SELECTION CRITERIA FOR USING NIGHTTIME CONSTRUCTION AND MAINTENANCE OPERATIONS

Final Report

SPR 322

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FINAL REPORT

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by

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16. Abstract

Like other state departments of transportation, the Oregon Department of Transportation (ODOT) has emphasized preservation of existing highways and bridges. Thus, ODOT has done construction and maintenance work at night in order to minimize the disruption of daytime traffic. However, nighttime operations produce a new set of concerns such as safety, public relations, productivity, and quality. Decision-making for using nighttime operations in Oregon has been subjective and has relied on judgment without the benefit of analytical data and evaluation criteria. Therefore, a decision model that facilitates the determination of when to use nighttime road construction and maintenance work was developed. From the literature review, 19 factors affecting decision-making were identified and used to create a survey. The investigators surveyed ODOT personnel, ODOT's contractors, and the representative personnel from other departments of transportation. After analyses of various perspectives, the overall result was fairly consistent with the results from the individual respondent groups. The results provided the ability to eliminate unimportant factors, determine weights of important factors, and build a decision model to improve the effectiveness of decision-making. The decision model was tested by applying it to actual ODOT 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 decisions because of the impact of congestion within the decision model. The decision model in this study provides a practical and useful tool to help decision makers in real work environments analyze when to use nighttime work. The model will be useful for making decisions consistently and provides a means to explain the decision to the stakeholders.

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Unclassified	Unclassified	68 + Appendices	

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
	NOTE: Volumes greater than 1000 L shall be shown in m^3.			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

SELECTION CRITERIA FOR USING NIGHTTIME CONSTRUCTION AND MAINTENANCE OPERATIONS

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LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
ADM	Assistant District Manager
AGC	Association of General Contractors
AMM	Area Maintenance Manager
ANOVA	Analysis of Variance
APM	Assistant Project Manager
CPF	Composite Pay Factor
DM	District Manager
DOT	Department of Transportation
HW	Highways
IRI	International Roughness Index
OCI	Overall Condition Index
ODOT	Oregon Department of Transportation
OKDOT	Oklahoma Department of Transportation
OSBEELS	Oregon State Board of Examiners for Engineering and Land Surveyors
PM	Project Manager
R	Region
SHW	State Highways
TAC	Technical Advisory Committee
TCPD	Traffic Control Plans Designer
TMM	Transportation Maintenance Manager
TSRM	Technical Services Resource Managers

1.0 INTRODUCTION

As the Oregon Department of Transportation (ODOT) has placed more emphasis on preservation of existing highways and bridges, daytime lane closures accommodating maintenance and construction activities are becoming a serious problem. Highways are already near capacity, and lane closures only add to the congestion. Seasonal traffic conditions are a consideration in rural areas where lane closures impact the levels of service on highways to and from popular recreational areas. More maintenance and construction activities now occur at night in order to counter the disruption of daytime traffic congestion.

Nighttime maintenance and construction eliminates the daytime disruption of traffic. However, this also raises a new set of factors and concerns, such as: cost, productivity, quality, noise, human factors, safety, public awareness, and lighting. In deference to the motoring public and business concerns, ODOT has used, and continues to use, nighttime operations for maintenance and construction activities on many of its high-volume highways. However, decision making for using nighttime operations is currently subjective and relies on judgment without the benefit of analytical data and/or evaluation criteria. This presents a serious challenge for ODOT 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. Flawed assessments about when to conduct maintenance and construction operations can certainly lead to greater costs for ODOT and the highway user, as well as elevate traffic and worker safety risks.

It is therefore critical that the important factors affecting these decisions be identified and prioritized for inclusion in a decision-making model. The focus of the decision model will be to facilitate the determination of when to conduct nighttime road construction and maintenance activities. The decision model should enable project planners and managers to minimize the impact to the public and workers, and increase the project's operational efficiency.

Due to the complex nature of the decision model, this project was conducted in three phases. Phase I consisted of a literature review and survey to help identify factors affecting nighttime construction and maintenance operations. Phase II developed the decision model to determine when to conduct nighttime operations based on the factors identified in the literature review. Phase III tested the results of the decision model against previous ODOT projects to check for consistency and accuracy.

2.0 LITERATURE REVIEW

The first step toward developing the nighttime construction decision model was to conduct a thorough literature review. A comprehensive search located articles on the purpose of nighttime work, the advantages and disadvantages of nighttime work, crash studies, the factors (parameters) affecting nighttime work, a comparison of daytime versus nighttime work (decision making system), guidelines for nighttime work, the estimation and analysis of capacity/delay, productivity/quality, and cost. The literature review included in this section highlights the most relevant literature. The remaining literature reviewed during this research is included in Appendix A, along with a bibliography of related research.

2.1 FACTORS (PARAMETERS) AFFECTING NIGHTTIME WORK

In order to decide when to conduct nighttime work, factors (parameters) affecting nighttime work must be identified and weighted. Several studies preliminarily identified and addressed the factors (*Shepard and Cottrell 1985; Price 1985*), but they did not include supporting data or explanations.

After studying surveys administered to state highway agencies, Hinze and Carlisle (*1990a and 1990b*) identified factors related to the decision to conduct nighttime construction. Data was collected using a two part survey questionnaire. Part I was given to construction engineers and transportation planners, and Part II was given to the project/resident 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 (including Oregon) 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, Hinze and Carlisle concluded that there was no significant difference between the cumulative response from all survey respondents and the responses of the individual states. Their study found that many agencies have recently been shifting towards awarding contracts to those contractors who are willing to conduct nighttime work. Each respondent rated each factor's importance on a scale of 1 being least important, to 7, being most important. Decision makers rated congestion and safety as the two most important factors.

Hinze and Carlisle (1990a) gathered data by telephone surveys of 18 contractors in 11 states (not including Oregon). 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. Greater than 75% of the contractors reported no problems with worker morale associated with nighttime work. The overall average contract cost for nighttime work was about 10% higher.

In their study, Hinze and Carlisle (1990a) 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 and Chedda (1991) and Ellis, Herbsman, Chedda, Epstein and Kumar (1993) took a different approach to identify and weighting the factors. The following factors were identified and 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 nighttime operations within the United States allowed the identification of the above factors. After determining the factors, each factor's importance and effect on nighttime work was evaluated. In addition, projects around Florida were studied to determine how nighttime work was conducted, and then guidelines for nighttime operation were developed.

After evaluating the factors it was 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. 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 crashes, even though crash rates were low. The final conclusion was that daytime and nighttime operations were not significantly different, especially with respect to cost. However, it was advised that 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) <u>Human factors:</u> age, visual acuity, response characteristics, and experience and familiarity

2) <u>Environmental factors:</u> weather conditions, fog/dust/smoke, wet/dry surfaces, and ambient glare and brightness

3) <u>Lighting factors:</u> geometric relationships, orientation, power of lamps, gradient uniformity, and glare

4) <u>Task-related factors:</u>

a) ***equipment attributes*** - speed, physical characteristics, response time

b) ***task physical attributes*** - type of target, size of target, appearance & reflectance, location, seeing distance

c) ***task qualitative attributes*** - importance of task, accuracy required, visual difficulty, visual fatigue

d) ***background factors*** - reflectivity of surface, surface brightness

e) ***operation attributes*** - type of facility, facility environment, traffic control, location on highway

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

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

1) <u>Traffic-related parameters:</u> congestion, safety, and traffic control

2) <u>Construction-related parameters:</u> productivity and quality

3) <u>Social parameters:</u> driver conditions and working conditions

4) <u>Economic parameters:</u> user costs, accident costs, maintenance costs, and construction costs

5) <u>Environmental parameters:</u> noise, fuel consumption, and air quality

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

The study by Ellis et al. (*1993*) identified factors in detail related only to the lighting issue during nighttime work, while the studies by Elrahman and Perry (*1994 and 1998*) included the lighting factor as a single factor in larger parameter category. These studies were intended to identify all possible factors that should be considered in making a decision. These factors should be weighted after investigating their importance for overall nighttime work. In addition, the studies by Hinze and Carlisle (*1990a and 1990b*) investigated each factors' importance, but the factors investigated were insufficient to cover all of the factors for nighttime work and the differential of the ranked values for the factors was too narrow.

2.2 COMPARISION OF DAYTIME VERSUS NIGHTTIME WORK (DECISION-MAKING SYSTEM)

After identifying the factors, one should develop decision-making steps to determine when to use nighttime work. Shepard and Cottrell (*1985*) introduced a brief guideline to help with making decisions about 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 nighttime work and closing the entire roadway, 6) decide on nighttime operations, and 7) after deciding to conduct nighttime work, plan for public notice and safety.

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

Traffic benefits and construction costs should be considered in the quantitative analysis. In order to justify 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 (higher labor costs, additional lighting requirements, and material availability) and potential savings (shortened duration and more efficient work environment due to off-peak traffic conditions).

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 question quantified the effectiveness of nighttime operations for the specific project on a scale of 1 to 5, 1 being not at all effective to 5 being very effective. After the completion of this form the evaluator could rate the five categories subjectively. Their study found that the form did not absolutely determine whether to conduct nighttime work or not, but underscored the issues the decision maker should consider regarding nighttime operations. Thus, the project planner should make the ultimate decision.

The above studies did not weight the factors by importance and gave limited examples of making decisions based on the established methods. 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 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: conduct a quantitative analysis (traffic delay costs, vehicle operating costs, construction costs) and a qualitative assessment.

