AN ABSTRACT OF THE DISSERTATION OF

Sang-Bin Park for the degree of Doctor of Philosophy in Industrial Engineering presented on May 2, 2003.
Title: Study of Multi-Criteria Decision-Making: Development of a Decision Model to Determine When to Conduct Nighttime Construction Road Work.

Abstract approved: ______________________
Kimberly D. Douglas

Many Departments of Transportation (DOTs) have done construction and maintenance work at night in order to minimize the disruption of daytime traffic, but nighttime operations produce a new set of concerns such as safety, public relations, productivity, and work quality. In addition, decision-making for using nighttime operations has been subjective and has relied on judgment without benefit of analytical data and evaluation criteria. Therefore, a decision model that truly facilitates the determination of when to use nighttime road construction and maintenance work has been developed.

A comprehensive list of well-defined and articulated factors was developed through extensive literature review, but prior research did not delineate the relative importance of the various factors. Thus, this research study surveyed Oregon DOT personnel, its contractors, and the representative personnel from other states' DOTs. After analyses of various perspectives, the overall result was fairly consistent with the results from the individual respondent groups. The results allowed the elimination of unimportant factors and the determination of the weights of important factors. Subsequently, the most important factors were analyzed for their impact on the choice between daytime versus nighttime work in selected states. This permitted the decision model to be generalized. Whenever possible, factors were quantified with tangible score values for daytime versus nighttime. Using this information, a decision model was developed.

The decision model was tested by applying it to actual projects and comparing the model's recommendations on when to conduct the projects with actual decision makers' decisions. The overall testing results were consistent with current decision makers' subjective judgments because of the impact of congestion, safety, and productivity in the decision model. In addition, sensitivity analysis showed the deviations of decision-making in the decision model. Finally, the decision model was evaluated by experts in this field to examine practicality, usefulness, and user-friendliness of the model. The decision model in this study has successfully provided a practical and useful tool to help decision makers in real work environments analyze when to use nighttime work. Also, the model will be useful in making decisions consistently and in providing a means to explain the decision to stakeholders.

Study of Multi-Criteria Decision-Making: Development of a Decision Model to Determine When to Conduct Nighttime Construction Road Work

by

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APPROVED:

Major Professor, representing Industrial Engineering

Head of Department of Industrial and Manufacturing Engineering

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Sang-Bin Park, Author

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LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
ADM	Assistant District Manager
AGC	Association of General Contractors
AMM	Area Maintenance Manager
ANOVA	Analysis of Variance
APAO	Asphalt Association of Oregon
APM	Assistant Project Manager
AZ	Arizona
CPF	Composite Pay Factor
CT	Connecticut
DM	District Manager
DOT	Department of Transportation
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
HAR	Highway Advisory Radio
HCM	Highway Capacity Manual
HPMS	Highway Pavement Management Systems
HW	Highways
I	Interstate
IES	Illuminating Engineering Society
IH	Interstate Highway
IL	Illinois

LIST OF ABBREVIATIONS (Continued)

IN	Indiana
IRB	Institutional Review Board
IRI	International Roughness Index
ME	Maine
MD	Maryland
MN	Minnesota
NCDOT	North Carolina Department of Transportation
NY	New York
OCI	Overall Condition Index
ODOT	Oregon Department of Transportation
OK	Oklahoma
OKDOT	Oklahoma Department of Transportation
OR	Oregon
OSBEELS	Oregon State Board of Examiners for Engineering and Land Surveyors
OHSA	Occupational Safety and Health Administration
OSU	Oregon State University
PA	Pennsylvania
PM	Project Manager
PMS	Pavement Management Systems
R	Region
SH	State Highway

LIST OF ABBREVIATIONS (Continued)

SHW	State Highway
SR	State Road
TAC	Technical Advisory Committee
TCPD	Traffic Control Plans Designer
TMM	Transportation Maintenance Manager
TSRM	Technical Services Resource Managers
TX	Texas
WDOT	Washington Department of Transportation

Dedicated to my parents and my spouse, whose support was invaluable.

STUDY OF MULTI-CRITERIA DECISION-MAKING: DEVELOPMENT OF A DECISION MODEL TO DETERMINE WHEN TO CONDUCT NIGHTTIME COSTRUCTION ROAD WORK.

1. INTRODUCTION

As most states' Departments of Transportation (DOTs) in the United States have placed more emphasis on the preservation of existing highways and bridges, daytime lane closures accommodating maintenance and construction activities are becoming a serious problem. Lane closures on highways or roads in urban areas already near capacity will add to congestion. Seasonal traffic conditions are an additional consideration in rural areas where lane closures impact levels of service on highways to and from popular recreational areas.

To counter the disruption of daytime traffic flow, more maintenance and construction activities are being accomplished at night. Nighttime maintenance and construction eliminates daytime disruption of traffic, but this also brings a new set of factors and concerns among them, cost, productivity, quality, noise, human factors, safety, public awareness, and lighting. In deference to public concerns, most DOTs have used, and continue to use, nighttime operations for maintenance and construction on many of their high volume highways.

1.1. PROBLEM STATEMENT

Decision making for using nighttime operations is currently subjective and relies on judgment without the benefit of analytical data and evaluation criteria. This presents a serious challenge for road construction and maintenance project delivery managers who must make critical decisions on how the project is to be carried out despite minimal guidelines and objective criteria to assist them. Lack of a systematic approach for making these decisions leaves the agency exposed to public criticism with no standard means to explain their decision-making. Flawed assessments about when to conduct maintenance and construction operations can certainly lead to greater costs for the Department of Transportation and the road user as well as elevated traffic and worker safety risks. It is therefore critical that the factors of importance to these decisions be identified and prioritized for inclusion in a decision making model.

1.2. RESEARCH OBJECTIVES

The objective of this study is to create a decision model that truly facilitates the determination of when to use nighttime road construction and maintenance work. In other words, the decision model should enable project planners to minimize the impact on the public and workers, and increase the project's operational efficiency. In order to achieve this research objective, the factors (parameters) affecting nighttime work must be identified and weighted. Using this information, a decision model must be developed and its effectiveness tested.

1.3. RESEARCH QUESTIONS

Based upon the research objectives, the research questions are formulated:

1) How should factors be weighted to effectively affect the decision on when to conduct nighttime construction and maintenance operations?
2) What factors influence decision-making and what process should be used to determine whether factors influence the decision-making or not?
3) How should qualitative factors be incorporated into the decision model to influence the decision?

1.4. RESEARCH CONTRIBUTION

The contribution of this dissertation is a decision making model to determine when to conduct nighttime roadwork. The original aspects of this contribution include 1) importance of weighting factors (attributes or parameters), 2) process of determining if factors will influence the decision, and 3) quantification methodology for qualitative factors. Existing studies do not weight factors affecting nighttime construction and maintenance operations and do not incorporate the use of weighting factors to make decisions. While the literature provides a comprehensive set of factors related to these decisions, in developing the model some factors were actually determined not to influence the decisions, and others were found to be components of other factors. After the elimination of unimportant and overlapping factors, a resulting set of critical factors was established.

The critical factors include both quantitative as well as qualitative aspects. Quantitative factors can be easily measured in the decision model, but qualitative factors require a methodology to incorporate them into the model. Some qualitative factors can be transformed into quantitative factors measurable by the decision model after an investigation of the characteristics of the qualitative factor, such as whether the factor can be quantitatively measured; other qualitative factors can be adapted to Go and No-Go Logic to be measured, which enables the decision model to make decisions robustly.

Thus, the decision model in this study will provide a practical and useful tool to help decision makers in real work environments analyze when to use nighttime work. In addition, the decision model should be useful in making decisions consistently and in providing means to explain the decision to stakeholders.

2. LITERATURE REVIEW

The first step toward developing a decision model to determine when to conduct nighttime roadwork was a thorough literature review on this topic. After reviewing the findings of previous studies related to nighttime construction and maintenance operations, this study divided the reviewed studies into the following categories: purpose of nighttime work, the advantages and disadvantages of nighttime work, factors (parameters) affecting nighttime work, investigation of an individual factor, comparison of daytime versus nighttime work (decision-making system).

2.1. PURPOSE OF NIGHTTIME WORK

There are many studies which state clearly the purpose of nighttime work. The earliest known work was by Lee (1969) who found that it was impractical to close freeway lanes during the daytime in a metropolitan area since this resulted in severe traffic congestion. According to Heine (1989), North Carolina Department of Transportation (NCDOT) decided to do nighttime work due to the combination of concern for public safety and convenience.

A New York State Department of Transportation study (1991) determined that nighttime work should be conducted to reduce conflicts between construction work and traffic flow, and to reduce the risk of traffic accidents involving workers and/or equipment and motorists. In addition, nighttime work was needed to reduce daytime traffic congestion and adverse impact on commercial businesses near construction sites.

Sherpard and Cottrell (1985) said that there were two primary reasons to do nighttime instead of daytime work: nighttime work allowed longer periods of light traffic than the off-peak period between morning and afternoon rushes, and nighttime work reduced traffic delays and congestion due to lane closing during the daytime. Finally, other studies (Ellis, Herbsman & Kumar, 1993; New York State Department of Transportation, 1995) made similar points about the purpose of the nighttime work.

Reviewing these studies reveals many reasons to work at night, notably congestion, worker and driver safety, local business impact, and longer working hours. In conclusion, the primary reason to conduct nighttime work is avoiding congestion.

2.2. ADVANTAGES AND DISADVANTAGES OF NIGHTTIME WORK

Lee (1969) addressed some advantages of nighttime work after the completion of three projects in California. Concrete was placed at the rate of more than 1.5 miles per night due to additional working hours and less interference from heavy traffic. In addition, the concrete cured more slowly at the cooler night temperatures so that the paving quality was improved.

Sherpard & Cottrell (1985) addressed several advantages and disadvantages of partial and complete roadway closure. For partial roadway closure, the advantages were preventing traffic congestion and driver delay, providing larger working areas enabling multiple work functions to be conducted simultaneously, and improving the working environment due to less traffic interference and cooler temperatures. The disadvantages were poorer driver conditions due to drowsiness, inattentiveness, and intoxication; poor driver visibility; complaints from residents due to noise; poor communication between the work site and the main office, media, and police; lower worker morale and difficulty in recruiting workers; difficulty in obtaining material, service from utilities, and service to repair equipment breakdowns; and higher costs due to differential pay, traffic control, and material acquisition. For complete roadway closure, the advantages were increasing worker safety, higher efficiency, safer environment for drivers, and shorter set-up times. The disadvantages were additional traffic control, noise, environmental considerations, consideration for the capacity of detour routes, complaints from the public due to detours, and additional costs for setting up detour routes.

Price (1985) indicated that cooler temperatures, safety, and reduced traffic were the advantages of nighttime work. However, worker morale problems arose from family and personnel problems due to working at night. In addition, there were some difficulties with communication between the night and day shifts and some difficulty with getting broken equipment repaired at night.

After a widening and resurfacing project on the I-40 freeway between Raleigh and Durham in North Carolina, Heine (1989) reported some disadvantages of nighttime work. It was more dangerous to work during the nighttime due to drunken drivers being on the road. Workers were excited when the nighttime work began, but they got tired of performing the nighttime work as the project progressed.

The advantages and disadvantages of nighttime work found through reviewing these studies are summarized in Table 2.1. According to the reviewed studies, it is hard to determine whether or not nighttime work is safer because of the conflict between the factors of a larger working environment at night versus poor driver and worker conditions. However, this study addresses this conflict through review and investigation of crash studies and data. At this stage, we note that the primary advantage of nighttime work is to reduce traffic congestion and a primary disadvantage is safety for workers as well as road users.

Table 2.1. Advantages and Disadvantages of Nighttime Work

Advantages	Disadvantages
Preventing traffic congestion	Poor driver and worker conditions (Safety)
Improving working environment (Safety)	Noise
Providing larger working areas	Poor communication
Higher productivity due to longer working hours	Difficulty in obtaining material and service
	Premium costs for nighttime work
	Domestic and social difficulties of night workers

2.3. FACTORS (PARAMETERS) AFFECTING NIGHTTIME WORK

In order to decide when to use nighttime work, factors affecting nighttime work must be identified and weighted. Several studies preliminarily identified the factors

(Sherpard & Cottrell 1985; Price 1985), and generally, these studies briefly addressed the factors without supporting data and explanations.

Hinze and Carlisle (1990a &1990b) identified factors related to the decision to conduct nighttime construction after studying state highway agencies' surveys. In order to collect data, a two-part survey questionnaire was designed. Part I was for construction engineers and transportation planners and Part II was for the workplace engineers associated with nighttime projects. Considerations for nighttime roadwork fell into two categories: decision-making concerns and performance concerns. Decision-making concerns are typically addressed before the project takes place and performance concerns address planning the project both before and during the nighttime work.

In the survey of construction engineers and transportation planners, data were collected from 21 different state highway agencies using a mail survey. Projects were investigated over a two-year span between 1987 and 1988, and a five-year span from 1984 to 1988. After statistical analysis, this study concluded that there was no significant difference between the cumulative response from all survey respondents and the responses of the individual states. This study found that many agencies have recently shifted towards awarding contracts to contractors who are conducting nighttime work. The importance of each factor was rated from 1 to 7 by each respondent. The most important factor was rated as 7, while the least important was rated as 1. Congestion and safety were rated as the most important factors for the decision makers.

In the survey of workplace engineers, telephone surveys were used to collect data in order to investigate eighteen contractors from eleven states. The average range of conducting nighttime work was 50%. While a few contractors responded that nighttime work was safer due to less traffic, the majority of contractors indicated that it was very dangerous. Regarding the worker morale issue, more than 75% of the contractors did not have any problems. The overall average contract cost for nighttime work was about 10% higher.

In conclusion, this study indicated that the cost of a project to the owner was likely to be less important in making a decision to conduct nighttime work as compared to the cost impacts on the users (drivers and passengers) resulting from congestion. In addition, safety and noise were other important factors affecting the decision.

The studies by Ellis, Herbsman, Kumar & Chheda (1991) and Ellis, Herbsman, Chhedda & Epstein (1993) took a different approach to identify and weight the factors. The following factors were identified, and these factors are categorized by their characteristics:

1) Construction-related factors: cost, quality, productivity, and noise
2) Traffic related factors: congestion, safety, and traffic control
3) Human factors: sleep, circadian rhythms, and social/domestic issues
4) Miscellaneous factors: public relations and information, supervision and communication, and supply and repair

A literature review and interviews with personnel who had experience in night operations in the United States allowed the identification of the above factors. After determining the factors, each factor's effect on nighttime work was addressed. In addition, projects around Florida were studied to determine how nighttime work was operated, and then guidelines for nighttime operation were developed.

After several hypothesis tests, this study concluded that cost, quality, and productivity were not significantly different between daytime and nighttime operations. The quality of nighttime work was mostly related to lighting, so with sufficient lighting, projects produced similar quality to daytime work. Hypothesis testing did not indicate significant differences in productivity levels between daytime and nighttime work. However, congestion was a primary factor when deciding on nighttime operation and safety was a secondary factor due to the severity of accidents, even though accident rates were low. The final conclusion was that daytime and nighttime operations were not significantly different, especially with respect to cost. However, this study advised that the evaluations and results would be different for different projects.

In 1993, Ellis et al. identified factors influencing task illumination requirements for nighttime work. These factors included:

1) Human factors: age, visual acuity, response characteristics, and experience and familiarity
2) Environmental factors: weather conditions, fog/dust/smoke, wet/dry surfaces, and ambient glare and brightness
3) Lighting factors: geometric relationships, orientation, power of lamps, gradient uniformity, and glare

4) Task-related factors:
   - Equipment attributes - speed, physical characteristics, response time
   - Task physical attributes - type of target, size of target, appearance & reflectance, location, visibility
   - Task qualitative attributes - importance of task, accuracy required, visual difficulty, visual fatigue
   - Background factors - reflectivity of surface, surface brightness
   - Operation attributes - type of facility, facility environment, traffic control, location on highway

Among these factors, speed, accuracy, importance, reflectance, seeing distance, and the size of objects were significant factors related to lighting.

Following the aforementioned studies, Elrahman and Perry (1994 & 1998) established a comprehensive set of factors (parameters) related to night operations. They used statistical data and findings from previous studies in order to identify these factors. Their factors were:

1) Traffic-related parameters: congestion, safety, and traffic control
2) Construction-related parameters: productivity and quality
3) Social parameters: driver condition and worker condition
4) Economic parameters: user cost, accident cost, maintenance cost, and construction cost
5) Environmental parameters: noise, fuel consumption, and air quality
6) Other parameters: scheduling, public relations, communication supervision, availability of material/equipment repair, and lighting

The afore-mentioned study by Ellis et al. (1993) identified in detail only the factors related to the lighting issue during nighttime work, while the study by Elrahman and Perry (1994 & 1998) was a broader study where the lighting factor was a single factor in another parameter category. These studies were intended to identify all possible factors that should be considered in making a decision. These factors were not weighted to establish their importance. In addition, the study by Hinze and Carlisle (1990a &1990b) investigated each factors' importance, but the number of investigated factors was not sufficient to cover all factors for nighttime work and the differential of the ranked values for the factors was too narrow.

After reviewing these studies, this study concluded that factors identified by Elrahman and Perry (1994 & 1998) are the most comprehensive set of factors related to nighttime work. This research study can use this set of factors as the basis for factor selection and priority. Table 2.2 compares the factors identified by Elrahman and Perry (1994 & 1998) and other studies.

Table 2.2. Comparison of Studies to Identify Factors Related to Nighttime Operations

Factor	Elrahman & Perry (1994 & 1998)	Hinze and Carlisle (1990a & 1990b)	Ellis et al. (1991 & 1993)	Ellis, Herbsman & Kumar (1993)
Congestion	Identified	Identified	Identified	N/A
Safety	Identified	Identified	Identified	N/A
Traffic control	Identified	N/A	Identified	N/A
Productivity	Identified	Identified	Identified	N/A
Quality	Identified	Identified	Identified	N/A
Driver condition	Identified	N/A	N/A	N/A
Worker condition	Identified	N/A	Identified	N/A
User cost	Identified	Identified	N/A	N/A
Accident cost	Identified	N/A	N/A	N/A
Maintenance cost	Identified	N/A	N/A	N/A
Construction cost	Identified	Identified	Identified	N/A
Noise	Identified	Identified	Identified	N/A
Fuel consumption	Identified	N/A	N/A	N/A
Air quality	Identified	N/A	N/A	N/A
Scheduling	Identified	Identified	N/A	N/A
Public relations	Identified	N/A	Identified	N/A
Communication supervision	Identified	N/A	Identified	N/A
Availability of material/equipment repair	Identified	N/A	Identified	N/A
Lighting	Identified	Identified	N/A	Identified

Note- N/A: Not Available

2.4. INVESTIGATION OF AN INDIVIDUAL FACTOR

In order to evaluate daytime versus nighttime alternatives in the decision model, many types of estimation and analysis can be utilized. Based upon factors identified by Elrahman and Perry (1994 & 1998), each identified factor can be expressed quantitatively or qualitatively in the decision model. Thus, the primary purpose of literature review in this section was to document information used to quantify factors related to nighttime operations in the model.

2.4.1. Congestion and User Cost

This study reviewed congestion and user cost factors together because the two factors are mutually dependent and many studies address them together. All of the delay estimation studies were based upon the Highway Capacity Manual (HCM) (Transportation Research Board, 1997) or Wang and Abrams's study (1981) to estimate delay. The first edition of the HCM was published in 1950, the second in 1965, and the third in 1985. The HCM was updated in 1994 and again in 1997.

Dudek et al. (1985) calculated work zone capacity and performed statistical estimates using regression. Sherpard and Cottrell (1985) used the above two studies to perform mathematical analysis of work zone capacity, delay, and expected traffic volume. Dixon and Hummer (1996) also conducted studies to estimate capacity and delay. The scope of the study by Dixon and Hummer (1996) was limited to North Carolina freeways, but this study indicated that these freeways were very similar to most freeways in the United States.

Martinelli and Xu (1996) studied two types of work zone delays, speed-reduction and congestion. Speed-reduction delays result from vehicles moving more slowly in work zones than on unencumbered freeways. Congestion delays occur when the hourly traffic volume is bigger than the capacity of a work zone for a significant period of time. In order to estimate traffic delay, a mathematical model was developed. A procedure was also established to estimate daily congestion delay under any given conditions. Alternative roadway closures were evaluated in terms of traffic control and additional road user costs.

Finally, the optimal work zone length for a project was calculated and procedures were developed.

A manual on user benefit analysis of highway and bus-transit improvements by the American Association of State Highway and Transportation Officials (1977) introduced mathematical calculation methods to conduct cost analyses related to highways such as user cost. Dudek et al. (1985) and Shepard and Cottrell (1985) used this manual on user benefit analysis of highway and bus-transit improvements as the basis of the cost analysis for their study.

After reviewing other studies, this study found that there are many studies and methods to estimate delay and user cost, however it is difficult for real decision makers to use them in order to support a decision about when to conduct nighttime operations. A traffic planner or engineer might use the former studies to estimate delay for each construction and maintenance project, but it is time consuming and complicated. Thus, this study found comprehensive and simple tools to estimate delays and user costs in work zone areas. The followings are the brief summaries of two tools used to estimate delays and user costs for construction and maintenance roadwork.

2.4.1.1. Quickzone Software

The Federal Highway Administration developed Quickzone software to estimates delays using equations from manuals such as the Highway Capacity Manual (Transportation Research Board, 1998) or a manual on user benefit analysis of highway and bus-transit improvements (American Association of State Highway and Transportation, 1977) as the basis for the software. This analytical tool allows users to estimate quickly and flexibly work zone delays supporting all four phases of the project development process- policy, planning, design, and operation (Mitretek Systems, 2001).

This study examined Quickzone version 0.99 for possible use by real decision makers in DOTs, but concluded that the program's complexity would prohibit its use by real users. It was difficult to design a specific layout for a project with the software and solve problems if a user encounters an error in running the software. In addition, the manual did not provide sufficiently clear and detailed instructions for using the software.

2.4.1.2. Lane Rental Method

Using Microsoft Excel, some DOTs have developed their own simple programs to estimate road user costs and lane rental fees due to closing lanes for construction and maintenance projects. Lane rental methods were originally developed by the British DOT in 1984 and have been used in the United States since 1990 (Herbsman, Chen and Epstein, 1995). This method transfers the road user costs that arise due to construction or maintenance operations to the contractor since the contractor must rent one or more lanes for closure.

An Excel spreadsheet developed by the Oklahoma DOT enables the estimation of road user costs in multiple lane roads. This spreadsheet was originally developed in OKDOT in 1997 (Zimmerman, 1997) and modified in 2000 and 2001. This spreadsheet is a very easy and user-friendly practical program for estimating road user costs. It utilizes lane rental methods to estimate road user costs and uses equations identical to the equations in the traditional calculation method. Users enter the necessary information, and obtain road user costs without hand calculations. Thus, this study decided to utilize this spreadsheet to estimate road user cost in the daytime versus nighttime and compare them in the decision model.

2.4.2. Safety

The most relevant source of information regarding safety is accident studies. However, there were no studies of accidents that occurred as a result of nighttime work. Many studies mentioned the crash frequency during nighttime work, but they did not draw any clear conclusions since they did not have sufficient statistical data. Lee (1969) was the first to address crash frequency related to nighttime work. The crash records during nighttime work were 12 crashes along the 13-mile length of roadwork, while 13 nighttime crashes were reported during the same calendar period during the previous year.

In 1977, Graham, Paulsen, and Glennon collected considerable crash data to study the relationship between construction work on roads and crash frequencies. A total of 79 projects in seven states were used to study crashes. About 20,000 crashes were recorded, which was the combined total of crashes before and during construction or maintenance on roads. Analyses of the before versus during construction work crashes and crash frequencies, regression analysis, and case studies were conducted. The results were that overall the crash frequency increased about 7% during construction work, but in 31% of the projects the crash frequency actually decreased during the work. Shorter duration and shorter length construction projects had higher crash frequencies. Also, there were higher crash frequencies in the places where 6-lane or 8-lane freeways were reduced to 1-lane in each direction. The total number of fatal crashes decreased during construction work. However, this study did not address daytime versus nighttime work.

According to statistical data, the number of night crashes was smaller than that of day crashes, but about 55 percent of all fatal crashes occurred at night (Lum, 1980). Lum collected crash data from 7 states between 1974 and 1975. The results indicated that the total number of crashes during construction and nighttime was higher than before construction, but this study did not draw this conclusion due to the small sample sizes. Only seven states collected data for the same year and the data were different from state to state, which prohibited effective comparisons.

Since there was no practical and reliable statistical crash study about nighttime work, it will be hard to use the former studies to adapt to future research about nighttime versus daytime work. Thus, the investigation of crash data in representative states in the United States is necessary to draw a conclusion and incorporate this factor.

2.4.3. Traffic Control

Many of the guidelines for nighttime work address traffic management and control. Also, the studies focused on how easily drivers identify the roadwork environment and what methods most effectively induce drivers to reduce their speed. Graham et al. (1977) conducted an experimental design in order to test speed reduction methods. The results were that enforcement patrols and lighted roads decreased speeds around their installation locations, but this speed reduction was effective only over a shorter length of highway. The initial period of construction time was less hazardous than later periods. Also, drivers usually drive depending on the road conditions rather than on signs.

Wang and Abrams (1981) found that the traffic control strategy of most projects was selected by subjective judgment based on engineering experience and knowledge, and familiarity with local conditions. Therefore, the objective of their study was to establish quantitative procedures to be applied in the early planning and design stages of highway construction or maintenance projects to select the most effective traffic control strategies for the project.

First, nine measures of effectiveness that should be considered to select a strategy were identified: delay, stops, fuel consumption, vehicle operating costs, accidents, cost of traffic control, cost of construction, air pollution, and business loss. Among the nine measures, delay, stops, fuel consumption, operating costs, and air pollution were deeply related to capacity and the speed of traffic flow. Therefore, they focused their efforts on collecting and analyzing data from six areas: 1) work zone capacity, 2) work zone speed patterns, 3) work zone accidents, 4) traffic control costs, 5) construction costs, and 6) business loss.

Seventeen state and local agencies were utilized to collect data. Equations from former studies and regression graphs were used to estimate costs, capacity and crash frequencies for each topical area. For example, in order to estimate the additional number of crashes due to construction or maintenance work, former crash data were collected and analyzed by type of traffic control such as number of lane closures or length of duration of closures. In the construction costs section, this study could not be generalized in a quantitative manner since various strategies of construction cost depend upon the location and type of project. Case studies were shown instead of establishing a standardized approach. To estimate business loss, sales taxes before and during construction work around the work area were gathered. For future study, this study suggested the collection of more data.

Lytton et al. (1985) also conducted a similar study to that of Graham et al. (1977). Data with respect to speed control methods (e.g., flagging, law enforcement, CMS (Changeable Message Signs), effective lane reduction, conventional signing, and rumble strips) were collected to determine which method was the most effective in reducing drivers' speeds. The results indicated that flagging and law enforcement were the most effective methods, and these methods could reduce speeds an average of 19% and 18%, respectively. Since these two studies did not separately investigate nighttime work, it is difficult to draw a conclusion for nighttime work.

Price (1985) established safety by the following instructions:

1) Variable message signs: These are designed to display one or more required flashing messages such as "Night Work Ahead" and can be read easily at 55 MPH.
2) Construction signs: These were illuminated to show the shape and color during day and night. A lantern was attached to the base of each sign to improve illumination, but this method was not effective.
3) Sequential arrow boards: These boards are additional warning and directional information devices. This study recommended using these boards instead of the variable message sign since these boards were easier to identify.
4) Channelization devices: Reflection cones were used in this project due to their convenience, good visibility and ease of understanding.
5) Uniformed traffic officers and flagmen: These staff were very valuable in this project, especially to control drunken drivers.

Recently, the Virginia Department of Transportation (2000) studied the effect of traffic control during nighttime work on motorists and transportation agency personnel. The methodology was to survey all 50 states' DOTs and motorists in Virginia, and to observe several nighttime work sites in Virginia to obtain information. This study then identified strategies to improve traffic control for nighttime work. The survey found that poor visibility, driver inattention, poor lighting and lack of maintenance of traffic control devices were common problems in nighttime work. This study could not find significant evidence of higher speeds at nighttime due to insufficient data. According to motorists' responses, traffic control for nighttime work was adequate. The traffic control strategies were similar to Price's study (1985).

The study by Wang and Abrams (1981) addressed the overall procedure of traffic control strategies, but other studies focused on only speed control methods in work zones. The procedure by Wang and Abrams is similar to the objective of this study to develop a decision model. However, their procedure is not for decision-making to determine when to conduct nighttime operations, but for selection of a traffic control strategy in work zones.

2.4.4. Quality

Price (1985) studied the overall quality of nighttime work using the I-70 resurfacing project in Colorado. The overall quality of the nighttime work was similar to daytime work. Three test results were given in this study. These were compaction, asphalt content, and field specific gravity. However, Price's study recommended that guardrail installation jobs should not be done during the nighttime due to difficulty with the aesthetic installation of guardrails.

Since there was no useful study upon which to base a conclusion of quality in daytime versus nighttime, this research study will investigate a specific quality metric measurement for construction and maintenance projects in daytime versus nighttime. A widely used as well as well-known quality measurement should be selected and investigated.

2.4.5. Construction Cost

Price (1985) indicated that the total cost at night for the I-70 resurfacing project between Quebec St. and Colorado Blvd. in Denver was 159% higher after the estimation of all costs, including time and dollar savings to the public due to nighttime work, and personnel and fuel costs due to delays.

Ellis and Kumar (1993) evaluated nighttime construction costs for the Florida Department of Transportation (FDOT). Since all projects are very unique and have unique work tasks, it is very difficult to compare between daytime and nighttime work. In order to solve this problem, eight different types of typical work served as the basis for comparison in this study. Examples of typical work include removal of existing pavement, regular excavation, and bituminous material-prime coat or tack coat. Data were gathered for all daytime and nighttime FDOT work sites. In addition, all actual nighttime projects were collected and the projects were converted to daytime projects for comparative purposes. The result was that nighttime construction costs (unit costs) were generally lower than daytime costs for FDOT projects. However, this paper drew this conclusion cautiously since eight nighttime projects were insufficient to draw accurate conclusions.

Every project has different user construction and maintenance costs, so previous studies focused on case studies instead of the generalization of comparison of daytime versus nighttime. This research needs to investigate whether there is any difference between daytime and nighttime operations, and if so, it needs to determine how much difference there is between them.

2.4.6. Public Relations

Some studies investigated responses to nighttime work sites by contractors, workers, drivers, and residents including drivers around the project area. Colle & McVoy, Inc. (1992 & 1993) conducted two case studies after the completion of I-35W and I-94 projects in Minnesota. The objective of the study of the I-35W project was measuring the effect of public information and creative traffic safety tools that had not been used before in mill and overlay work on I-35W. This project was conducted between 8 PM and 5 AM for 12 days and the length of the work zone was 4.5 miles, running through Minneapolis and its southern suburbs. The Highway Advisory Radio (HAR) system provided information about alternative routes and was first used for this type of project in Minnesota. Safety tools such as reflective uniforms for workers and reflective tape on construction equipment were created for this project. In addition, various types of traffic control such as patrolmen, flagmen, and speed limit signs were used.

To collect data on the above items, people who were driving in the work area on I-35W were surveyed. The majority of people saw and heard the construction information and used alternative routes instead of driving on I-35. The HAR system did work to give information to drivers, and drivers could identify all safety tools easily. Therefore, the overall impression of this project was good (73%) and congestion was less than for other projects (48%). For better understanding, this report provided many other statistics based upon interest and traffic counts before and after construction.

For the I-94 case study, survey methods were used and compared to the I-35W project and the objective of this study was same as that of the I-35W project. In this study, respondents were separated into three different categories: motorists, residents, and businesses and their workers. For this project, television commercials were used to provide information about alternative routes during the work hours instead of sending direct mailings and this method proved to be useful to the public. Other major tools utilized to inform the public were highway signs and HAR. The overall evaluation of this project was worse than that for the I-35W project because of more traffic congestion. For better understanding, this report provided many statistics based upon different types of opinions and upon the previous project. Since this study did not further address and analyze why the I-94 project was worse than the I-35W project, it is difficult to improve the methodology of nighttime work for future study from these results.

These studies investigated public relations after the completion of projects. In this research the decision model needs to compare public relations in daytime and nighttime alternatives before starting a project, so it needs to obtain objective criteria for a successful decision for real users.

2.4.7. Lighting

Ellis et al. (1993) conducted a major study about lighting issues. According to research by the FDOT, work zone lighting was the main factor related to quality and safety during nighttime work. No prior study focused on the lighting issue and only six states in this country had some form of lighting standards before this study. This study focused on the determination of optimum and minimum light intensity levels, optimal arrangements of light sources, and the standardization of work zone lighting.

Three illumination level categories were developed using many different types of standards such as IES (Illuminating Engineering Society) and OSHA (Occupational Safety and Health Administration). These illumination level categories included: 1) a recommendation for general illumination in the work zone, 2) lighting on and around construction equipment, and 3) efficient visual performance required for certain tasks. Finally, general guidelines were developed. Other guidelines by the New York State Department of Transportation (1995) and the National Cooperative Highway Research Program (1996) used this study to establish their standards.

Prior studies have not addressed the comparison of daylight and artificial light. Thus, this study needs to decide whether it is necessary to conduct experiments of the comparison or collect data for further investigations. However, this study can tentatively assume that if night workers follow lighting standards, the lighting environment can be similar to daylight environment.

