Developing a Decision Support Tool for Nighttime Construction in Highway Projects

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Abstract: This paper presents a decision support tool that is intended to help highway agencies in evaluating the suitability of nighttime construction for highway projects. This tool was developed as part of a research project sponsored by the Illinois Department of Transportation. The tool is a simple software package that was developed using a Microsoft Excel spreadsheet and Visual Basic for Applications. The proposed tool utilizes the cost-effectiveness analysis as a basis for comparison between daytime and nighttime operations. The proposed tool is mainly used whenever night shift is thought of as an alternative to the conventional daytime shift. Nonetheless, the tool is also generic in the sense that it can be used to compare different alternative plans such as different lane closure strategies or scheduling alternatives.

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Introduction

Highway work zones as related to maintenance and reconstruction activities usually cause serious disruptions to traffic, thus resulting in significant delays, increased fuel consumption, and other negative impacts on environment and society. Scheduling construction activities during nighttime, when traffic demand is typically at its lowest levels, is being viewed by many transportation agencies as an effective means to alleviate the impact of work zones on the traveling public. However, other work-related aspects may be affected by nighttime and therefore an informed decision on nighttime construction should take into consideration all these impacts for the specific situation at hand. This is a relatively difficult and challenging task due to the many factors that can be affected by nighttime and the lack of quantitative tools to assess the impact of nighttime on some of these factors. This assessment is essential in making any meaningful comparison between daytime and nighttime work for a given highway project.

This paper presents a decision support tool that was developed as part of a research project sponsored by the Illinois Department of Transportation to help in the selection of night shifts for highway projects. This tool, which is a computer software called EVALUNITE, can also be used in the evaluation of alternative plans for highway projects in general, such as the evaluation of different lane closure strategies, various scheduling alternatives, etc.

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Problem Statement

Although nighttime construction is being used increasingly by state Departments of Transportation (DOTs) and other highway agencies to conduct highway maintenance and reconstruction projects, the literature suggests 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. This is mainly because the full picture of nighttime construction in terms of its advantages and disadvantages is not fully clear for most highway agencies, as the use of this strategy in their projects is a fairly new practice. Moreover, no analysis tools are currently available to help highway agencies in evaluating the suitability of nighttime construction for highway projects. This evaluation is essential whenever night shifts are thought of as an alternative scheduling strategy to avoid serious disruptions to traffic during daytime.

Previous Studies

Despite the increasing use of night shifts in highway projects, the literature review suggests that only a limited number of studies addressed the decision on using night shifts in highway projects. Most of those studies dealt with identifying the factors that should be considered in making this decision and only a couple of studies went further to suggest a decision framework for nighttime projects without providing a means to carry out the appropriate analyses for impact assessment.

One of the earliest studies to address this issue was conducted by New York Department of Transportation (Elrahman and Perry 1998). This study proposed a general framework for comparative analysis between nighttime and daytime construction operations to be part of the selection process. The proposed framework consisted of the following sequential steps:

1. Evaluate the proposed project;
2. Assess roadway occupancy;
3. Identify traffic control alternatives;

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4. Analyze volume/capacity relationships;
5. Identify capacity-improving techniques;
6. Quantify impacts;
7. Assess feasibility of a night schedule; and
8. Select preferred alternative.

A much more comprehensive framework for planning nighttime highway construction and maintenance was proposed by Bryden and Mace (2002). In this study, a structured decision process for nighttime construction operations was outlined and discussed with a high level of detail that could provide valuable guidance for those involved in planning highway projects. Nonetheless, as with the first study by Elrahman and Perry (1998), this study did not provide tools that can assist agency personnel to do the analyses involved in the proposed framework.