7) Assess the feasibility of a nighttime schedule: estimation of nighttime operations 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

    c) Develop measures for each objective and weigh 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. This 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. 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 of only daytime work instead of both daytime and nighttime work. These improvements were a critical part of their study.

2.3 CONCLUSIONS FROM THE LITERATURE REVIEW

Elrahman and Perry (*1994 and 1998*) established a comprehensive set of factors (parameters) related to nighttime operations. 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

After completing the literature review, it was concluded that the above 19 factors were well-established and were acceptable to utilize for the ODOT decision model. Thus, all 19 factors were used to create the survey. 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 weighting the factors, 2) inadequate methods to quantify the factors in daytime versus nighttime, and 3) the absence of a practical decision model for real application. Therefore, this study focused on addressing the problems of former studies to create a useful and reliable decision model for ODOT users.

3.0 PHASE I: FACTOR IDENTIFICATION AND SURVEY

A thorough literature review revealed a list of factors considered to be relevant in the decision-making process to conduct daytime versus nighttime construction and maintenance work. In order to confirm and clarify the level of importance of each of these factors, a comprehensive survey was designed. Surveys were administered to two main groups: ODOT employees involved with nighttime construction and maintenance activities, and private contractors. For comparative purposes the survey was also sent to personnel from other Department's of Transportation across the nation.

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

3.1 STRUCTURE OF OREGON

Before identifying the personnel within ODOT that received the survey, a basic knowledge of the structure of ODOT needs to be understood. ODOT has divided Oregon into five operational regions as shown in Figure 3.1. Each region has been divided into smaller districts (15 through out the state). These districts monitor and maintain the construction and maintenance operations within their jurisdiction. Table 3.1 shows the operational structure of ODOT throughout the state.

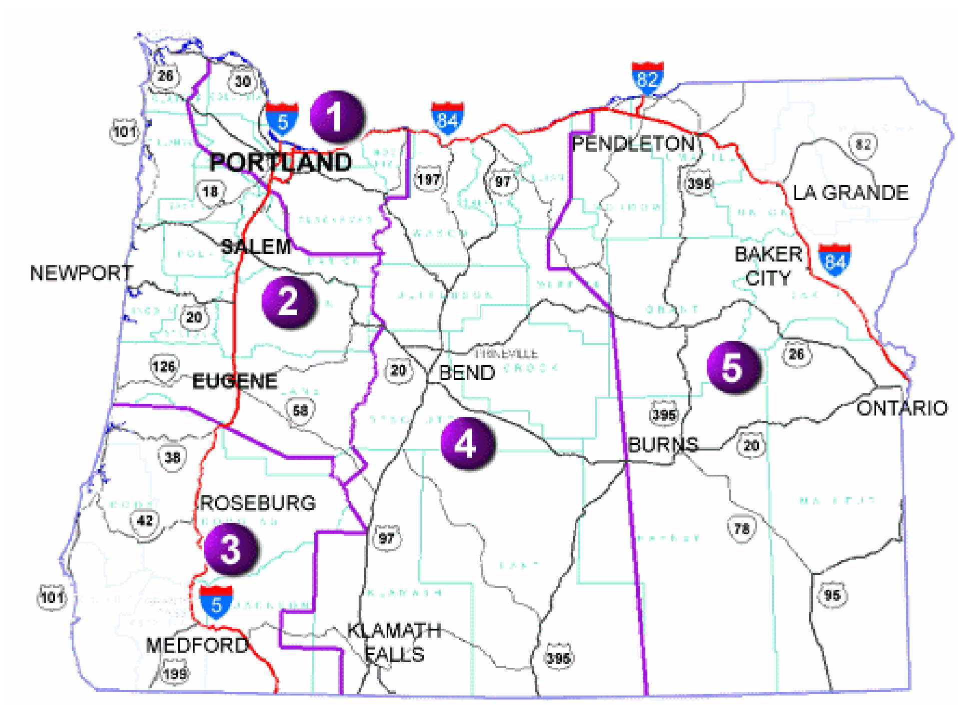

Figure 3.1: ODOT Regions

Table 3.1: The regional operational structure of ODOT

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

According to the Population Research Center at Portland State University (*2002*), the estimated population of Oregon as of July 1, 2002 was 3,504,700. Figure 3.2 shows the percentages of the estimated population by ODOT Regions. Note that although Region 1 is the smallest in geographical area it contains almost 45% of the total states population.

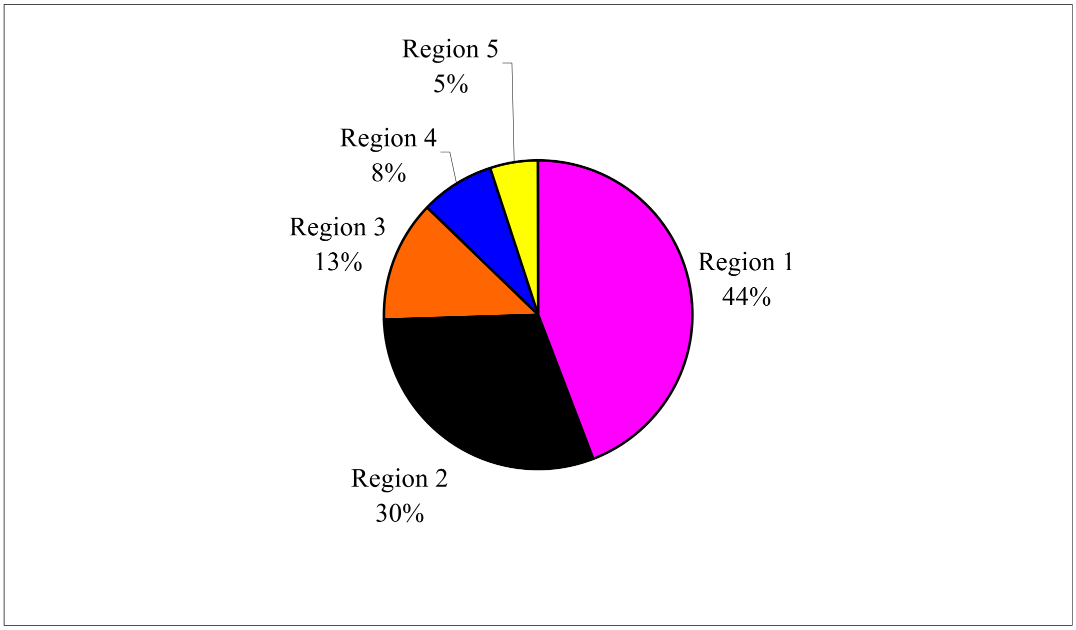

Figure 3.2: Percentages of Oregon population by regions

3.2 IDENTIFYING SURVEY PERSONNEL

An understanding of the general structure and operations of ODOT helped to determine which personnel should be surveyed. It was decided that personnel within both construction and maintenance operations should be surveyed at the district level.

Construction operations consist mainly of new road construction; including highways, and the rehabilitation of roads, such as paving. Project Managers (PM) coordinate and manage the construction operations within their geographical area. Their staff consists of an Assistant Project Manager (APM), Project Coordinators, several support positions and comprising the majority of the staff are Project Inspectors. Generally, one inspector monitors each construction project by supervising the project to ensure that the project design is followed and the quality of work is acceptable to ODOT standards. All of the positions within the Project Manager's office were administered the survey.

Maintenance personnel work on a very wide range of projects such as repairing roads and bridges, short length paving, road cleaning due to snow, mowing shoulders, sign replacement, guardrail repair, and pavement patching. The District Managers (DM) supervise the maintenance operations within their district. Their staff consists of an Assistant District Manager (ADM), Transportation Maintenance Managers (TMM) or Area Maintenance Managers (AMM), maintenance coordinators, and various other support staff. Each of the five ODOT Regions are divided into several smaller districts. Within each district a TMM or AMM monitors smaller geographical areas. Generally, each maintenance location has permanent workers and facilities to conduct maintenance activities.

Thus, it was necessary to survey PM and DM staff from within ODOT, as well as contractors to gain a comprehensive perspective. In addition, the project's Technical Advisory Committee (TAC) recommended that other personnel involved in construction or maintenance projects, such as Traffic Control Plans Designers (TCPD) and Technical Services Resource Managers (TSRM) should also be included in the survey. The Traffic Control Plan Unit is a statewide team located at the Salem ODOT Headquarters. TCPDs produce a working set of contract plans for the traffic control portion of a project. 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 project.

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

Finally, personnel outside of Oregon were surveyed to compare Oregon's priorities with those of other DOTs. Representative decision makers from the other DOTs were invited to respond to an electronic version of the survey. Therefore, this study ultimately surveyed five different types of personnel. Figure 3.3 shows a graphic representation of the categories of personnel surveyed.

