completely unsuited to 5 = Perfectly suited)

CONSTRUCTION ACTIVITY	1	2	3	4	5	No experience
Earthwork: excavation/embankment/backfill	☐	☐	☐	☐	☐	☐
Landscaping: seeding/mulch/sodding/planting	☐	☐	☐	☐	☐	☐
Erosion control: riprap/ditch lining	☐	☐	☐	☐	☐	☐
Sub-grade	☐	☐	☐	☐	☐	☐
Sub-base and Base course	☐	☐	☐	☐	☐	☐
Construction of bituminous surfaces and pavements	☐	☐	☐	☐	☐	☐
Concrete pavement and sidewalks	☐	☐	☐	☐	☐	☐
Shoulders: bituminous and Portland cement concrete	☐	☐	☐	☐	☐	☐
Bridge Construction	☐	☐	☐	☐	☐	☐
Culverts and sewers	☐	☐	☐	☐	☐	☐
Drainage structures	☐	☐	☐	☐	☐	☐
Guardrail and fences	☐	☐	☐	☐	☐	☐
Work traffic control	☐	☐	☐	☐	☐	☐
Highway signing	☐	☐	☐	☐	☐	☐
Pavement marking: striping and markers	☐	☐	☐	☐	☐	☐
Electrical wiring and cables	☐	☐	☐	☐	☐	☐
Concrete sawing	☐	☐	☐	☐	☐	☐
Electrical poles and posts: lighting/traffic signals	☐	☐	☐	☐	☐	☐
Please list any additional construction activities						
1.	☐	☐	☐	☐	☐	
2.	☐	☐	☐	☐	☐	
3.	☐	☐	☐	☐	☐	

Section C: Traffic-Related Issues

15. If delay and congestion are one of the factors that are considered by your agency in selecting night shifts or in estimating road user costs, what are the tools / methods your agency use to estimate delay and congestion at work zones?
    - ☐Manual simple queuing analysis
    - ☐Software:
        - ☐QUEWZ
        - ☐QuickZone
        - ☐Other: please specify ______
    - ☐ None

16. In estimating road user costs, what is the value for delay cost used by your agency?

____

17. Does your agency use dollar values in estimating traffic accident costs?

☐Yes ☐No

If yes, what are these values?

____

18. In planning traffic control at work zones, temporary traffic control plans are prepared by:

☐Your agency
☐Contractor
☐Jointly by your agency & contractor

20. Does traffic control during nighttime construction involve extra cost as compared with daytime construction?

☐Yes ☐No

If yes, please select the range of extra cost from the following:

☐ 0%-20%
☐ 20%-40%
☐ 40%-60%
☐ 60%-100%
☐ Don't know

21. Based on your past experience, estimation of delay and congestion in planning <u>daytime</u> construction activities is:

☐ Accurate
☐ Somewhat accurate
☐ Inaccurate: check one of the boxes below
☐ Overestimation of delay & congestion
☐ Underestimation of delay & congestion
☐ Both (based on circumstances)

Section D: Social, Economic, & Environmental Issues

22. Does your agency estimate the following nighttime impacts? (Check the ones that apply)

☐ Noise to residential areas
☐ Impact on surrounding business
☐ Air pollution / Energy consumption
☐ Light Trespassing

23. If yes to any of boxes in 21 above, please briefly describe how these impacts are estimated.

____

24. During the past five years, please indicate:

The total number of nighttime construction projects that you worked on: ☐

The total number of all the projects that you worked on: ☐

25. Please provide any additional comments or explanations:

____
____
____
____
____
____
____

PLEASE ATTACH ANY WRITTEN POLICIES OR PROCEDURES REGARDING NIGHTTIME CONSTRUCTION YOU CAN SHARE.

We wish to express our gratitude for your valuable time and effort in responding to this questionnaire

Please complete this questionnaire and return to:

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Department of Civil Engineering and Construction
Bradley University
1501 W. Bradley Avenue
Peoria IL, 61625

Email: alkasiy@bradley.edu
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APPENDIX C: IDOT CONTRACTORS QUESTIONNAIRE SURVEY

BRADLEY
UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING AND CONSTRUCTION

QUESTIONNAIRE SURVEY
ITRC PROJECT IVA-H2, FY 00/01

NIGHTTIME CONSTRUCTION: EVALUATION OF CONSTRUCTION OPERATIONS

CONTRACTORS SURVEY

This survey is intended for the evaluation of nighttime construction operations in the State of Illinois. The objective is to investigate the different issues that are related to nighttime construction work. Your cooperation in responding to this questionnaire is greatly appreciated. Any information you provide in this survey will remain strictly confidential.