Only one recent study by Park et al. (2003) proposed such a tool in an attempt to quantify the factors that need to be considered in making decisions on nighttime construction. This tool is a computer model developed in a Microsoft Excel spreadsheet that utilizes ranking techniques in assessing the different aspects of nighttime work. Although there is a dire need in practice for such an analysis tool, the proposed model is somewhat superficial and too simplistic for the following reasons:

- Ranking techniques are utilized for all relevant factors, including those that can reasonably be estimated in dollar value. This major flaw adds a lot of subjectivity to the analysis and affects the credibility of the results.
- Many factors were eliminated from the model because they were found less important in a survey that was conducted with the Oregon DOT (Park et al. 2003). This survey, which utilized scores for different aspects of nighttime work, was based solely on perception and judgment. Also, no scientific or logical basis was followed in eliminating those factors.
- Model is designed specifically for the Oregon DOT and, therefore, is not applicable to other state DOTs or other highway agencies.

Besides these studies, a few other studies were identified in the literature that investigated the various issues involved in making decisions on nighttime construction (Al-Kaisy and Nassar 2003; Ellis 1993; Hancher and Taylor 2000; Hinze and Carlisle 1990a,b).

Model Description

EVALUNITE is a simple software package that helps to assess 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. Nonetheless, the model is also generic in the sense that it can be used to compare different alternatives such as different lane closure scenarios or scheduling alternatives.

The software was developed using Microsoft Excel spreadsheet and Visual Basic for Applications (VBA). It has a user-friendly interface that leads the user through the process of data input and program running in a very simple manner. As most input data are specific to the situation at hand and may differ greatly from one project to another, they are user specified to the model. However, default values were set for most input variables in case the required information is not available to the user. This feature is very useful given the fact that users may not have all the input data, especially at the planning stage of the project. These default values were selected based on findings from previous studies as well as the results of questionnaire surveys that were conducted as part of this research project.

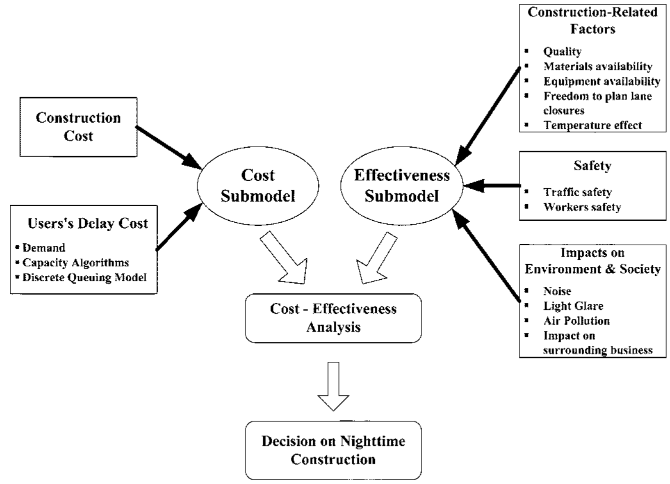

Fig. 1. Schematic diagram of the proposed decision-making tool

Model Structure

The proposed model utilizes the cost-effectiveness analysis as a basis for the comparison between daytime and nighttime projects. This technique provides a general and flexible framework for providing information to aid in making decisions rather than establishing a decision rule (Khisty and Lall 2003). The technique is well known for its suitability and efficiency in evaluating transportation alternatives. As with most transportation (or other public) projects, factors related to decisions on nighttime construction are of two types. The first type involves those factors that can easily be assessed in monetary terms (typically dollar), whereas the second type involves those factors that can only be described in words, i.e., subjectively (e.g., noise, disruption to adjacent communities, etc.). Therefore, an explicit economic analysis (such as the cost-benefit analysis) cannot be used to address the problem at hand.

The model consists mainly of two main submodels; the cost submodel and the effectiveness submodel. The cost submodel assesses all the variables that can be quantified using dollar values, whereas the effectiveness submodel evaluates other important variables that can only be assessed qualitatively. Using the priorities and objectives set by the highway agency, decision makers should be able to use the information provided by the model in making appropriate decisions regarding scheduling construction work during nighttime. A schematic diagram showing the model structure is provided in Fig. 1.