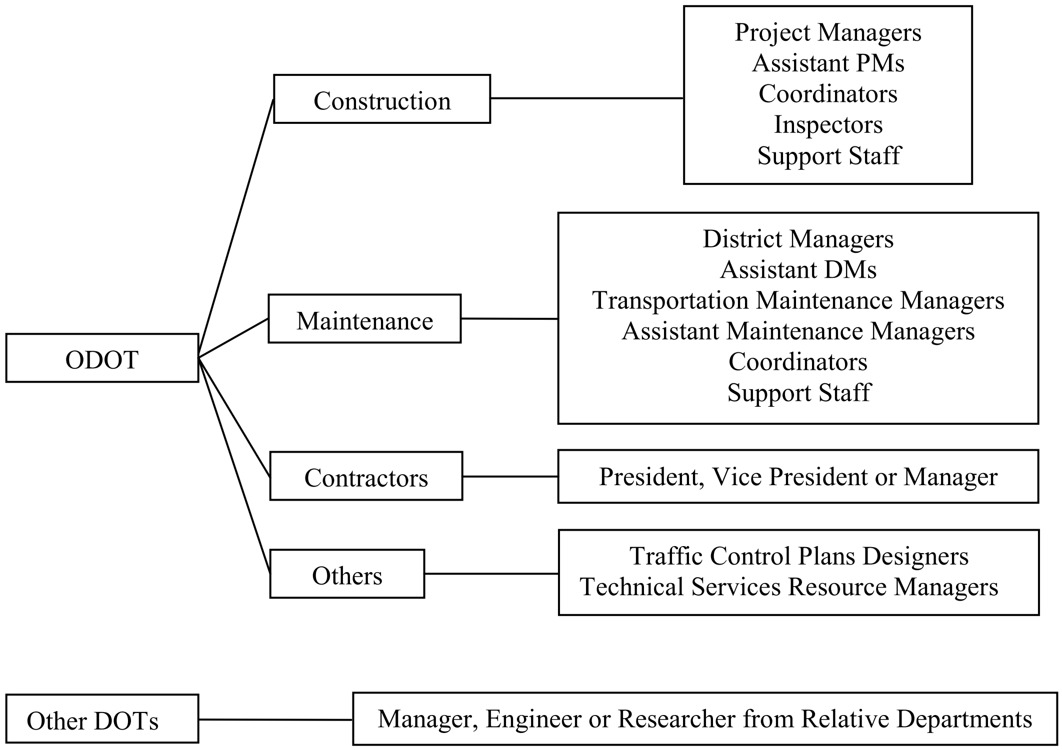

Figure 3.3: Surveyed personnel

3.3 DEVELOPING AND CONDUCTING THE SURVEY

The purpose of the survey was to discover if the factors identified in the literature review were important within the state of Oregon, and if so, to rank their relative importance. The information gathered would then be incorporated into a daytime versus nighttime construction and maintenance decision model.

The survey was developed based upon the 19 factors identified during the literature review and consisted of two parts, referred to as “indicating” and “ranking” the factors. Both formats were included in the survey to determine the relative importance between the factors and to check for consistencies between the two response methods. Open-ended questions were included at the end of the survey to acquire additional information.

For “indicating” the factors, participants were asked to rate each factor from 1 to 7, where 1 is the lowest and 7 the highest based on importance. “Ranking” the factors, asked respondents to rank all 19 factors from 1 to 19, 1 being the most important factor and 19 being the least important factor. Both methods were used (indicating and ranking) to investigate whether each factor has consistent importance between the two methods.

In addition to ranking the importance of the factors, the survey participants gave their personal preference between daytime and nighttime work, along with an explanation of their preference. Finally, the survey respondents were asked if there was any other information they would like to share. The survey instrument is included in Appendix B.

The survey was administered to three core groups, each being given relatively the same survey at different times and locations. (Contractors and representatives from other DOTs were given surveys with two additional questions, as described below.) It was 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 principal investigators visited each office during its regular staff meeting and surveyed them after providing a brief explanation about the ODOT project and the survey. The response rate for the survey was exceptional at over 90%. To avoid a bias amongst the participants, the principal investigators did not answer any questions until after the survey was completed.

To survey the contractors, the principal investigators attended an annual meeting of the Association of General Contractors (AGC) and met with contractors and attending ODOT project personnel. Surveys were distributed to the contractors attending the meeting. They were generally president, vice president or managers within their organizations. In addition, AGC faxed a copy of the survey to all of its members. The faxed distribution allowed the contractors to fax back their responses, which significantly increased the response rate. In order to classify the responses from the contractors, two additional questions were added to the survey about their experience with nighttime work and the type of work they do (e.g., bridges, paving and/or excavation).

The survey administered to the other DOTs was web-based and distributed via a national e-mail listserv. The web-based 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.

3.4 SURVEY RESULTS

The results of this survey are understood most thoroughly by considering them from various perspectives. Overall results of everyone that completed the survey are shown. Each category of respondents is then presented separately (PMs, DMs, contractors and other state DOTs). Comparative analyses between overall results and each individual category are presented. In addition, PM and DM results were analyzed by ODOT regions and positions to investigate any differences in location or position. Finally, a summary is presented of the respondents' preference of working during the day or at night. Respondent information about TSRMs and TCPDs as well as further analyses of the survey results is included in Appendix C.

3.4.1 Respondent Demographics

Figure 3.4 shows the demographics of the survey respondents. In total, 446 surveys were completed. Table 3.2 details which DOTs responded to the survey and if a department provided multiple responses. The response rate was 50% for DOTs from across the nation.

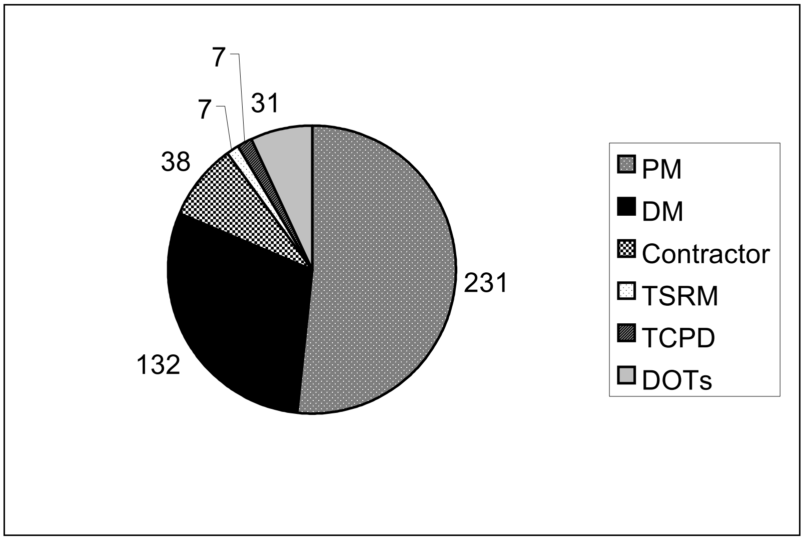

Figure 3.4: Responses by respondent type

Table 3.2: Responses from other DOTs

DOTs Responding to the Survey		DOTs Not Responding to the Survey
	Number of Responses	
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	31	Total 25

3.4.2 Overall Results

Table 3.3 provides the results from all respondents considered as a single group. The factors are sorted in ascending order by the "indicating" value. The table is divided into four sections with bold lines. These sections represent where the factors could be divided such that the factors in each section appear in both the indicating and ranking categories. For both the indicating and ranking categories, safety, traffic control, and congestion were the most important factors affecting nighttime work. These are in section 1 of Table 3.3. Similarly, air quality and fuel consumption were ranked as the least important for both categories (section 4 of Table 3.3). The five factors in these two sections are shaded dark and light gray, respectively in Tables 3.4-7 to visually illustrate their relative importance to the different respondent groups.

Table 3.3: Overall results

Overall (n=446)				
	Indicating		*Ranking*	
	Factor	**Average**	**Factor**	**Average**
1	Safety	6.44	Safety	2.08
	Traffic Control	6.07	Traffic Control	4.05
	Congestion	5.98	Congestion	4.83
2	Lighting	5.84	Quality	6.64
	Quality	5.40	Productivity	7.32
	Public Relations	5.32	Worker Condition	7.90
	Worker Condition	5.19	Driver Condition	8.76
	Productivity	5.11	Lighting	9.12
	Scheduling	5.07	Public Relations	9.42
	Driver Condition	5.04	Construction Cost	10.16
	Construction Cost	4.94	Scheduling	10.23
	Accident Cost	4.92	Accident Cost	11.13
3	Availability of Material/Equipment Repair	4.70	Noise	11.74
	Communication Supervision	4.64	User Cost	11.91
	Noise	4.57	Maintenance Cost	12.16
	User Cost	4.52	Availability of Material/Equipment Repair	12.20
	Maintenance Cost	4.46	Communication Supervision	12.61
4	Air Quality	3.27	Air Quality	15.24
	Fuel Consumption	2.89	Fuel Consumption	16.43

The second and third sections enumerate the factors of secondary and tertiary importance, respectively. The method for dividing the sections is the presence of each factor within a section. For example, even though the factor "lighting" ranked higher in the indicating category, it can be found in the second section of both the indicating and ranking categories.

The factors in the uppermost section (1) were consistent with the majority of groups surveyed (PMs, DMs, TSRMs, TCPDs, and other DOTs), except for the contractors. The least important factors (air quality and fuel consumption) were likewise consistent across all groups, including contractors.

In order to decide whether the overall results can be used as a direct representation of the population, results by each personnel category were individually examined. Comparing each personnel group was necessary to distinguish any significant differences amongst the groups.

3.4.3 PMs Personnel Results

Figure 3.5 shows the breakdown of survey respondents from the PM's office. Table 3.4 illustrates the survey results of the PM's personnel. The factors within sections one and six of Table 3.4 are consistent with the survey's overall analysis. According to the results from the PM's personnel, the six factors within section two were of concern during nighttime work. Comments indicated that many inspectors experienced incidents during nighttime construction due to impaired drivers. From this analysis, one could conclude that the four cost factors (accident cost, construction cost, user cost, and maintenance cost) are less important than the other factors to the PM's personnel. However, it is necessary to examine these cost factors further within the other response groups to determine their importance.