Name: ____

Position: ____

Contractor's Name: ____

Date: ____

Section A: Nighttime Construction Practice

1. Rate the following working shifts in terms of your preference as a contractor to perform highway construction work (1 = Not preferable, 3 = Same, 5 = Preferable).

	1	**2**	**3**	**4**	**5**	**No experience**
Daytime Shifts only	☐	☐	☐	☐	☐	☐
Nighttime Shifts only	☐	☐	☐	☐	☐	☐
Dual Shifts	☐	☐	☐	☐	☐	☐

2. Rate the following issues in terms of their relative advantage or disadvantage during nighttime work (1 = extremely disadvantageous, 3 = same, 5 = extremely advantageous)

BENEFITS	**1**	**2**	**3**	**4**	**5**
Length of work hours	☐	☐	☐	☐	☐
Impact on surrounding businesses	☐	☐	☐	☐	☐
Personnel Scheduling issues	☐	☐	☐	☐	☐
Equipment Scheduling issues	☐	☐	☐	☐	☐
Difficulty of Traffic control	☐	☐	☐	☐	☐
Temperature and environmental working conditions	☐	☐	☐	☐	☐
Noise	☐	☐	☐	☐	☐
4.4.1.1.1.1.1.1.1 Traffic accident rates	☐	☐	☐	☐	☐
Worker accident rates	☐	☐	☐	☐	☐
Materials availability problems	☐	☐	☐	☐	☐
Equipment maintenance problems	☐	☐	☐	☐	☐
Other: specify					
5.	☐	☐	☐	☐	☐
6.	☐	☐	☐	☐	☐

3. Based on your experience, rate the following contracting methods in terms of suitability for nighttime construction (1 = Completely unsuited to 5 = Perfectly suited)

CONTRACTING METHOD	1	2	3	4	5	No Experience
Traditional[1]	☐	☐	☐	☐	☐	☐
Design Build[2]	☐	☐	☐	☐	☐	☐
A+B[3]	☐	☐	☐	☐	☐	☐
Lane Rental[4]	☐	☐	☐	☐	☐	☐
Warranty Contracting[5]	☐	☐	☐	☐	☐	☐
Job Order Contracting[6]	☐	☐	☐	☐	☐	☐
Others, Specify						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐

Section B: Construction Cost Issues

3. What are the main extra line items for nighttime work in addition to lighting (lights, generators) and additional traffic control (extra traffic cones, etc…)?

____
____
____

4. What pay item does this extra cost usually go under?

____
____

[1] Traditional Definition: Traditionally highway projects are designed, bid, and built with the contract awarded to the lowest bidder.

[2] Design Build Definition: When a single entity provides both the design and construction through a single contract between the owner and the Design-Build firm.

[3] A+B Definition: A cost plus time bidding procedure that selects the low bidder based on a monetary combination of the contract bid items (A) and the time (B) needed to complete the critical portion of the project

[4] Lane Rental Definition: An innovative contracting technique by which a contractor is charged a fee for occupying lanes or shoulders to do the work.

[5] Warranty Contracting Definition: “A guarantee of the integrity of a product and of the makers responsibility for the replacement or repair of deficiencies.”

[6] Job Order Contracting Definition: The combining of like projects into one contract that is administered by the owner/agency.