Cost Submodel

This submodel is concerned with the variables that can be quantified in monetary value. It was decided to include all those variables regardless whether the cost is paid for by an agency's operating budget or by the users of the system. For example, delay and vehicle operating costs are carried out by road users and not by highway agencies. The main reason to combine all types of cost in this submodel is that highway projects are generally public projects where no direct return is expected by the operating agency (with the exception of some toll facilities). Therefore, all costs incurred by the agency or the traveling public need to be taken into consideration in comparing different alternatives.

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The cost submodel consists of two different cost modules; users delay module and construction cost module. A detailed description of each of these modules is provided in the following.

Users Delay Module

Delay in this model refers to the time spent when vehicles are in a queue waiting to pass the work zone. Delays due to slow down, acceleration, and traveling at less than the desired speed are not accounted for by this model. However, it should be clear 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 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 (24 h) into small time intervals (increments). For each interval, the estimated demand is compared with the capacity of work zone to check if there is a delay incurred by road users when in queue during that particular interval. If demand is found less than or equal to the 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 road users in the following two situations:

1. If demand is less than or equal to the capacity of work zone during the specific time interval but there is a queue from the previous time interval.
2. If demand is greater than capacity during that particular time interval.

The time interval used by the delay module is 5 min. For each time interval, the model updates the status of the queue at the lane closure and the number of vehicles in the queue. The model then estimates the total amount of delay in vehicle hours for the total duration of lane closure. More details on the demand-capacity analysis are provided in May (1990).

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. The main information that is needed to run the delay model is as follows:

- Number of normal lanes.
- Number of open lanes.
- Start time (lane closure).
- End time (lane closure).
- Hourly volumes of traffic demand for a typical working day.
- Duration of project in working days.
- Percentage of heavy vehicles.
- Estimated % of traffic diverted to alternative routes.
- Estimated delay cost (dollar/h).
- Type of work zone (short-term maintenance versus long-term reconstruction).
- For short-term maintenance
    1. Presence of ramp within 150 m of start of activity area.
    2. Intensity of work activity.
- For long-term reconstruction zones
    1. Side of lane closure (left or right).
    2. Weekend or weekday.

Estimating Traffic Demand

Traffic patterns at any highway facility may be estimated with reasonable accuracy from historical traffic volume records. There data are 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 when reliable historical data on traffic demand at the site of interest are not available.

Traffic demand patterns may be affected at a particular site after the onset of construction work due to change in travel time and/or the effect of work activity and temporary traffic control plans on driver convenience. Many highway agencies devise route diversion plans as part of planning work zones on major highway facilities, especially when construction work is performed during daytime. These plans are intended to alleviate the congestion at the affected area by encouraging the users to utilize other alternative routes. The delay module presented here recognizes this fact, and therefore the user is prompted to enter the estimated percentage of traffic that is expected to use alternative route(s). This will be used along with the typical weekday or weekend hourly volumes for the 24 h period.

Estimating Work Zone Capacity

To estimate users' delay, the model roughly estimates traffic demand at the affected area as well as the capacity of the work zone before and after lane closure. Estimation of traffic demand is pretty straightforward as discussed in the previous section. However, estimating work zone capacity is much more complicated. In this context, capacity at work zone represents the maximum number of vehicles that can reasonably be expected to pass through the work zone under specific geometric, traffic, and control conditions. Work zone capacity for temporary maintenance work zones is significantly different from that of long-term reconstruction work zones. Short-term maintenance work zones refer to those work zones that are delineated using temporary plastic barrels and cones. On the other hand, long-term reconstruction zones refer to work zones that are delineated using portable concrete barriers. Although many similarities exist between the two types of work zones, capacity of long-term reconstruction zones on multilane 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 the 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.