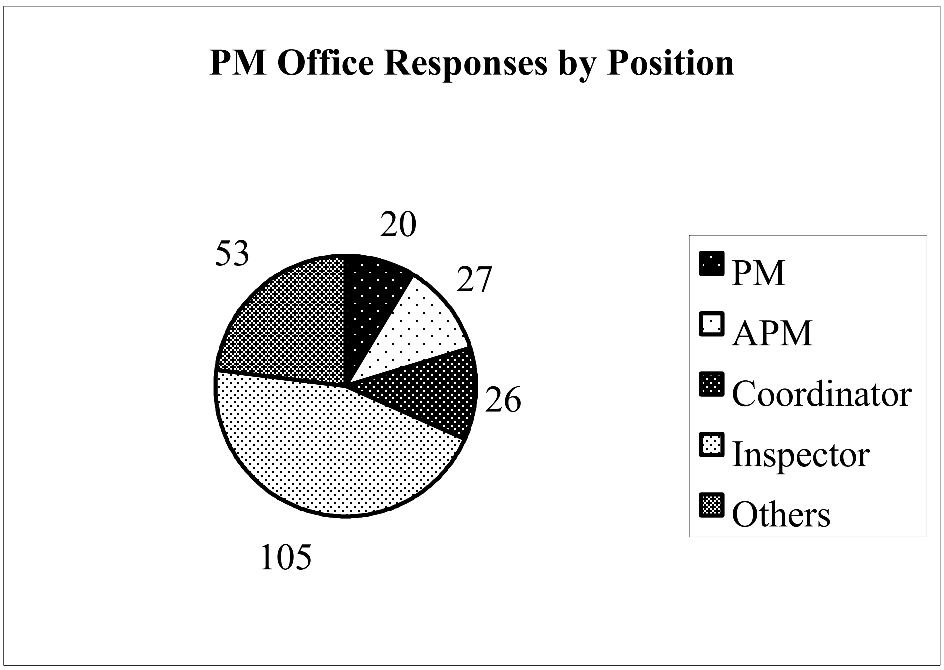

Figure 3.5: Survey respondents from PM's office

Table 3.4: PM's personnel results

	PM (n=231)			
	Indicating		*Ranking*	
	Factor	**Average**	**Factor**	**Average**
1	Safety	6.55	Safety	1.90
	Traffic Control	6.13	Traffic Control	3.94
	Congestion	5.89	Congestion	5.06
2	Lighting	5.89	Quality	6.18
	Quality	5.47	Productivity	7.54
	Public Relations	5.26	Worker Condition	7.61
	Worker Condition	5.15	Driver Condition	8.05
	Productivity	5.04	Lighting	8.93
	Driver Condition	5.02	Public Relations	9.62
3	Scheduling	4.89	Construction Cost	9.74
	Accident Cost	4.86	Scheduling	10.53
	Construction Cost	4.81	Noise	11.23
	Noise	4.70	Accident Cost	11.44
4	Communication Supervision	4.51	User Cost	12.21
	User Cost	4.37	Communication Supervision	12.34
5	Availability of Material/Equipment Repair	4.25	Maintenance Cost	13.39
	Maintenance Cost	4.17	Availability of Material/Equipment Repair	13.54
6	Air Quality	3.53	Air Quality	14.89
	Fuel Consumption	3.02	Fuel Consumption	16.12

PM's personnel results appear to be consistent with the perspective one would expect. For example, PMs are not typically impacted by construction issues such as, availability of material, equipment repairs, or communication supervision, and consider them to be of lesser importance. The maintenance cost factor is low in importance to PMs and their personnel due to the lack of activity with maintenance operations.

3.4.4 DMs Personnel Results

Figure 3.6 shows the breakdown of survey respondents from the DM's office. Table 3.5 shows the survey results for the DM's personnel. The factors of communication supervision, user cost, and noise (section three) were rated relatively low in importance. Since the project length of DMs' operations is relatively short; communication supervision and noise are consequently low in priority. Some maintenance projects can be completed within one day or over several days. It is interesting to note that "user cost" is ranked as un-important by both DMs as well as PMs, even though this factor is related to congestion.

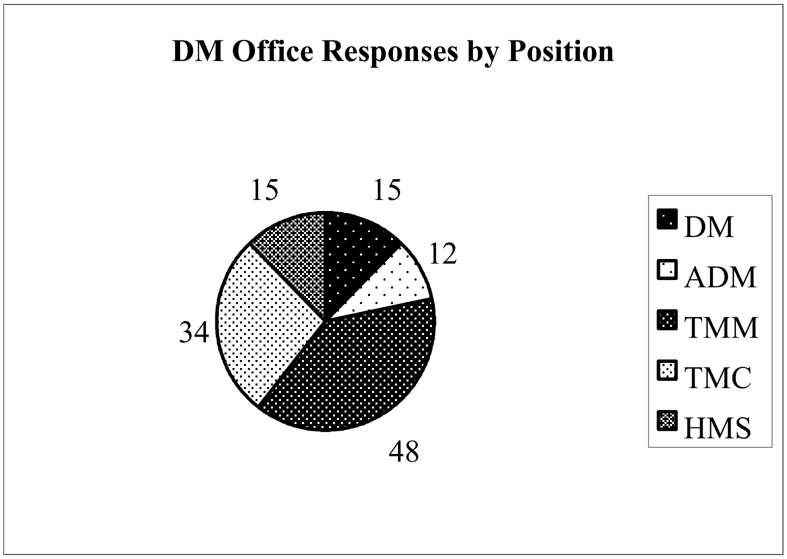

Figure 3.6: Survey respondents from DM's office

Table 3.5: DM's personnel results

DM (n=132)				
	Indicating		*Ranking*	
	Factor	**Average**	**Factor**	**Average**
1	Safety	6.41	Safety	1.89
	Traffic Control	6.21	Traffic Control	3.68
	Congestion	6.10	Congestion	4.80
2	Lighting	5.99	Productivity	7.48
	Public Relations	5.60	Quality	7.61
	Quality	5.48	Worker Condition	7.67
	Availability of Material/Equipment Repair	5.44	Lighting	8.91
	Maintenance Cost	5.34	Driver Condition	9.06
	Worker Condition	5.31	Public Relations	9.32
	Scheduling	5.27	Maintenance Cost	9.45
	Driver Condition	5.24	Availability of Material/Equipment Repair	9.92
	Accident Cost	5.14	Scheduling	10.03
	Productivity	5.13	Accident Cost	11.28
	Construction Cost	5.03	Construction Cost	11.61
3	Communication Supervision	4.85	User Cost	12.41
	User Cost	4.69	Communication Supervision	12.73
	Noise	4.42	Noise	13.22
4	Air Quality	3.06	Air Quality	15.66
	Fuel Consumption	2.91	Fuel Consumption	16.93

Due to the characteristics of DMs operations, the maintenance cost factor is ranked high compared to the results for PMs. In addition, the availability of materials and equipment repairs are ranked higher for DMs since many projects can be finished within a day if there are no problems with the materials or equipment.

3.4.5 Contractors' Results

Table 3.6 shows the contractors' results from the survey. There are obvious differences when compared to the other groups surveyed. Traffic control and congestion factors ranked relatively low with the contractors, but productivity, construction cost, and quality factors all ranked high. Even though lighting is listed third in the indicating category it was not considered an important factor due to its inconsistency in the ranking category, where it is listed tenth. For contractors, productivity and construction costs are very important due to their direct relation to profit. Thus, factors such as public relations, user cost, noise, maintenance cost, air quality and fuel consumption are related less to profits and are ranked lower in importance.

Table 3.6: Contractors' results

Contractors (n=38)			
Indicating		*Ranking*	
Factor	**Average**	**Factor**	**Average**
Safety	6.29	Safety	3.00
Productivity	6.03	Productivity	4.52
Lighting	5.84	Traffic Control	5.36
Traffic Control	5.68	Quality	5.91
Construction Cost	5.68	Congestion	6.06
Quality	5.66	Construction Cost	7.33
Congestion	5.63	Worker Condition	7.69
Availability of Material/Equipment Repair	5.58	Accident Cost	9.59
Worker Condition	5.50	Driver Condition	9.75
Scheduling	5.34	Lighting	9.79
Communication Supervision	5.06	Scheduling	10.21
Driver Condition	4.97	Availability of Material/Equipment Repair	10.24
Accident Cost	4.94	Communication Supervision	11.45
Public Relations	4.34	Public Relations	11.64
User Cost	3.97	User Cost	12.21
Noise	3.84	Maintenance Cost	12.56
Maintenance Cost	3.69	Noise	12.61
Air Quality	2.42	Air Quality	14.91
Fuel Consumption	2.28	Fuel Consumption	16.31

3.4.6 Other DOTs' Results

Table 3.7 shows the survey respondents' results from other DOTs. Respondents typically were in positions such as, engineer, researcher or manager of the relative department. Public relations and user cost factors are of relatively high importance for other DOTs. This is a reasonable result, as one would expect these factors to be ranked high since congestion and traffic control are in the top three most important factors and are closely related to public relations and user cost. However, the quality factor is ranked fourteenth in the indicating category and fifth in the ranking category. This makes it difficult to conclude whether other DOTs consider the quality factor to be very important or not. Since participating personnel are in higher positions in some DOTs they may not directly participate in construction and/or maintenance projects. Thus, communication supervision and the availability of material/equipment repair factors are ranked low. In addition, construction cost and maintenance cost factors are ranked low. This study raises the question of whether other DOTs do not consider construction and maintenance costs to be critical, as long as the public and the workers are satisfied about safety and congestion issues.