5. Would you as a contractor prefer to bid lighting costs as a separate pay item?

☐Yes ☐No

7. Based on your experience, how does the ***Labor***, ***personnel and supervision*** cost of the following nighttime jobs compare to similar daytime (1 = over 25% higher, 2 = 0 to 25% higher, 3 approximately the same, 4 = 0 to 25% lower, 5 = over 25% lower)

Maintenance Activity	**1**	**2**	**3**	**4**	**5**	**No experience**
Repair of concrete pavement	☐	☐	☐	☐	☐	☐
Milling and Removal	☐	☐	☐	☐	☐	☐
Resurfacing	☐	☐	☐	☐	☐	☐
Bridge Decks Rehabilitation and Maintenance	☐	☐	☐	☐	☐	☐
Pot Hole Filling	☐	☐	☐	☐	☐	☐
Waterproofing/Sealing	☐	☐	☐	☐	☐	☐
Crack Filling	☐	☐	☐	☐	☐	☐
Surface Treatment	☐	☐	☐	☐	☐	☐
Reworking Shoulders	☐	☐	☐	☐	☐	☐
Concrete sawing	☐	☐	☐	☐	☐	☐
Construction of bituminous surfaces and pavements	☐	☐	☐	☐	☐	☐
Work traffic control	☐	☐	☐	☐	☐	☐
Shoulders: bituminous and Portland cement concrete	☐	☐	☐	☐	☐	☐
Highway signing	☐	☐	☐	☐	☐	☐
Pavement marking: striping and markers	☐	☐	☐	☐	☐	☐
Please list any additional maintenance activities						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐

8. Based on your experience, how does the ***Equipment*** (Rental, Operation and Maintenance) and **material** cost (Delivery cost and price) of the following nighttime jobs compare to similar daytime jobs (1 = over 25% higher, 2 = 0 to 25% higher, 3 approximately the same, 4 = 0 to 25% lower, 5 = over 25% lower)

Maintenance Activity	1	2	3	4	5	No experience
Repair of concrete pavement	☐	☐	☐	☐	☐	☐
Milling and Removal	☐	☐	☐	☐	☐	☐
Resurfacing	☐	☐	☐	☐	☐	☐
Bridge Decks Rehabilitation and Maintenance	☐	☐	☐	☐	☐	☐
Pot Hole Filling	☐	☐	☐	☐	☐	☐
Waterproofing/Sealing	☐	☐	☐	☐	☐	☐
Crack Filling	☐	☐	☐	☐	☐	☐
Surface Treatment	☐	☐	☐	☐	☐	☐
Reworking Shoulders	☐	☐	☐	☐	☐	☐
Concrete sawing	☐	☐	☐	☐	☐	☐
Construction of bituminous surfaces and pavements	☐	☐	☐	☐	☐	☐
Work traffic control	☐	☐	☐	☐	☐	☐
Shoulders: bituminous and Portland cement concrete	☐	☐	☐	☐	☐	☐
Highway signing	☐	☐	☐	☐	☐	☐
Pavement marking: striping and markers	☐	☐	☐	☐	☐	☐
Please list any additional maintenance activities						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐

Section C: Construction Quality and Production

9. Based on your experience, in general how does the quality of the following nighttime jobs compare to similar daytime jobs (measured by problems or percent of redo work not meeting specs) (1 = over 25% higher, 2 = 0 to 25% higher, 3 approximately the same, 4 = 0 to 25% lower, 5 = over 25% lower)

Maintenance Activity	**1**	**2**	**3**	**4**	**5**	**No experience**
Repair of concrete pavement	☐	☐	☐	☐	☐	☐
Milling and Removal	☐	☐	☐	☐	☐	☐
Resurfacing	☐	☐	☐	☐	☐	☐
Bridge Decks Rehabilitation and Maintenance	☐	☐	☐	☐	☐	☐
Pot Hole Filling	☐	☐	☐	☐	☐	☐
Waterproofing/Sealing	☐	☐	☐	☐	☐	☐
Crack Filling	☐	☐	☐	☐	☐	☐
Surface Treatment	☐	☐	☐	☐	☐	☐
Reworking Shoulders	☐	☐	☐	☐	☐	☐
Concrete sawing	☐	☐	☐	☐	☐	☐
Construction of bituminous surfaces and pavements	☐	☐	☐	☐	☐	☐
Work traffic control	☐	☐	☐	☐	☐	☐
Shoulders: bituminous and Portland cement concrete	☐	☐	☐	☐	☐	☐
Highway signing	☐	☐	☐	☐	☐	☐
Pavement marking: striping and markers	☐	☐	☐	☐	☐	☐
Please list any additional maintenance activities						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐

10. Based on your experience, in general how do the production rates of the following nighttime jobs compare to similar daytime jobs (1 = over 25% higher, 2 = 0 to 25% higher, 3 approximately the same, 4 = 0 to 25% lower, 5 = over 25% lower)

Maintenance Activity	**1**	**2**	**3**	**4**	**5**	**No experience**
Repair of concrete pavement	☐	☐	☐	☐	☐	☐
Milling and Removal	☐	☐	☐	☐	☐	☐
Resurfacing	☐	☐	☐	☐	☐	☐
Bridge Decks Rehabilitation and Maintenance	☐	☐	☐	☐	☐	☐
Pot Hole Filling	☐	☐	☐	☐	☐	☐
Waterproofing/Sealing	☐	☐	☐	☐	☐	☐
Crack Filling	☐	☐	☐	☐	☐	☐
Surface Treatment	☐	☐	☐	☐	☐	☐
Reworking Shoulders	☐	☐	☐	☐	☐	☐
Concrete sawing	☐	☐	☐	☐	☐	☐
Construction of bituminous surfaces and pavements	☐	☐	☐	☐	☐	☐
Work traffic control	☐	☐	☐	☐	☐	☐
Shoulders: bituminous and Portland cement concrete	☐	☐	☐	☐	☐	☐
Highway signing	☐	☐	☐	☐	☐	☐
Pavement marking: striping and markers	☐	☐	☐	☐	☐	☐
Please list any additional maintenance activities						
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐

Section D: Social and Physical Issues

11. How many hours of sleep do you usually get on nighttime jobs?

____

12. How many hours per day do you usually work in nighttime projects?

____

13. Does working on nighttime jobs affect your social life?

____

14. How much extra pay that would make nighttime work worthwhile for you?

____

15. During the past five years, please indicate:

The total number of nighttime construction projects that you worked on: [ ]

The total number of all the projects that you worked on: [ ]

16. Please provide any additional comments or explanations:

____
____
____
____
____
____

We wish to express our gratitude for your valuable time and effort in responding to this questionnaire

Please complete this questionnaire and return to:

Prof. Ahmed Al-Kaisy
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APPENDIX D: SAFETY ASPECTS AT WORK ZONES IN THE STATE OF ILLINOIS

Introduction

Safety at work zones is a major concern for the traveling public, the transportation agencies, and the construction industry. Available national statistics show that there were 772 people killed and 39,000 injured in motor vehicle crashes in construction work zones in 1998. This safety concern is associated with both the traveling public and construction workers.

Establishing work zones for construction and maintenance activities through lane closures poses inherent hazards for road users approaching and traveling through the work zone. Restrictions imposed by work zone activity area delineation (using plastic cones/barrels or portable concrete barriers), distraction and/or deterioration in visibility due to ongoing work activities, and lack of familiarity with the work zone (mostly by non-commuter drivers) are believed to be the main causes for the increased accident risks at work zones. During nighttime, poor visibility, inadequate lighting, worker fatigue, driver's drowsiness, and substance abuse are all additional factors that are believed to contribute to an increased accident risks.

From the workers' safety point of view, nighttime construction is also believed to pose unique risks due to the lower visibility for drivers and equipment operators during nighttime as well as the high proportion of drivers under the effect of fatigue, drugs, or alcohol.

Safety Data in Illinois

The data that was used in this analysis came from Fatality Analysis Reporting System (FARS) web-based encyclopedia of the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation. The data is available online at http://www-fars.nhtsa.dot.gov/

This database involves various information on fatal crashes in the State of Illinois. Some of this information is related to location type as related to the presence of construction and maintenance work, area setting type (urban versus rural), highway characteristics (functional classification and type of traffic flow separation), lighting conditions, weather conditions, time of day, and the number of fatalities as well as people involved in each accident.