Although the *Highway Capacity Manual* (HCM) provides procedures for estimating capacity at maintenance zones on multilane 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 described in the following.

Estimating Capacity at Long-Term Reconstruction Zones

The HCM does not provide analytical procedures to estimate work zone capacity at long-term reconstruction zones. Instead, it provides two capacity estimates 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 EVALUNITE utilizes a recent procedure to estimate the capacity of long-term reconstruction zones that is developed by Al-Kaisy and Hall (2003). This procedure is based

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Table 1. Recommended Adjustment Factors for the Proposed Capacity Model

Adjustment factor	Recommended values
Heavy vehicles (f_{HV})	The model utilizes the same *Highway Capacity Manual* 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
Nonadditive 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

on empirical data that were collected at several reconstruction sites in Ontario, Canada. The model proposed by this procedure is shown in the following:

$$C = C_b f_{HV} f_d f_w f_s f_r f_l f_i \qquad (1)$$

where C=work zone capacity under prevailing conditions in vehicles per hour per lane; C_b=base work zone capacity in pcphpl (for freeways use 2,000 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; and f_i=adjustment factor for nonadditive interactive effects.

The adjustment factors for prevailing conditions are provided in Table 1. The model utilizes a base capacity estimate for freeway reconstruction zones of 2,000 pcphpl (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 (TRB 2000) and presented in the previous section.

It is recognized that some of these prevailing conditions may not be available to the users of the proposed tool. Therefore, default values were assigned to these conditions and the user is encouraged to enter the project-specific information when available.

Estimating Capacity at Short-Term Maintenance Zones

The methodology used to estimate capacity at maintenance work zones is the same methodology provided by the HCM (TRB 2000) that is developed by Krammes and Lopez (1994). The procedure utilizes the following capacity model:

$$c_a = (1{,}600 + I - R) f_{HV} N \qquad (2)$$

where c_a=adjusted mainline capacity; I=adjustment for type, intensity, and location of work activity; R=adjustment for ramps; and f_{HV}=adjustment factor for heavy vehicles; and N=number of lanes open through the short-term work zone.

The adjustment I falls in the range -160 to $+160$ passenger car per hour per lane (pcphpl) for work activity that is more or less intense than normal ($\pm 10\%$ of basic per-lane capacity of 1,600 pcphpl).

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

$$f_{HV} = 1/[1 + P_{HV}(E_{HV} - 1)] \qquad (3)$$

where P_{HV}=proportion of heavy vehicles in the traffic stream and E_{HV}=passenger car equivalency factor used for heavy vehicles.

Construction Cost Module

The construction cost module estimates the total costs for nighttime construction based on the estimated construction cost during daytime and the increase (or decrease) in total cost due to nighttime operations. The increase in construction cost may be incurred due to the increase in one or more of the following cost items:

- Decreased/increased productivity cost;
- Traffic control costs;
- Overtime shift pay scale/nighttime pay differential;
- Extra lighting cost;
- Nighttime apparel;
- Extra material costs;
- Extra equipment costs; and

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Table 2. EVALUNITE Scoring Procedure to Estimate Effectiveness for a Hypothetical Project

Group	Factor	Weight	Rating		Group total	
			Daytime	Nighttime	Daytime	Nighttime
Environmental and social factors	Noise disturbance		3	1		
	Economic impacts on surroundings business	6	1	4		
	Light glare to motorist		4	1		
	Air pollution		3	2		
	Mean rating		2.75	2.00	16.50	12.00
Safety factor	Traffic safety	9	4	1		
	Worker's safety		3	2		
	Mean rating		3.50	1.50	31.50	13.50
Construction-related factors	Materials/equipment availability	4	4	3		
	Freedom to plan lane closures		1	3		
	Work quality		3	3		
	Temperature		3	4		
	Mean rating		2.75	3.25	11.00	13.00
	Overall effectiveness				59.00	38.50

- Other indirect costs (e.g., additional insurance cost for nighttime work).