Table 3.7: Other DOTs' results

	DOTs (n=31)			
	Indicating		*Ranking*	
	Factor	**Average**	**Factor**	**Average**
1	Congestion	6.57	Safety	2.41
	Safety	6.07	Congestion	2.93
	Traffic Control	6.03	Traffic Control	4.66
2	Public Relations	5.93	Public Relations	6.03
	User Cost	5.53	Quality	6.61
	Scheduling	5.30	User Cost	7.38
	Lighting	5.10	Productivity	7.66
	Noise	4.73	Scheduling	8.83
	Worker Condition	4.65	Noise	9.45
	Productivity	4.53	Accident Cost	10.29
	Driver Condition	4.48	Lighting	10.45
	Accident Cost	4.48	Worker Condition	10.50
3	Communication Supervision	4.40	Driver Condition	11.21
	Quality	4.38	Construction Cost	11.25
	Construction Cost	4.24	Availability of Material/Equipment Repair	12.93
	Availability of Material/ Equipment Repair	4.24	Maintenance Cost	13.43
	Maintenance Cost	3.74	Communication Supervision	14.36
4	Air Quality	3.46	Air Quality	16.29
	Fuel Consumption	2.68	Fuel Consumption	17.00

3.4.7 Comparison between PMs and DMs

It is necessary to compare the overall results 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. The results of PMs and DMs surveys needed more in depth analysis since the sample size was large, consists of different regions and positions, and encompasses different operations (construction versus maintenance).

To compare regions and positions in personnel categories (e.g., PMs, DMs), an ANOVA test was used. The p values of less than .05 were considered to be significant. A hypothesis test was used to investigate whether there are any differences between PMs' and DMs' responses. Table 3.8 shows the results of the ANOVA test.

Table 3.8: ANOVA and hypothesis tests for regions and positions by categories

	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 Mat'/Equip' 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

Six factors in the indicating category and five factors in the ranking category are different. In particular, the maintenance cost and availability of material/equipment repair factors significantly differ in both the indicating and ranking categories. DMs weight these two factors more heavily, which is a representative characteristic of the DM category. The construction cost and noise factors ranked higher by the PMs than by the DMs. Since the length of projects for PMs are generally longer than for DMs, PM personnel consider these two factors to be more critical. However, even though other factors are different in either the indicating or ranking category, the factors' ranked positions are similar, so the impact of the differences is minimized.

3.4.8 Preference of Work Time and Other Information

The survey also asked participants for their preference of either daytime or nighttime work: 83% of respondents preferred daytime work, 7% preferred nighttime work, and 10% expressed no preference. Figure 3.7 shows the distribution of work preference among those surveyed. These overall results are very similar to those of the various personnel categories.

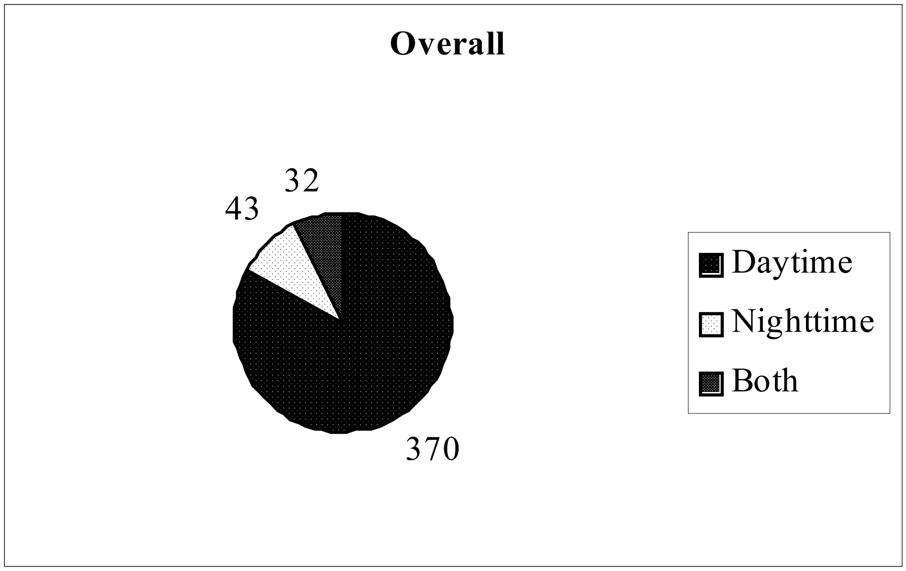

Figure 3.7: Respondents preference for nighttime or daytime work

From the written responses, personal schedules and safety were the main reasons why respondents preferred daytime work. While working at night, workers' available time to spend with family and friends is reduced. Even though some respondents agreed that working at night was better for productivity, congestion, and safety; they did not want to disrupt their personal lives by conducting the work at night. Many respondents felt that working at night was more dangerous than working during the day, based on past crashes during nighttime work. In addition, several respondents wrote that sleeping during the day was not good for biological rhythms, and that people should sleep at night and do activities during the day.

Some respondents preferred to work at night because the reduced traffic enables workers to be more productive while working in a safer environment. It can be concluded that many workers think that working at night is not bad based on their experiences, but it is not preferable due to the effect that it has on their personal lives.

Those surveyed were given the opportunity to respond to an open-answer comment question. The respondents that answered typically provided more detailed information concerning why working either at night or during the day was better.

When investigators surveyed other DOTs, the survey asked additionally whether they conduct nighttime work. A majority of the DOTs conduct nighttime work if they need to, due to high traffic volumes and congestion. Out of all of the DOTs responding to the survey, Montana was the only state that did not perform nighttime work. The lack of nighttime work in Montana is due to the low traffic volumes during the day.

3.5 SURVEY CONCLUSIONS

This survey allowed for a multi-perspective analysis of the importance of factors affecting nighttime work. The overall results were summarized and comparisons were made among the individual personnel categories to investigate whether the overall results were consistent with them. Based on this analysis, the overall results were fairly consistent with the results from the individual respondent groups, with the exception of the cost factors. Even though the factors of noise, communication supervision, and availability of material/equipment repairs were slightly different, these factors are not likely to significantly influence the decision-making process of when to conduct nighttime work.

The literature suggests that nighttime work produces good productivity and quality, and often provides safer working environments. The survey results indicate that most people do not want to work at night because of the disruption to their personal lives. Using the results of this survey and the recommendations from the TAC, the factors can be weighted and used to develop a decision model to help decide when nighttime work should be conducted.

4.0 PHASE II: DECISION MODEL DEVELOPMENT

It was necessary to identify and clarify critical factors affecting nighttime construction and maintenance work. This study eliminated factors that did not aid in differentiating between a daytime or nighttime preference. In Phase I, a survey was used to determine the importance of factors characterized by respondent groups. Further investigation was necessary to determine the detailed characteristics of each factor to be incorporated into the decision model. Qualitative factors were then transformed into quantitative values (wherever possible), and a decision model was created based on those values.

4.1 ELIMINATION OF UNIMPORTANT FACTORS

As described in Section 3.4.2 the overall results were fairly consistent amongst the respondent categories, with the exception of the cost factors. Even though the communication supervision and availability of material/equipment repair factors were slightly different; based on the TAC's recommendation, these factors were not likely to significantly influence the decision-making process of when to conduct nighttime work. In addition, there were no significant differences in the survey results between construction and maintenance operations. Therefore, the overall results of the survey (rather than individual group results) were used for the development of the decision model.

Within Section 3.4.2, Table 3.3 lists the overall results of the 19 factors. Factors in the third and fourth sections of Table 3.3 were eliminated from the decision model because of their relatively low impact on the decision between nighttime and daytime operations. Factors in the first and second sections were considered important to the decision making process and those 12 were included in the model.

4.2 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 was different for the overall results compared to the construction and maintenance personnel results, it was necessary to investigate all of the average values. If there were any significant differences in values between the overall, construction, and maintenance respondent groups, then two differently weighted values were necessary for the construction and maintenance operations in the decision model.

Table 4.1 shows the weight of factors in the indicating and ranking categories as defined by the overall, construction, and maintenance respondent groups. Differences between the two consecutive factors in the hierarchy were obtained in the indicating and ranking categories, respectively. Then each weight was established after considering the magnitude of the difference between factors, and the absolute value of each factor. After obtaining the weight of each factor in the indicating and ranking categories, it was necessary to compare them with the other respondent groups. Table 4.1 shows the comparison.

Table 4.1: Weight of factors by overall, construction, and maintenance groups

	Indicating				Ranking			
	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
	Factor	***Indicating***	***Difference***	***Weight***	***Factor***	***Ranking***	***Difference***	***Weight***
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
	Factor	***Indicating***	***Difference***	***Weight***	***Factor***	***Ranking***	***Difference***	***Weight***
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

After examining the different values of each factor in each respondent group, an overall value for each factor was produced for the final weight. Since the values of the majority of factors were consistent between the ranking and indicating categories they were easily sorted by weight. The factors of congestion and lighting, however, were not consisted between the ranking and indicating categories. The weighted value of the congestion factor was 2 in the indicating category and 3 in the ranking category for all three respondent groups. Finally, the weights of the factors were established based on the values of each factor. For the decision model the overall respondent groups' indicating weights were used (Table 4.1 in **bold**).