Data Processing

For each crash, the database provides the number of fatalities, the number of people involved, and pedestrians involved. In order to investigate the rate of accidents at work zones, traffic information is needed. An extensive effort was made to get the appropriate traffic data in the State of Illinois, but it could not be found in any published or unpublished government reports. Also, in order to investigate the severity of accidents at work zones, it would be useful to have not only fatal accidents but also other types of accidents so that appropriate measures could derived. Given the limitation in the crash data available, the following measures were established to be used in their investigation:

1. Number of fatal crashes
2. Number of fatalities
3. Average number of fatalities per crash
4. Ratio of fatalities to total number of people involved in crashes

Fatal Crashes in the State of Illinois for the Period 1994-2001

The data that is used in this analysis involved fatal crashes in the State of Illinois for the period between 1994 and 2001. A total of 10454 fatal crashes were reported in the state during that period.

Figure D-1 shows the frequency of fatal crashes by year for the reporting period in the State of Illinois. As shown in this figure, there was a decline in fatal crashes that took place between 1995 and 1998. Beyond 1998, the number of accidents generally remained around the same low level reached in 1998 despite a very slight increase that could be attributed to the random variation in crash occurrence.

Out of the total number of fatal crashes, only about 2% occurred at work zones while the remaining 98% occurred at normal highway facilities. This breakdown of fatal crashes by location type is shown in Figure D-2.

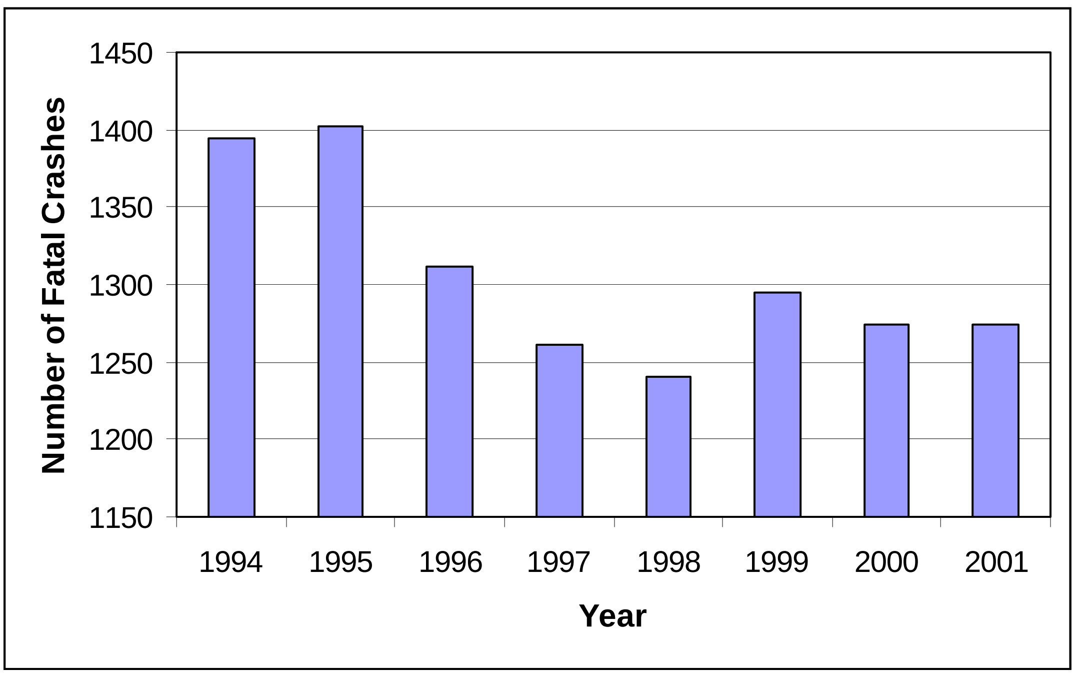

Figure D-1. Fatal Crashes in the State of Illinois for the period 1994-2001.