The literature suggests that nighttime construction is generally associated with higher construction cost. The surveys conducted in the course of this research project confirmed this fact (Al-Kaisy and Nassar 2003).

The proposed model, EVALUNITE, offers the users two options for estimating the construction cost increase (or decrease). If the agency has an estimate of this increase from historical data or from alternate bid amounts, users can input the estimated construction cost for daytime and nighttime. In the absence of this information, the users can utilize figures that are based on the results of the project surveys. The model employs a simple probabilistic approach that is based on the fact that the percentage increase in construction costs generally follows the normal distribution. In this approach, the increase in construction cost is determined from the mean and standard deviation of the extra construction cost obtained from survey results and the degree of certainty (confidence level) specified by the user. Given a certain degree of certainty, EVALUNITE calculates the maximum expected percentage of increase in construction cost.

Effectiveness Submodel

Other than road user costs and construction costs, all other aspects of nighttime operations are incorporated in the effectiveness submodel. Those aspects are typically very difficult to quantify in dollar values with reasonable certainty. Qualitative decision-making factors are divided into three groups:

1. Environmental and social factors;
2. Traffic and workers safety; and
3. Construction-related factors.

The first group involves four different aspects: noise disturbance, economic impacts on surrounding businesses, light glare to motorists, and air pollution. The second group involves two safety aspects: traffic safety and worker safety. Finally, the third group involves four construction-related aspects: materials/equipment availability, freedom to plan lane closures, work quality, and temperature effect. Although worker safety may be viewed as a construction-related aspect, it was treated differently (included with traffic safety in a separate group) as it represents a major concern during nighttime and may have more significant importance than other construction-related variables. Moreover, safety of the traveling public and construction workers is mostly interrelated at highway work zones. Table 2 shows the effectiveness submodel scoring technique of EVALUNITE.

As shown in Table 2, the user is required to enter a weight that represents the relative importance of the group of factors under consideration, i.e., environmental/social, safety, and construction-related factors. These weights can reasonably be estimated by the users based on the priorities set by the agency. A numerical scale from 1 to 10 is provided for this purpose with 1 referring to "not important" and 10 being "very important."

After selecting the level of importance of each group of factors, the user is required to evaluate each single factor during daytime and nighttime using a four-level descriptive scale generally ranging from the least favorable to the most favorable. It should be clear that sensitivity to each of the factors involved in the effectiveness submodel may vary significantly from one project to another (for instance, noise may be a major concern for a certain project close to residential areas, yet it is not an issue for another project in a rural area).

EVALUNITE then converts these subjective assessments into scores, taking the mean value for each group, and finally calculates a single index for each alternative that represents the overall effectiveness. This index is found by multiplying the weight (relative importance) of each group of factors by the mean of scores for the various factors in that group and adding the product of the three groups together. This calculation of the index is shown in the following formula:

$$\text{Overall effectiveness} = \sum_{i=1}^{n} \left[\sum_{j=1}^{m} (S_{ij}/m_i) W_i \right]_i \tag{4}$$

where S_{ij}=score representing the "severity of effect" given to any factor j within group i; W_i=weight representing the "relative importance" given to group i; n=number of groups (categories); and m=number of factors within group i.

Evaluation and Choice

Upon running the model, EVALUNITE provides the user with the total cost including construction and road user costs and the ef-

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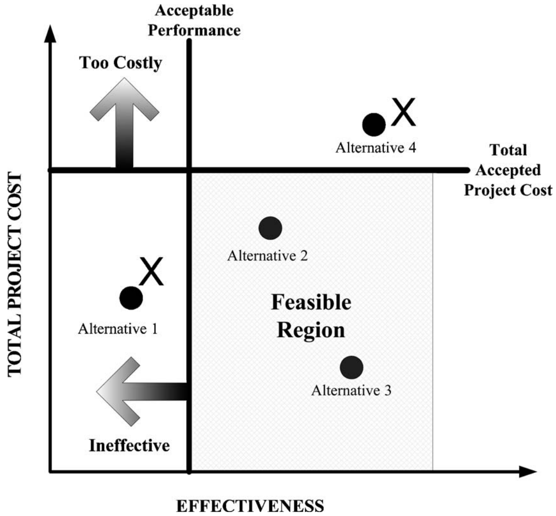