4.3 IDENTIFICATION OF SUB-FACTORS AND FURTHER ELIMINATION OF FACTORS

In order to develop the decision model, important factors were quantified with tangible values. 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 presented in Table 4.2.

Table 4.2: Identification of sub-factors and elimination of factors

Factor	Sub-Factors	Note
Safety	**Crash and Fatality**	
	Visibility (Lighting)	
	Traffic control	
Traffic Control	**Traffic control equipment (Devices)**	Eliminated
	Arrangement of traffic control equipment	
	Traffic control strategies	
Congestion	Volume - Capacity = Congestion	
	Congestion * User costs = $	
	User costs: Personnel cost and Vehicle costs	
Lighting	Lighting levels	Eliminated
	Arrangement of light sources	
	Lighting equipment	
Quality	**Measurements**	
	Temperature	
	Interference from traffic	
	Visibility (Lighting)	
	Worker condition	
Public Relations	**Local Impact including business impact**	
	Public campaign	
	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**	
	Availability of material, equipment and spare parts	
Driver Condition	*Safety/Accident*	Eliminated
	Substance abuse and Fatigue	
	Anger and frustration caused by delays	
Construction Cost	Overtime and night premium pay	Eliminated
	Increase material costs	
	Lighting expense	
	Additional traffic control devices	
Accident Cost	Substance abuse and Fatigue	Eliminated
	Visibility (Lighting)	
	Type of traffic control devices	

After the identification of sub-factors, the TAC suggested that the five factors of traffic control, lighting, driver condition, construction cost and accident cost be eliminated from the decision model based on the following assumptions:

- **Traffic Control-** In Oregon there are no significant differences in traffic control for daytime versus nighttime construction and maintenance operations even though the factor was weighted as a 3, the second highest value. For work performed during the day or at night traffic control is present in either scenario.

- **Lighting-** It is not necessary to purchase lighting equipment for every operation, and since lighting expense is not a large portion of the total project cost (lighting is usually a bid item within the contract) it was eliminated as a factor.

- **Driver Condition & Accident Costs-** Driver conditions and accident costs were eliminated since they are included within the safety factor.

- **Construction Cost-** Since additional construction costs such as premium pay for workers, material, and equipment are not a large portion of the total construction cost, the factor was eliminated.

After these eliminations, seven factors (safety, congestion, quality, public relations, worker conditions, productivity and scheduling) affecting nighttime operations were used for the development of the decision-making model to determine when to conduct nighttime operations.

4.4 QUANTIFICATION OF CRITICAL FACTORS

After identifying the sub-factors of each of the seven critical factors affecting nighttime operations, each sub-factor (characteristic) was quantified with tangible values to compare daytime and nighttime operations in the decision model. The seven critical factors, their weights and sub-factors (characteristics) are shown in Table 4.3. For some characteristics it was necessary to collect data from within Oregon, 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 4.3: Critical factors for the decision model and its 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, Composite pay factor, and Overall Condition Index
Public Relations	1	Local Impact including business impact and Noise
Worker Condition	1	Performance levels
Productivity	1	Daily paving productivity
Scheduling	1	Availability of personnel, material and equipment

4.4.1 Safety

To quantify the safety factor, crash data were analyzed to provide tangible evidence about safety during the day versus at night. Crashes during the day (6 a.m. to 5:59 p.m.) versus at night (6 p.m. to 5:59 a.m.) as well as the proportion of fatal crashes during the day versus at night in work zones and non-work zone areas were investigated. Crash data were collected from all Interstate, U.S., and State Highways by each ODOT Region in Oregon, and all roads including highways in the largest city of each region: Portland, Salem, Medford, Bend and Pendleton. The data provided the total yearly crashes from 1998 to 2000 for each ODOT region.

After analyzing the crash data, the following conclusions were drawn:

1) Crash frequencies during the day are much higher than at night since the traffic volumes are greater. Thus, there are more opportunities for crashes to occur.

2) Construction or maintenance operations do not significantly affect the increase in the amount of crashes in Regions 1 and 2.

3) In Regions 3, 4, and 5, there are more crashes during the daytime within a work zone (128% increase), but it is difficult to ensure this since nighttime operations may not be frequently conducted.

4) Fatal crashes occurring at night and in a work zone are eight times higher than those occurring during the day.

Table 4.4 shows the ratio of daytime versus nighttime crashes. The ratio represents crashes occurring during the day, divided by crashes occurring at night; all resultant ratio values are shown in Table 4.4. Since traffic volumes during the day are higher than at night, there are generally more crashes during the day, so it may be necessary to compare crash analyses by traffic volumes as well as different hours. However, the major concern for the crash analyses was to estimate tangible values for judging when it is safer to conduct construction and maintenance operations, during the day or at night. Thus, the crash analyses considered only actual values of crashes in daytime versus nighttime.

Table 4.4: Crash ratio of daytime versus nighttime (daytime/nighttime) in Oregon

	Year	*R1 HW*	*R2 HW*	*Portland*	*Salem*	**Average**
Work zone	1998	3.00	3.45	3.56	3.23	**3.31**
	1999	3.57	5.00	7.25	3.5	**4.83**
	2000	3.38	2.46	5.33	12	**5.79**
	Total	3.28	3.63	4.89	3.71	**3.88**
Non-work	1998	3.24	3.64	3.20	3.72	**3.45**
	1999	3.32	3.50	3.31	3.66	**3.45**
	2000	3.25	3.32	3.09	3.8	**3.36**
	Total	3.27	3.49	3.20	3.72	**3.42**

	Year	*R3 HW*	*R4 HW*	*R5 HW*	*Medford*	*Bend*	*Pendleton*	**Average**
Work zone	1998	10.00	2.33	11.00	8.50	N/A	N/A	**7.96**
	1999	7.57	11.00	4.00	N/A	3.00	N/A	**6.39**
	2000	23.00	3.33	8.00	N/A	N/A	N/A	**11.44**
	Total	9.67	4.00	7.67	13.50	8.00	N/A	**8.57**
Non-work	1998	2.87	2.94	2.37	4.26	4.94	5.81	**3.86**
	1999	3.15	2.93	2.52	4.84	4.61	4.56	**3.77**
	2000	3.23	3.09	2.07	4.41	5	4.28	**3.68**
	Total	3.07	2.99	2.31	4.48	4.84	4.87	**3.76**

Note: R1 HW = Region 1 Highways

In the decision model, two types of quantified values for the safety factor were used, including the crash ratio and fatality ratio in daytime versus nighttime work-zones. For the crash ratios, 3.88 was used for Regions 1 and 2; and 8.57 was used for the other three regions. The ratio of 8 was used for the fatality sub-factor for all of Oregon. The TAC recommended that the crash and fatal crash frequencies be equally weighted to accurately represent the safety factor. A thorough summary of the Oregon crash analysis is provided in Appendix D.

4.4.2 Congestion

This research found that using road user cost was the best way to quantify the congestion factor. There are three possible ways to compute the road user cost:

1) Traditional calculation methods: 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*) to estimate road user cost.

2) Lane rental method: some departments of transportations have developed their own simple programs using Microsoft Excel to estimate road user cost and lane rental fees due to closing lanes for construction and maintenance projects. Lane rental methods were originally developed by the British Department of Transportation 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.

3) Quickzone software: Developed by the Federal Highway Administration to estimate delay. This analytical tool allows users to estimate quickly and flexibly work zone delay, supporting all four phases such as policy, planning, design and operation of the project development process (*Mitretek Systems 2001*).

ODOT experimented with the lane rental method in the early 1990s (*Herbsman and Ellis 1995; Herbsman and Glagola 1998*), but no longer uses it to estimate user cost, nor was ODOT able to obtain any documentation for the lane rental method. This study examined *Quickzone* version 0.99 for possible use by decision makers within ODOT, but it was concluded that the program's complexity would prohibit its use by ODOT users.

After thorough investigation of various methods to estimate road user cost, the following methods are recommended for two different road configurations:

1) Single lane in each direction:

In order to estimate road user costs, traditional calculation methods are considered the most appropriate and ODOT decision makers are able to use this method without additional training. However, if the road has a shoulder greater than 8 feet (2.5 meters) wide, it should be considered two lanes instead of a single lane in each direction and the estimation could be best obtained by the following multiple lane method.

2) Multiple lanes in each direction:

An Excel spreadsheet developed by the Oklahoma Department of Transportation (OKDOT) enables the estimation of road user costs associated with multiple lane roads. The spreadsheet was originally developed by OKDOT in 1997 (*Oklahoma Department of Transportation 1997*) and then modified in 2000 and 2001. The spreadsheet is very user-friendly and is a practical program for estimating road user costs. The spreadsheet utilizes lane rental methods to estimate road user costs and uses equations identical to those used in the traditional calculation method. Users enter the necessary information into the spreadsheet and obtain road user costs without hand calculations. The User's Guide to estimate road user costs using the spreadsheet is provided in Appendix E.

After using one of the above methods, decision makers can estimate road user costs in the daytime versus nighttime and compare them in the decision model to quantify the congestion factor, as well as produce an overall score value for each alternative.