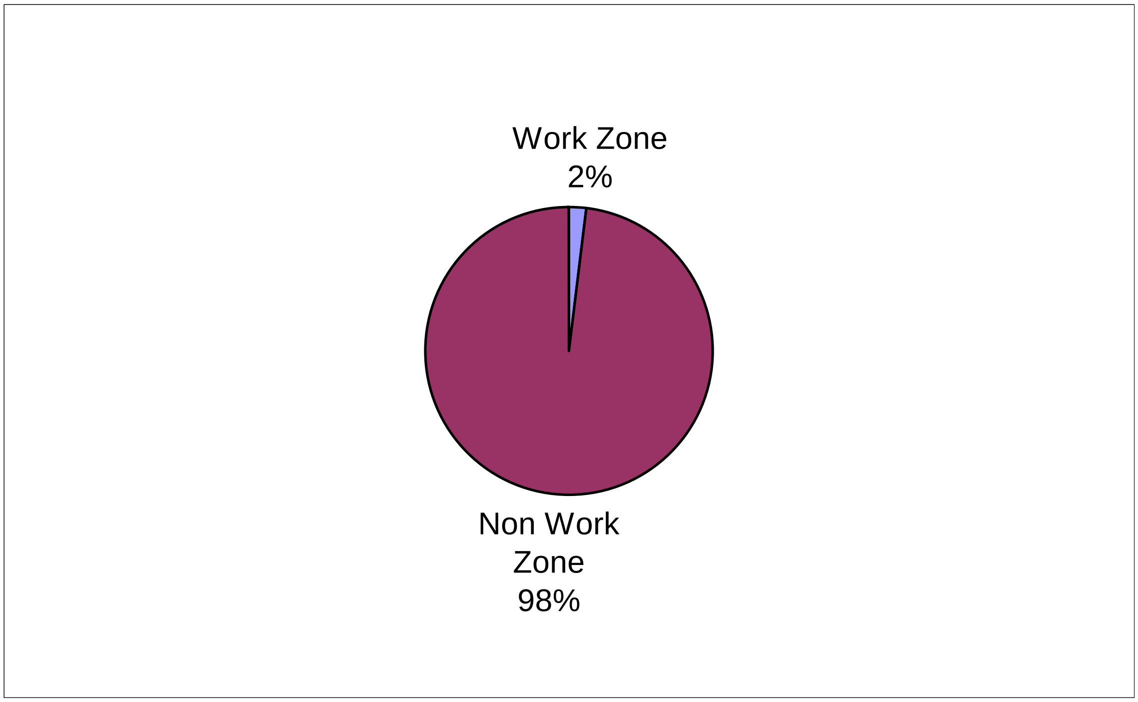

Figure D-2. Fatal Crashes in Illinois by Location Type

Location Type and Light Condition

The number of fatal crashes and the ratio of fatalities to total people involved within and outside work zones under various light conditions are provided in Tables D-1 and D-2 respectively.

Table D-1: Number of Fatal Crashes by Location Type & Light Condition

	Light Conditions				
Location Type	Dark	Dark but Lighted	Dawn	Daylight	Dusk
Work Zone	58	46	3	110	5
Non Work Zone	2970	2137	162	4760	177

Table D-2: Ratio of Fatalities to People Involved by Location Type & Light Condition

	Light Conditions				
Location Type	Dark	Dark but Lighted	Dawn	Daylight	Dusk
Work Zone	0.430	0.398	0.273	0.350	0.294
Non Work Zone	0.473	0.392	0.478	0.391	0.386

Around 2.2% of fatal crashes in Illinois (58 out of 2970 crashes) occurred at work zones for the period 1996-2001. While this percentage may not sound significant, it is considered reasonable given the small proportion of work zones compared to the total highway network involved in these statistics.

A quick examination of Table 4 reveals two important findings. The first is that the severity of fatal crash accidents in darkness is higher than when there is lighting both within and outside work zones. Also, work zone accidents that occurred during daylight are less severe than those that occurred in darkness or under artificial illumination. However, the severity of accidents outside work zones is roughly the same both in daylight and under artificial illumination. This observation may suggest a very important finding; that is lighting of work zones is not as effective in improving the visibility required for the driving task as that of normal highways outside of work zones. This finding, if proven true, confirms the need to develop standards for an effective work zone lighting for nighttime projects. Crash severity at work zones under different light conditions is shown in Figure D-3.