2.4.8. Worker Condition

There is no study addressing the factor of worker condition for nighttime work in construction and maintenance roadwork, so this study found literature in all fields related to worker condition in daytime versus nighttime. There are several references concerning shift work in industry which addressed various physiological issues related to shift work (Folkard et al., 1985, Fraser, 1989, Grandjean, 1988, and Kroemer et al., 1994 & 1997). They addressed circadian (diurnal) rhythms, sleep, and the scheduling of shift work. For circadian rhythms, typical variations in body functions over the day by body temperature, heart rate, blood pressure, and Potassium (K^+) excretion were discussed. For sleep, sleeping stages and the quantity and quality of sleeping were addressed. In addition, some examples were provided to schedule the shift work. However, most studies found that it is difficult to conclude how much there is for workers during the night shift due to difficulties in measuring and the different physiological conditions of people.

Colquhoun et al. (1978) briefly mentioned that the poorest performance was observed during the midnight-to-dawn hours and a smaller decrease in performance is observed during the mid-afternoon. Monk and Folkard (1985) analyzed the performance levels of shift work observed in six previous studies:

1) Browne (1949)
2) Bjerner and Swensson (1953)
3) Prokop and Prokop (1955)
4) Wojtczak-Jaroszowa and Pawlowska-Skyba (1967)
5) Hildebrandt, Rohmert and Rutenfranz (1974)
6) Folkard, Monk and Lobban (1978)

Additionally, Monk et al. (1996) studied the above six studies further using a Meta-analysis. In both studies, they concluded that performance levels of nighttime work are about 30-50% lower than daytime work.

All six studies were reviewed, but it was concluded that the overall analysis using six studies by Monk et al. was not applicable to this research since two studies were not done using real measurements of shift work performance. Prokop and Prokop (1955) surveyed truck drivers in Germany to investigate when it was difficult to drive on the road for 24-hour cycles instead of measuring the real performance of the truck drivers. In addition, the study by Folkard, Monk and Lobban (1978) is not applicable since the relationship between patients' accidents and nurses' circadian rhythms is vague. The studies by Brwon (1949), Bjerner & Swensson (1953), and Hildebrandt, Rohmert and Rutenfranz (1974) compared errors in daytime versus nighttime shifts instead of measuring physical conditions of workers such as the speed of workers. Thus, these studies cannot be well-incorporated into the consideration of worker condition in daytime versus nighttime.

This study found two studies, one by Wojtczak-Jaroszowa & Pawlowska-Skyba (1967) and another by Tilley Wilkinson (1982) that measured such worker conditions as speed of work and reaction time in daytime versus nighttime. They concluded that worker condition at nighttime is about 10% lower compared to daytime. This conclusion is applicable to this research study and is incorporated into the development of a decision model. Below are the findings from the two studies.

2.4.8.1. The Study by Wojtczak-Jaroszowa and Pawlowska-Skyba, (1967)

This study conducted experiments with five female workers in a clothing factory and five male workers in a glass factory in Poland. The workers selected had at least 10 years' working experience in their company and in both companies, they were being rotated in 3 shifts. In the clothing factory, 5000 measurements based on the speed of one stitch of sewing were collected. In the glass factory, 3680 measurements were collected using the speed of spinners.

Table 2.3 shows the time schedule of shift work in both companies. Figures 2.1 and 2.2 show the measured speed of work in each time period by different shifts. For example, period I covers 5:30-6:30 for the morning shift, 13:30-14:30 for the afternoon shift, and 21:30-22:30 for the night shift in the clothing fabrication company in Figure 2.2.

According to the results in hypothesis tests, there is a significant difference only between the morning and night shifts in the clothing factory. Other shifts did not have any significant differences between them.

Table 2.3. Shift Work Schedules in Both Companies

Shift	Clothing	Glass
Morning (M)	5:30-13:30	6:00-14:00
Afternoon (A)	13:30-21:30	14:00-22:00
Night (N)	21:30-5:30	22:00-6:00

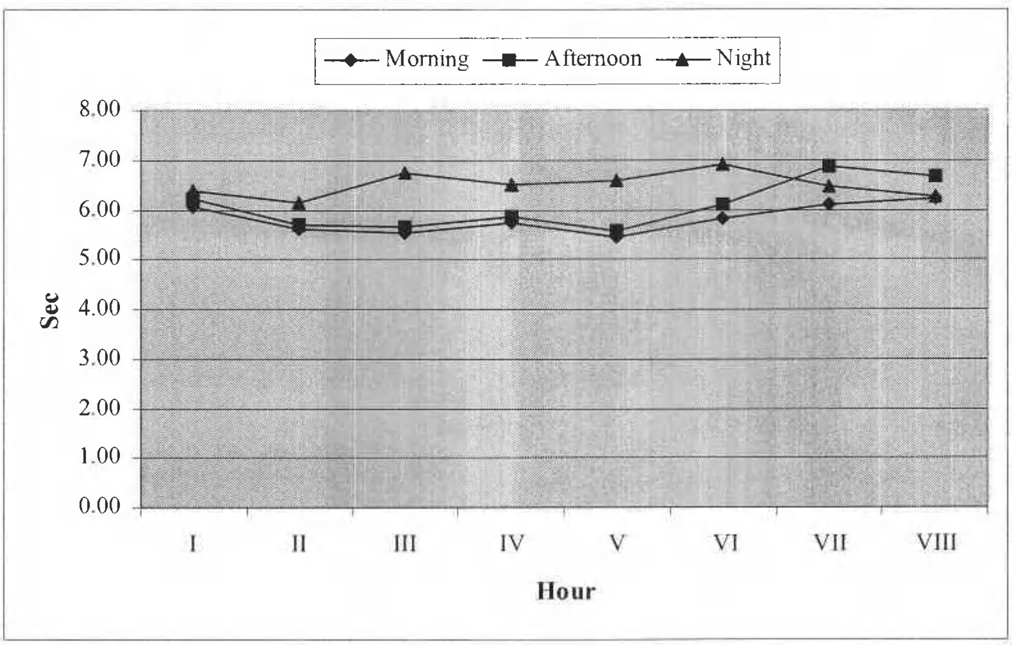

Figure 2.1. The Speed of Work in Different Shifts in the Clothing Factory

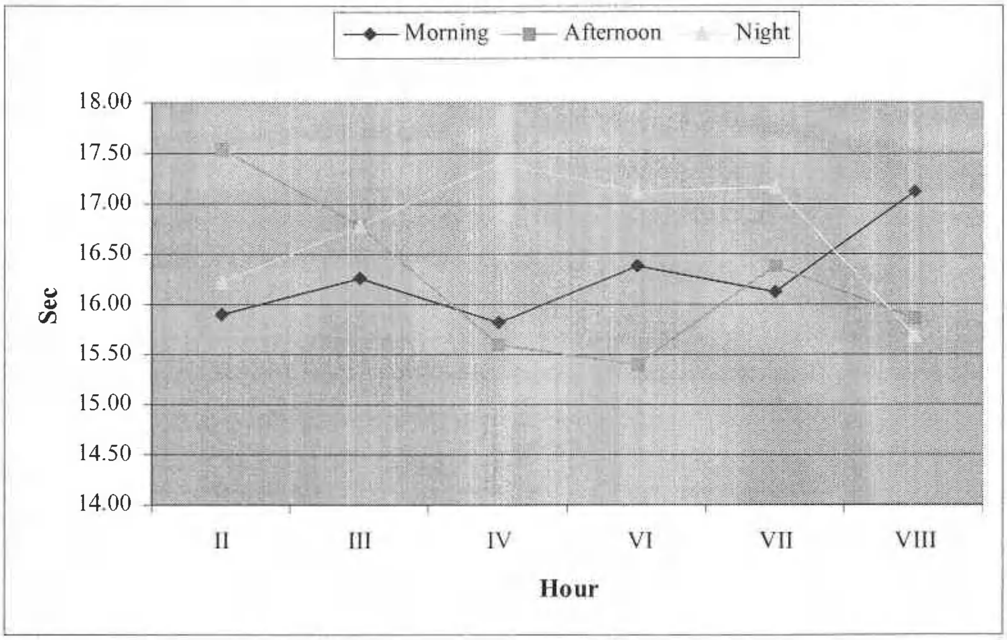

Figure 2.2. The Speed of Work in Different Shifts in the Glass Factory

Table 2.4. Comparison of Performance Levels in Different Shfits

Shift	Time								
	I	II	III	IV	V	VI	VII	VIII	Average
Clothing Industry									
M vs. N	5.28	9.07	21.70	13.61	20.66	18.73	6.24	0.80	11.73
A vs. N	2.41	7.92	18.69	11.09	18.49	13.09	-5.55	-6.14	6.89
M+A vs. N	3.82	8.50	20.18	12.34	19.57	15.84	0.00	-2.79	9.26
Glass Industry									
M vs. N		1.95	3.20	10.11		4.52	6.39	-8.46	2.82
A vs. N		-7.47	0.00	11.60		11.24	4.83	-1.20	2.90
M+A vs. N		-2.99	1.57	10.85		7.77	5.60	-4.97	2.86

An analysis of the comparison of performance levels in different shifts in both companies is shown in Table 2.4, using the data available from this study. In the clothing factory, it can be concluded that the performance level of female workers at night is

11.73% lower than in the morning, 6.89% lower in of the afternoon, and 9.26% lower than a combination of morning and afternoon. Also, in the glass factory, the performance level of male workers at night is 2.82% lower than in the morning, 2.90% lower than in the afternoon, and 2.86% lower than in a combination of the morning and afternoon.

Female workers' performance level in the clothing company showed a bigger difference between shifts than the performance level of male workers' in the glass company. However, the data gathered from the glass company did not include all 8 working hours since the first and fifth time periods were excluded due to no working processes during the periods. This may influence the decrease in the gap of the performance level between shifts. Moreover, there is only a significant difference between morning and night shifts in the clothing factory based upon the results of hypothesis tests. It is possible to conclude that the performance level of night shifts is about 11.73% lower that that of morning shifts.

2.4.8.2. The Study by Tilley Wilkinson, Warren, Watson, and Drud (1982)

Tilley et al. conducted an experiment with two groups of six workers who were a mean age of 43 with a range from 30 to 60 years old, from Cadbury Schweppes, Limited, in Cambridge over a 2-year period. The workers in the group were divided into three sections: morning, afternoon, and night. Each had two workers working on the same shift. First, this study measured the quantity of sleep. Workers on the night shift had 1.5 hours less sleep than workers on the afternoon shift, average sleep times being 5.5 hours and 7 hours, respectively. This represents a 25% reduction in sleeping time.

In order to measure the performance level of shift workers, this study measured simple unprepared reaction time. Figures 2.3 and 2.4 show the results. Figure 2.3 is the result of the first half of the test and figure 2.4 is the second half of the test. The results indicate that the simple reaction time of night-shift workers was poorer with successive nights on the night shift as the task duration increased.

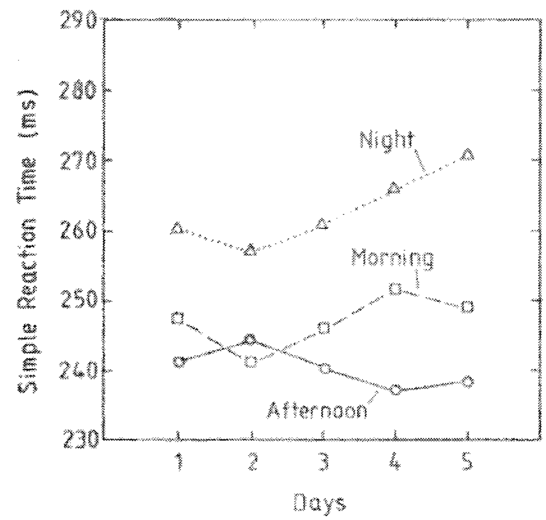

Figure 2.3. Reaction Time I (Tilley, et al., 1982)

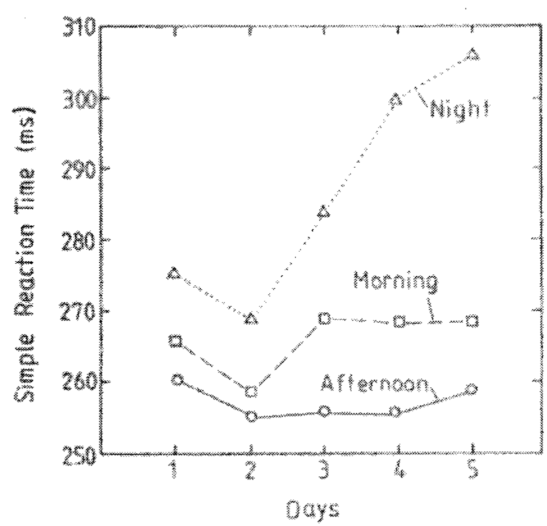

Figure 2.4. Reaction Time II (Tilley, et al., 1982)

Table 2.5 shows a comparison of the performance level of night versus day shifts, based upon the above data. The data lead to the conclusion that the performance level of the nighttime shift is 7 or 9 % lower than that of the morning shift or the combination of the morning and afternoon shifts.

Table 2.5. Simple Reaction Time on Each Day of the Three Shifts

First Half of Test							
Days	1	2	3	4	5	SUM	AVG
Morning (M)	247.50	242.00	246.00	252.00	249.50	1237.00	247.40
Afternoon (A)	241.50	245.00	240.00	237.50	238.50	1202.50	240.50
Night (N)	261.50	257.50	262.00	266.00	271.50	1318.50	263.70
(M+A)/2	244.50	243.50	243.00	244.75	244.00	1219.75	243.95
M vs. N	0.06	0.06	0.07	0.06	0.09	0.07	0.07
(M+A)/2 vs. N	0.07	0.06	0.08	0.09	0.11	0.08	0.08
Second Half of Test							
Morning (M)	266.00	259.00	269.00	268.50	269.00	1331.50	266.30
Afternoon (A)	260.00	255.50	257.00	257.00	259.00	1288.50	257.70
Night (N)	275.50	269.00	284.50	300.00	306.50	1435.50	287.10
(M+A)/2	263.00	257.25	263.00	262.75	264.00	1310.00	262.00
M vs. N	0.04	0.04	0.06	0.12	0.14	0.08	0.08
(M+A)/2 vs. N	0.05	0.05	0.08	0.14	0.16	0.10	0.10

Overall		
	SUM	AVG
Morning (M)	2568.50	256.85
Afternoon (A)	2491.00	249.10
Night (N)	2754.00	275.40
(M+A)/2	2529.75	252.98
M vs. N	0.07	
(M+A)/2 vs. N	0.09	

Note: Performance at night is 9% lower.

2.4.9. Summary of an Individual Factor

After reviewing literatures related to each factor affecting nighttime work, this study found that researchers studied several factors, which are congestion, user cost, safety, traffic control, quality, construction cost, public relations, lighting, and worker condition, summarized in Table 2.3. This information will be useful to investigate these factors at any stage of development of a decision model.

Table 2.6. Summary of an Individual Factor Investigation

Factor	Discussed Issue	Studies
Congestion	Theoretical delay estimation	Transportation Research Board (1997)
		Wang & Abrams (1981)
		Duderk et al. (1985)
		Shepard & Cottrell (1985)
		Dixon & Hummer (1996)
	Types of delay	Martinelli & Xu (1996)
User Cost	Theoretical user cost estimation	American Association of State Highway (1977)
		Duderk et al. (1985)
		Shepard & Cottrell (1985)
		Mitretek Systems (2001)
		Zimmerman (1997)
Safety	Crash study	Lee (1969)
		Graham et al. (1977)
		Lum (1980)
Traffic Control	Selection of traffic control strategy	Wang & Abrams (1981)
	Speed control method	Graham et al. (1977)
		Lytton et al. (1985)
		Price (1985)
		Virginia DOT (2000)
Quality	Case study for the comparison	Price (1985)
Construction Cost	Case study for the comparison	Price (1985)
		Ellis & Kumar (1993)
Public Relations	Case study for media usability and its public response	Colle & McVoy, Inc., (1992 & 1993)
Lighting	Lighting standard	Ellis et al. (1993)
		New York DOT (1995)
		National Cooperative Highway Research Program (1996)
Worker Condition	Performance levels in day vs. night	Wojtczak-Jaroszowa & Pawlowska-Skyba (1967)
		Tilley Wilkinson et al. (1982)

2.5. COMPARISON OF DAYTIME VERSUS NIGHTTIME WORK (DECISION MAKING SYSTEM)

After identifying the factors, decision-making steps should be developed to determine when to use nighttime work. Sherpard and Cottrell (1985) introduced a brief guideline to help with making decisions to conduct nighttime operations. Their steps include: 1) evaluate the proposed project, 2) examine relevant traffic data, 3) estimate roadway capacities, 4) estimate potential daytime delays, 5) analyze feasibility of night work and closing the entire roadway, 6) decide on night operations, and 7) after deciding to conduct nighttime work, plan for public notice and safety.

The New York State Department of Transportation (1991) provided a different guideline that consists of two steps to analyze proposals for the possibility of nighttime work. The first step is a qualitative analysis to examine the feasibility of the proposal and the second step is a quantitative analysis to compare with other proposals. For the qualitative analysis, safety, quality, and community impact should be addressed. In order to provide a safe environment to motorists, workers, and inspectors, high quality conditions such as adequate visibility and adequate support and cooperation from government agencies and the public are necessary. Adequate visibility, proper temperatures, and minimizing the duration of nighttime work are required to produce good quality. To minimize community impact, compliance with State and local ordinances, advance publicity and coordination, and proper mitigation of noise and glare impacts are needed.

Traffic benefits and construction costs should be considered in the quantitative analysis. In order to do nighttime work, significant benefits such as feasible traffic volumes and community impacts should be proved. For construction costs, reasonable direct cost tradeoffs should be produced between potential increased costs such as higher labor costs, additional lighting requirements, and material availability and potential savings such as shortened duration and more efficient work environment due to off-peak traffic conditions.

The above studies did not weight the factors by importance and gave limited examples to make decisions based on the established methods. In other words, there were no supporting examples to prove the newly introduced methods. Elrahman and Perry (1994) mitigated this weakness by establishing a decision-making system. They suggested eight steps to determine the most efficient alternative between the daytime and nighttime work:

1) Evaluate the proposed project: description of the work and assembling the necessary information that provides traffic and roadway data for the work.
2) Assess roadway occupancy: examination of the relationship between traffic demands and roadway capacity.
3) Identify traffic-control alternatives: the determination of appropriate traffic-control strategies.
4) Analyze volume/capacity relationships: the determination of work-zone capacities of the various work-zone strategies, comparing them to traffic volume, and the calculation of queue length and duration if volume exceeds capacity.
5) Identify capacity-improving techniques: the determination of additional techniques to reduce delays and congestion.
6) Quantify impacts: conducting a quantitative analysis (traffic delay costs, vehicle operating costs, construction costs) and a qualitative assessment.
7) Assess feasibility of a night schedule: estimation of night operation if daytime strategies fail to accommodate traffic demand. The estimation steps are identical to the above steps from 1 to 6.
8) Select the preferred alternative: the determination of cost-effectiveness
   a) Identify goals and objectives for the project
   b) Determine relative importance of each goal and objective within a goal
   c) Develop measures for each objective and weight each measure of effectiveness or each objective
   d) Rate the objectives on a scale from 0 to 10 for each alternative of each measure of effectiveness
   e) Multiply the objective weight by its rating and sum to obtain a single rating for each alternative
   f) Compare the single rating for each alternative and select the option that has the highest ratio, either total or incremental.

A simple example was shown to help understand these steps. All mathematical equations to calculate or estimate various values in the above steps used other studies' methods such as those in McFarland and Schafer (1975), Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (1977), Wand and Abrams (1981), Transportation Research Board (1985), and Lytton, Dudek, Richards, and Wunderlich (1985).

Hancher and Taylor (2000) developed a nighttime project evaluation form for the potential of a specific project, consisting of five categories of project issues: traffic, economical, social, construction and other project-related issues. Each questions quantified the effectiveness of nighttime operations for the specific project on a scale of 1 (not at all effective) to 5 (very effective). After the completion of this form the evaluator could rate the five categories subjectively. This study found that this form did not absolutely determine whether to conduct nighttime or not, but underscored the issues the decision maker should consider regarding nighttime operations. Thus, the project planner should make the ultimate decision.

The study by Elrahman and Perry (1994) provided the best approach for determining when to use nighttime work, but it was not practical to adapt to real projects because of the impracticality of the analysis tool. There is an opportunity for inconsistent use between different decision makers even within a specific agency. Factors related to nighttime operations should be included, estimated, weighted, and compared for both daytime and nighttime operations. In addition, the above steps originated from analysis only of daytime work instead of both daytime and nighttime work. These improvements will be the most important part of this study.

2.6. CONCLUSIONS FROM THE LITERATURE REVIEW

Elrahman and Perry (1994 & 1998) established a comprehensive set of factors (parameters) related to night operations. Their factors were:

1) <u>Traffic-related parameters:</u> congestion, safety, and traffic control
2) Construction-related parameters: productivity and quality
3) <u>Social parameters:</u> driver condition and worker condition
4) <u>Economic parameters:</u> user cost, accident cost, maintenance cost, and construction cost
5) <u>Environmental parameters:</u> noise, fuel consumption, and air quality

6) Other parameters: scheduling, public relations, communication supervision, availability of material/equipment repair, and lighting

After literature review, it was concluded that the above 19 factors were well-established and were acceptable to utilize for the decision model in this study. Thus, all 19 factors were used to conduct this research. However, what was not available in the literature was any information on the relative importance of these factors in making decisions concerning daytime versus nighttime work. Thus, the decision was made to administer a survey to gain this information.

The limitations of the prior decision models were: 1) the lack of factors' weights, 2) inadequate methods to quantify the factors in daytime versus nighttime, and 3) the absence of a decision model that will allow consistency of decision making within an agency. Therefore, this study focused on addressing the problems of former studies to create a useful and reliable decision model for real users in the United States.

3. METHODOLOGY

This research consists of two phases: Phase I is determining the type of research appropriate for this study and identifying factors affecting nighttime construction and maintenance operations through a literature review and survey, and Phase II is developing the decision model to determine when to conduct nighttime operations. Figure 3.1 shows the flow chart of this research methodology.

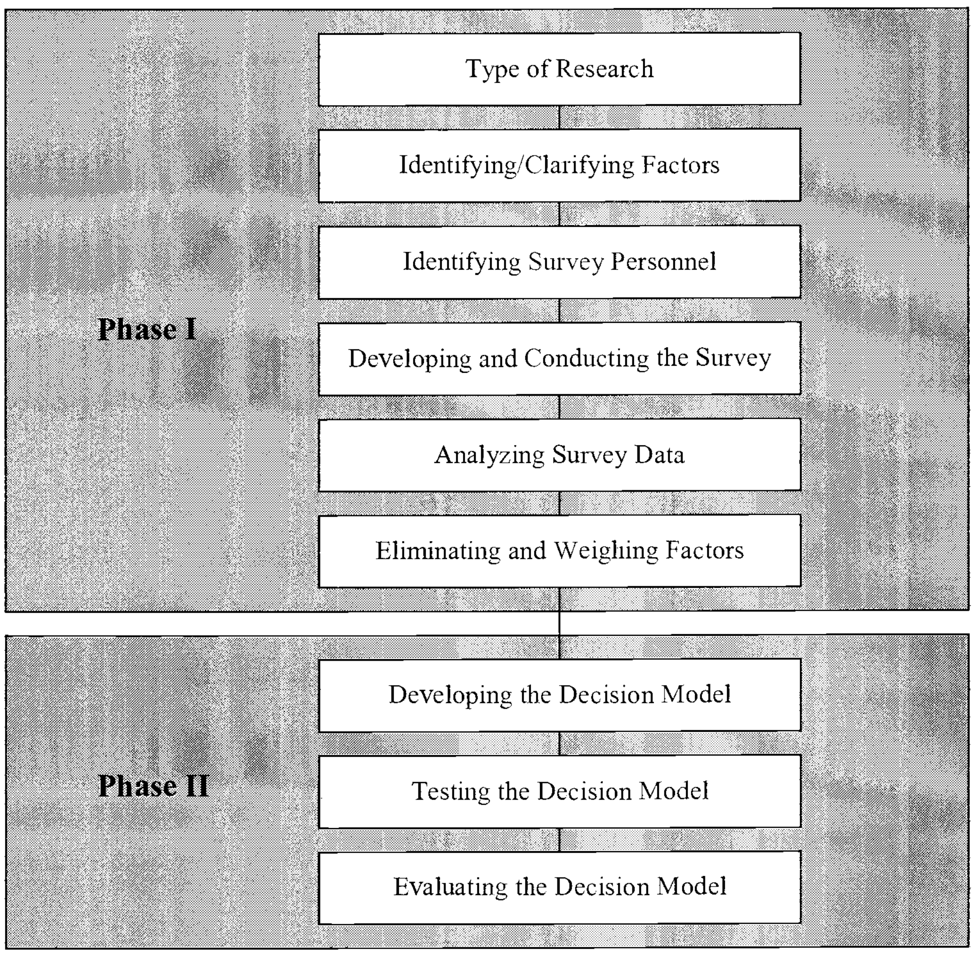

Figure 3.1. Flow Chart of Research Methodology

3.1. RESEARCH PHASE I

In order to create a decision model in this project, it was necessary first to determine the research type and identify/clarify factors affecting nighttime construction and maintenance roadwork. Through reading the literature, factors affecting nighttime operations can be identified and surveys can be conducted to clarify the factors. In this section, the method of conducting the survey is discussed: how to select survey personnel, how to develop the survey, how to survey, and how to analyze the data. The elimination of unimportant factors affecting nighttime operations and weighing of important factors is addressed.

3.1.1. Type of Research

According to Webster's Dictionary of the English Language, research is "a studious inquiry or examination, especially a critical and exhaustive investigation or experimentation having for its aim the discovery of new facts and their correct interpretation, the revision of accepted conclusions, theories, or laws in the light of newly discovered facts or the practical application of such conclusions, theories, or laws (Merriam-Webster)." Thus, research can be described by the research type it pursues as well as by the research questions it purports to answer.

Many researchers such as Bernal (1956), Williams and Stevenson (1963), Hillway (1964), Ross (1974), and Mauch and Birch (1983) addressed these types of research. Since basic research (pure or fundamental) and applied research (practical or technical) are the primary research types within universities and among scholars, only these two research types are discussed. Patton (1990) described five research types as shown in Table 3.1. Summative evaluation, formative evaluation, and action research can be conducted in real-world settings such as organizations and industries. Thus, it is difficult to generalize beyond the specific intervention being studied under these research types (Patton, 1990).

This research is not basic research because it does not pursue knowledge as an end in itself. This research is applied research because it contributes knowledge that will help people understand the nature of a problem so as to effectively control their environment.

In other words, this research provides a decision-support tool for decision makers who determine when to conduct nighttime construction and maintenance roadwork operations. These decision makers currently do not have any systematic decision model to make their decisions.

Table 3.1. Type of Research

Types of Research	Purposes	Focus of Research	Desired Results	Desired Level of Generalization
Basic research	Knowledge as an end in itself; discover truth.	Questions deemed important by one's discipline or personal intellectual interest.	Contribution to theory	Across time and space (ideal)
Applied research	Understand the nature and sources of human and social problems.	Questions deemed important by society.	Contribution to theories that can be used to formulate problem-solving programs and interventions	Within as general a time and space as possible, but clearly limited application context
Summative evaluation	Determine effectiveness of human interventions and actions (programs, policies, personnel, products).	Goals of the intervention	Judgments and generalizations about effective types of interventions and the conditions under which those efforts are effective	All interventions with similar goals
Formative evaluation	Improving an intervention: a program, policy, organization, or product.	Strengths and weakness of the specific program, policy, product, or personnel being studied.	Recommendation for improvements	Limited to specific setting studied
Action research	Solve a problem in a program, organization, or community.	Organization and community problems.	Immediate action; solving problems as quickly as possible	Here and now

Source: Patton (1990)

3.1.1.1. Triangulation

Triangulation was used to insure validity of this research. According to Patton (1990), triangulation is one of the important ways to strengthen a study design. This approach utilizes several kinds of methods and/or data, including using both quantitative and qualitative components. Patton (1990) and Miles & Huberman (1994) provided four types of triangulation to design a study:

1) Data triangulation: the use of various data sources in a study
2) Investigator triangulation: the use of several different researchers or evaluators
3) Theory triangulation: the use of multiple perspectives to interpret a single set of data
4) Methodological triangulation: the use of multiple methods to study a single problem or program.

Through triangulation, a study can eliminate the risks of some types of errors such as the Type 1 error, believing a statement to be true when it is not, and the Type 2 error, rejecting a statement which, in fact, is true (Silverman 1993). This study used data triangulation to identify survey personnel and methodological triangulation to develop the survey.

3.1.1.2. Criteria for Judging Research Method

Marshall and Rossman (1989) showed that researchers must respond to the following questions in qualitative research:

1) Are the findings of the study truthful? What kinds of criteria can we judge them on?
2) Are these findings applicable to another environment or group of people?
3) Is it possible to replicate the findings under the same participants in the same context?
4) Are the findings reflective of the subjects and the inquiry itself rather than the product of the researcher's biases or prejudices?

Yin (1994) addressed the answer to the above questions by Marshall and Rossman (1989). Trustworthiness, credibility, confirmability, and data dependability are four tests to measure the quality of any empirical social research. Based upon these four concepts, Yin established tactics for four research design tests for case study research, shown in Table 3.2. He mentioned that these tactics are usable to deal with these four tests in case study research as well as all other types of research. The shaded tactics were used in this research.

In this research, data triangulation was a tactic that used multiple sources of evidence to increase construct validity. In order to identify/clarify factors affecting nighttime operations, multiple sources of data were collected. In the data analysis after the survey, the results were considered from various perspectives such as overall, positions, and regions. This is pattern matching, which can increase internal validity. By doing this, the survey result can build various explanations by various perspectives and this also increases the internal validity of this research.

Table 3.2. Tactics for Four Research Design Tests

Tests	Tactic	Phase of research in which tactic occurs
Construct validity	*use multiple sources of evidence	data collection
	*establish chain of evidence	data collection
	*have key information review draft case study report	data collection
Internal validity	*do pattern-matching	data analysis
	*do explanation-building	data analysis
	*do time-series analysis	data analysis
External validity	*use replication logic in multiple-case studies	research design
Reliability	*use case study protocol	data collection
	*develop case study data base	data collection

Source: Yin (1994)

This research provided a generalized decision model for decision makers. This enabled replication of logic and then increased external validity. To test the reliability of the decision model this study developed, the decision model was tested on at least 10 former or future projects, which is a tactic for using replication logic in multiple-case studies. This research used case study protocol and maintained evidence of studies using tabular materials such as surveys and other quantitative data for data collection. These enabled us to assess reliability of the research studies.

3.1.1.3. Technical Advisory Committee (TAC)

For this research, a group of experts, called the Technical Advisory Committee (TAC), guided and examined the many processes of this research. These experts are members of Oregon Department of Transportation (ODOT), Federal Highway Administration (FHWA), Asphalt Pavement Association of Oregon (APAO), and Morse Bros., Inc. which is one of the contractors in ODOT.

3.1.2. Identifying/Clarifying Factors

After the literature review, it was concluded that the 19 factors by Elrahman and Perry (1994 & 1998) were well established, comprehensive and appropriate to utilize for this study. Their factors were:

1) Traffic-related parameters: congestion, safety, and traffic control
2) Construction-related parameters: productivity and quality
3) Social parameters: driver conditions and working conditions
4) Economic parameters: user costs, accident costs, maintenance costs, and construction costs
5) Environmental parameters: noise, fuel consumption, and air quality
6) Other parameters: scheduling, public relations, communication supervision, availability of material/equipment repair, and lighting

However, what was not available in the literature was any information on the relative importance of these factors in making decisions concerning daytime versus nighttime work. Thus, all 19 factors from Perry (1994 & 1998) were used to create a survey. In order to confirm the importance of these factors and clarify differences in importance between factors, a comprehensive survey was made of both Oregon state personnel that have experience in construction and maintenance operations, as well as critical decision makers from other states.

3.1.3. Identifying Survey Personnel

In this research, identifying survey personnel was the first instance where triangulation was used. The survey used data triangulation in the survey response groups. Thus, surveys were administered to both employees of the state and contractors in Oregon. In addition, Department of Transportation personnel from other states were surveyed in order to examine other states' current practices for comparative purposes.

After collecting the survey data, the responses were analyzed by personnel category (construction vs. maintenance), positions, and geographical location to investigate whether there were any significant differences between categories, positions, or geographies.

3.1.3.1 Structure of Oregon

Oregon Department of Transportation (ODOT) divides Oregon by five operational regions, illustrated in Figure 3.2. Also, each region has several sub-operational units in cities to conduct construction and maintenance operations. Table 3.3 shows the operational structure of Oregon. According to the Population Research Center at Portland State University, the estimated population of Oregon as of July 1, 2002 is 3,504,700 (Population Research Center, 2002). Figure 3.3 shows the percentages of the estimated population by regions.