4.4.3 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 of comparing the quality of daytime versus nighttime construction. Currently, ODOT uses three methods to measure paving quality: International Roughness Index (IRI), Composite Pay Factor (CPF), and Overall Condition Index (OCI). IRI measures longitudinal pavement profiles to evaluate pavement condition and remaining life. CPF is intended to measure, through statistical analysis, the quality of the material that contractors produce and use during paving; resulting in the anticipated performance and quality of the pavement. OCI considers condition measurements such as the amount of rutting, cracking, raveling, and bleeding present on pavements within ODOT's transportation system and is assessed every two years.

The TAC recommended using the IRI method to compare daytime versus nighttime pavement quality. From 1998 to 2000 ODOT conducted 124 paving projects. From the 124 projects, 81 were identified for possible IRI comparisons. Differences between IRI measurements before and after paving for daytime versus nighttime work were compared. The result of the comparison was that the IRI of nighttime projects was 3% higher than for projects conducted during the day (Table 4.5). Even though IRI values for interstates, urban national highways, and rural national highways are different, the sample sizes are too small to draw significant conclusions. Therefore, the overall values of IRI from all 81 projects were used in the model.

Table 4.5: Paving quality in daytime versus nighttime

Classification	Urban/Rural	Sample size		% of IRI Improvement		Ratio	
		Day	Night	Day	Night	Day	Night
Interstate Highway	N/A	6	7	22.90	21.90	1	0.96
National Highway	Urban	6	10	16.17	28.84	1	1.78
	Rural	37	15	27.22	26.00	1	0.96
	Urban/Rural	43	25	25.68	27.13	1	1.06
Overall		49	32	25.33	26.00	1	1.03

4.4.4 Worker Condition

During this research, it was impossible to conduct experiments to measure worker conditions in different shifts due to time and budget limitations. Thus, the investigation of published literature was the preferred method for collecting 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 the impact, 2) all individuals had different physiological conditions, and 3) there were very few studies to investigate it.

The investigation of performance levels of shift work was reviewed. Some studies measured performance levels in different shifts so that productivity in real work settings was measured. 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 the "productivity" included as a factor in this model. The term "productivity" as used in this research refers to the productivity of the paving length, or the time spent to finish a specific construction or maintenance activity in different shifts. The term "productivity" as used in the shift work literature refers to the productivity of workers at various manufacturing factories or service facilities.

After reviewing the literature of shift work, it was determined that a very small number of studies have measured the performance levels of shift work. Only two studies, by Tilley Wilkinson, Warren, Watson, & Drud (*1982*) and by Wojtczak-Jaroszowa and Pawlowska-Skyba, (*1967*) contained the applicable quantitative values of worker conditions in shift work. Tilley et al. (*1982*) found that simple reaction time for the 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 night is about 10% lower than during the day. 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. A thorough summary of worker conditions is provided in Appendix F.

4.4.5 Productivity

As was the case with the quality factor, measuring paving productivity was the most appropriate method for comparing the productivity of daytime versus nighttime construction. Thus, this study collected productivity data from the same 124 paving projects used for the quality factor and compared tons per hour of pavement for daytime versus nighttime construction. There were two strategies used for collecting the data: 1) select only paving projects from the 124 projects already identified, and 2) 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 unless specific restrictions for a project were provided.

In total, 16 daytime projects and 17 nighttime projects were selected. The average productivity for the daytime projects was 163.99 tons per hour, while the average for the nighttime projects was 202.34 tons per hour. Therefore, from 1998 to 2000, the productivity of nighttime paving projects was 123% higher than the productivity of daytime paving projects.

4.4.6 Public Relations and Scheduling

These two factors are difficult to truly quantify for daytime versus nighttime construction and maintenance activities. According to the survey and the generalization of the literature review, noise and local business impacts were the major issues for public relations; availability of workers at night was the primary concern for scheduling. The difference of noise during the day and at night can be measured, but the difference cannot control the <u>decision</u> of when to conduct a project. The decision should be based on whether noise levels allow conducting a project at night or not.

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

4.5 CREATION OF THE DECISION MODEL

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

4.5.1 Theoretical Decision Model

The principles of the decision model were to accumulate each value or sub-factor, multiply the accumulated value of the factor by its respective weight, and then add the products for each alternative (either daytime or nighttime). The highest total value among the alternatives would be selected as the best design. Equation 4-1 shows the principle of the decision model used in this study.

$$U_i = \sum_{j=1}^{m} W_j \left(\frac{1}{n}\sum_{k=1}^{n} V_{ijk}\right) \tag{4-1}$$

Where, U_i = *aggregate* score of alternative
W_j = *importance* weight for factor j
V_{ijk} = score of sub-factor k of factor j on alternative i
i = alternative
j = factor
k = sub-factor
n = number of sub-factor

4.5.2 Computation of the Factors in the Decision Model

After the quantification of factors, the fixed value of each factor in the decision model was obtained. Table 4.6 shows the values of factors in the decision model, except for the congestion factor as it varies by project. The highest score of a sub-factor or factor on each alternative (nighttime or daytime) in the decision model is 1; meanwhile the lowest is 0.

Table 4.6: Values of factors in the decision model

Factor	Weight	Daytime			Nighttime		
Safety		Crash		Fatality	Crash		Fatality
		R1 or R2	Others		R1 or R2	Others	
	4	0.260	0.120	1.000	1.000	1.000	0.125
Quality	2	0.970			1.000		
Public Relations	1	0.000			0.000		
Worker Condition	1	1.000			0.900		
Productivity	1	0.810			1.000		
Scheduling	1	0.000			0.000		

Note: R1=Region 1
Others=Interstate, US and State Highways in Region 3, 4 and 5

Based upon the values presented in Table 4.6, Table 4.7 provides sub-total scores of the decision model, excluding the congestion factor. From Table 4.7, two aspects were found: 1) a daytime sub-total score in Region 1 or Region 2 is higher than a nighttime score, but 2) a daytime sub-total score in other regions is lower than a nighttime score. However, the total score with consideration of the congestion factor would be changed due to higher user costs in the daytime. Table 4.8 shows the estimation method for scores in daytime versus nighttime work for the congestion factor.

Table 4.7: Estimation of factors' scores and sub-total scores in the decision model

Factor	Weight	Daytime		Nighttime	
		R1 or R2	Others	R1 or R2	Others
Safety	4	2.52	2.24	2.25	2.25
Quality	2	1.94	1.94	2.00	2.00
Public Relations	1	0.00	0.00	0.00	0.00
Worker Condition	1	1.00	1.00	0.90	0.90
Productivity	1	0.81	0.81	1.00	1.00
Scheduling	1	0.00	0.00	0.00	0.00
Sub-Total Scores		**6.27**	**5.99**	**6.15**	**6.15**

Table 4.8: 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	1.0
Y is not = 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
	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

4.5.3 Development of the Decision Making Model

The decision model was designed using Visual Basic software to make it simple and easy to understand and use. Tables 4.6 and 4.7 did not provide information for public relations, scheduling, or 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 for each alternative (Figure 4.1). A detailed discussion of the questions in the decision model is provided below:

1) Is the project duration less than 3 days?: This is related to worker condition and scheduling. For worker condition, a planned project should be checked for a duration of less than 3 days. If the duration is less than 3 days, a pop-up question appears, as shown in Figure 4.2 (a), and asks whether other projects can be scheduled back-to-back to make the duration of the work greater than 3 days. The primary purpose of the pop-up question is to make the decision-making robust within the decision model. If it is possible, the total scores and recommendation are provided after the completion of questionnaires within the decision model; otherwise the decision model recommends conducting the work during the daytime without the comparison of total scores due to the selection of "no-go". This logic is similar to a Go and No-Go gauge.

2) 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, then the total scores and recommendation are provided; otherwise the decision model recommends the daytime option without the comparison of the total scores.

3) What region is this project in?: This is a location question used to estimate crash frequencies since they differ throughout the state.

4) Will noise levels prevent this work from being done at night due to current local ordinances?: This is concerned with noise, a characteristic of the public relations factor. There are two pop-up questions, Figure 4.2 (b) and (c) that ask more detailed questions, associated with noise.

5) Will the project result in unacceptable local business access during daytime?: This addresses the local business impact with respect to the public relations factor.

6) What are the user costs of each alternative?: This question asks for an estimate of the congestion value for each alternative. After entering the dollar amount of road user costs determined by the previously recommended methods, the decision model computes the ratio value and determines score values for the alternatives by the method shown in Table 4.8.