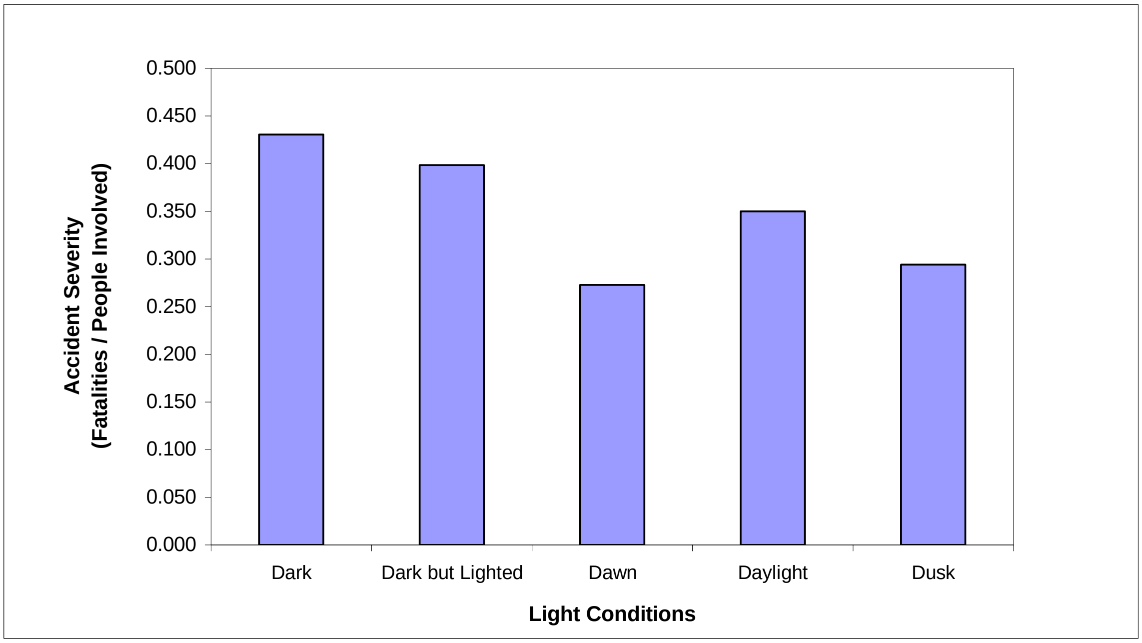

Figure D-3. Work Zone Crash Severity under Various Light Conditions

Type of Work Zone Versus Time of Day

The ratio of fatalities to people involved in crashes at different types of work zones during day and night is shown in Table D-3.

Table D-3. Crash Severity by Work Zone Type and Time of day

	Time of Day		
Work Zone Type	Day	Night	Other
Construction	0.357	0.417	0.286
Maintenance	0.315	0.353	------
Utility	0.250	0.500	------
Unknown	0.750	0.500	------

It is apparent from the figures provided in this table that the severity of crashes during nighttime projects is significantly higher than those of daytime projects. While this is true for all types of work zones, it is particularly significant at utility work sites. One possible reason is that these temporary work zones do not involve the same amount of planning and preparation to ensure safety of workers and the traveling public as do construction and maintenance zones. Another important trend in this table is the fact that crash severity at construction zones is higher than those at maintenance zones both during the day and during the night.

Area Setting

Crash severity within and outside work zones in urban and rural areas is shown in Figure D-4 and provided in Table D-4.