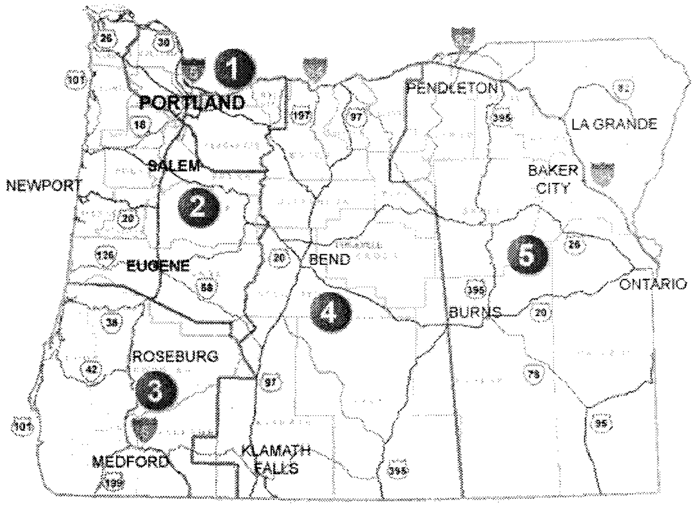

Figure 3.2. Operations Division in Oregon (ODOT, 2003)

Table 3.3. The Operational Structure of Oregon

Region	Construction Operations	Maintenance Operations
1	Troutdale	Portland
	Tigard	Clackamas
	Portland	Troutdale
	Beaverton	
	Milwaukie	
2	Salem	Astoria
	Astoria	Salem
	Eugene	Corvallis
	Corvallis	Springfield
3	Coquille	Roseburg
	White City	White City
	Roseburg	
4	Bend	Bend
	The Dalles	The Dalles
	Klamath Falls	Klamath Falls
5	Ontario	Pendleton
	La Grande	La Grande
	Herminston	Ontario

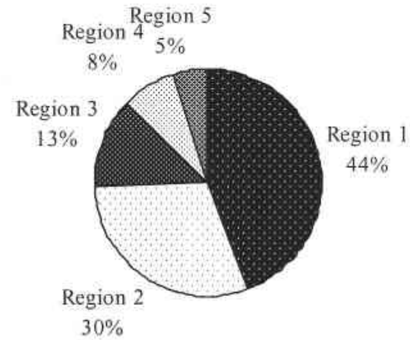

Figure 3.3. Percentages of Oregon population by regions

3.1.3.2. Survey Personnel

An investigation of general operations in ODOT allowed this study to determine which personnel should be surveyed. Construction operations are mainly new road construction, including highways, and rehabilitation of roads, such as paving. The Project Managers (PM) are in charge of the construction operations and their staff consists of an Assistant Project Manager (APM), Coordinators, Inspectors, and other positions. Generally, one inspector monitors each construction project through supervising the project to ensure both that the procedures follow the project plan and work quality is acceptable. Workers used for these construction projects are typically from local contractors. The workers from these local contractors are generally seasonal workers since, excluding long-term projects, ODOT does not usually do construction projects during the rainy seasons. As the survey was conducted during the winter months, it was infeasible to survey actual hands-on contractor personnel. To compensate, it was possible to obtain useful actual hands-on information from inspectors who were monitoring the processes of the projects. However, the infeasibility to survey actual hands-on contractor personnel can limit the survey results in this study.

Maintenance personnel work on a very wide range of projects such as repairing roads and bridges, short length paving, road cleaning due to snow, repairing electronic and mechanical systems in dams, mowing shoulders, sign replacement, guardrail repair, and pavement patching. The District Managers (DM) are the supervisors of maintenance operations and their staff consists of an Assistant District Manager (ADM), Transportation Maintenance Managers (TMM) or Area Maintenance Managers (AMM), Coordinators, and other positions. Each district office is divided according to county and a TMM or AMM monitors each smaller location. Generally, each location has permanent workers and facilities for maintenance projects. This study was able to survey actual hands-on maintenance personnel since they are permanent employees of ODOT.

Thus, it was necessary to survey PM and DM staff as well as contractors to gain a comprehensive perspective. In addition, the study's TAC recommended that this study survey other personnel involved in construction or maintenance projects, such as Traffic Control Plans Designers (TCPDs) and Technical Services Resource Managers (TSRMs). The Traffic Control Planning Unit is a statewide team, and they are located at the Salem headquarters. TCPDs produce a working set of contract plans for the Traffic Control portion of the project. In order to establish a plan, TCPDs collect a wide array of information regarding the geometry of the work site, traffic volumes, details for bridges, the type of work being done, and construction techniques. In addition, they are responsible for compiling a cost estimate for the Traffic Control Devices used in the Traffic Control Project.

TSRMs are located in five regions of Oregon. They ensure that construction projects are successfully delivered by coordinating cooperation among the regions. The main elements considered when monitoring each project are on time, on budget, right scope, quality, and customers' needs. They are also responsible for statewide technical discipline of roadway engineering such as consistency, efficiency, and product quality (legal and sound engineering, biddable and constructible projects), developing an engineering force for the future, and meeting Oregon State Board of Examiners for Engineering and Land Surveyors (OSBEELS) requirements.

Finally, this study surveyed personnel outside of Oregon to compare Oregon's priorities with those of other states to insure generalizability. Thus, representative decision makers from other states were invited to respond to an electronic version of the survey.

Therefore, this study ultimately surveyed five different types of personnel. Figure 3.4 shows a graphic representation of the categories of personnel surveyed.

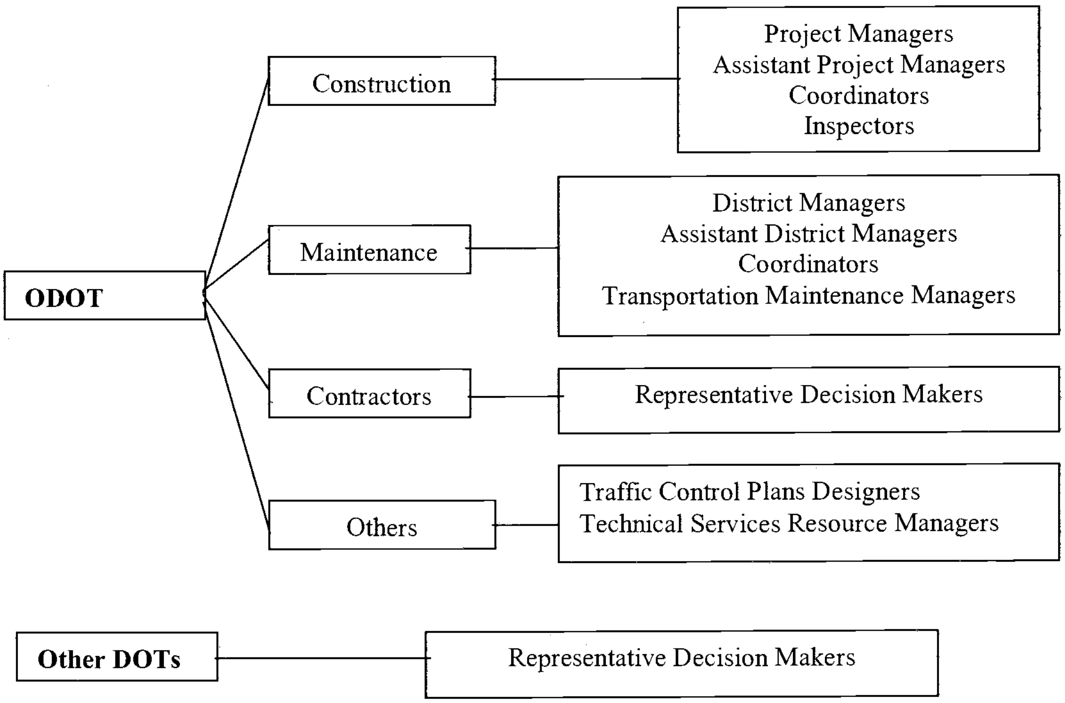

Figure 3.4. Surveyed Personnel

3.1.4. Developing and Conducting the Survey

The purpose of the survey was to discover if the factors identified in the literature were important, and if so, to rank their relative importance. This information then would be incorporated into a decision model to assist in making determinations of whether daytime or nighttime construction and maintenance work should be done. The survey was developed based upon the 19 factors identified from the literature. It consisted of two parts, which will be referred to as "indicating" and "ranking" factors. The reason for including both formats in the survey was to determine the relative importance between factors and to check for consistencies between the two response methods. This methodological triangulation made use of multiple methods to study a single problem or program (Patton, 1990). Open-ended questions were included at the end to acquire additional information.

For the indicating factors, participants were asked to rate each factor from 1 to 7, where 1 is the lowest and 7 the highest level of importance. For ranking factors, the survey asked respondents to rank all 19 factors from 1 to 19, with 1 being the most important factor and 19 being the least important factor. Through using indicating and ranking factors, this study enabled us to investigate whether each factor has consistent importance between the indicating and ranking methods. This is one of methods triangulation in this research study. However, the indicating and ranking factors may have produced a single-source bias that would limit this study. In other words, the respondents' schemas influence their answers to two or more separate survey measures, inflating the measures' shared variance. In addition, survey participants gave their preferences between daytime and nighttime work along with the reason for their preferences. Finally, respondents were asked if there was any other information they would like to share. The completed format of survey was shown in Appendix A.

After developing the survey, the researcher decided to visit all of the PM and DM offices across the state as well as regular TCPD and TSRM meetings to increase response rates since other approaches (e.g., mail, telephone, web-based) traditionally have shown response rates lower than 30%. The researcher, or his representative, visited each office during its regular meeting time and surveyed staff after providing a brief explanation about this study and the survey. Thus, the response rate for this survey was exceptional at over 90%. In order not to create bias between participants, investigators did not answer questions from participants during the survey completion.

In order to survey contractors, investigators attended an annual meeting of the Association of General Contractors (AGC) and met with both contractors and ODOT personnel. Surveys were distributed to the contractors who attended this meeting, and in addition, AGC faxed a copy of the survey to all of its members. The faxed distribution allowed the contractors to fax back their response, and this significantly increased the response rate. In order to classify the responses from the contractors questions about their experience with nighttime work and the type of work they do (e.g., bridges, paving, excavation) were added to the survey.

In order to survey other state departments of transportation (DOTs), a web-based survey was used. The survey added two questions to the original survey: 1) experience with nighttime work in their state and 2) the decision process they use to determine when to conduct nighttime work.

3.1.5. Analyzing Survey Data

In order effectively to understand the results of the survey, the results must be considered from various perspectives. First, the overall results which combine PMs, DMs, Contractors, TSRMs, TCPDs, and other DOTs were investigated. Also, the categories of responses then were analyzed. Second, comparative analyses between overall results and each individual category were developed because it was necessary to compare the overall result to each individual category to check for internal consistency. In particular, if there is a significant difference between ODOT personnel and other ODOTs, a single decision model cannot serve as the only model as to when to conduct nighttime operations for all States. Finally, the results of the PMs and DMs surveys needed more in-depth analysis since the sample size was large and consisted of different regions and positions. In addition, any differences between PMs and DMs had to be investigated since their operations vary (construction versus maintenance work).

3.1.6. Eliminating and/or Weighting Factors

After analyzing survey data, it was necessary to consider whether all 19 factors should be included in the decision model. If certain factors are consistently indicated and ranked relatively low across all personnel categories, the factors may be considered to be unimportant in affecting decision-making as to when to conduct nighttime operations. Thus, significant factors affecting nighttime operations could be identified.

Then, the importance (weight) of each factor could be identified by using the indicating and ranking values of each factor from the survey results. However, this task definitely depended on the results of the survey. If there are significant differences between Oregon and other states and/or construction and maintenance operations, the decision model should be robust and include multiple decision strategies and weighting values corresponding to the different populations. Otherwise, values from the overall survey result could be considered to be generalizable to the entire state.

3.2. RESEARCH PHASE II

Having determined the critical factors, further investigation was necessary to develop the decision model since each factor has its own characteristics and the values of the characteristics should be used in the decision model. Some factors were necessary to collect data in selected states, so this study divided the state into four different categories in order to generalize the decision model. In addition, qualitative factors should be transformed to quantitative values wherever possible, and a decision model could be created. After the model was created, testing and evaluating methods were addressed to test the validity and reliability of the decision model.

3.2.1. Generalization of Study: Selection of States

In order to generalize the decision model for Departments of Transportation (DOTs) in the United States, it was necessary to select representative states and divide them by state types based upon population, registered driver population, registered vehicles, area, and lengths of roads. Data by the Bureau of Transportation Statistics (2002) and the United States Census Bureau (2000) enabled this study to divide the states into four different state types. In addition, TAC members recommended several states by characteristics of states and reputation of states' DOTs.

Table 3.4 shows the four state types for this study. Even though the detailed numbers were obtained from the Bureau of Transportation Statistics (2002) and are based on 2000 data, the selection strategies of state types were based upon multiple data and resources. This is another example of data triangulation in this research.

At one end of the spectrum, Type 1 states are the most populated with the most heavy traffic density areas. At the other end, Type 4 states are the least populous with the fewest heavy traffic density areas. Type 2 and type 3 states fall between there two extremes. For example, although Oregon and Maine are similar, this study separated them because of the amount of data available for Oregon, so Oregon was considered an independent state type.

Table 3.4. Selected States by Type Category

Type	State	People/square mile by state	Licensed People/square mile by state	Registered vehicle/square mile by state	Registered vehicle/NHS road (mile)
1	CT	614.28	478.46	524.44	3019.21
	IL	214.43	137.45	158.29	1611.83
	IN	166.95	109.18	156.20	2009.46
	MD	426.89	272.62	314.09	2704.33
	NY	348.35	199.57	189.85	2012.07
	PA	266.64	178.68	205.73	1739.94
2	AZ	45.00	30.12	34.73	1467.62
	MN	56.58	33.82	54.90	1203.17
	OK	49.36	32.83	43.95	924.79
	TX	77.63	50.12	53.08	1061.20
3	OR	34.78	25.36	31.42	822.96
4	ME	36.03	26.00	29.76	816.28

Source: Bureau of Transportation Statistics (2002)

3.2.2. Developing the Decision Model

Each factor has its own characteristics (sub-factors). By focusing on this point in the reviewed literature, characteristics (sub-factors) of each significant factor were identified. Necessary data for each characteristic on nighttime versus daytime operations were collected from related literature, ODOT, and other DOTs. Some sub-factors had quantitative values so that the values could be directly used for a decision model.

However, if a sub-factor contains qualitative value of characteristics, the sub-factor had to be transferred to quantitative values.

For example, safety, a qualitative factor, was one of the factors affecting nighttime operations. Accidents could be a primary sub-factor of safety, but this characteristic was also qualitative. One way to quantify this characteristic was investigating crash rates. Thus, crash rates in Oregon and other states were collected on both daytime and nighttime, with and without construction/maintenance operations, in Oregon and other states. After analyzing the data, crash rates of daytime versus nighttime were expressed as a ratio value which can be usable for the decision model. If there is no significant difference between accident rates of metropolitan areas and rural areas or among states, a single ratio value could be used for the decision model, otherwise, multiple values will be used according to various conditions such as different states or traffic volumes.

Each value of the sub-factors was accumulated and the accumulated value of each factor was multiplied by its respective importance weight and the products were added for each alternative such as daytime and nighttime work. Therefore, the best alternative (daytime or nighttime) that could be selected has the highest total value among the alternatives. Thus, the following equation shows a theoretical decision model in this study:

$$U_i = \sum_{j=1}^{m} W_j \left(\frac{1}{n} \sum_{k=1}^{n} V_{ijk}\right)$$

Where,

Ui = aggregate score of alternative
Wj = importance weight for factor j
$Vijk$ = score of sub-factor k of factor j on alternative i
i = alternative
j = factor
k = sub-factor
m = number of factors
n = number of sub-factors

In the above decision model, $Vijk$ is a variable element that is considered linearly in the model instead of non-linearly in order to make it easy for real users to understand the structure of the decision model. This can be a limitation of the theoretical decision model in this study.

The decision model in the research attempted to accomplish the following two objectives. First, the goal was to develop a decision model that would be simple and easy to understand and use by real decision makers. The model was developed using popular computer software, Visual Basic 6.0. Second, the decision model should be generalized for the widest possible use, ideally throughout the United States. A single decision model could have different quantified values of a factor if there are any significant differences between states or cities, construction and maintenance operations, or other appropriate distinguishing characteristics. Thus, a decision maker can select the proper environment of his/her area to make a decision.

3.2.3. Testing the Decision Model

It was necessary to first determine the proper number of sample projects for testing. According to Yin (1994), in multiple-case study analysis each case must be carefully selected so that it either predicts similar results (a literal replication) or produces contrasting results but for predictable reasons (a theoretical replication). He states that the ability to conduct six to ten case studies is similar to the ability to conduct six to ten experiments on related topics. Two or three cases would typically be literal replications and four to six cases may pursue two different patterns of theoretical replications. Therefore, if all the cases (six to ten cases) turn out as predicted, the cases would support the initial set of propositions, otherwise the initial propositions must be revised and retested with another set of cases.

In this study, at least 10 former and future construction or maintenance projects that will be conducted during daytime or nighttime were selected to be tested. Table 3.5 shows selection strategies for testing projects with the decision model. Based upon the strategies, various types of projects were selected. Through testing, the decision model enabled a comparison between the actual daytime/nighttime decision on a given project and the recommendation for that project by the decision model. The model also provided a suggestion regarding when to conduct a project in the future.

Table 3.5. Selection Strategies for Testing Projects

Strategy	Category
Type of State	Type 1, 2, 3, and 4 State
Type of Work	Construction and Maintenance
Type of Work Duration	Less and More than 3 days
Type of Work Status	Former, Current, and Future Project
Type of Scheduled Work	Daytime and Nighttime
Type of Workplace	Interstate-Urban, Interstate-Rural, Arterial-Urban, and Arterial-Rural

3.2.4. Evaluating the Decision Model

According to Patton (1990), the usefulness of applied research is judged whether human actions and intentions became more effective or not, and by its practical utility to decision makers, policymakers and others having a stake in efforts to improve the world. Thus, this research study needs to evaluate the decision model's practicality, usefulness, and user-friendliness for potential real users. In order to assess this outcome, practitioners should assess the usefulness of the model.

This study assessed usefulness and practicality. A group of State Traffic Design Engineers in the Washington Department of Transportation (WDOT) was asked to review the model. They are similar to the Traffic Control Plans Designers (TCPDs) in ODOT. Both groups produce a working set of contract plans for the Traffic Control portion of the project and investigate a wide array of information regarding the geometry of the work site, traffic volumes, details for bridges, the type of work being done, and construction techniques. Since this study did not include Washington State in the state types categories, the experts from WDOT who participated were able to evaluate this study with objective views as well as provide perceptions and expertise without any biases.

In order to successfully design the evaluation of this research, this study followed the general institutional policy of the Oregon State University (OSU) Institutional Review

Board (IRB) for safeguarding the rights and welfare of humans in research, as mandated by federal regulation. Based upon the policy, a protocol was developed:

1) **Objective of evaluation**: This study sought to evaluate the decision model and whether or not the model supports project planners (decision makers) in minimizing the impact on the public and workers, and increasing the project's operational efficiency.
2) **Participant Population**: This study did not investigate characteristics of the State of Washington due to geographic similarities. Thus, the Washington Department of Transportation (WDOT) was a good participant population to evaluate the decision model. Representative decision makers who are managers or engineers in WDOT voluntarily participated in the evaluation. The total number of participants in this study was estimated from 5 to 10. This evaluation did not restrict evaluation to any gender or ethnic groups. The only restriction was to representative decision makers for nighttime road operations.
3) **Methods and Procedures**: The study planned to give a presentation about the creation of the decision model and also demonstrate the decision model during the presentation. After the presentation, this study surveyed the participants focusing on issues of practicality, usefulness, and user-friendliness for approximately 5 minutes (See Appendix B). This method used a panel of experts in the field by collecting their opinion through feedback questionnaires. Since the majority opinion is represented by the median, this method did not necessarily have to have a complete agreement by all panelists.
4) **Risks and Compensations**: There were no foreseeable risks or compensations to participants in this study.
5) **Benefits**: After the completion of this survey, the decision model to determine when to conduct nighttime road construction and maintenance operations will be evaluated. The WDOT participants in this study can have a copy of the research paper with the decision model if they want to utilize it for their personnel.
6) **Informed Consent Process**: Participation in all aspects of this research was voluntary. Informed consent documents were used prior to surveying the participants. Only those participants who agreed to participate were surveyed. All elements of informed consent were included within the instructions of the survey.

7) **Anonymity or Confidentiality**: Individual names were not necessary to evaluate the decision model in this study. The survey only identified the organization and the general position.

4. RESULTS OF PHASE I

A thorough literature review revealed a list of factors considered to be relevant in decision-making on conducting daytime versus nighttime construction and maintenance work. In order to confirm the importance of these factors and clarify level of importance of the factors, a comprehensive survey was made of state personnel that have experience in construction and maintenance operations in the ODOT. Surveys were administered to both employees of the state and contractors. In addition, Department of Transportation personnel from other states were surveyed.

After collecting the survey data, the responses were analyzed by personnel category (construction vs. maintenance), positions, and geographical location to investigate whether there were any significant differences between categories, positions, or location. An overview of the survey process and results is provided below.

It was necessary to identify/clarify critical factors affecting nighttime construction and maintenance roadwork. In other words, this study eliminated factors that did not aid in differentiating between a daytime or nighttime preference. The weights of important factors were obtained using results from the survey.

4.1. SURVEY RESULTS

The results of this survey will be understood most thoroughly by considering them from various perspectives. First, overall results which combine PMs, DMs, contractors, TSRMs, TCPDs, and other DOTs are shown. The categories of responses will then be discussed. Finally, comparative analyses between overall results and each individual category will be presented. In addition, PM and DM results are analyzed by regions and positions to investigate any differences that might arise among regions or positions. The preference of work time and other information will be addressed last.

4.1.1. Respondent Demographics

Figure 4.1 shows the demographics of the survey respondents. In total, 446 surveys were completed. Table 4.1 details which states responded to the survey and if a state provided multiple responses. The response rate was 50% from states across the nation.

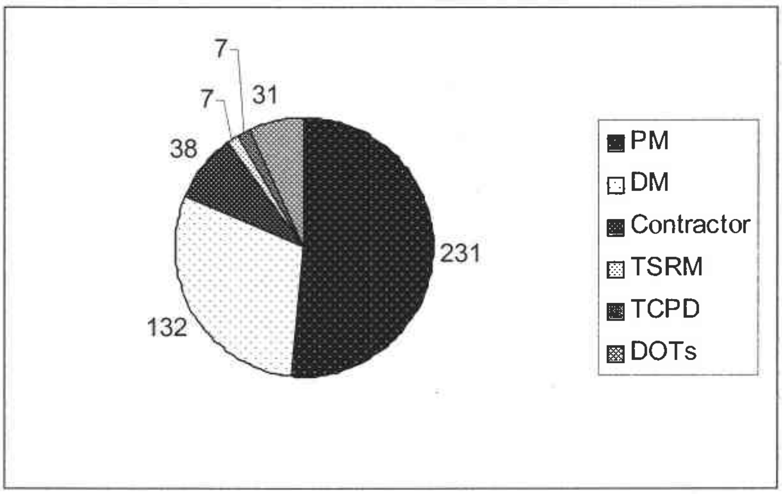

Figure 4.1. Responses by Respondent Type

Table 4.1. Responses from Other States

Response States	Number of Response	Non-Responsive States
Arizona	1	Alabama
Colorado	1	Alaska
Connecticut	1	Arkansas
Delaware	1	California
Florida	1	Hawaii
Georgia	1	Idaho
Illinois	1	Kansas
Indiana	2	Maine
Iowa	1	Maryland
Kentucky	1	Massachusetts
Louisiana	4	Minnesota
Michigan	1	Mississippi
Montana	1	Missouri
Nebraska	1	New Hampshire
Nevada	1	New Mexico
New Jersey	1	North Carolina
New York	2	North Dakota
Oklahoma	1	Ohio
Pennsylvania	1	Rhode Island
Tennessee	1	South Carolina
Utah	1	South Dakota
Virginia	2	Texas
Washington	1	Vermont
Wisconsin	1	Washington D.C.
Wyoming	1	West Virginia
Total 25 States	31	Total 25 States

4.1.2. Overall Results

Table 4.2 provides the results from all respondents considered as a single group. The factors are sorted by ascending order of the "indicating" value. The table is divided into four sections with bold lines. These lines represent locations where the factors could be divided such that the factors in each section appear in both the indicating and ranking factors. This method utilizes methods triangulation to seek consistency of findings. In other words, for both the indicating and ranking factors, safety, traffic control, and congestion were the most important factors affecting nighttime work. These are in the top section of Table 4.2. Similarly, air quality and fuel consumption were ranked as the least important for both categories. These are in bottom section of Table 4.2. The five factors in these two sections are shaded with dark and light gray colors respectively in Tables 4.3-6 to visually illustrate their relative importance to the different groups.

Table 4.2. Overall Result

Overall (n=446)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Safety	6.44	1.07	Safety	2.08	2.48
Traffic Control	6.07	1.17	Traffic Control	4.05	2.69
Congestion	5.98	1.34	Congestion	4.83	4.53
Lighting	5.84	1.52	Quality	6.64	3.81
Quality	5.40	1.55	Productivity	7.32	3.87
Public Relations	5.32	1.41	Worker Condition	7.90	4.16
Worker Condition	5.19	1.61	Driver Condition	8.76	4.26
Productivity	5.11	1.37	Lighting	9.12	5.30
Scheduling	5.07	1.61	Public Relations	9.42	4.65
Driver Condition	5.04	1.56	Construction Cost	10.16	4.35
Construction Cost	4.94	1.57	Scheduling	10.23	4.61
Accident Cost	4.92	1.66	Accident Cost	11.13	4.38
Availability of Material/Equipment Repair	4.70	1.87	Noise	11.74	4.74
Communication Supervision	4.64	1.67	User Cost	11.91	4.46
Noise	4.57	1.82	Maintenance Cost	12.16	4.24
User Cost	4.52	1.59	Availability of Material/Equipment Repair	12.20	5.12
Maintenance Cost	4.46	1.74	Communication Supervision	12.61	4.63
Air Quality	3.27	2.04	Air Quality	15.24	4.09
Fuel Consumption	2.89	1.85	Fuel Consumption	16.43	3.51

The second and third sections enumerate the factors of secondary and tertiary importance, respectively. The method for separating the sections is the presence of each factor in the section. For example, even though the lighting factor was ranked differently in the indicating and ranking cases, the factor can be found in the second section in both categorizations.

The factors in the upper section were consistent across all groupings (PMs, DMs, TSRMs, TCPDs, and other DOTs), except for the contractors. The least important factors were likewise consistent across all groups, including the contractor responses.

In order to decide whether the overall results can be used as a direct representation of the population, results by each personnel category should be individually examined, and it is necessary to compare them to know whether there are any significant differences among any categories.

4.1.3. PM Office Results

Table 4.3 illustrates the survey results from PM personnel. The data between the highest and lowest factors' sections are divided into three sections by bold lines. The first section contains the six factors that can be expected to be the second most important set of factors in nighttime work. From their experience, many inspectors, as well as other personnel, found these issues to be of concern during nighttime work. Comments indicated that many inspectors experienced accidents due to drunken drivers. From this analysis, one could conclude that the four types of cost factors (accident cost, construction cost, user cost, and maintenance cost) are less important than the other factors to the PM personnel. It is necessary to examine those cost factors further in the other response groups.

PM results appear to be consistent with the perspective one would expect. For example, since contractors rather than PMs are impacted by construction issues such as availability of material, equipment repair, and communication supervision, PMs considered these factors to be of lesser importance. Also, the maintenance cost factor is low because this issue is not within their domain.

Table 4.3. Project Managers' Offices Results

PM (n=231)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Safety	6.55	0.92	Safety	1.90	2.12
Traffic Control	6.13	1.12	Traffic Control	3.94	2.58
Congestion	5.89	1.33	Congestion	5.06	4.48
Lighting	5.89	1.47	Quality	6.18	4.00
Quality	5.47	1.55	Productivity	7.54	3.88
Public Relations	5.26	1.36	Worker Condition	7.61	4.05
Worker Condition	5.15	1.58	Driver Condition	8.05	3.99
Productivity	5.04	1.36	Lighting	8.93	5.33
Driver Condition	5.02	1.47	Public Relations	9.62	4.61
Scheduling	4.89	1.61	Construction Cost	9.74	4.02
Accident Cost	4.86	1.60	Scheduling	10.53	4.57
Construction Cost	4.81	1.58	Noise	11.23	4.72
Noise	4.7	1.75	Accident Cost	11.44	4.24
Communication Supervision	4.51	1.67	User Cost	12.21	4.26
User Cost	4.37	1.49	Communication Supervision	12.34	4.67
Availability of Material/Equipment Repair	4.25	1.83	Maintenance Cost	13.39	3.72
Maintenance Cost	4.17	1.68	Availability of Material/Equipment Repair	13.54	4.85
Air Quality	3.53	1.96	Air Quality	14.89	4.06
Fuel Consumption	3.02	1.77	Fuel Consumption	16.12	3.58

4.1.4. DM Office Results

Table 4.4 shows the results for the surveys from DM personnel. There are two sections between the highest and the lowest sections. The factors of communication supervision, user cost, and noise were rated relatively lower in importance. Since the project length of DMs' operations is relatively short, communication supervision and noise are consequently lower in priority. Some maintenance projects can be conducted in one day or over a couple of days. It is interesting to note that the user cost factor is ranked as not important by both DMs as well as PMs, even though this factor is related to congestion.

Table 4.4. District Managers' Office Results

DM (n=132)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Safety	6.41	1.19	Safety	1.89	2.45
Traffic Control	6.21	1.17	Traffic Control	3.68	2.74
Congestion	6.10	1.31	Congestion	4.80	4.90
Lighting	5.99	1.43	Productivity	7.48	3.99
Public Relations	5.60	1.30	Quality	7.61	3.59
Quality	5.48	1.52	Worker Condition	7.67	4.11
Availability of Material/Equipment Repair	5.44	1.75	Lighting	8.91	5.35
Maintenance Cost	5.34	1.48	Driver Condition	9.06	4.40
Worker Condition	5.31	1.58	Public Relations	9.32	4.70
Scheduling	5.27	1.62	Maintenance Cost	9.45	4.02
Driver Condition	5.24	1.62	Availability of Material/Equipment Repair	9.92	4.96
Accident Cost	5.14	1.57	Scheduling	10.03	4.53
Productivity	5.13	1.36	Accident Cost	11.28	4.40
Construction Cost	5.03	1.50	Construction Cost	11.61	4.32
Communication Supervision	4.85	1.58	User Cost	12.41	4.17
User Cost	4.69	1.48	Communication Supervision	12.73	4.63
Noise	4.42	1.88	Noise	13.22	4.56
Air Quality	3.06	2.15	Air Quality	15.66	4.20
Fuel Consumption	2.91	1.94	Fuel Consumption	16.93	3.28

Due to the characteristics of DM operations, maintenance cost is highly ranked compared to the results for PMs. In addition, availability of material and equipment repair is higher since many projects can be finished within a day if there are no problems with availability of material or no breakdown of equipment.

4.1.5. Contractors' Results

Table 4.5 shows the contractors' results and there are obvious differences as compared to other results. The traffic control and congestion factors are ranked relatively low among contractors, but productivity, construction cost, and quality factors are highly ranked. Even though lighting is ranked third in the indicating factors, it is not consistent with its ranking in ranking factors, where it is ranked tenth. For contractors, productivity and construction costs are very important factors because these factors are directly related to profits. Thus, factors such as public relations, user cost, noise, maintenance cost, air quality, and fuel consumption that are not related to profits ranked lower in importance.

Table 4.5. Contractors' Results

Contractors (n=38)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Safety	6.29	1.11	Safety	3.00	3.46
Productivity	6.03	1.05	Productivity	4.52	2.93
Lighting	5.84	1.38	Traffic Control	5.36	2.83
Traffic Control	5.68	1.30	Quality	5.91	3.32
Construction Cost	5.68	1.47	Congestion	6.06	3.90
Quality	5.66	1.28	Construction Cost	7.33	4.21
Congestion	5.63	1.57	Worker Condition	7.69	4.35
Availability of Material/Equipment Repair	5.58	1.42	Accident Cost	9.59	4.90
Worker Condition	5.50	1.52	Driver Condition	9.75	4.39
Scheduling	5.34	1.49	Lighting	9.79	5.42
Communication Supervision	5.06	1.60	Scheduling	10.21	4.68
Driver Condition	4.97	1.62	Availability of Material/Equipment Repair	10.24	5.30
Accident Cost	4.94	1.91	Communication Supervision	11.45	4.82
Public Relations	4.34	1.70	Public Relations	11.64	4.50
User Cost	3.97	2.03	User Cost	12.21	4.79
Noise	3.84	2.01	Maintenance Cost	12.56	3.93
Maintenance Cost	3.69	2.03	Noise	12.61	4.58
Air Quality	2.42	2.13	Air Quality	14.91	4.56
Fuel Consumption	2.28	2.05	Fuel Consumption	16.31	4.25

4.1.6. Other DOTs' Results

Table 4.6 shows other state DOTs' results. Typical positions of respondents were manager, engineer, or researcher. The public relations and user cost factors are relatively higher in this category, which is a reasonable result as one would expect these to be ranked highly since congestion and traffic control are in the top 3 most important factors and these factors are related to public relations and user cost. However, the quality factor is ranked fourteenth in indicating whereas it is rated fifth in ranking.

Table 4.6. Other DOTs' Results

DOTs (n=31)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Congestion	6.57	1.19	Safety	2.41	2.32
Safety	6.07	1.20	Congestion	2.93	3.93
Traffic Control	6.03	1.13	Traffic Control	4.66	2.72
Public Relations	5.93	1.26	Public Relations	6.03	3.42
User Cost	5.53	1.74	Quality	6.61	3.00
Scheduling	5.30	1.51	User Cost	7.38	4.44
Lighting	5.10	1.97	Productivity	7.66	3.09
Noise	4.73	1.68	Scheduling	8.83	4.51
Worker Condition	4.65	1.87	Noise	9.45	4.05
Productivity	4.53	1.50	Accident Cost	10.29	4.81
Driver Condition	4.48	1.56	Lighting	10.45	5.22
Accident Cost	4.48	2.03	Worker Condition	10.50	3.77
Communication Supervision	4.40	2.02	Driver Condition	11.21	3.96
Quality	4.38	1.78	Construction Cost	11.25	4.44
Construction Cost	4.24	1.60	Availability of Material/Equipment Repair	12.93	4.42
Availability of Material/ Equipment Repair	4.24	1.81	Maintenance Cost	13.43	4.25
Maintenance Cost	3.74	1.48	Communication Supervision	14.36	3.75
Air Quality	3.46	1.77	Air Quality	16.29	2.81
Fuel Consumption	2.68	1.73	Fuel Consumption	17.00	3.03

This makes it difficult to conclude whether other states consider the quality factor to be very important or not. Since participating personnel are in higher positions in other states, they may not directly participate in construction or maintenance projects at workplaces. Thus, communication supervision and availability of material/equipment repair factors are ranked lower. In addition, construction cost and maintenance cost are ranked lower. This study raises the question of whether DOTs do not consider construction and maintenance costs to be critical as long as the public and workers are satisfied about safety and congestion issues.