Fig. 2. Cost-effectiveness graphical presentation of multiple alternatives

fectiveness of the daytime and nighttime shifts expressed in a single index value. Also, the model provides the ratio of effectiveness to cost similar to the benefit-cost economic analysis technique. Moreover, as a graphical presentation of the results, the software creates two bar charts with each run that plots the total cost and the overall effectiveness of the two alternatives.

In the case of two alternative work plans (e.g., day versus night), it would be rather straightforward to compare the cost and effectiveness of the two alternative plans taking into consideration project constraints. In case of multiple plans (e.g., day versus night with different lane closure scenarios), it would be helpful to plot the effectiveness versus cost, as shown in Fig. 2. Effectiveness in Fig. 2 refers to the degree an alternative meets project objectives, whereas total project cost represents the resources expended and other quantifiable social costs such as motorist delay. For a specific highway project, a threshold typically exists below which effectiveness is considered unacceptable (in many cases this threshold value coincides with the effectiveness of the do-nothing alternative). Similarly, total project cost is typically subject to some limiting values due to budget constraints. Those threshold values create a zone on the graph where alternative are considered "feasible." This will help to exclude some of the alternatives from further consideration due to high cost or low performance.

Although EVALUNITE provides very important information that helps highway agency personnel in making informed decisions concerning the suitability of nighttime construction operations, it should be clear that the cost-effectiveness analysis does not yield decisions, but rather improves the likelihood that a decision is good by sharpening the intuition and judgment of the decision maker through the systematic and efficient use of information (Bryden and Masc 2002).

Model Application: An Example

In this section, a hypothetical example of a highway maintenance project is employed to explain the use of the proposed model.

A highway agency is contemplating the use of nighttime construction in a project which would require the closure of the rightmost lane of a three-lane directional freeway mainline. The length of closure is 2 mi (3.218 km) and the expected duration of work is 5 days. The freeway is located in a well-developed suburban area. The intensity of work activity is expected to be moderate. There is an on-ramp within 350 ft (106.7 m) of the lane closure that will remain in service during construction. Average traffic volumes on weekdays as observed recently at the construction site are provided in Table 3. The percentage of heavy vehicles on this freeway segment is around 6% during daytime and 11% during nighttime. It is the agency's practice to use route diversion strategies during daytime lane closures. This will result in an estimated 5% shift of normal traffic to alternative routes. Also, it is estimated that setting up and removing the lane closure would require around 1 h during the off-peak night shift versus 2 h during the day shift.

Table 3. Average Hourly Volume on a Typical Weekday at the Construction Site of the Example Project

Time (hrs)	Average volume (vph)	Time (hrs)	Average volume (vph)	Time (hrs)	Average volume (vph)
0000–0100	1,090	0800–0900	4,200	1600–1700	4,850
0100–0200	1,050	0900–1000	3,150	1700–1800	5,150
0200–0300	990	1000–1100	2,620	1800–1900	3,680
0300–0400	1,180	1100–1200	2,130	1900–2000	2,800
0400–0500	1,390	1200–1300	1,950	2000–2100	2,280
0500–0600	2,350	1300–1400	2,000	2100–2200	1,950
0600–0700	4,600	1400–1500	2,325	2200–2300	1,320
0700–0800	5,100	1500–1600	3,170	2300–2400	1,150

Note: vph=vehicles per hour.