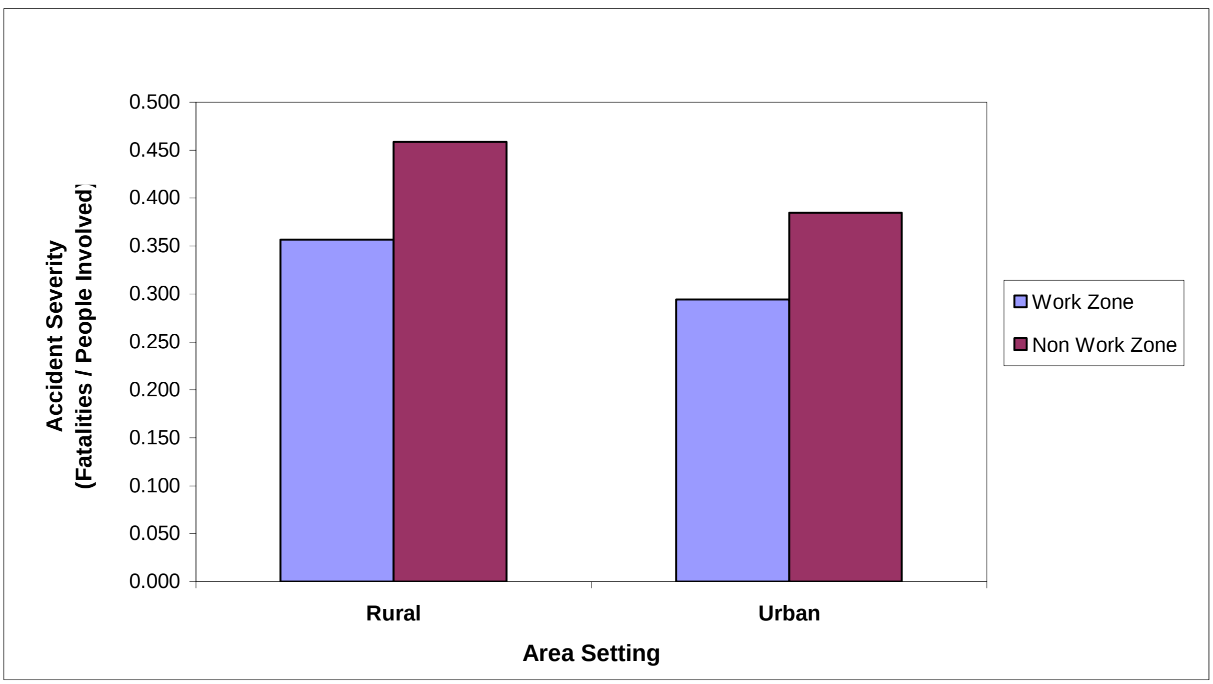

Figure D-4. Crash Severity by Area Setting Within and Outside Work Zones

Table D-4. Crash Severity by Area Setting Within and Outside Work Zones

	Area Setting	
Location Type	Rural	Urban
Work Zone	0.357	0.294
Non Work Zone	0.459	0.385

At first glance, Figure D-4 reveals that crashes in rural areas are generally more severe that those in urban areas. While this finding may be somewhat expected, it is unexpected to see that work zone crashes are less severe than other crashes on normal highways. Further thought into this pattern would interpret the lower severity of work zone crashes to the lower vehicular speeds at work zones since speed is one of the most important determinants of crash severity. The rates of fatalities to people involved shown in Table D-4 indicates that the rates at work zones are roughly 20%-25% lower than those outside work zones.

Functional Classification of Highways

Table D-5 shows the number of crashes within and outside work zones by area setting and highway functional classification.

Table D-5. Fatal Crashes by Area Setting and Functional Classification of Highways in Illinois

	Area Setting & Functional Classification					
	Rural			Urban		
Location Type	Rural Local	Rural Collector	Rural Arterial	Urban Local	Urban Collector	Urban Arterial
Work Zone	2	22	63	29	1	72
Non Work Zone	975	1307	2057	1915	355	3623

Major and minor arterials including limited access facilities witnessed the highest proportion of fatal crashes both within and outside work zones. Also, this table shows that crashes on urban collector streets are only a small proportion of total urban fatal crashes within and outside work zones when compared with rural areas.

Highway Classification by Traffic Flow

Highways were classified according to traffic flow into one-way and two-way. In turn, two-way traffic is classified into divided with traffic barrier, divided without traffic barrier, and not physically divided. Table D-6 shows the number and severity of fatal crashes within and outside work zones by traffic flow highway classification in the State of Illinois.

The figures in this table suggest that crashes on undivided two-way highways are generally more severe than those on divided highways. This observation is expected as physically separating traffic flows on the roadway tends to minimize conflict between opposing traffic streams.

Table D-6. Crash Numbers and Severity by Traffic Flow Type in the State of Illinois.

	Traffic Flow Type			
	Two-Way Traffic			One-Way Traffic
Location Type	Divided Highway (With Traffic Barrier)	Divided Highway (Without Traffic Barrier)	Not Physically Divided	
Work Zone	62 (0.348)*	48 (0.327)	107 (0.417)	5 (0.500)
Non Work Zone	1713 (0.382)	1803 (0.379)	6584 (0.436)	131 (0.361)

* Values in brackets are rate of fatalities to people involved.