4.1.7. Analyses of Comparisons

It is necessary to compare the overall result to each individual category to check for internal consistency and to determine if one decision model can meet the decision needs of both groups or if two models are needed. In addition, the results of PMs and DMs surveys need more in depth analysis since the sample size is large, consists of different regions and positions, and encompasses different operations (construction versus maintenance work).

4.1.7.1. Comparison between Overall and Individual Personnel

In order to compare the overall result to individual results, the top 12 most important factors in the overall result were ranked from first to twelfth. The four tables in Appendix C show where the top 12 appear in the other response groups, with exception of TSRMs and TCPDs due to small sample sizes. As expected, the PMs' result is very similar to the overall result because the total number of PMs' is more than half of the total participants. For the DMs, availability of material/equipment repair and maintenance cost factors are ranked in the top 12, whereas availability of material/equipment repair and communication supervision factors are ranked in the top 12 among contractors. These results show the characteristics of operations among DMs and contractors.

In the results for DOTs, user cost, noise, and communication supervision are ranked in the top 12. This means that public relations issues are important for decision makers in DOTs. Alternatively, since they do not work directly at nighttime at workplaces, they may not consider operational factors to be as important. Other states view user cost to be more important than personnel within Oregon. Therefore, the top 12 most important factors in the overall result are consistently shown at or near the top of each individual personnel category. The next seven factors below the top 12 are considered as less important factors for decision-making, and were therefore eliminated.

4.1.7.2. Comparative Analysis of PMs and DMs

Since there were a large number of participants in the PM and DM samples, it is necessary to compare their responses by regions or positions. In addition, any differences between PMs and DMs have to be investigated. Table 4.7 shows these investigations. In order to compare regions or positions in personnel categories, an ANOVA test was used and a hypothesis test was used to investigate whether there are any differences between the PMs and DMs' responses. Bold factors in Table 4.7 are the top 12 most important factors in the overall result.

For indicating and ranking factors by region and position in PMs, the top 12 factors are shown in bold in Table 4.7. These factors do not have significant differences except for construction cost and public relations. However, the other seven factors that are less important in the overall results have significant differences between regions and positions, especially positions. If these seven factors had been incorporated, multiple decision models for this study would be required to accurately reflect the different perspectives.

For indicating and ranking factors by region in DMs, the seven less important factors are significantly different in the analyses. The main reason for the difference was that the research methodology was not followed consistently for one of the DM offices. This was due to circumstances beyond the investigator's control. Specifically, when the investigator visited a DM office in Bend, the meeting was canceled without notice due to

Table 4.7. ANOVA and Hypothesis Tests for Regions and Positions by Categories

Factor	p- value						Hypothesis Test	
	PM				DM		PM vs. DM	
	IR	IP	RR	RP	IR	RR	I	R
Congestion	0.22	0.51	0.95	0.08	0.31	0.92	NE	E
Safety	0.51	0.77	0.63	0.25	0.00	0.00	E	E
Traffic Control	0.84	0.26	0.69	0.09	0.08	0.10	E	E
Productivity	0.73	0.14	0.76	0.42	0.28	0.17	E	E
Quality	0.82	0.67	0.83	0.60	0.02	0.15	E	NE
Driver Condition	0.87	1.00	0.70	0.56	0.53	0.45	E	E
Worker Condition	0.18	0.81	0.16	0.53	0.00	0.20	E	E
User Cost	0.54	0.10	0.70	0.01	0.26	0.69	E	E
Accident Cost	0.29	0.42	0.52	0.25	0.07	0.12	NE	E
Maintenance Cost	0.41	0.34	0.84	0.91	0.18	0.11	NE	NE
Construction Cost	0.74	0.02	0.64	0.67	0.22	0.47	E	NE
Noise	0.04	0.03	0.00	0.04	0.33	0.35	E	NE
Fuel Consumption	0.32	0.00	0.38	0.71	0.04	0.53	E	E
Air Quality	0.86	0.00	0.33	0.22	0.06	0.42	E	E
Scheduling	0.39	0.48	0.70	0.22	0.93	0.21	NE	E
Public Relations	0.04	0.11	0.44	0.09	0.34	0.18	NE	E
Communication Supervision	0.89	0.08	0.11	0.04	0.36	0.03	E	E
Availability of Material/Equipment Repair	0.94	0.00	0.23	0.00	0.03	0.29	NE	NE
Lighting	0.69	0.06	0.19	0.06	0.10	0.00	E	E

<Note> IR: Indicating by Regions
IP: Indicating by Positions
RR: Ranking by Regions
RP: Ranking by Positions
I: Indicating
R: Ranking
NE: Not Equal; Reject Hypothesis
E: Equal; Do not Reject Hypothesis
Shaded with gray: Factor has a p-value lower than 0.05

busy schedules. The DM requested that the survey forms be left in the office with a request that individuals fill them out and return them by mail. Unfortunately, they returned only one form, which was a consensus response from four people: a DM, an ADM, and two TMMs. Thus, the data used represented an average value and the value of the standard deviation was zero. The zero value significantly affects the ANOVA test. The lighting factor is the only factor that was not affected by the difference in method used by the Bend district in Region 4.

4.1.7.3. Comparison between PMs and DMs

A hypothesis test was used to investigate whether there are any differences between PMs' and DMs' responses. Table 4.7 shows the results. Six factors in indicating and the five factors in ranking are different. In particular, the maintenance cost and availability of material/equipment repair factors significantly differ in both indicating and ranking factors. This means that DMs weight these two factors more heavily which is a representative characteristic of the DM category. The construction cost and noise factors are higher in rankings by PMs, but there in no difference in ranking. Since the length of projects for PMs is generally longer than for DMs, PM personnel consider these two factors to be more critical. However, even though other factors are different in either indicating or ranking, the factors' ranked positions are similar, so the impact of these differences is minimized.

4.1.8. Preference of Work Time and Other Information

The survey also asked participants for their preference between daytime and nighttime work: 83% of respondents prefer daytime work, 7% prefer nighttime work, and 10% expressed no preference. These overall results are very similar to those of the various personnel categories. From the text responses, the main reason why people prefer daytime work is personal schedules and safety. If workers have to work at nighttime, they have reduced time available to their family or friends. Even though some participants agreed that working at night was better for productivity, congestion, and safety, they just did not want to disrupt their personal lives. Many participants felt that working at night is more dangerous than working during the day, and some participants shared their accident experiences while working at nighttime. In addition, participants wrote that sleeping in the daytime instead of at night is not good for biological rhythms, and they argued that humans should sleep at night and activity during the daytime.

The participants who preferred to work at nighttime said that working at night is better because the reduced traffic during the nighttime enables workers to be more productive and work in a safer environment. It can be concluded that many workers think that working at nighttime is not bad based on their experiences, but it is not preferable because of the effect on their personal lives. To the question that asked if there was anything else they would like to share, participants typically provided more detailed information concerning why working at daytime or nighttime is better.

When investigators surveyed contractors and other states' DOTs, the survey asked additionally whether they do nighttime work. All participants responded that the state conducts nighttime work if the state needs to do so. In addition, of all the state respondents to the survey, only Montana did not perform nighttime work. The representative from Montana said that they do not need to conduct nighttime work due to low traffic volumes in the daytime.

4.2. ELIMINATION OF UNIMPORTANT FACTORS

After investigation of individual personnel categories, Table 4.2 summarizes the overall results from the survey, which were fairly consistent with the exception of the cost factors, especially for the top 12 most important factors in the overall results. Even though the noise, communication supervision, and availability of material/equipment repair factors were slightly different, these factors were not likely to significantly influence the decision-making on when to conduct nighttime work. In addition, there was no significant difference in the survey results between construction and maintenance operations. Therefore, the overall results of the survey were used for the development of a single decision model for when to conduct nighttime operations.

Factors in the third and fourth sections of the overall results were eliminated from the decision model as they were considered to have relatively little impact on the decision between nighttime and daytime operations. However, factors in the primary and secondary sections were important factors affecting nighttime operations and had to be considered in the decision model. Therefore, the 19 factors were reduced to 12 factors for the next step in developing the decision model. Appendix C shows a detailed comparison based upon the 12 factors selected based upon the overall results and the PM office, DM office, contactors, and other DOTs results.

4.3. WEIGHTING OF IMPORTANT FACTORS

In order to weight the important factors affecting nighttime construction and maintenance operations, the average values in the survey were used. Since the average value of each factor in the overall results was different from the value in the results for the construction and maintenance personnel, it was necessary to investigate all the average values. If there is any significant difference between overall, construction, and maintenance, two differently weighted values are necessary for construction and maintenance operations in the decision model.

Table 4.8 shows how to weight factors in the indicating and ranking factors of overall, construction and maintenance. Differences between the two consecutive factors in the hierarchy were obtained in the indicating and ranking categories, respectively. Each weight was established after consideration of the magnitude of the difference between factors and the value of the factors from the survey result. After obtaining the weight of each factor by indicating and ranking each category, it was necessary to compare them; Table 4.8 shows that comparison.

After examining the different values of each factor, an overall value for each factor was produced for the final weight value for each factor. Since the weight values of each factor were very consistent, most factors were easily sorted by weight, except for congestion and lighting. The weight value of the congestion factor was 2 in the indicating method and 3 in the ranking method. Finally, the weights of the factors for the decision model were established and the weight of each factor is identical to the indicating of overall result with bold in Table 4.8. Since the process of establishing weights is somewhat intuitive, sensitivity analysis will be used in later stages of the research to assess the impact of factor weights.

Table 4.8. Weight by Overall, Construction and Maintenance

	Factor	Indicating	Difference	Weight	Factor	Ranking	Difference	Weight
Overall	Safety	6.44		4	Safety	2.08		5
	Traffic Control	6.07	-0.36	3	Traffic Control	4.05	1.97	3
	Congestion	5.98	-0.09	2	Congestion	4.83	0.79	3
	Lighting	5.84	-0.15	2	Quality	6.64	1.81	2
	Quality	5.40	-0.44	2	Productivity	7.32	0.68	1
	Public Relations	5.32	-0.08	1	Worker Condition	7.90	0.58	1
	Worker Condition	5.19	-0.14	1	Driver Condition	8.76	0.86	1
	Productivity	5.11	-0.08	1	Lighting	9.12	0.36	1
	Scheduling	5.07	-0.03	1	Public Relations	9.42	0.30	1
	Driver Condition	5.04	-0.04	1	Construction Cost	10.16	0.74	1
	Construction Cost	4.94	-0.10	1	Scheduling	10.23	0.07	1
	Accident Cost	4.92	-0.01	1	Accident Cost	11.13	0.90	1
Construction	Safety	6.55		4	Safety	1.90		4
	Traffic Control	6.13	-0.42	3	Traffic Control	3.94	2.04	3
	Congestion	5.89	-0.24	2	Congestion	5.06	1.12	3
	Lighting	5.89	0.00	2	Quality	6.18	1.13	2
	Quality	5.47	-0.42	1	Productivity	7.54	1.36	1
	Public Relations	5.26	-0.21	1	Worker Condition	7.61	0.07	1
	Worker Condition	5.15	-0.10	1	Driver Condition	8.05	0.44	1
	Productivity	5.04	-0.11	1	Lighting	8.93	0.88	1
	Driver Condition	5.02	-0.02	1	Public Relations	9.62	0.70	1
	Scheduling	4.89	-0.13	1	Construction Cost	9.74	0.12	1
	Accident Cost	4.86	-0.03	1	Scheduling	10.53	0.79	1
	Construction Cost	4.81	-0.04	1	Accident Cost	11.44	0.91	1
Maintenance	Safety	6.41		3	Safety	1.89		4
	Traffic Control	6.21	-0.20	2	Traffic Control	3.68	1.79	3
	Congestion	6.10	-0.11	2	Congestion	4.80	1.12	3
	Lighting	5.99	-0.11	2	Productivity	7.48	2.68	2
	Public Relations	5.60	-0.39	1	Quality	7.61	0.13	2
	Quality	5.48	-0.12	1	Worker Condition	7.67	0.06	2
	Worker Condition	5.31	-0.14	1	Lighting	8.91	1.24	1
	Scheduling	5.27	-0.03	1	Driver Condition	9.06	0.15	1
	Driver Condition	5.24	-0.04	1	Public Relations	9.32	0.26	1
	Accident Cost	5.14	-0.03	1	Scheduling	10.03	0.13	1
	Productivity	5.13	-0.10	1	Accident Cost	11.28	0.58	1
	Construction Cost	5.03	-0.01	1	Construction Cost	11.61	1.25	1

4.4. IDENTIFICATION OF SUB-FACTORS AND ELIMINATION OF FACTORS

In order to develop the decision model, important factors should be quantified with tangible values, so it was necessary to further define each factor's characteristics (sub-factors) which could then be differentiated with tangible values for daytime versus nighttime operations. Characteristics (sub-factors) of each important factor were identified and are shown in Table 4.9. Each characteristic in boldface type is the primary characteristic of each factor and these can be used to quantify the factor in the decision model. Each italicized characteristic is a characteristic that is found in another factor, so it is not necessary to consider those characteristics in the decision model.

After the identification of sub-factors, this study asked the TAC to evaluate this study and they suggested that the five factors of traffic control, lighting, driver condition, construction cost, and accident costs could be eliminated in the decision model. In construction and maintenance worksites, there are no significant differences in traffic control for daytime versus nighttime operations even though this factor is weighted as 3, the second highest value. In order to conduct nighttime operations, it is necessary to have additional devices or equipment, but most of them do not need to be purchased for every nighttime operation, and they are installed at every worksite even if nighttime work is not being done. Thus, traffic control can be eliminated from the decision-making model. However, this study did not check this assumption of eliminating the traffic control factor with other state DOTs' personnel. Thus, this is a limitation of this study.

For nighttime work, workers always follow the standards for lighting, so the difference in lighting between artificial light and sunlight is not a problem. Furthermore, it is not necessary to purchase lighting equipment for every operation, and lighting expense is not a big portion of the total project cost so the lighting factor was eliminated.

Driver conditions and accident costs are directly related to the accident aspect in the safety factor, thus the safety factor will cover these issues. Since additional construction costs such as premium pay for workers, material, and equipment are not a huge portion of the total construction cost, this factor was eliminated. Therefore, after these eliminations which are shaded in Table 4.9, seven critical factors affecting nighttime operations were used for the development of the decision model to determine when to conduct nighttime operations.

Table 4.9. Identification of Sub-Factors and Elimination of Factors

Factor	Sub-Factors (Characteristic)
Safety	**Crash and Fatality**
	Visibility (Lighting), Traffic Control
Traffic Control	Traffic control equipment (devices) and its arrangement
	Traffic control strategies
Congestion	**Congestion * User costs = $**
Lighting	Lighting equipment, lighting levels and lighting arragement
Quality	**Measurements**
	Temperature, Interference from traffic
	Visibility (Lighting), Worker condition
Public Relations	**Local Impact including business impact and Noise**
Worker Condition	**Performance levels**
	Fatigue caused by sleep deprivation
	Social and domestic adjustment difficulties
Productivity	**Measurements**
	Visibility (Lighting)
	Interference from traffic, working hours
	Communication supervision
	Availability of supply of materials and spare parts
Scheduling	**Availability of workers and other personnel**
Driver Condition	*Safety/Accident*
	Substance abuse and Fatigue
	Anger and frustration caused by delays
Construction Cost	Night premium pay: worker, material and equipment
Accident Cost	Substance abuse and Fatigue
	Visibility (Lighting)

4.5. CONCLUSION FROM PHASE I

The survey allowed for a multi-perspective analysis of the importance of factors affecting nighttime work. The overall results have been summarized and comparisons made among the individual personnel categories to investigate whether the overall result is consistent with them. Based on this analysis, the overall results are fairly consistent with the results from the individual respondent groups.

While the literature suggests that nighttime work produces good productivity and quality, and often provides safer working environments, these survey results indicate that most people do not want to work at night because of the disruption to their private lives. This study has successfully characterized the importance of factors related to daytime versus nighttime decision-making. Using the results of this survey and the recommendations of the TAC, the factors were weighted and eliminated. From there, a decision model can be developed to improve the effectiveness of decision-making in determining when nighttime work should be conducted.

5. RESULTS OF PHASE II

After Phase I, the first objective of this study was to quantify each critical factor of the daytime and nighttime alternatives. Then, a decision model was created for real world application. The decision model was tested on real projects in the states selected for this study and any differences between the decision makers and the decision model's decisions were examined. In addition, sensitivity analyses were conducted to investigate the effect of changing some factors' weights on the model's decision. Finally, the decision model was evaluated by the experts in the field and potential users.

5.1. QUANTIFICATION OF CRITICAL FACTORS

After identification of the sub-factors of the critical factors affecting nighttime operations and development of the theoretical decision model, each sub-factor (characteristic) was quantified with tangible values in order to compare daytime and nighttime operations in the decision model (Table 5.1). For some characteristics, it was necessary to collect data in selected states, while for others, it was necessary to obtain information from related fields or experts. After quantification of these characteristics, the specific values were included in the decision model.

Table 5.1. Critical Factors for the Decision Model: Weights and Characteristics

Factor	Weight	Characteristic (Sub-Factor)
Safety	4	Crash frequency and Fatality frequency
Congestion	2	Congestion * User costs = $
Quality	2	International roughness index (IRI)
Public Relations	1	Local Impact including business impact and Noise
Worker Condition	1	Performance levels
Productivity	1	Daily paving productivity
Scheduling	1	Availability of workers and other personnel

5.1.1. Safety

In order to quantify this factor, crash data were analyzed to provide tangible evidence about safety at daytime versus nighttime. Crashes in daytime (6 a.m. to 5:59 p.m.) versus nighttime (6 p.m. to 5:59 a.m.) and the proportion of fatal crashes taken from the total number of crashes during daytime versus nighttime in work zone and non-work zone areas were investigated. Crash data were collected from one state in each Type (Pennsylvania, Texas, Oregon, and Maine), and crash data were also requested from each state DOT by regions, road types and from the largest city of each region for daytime versus nighttime in work zone versus non-work zone. However, many DOTs did not respond to the request for data because of their heavy workloads. Thus, this study analyzed the data based upon the data provided and available, so there are some differences in the crash analyses among states. The data provided the total yearly crashes from 1998 to 2000 or from 1998 to 2001 from each state. Table 5.2 shows how this study analyzed the data by region or road type in each state.

Table 5.2. States Investigated and Analysis Strategy for Crash Study

State	Sorted by	Detailed
Pennsylvania	Region	Overall State
Texas	Road Type	Highways: Interstate, US & State, Turnpike & Toll, and Belt 8 & Toll Bridge
		Non-Highways (Others): Farm to Market, County Road, City Street, Alley
Oregon	Region and the largest City	Region 1 & 2 and Portland & Salem
		Region 3, 4 & 5 and Medford, Bend & Pendleton
Maine	Road Type	Highways: State and Toll
		Non-Highways (Others): State Aid and Town Way

Based upon analysis of the crash data, we concluded:

1) Crash frequencies in the daytime are higher since traffic volumes are higher. Thus, there are more possibilities for crashes to occur.

2) Construction or maintenance operations do lead to an increase in crashes in most places from which data were collected, except for highways in Texas.
3) In Regions 3, 4, and 5 in Oregon and on non-highways in Maine, there are many more crashes in the daytime in work zones, but it is difficult to analyze this since nighttime operations may not be frequently conducted.
4) In all places except for highways in Texas, fatal crashes during the nighttime in work zones are significantly higher than in daytime.

Table 5.3 shows the crash ratio and fatal crash ratio of daytime versus nighttime. The ratio represents crashes and fatal crashes in the daytime divided by crashes at nighttime. Since daytime traffic volumes are higher than these in the nighttime, there are generally more crashes during the daytime, so it may be necessary to compare crash analyses by traffic volumes as well as by day versus night. However, the major concern in the crash analyses was to estimate tangible values for judging when it is safer to conduct construction and maintenance operations between daytime versus nighttime. Thus, the crash analyses considered only the actual values of accidents in daytime versus nighttime.

Table 5.3. Average Crash and Fatal Crash Ratio of Daytime versus Nighttime (Daytime/Nighttime) in Three States

Type		Work zone		Non-Work zone	
		Crashes	Fatal	Crashes	Fatal
Pennsylvania		2.5198	0.3914	1.6959	0.5795
Texas	Highways & Tolls	2.0169	1.6620	1.9307	0.4432
	Others	1.8623	0.3291	1.4980	0.8931
Oregon	Region 1 & 2	3.8799	0.1166	3.4203	0.5426
	Region 3, 4 & 5	8.5667		3.7587	
Maine	Highways	2.9643	0.1380	1.7132	0.8275
	Others	3.6498	0.6527	1.6835	0.5023

In the decision model, two types of quantified values for the safety factor were used, including the crash ratio and fatal crash ratio in daytime versus nighttime in work zones. For example, in Oregon, the crash ratios of 3.88 was used for Region 1 and Region

2, and the ratio of 8.57 was used for other regions, while the ratio of 0.12 was used for all of Oregon in the fatal crash sub-factor. The Oregon TAC recommended that the crash and fatal crash frequencies be equally weighted to represent safety. The detailed data of the crash study are provided in Appendix D.

5.1.2. Congestion

This study found that using road user costs was the best way to quantify the congestion factor because the costs results primarily from congestion; the overall costs arise from delays caused by lane closures in work zones. After the literature review, this study decided to utilize the spreadsheet developed by the Oklahoma DOT to estimate road user costs in daytime versus nighttime and compare them in the decision model. This spreadsheet requires only simple information such as the type of road, the annual average daily traffic (AADT), percentage of trucks, number of lanes, and posted speed. The method for use of this spreadsheet is provided in Appendix E.

The limitation of this spreadsheet is that it is not able to estimate road user cost in a single lane in each direction. However, if the road has a shoulder which is at least 8-feet wide, it can be considered to be two lanes instead of a single lane in each direction and the estimation can best be obtained by the multiple lane method. In addition, the maximum number of lanes needed in each direction to estimate road user cost is 4 lanes. This study could not find the exact percentage of roads that have more than 4 lanes in each direction in the United States.

5.1.3. Quality

Paving projects are the primary type of project for which the decision model will be used. Measuring paving quality was the most appropriate method for comparing the quality of daytime versus nighttime work. Generally, the profile of roads is used to measure paving quality and this enables DOTs to monitor the condition of a road network for pavement management systems (PMS) and to evaluate the quality of newly constructed or repaired sections.

There are currently several methods used to measure the profile in DOTs, but this study found from the TAC and pavement management engineers in DOTs that the International Roughness Index (IRI) is a broad method in the United States because each DOT regularly assess IRI every one or two years in their highways including Interstate, US, State, Turnpike, and Toll highways and reports it to Federal Highway Administration (FHWA) to construct Highway Pavement Management Systems (HPMS). The IRI measures longitudinal pavement profiles to evaluate pavement condition and remaining life.

Therefore, we decided to use the IRI to compare the quality of daytime versus nighttime work. This study requested IRI data from several states, DOTs to generalize for use by the widest possible DOTs in the United States. This is another example of data triangulation. This study collected paving projects from 1996 to 2002 in selected states to compare IRI improvements and the differences between IRI measurements before and after paving, and in daytime versus nighttime. Most states had IRI measurements before and after specific paving projects, but some states did not. If before and after IRI were not available, this study received the HPMS database from the state and obtained before and after IRI measurements based upon projects' information from the database such as month and year paved, specific location (mile post), and the length of paving.

Table 5.4 shows the results of paving quality analysis (IRI) in daytime versus nighttime projects and the detailed data are provided in Appendix F. This study concluded that there are no significant quality differences between daytime and nighttime in selected samples of states except for the type 4 state, Maine. In Maine, the IRI for the nighttime was 69% lower than that of the daytime. Compared to other state types, the sample sizes in Maine are too small to draw a conclusion. In addition, this study found that the daytime projects had incentives for paving contactors, while the nighttime projects did not, so contactors surveyed for this study who performed nighttime projects did not devote themselves to increasing paving quality in Maine. However, the results obtained from Maine will be used in the decision model. In sensitivity analysis in later stages of the research, equal quality assumption in daytime and nighttime projects will be used to test the decision model to investigate whether or not the original decisions made are changed by passing through the model.

In this study, we eliminated the lighting factor because if workers follow lighting standards, the difference between artificial and sunlight is not an issue. With the exception of Maine, the conclusion that there are no significant quality differences between daytime and nighttime paving projects support our decision.

Table 5.4. Results of Paving Quality Daytime versus Nighttime

Type	State	Day/Night	Average (%)	Standard Deviation	Count	p-value
1	PA, MD, CT, and NY	Daytime	44.92	17.51	18	0.3176
		Nighttime	39.17	18.41	23	
2	TX, AZ, and OK	Daytime	48.03	17.10	30	0.0781
		Nighttime	37.49	21.90	16	
3	OR	Daytime	25.33	13.08	49	0.6207
		Nighttime	27.13	17.58	25	
4	ME	Daytime	55.39	5.53	4	0.0089
		Nighttime	17.17	21.39	6	

5.1.4. Worker Condition

Budget limitations made the conducting of experiments to measure worker conditions in different shifts unfeasible. Thus, we investigated the published literature in order to collect information about worker conditions in different shifts and to quantify the factor. However, most studies carefully concluded that it was difficult to measure the impact on workers during the night shift since 1) it was difficult to measure, 2) all individuals had different physiological conditions, and 3) there were very few studies to have investigated it.

The investigation of performance levels of shift work was reviewed in the literature survey. Some studies measured performance levels in different shifts so as to measure productivity in real work settings. Productivity was also found to be one of the factors affecting nighttime operations in this research. However, the term "productivity" in the shift work literature is different from productivity as a factor in this model. Productivity in our model must be productivity of the paving length or the time spent to finish a certain construction or maintenance roadwork in different shifts. Productivity in the shift work literature is productivity of workers at various manufacturing factories or service facilities.

After reviewing the shift work literature, it was determined that a very small number of studies measure the performance levels of shift work. Only two studies, by Tilley Wilkinson, Warren, Watson, & Drud (1982) and Wojtczak-Jaroszowa and Pawlowska-Skyba, (1967) had the applicable quantitative values of worker conditions in shift work. Tilley et al. (1982) showed that the simple reaction time for nighttime shift was 7% slower than for the morning shift and 9% slower than the combination of morning and afternoon shifts. Wojtczak-Jaroszowa and Pawlowska-Skyba (1967) found that the speed of work was 11.73% lower in night shifts. Therefore, worker productivity at nighttime is about 10% lower than in daytime. In addition, the performance levels of night shifts were the worst on Mondays and Tuesdays. Thus, it was concluded that projects whose duration is less than 3 days are not suitable for nighttime work.

5.1.5. Productivity

As was the case for the quality factor, measuring paving productivity was the most appropriate method for comparing the productivity of daytime versus nighttime. Thus, this study collected daily productivity data from the Departments of Transportation or paving contractors in the United States from 1998 to 2002 and compared tons per hour in daytime versus nighttime. Table 5.5 shows participant organizations for paving productivity data.

Table 5.5. Organizations Providing Paving Productivity Data

Type	Organization
1	Gallagher Asphalt Co., Illinois
	Milestone Contractors, L.P., Indiana
	Pennsylvania Department of Transportation
2	Bauerly Companies, Minnesota
	Texas Department of Transportation
3	Oregon Department of Transportation
4	Blue Rock Industries Co.
	Lane Construction
	Pike Industries Co.

There were two strategies to collect data: 1) select only paving projects, and 2) if specific restrictions for a project were provided, the restrictions were directly used to estimate actual working hours, otherwise daytime projects were assumed to work 8 hours per day from Monday to Friday while nighttime projects were assumed to work 10 hours per day from Monday to Thursday. However, it was not possible to obtain raw data on productivity in Maine, and only three contractors provided statements that estimated, based upon their experiences, that there is generally 20 % lower daily productivity in the daytime compared to night. Table 5.6 shows the results of daily paving productivity in daytime versus nighttime and Appendix G shows the detailed data collected from state Departments of Transportation or paving contractors.

After data analysis, this study found that all paving data collected have non-normality in the data and this violates the assumption of normal distribution to compare the means, so it was necessary to use the Kruskal-Wallis test to compare the median instead of the means. Thus, the Kruskal-Wallis test considers the null hypothesis that the median within each group of data is the same. Since the p-values are less than 0.05 for all tests for each state type between daytime and nighttime paving productivity, there are statistically significant differences among the medians. Therefore, this study used these results in the decision model and Table 5.6 shows ratio values of daytime and nighttime productivity for each state type after the Kruskal-Wallis tests.

Table 5.6. Results of Daily Paving Productivity in Daytime versus Nighttime

Type	State	Day/Night	Average (ton/hour)	Standard Deviation	Median (ton/hour)	Count	Ratio Value
1	IL, IN, PA	Daytime	88.00	51.55	75.30	95	**0.6343**
		Nighttime	141.14	76.84	118.72	72	**1.0000**
2	TX, MN	Daytime	96.32	52.08	88.81	31	**0.5958**
		Nighttime	165.46	97.98	149.07	33	**1.0000**
3	OR	Daytime	174.82	109.41	137.52	412	**0.7109**
		Nighttime	211.38	110.26	193.44	265	**1.0000**
4	ME	Daytime	N/A	N/A	N/A	N/A	**0.8000**
		Nighttime	N/A	N/A	N/A	N/A	**1.0000**

According to Table 5.6, it can be concluded that the average daily paving productivities in daytime were lower in all places. The daily productivities of daytime were 37%, 40%, 29%, and 20% lower those that of nighttime in Type 1, 2, 3, and 4 states, respectively. This arose from the fact that nighttime working hours are generally longer due to less traffic at night, so it reduced disturbances to workers from road drivers and resulted in better environments for paving.

5.1.6. Public Relations and Scheduling

These two factors are difficult to quantify accurately for daytime versus nighttime. According to the literature and real work environments, noise and local business impacts were the major issues for public relations, and availability of workers at nighttime was the primary concern for scheduling. The difference between noise levels in daytime and nighttime can be measured, but this difference cannot control the decision when to conduct a project. The decision should be affected by whether noise levels allow conducting a project at nighttime or not. Business impacts are similar to noise issues; the comparison of sales taxes in local businesses before and during a project can provide an accurate measurement of the differences in the effect between daytime and nighttime operations, but this difference cannot be measured prior to a project's inception. Additionally, some states do not have a sales tax, such as Oregon.

Availability of workers is a concern generally for nighttime but not for daytime operations, so if night shift workers are available, a decision maker can plan to conduct nighttime work, otherwise a nighttime work plan must not be considered. Therefore, these characteristics (sub-factors) of these two factors are incorporated with "go" or "no-go" options in the decision model. If these characteristics are acceptable for a specific project for daytime or nighttime operations in the decision model, the model continues to estimate the total scores of alternatives in all critical factors, otherwise the decision model provides a decision based on the go/no-go sub-factor, and estimates the total scores and provides a recommendation such as doing only daytime or nighttime work.

5.1.7. Scope and Limitations of Quantification of Critical Factors

In order to make a decision when to conduct nighttime roadwork, critical factors were investigated in daytime versus nighttime. Some factors are explanatory (input), such as scheduling and worker condition, and other factors are response (output), such as safety, congestion, quality, productivity, and public relations in construction and maintenance road operations. However, all explanatory and responsive factors should be factored in the decision before starting a project. Thus, this study investigated the critical factors needing to be quantified, and the obtained comparison values in daytime versus nighttime will be used in the decision model.

There are some limitations to the quantification of critical factors. In order to generalize the decision model, this study collected data from multiple states, organizations, and other resources using data triangulation. However, this study had difficulties in collecting sufficiently large sample sizes because of the heavy workloads in many DOTs. This study was able to obtain relatively large samples for Oregon as compared to other DOTs because the Oregon Department of Transportation (ODOT) funded this research. Thus, it might be difficult to make a conclusion relevant to all populations with comparatively small sample sizes outside of Oregon. Since this research consists of case studies, the data collected were used to develop the decision model and to make a conclusion within samples collected for this research.

In addition, quantifications of paving quality and productivity did not separate the data by paving materials, paving thickness, paving length, and project durations because this study could not acquire sufficient samples to separate them and compare by such categories. Thus, this study considered only daytime versus nighttime paving projects to measure paving quality and productivity.

5.2. CREATION OF THE DECISION MODEL

In order to develop the decision model, a theoretical decision model was first developed and critical factors were quantified in the daytime and nighttime alternatives. Based upon the theoretical model and quantifications of factors, estimations of factors in daytime and nighttime were computed. Using the information obtained, the decision model was programmed for real users.

5.2.1. Computation of Factors in the Decision Model

After the quantifications of factors, the fixed values of factors in the decision model were obtained. Tables 5.7 and 5.8 show the values of factors in each state type, except for the congestion factor in the decision model because the value of the congestion factor varies by project. The highest score in the decision model of a sub-factor or factor on each alternative is 1, while the lowest is 0. For example, the crash ratio (daytime / nighttime) in daytime versus nighttime in the work zones of type 1 states in Table 5.3 is 2.5198. This means that work zone crashes occur 2.5198 times more frequently in daytime versus nighttime. Since the crash ratio is lower at night, the crash value of safety in nighttime became 1; while the crash value in daytime can be computed from 1 / 2.5198 = 0.3969 (see Table 5.7).

Public relations and scheduling factors have zero values in both alternatives because these factors were judged by the "go" and "no-go" options. Even though worker condition has a value of 1 in the daytime, and 0.9 in nighttime, this factor also has a "go" and "no-go" option because this study concluded that working fewer than 3 nights significantly decreased the performance levels of workers.