The agency would like to assess the potential benefits of using a night shift as an alternative to daytime shift on weekdays. Road user delay cost from similar studies is estimated at \$8/h. Using historical data from similar projects, the estimated construction cost for this project is \$586,000 using daytime work shift with an estimated increase in construction cost of 15.8% for nighttime work shift.

Evaluation. The situation presented in this example is a simple one where only two alternatives are being evaluated. The high traffic volumes on the well-traveled freeway segment are expected to show significant road user delay during daytime when capacity of the construction zone falls below demand levels. The following information needs to be input to the evaluation software:

- Number of normal lanes: 3;
- Number of open lanes: 2;
- Start time (lane closure): 2200 hrs (night shift); 0600 hrs (day shift);
- End time (lane closure): 0700 hrs (night shift); 1600 hrs (day shift);
- Hourly volumes of traffic demand for a typical working day: values in Table 3;
- Duration of project in working days: 5 days;
- Percentage of heavy vehicles: 6% (day shift); 11% (night shift);
- Estimated % of traffic diverted to alternative routes: 5 % (day shift only);
- Estimated user delay cost: \$8/h (borrowed from similar studies);
- Type of work zone: short-term temporary work;
- Presence of ramp within 150 m of start of activity area: yes;
- Intensity of work activity: moderate;
- Estimated construction cost (daytime shift): \$586,000; and

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Table 4. EVALUNITE Results for the Daytime and Nighttime Shift Comparison of the Example Project

Evaluation metric	Daytime shift	Nighttime shift
Quantitative analysis		
Users' delay cost	$2,089,033	$186,396
Construction cost	$586,000	$678,588
Total cost	**$2,675,033**	**$864,984**
Qualitative analysis		
Environmental and social factors	22	18
Safety factors	21	9
Construction-related factors	13	13
Overall effectiveness	**56**	**40**

- Increase in construction cost for nighttime shift: 15.8%.

Table 4 shows the results of the evaluation between the daytime and nighttime shifts as generated by EVALUNITE. The upper part of Table 4 is concerned with the estimated cost for the two alternative work shifts, including road user and construction costs. Apparently, the serious disruption to traffic caused by this lane closure resulted in a significantly high toll in road user costs. Therefore, from an economic perspective, the total cost for the daytime shifts appears to be considerably higher than that of the night shift.

The lower part of Table 4 provides the effectiveness of the two alternative work shifts. As shown in Table 2, the input for the effectiveness submodel involves weights for three different groups of factors and an assigned descriptive rating to each factor. In this project, the agency assigned weights of 2, 3, and 1 for the environmental, safety, and construction-related groups of factors. Ratings were assigned to reflect the pros and cons of using night and day shifts at this particular site. Day shift received favorable ratings on noise, light glare, traffic and work accident risks, work quality, and equipment/materials availability. Night shift received favorable ratings on all other factors with the exception of temperature, which received the same rating for both alternatives. As shown in Table 4, the overall effectiveness of night shift was found to be significantly lower than that of the day shift with worker and traffic safety being the major drawback during nighttime.

Summary and Recommendations

This paper discussed the development of a software tool that is intended to help highway agencies in making decisions on nighttime construction. The software utilizes cost-effectiveness analysis, which is used to evaluate complex multifaceted problems. Both quantitative and qualitative transportation and construction variables are involved in the proposed model. The various components of the model and the underlying concepts were discussed in this paper.

The proposed tool is applicable to all situations when night shifts are thought of as an alternative to conventional daytime shifts in highway projects at freeways and multilane highways. Also, the tool could be used to evaluate various lane closure strategies or the use of work shifts during weekends (as opposed to weekdays). However, the model is not applicable to construction projects on two-lane highways where only a single lane is open to traffic at the construction zone. It is recommended that future research focus on the expansion of the delay estimate model component to include two-lane highways as they constitute a significant part of the highway system. Also, the use of more extensive information on the effect of nighttime on construction costs will increase the accuracy of model results.

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