Table 5.7. Values of Factors without Congestion and Estimation of Factors' Scores in the Decision Model (Type 1 and 2)

Type	Factor	Weight	Daytime		Score	Nighttime		Score
Type 1	Safety	4	**Crash**	**Fatality**	2.7937	**Crash**	**Fatality**	2.7827
			0.3969	1.0000		1.0000	0.3914	
	Quality	2	1.0000		2.0000	1.0000		2.0000
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.6343		0.6343	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				6.4280			**6.6827**
Type 2: Highways	Safety	4	**Crash**	**Fatality**	2.1950	**Crash**	**Fatality**	4.0000
			0.4958	0.6017		1.0000	1.0000	
	Quality	2	1.0000		2.0000	1.0000		2.0000
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.5958		0.5958	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				5.7908			**7.9000**
Type 2: Non-Highways	Safety	4	**Crash**	**Fatality**	3.0740	**Crash**	**Fatality**	2.6581
			0.5370	1.0000		1.0000	0.3291	
	Quality	2	1.0000		2.0000	1.0000		2.0000
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.5958		0.5958	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				**6.6697**			6.5581

Table 5.8. Values of Factors without Congestion and Estimation of Factors' Scores in the Decision Model (Type 3 and 4)

Type	Factor	Weight	Daytime		Score	Nighttime		Score
Type 3: Region 1 & 2	Safety	4	**Crash**	**Fatality**	2.5155	**Crash**	**Fatality**	2.2332
			0.2577	1.0000		1.0000	0.1166	
	Quality	2	1.0000		2.0000	1.0000		2.0000
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.7109		0.7109	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				**6.2264**			6.1332
Type 3: Others	Safety	4	**Crash**	**Fatality**	2.2334	**Crash**	**Fatality**	2.2332
			0.1167	1.0000		1.0000	0.1166	
	Quality	2	1.0000		2.0000	1.0000		2.0000
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.7109		0.7109	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				5.9443			**6.1332**
Type 4: Highways	Safety	4	**Crash**	**Fatality**	2.6747	**Crash**	**Fatality**	2.2759
			0.3373	1.0000		1.0000	0.1380	
	Quality	2	1.0000		2.0000	0.3100		0.6200
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.8000		0.8000	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				**6.4747**			4.7959
Type 4: Non-Highways	Safety	4	**Crash**	**Fatality**	2.5480	**Crash**	**Fatality**	3.3055
			0.2740	1.0000		1.0000	0.6527	
	Quality	2	1.0000		2.0000	0.3100		0.6200
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.8000		0.8000	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				**6.3480**			5.8254

Based upon the values in Tables 5.7 and 5.8, sub-total scores of the decision model without the congestion factor were computed. From these data, two aspects were found. The sub-total scores for daytime in type 1 states, type 2 states' highways, and type 3 states' non-highways are lower than the score for nighttime, but the sub-total scores for daytime are higher than those for nighttime in other places. However, with the consideration of the congestion factor, the total score for the decision would change because of higher user costs in the daytime. Table 5.9 shows the estimation method of scores in daytime versus nighttime for the congestion factor.

Table 5.9. Estimation Method of Congestion Factor with User Cost in Daytime and Nighttime

User Cost Ratio in Daytime (X) versus Nighttime (Y)		Score	
		Daytime	Nighttime
Y = 0.0;		0.0	1.0
	0.0 <= X/Y < 0.1	1.0	0.0
	0.1 <= X/Y < 0.2	1.0	0.1
	0.2 <= X/Y < 0.3	1.0	0.2
	0.3 <= X/Y < 0.4	1.0	0.3
	0.4 <= X/Y < 0.5	1.0	0.4
	0.5 <= X/Y < 0.6	1.0	0.5
	0.6 <= X/Y < 0.7	1.0	0.6
	0.7 <= X/Y < 0.8	1.0	0.7
	0.8 <= X/Y < 0.9	1.0	0.8
	0.9 <= X/Y < 1.0	1.0	0.9
Y is not = 0.0;	X/Y = 1.0	1.0	1.0
	1.0 < X/Y < 2.0	0.9	1.0
	2.0 <= X/Y < 3.0	0.8	1.0
	3.0 <= X/Y < 4.0	0.7	1.0
	4.0 <= X/Y < 5.0	0.6	1.0
	5.0 <= X/Y < 6.0	0.5	1.0
	6.0 <= X/Y < 7.0	0.4	1.0
	7.0 <= X/Y < 8.0	0.3	1.0
	8.0 <= X/Y < 9.0	0.2	1.0
	9.0 <= X/Y < 10.0	0.1	1.0
	10.0 <= X/Y	0.0	1.0

5.2.2. Development of Decision Model

The decision model was designed using Visual Basic software to make it simple and easy to understand and use by real decision makers. The data in Table 5.7 and 5.8 did not provide information on public relations, scheduling factors, and the sub-factor of worker condition being less than 3 days of work. Thus, these qualitative aspects were considered and added to develop the decision model. Several questions were developed to estimate each score value in each alternative (Figure 5.1). A detailed discussion of questions in the decision model is provided below.

5.2.2.1. To Which Type Is Your State Most Similar?

This question is a state type question to estimate crash and fatality frequencies, productivity, and quality since they differ among states. This study suggests that if the state is not listed in the types, a user should select the most similar state type based upon strategies such as the ratio of licensed people and square mile by state, the ratio of registered vehicle and square mile by state, and the ratio of registered vehicle and NHS road (mile), as listed in Table 3.4.

After selection of state type, a pop-up question asks whether the user wants to use the default factor values determined by this research because this decision model has been validated using a robust research method (Figure H.1 in Appendix H). If a user selects the "yes" option, the decision model would use the default factor values of safety, quality, and productivity. Otherwise, the second pop-up question asks to enter the necessary information to compute the factor values (Figure H.2). A user should enter the average total number for months or years of crash and fatal crash frequencies, the percentage of quality improvement, and daily paving productivity (ton/hour) in daytime versus nighttime in the user's region or area.

If a user selects a type of state other than type 1, a pop-up question asks to estimate crash and fatality frequencies since the frequencies differ in highways and non-highways in type 2 and 4 states (Figure H.3), and regions 1 and 2, and regions 3, 4 and 5 in the type 3 state (Figure H.4). The primary purpose of the pop-up questions is to make the decision-making robust in the decision model.

5.2.2.2. Is the Project Duration Less Than 3 Days?

Using "go" and "no-go" logic, this question is related to worker condition and scheduling. For worker condition, a planned project should be checked for duration of less than 3 days. If the duration is less than 3 days, a pop-up question (Figure H.5) asks whether other projects can be scheduled back-to-back with the project to make the duration of work greater than 3 days. If it is possible, the total scores and recommendation are provided after the completion of questionnaires; otherwise the decision model recommends conducting work during the daytime without the comparison of total scores in daytime and nighttime due to the selection of "no-go."

5.2.2.3. Do You Have Workers Who Can Be Scheduled for Night Work?

This question also uses a Go and No-Go logic for the scheduling factor. If a user has nighttime workers available, the total scores and recommendation are provided, with the recommendation based upon the comparison of total scores to the completion of questions in the model. If the user indicates that night workers are not available, the decision model recommends daytime options.

5.2.2.4. Will Noise Levels Prevent This Work Being Done at Night Due to Current Local Ordinances?

This question concerns the noise issue, which is one of the characteristics of public relations. If noise levels do not prevent the project, the total scores of the model and a recommendation are provided, with the recommendation based upon the comparison of total scores by the completion of the questions. If noise levels are prohibitive and a user answers "yes", a pop-up question will ask: Would a noise variance be possible? (Figure H.6). If the user answer yes, the total scores of the model and a recommendation are provided after the completion of the questions. Otherwise, a user will meet a second pop-up question: Can work be scheduled such that the noisiest portions of the work can be done and meet local ordinances? (Figure H.7). If the user answers "yes", the total scores of the model and the recommendation are based upon all questions in the model. If the user answers "no", No-Go Logic captures this answer in the model and the decision model recommends conducting the project at daytime without a comparison of total scores.

5.2.2.5. Will the Project Result in Unacceptable Local Business Access During Daytime?

This addresses the local business impact in the public relations factor. The user must use his professional judgment to determine what constitutes unacceptable local business access in a work zone. This study recommends that it is unacceptable if there is no access for road users to get to business areas in the work zone. As long as there is any single access for road users to business areas, the project will allow acceptable local business access during daytime. However, road user costs in the daytime due to closure of roads in the work zone will be increased and this affects the total score in daytime. Thus, if a user answers "yes", the total scores of the model and the recommendation are provided and the recommendation is based upon the comparison of total scores, but if a user answers no, No-Go Logic captures this answer in the model and the model recommends conducting at nighttime.

5.2.2.6. What Are the User Costs of Each Alternative?

The purpose of last question is to estimate the congestion score values for the alternatives. After entering the dollar amount of road user costs determined by the spreadsheet provided by the Oklahoma Department of Transportation, which has a user guide available (Appendix E), the decision model computes the ratio value and determines score values for the alternatives by the method shown in Table 5.9. A spreadsheet can estimate road user costs for roads ranging in size from a single lane to 4 lanes in each direction closing with no lane closure up to a 3-lane closure. If a project needs to completely close lanes in the work zone and use detours during the project, the detour road information should be inputted into the spreadsheet instead of the road information in the work zone.

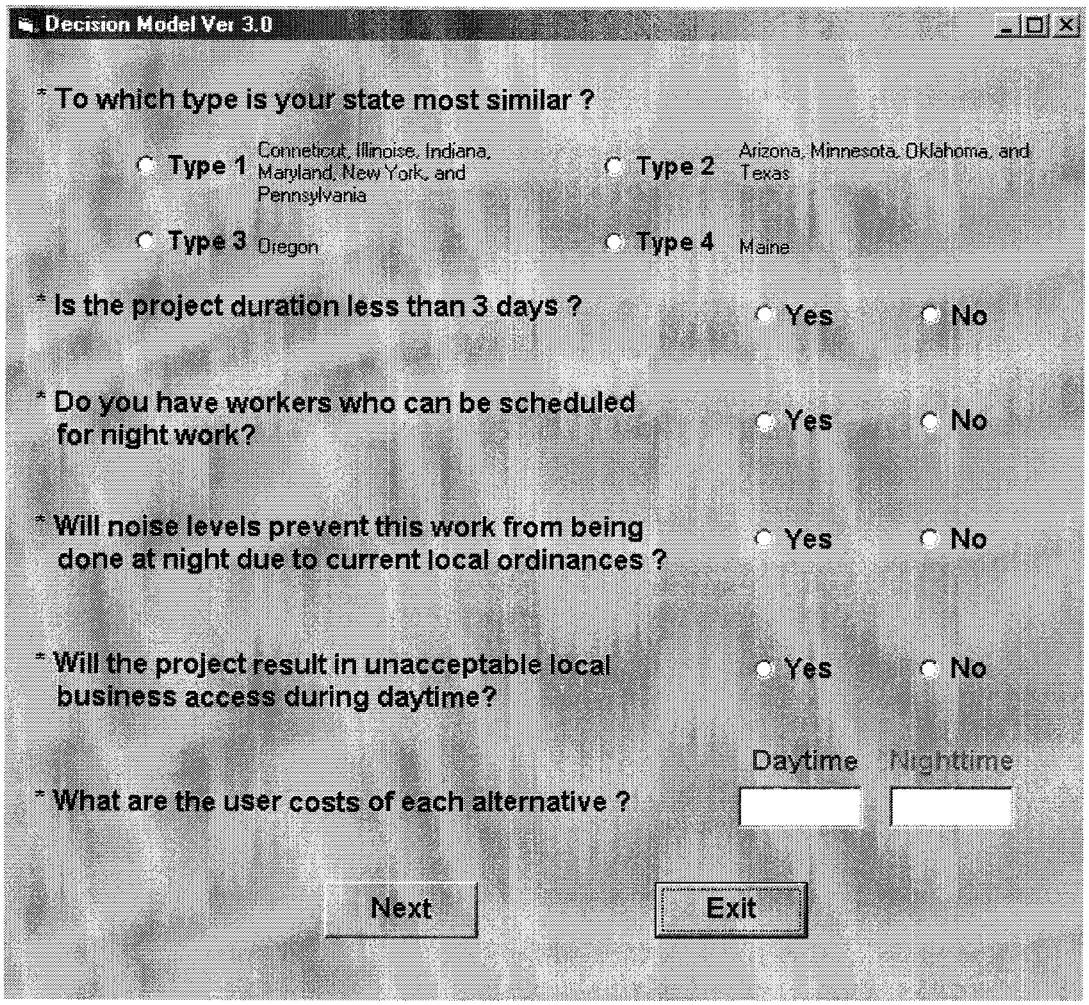

Figure 5.1. Questions in the Decision Model

5.2.3. Go and No-Go Logic in the Decision Model

Except for the first and sixth questions in Figure 5.1, all questions are related to the public relations, scheduling, and worker condition factors for Go and No-Go logic in the decision model. Table 5.10 shows how the decision model provides recommendations for these questions.

Table 5.10. Questions for Go and No-Go Logic and Its Recommendations

Question	Answer	Sub-Question	Answer	Sub-sub Question	Answer	No-Go and Its Recommendation	Conflict in No-Go?	Recommendation	Reason
Q.1	Yes	Q.1-1	Yes			N/A		Bigger score	Bigger Score
			No			**Daytime**	Yes	**Both**	**Conflicts in No-Go**
							No	**Daytime**	**Worker Condition**
	No					N/A		Bigger score	Bigger Score
Q.2	Yes					N/A		Bigger score	Bigger Score
	No					**Daytime**	Yes	**Both**	**Conflicts in No-Go**
							No	**Daytime**	**Scheduling**
Q.3	Yes	Q.3-1	Yes			N/A		Bigger score	Bigger Score
			No	Q.3-2	Yes	N/A		Bigger score	Bigger Score
					No	**Daytime**	Yes	**Both**	**Conflicts in No-Go**
							No	**Daytime**	**Noise**
	No					N/A		Bigger score	Bigger Score
Q.4	Yes					**Nighttime**	Yes	**Both**	**Conflicts in No-Go**
							No	**Nighttime**	**Local Business**
	No					N/A		Bigger score	Bigger Score

Note:

Q. 1: Is the project duration less than 3 days?

Q. 1-1: Can other nighttime projects be done back-to-back with this project to make the duration or work greater than 3 days?

Q. 2: Do you have workers who can be scheduled for night work?

Q. 3: Will noise levels prevent this work from being done at night due to current local ordinances?

Q. 3-1: Would a noise variance be possible?

Q. 3-2: Can work be scheduled such that noisiest portions of the work can be done and meet local ordinances?

Q. 4: Will the project result in unacceptable local business access during daytime?

If daytime and nighttime recommendations by Go and No-Go logic conflict in the decision model, the model recommends working in either daytime or nighttime. Thus, the decision maker must decide based upon the relative importance of the factors for that specific project.

5.2.4. Examples using Decision Model

After entering the necessary information, an overall score for each alternative is computed and a recommendation is made. Figure 5.2 shows an example of a project result from the decision model. The decision model provides the recommendation of a working schedule with an explanation. After clicking "More", the decision model provides detailed information to estimate total scores in alternatives (see Figure 5.3 for an example). This example recommends working at nighttime because total score (8.6828) of nighttime is higher that that of daytime (8.2283). Figure 5.3 shows the detailed information of the score values of factors in the decision model.

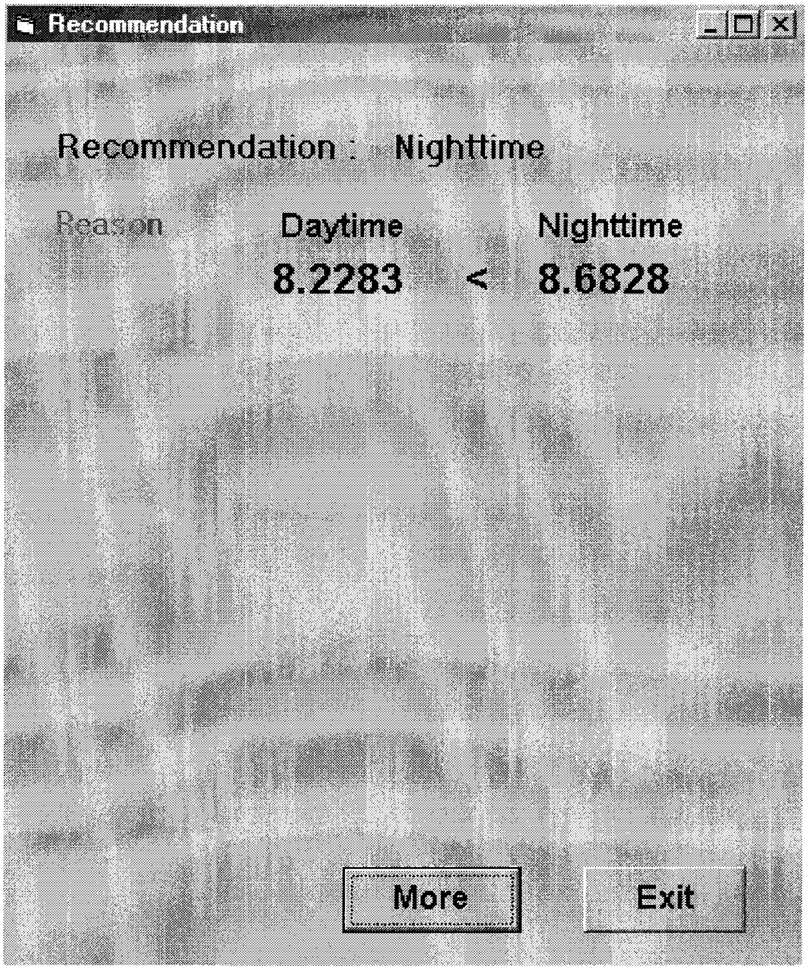

Figure 5.2. An Example of the Decision Model's Result

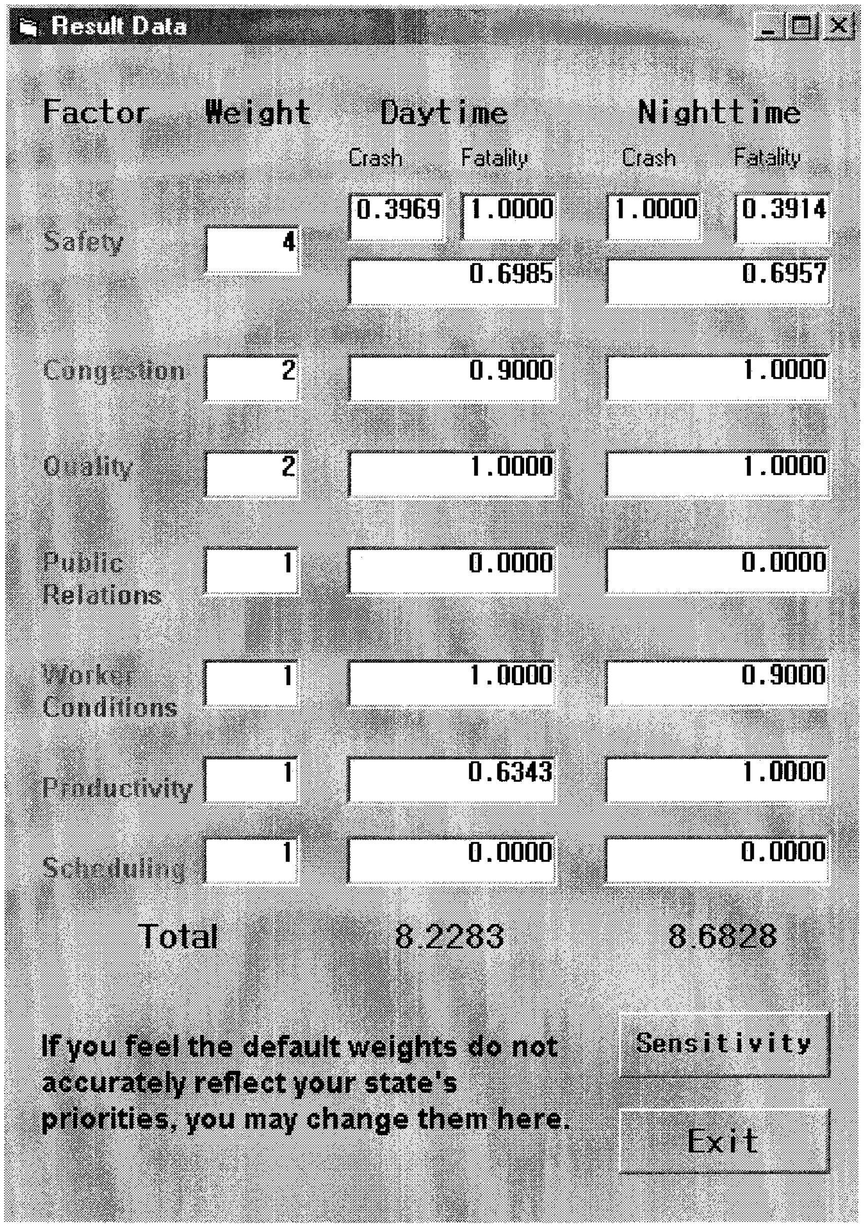

Figure 5.3. An Example of Detailed Information in the Decision Model's Result

Figure 5.4 shows an example of a recommendation of working either daytime or nighttime in the decision model. If a project's duration is less than 3 days, the decision model recommends it be done in the daytime, while if a project results in unacceptable local business access during daytime, the decision model recommends it be done at night. Thus, the decision model recommends either daytime or nighttime in this situation. A decision maker can select his/her preference-working schedule by consideration of a higher priority factor in the specific situation.

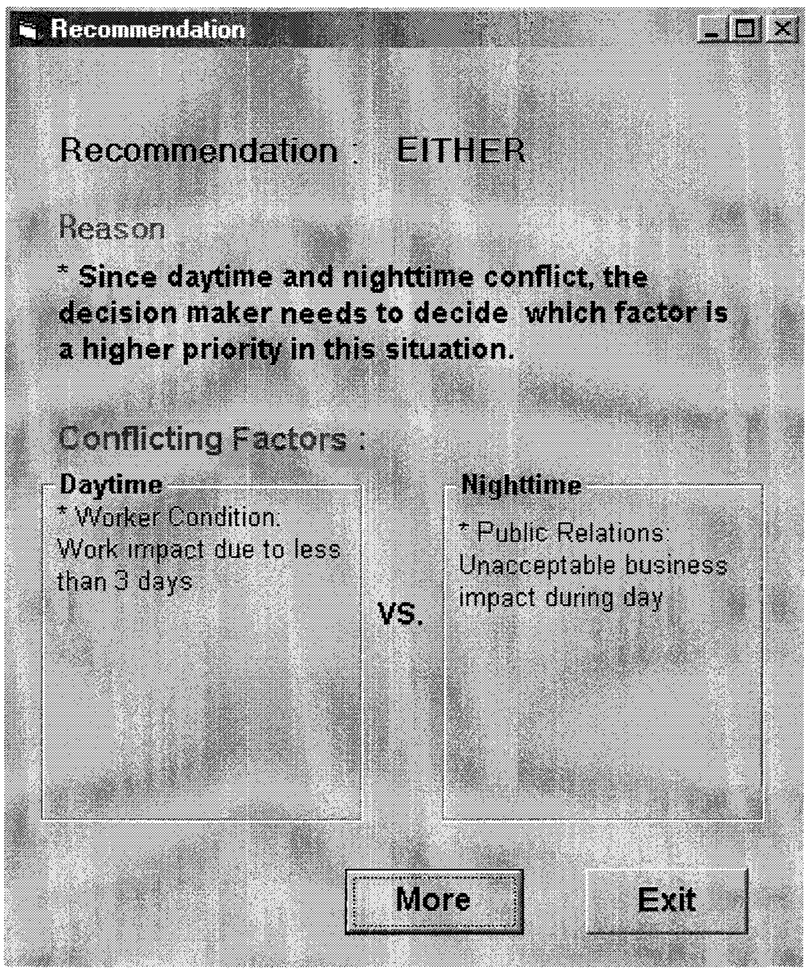

Figure 5.4. An Example of Either Recommendation in the Decision Model

5.2.5. Sensitivity of Factor Weights

In Figure 5.3, which shows the detailed computation information in the model, there is an option for sensitivity. If a user selects "sensitivity," the model shows another screen to enter different weight values of factors in the model (Figure 5.5). This study addressed earlier in the discussion of weighting of important factors that the process of establishing weights is somewhat intuitive, so sensitivity analysis would be used.

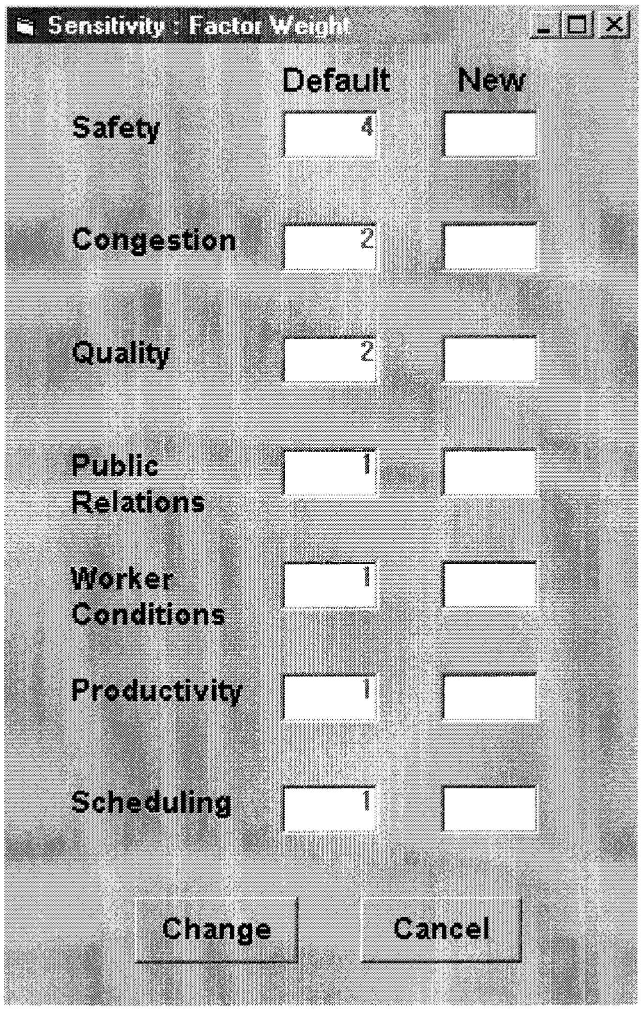

Figure 5.5. Sensitivity of Factor Weights in the Decision Model

The user can enter a new weight of each factor and see how the computations of the total scores in alternatives change in "Result Data" (Figure 5.3). Based on the results of this study, we recommend that if a user wants to make a decision based upon new weights, the user should have supportive judgments for the changes, otherwise the decision will not efficiently provide a recommendation for a project. In sensitivity analysis, real projects tested in this study would show whether or not a decision changed by new weights of factors, especially safety and congestion, because these two factors are the most critical factors considered by real decision makers.

5.2.6. Interpretation of Recommendations in the Decision Model

There are three types of recommendations in the decision model:

1) Recommendation by the comparison of total scores in daytime versus nighttime: The model provides a recommendation based upon the alternative with higher total score.
2) Recommendation by No-Go Logic: The decision model recommends an alternative without the comparison of total scores in daytime and nighttime due to a "no-go" result for one of the factors. However, a user can check the total scores in daytime and nighttime by clicking "More". The scores provided assume the "no-go" result did not occur. In other words, the numeric scores do not account for the "no-go" result.
3) Recommend either alternative: The model can recommend working in either daytime or nighttime because the daytime and nighttime decisions conflict in the No-Go Logic. For example, if a project's duration is less than 3 days, the decision model recommends it be done at daytime, while if a project results in unacceptable local business access during daytime, the decision model recommends it be done at night. Thus, the decision model recommends either daytime or nighttime in this situation. A decision maker can select his/her preference for a working schedule by the considering which factor has higher priority in the situation. Again, the user can see total scores for daytime and nighttime by clicking "More", and may choose to include this information as a consideration in making his decision. As

previously mentioned, when "Go No-Go" logic determines a recommendation, the numeric scores do not affect the "no-go" result.

5.3. TESTING THE DECISION MODEL

The decision model was tested with real construction and maintenance projects in states selected for this research to check whether the recommendations by the decision model are consistent with current decision makers' subjective decisions. Based upon the strategies in Table 3.5, various types of projects were selected. A total of 27 projects were selected and tested for this study. The detailed information of each project is provided in Appendix I.

With information obtained on the projects, user costs in daytime versus nighttime performance of each project were estimated and a total score of the alternatives was computed with the decision model developed in this research. Table 5.11 shows the results of the testing projects. Many project and maintenance managers planned their projects for the nighttime due to heavy traffic congestion in the daytime. Operation schedules in the status column are current decisions to conduct projects by project/district managers. When they did not provide a project's alternative schedule in daytime, the same time frame was applied to estimate user costs. For example, if a project was conducted from 9 p.m. to 5 a.m., a daytime schedule was applied from 9 a.m. to 5 p.m.

Table 5.11. Test Results of the Decision Model

Project # & Name	User Costs ($)		Total Score in the Model		Recommendation	Reason	Status
	Day	Night	Day	Night			
1. PA I95 Air	1592	902	N/A	N/A	Daytime	Less than 3 days	Both
2. PA SR202	99918	746	N/A	N/A	Either	Less than 3 days vs. Local business	Both
3. CT I91	216	132	8.23	8.68	Nighttime	8.23 < 8.68	Both
4. CT I95	176	108	8.23	8.68	Nighttime	8.23 < 8.68	Both
5. CT I91#2	230	140	8.23	8.68	Nighttime	8.23 < 8.68	Both
6. TX SH75	360	146	N/A	N/A	Nighttime	Local Business	Nighttime
7. TX IH45	5734940	52756	5.79	9.90	Nighttime	5.79 < 9.90	Nighttime
8. TX SH358	120702	250	5.79	9.90	Nighttime	5.79 < 9.90	Both
9. TX SH358#2	120702	250	5.79	9.90	Nighttime	5.79 < 9.90	Both
10. TX US287	552	94	6.79	9.90	**Nighttime**	6.79 < 9.90	**Daytime**
11. AZ SR69	670	140	6.99	9.90	Nighttime	6.99 < 9.90	Nighttime
12. AZ SR68	249144	232	5.79	9.90	Nighttime	5.79 < 9.90	Nighttime
13. AZ SR89	225571	250	5.79	9.90	Nighttime	5.79 < 9.90	Nighttime
14. OR I5	173252	137	5.94	8.13	Nighttime	5.94 < 8.13	Both
15. OR I84	2525686	9301	6.23	8.13	Nighttime	6.23 < 8.13	Nighttime
16. OR US97	286	64	N/A	N/A	Nighttime	Local Business	Nighttime
17. OR I84#2	156	155	7.74	8.13	Nighttime	7.74 < 8.13	Nighttime
18. OR Port of Entry	110	52	7.54	8.13	Nighttime	7.54 < 8.13	Nighttime
19. OR I5#2	1341409	1932	6.23	8.13	Nighttime	6.23 < 8.13	Nighttime
20. OR Pendleton	164	55	N/A	N/A	**Daytime**	Less than 3 days	**Nighttime**
21. OR 8	313	72	N/A	N/A	Nighttime	Local Business	Nighttime
22. OR 8#2	115	26	N/A	N/A	Nighttime	Local Business	Not Decided yet
23. OR 43	149	36	N/A	N/A	Either	Less than 3 days vs. Local business	Daytime
24. OR Bridge	1565270	208	6.23	8.13	Nighttime	6.23 < 8.13	Nighttime
25. ME R4	294	68	7.67	6.80	**Daytime**	7.67 > 6.80	**Nighttime**
26. ME I95	235	57	7.67	6.80	**Daytime**	7.67 > 6.80	**Nighttime**
27. ME I95#2	235	57	7.67	6.80	**Daytime**	7.67 > 6.80	**Nighttime**

The original strategy of type of scheduled work focused only on daytime and nighttime. However, this study found that several projects were conducted in both daytime and nighttime (shaded gray in Table 5.12), so we decided to test both scheduled projects to compare with the decisions by the decision model. This study assumed that decision makers for projects conduced in both schedules did not seriously consider user costs in the difference between daytime and nighttime compared to other decision makers. In addition, the comparison of decisions between the decision model and decision makers would exclude projects scheduled for both time frames because the purpose of the decision model is to select one alternative.

The decision model sometimes provides a recommendation of "either". If some factors conflict with each other by No-Go options in the decision model, the decision model provides the "either" recommendation. The decision maker in this situation needs to select the higher priority, and perform the work accordingly.

5.3.1. Findings from the Test Results

From the testing results, this study found many differences between the decision-making in the decision model and decisions by real decision makers. The following are facts produced through testing of the decision model:

5.3.1.1. Consistency of Decision-Making

Of 19 projects, excluding projects in which both day and night work had been scheduled, the recommendations for 14 projects in the decision model are consistent with current decision makers' decisions, which means that the model is consistent with current decision makers' actual decisions and reliable for use as a decision-making tool. Five projects had different decision model recommendations than the actual decision. These were: a) the US 287 project in Texas is being conducted during the day, while the decision model recommended nighttime work, b) the as-yet unstarted project in Pendleton, Oregon is slated to be done at night, whereas the decision model recommended it be done during the daytime due to the project being shorter than 3 days in duration, and c) the three projects in Maine were done in the nighttime, while the decision model recommended daytime.

5.3.1.2. High Feasibility of Nighttime Operations

The decision model recommended work be conducted in the daytime for four of the projects, as these were the projects that could be accomplished in a short duration, and recommended daytime work for all projects tested in Maine. All of the other projects, except for one, were recommended for nighttime work because congestion and negative impact on local businesses would be minimized. This means that nighttime operations are more economical and better for the local residents and businesses in work zones. This result supports current decision makers' choices for nighttime operations in order to reduce congestion and the impact on local businesses.

5.3.1.3. Adaptation of Go and No-Go Logic

In the decision model's recommendations, 19 projects' recommendations were based upon the magnitude of total scores in the day versus night alternatives, while the other eight projects' recommendations depended on Go and No-Go logic rather than on the magnitude of the total scores. In the decision model, there are four criteria of the Go and No-Go logic: work duration, the availability of nighttime shifts, the impact of noise, and the impact on local businesses. This illustrates that safety and congestion are not the only critical factors to be considered in determining when to conduct nighttime operations. In particular, the impact on local businesses in work zones and the duration of the work are highly important to the decision.

5.3.1.4. Feasibility of Either Daytime or Nighttime

Project numbers 2 and 23 received a recommendation of work in either daytime or nighttime because of the conflict between the factors of work duration and the impact on local businesses. This recommendation was in lieu of a comparison of total scores in daytime versus nighttime. Thus, the decision maker needs to decide subjectively based upon a priority hierarchy for the project. This study was unable to ascertain whether the decision maker of project number 2 considered the conflict between the factors of work duration and the impact on local businesses in the work zone because this project was conducted in both daytime and nighttime.

5.3.1.5. Impact of Congestion in the Decision Model

Congestion impacts the result of the decision model in two ways. First, the differences of user costs in daytime and nighttime are tremendous on major highways particularly in large cites. Generally, the score in daytime is zero, but the score in nighttime is 2 in the total scores. This difference results in a recommendation of performing work in the nighttime instead of daytime. Secondly, this study found that it is possible to neglect differences of a couple hundred dollars in user costs between the two time frames. Even though the projects tested here presented such an instance, if this difference is disregarded, the decision model recommends daytime rather than nighttime. However, this study limits the parameters so as not to provide the range of user costs amount to be negligible because a project's duration, location and type of work affect the range of the amount. This study recommends that decision makers should decide the range of the amount of user costs.

5.3.1.6. Impact of Local Businesses in Work Zones

In the results, the presence of local businesses in work zones was a major reason to conduct nighttime work in lower traffic volume areas. Even though the amount of user costs in both daytime and nighttime is not great, the decision model recommends conducting operations at night.

5.3.2. Impact of the Congestion Factor in the Decision Model

This study investigated the impact on the decision making in the model with and without the congestion factor in depth because the primary concern for nighttime operation is congestion.

5.3.2.1. Without Congestion Factor in the Decision Model

Without considering the congestion factor, the sum of the score in the decision model is always consistent in various projects. Table 5.12 shows the calculated sub-total scores based upon Tables 5.7 and 5.8 in the decision model without the consideration of the congestion factor. In all type 1 roads, in type 2 highways, and in type 3 in region 3, 4 and 5, daytime scores are inferior to nighttime scores without considering congestion which means that nighttime is always better even though the congestion factor is excluded. In other places, daytime scores are superior to nighttime, so it is necessary to check how the decision varies by adding the congestion factor in the model.

Table 5.12. Sub-Total Scores in the Model without Congestion Factor

Type	Daytime	Nighttime	Day-Night
Type 1	6.4280	6.6827	**-0.2548**
Type 2- Highways	5.7908	7.9000	**-2.1092**
Type 2- Non-Highways	6.6697	6.5581	0.1116
Type 3- Region 1 & 2	6.2264	6.1332	0.0932
Type 3- Region 3, 4 & 5	5.9443	6.1332	**-0.1889**
Type 4- Highways	6.4747	4.7959	1.6788
Type 4- Non-Highways	6.3480	5.8254	0.5226

5.3.2.2. With the Congestion Factor in the Decision Model

In Table 5.12, the score differences are 0.1116, 0.0932, 1.6788, and 0.5226 for bigger magnitude in daytime. This bigger magnitude in the daytime decreases and is finally exceeded by the magnitude in the nighttime if the congestion factor is added in the decision model. Figures 5.6, 5.7, 5.8, and 5.9, respectively, show the deviation of the total scores for each state type in the decision model by the congestion factor in different ratios of daytime and nighttime user costs. This result shows that the congestion factor critically affects the decision of when to conduct nighttime operations, provided that worker conditions, scheduling, and public relations do not influence the decision.

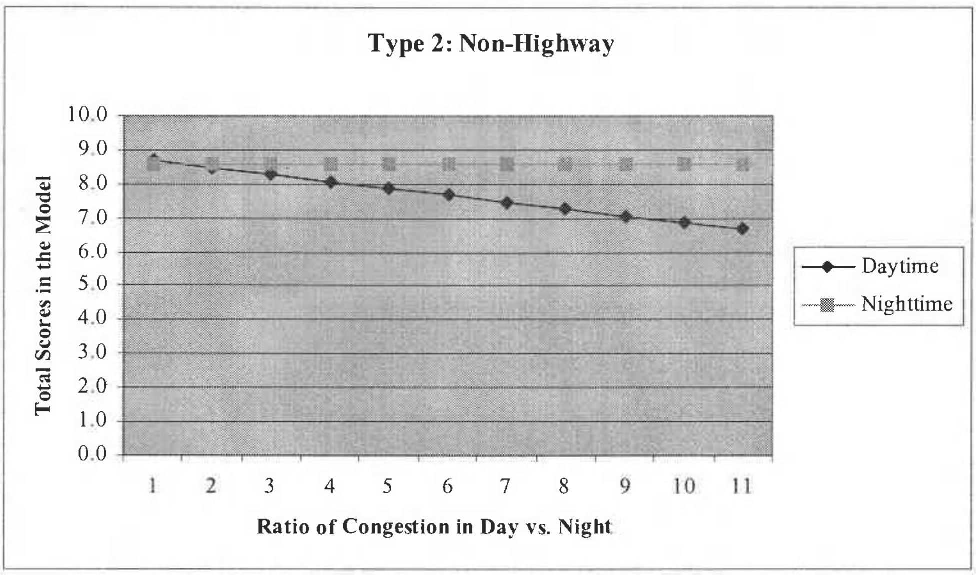

Figure 5.6. Deviation in Decision-Making by Congestion Factor (1)

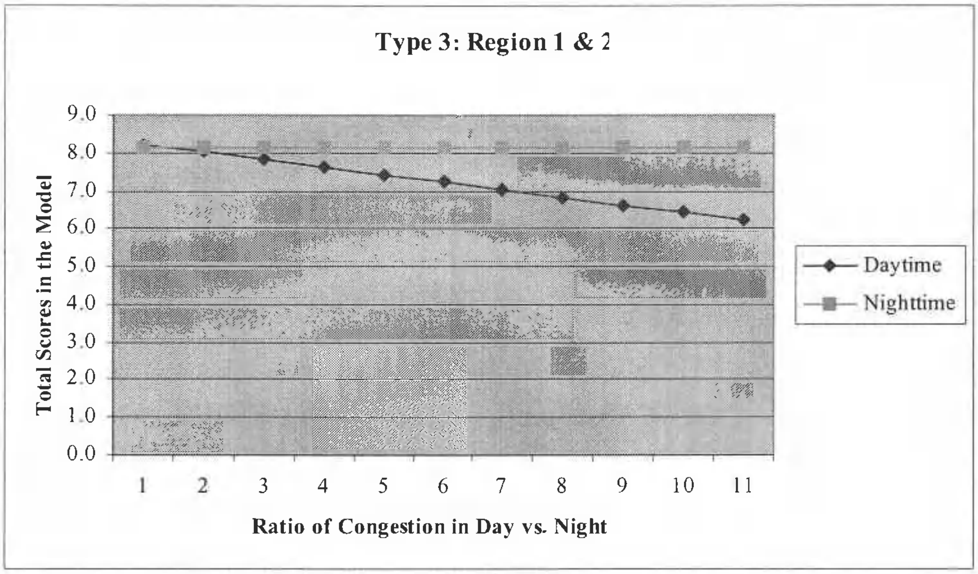

Figure 5.7. Deviation in Decision-Making by Congestion Factor (2)

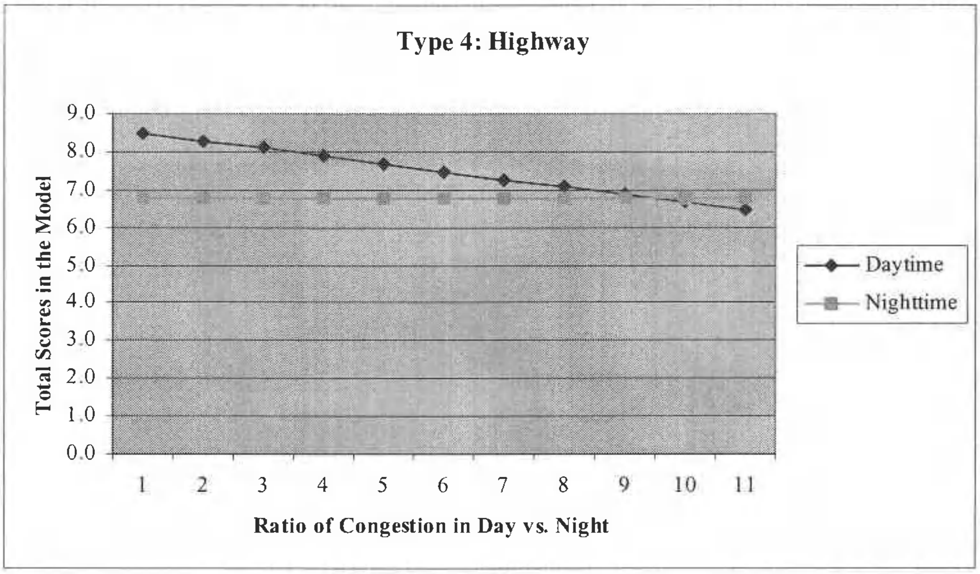

Figure 5.8. Deviation in Decision-Making by Congestion Factor (3)

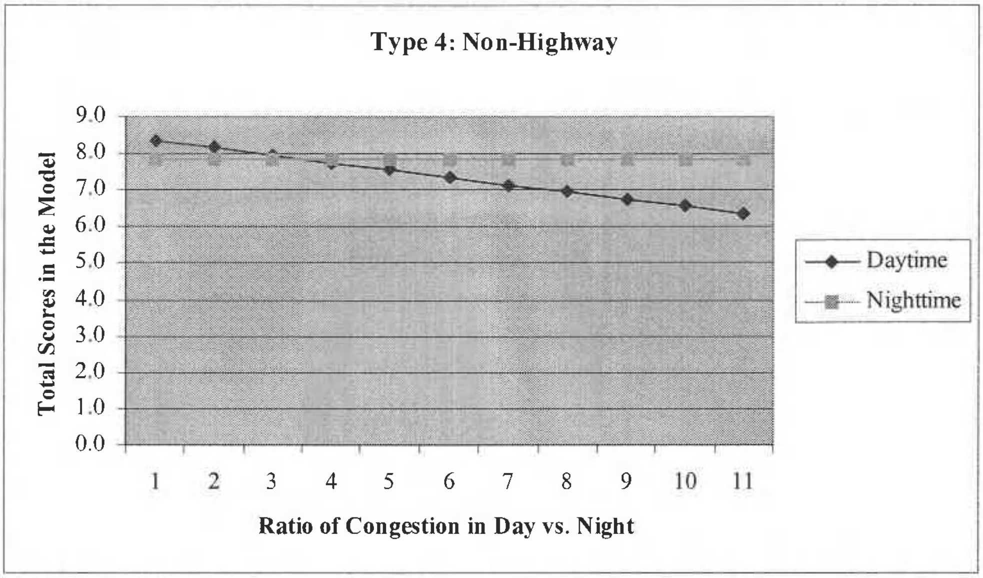

Figure 5.9. Deviation in Decision-Making by Congestion Factor (4)

5.3.3. Limitations of the Testing Results with the Decision Model

For testing the decision model, five projects from Type 1 states were tested, but the actual decisions by the decision makers were to conduct work on both schedules. As a result, we are unable to conclude that most of the projects in Type 1 states are conducting work on both day and night schedules without comparison between daytime and nighttime alternatives. This study tried to collect larger numbers of projects to increase of reliability of testing the model, but it was difficult to collect data on many projects in all state types, except for the type 3 state, Oregon.

This decision model separated type 2 and 4 states into 2 different road types, i.e. highways, including Interstate, US, State Turnpike, and Toll highways, and non-highways. During the testing, no projects in non-highways in two types of states were tested because projects in non-highway areas were not available. In fact, DOTs conduct a large portion of construction and maintenance roadwork on highways. Fortunately, this study did succeed in collecting data on various projects in the type 3 state, Oregon. Eleven projects satisfied all selection strategies for testing the decision model. Furthermore, the results in Oregon strongly support the findings of testing projects, such as the high consistency of decision-making and high feasibility of nighttime operations.

In testing the decision model with the projects selected, some projects have relatively small differences in total scores between daytime and nighttime. For example, the daytime total score is 8.23, and the nighttime total score is 8.68 for project numbers 3, 4, and 5 in Table 5.11, while daytime is 5.79 and nighttime is 9.90 for project numbers 7, 8, 9, 12, and 13. The decision model recommends selecting the higher score, but this is limiting because it does not incorporate the variances in the decision model for users. In other words, the model does not provide confidence intervals for each total score to enable users to decide if that difference is significant enough to distinguish.

5.4. SENSITIVITY ANALYSIS

The safety and congestion factors are the critical factors in the decision model, with weights of 4 and 2, respectively. Through sensitivity analysis, this study can examine how sensitive the decision model is to fluctuations in different weight values of the safety and congestion factors. Fluctuations in different weight values of two factors are important to see just how much deviation there is in the decision-making. In addition, there are no differences in the quality factor between daytime and nighttime except for the Type 4 state, Maine. This study also performed a sensitivity analysis for the quality factor with projects tested in Maine.

5.4.1. Sensitivity Analysis with the Safety and Congestion Factors

The modification of weights in this analysis focused on inserting a higher weight for congestion compared to safety in the decision model as well as a lower weight for safety compared to congestion. The following equation shows the sensitivity analysis of safety and congestion factors in the decision model based upon the theoretical equation of the decision model presented in the Methodology section of the dissertation. Weights of safety and congestion that are W_j in the following equation were varied from 2 to 4 in the model to investigate whether the resulting decision by the model changes or not.

$$U_N - U_D = \left\{ \sum_{j=1}^{m} W_j \left(\frac{1}{n} \sum_{k=1}^{n} V_{Njk}\right) \right\} - \left\{ \sum_{j=1}^{m} W_j \left(\frac{1}{n} \sum_{k=1}^{n} V_{Djk}\right) \right\}$$

Where,

U_N = aggregate score of nighttime
U_D = aggregate score of daytime
W_j = importance weight for factor j
V_{Njk} = score of sub-factor k of factor j on nighttime
j = factor
k = sub-factor
m = number of factors
n = number of sub-factors

Figures 5.10, 5.11, and 5.12 show the deviation of the difference in total scores between nighttime and daytime (Nighttime-Daytime) in the decision model. Tables J.1, J.2, J.3, and J.4 in Appendix J show the detailed computation of the total scores in daytime and nighttime and the different weights of the two factors modified from 2 to 4. Nineteen projects were tested by sensitivity analysis, namely those that had recommended operation schedules based upon the differences of their total scores rather than a Go and No-Go gauge.

After checking all of the total scores in the table, one might conclude that the total scores in the nighttime are superior to those in the daytime, except for three projects in Maine. Therefore, decisions are not changed regardless of the higher weights of the congestion factor in three state types. In the quantification of the quality factor, there are no quality differences between daytime and nighttime except for Maine. This results in different findings in the sensitivity analysis, so this study assumed that there is no quality difference between both and tested projects 25, 26, and 27 in Maine to investigate whether the decision changes or not in the next stage.

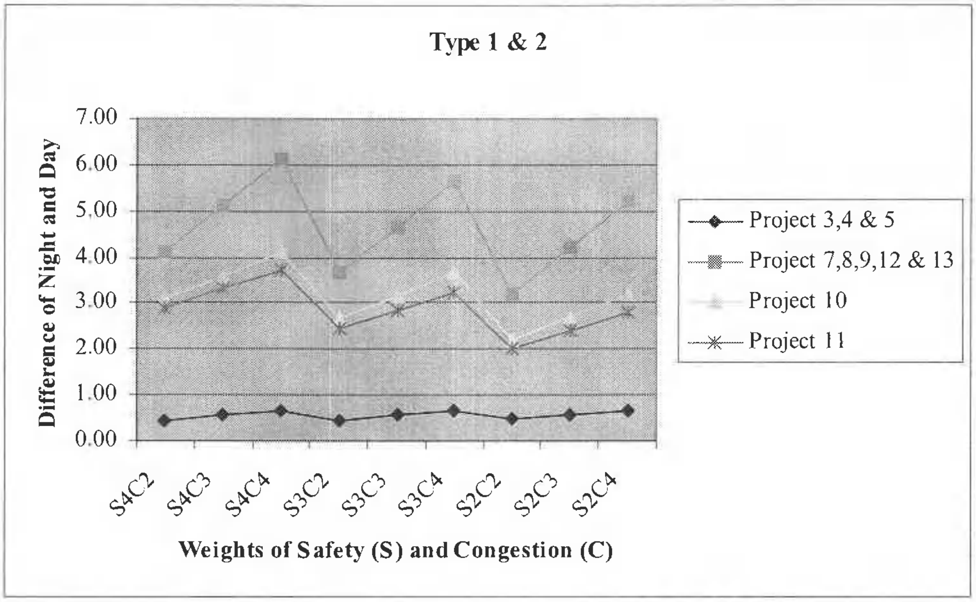

Figure 5.10. Sensitivity Analysis with Safety and Congestion Factors in the Model (1)

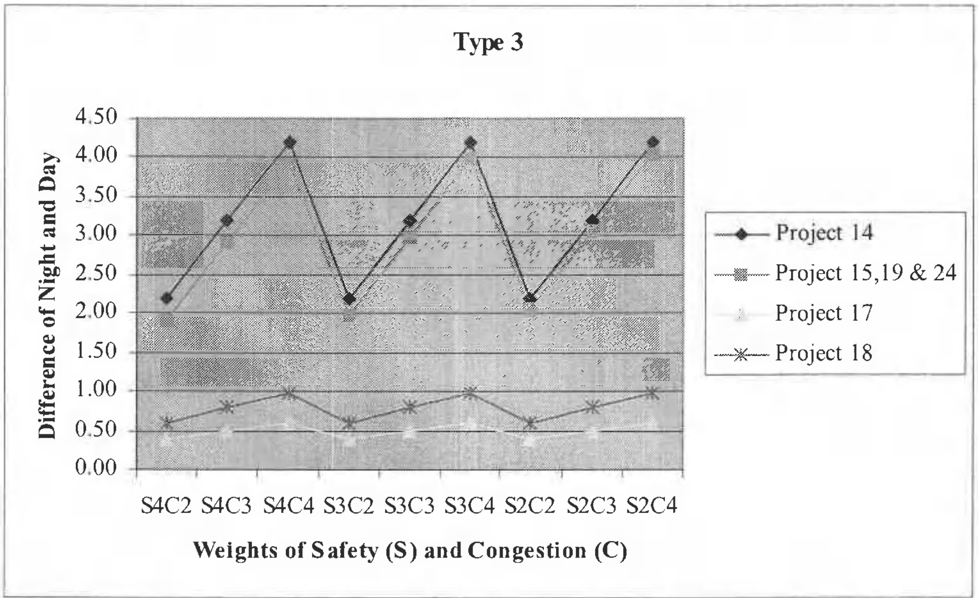

Figure 5.11. Sensitivity Analysis with Safety and Congestion Factors in the Model (2)

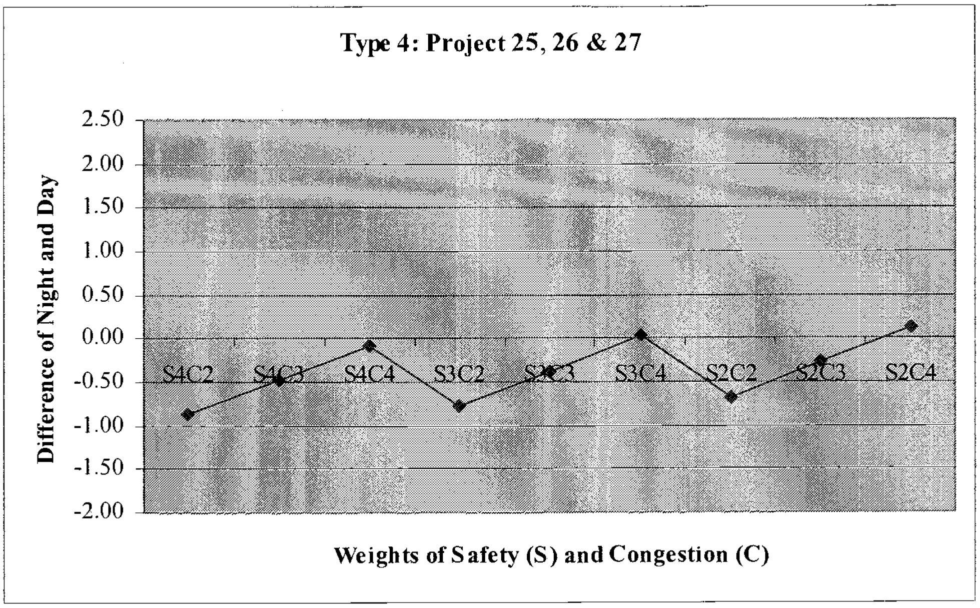

Figure 5.12. Sensitivity Analysis with Safety and Congestion Factors in the Model (3)

5.4.2. The Quality Factor in the Type 4 State, Maine

This analysis hypothesized that there are no quality differences between daytime and nighttime in Maine to investigate whether the decision impact in the model was influenced or not. Table 5.13 shows new computations of the model without the congestion factor because this varies by project. The sub-total scores of nighttime were changed from 4.7959 (Table 5.8) to 6.1759 in highways and from 5.8254 (Table 5.8) to 7.2055 in non-highways. In highways, daytime is still superior to nighttime, but the magnitude is significantly decreased. Taking the quality factor into account in the calculations changed the model's recommendation for non-highways roads in Maine, with nighttime works now preferred over daytime. These changes will affect the recommendations by the decision model.

Table 5.13. New Factor Scores in the Model without the Congestion Factor

Type	Factor	Weight	Daytime		Score	Nighttime		Score
Type 4: Highways	Safety	4	Crashes	Fatal	2.6747	Crashes	Fatal	2.2759
			0.3373	1.0000		1.0000	0.1380	
	Quality	2	1.0000		2.0000	1.0000		2.0000
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.8000		0.8000	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				**6.4747**			**6.1759**
Type 4: Non-Highways	Safety	4	Crashes	Fatal	2.5480	Crashes	Fatal	3.3055
			0.2740	1.0000		1.0000	0.6527	
	Quality	2	1.0000		2.0000	1.0000		2.0000
	Public Relations	1	0.0000		0.0000	0.0000		0.0000
	Worker Condition	1	1.0000		1.0000	0.9000		0.9000
	Productivity	1	0.8000		0.8000	1.0000		1.0000
	Scheduling	1	0.0000		0.0000	0.0000		0.0000
	Sub-Total Scores				**6.3480**			**7.2055**

Table 5.14 describes how the recommendations by the decision model are changed with four projects that were tested by the decision model. The decision model originally recommended conducting roadwork in the daytime, while the model now recommends working at night. Thus, if a user of the decision model thinks his/her state is similar to the type 4 state, this study recommends considering the quality issue discussed here. The user might investigate the quality differences, if it is possible, otherwise the user might explore "sensitivity" in the decision model. If this study obtains larger samples of quality data and proves that there are no differences like other states' type, the testing results with projects would more strongly support the findings of the testing with the decision model, such as consistency of decision-making, feasibility of nighttime operations, and impact of congestion in the decision model.

Table 5.14. Comparison of New and Original Recommendations in the Model

Project #	New Decision Model		Original Decision Model	
	Daytime	Nighttime	Daytime	Nighttime
25	7.6757	**8.1759**	**7.6747**	6.7959
26	7.6757	**8.1759**	**7.6747**	6.7959
27	7.6757	**8.1759**	**7.6747**	6.7959

5.5. EVALUATION OF THE DECISION MODEL

Based upon the protocol for the evaluation (please see the Methodology section), this study visited a group of State Traffic Design Engineers in WDOT. After the presentation of this study and a demonstration of the decision model, the group participated in a survey in which they shared their opinions about the practicality, user-friendliness, and usefulness of the decision model. In addition, this study asked whether WDOT would consider using this model to support decisions in the future. The survey participants were five engineers. Table 5.15 shows their responses. Each number in the table represents the frequency of responses for each question, and the median represents the overall response from the group for this question.

Table 5.15. Results of the Survey to Evaluate the Decision Model

Criteria	Strongly Agree	Agree	Moderate	Disagree	Strongly Disagree	Median
Practicality	0	3	1	1	0	Agree
User-Friendliness	1	2	2	0	0	Agree
Usefulness	0	2	3	0	0	Moderate
Should WDOT use it?	0	1	3	1	0	Moderate

The median of the questions on practicality and user-friendliness scored as "agree" and the other two questions on usefulness and possibility of the model's use in WDOT scored as "moderate." Based upon this result, this study concludes that the decision model can provide a practical and useful tool to help decision makers in the Traffic Design Engineers' Office in WDOT analyze when to use nighttime work. The survey asked participants to share their reason if their answer was 4 or 5 in any of the questions.

The person who answered, "disagree" for practicality and possibility of the model's use in WDOT mentioned that this study mainly dealt with paving projects to quantify critical factors in the decision model, but there are many other types of jobs performed at nighttime. The participant stated further that it was necessary to design the model based upon cost to society. Since all participants left after the survey and there is no personal information on the survey questionnaires, this study could not obtain more detailed information on how this respondent defined the cost to society.

This study believes that the user cost in the congestion factor, noise, and business impact in the public relations factors address the issue of cost to society in the decision model. Also, there are many jobs for DOTs, but the primary nighttime job in DOTs is paving and it is difficult to measure productivity and quality of other job types in daytime versus nighttime due to the lack of quantifiable data.

5.6. CONCLUSION FROM PHASE II

The primary objective of this study was the creation of a decision model that truly facilitates the decision of when to use nighttime road construction and maintenance work. After identifying and weighting critical factors affecting nighttime work, the decision model was created. This study tested the decision model on real projects and conducted sensitivity analysis with the safety and congestion factors. In addition, the model was evaluated by a group of experts in this field.

Based upon the information collected for and by this study, we demonstrated that nighttime work was superior because of the impacts to safety, productivity, and congestion, provided that public relations issues such as noise and local business impact did not create problems in the work zone. In Type 1 roads, type 2 highways, and type 3 in regions 3, 4 and 5, nighttime operations were better without consideration of congestion because of better environments based on crash, fatality, and productivity issues. However, in other state types, the congestion factor played a critical role in the consideration of nighttime operations because daytime operations were better without congestion, but nighttime operation was better with congestion. Therefore, based on these results, this study suggests that decision makers should consider safety, congestion, productivity, and public relations instead of only safety or congestion in the decision to determine when to conduct nighttime construction and maintenance roadwork.

6. CONCLUSION

6.1. SUMMARY

Many departments of transportation (DOTs) in the United States have emphasized preservation of existing highways and bridges rather than constructing new facilities. Many construction and maintenance activities have been accomplished at night in order to counter the disruption of daytime traffic. However, nighttime operations produce a new set of concerns such as safety, public relations, productivity, quality, and the impact on workers. Decision-making for using nighttime operations in DOTs has been subjective and has relied on judgment without the benefit of analytical data and evaluation criteria. In addition, the prior decision models in this field were not practical to DOTs because of the absence of a practical decision model for use by real users.

This study's main contribution has been to create a decision model that truly facilitates the determination of when to use nighttime road construction and maintenance work. In order to achieve this, the study considered the importance of weighting factors affecting nighttime operations, the process of determining if factors influenced the decision, and quantification methodology for qualitative factors.

After a literature review, we identified 19 sufficiently well established factors that affect decision-making which were utilized in developing the decision model for DOTs. All 19 factors were used to create the survey. The survey in this study has successfully characterized the importance of factors related to daytime versus nighttime decision-making. After analysis of various perspectives, the overall result was fairly consistent with the results from the individual respondent groups. The results provided the ability to determine weights and to build a decision model to improve the effectiveness of decision-making.

Using the results of this survey and the recommendations of the TAC, twelve unimportant factors were eliminated and seven important/critical factors were identified and weighted. The seven critical factors were quantified after a detailed investigation of each factor. Finally, the decision model was developed to determine when nighttime work should be conducted.

The decision model was tested by applying it to real projects and comparing its recommendations on when to conduct the projects with actual decision makers' decisions. The overall testing results were consistent with current decision makers' subjective judgments because of the impact of safety, productivity, and congestion in the decision model. In addition, sensitivity analysis showed the deviations of decision-making in the decision model. The analysis concluded that decision-making did not change regardless of changing the weights of the safety and congestion factors. In addition, this study asked a group of experts from WDOT to evaluate this study. They moderately agreed to the decision model was practical, user-friendly, and useful.

The decision model in this study has successfully provided a practical and useful tool to help decision makers in real work environments to analyze when to use nighttime work. In addition, the decision model will be useful in making decisions consistently and in providing a means to explain the decision to stakeholders.

6.2. RECOMMENDATIONS FOR FUTURE STUDY

There are several recommendations for future study. These include:

- Researchers could seek to replicate this Oregon personnel survey with other states to strengthen its results, even though this study used data triangulation for the survey.
- Researchers can collect larger samples for crashes, quality, and productivity from more states or all states in the United States. This will enable the construction of a database for DOTs in the decision model. In addition, the researcher can separate the quality and productivity data by paving materials, paving thickness, paving length, and project durations to investigate whether there is any differences of quality and productivity as related to these factors, and the results can be used to quantify paving quality and productivity in the decision model. If researchers do so, the comparison of quality and productivity in daytime versus nighttime would be stronger to support the decision model.

- Researchers can investigate factors for Go and No-Go Logic in the decision model such as worker conditions, public relations, and scheduling. Also, this study utilized industrial data from the literature to quantify worker conditions in the day versus at night. The researcher can investigate worker conditions in construction and maintenance roadwork by considering such things as reaction time on a simple task, or the average hourly rate on a task. Also, researchers can examine whether the performance level in the first two days (Monday and Tuesday) is significantly lower after experiments or collecting data from DOTs. This would enable the researcher to quantify the worker condition factor instead of Go and No-Go Logic. Also, noise measurements in work zones can be collected and the researcher can investigate the effect of noise to residents in the work zone to quantify public relations in the decision model. For local business impact, the researcher can examine and collect the data of sales variations of local businesses in work zones before and during construction, or maintenance operations to quantify public relations in the decision model. In addition, future study can collect data related to scheduling in daytime versus nighttime operations and quantify the factor in the decision model.
- This study evaluated the decision model with a group of State Traffic Design Engineers in WDOT due to accessibility and budget limitations. However, more comprehensive evaluations would help to strengthen the decision model.
- Finally, researchers can develop the decision model based upon traffic volumes instead of by state to generalize the decision model. This should assume that there are no significant differences for factors such as crashes, quality and productivity among states in work zones.

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APPENDICES

APPENDIX A. SURVEY FORMAT

Factors in Selecting between Daytime and Nighttime Work

Currently, Oregon Department of Transportation has utilized nighttime construction and maintenance to reduce the disruption of traffic during the daytime, but this also raises a new set of issues and concerns such as safety, public awareness, productivity, and quality. Therefore, the objective of this survey is to determine the importance of the factors affecting nighttime work. After this survey, a decision making model will be developed to determine when to use nighttime work.

Your expertise is critical in determining the relative importance of the various factors. Moreover, the resulting decision model should be beneficial to you since your opinions will be incorporated. Thank you in advance for taking the time to fill out this survey!

This study is a cooperative effort between Oregon State University and the Oregon Department of Transportation.

1. In responding to the following questions, please consider the importance of these factors with respect to making a decision to do a project at night or during the day. Circle the correct number or symbol to indicate the level of importance of the following factors affecting nighttime work. "7" indicates high importance, "1" indicates low importance, and "0" indicates no importance. If you do not have information or awareness of a particular factor, circle "NA".

	High						Low	No Importance	No Awareness
Traffic Related Parameters	7	6	5	4	3	2	1	0	NA
1. Congestion	7	6	5	4	3	2	1	0	NA
2. Safety	7	6	5	4	3	2	1	0	NA
3. Traffic Control	7	6	5	4	3	2	1	0	NA
Construction Related Parameters	7	6	5	4	3	2	1	0	NA
1. Productivity	7	6	5	4	3	2	1	0	NA
2. Quality	7	6	5	4	3	2	1	0	NA
Social Parameters	7	6	5	4	3	2	1	0	NA
1. Driver Condition	7	6	5	4	3	2	1	0	NA
2. Worker Condition	7	6	5	4	3	2	1	0	NA
Economic Parameters	7	6	5	4	3	2	1	0	NA
1. User Cost	7	6	5	4	3	2	1	0	NA
2. Accident Cost	7	6	5	4	3	2	1	0	NA
3. Maintenance Cost	7	6	5	4	3	2	1	0	NA
4. Construction Cost	7	6	5	4	3	2	1	0	NA
Environmental Parameters	7	6	5	4	3	2	1	0	NA
1. Noise	7	6	5	4	3	2	1	0	NA
2. Fuel Consumption	7	6	5	4	3	2	1	0	NA
3. Air Quality	7	6	5	4	3	2	1	0	NA
Additional Parameters									
1. Scheduling	7	6	5	4	3	2	1	0	NA
2. Public Relations	7	6	5	4	3	2	1	0	NA
3. Communication Supervision	7	6	5	4	3	2	1	0	NA
4. Availability of Material/ Equipment Repair	7	6	5	4	3	2	1	0	NA
5. Lighting	7	6	5	4	3	2	1	0	NA
Other (Please, list.):									
1	7	6	5	4	3	2	1	0	NA
2	7	6	5	4	3	2	1	0	NA
3	7	6	5	4	3	2	1	0	NA

2. To help differentiate the factors further, please rank the following factors by giving "1" to the most important factor, "2" to the second most importance factor, and so on. The least important factor will have the number "19". Again, remember that you are ranking the factors with respect to making a decision to do a project at night or during the day.

Congestion	______
Safety	______
Traffic Control	______
Productivity	______
Quality	______
Driver Condition	______
Worker Condition	______
User Cost	______
Accident Cost	______
Maintenance Cost	______
Construction Cost	______
Noise	______
Fuel Consumption	______
Air Quality	______
Scheduling	______
Public Relations	______
Communication Supervision	______
Availability of Material/Equipment Repair	______
Lighting	______

3. Do you prefer daytime work or nighttime work?

______ Daytime ______ Nighttime

4. Why?

____

____

____

____

5. Is there any additional information you would like to share?

____

____

____

____

____

6. Would you like to receive a copy of the results of this survey?

__________Yes __________No

Please provide your contact information or attach a business card (Optional).

Name: ______________________________

Address: ______________________________

____

____

____

Phone: ______________________________

e-mail: ______________________________

If you have any questions or comments, feel free to contact:

Kimberly. D. Douglas, Ph.D., P.E.	541-737-3644	kimberly.d.douglas@orst.edu
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Please mail your response to:
Nighttime Construction Project
118 Covell Hall
Oregon State University
Corvallis, OR 97331

APPENDIX B. SURVEY FORMAT FOR EVALUATION OF THE DECISION MODEL

Evaluation of the Decision Model to Determine When to Conduct Nighttime Road Construction and Maintenance Operations

Many decision makers in many states' of Department of Transportation (DOTs) have decided to conduct nighttime operations based upon their subjective manners without benefit of analytical data and evaluation criteria, therefore this study created to decision model to support their decision. Therefore, this study would like to evaluate the decision model to real potential users focusing on practicality, usefulness, and user-friendliness.

Your expertise is critical in evaluating the decision model. Moreover, the resulting decision model should be beneficial to you since your opinions will be incorporated. Thank you in advance for taking the time to fill out this survey!

This study is a cooperative effort between Oregon State University and the Oregon Department of Transportation.

Please circle the correct number to answer the following questions.

* Do you think that the decision model truly facilitate all factors affecting the decision-making to determine when to conduct nighttime operations?

1. Strongly Agree 2. Agree 3. Moderate 4. Disagree 5. Strongly Disagree

If your answer is 4 or 5 in the above question, could you share your reason to choose this?

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* Do you think that the decision model is easy to use for real decision makers including local project managers?

1. Strongly Agree 2. Agree 3. Moderate 4. Disagree 5. Strongly Disagree

If your answer is 4 or 5 in the above question, could you share your reason to choose this?

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* Do you think that the decision model is useful to support real decision makers' decisions?

1. Strongly Agree 2. Agree 3. Moderate 4. Disagree 5. Strongly Disagree

If your answer is 4 or 5 in the above question, could you share your reason to choose this?

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* Do you want to use this decision model to support your decision in future if it is possible?

1. Strongly Agree 2. Agree 3. Moderate 4. Disagree 5. Strongly Disagree

If your answer is 4 or 5 in the above question, could you share your reason to choose this?

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* Is there any additional information you would like to share ?

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If you have any question or comments, feel free to contact:

Sang-Bin Park 541-346-3644 parksa@engr.orst.edu

Thank you for your time.

APPENDIX C. ANALYSIS OF SURVEY RESULTS

Table C.1. Comparison between Overall Results and PM Office Results

PM (n=231)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Safety	6.55	0.92	Safety	1.90	2.12
Traffic Control	6.13	1.12	Traffic Control	3.94	2.58
Congestion	5.89	1.33	Congestion	5.06	4.48
Lighting	5.89	1.47	Quality	6.18	4.00
Quality	5.47	1.55	Productivity	7.54	3.88
Public Relations	5.26	1.36	Worker Condition	7.61	4.05
Worker Condition	5.15	1.58	Driver Condition	8.05	3.99
Productivity	5.04	1.36	Lighting	8.93	5.33
Driver Condition	5.02	1.47	Public Relations	9.62	4.61
Scheduling	4.89	1.61	Construction Cost	9.74	4.02
Accident Cost	4.86	1.60	Scheduling	10.53	4.57
Construction Cost	4.81	1.58	Noise	11.23	4.72
Noise	4.7	1.75	Accident Cost	11.44	4.24
Communication Supervision	4.51	1.67	User Cost	12.21	4.26
User Cost	4.37	1.49	Communication Supervision	12.34	4.67
Availability of Material/Equipment Repair	4.25	1.83	Maintenance Cost	13.39	3.72
Maintenance Cost	4.17	1.68	Availability of Material/Equipment Repair	13.54	4.85
Air Quality	3.53	1.96	Air Quality	14.89	4.06
Fuel Consumption	3.02	1.77	Fuel Consumption	16.12	3.58

Table C.2. Comparison between Overall Results and DM Office Results

DM (n=132)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Safety	6.41	1.19	Safety	1.89	2.45
Traffic Control	6.21	1.17	Traffic Control	3.68	2.74
Congestion	6.10	1.31	Congestion	4.80	4.90
Lighting	5.99	1.43	Productivity	7.48	3.99
Public Relations	5.60	1.30	Quality	7.61	3.59
Quality	5.48	1.52	Worker Condition	7.67	4.11
Availability of Material/Equipment Repair	5.44	1.75	Lighting	8.91	5.35
Maintenance Cost	5.34	1.48	Driver Condition	9.06	4.40
Worker Condition	5.31	1.58	Public Relations	9.32	4.70
Scheduling	5.27	1.62	Maintenance Cost	9.45	4.02
Driver Condition	5.24	1.62	Availability of Material/Equipment Repair	9.92	4.96
Accident Cost	5.14	1.57	Scheduling	10.03	4.53
Productivity	5.13	1.36	Accident Cost	11.28	4.40
Construction Cost	5.03	1.50	Construction Cost	11.61	4.32
Communication Supervision	4.85	1.58	User Cost	12.41	4.17
User Cost	4.69	1.48	Communication Supervision	12.73	4.63
Noise	4.42	1.88	Noise	13.22	4.56
Air Quality	3.06	2.15	Air Quality	15.66	4.20
Fuel Consumption	2.91	1.94	Fuel Consumption	16.93	3.28

Table C.3. Comparison between Overall Results and Contractors' Results

Contractors (n=38)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Safety	6.29	1.11	Safety	3.00	3.46
Productivity	6.03	1.05	Productivity	4.52	2.93
Lighting	5.84	1.38	Traffic Control	5.36	2.83
Traffic Control	5.68	1.30	Quality	5.91	3.32
Construction Cost	5.68	1.47	Congestion	6.06	3.90
Quality	5.66	1.28	Construction Cost	7.33	4.21
Congestion	5.63	1.57	Worker Condition	7.69	4.35
Availability of Material/Equipment Repair	5.58	1.42	Accident Cost	9.59	4.90
Worker Condition	5.50	1.52	Driver Condition	9.75	4.39
Scheduling	5.34	1.49	Lighting	9.79	5.42
Communication Supervision	5.06	1.60	Scheduling	10.21	4.68
Driver Condition	4.97	1.62	Availability of Material/Equipment Repair	10.24	5.30
Accident Cost	4.94	1.91	Communication Supervision	11.45	4.82
Public Relations	4.34	1.70	Public Relations	11.64	4.50
User Cost	3.97	2.03	User Cost	12.21	4.79
Noise	3.84	2.01	Maintenance Cost	12.56	3.93
Maintenance Cost	3.69	2.03	Noise	12.61	4.58
Air Quality	2.42	2.13	Air Quality	14.91	4.56
Fuel Consumption	2.28	2.05	Fuel Consumption	16.31	4.25

Table C.4. Comparison between Overall Results and Other DOTs' Results

DOTs (n=31)					
Indicating			*Ranking*		
Factor	AVG	SD	Factor	AVG	SD
Congestion	6.57	1.19	Safety	2.41	2.32
Safety	6.07	1.20	Congestion	2.93	3.93
Traffic Control	6.03	1.13	Traffic Control	4.66	2.72
Public Relations	5.93	1.26	Public Relations	6.03	3.42
User Cost	5.53	1.74	Quality	6.61	3.00
Scheduling	5.30	1.51	User Cost	7.38	4.44
Lighting	5.10	1.97	Productivity	7.66	3.09
Noise	4.73	1.68	Scheduling	8.83	4.51
Worker Condition	4.65	1.87	Noise	9.45	4.05
Productivity	4.53	1.50	Accident Cost	10.29	4.81
Driver Condition	4.48	1.56	Lighting	10.45	5.22
Accident Cost	4.48	2.03	Worker Condition	10.50	3.77
Communication Supervision	4.40	2.02	Driver Condition	11.21	3.96
Quality	4.38	1.78	Construction Cost	11.25	4.44
Construction Cost	4.24	1.60	Availability of Material/Equipment Repair	12.93	4.42
Availability of Material/ Equipment Repair	4.24	1.81	Maintenance Cost	13.43	4.25
Maintenance Cost	3.74	1.48	Communication Supervision	14.36	3.75
Air Quality	3.46	1.77	Air Quality	16.29	2.81
Fuel Consumption	2.68	1.73	Fuel Consumption	17.00	3.03

APPENDIX D. ANALYSIS OF CRASH DATA

Table D.1. Total Crash Analysis in Pennsylvania between 1998 and 2000

District	Daytime	Nighttime	Ratio (Day/Night)
	Total Crashes	Total Crashes	Total Crashes
01	165	80	2.0625
02	147	49	3.0000
03	146	40	3.6500
04	180	59	3.0508
05	487	217	2.2442
06	1263	535	2.3607
08	989	415	2.3831
09	125	60	2.0833
10	130	51	2.5490
11	427	187	2.2834
12	285	139	2.0504
Average			**2.5198**

Table D.2. Fatal Crash Analysis in Pennsylvania between 1998 and 2000

District	Daytime		Nighttime		D vs. N
	# of Fatal	% against total crash	# of Fatal	% against total crash	Ratio of % in D vs. N (N=1.00)
1	0	0.0000	4	0.0500	0.0000
2	1	0.0068	2	0.0408	0.1667
3	3	0.0205	2	0.0500	0.4110
4	1	0.0056	1	0.0169	0.3278
5	5	0.0103	6	0.0276	0.3713
6	5	0.0040	4	0.0075	0.5295
8	12	0.0121	13	0.0313	0.3873
11	1	0.0023	4	0.0214	0.1095
12	5	0.0175	2	0.0144	1.2193
Average					**0.3914**

Table D.3. Total Crash Analysis in Texas between 1998 and 2000

Road Type	Daytime	Nighttime	Ratio (Day/Night)
	Total Crashes	Total Crashes	Total Crashes
US & State	9045	4433	2.0404
Interstate	6500	3635	1.7882
Turnpike & Toll	40	18	2.2222
Belt 8/Toll Bridge	0	0	N/A
Average of Highways			**2.0169**
Farm to Market	2288	1133	2.0194
County Road	648	299	2.1672
City Street	5328	2355	2.2624
Other (Alley)	2	2	1.0000
Average of Non-Highways			**1.8623**

Table D.4. Fatal Crash Analysis in Texas between 1998 and 2000

Road Type	Daytime		Nighttime		D vs. N
	# of Fatal	% against total crash	# of Fatal	% against total crash	Ratio of % in D vs. N (N=1.00)
US & State	78	0.0086	84	0.0186	0.4637
Interstate	38	0.0058	57	0.0013	4.5222
Turnpike & Toll	0	0.0000	1	0.0526	0.0000
Average of Highways					**1.6620**
Farm to Market	24	0.0105	23	0.0199	0.5272
County Road	4	0.0062	8	0.0261	0.2369
City Street	11	0.0021	22	0.0093	0.2231
Average of Non-Highways					**0.3291**

Table D.5. Total Crash Analysis in Oregon between 1998 and 2000

Road Type	Daytime	Nighttime	Ratio (Day/Night)
	Total Crashes	Total Crashes	Total Crashes
Region 1 Highway	266	81	3.2840
Region 2 Highway	178	49	3.6327
Portland	186	38	4.8947
Salem	89	24	3.7083
Average			**3.8799**
Region 3 Highway	116	12	9.6667
Region 4 Highway	28	7	4.0000
Region 5 Highway	23	3	7.6667
Medford	27	2	13.5000
Bend	8	1	8.0000
Pendleton	5	0	#DIV/0!
Average			**8.5667**

Table D.6. Fatal Crash Analysis in Oregon between 1998 and 2000

Road Type	Daytime		Nighttime		D vs. N
	# of Fatal	% against total crash	# of Fatal	% against total crash	Ratio of % in D vs. N (N=1.00)
Region 1 Highway	1	0.3800	3	3.7000	0.1027
Region 5 Highway	1	4.3500	1	33.3300	0.1305
Average					**0.1166**

Table D.7. Total Crash Analysis in Maine between 1998 and 2001

Road Type	Daytime	Nighttime	Ratio (Day/Night)
	Total Crashes	Total Crashes	Total Crashes
State Highway	1312	362	3.6243
Toll Highway	212	92	2.3043
Average of Highway			**2.9643**
State Aid	368	82	4.4878
Town Way	239	85	2.8118
Average of Non-Highway			**3.6498**

Table D.8. Fatal Crash Analysis in Maine between 1998 and 2001

Road Type	Daytime		Nighttime		D vs. N
	# of Fatal	% against total crash	# of Fatal	% against total crash	Ratio of % in D vs. N (N=1.00)
State Highway	1	0.0008	1	0.0028	0.2759
Toll Highway	0	0.0000	1	0.0109	0.0000
Average of Highway					**0.1380**
State Aid	3	0.0082	1	0.0122	0.6685
Town Way	1	0.0001	1	0.0001	0.6370
Average of Non-Highway					**0.6527**

APPENDIX E. USERGUIDE TO ESTIMATE ROAD USER COSTS

1. Background

This study used road user cost to quantify the congestion factor. An Excel spreadsheet developed by Oklahoma Department of Transportation enables the estimation of road user cost. In 1997, Karl Zimmerman in Oklahoma Department of Transportation originally created this spreadsheet using Quattro Pro. Then, Richard Jurey in Federal Highway Administration modified Zimmerman's spreadsheet and converted to Excel spreadsheet in 2000 and 2001.

2. Structure of The Spreadsheet

This spreadsheet consists of four sections.

1) Information and Instructions: This section briefly introduced this spreadsheet and stated information required to enter to estimate road user cost for a specific project.
2) Lane Rental (LR) Input sheet: A user needs to enter information required in colored cells with light yellow are input cells in this sheet. After entering the necessary information, the user can see the results of user cost by each hour for the project in this sheet.
3) LR Table sheet: If the user has specific traffic volumes instead of AADT in the project area, this sheet enables to user to estimate road user cost. Also, the user can enter K-factors defined by the user instead of standard K-factor by Highway Capacity Manual. If the user has this information, the accuracy of user cost's estimation is higher. If the user does not have this information, the user can disregard this sheet.
4) LR Calculation sheet: This sheet shows the detailed calculation of user cost estimation in LR input sheet or LR table sheet.

Overall, a user can determine an estimation of user cost and obtain it in only LR input sheet if he/she does not have specific traffic volumes or a K-factor defined by the user.

3. Required Information

1. Project name
2. Analysis code: There are six codes. Interstate urban (IU), interstate rural (IR), arterial urban (AU), and arterial rural (AR) are the types of road for a project. If a user has specific K-factor or traffic volumes, the user can select user defined factors (UF), and user defined volumes (UV).
3. AADT: Enter AADT of both directions.
4. Percent of trucks
5. Number of lanes (one direction)
6. Free flow speed (mph): This speed is a posted speed in the road area.
7. Maximum queue length limit (miles): The queue length limit is the first practical diversion point for traffic to take an alternate route around the bottleneck. If a user does not want to limit queue length or to make the user cost estimation conservative, enter the largest number, 99 in this cell.
8. Confidence level (%): This is not a statistical confidence interval. It's a percentile and just the y-axis of Figure 6-12 in the 1997 Highway Capacity Manual. Zimmerman recommended that 50th percentile as about the best a user could reasonably do.
9. Delay ($/hour) passenger car: This study used 12.85.
10. Fuel cost ($/gal): This study used 1.55.
11. Average # people per vehicle: This study used 1.25.
12. # of Lanes closed (one direction): Enter # of lanes closed during working in each hour.

4. Special Cases

(1) Single lane in each direction: If there is a single lane in each direction in a work zone and the road has a shoulder which is at least 8-feet wide, it can be considered to be two lanes instead of a single lane in each direction.

(2) Complete lane closure: This spreadsheet cannot estimate road user cost if all lanes in either direction are closed. In order to obtain user cost for the decision model, a user should estimate user cost on detour roads for a project with this spreadsheet.

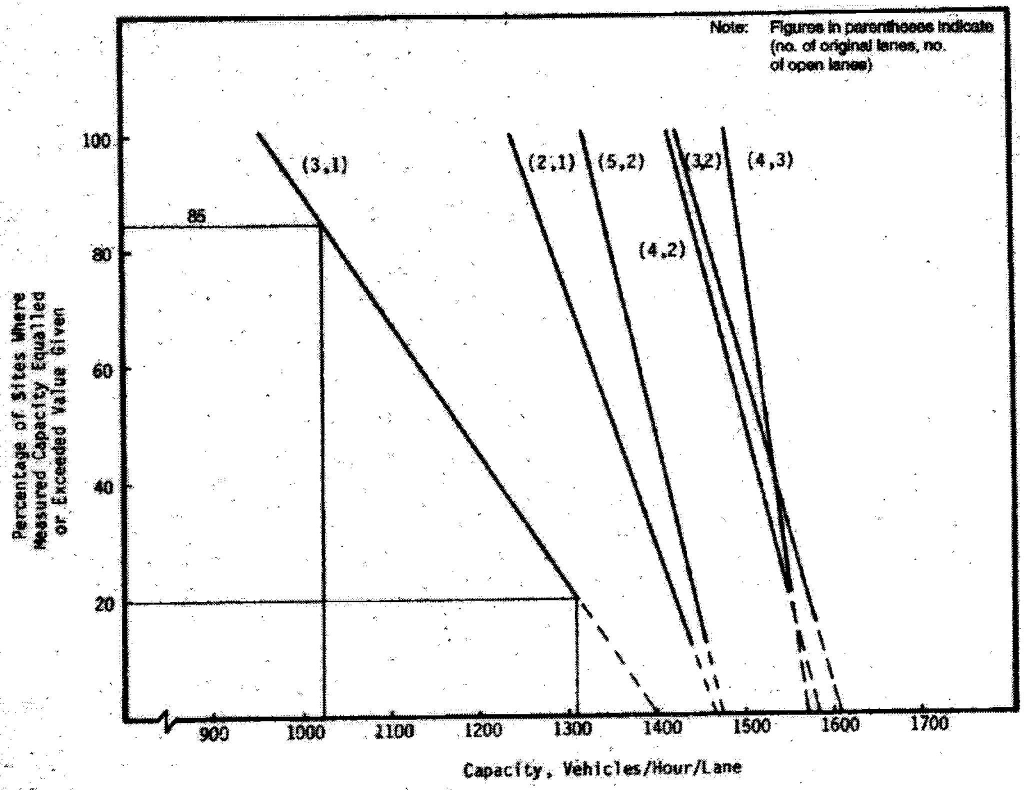

Figure 6-12. Cumulative distribution of observed work-zone capacities (9).

Figure E.1. The Reference Figure from Highway Capacity Manual

APPENDIX F. PAVING QUALITY STUDY

Table F.1. Daytime Paving Quality in Type 1 States

Year	Project Name or Road # / State	Project Length (mile)	% Improvement	Average	Standard Deviation	Median
2002	SR 895, PA	7.95	62.37			
2002	SR 1009, PA	4.26	45.45			
2002	SR 402, PA	7.70	49.23			
2002	SR 115, PA	7.23	69.14			
2002	SR 534, PA	8.87	54.59	56.16	9.65	54.59
2001	US 219, MD	2.25	39.81			
2001	US 50, MD	1.00	41.33			
2001	US 301, MD	4.75	33.64			
2001	MD 86, MD	4.00	36.30			
2001	MD 136, MD	3.08	59.52	42.12	10.18	39.81
2002	I-91, CT	3.05	43.15			
2001	I-395, CT	18.17	53.61			
2000	I-395, CT	9.47	2.34	33.03	27.09	43.15
1999	NY	N/A	66.00			
1999	NY	N/A	25.00			
1999	NY	N/A	32.00			
1999	NY	N/A	27.00			
1999	NY	N/A	68.00	43.60	21.52	32.00
Daytime				**44.92**	**21.52**	**32.00**

Table F.2. Nighttime Paving Quality in Type 1 States

Year	Project Name / State	Project Length (mile)	% Improvement	Average	Standard Deviation	Median
2002	SR 4040, PA	4.00	37.96			
2002	SR 4003, PA	5.82	38.32			
2002	SR 863, PA	10.75	43.14			
2002	SR 61, PA	0.79	-5.26			
2002	SR 0202, PA	N/A	32.61			
2002	I-95 Air, PA	N/A	39.07	30.97	18.07	38.14
2001	IS 05, MD	2.30	33.01			
2001	MD 695, MD	2.20	11.21			
2001	IS 70, MD	3.20	29.31			
2001	IS 595, MD	2.20	25.56			
2001	IS 95, MD	4.90	51.55	30.13	14.55	29.31
2002	I-91, CT	10.67	50.89			
2002	I-95, CT	1.67	53.79			
2001	I-91, CT	10.67	45.27			
2001	Trumbull, CT	11.19	68.85			
2001	Middletow, CT	5.78	14.89			
2001	I-81, CT	7.43	45.00			
2000	I-395, CT	6.2	62.80	48.78	17.34	50.89
1999	NY	N/A	62.00			
1999	NY	N/A	66.00			
1998	NY	N/A	25.00			
1997	NY	N/A	46.00			
1999	NY	N/A	24.00	44.60	19.82	46.00
Nighttime				**39.17**	**18.41**	**39.07**

Table F.3. Daytime Paving Quality in Type 2 States

Year	Project Name or Road # / State	Project Length (mile)	% Improvement	Average	Standard Deviation	Median
2002	IH-20, TX	7.00	37.29			
2002	US 287, TX	11.00	53.26			
2002	TX	4.40	59.32	49.96	11.38	53.26
1998	IM 40-04-154, AZ	8.4	12.27			
2000	IM 40-05-103, AZ	11.81	66.64			
1998	IM 10-06-122, AZ	5.3	12.47			
1998	IM 10-05-75, AZ	6.01	25.57			
1998	IM40- 4-151, AZ	5.84	80.85			
2000	IM 15-01-048, AZ	5.33	61.13			
1999	IM 40-03-084, AZ	8.21	38.33			
1999	IM 40-04-155, AZ	6.86	32.79			
2000	IM 40-04-157, AZ	6.8	57.30			
2000	IM 15-01-048, AZ	5.32	61.13			
1998	IM 19- 1-125, AZ	4.25	28.57			
1998	ACIM 19- 1-117, AZ	10.68	52.68			
1998	IM19- 1-125, AZ	4.25	32.84			
1999	IM 10-05-078, AZ	7.4	51.21			
1999	IM 17-02-121, AZ	12.96	63.81			
2000	IM 17-02-125, AZ	5.39	67.86			
1999	IM 17-01-327, AZ	2.49	61.55			
1998	IM 40- 1- 84, AZ	1.76	52.83			
1998	IM 40-02-122, AZ	10.25	46.03	47.68	19.32	52.68
1998	IM-40-6(261)271 E, OK	4.65	60.12			
1998	IM-40-6(261)271 W, OK	4.65	64.02			
2000	IM-40-5(343)194 E, OK	6.46	29.27			
2000	IM-40-5(343)194 W, OK	6.46	28.41			
1999	IM-40-1(064)000 E, OK	7.70	52.63			
1999	IM-40-1(064)000 W, OK	7.70	64.84			
1999	IM-40-5(344)186 E, OK	7.24	43.33			
1999	IM-40-5(344)186 W, OK	7.24	42.57	48.15	14.61	47.98
Daytime				**48.03**	**17.10**	**52.65**

Table F.4. Nighttime Paving Quality in Type 2 States

Year	Project Name or Road # / State	Project Length (mile)	% Improvement	Average	Standard Deviation	Median
2002	IH-35, TX	3.00	58.58			
2002	IH-35, TX	11.30	-3.02	27.78	43.56	27.78
	STP 366 (36), AZ	2	13.84			
	STP 067-1(11)P, AZ	12	31.65			
2003	STP-089-A(1)P, AZ	3.16	18.05			
2002	STP-089-B(1)P, AZ	4.67	92.04			
2000	STP-029-1(23)P, AZ	6.14	53.10			
1999	STP039-01-36P, AZ	3.7	33.04	40.29	28.86	32.34
1996	IM-35-3(24)128 N, AZ	1.22	49.59			
1996	IM-35-3(24)128 S, AZ	1.22	54.62			
1996	IM-40-5(30)153 E, AZ	4.37	40.34			
1996	IM-40-5(30)153 W, AZ	4.37	31.03			
1996	IMC-55(979) E, AZ	4.00	39.09			
1996	IMC-55(979) W, AZ	4.00	23.71			
2000	IMC-155N(227) E, AZ	1.80	40.95			
2000	IMC-155N(227) W, AZ	1.80	23.23	37.82	11.32	39.71
Nighttime				**37.49**	**21.90**	**36.06**

Table F.5. Daytime Paving Quality in Type 3 State (Oregon)

Year	Contract #	Hwy #	Project Length (mile)	% Improvement	Average	Standard Deviation	Median
2000	12269	006	9.06	18.33			
2000	12324	002	25.53	18.61			
1999	12155	001	11.15	22.92			
1999	12126	002	13.79	24.32			
1998	11864	1	8.89	35.27			
1998	12020	1	7.29	17.72			
2000	12364	028	1.23	2.76			
1999	11981	007	4.02	37.90			
1999	12156	007	2.05	20.14			
1999	11908	009	1.01	19.12			
1998	11900	9	12.47	14.31			
1998	11841	455	1.32	2.77			
2000	12253	007	11.25	13.12			
2000	12306	009	8.88	47.92			
2000	12319	009	2.16	38.72			
2000	12237	028	10.41	43.55			
2000	12347	035	6.82	34.05			
2000	12408	045	2.62	25.82			
2000	12369	053	4.27	15.88			
1999	12255	004	10.96	35.63			
1999	12252	004	13.79	5.05			
1999	12276	007	8.53	43.00			
1999		009	0.62	48.91			
1999	12145	009	0.7	0.14			
1999	11939	015	3.75	17.17			
1999	11807	018	5.89	1.75			
1999	12218	019	7.95	29.58			
1999	12267	026	8.31	35.60			
1999	12249	035	7.6	33.07			
1999	12243	042	26.96	20.87			
1999	12241	053	14.73	25.84			
1999	12226	092	4.74	39.86			
1999	12195	174	2.03	32.33			
1998	12102	4	6.5	4.98			

Table F.5. Daytime Paving Quality in Type 3 State (Continued)

Year	Contract #	Hwy #	Project Length (mile)	% Improvement	Average	Standard Deviation	Median
1998	12102	4	23.62	41.09			
1998	12061	4	11.22	15.87			
1998	12051	8	5.3	28.83			
1998	12059	9	10.69	32.60			
1998	12029	9	2.44	22.34			
1998	12102	18	11.25	34.54			
1998	12025	25	8	25.83			
1998	12138	26	3.16	16.30			
1998	12017	26	4.91	18.76			
1998	11765	35	1.22	37.06			
1998	12060	35	3.74	49.34			
1998	12092	42	12.5	21.39			
1998	12080	45	5.63	37.93			
1998	12100	53	13.52	10.80			
1998	11637	162	8.94	21.68			
Daytime					**25.33**	**13.08**	**24.32**

Table F.6. Nighttime Paving Quality in Type 3 State (Oregon)

Year	Contract #	Hwy #	Project Length (mile)	% Improvement	Average	Standard Deviation	Median
2000	12394	004	8.87	26.29			
2000	12235	025	2.56	57.90			
2000	12365	091	4.79	48.67			
2000	12412	092	2.08	53.87			
1999	12232	009	0.64	36.94			
1999	12104	054	5.93	31.67			
1999	12257	092	7.12	8.56			
1998	11922	5	0.67	4.62			
1998	12093	9	2.4	31.52			
1998	12041	9	2	-11.65			
2000	12392	004	11.6	10.30			
2000	12420	009	6.5	46.47			
2000	12202	018	6.17	26.65			
2000	12420	047	5.1	44.32			
2000	12357	162	11.03	22.12			
2000	12345	162	2.37	33.54			
2000	12345	162	7.73	25.58			
1999	12220	025	7.59	22.44			
1999	12182	162	0.48	35.30			
1999	12182	162	7.26	39.87			
1998	12117	9	4.33	37.70			
1998	12081	9	0.56	-6.36			
1998	12024	16	12.13	17.37			
1998	12034	25	6.62	16.17			
1998		162	2.8	18.48			
Nighttime					**27.13**	**17.58**	**26.65**

Table F.7. Daytime and Nighttime Paving Quality in Type 4 State (Maine)

Year	Hwy # / State	Project Length (mile)	% Improvement	Average	Standard Deviation	Median
2002	Route 8/11/27, ME	6.38	58.78			
2002	Route 1, ME	2.91	47.35			
2002	Route 156, ME	8.74	56.18			
2002	Route 201, ME	11.06	59.24			
Daytime				**55.39**	**5.53**	**57.48**
1998	Route 1, ME	3.92	-6.72			
2002	Route 4, ME	4.25	35.56			
2002	Route 25, ME	6.75	-12.50			
2002	I-95, ME	6.90	33.26			
			32.02			
2002	I-95, ME	3.20	21.41			
Nighttime				**17.17**	**21.39**	**26.72**

APPENDIX G. PAVING PRODUCTIVITY STUDY

Table G.1. Daytime Daily Paving Productivity in Type 1 States

Project Name / State	**Productivity Samples (ton/hour)**					
I-80, IL	230.13	215.00	140.00	125.75	160.33	
MLK Dr., IL	101.50	157.43	136.12	172.32	123.83	
Columbus, Indiana City Street, IN	33.03	42.05	38.26	30.30	20.05	46.02
	44.69	53.70	54.77	48.01	60.33	43.87
	35.30	41.91	38.97	29.65	34.41	29.69
	13.36	52.39	57.94	22.67	44.61	29.22
	43.43					
Walmart Supercenter-2002, IL	78.16	87.34	88.29	74.09	74.20	75.30
	33.86	40.39	50.55	54.85	56.91	58.58
	27.89	67.10	56.38	51.24	22.78	
SR 895, PA	114.77	78.55	117.72	106.43	63.60	66.28
	61.01	28.91	54.65	46.22		
SR 1009, PA	103.25	101.30	104.90	107.17	96.22	
SR 402, PA	145.56	124.23	148.12	117.80	149.53	131.48
	35.20	15.08	104.15	95.62		
SR 115, PA	156.70	172.42	156.81	147.25	133.62	124.65
	116.97	105.85	125.18			
SR 534, PA	94.90	189.84	151.62	203.19	195.79	146.76
	61.19	85.10	125.09			
Average	**88.00**					
Standard Deviation	**51.55**					
Median	**75.30**					
Sample Size	**95**					

Table G.2. Nighttime Daily Paving Productivity in Type 1 States

Project Name / State	Productivity Samples (ton/hour)					
I-80, IL	169.62	157.24	190.57	194.63	209.75	
I-90/I-94, IL	122.00	117.50	99.13	109.50	123.50	140.10
	133.25					
I-70 Wayne County Night Paving, IN	130.86	112.61	105.58	137.52	122.89	123.70
	129.94	80.29	150.80	100.40	128.00	105.20
	106.95	122.63	132.00	110.30	99.86	
SR 0202 SEC M10, PA	264.67	216.45	256.28	275.82	252.38	210.34
	216.12	109.06	111.22	143.37		
I-95 Air/PA	288.76	449.65	306.42	264.48	256.40	
SR 61/PA	72.50	355.24				
SR 4003/PA	91.94	80.92	113.57	93.00	65.39	97.17
	103.98	73.45				
SR 4040/PA	127.60	126.65	130.14	110.77	12.07	
SR 863/PA	96.59	109.90	98.46	95.70	119.94	91.53
	67.56	56.46	94.03	89.85	10.17	86.62
	103.31					
Average	**141.14**					
Standard Deviation	**76.84**					
Median	**118.72**					
Sample Size	**72**					

Table G.3. Daytime and Nighttime Daily Paving Productivity in Type 2 States

Project Name / State	Productivity Samples (ton/hour)					
Daytime						
US385, TX	163.05	204.83	256.99	110.90		
Loop 353, TX	100.51	101.33	138.88	105.67	42.64	46.62
	30.93	31.92	105.61	18.83		
Pecan Valley Dr., TX	73.64	60.81	97.36	79.37	61.11	72.69
	88.81	106.56	56.91	113.39	155.49	50.36
IH 410, TX	168.44	79.33	96.27	85.30	81.30	
Average	**96.32**					
Standard Deviation	**52.08**					
Median	**88.81**					
Sample Size	**31**					
Nighttime						
BS158B, TX	122.32	192.46	162.60	63.71	158.68	120.76
	138.33	115.51	177.82			
Loop 1604, TX	147.07	161.59	153.63	135.22	41.50	36.32
	130.16	156.64	154.49	177.61	162.72	136.45
	149.07	133.08	123.74	100.04	65.95	102.59
	164.40	159.53				
MN	410.67	384.09	452.25	369.30		
Average	**165.46**					
Standard Deviation	**97.98**					
Median	**149.07**					
Sample Size	**33**					

Table G.4. Daytime Daily Paving Productivity in Type 3 State (Oregon)

Project # / Year	Working Days	Average Productivity (ton/hour)
12184 / 2000	7	142.37
12226 / 1999	17	86.18
12117 / 1998	20	101.83
11939 / 1999	6	174.14
12347 / 2000	13	182.78
12408 / 2000	5	200.35
12080 / 1998	9	112.22
12083 / 1998	3	531.92
12059 / 1998	8	229.44
12241 / 1999	20	271.88
12092 / 1998	17	208.77
12100 / 1998	12	217.75
12102 / 1998	87	256.65
12061 / 1998	62	88.61
12218 / 1999	45	77.81
12315 / 2000	45	137.34
12237 / 2000	28	140.09
12212 / 1999	8	627.64
Average	**174.82**	
Standard Deviation	**109.41**	
Median	**137.52**	
Sample Size	**412**	

Table G.5. Nighttime Daily Paving Productivity in Type 3 State (Oregon)

Project # / Year	**Working Days**	**Average Productivity (ton/hour)**
12412 / 2000	3	175.78
12181 / 1999	21	193.44
12042 / 1998	6	181.94
12101 / 1998	22	382.43
12119 / 1998	19	306.18
12023 / 1998	12	74.60
12308 / 2000	9	200.62
12093 / 1998	9	161.73
12357 / 2000	31	120.61
12182 / 1999	16	206.15
12064 / 1998	12	223.91
11910 / 1998	23	149.77
12220 / 1999	41	296.53
12034 / 1998	23	128.86
12024 / 1998	7	309.54
12096 / 1998	11	165.83
Average	**211.38**	
Standard Deviation	**110.26**	
Median	**193.44**	
Sample Size	**265**	

APPENDIX H. POP-UP QUESTIONS IN THE DECISION MODEL

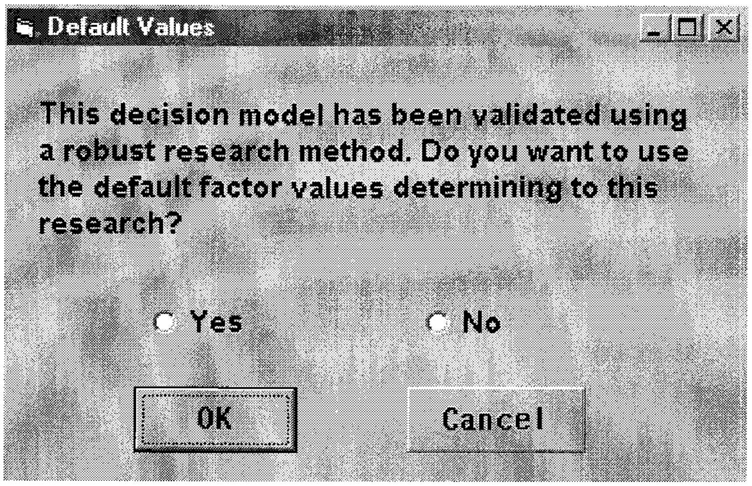

Figure H.1. The Pop-Up Screen for the First Question

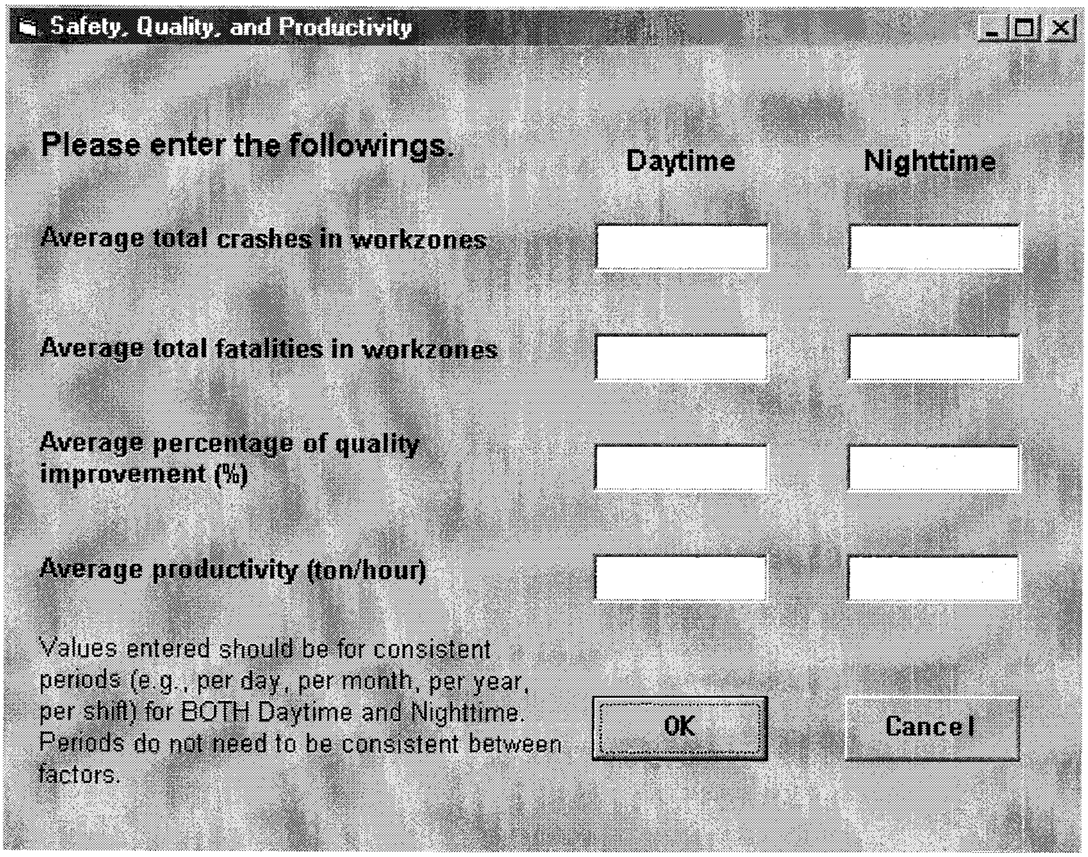

Figure H.2. The Second Pop-Up Screen for the First Question

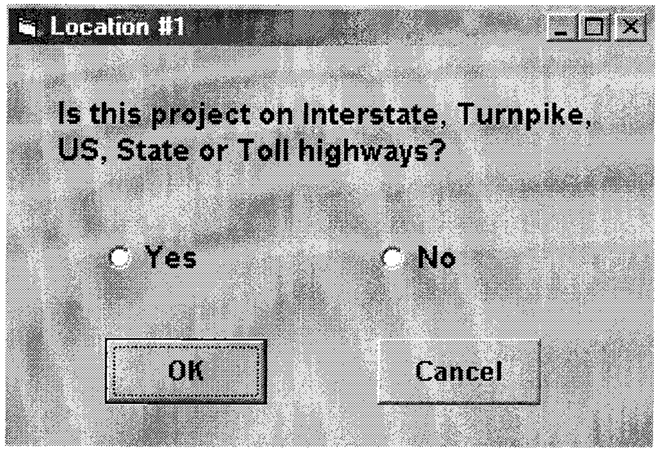

Figure H.3. The Location Pop-Up Screen in Type 2 and 4 States for the First Question

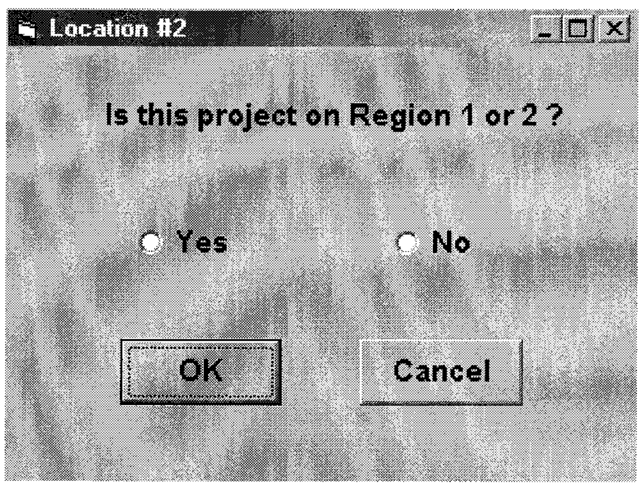

Figure H.4. The Location Pop-Up Screen in Type 3 State for the First Question

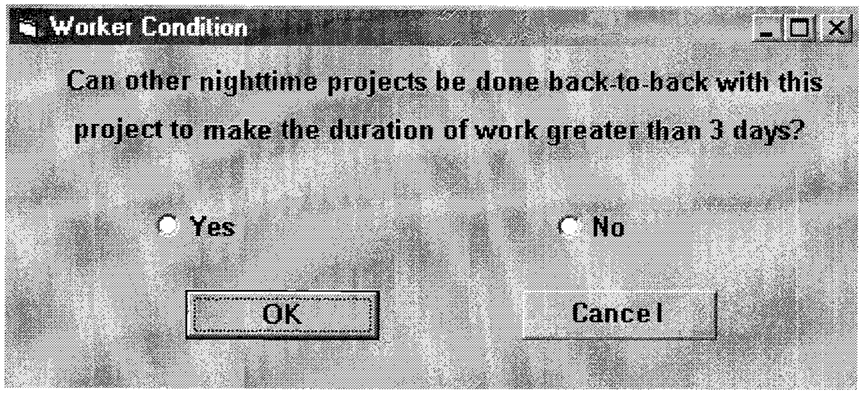

Figure H.5. The Pop-Up Screen for the Second Question

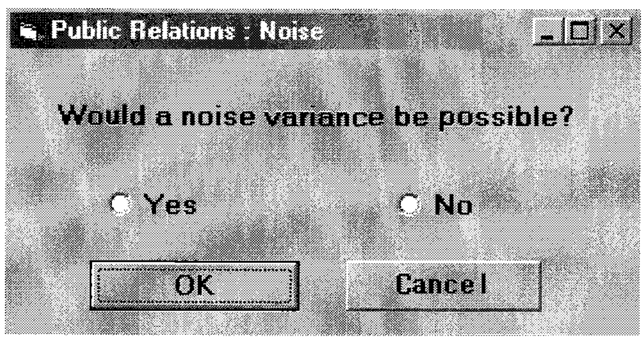

Figure H.6. The Pop-Up Screen for the Fourth Question

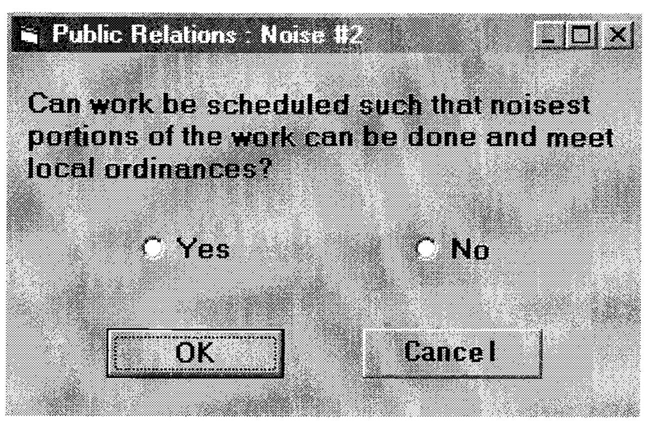

Figure H.7. The Second Pop-Up Screen for the Fourth Question

APPDENDIX I. PROJECT INFORMATION

Table I.1. Questions for Project Information

Question #	Questions
0	Project Number and Name Given by This Study
1	Project Name
2	State
3	Contract Number
4	Location of the project
5	Name of Project Manager
6	Project Type (Construction/Maintenance)
7	Project Status (Former/Current/Future)
8	Decision of Project Schedule (Daytime/Nighttime/Both)
9	Is the project a paving project? (Yes/No)
10	Is the project duration less than 3 days? (Yes/No)
11	If it is yes, can other nighttime project be done-back-to with this project to make the duration of work greater than 3 days? (Yes/No)
12	Do you have workers who can be scheduled for night work? (Yes/No)
13	Is this project on the State Highway System? (Yes/No)
14	Will noise levels prevent this work being done at night due to current local ordinances? (Yes/No)
15	If it is yes, would a noise variance be possible? (Yes/No)
16	If it is no, can work be scheduled such that nosiest portions of the work can be done and meet local ordinances? (Yes/No)
17	Will the project result in unacceptable local business access during daytime? (Yes/No)
	Information for estimation of user cost:
18	What location category is this project? (Interstate-Urban/Interstate-Rural/Arterial-Urban/Arterial-Rural)
19	Which direction plans to be worked?
20	What is the AADT (both directions) in the project area?
21	What is the percentage of trucks?
22	What is the number of lanes (one direction)?
23	What is the free flow speed (mph)? (What's the posted speed limit?)
24	If the project will be conducted (or was conducted) at daytime, what are the starting and ending times in each day? How many lanes will be closed (or was closed) in each direction during working?
25	If the project will be conducted (or was conducted) at nighttime, what are the starting and ending times in each day? How many lanes will be closed (or was closed) in each direction during working?

Table I.2. Project Information (1)

#	**Answers**				
0	1. PA I95 Air	2. PA SR202	3. CT I91	4. CT I95	5. CT I91 #2
1	I-95 AIR	SR 202 M10	I-91 resurfacing	I-95 resurfacing	I-91 resurfacing
2	PA	PA	CT	CT	CT
3	065336	063330	164-224	094-202	046-118
4	I-95 @ Phila. Airport	US 202 Delaware County	Windsor	New London	Enfield
5	G. D.	R. M.	Jaspal Jutla	Brian Gustafson	Jaspal Jutla
6	Construction	Construction	Construction	Construction	Construction
7	Former	Former	Former	Former	Former
8	Both	Both	Both	Both	Both
9	Yes	Yes	Yes	Yes	Yes
10	Yes	Yes	No	No	No
11	N/A	N/A	N/A	N/A	N/A
12	Yes	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes	Yes
14	No	No	No	No	No
15	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A
17	No	Yes	N/A	N/A	N/A
18	Interstate Urban	Arterial Urban	Interstate-Urban	interstate-urban	interstate-urban
19	Both	Both	Both	Both	Both
20	120,000	47,900	16000	13000	17000
21	13 %	13 %	15 %	15 %	15 %
22	4 lanes	2 lanes	4 lanes	3 lanes	3 lanes
23	55 mph	45 mph	65 mph	65 mph	65 mph
24	9 am to 3 pm , close 1 lane	9 am to 3 pm	9 AM to 3 PM, one lane	9 AM to 3 PM, one lane	9 AM to 3 PM, one lane
25	close 1 lane then up to 2 lanes	7 pm to 4:30 am	7 PM to 6 AM, two lanes	7 PM to 6 AM, two lanes	7 PM to 6 AM, two lanes

Table I.3. Project Information (2)

#	Answers		
0	6. TX SH75	7. TX IH45	8. TX SH358
1	SH 75 & FM 1097	IH 45 Plane & resurface	SH 358 thermoplastic restripping contract
2	Texas	Texas	Texas
3	CSJ 0110-03-048, etc.	CSJ 0110-04-0169	RMC 6082-92-001
4	SH 75 & FM 1097 in Montgomery Co.	IH 45 in Montgomery Co.	SH 358 in Nueces County
5	Karen G. Baker, P.E.	Karen G. Baker, P.E.	Martin Horst
6	Construction	Construction	Maintenance
7	Former	Former	Former
8	Nighttime	Nighttime	Both
9	Yes	Yes	No
10	No	No	No
11	N/A	N/A	N/A
12	Yes	Yes	Yes
13	Yes	Yes	Yes
14	No	No	No
15	N/A	N/A	N/A
16	N/A	N/A	N/A
17	Yes (in daytime)	No	No
18	Urban collector	Urban Interstate	Arterial-Urban
19	Both	Both	Both
20	SH 75:11,500-17,300, FM 1097:9500-12,000	109,000	95000
21	10 %	13 %	5 %
22	2 lanes	2 lanes	3 lanes
23	35mph to 55 mph	55 mph	60 mph
24	No lane closure Sun.- Thurs. 6AM-7PM, Fri. 6AM-12PM, and Sat.	No daytime lane closures	One lane closure: 7AM - 5PM, 7AM to 1PM on weekends
25	One lane closure Sun.-Thurs. 7PM-6AM and Fri. 12AM-6AM	One lane closure 9PM-6AM (Northbound) and 9PM-5AM (Southbound)	One lane closure between 10PM - 5AM

Table I.4. Project Information (3)

#	**Answers**			
0	9. TX SH358#2	10. TX US287	11. AZ SR69	12. AZ SR68
1	SH 358 Prefabricated Pavement Markings Maintenance Contract	US 287, CSJ 0172-05-066	Mendecino Dr to Walker Rd	Walker Rd to Heather Heights Dr
2	Texas	TX	Arizona	Arizona
3	RMC 6084-65-001	HP913(1)	H453901C	H525401C
4	SH 358 in Nueces County	US 287 (NW of Waxahachie)	SR 69: MP 286.75 to MP 292.84	SR 69: MP 292.84 to MP 296.00
5	Martin Horst	Rickey Ayers		John Melanson
6	Maintenance	Construction	Construction	Construction
7	Former	Current	Former	Former
8	Both	Daytime	Nighttime	Nighttime
9	No	Yes	Yes	Yes
10	No	No	No	No
11	N/A	N/A	N/A	N/A
12	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes / SR 69	Yes / SR 69
14	No	No	No	No
15	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A
17	No	No	No	No
18	Arterial-Urban	AR	Arterial Rural	Arterial Rural
19	Both	Depend on the phase, route of traffic	Both	Both
20	95000	22000	21,931 to 23,938	23,938 to 39,643
21	5 %	16.4 %	5 %	5 %
22	3 lanes	2 lanes	2 lanes	2 lanes
23	60 mph	55 mph	45-55 mph	45 mph
24	One lane closure between 7AM - 5PM, 7AM to 1PM on weekends (both)	No work before sunrise permitted, traffic rerouted during phases of construction, lane closures will need to occur for some work	N/A	N/A
25	One lane closure between 10PM - 5AM (both)		8:00 PM Sunday thru 6:00 AM Friday except holidays 1-2 Lanes closed	8:00 PM Sunday thru 6:00 AM Friday except holidays 1-2 Lanes closed

Table I.5. Project Information (4)

#	Answers			
0	13. AZ SR 89	14. OR I5	15. OR I84	16. OR US97
1	Sheldon St to Jct SR 89A	I-5 Medford	I-84 Resurfacing	US 97 Bend Resurfacing
2	Arizona	OR	OR	OR
3	H489801C	12746	12708	12394
4	SR 89: MP 312.33 to MP 317.00	Same as the above	Same as the above	Same as the above
5	John Melanson	Joseph Thomas	Marge West	Jon Heacock
6	Construction	Construction	Construction	Construction
7	Former	Current	Current	Former
8	Nighttime	Both	Nighttime	Nighttime
9	Yes	Yes	Yes	Yes
10	No	No	No	No
11	N/A	N/A	N/A	N/A
12	Yes	Yes	Yes	Yes
13	Yes / SR 89	Yes	Yes	Yes
14	No	No	Yes	Yes
15	N/A	N/A	Yes	Yes
16	N/A	N/A	N/A	N/A
17	No	No	No	Yes
18	Arterial Rural	Interstate-Rural	Interstate-Urban	Arterial Urban
19	Both	Both	Both	Both
20	39,400 to 17,497	40600	160000	24000-30000
21	14 %	15 %	15 %	12 %
22	2 to 1 lane	2 lanes	3 lanes	2 lanes
23	35 to 55 mph	55 mph	55 mph	35-45 mph
24	N/A	Both day and night	No closure 5am-8pm & weekends 9am-9pm	Could not be done.
25	8 PM Sunday thru 6 AM Friday- 1 Lane closed	Both day and night	One lane 9PM-6AM (E), One lane 8PM-5AM (W), Two lane 11PM-5AM (Both)	9PM-6AM- 2 lanes closed

Table I.6. Project Information (5)

#	**Answers**			
0	17. OR I84#2	18. OR Port of Entry	19. OR I5#2	20. OR Pendleton
1	I-84 Resurfacing	The Port of Entry	I-5 Pavement Preservation in North Portland	Viaduct Seal Prj.
2	OR	OR	OR	OR
3	12776	12576	12460	Maintenance
4	Same as the above	Same as the above	Same as the above	Pendleton
5	Patrick Cimmiyotti	Tom Feeley	Earl Mershon	Terry Mcartor
6	Construction	Construction	Construction	Maintenance
7	Future	Former	Current	Future
8	Nighttime	Nighttime	Nighttime	Nighttime
9	Yes	Yes	Yes	No
10	No	No	No (2 years)	Yes (2 days)
11	N/A	N/A	N/A	N/A
12	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes
14	No	No	Yes	No
15	N/A	N/A	Yes	N/A
16	N/A	N/A	N/A	N/A
17	No	No	No	No
18	Interstate-Rural	Interstate-Rural	Interstate-Urban	Arterial-Urban
19	Both	Both	Both	Both
20	10700	6900	130000	14600
21	15 %	33 %	9 %	15 %
22	2 lanes	1 lane	2 or 3 lanes	1 lane
23	65 mph	55 mph	55 mph	35 mph
24	7AM-7PM with one lane	No	No closures.	Too much traffic during the day
25	7PM-7AM- one lane	One lane- 6PM to 6AM.	Sun - Thr in 3-lane: close 1 at 8PM, 2 at 10:30PM. Ropen by 5:30 AM.	7PM-4:30AM, one lane closed in one direction, the turn lane will be used.

Table I.7. Project Information (6)

#	Answers			
0	21. OR 8	22. OR 8#2	23. OR 43	24. OR Bridge
1	OR 8 Grind Inlay Beaverton	OR 8 Grind Inlay Forest Grove	OR 43 Overlay	Repair bridge
2	OR	OR	OR	OR
3	N/A	N/A	N/A	N/A
4	Beaverton	Forest Grove	West Linn	N/A
5	Ron Kroop	Ron Kroop	Ron Kroop	Larry Olson
6	Maintenance	Maintenance	Maintenance	Maintenance
7	Former	Future	Former	Former
8	Nighttime	Not Yet	Daytime	Nighttime
9				No
10	No	No	Yes (I day)	No (3day Project)
11	N/A	N/A	No	N/A
12	Contract	Contract	Yes	Yes
13	Yes	Yes	Yes	Yes
14	Yes	Yes	Yes	No
15	Yes	Yes	Yes	N/A
16	N/A	N/A	N/A	N/A
17	Yes	Yes	Yes	No
18	Arterial-Urban	Arterial-Urban	Arterial-Urban	Interstate-Urban
19	Both	Both	Both	Inbound
20	40000	15000	20000	157200
21	5 %	3 %	3 %	20 %
22	2 lanes	2 lanes	2 lanes	4 lanes
23	35-45 mph	23-35 mph	35 mph	55 mph
24		Not Yet	7AM-3PM, 1 lane closure	Impossible to close lanes
25	9PM-5AM, 1 lane closure	Not Yet		11PM-5AM, 2 lane closed

Table I.8. Project Information (7)

#	Answers		
0	25. ME R4	26. ME I95	27. ME I95#2
1	Auburn Route 4	I-95 SB	I-95 SB#2
2	ME	ME	ME
3	NH-0115(00)E	IM-95-6603(00)E	IM-95-8117(00)E
4	Auburn Route 4	Brunswick-Freeport	Freeport-Yarmouth
5	Richard Crawford	Gary Trussell	Gary Trussell
6	Construction	Construction	Construction
7	Former	Former	Former
8	Nightime	Nighttime	Nighttime
9	Yes	Yes	Yes
10	No	No	No
11	N/A	N/A	N/A
12	Yes	Yes	Yes
13	Yes	Yes	Yes
14	No	No	No
15	N/A	N/A	N/A
16	N/A	N/A	N/A
17	No	No	No
18	Arterial-Urban	Interstate-Urban	Interstate-Urban
19	Both	Southbound	Southbound
20	15441	25240	25240
21	15 %	15 %	15 %
22	2 lanes	2 lanes	2 lanes
23	45 mph	65 mph	65 mph
24	N/A	N/A	N/A
25	N/A	N/A	N/A

APPENDIX J. SENSITIVITY ANALYSIS

Table J.1. Sensitivity Analysis with Safety and Congestion Factor (1)

Project #	Project Name	S4C2		S4C3		S4C4	
		Decision Model		Decision Model		Decision Model	
		Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
3	CT I91	8.2280	**8.6827**	9.1280	**9.6827**	10.0280	**10.6827**
4	CT I95	8.2280	**8.6827**	9.1280	**9.6827**	10.0280	**10.6827**
5	CT I91#2	8.2280	**8.6827**	9.1280	**9.6827**	10.0280	**10.6827**
7	TX IH45	5.7908	**9.9000**	5.7908	**10.9000**	5.7908	**11.9000**
8	TX SH358	5.7908	**9.9000**	5.7908	**10.9000**	5.7908	**11.9000**
9	TX SH358#2	5.7908	**9.9000**	5.7908	**10.9000**	5.7908	**11.9000**
10	TX US287	6.7908	**9.9000**	7.2908	**10.9000**	7.7908	**11.9000**
11	AZ SR69	6.9908	**9.9000**	7.5908	**10.9000**	8.1908	**11.9000**
12	AZ SR68	5.7908	**9.9000**	5.7908	**10.9000**	5.7908	**11.9000**
13	AZ SR89	5.7908	**9.9000**	5.7908	**10.9000**	5.7908	**11.9000**
14	OR I5	5.9443	**8.1332**	5.9443	**9.1332**	5.9443	**10.1332**
15	OR I84	6.2264	**8.1332**	6.2264	**9.1332**	6.2264	**10.1332**
17	OR I84#2	7.7443	**8.1332**	8.6443	**9.1332**	9.5443	**10.1332**
18	OR Port of Entry	7.5443	**8.1332**	8.3443	**9.1332**	9.1443	**10.1332**
19	OR I5#2	6.2264	**8.1332**	6.2264	**9.1332**	6.2264	**10.1332**
24	OR Bridge	6.2264	**8.1332**	6.2264	**9.1332**	6.2264	**10.1332**
25	ME R4	**7.6747**	6.7959	**8.2747**	7.7959	**8.8747**	8.7959
26	ME I95	**7.6747**	6.7959	**8.2747**	7.7959	**8.8747**	8.7959
27	ME I95#2	**7.6747**	6.7959	**8.2747**	7.7959	**8.8747**	8.7959

Note: S4C2- Safety with weight 4 and Congestion with weight 2
S4C3- Safety with weight 4 and Congestion with weight 3
S4C4- Safety with weight 4 and Congestion with weight 4

Table J.2. Sensitivity Analysis with Safety and Congestion Factor (2)

Project #	Project Name	S3C2		S3C3		S3C4	
		Decision Model		Decision Model		Decision Model	
		Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
3	CT I91	7.5296	**7.9871**	8.4296	**8.9871**	9.3296	**9.9871**
4	CT I95	7.5296	**7.9871**	8.4296	**8.9871**	9.3296	**9.9871**
5	CT I91#2	7.5296	**7.9871**	8.4296	**8.9871**	9.3296	**9.9871**
7	TX IH45	5.2420	**8.9000**	5.2420	**9.9000**	5.2420	**10.9000**
8	TX SH358	5.2420	**8.9000**	5.2420	**9.9000**	5.2420	**10.9000**
9	TX SH358#2	5.2420	**8.9000**	5.2420	**9.9000**	5.2420	**10.9000**
10	TX US287	6.2420	**8.9000**	6.7420	**9.9000**	7.2420	**10.9000**
11	AZ SR69	6.4420	**8.9000**	7.0420	**9.9000**	7.6420	**10.9000**
12	AZ SR68	5.2420	**8.9000**	5.2420	**9.9000**	5.2420	**10.9000**
13	AZ SR89	5.2420	**8.9000**	5.2420	**9.9000**	5.2420	**10.9000**
14	OR I5	5.3860	**7.5749**	5.3860	**8.5749**	5.3860	**9.5749**
15	OR I84	5.5975	**7.5749**	5.5975	**8.5749**	5.5975	**9.5749**
17	OR I84#2	7.1860	**7.5749**	8.0860	**8.5749**	8.9860	**9.5749**
18	OR Port of Entry	6.9860	**7.5749**	7.7860	**8.5749**	8.5860	**9.5749**
19	OR I5#2	5.5975	**7.5749**	5.5975	**8.5749**	5.5975	**9.5749**
24	OR Bridge	5.5975	**7.5749**	5.5975	**8.5749**	5.5975	**9.5749**
25	ME R4	**7.0060**	6.2269	**7.6060**	7.2269	8.2060	**8.2269**
26	ME I95	**7.0060**	6.2269	**7.6060**	7.2269	8.2060	**8.2269**
27	ME I95#2	**7.0060**	6.2269	**7.6060**	7.2269	8.2060	**8.2269**

Note: S3C2- Safety with weight 3 and Congestion with weight 2
S3C3- Safety with weight 3 and Congestion with weight 3
S3C4- Safety with weight 3 and Congestion with weight 4

Table J.3. Sensitivity Analysis with Safety and Congestion Factor (3)

Project #	Project Name	S2C2		S2C3		S2C4	
		Decision Model		Decision Model		Decision Model	
		Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
3	CT I91	6.8311	**7.2914**	7.7311	**8.2914**	8.6311	**9.2914**
4	CT I95	6.8311	**7.2914**	7.7311	**8.2914**	8.6311	**9.2914**
5	CT I91#2	6.8311	**7.2914**	7.7311	**8.2914**	8.6311	**9.2914**
7	TX IH45	4.6933	**7.9000**	4.6933	**8.9000**	4.6933	**9.9000**
8	TX SH358	4.6933	**7.9000**	4.6933	**8.9000**	4.6933	**9.9000**
9	TX SH358#2	4.6933	**7.9000**	4.6933	**8.9000**	4.6933	**9.9000**
10	TX US287	5.6933	**7.9000**	6.1933	**8.9000**	6.6933	**9.9000**
11	AZ SR69	5.8933	**7.9000**	6.4933	**8.9000**	7.0933	**9.9000**
12	AZ SR68	4.6933	**7.9000**	4.6933	**8.9000**	4.6933	**9.9000**
13	AZ SR89	4.6933	**7.9000**	4.6933	**8.9000**	4.6933	**9.9000**
14	OR I5	4.8276	**7.0166**	4.8276	**8.0166**	4.8276	**9.0166**
15	OR I84	4.9687	**7.0166**	4.9687	**8.0166**	4.9687	**9.0166**
17	OR I84#2	6.6276	**7.0166**	7.5276	**8.0166**	8.4276	**9.0166**
18	OR Port of Entry	6.4276	**7.0166**	7.2276	**8.0166**	8.0276	**9.0166**
19	OR I5#2	4.9687	**7.0166**	4.9687	**8.0166**	4.9687	**9.0166**
24	OR Bridge	4.9687	**7.0166**	4.9687	**8.0166**	4.9687	**9.0166**
25	ME R4	**6.3373**	5.6579	**6.9373**	6.6579	7.5373	**7.6579**
26	ME I95	**6.3373**	5.6579	**6.9373**	6.6579	7.5373	**7.6579**
27	ME I95#2	**6.3373**	5.6579	**6.9373**	6.6579	7.5373	**7.6579**

Note: S2C2- Safety with weight 2 and Congestion with weight 2
S2C3- Safety with weight 2 and Congestion with weight 3
S2C4- Safety with weight 2 and Congestion with weight 4

Table J.4. Difference of Nighttime and Daytime Scores in the Decision Model in Sensitivity Analysis with Safety and Congestion Factor

Project #	Nighttime-Daytime								
	S4C2	S4C3	S4C4	S3C2	S3C3	S3C4	S2C2	S2C3	S2C4
3	0.4548	0.5548	0.6548	0.4575	0.5575	0.6575	0.4602	0.5602	0.6602
4	0.4548	0.5548	0.6548	0.4575	0.5575	0.6575	0.4602	0.5602	0.6602
5	0.4548	0.5548	0.6548	0.4575	0.5575	0.6575	0.4602	0.5602	0.6602
7	4.1092	5.1092	6.1092	3.6580	4.6580	5.6580	3.2067	4.2067	5.2067
8	4.1092	5.1092	6.1092	3.6580	4.6580	5.6580	3.2067	4.2067	5.2067
9	4.1092	5.1092	6.1092	3.6580	4.6580	5.6580	3.2067	4.2067	5.2067
10	3.1092	3.6092	4.1092	2.6580	3.1580	3.6580	2.2067	2.7067	3.2067
11	2.9092	3.3092	3.7092	2.4580	2.8580	3.2580	2.0067	2.4067	2.8067
12	4.1092	5.1092	6.1092	3.6580	4.6580	5.6580	3.2067	4.2067	5.2067
13	4.1092	5.1092	6.1092	3.6580	4.6580	5.6580	3.2067	4.2067	5.2067
14	2.1889	3.1889	4.1889	2.1889	3.1889	4.1889	2.1890	3.1890	4.1890
15	1.9068	2.9068	3.9068	1.9774	2.9774	3.9774	2.0479	3.0479	4.0479
17	0.3889	0.4889	0.5889	0.3889	0.4889	0.5889	0.3890	0.4890	0.5890
18	0.5889	0.7889	0.9889	0.5889	0.7889	0.9889	0.5890	0.7890	0.9890
19	1.9068	2.9068	3.9068	1.9774	2.9774	3.9774	2.0479	3.0479	4.0479
24	1.9068	2.9068	3.9068	1.9774	2.9774	3.9774	2.0479	3.0479	4.0479
25	-0.8788	-0.4788	-0.0788	-0.7791	-0.3791	0.0209	-0.6794	-0.2794	0.1206
26	-0.8788	-0.4788	-0.0788	-0.7791	-0.3791	0.0209	-0.6794	-0.2794	0.1206
27	-0.8788	-0.4788	-0.0788	-0.7791	-0.3791	0.0209	-0.6794	-0.2794	0.1206

Note: S4C2- Safety with weight 4 and Congestion with weight 2
S4C3- Safety with weight 4 and Congestion with weight 3
S4C4- Safety with weight 4 and Congestion with weight 4