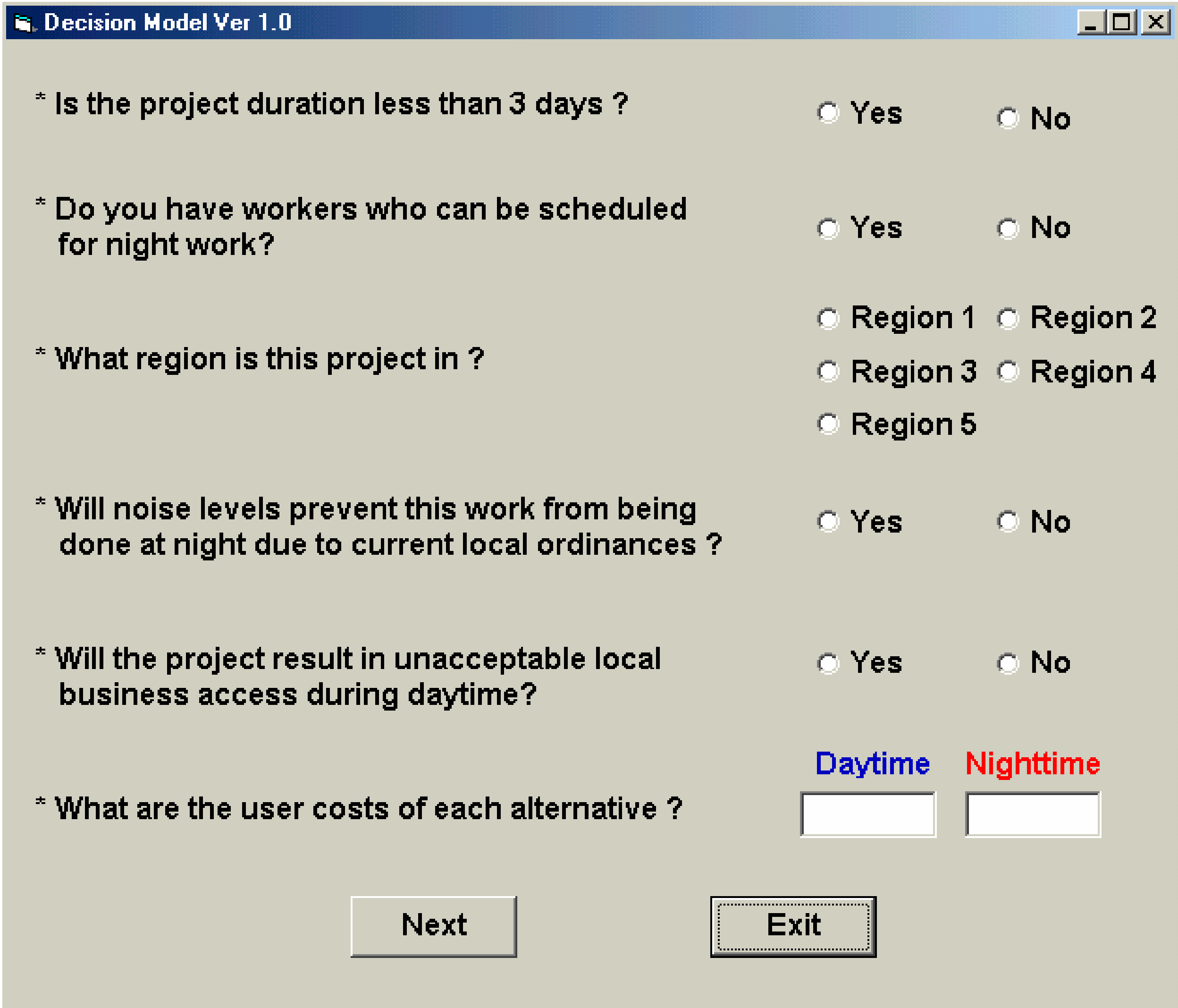

Figure 4.1: Questions in the decision model

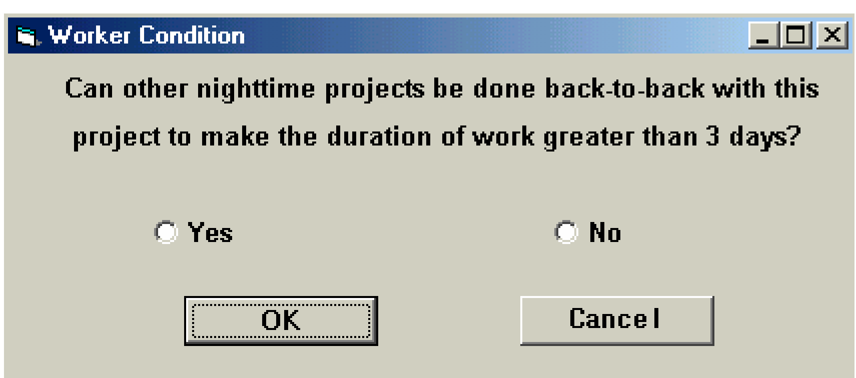

Figure 4.2 (a): The pop-up question for the first question

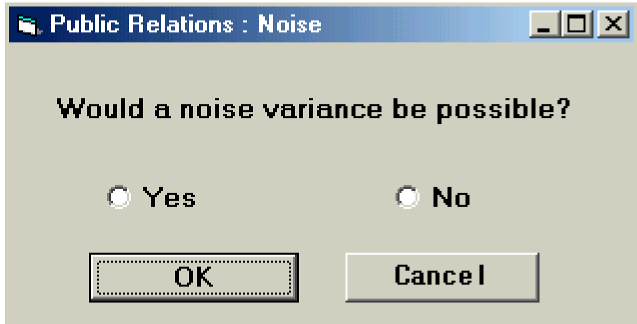

Figure 4.2 (b): The first pop-up question for the fifth question

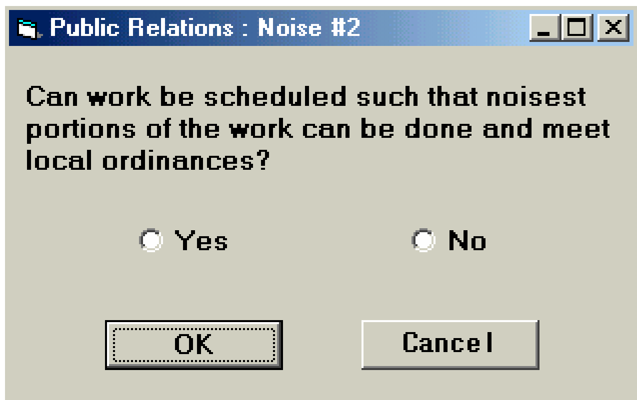

Figure 4.2 (c): The second pop-up question for the fifth question

With the exception of questions three and six in Figure 4.1, all of the questions are related to the public relations, scheduling, and worker condition factors for the Go and No-Go logic in the decision model. Table 4.9 shows how the decision model provides recommendations for these questions. If daytime and nighttime recommendations based on the Go and No-Go logic conflict, then the model recommends working in either the daytime or nighttime. Thus, the decision maker must decide the relative importance of these factors for that specific project.

Table 4.9: Decision model's questions for go and no-go gauge and its recommendations

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

Note:
Q.1: Is the project duration less than 3 days?
Q1-1: 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?

4.5.4 Example of a Decision Model Result

After entering the necessary information, an overall score for each alternative is computed and a recommendation is made. Figure 4.3 is an example of a project result from the decision model. The decision model provides the recommendation of a working schedule with an explanation. By clicking the "More" button, the decision model provides detailed information used to estimate the total scores for each alternative; Figure 4.4 provides an example of this detail. In the decision model, the maximum obtainable scores are 8.27 for daytime and 8.15 for nighttime. The minimum scores are 6.27 for daytime and 6.15 for nighttime. The scores for daytime are higher than nighttime because the score value of the safety factor for daytime was superior to nighttime. However, the difference of road user costs for daytime versus nighttime will be significantly higher in most construction and maintenance projects and will affect the estimated total scores for both alternatives.

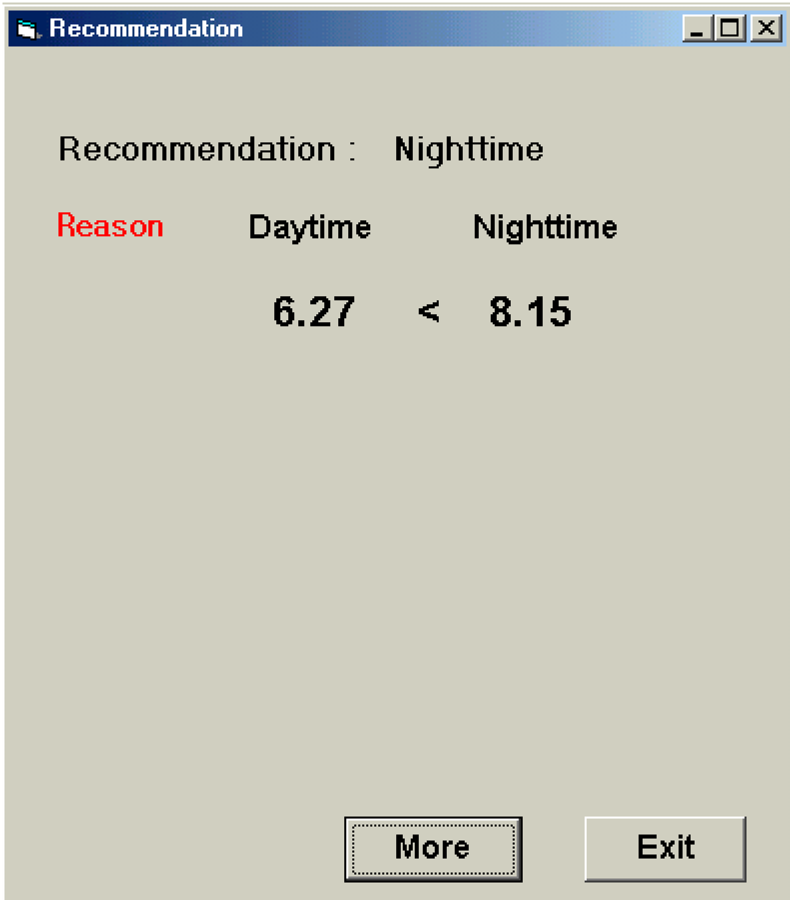

Figure 4.3: An example of the decision model's result

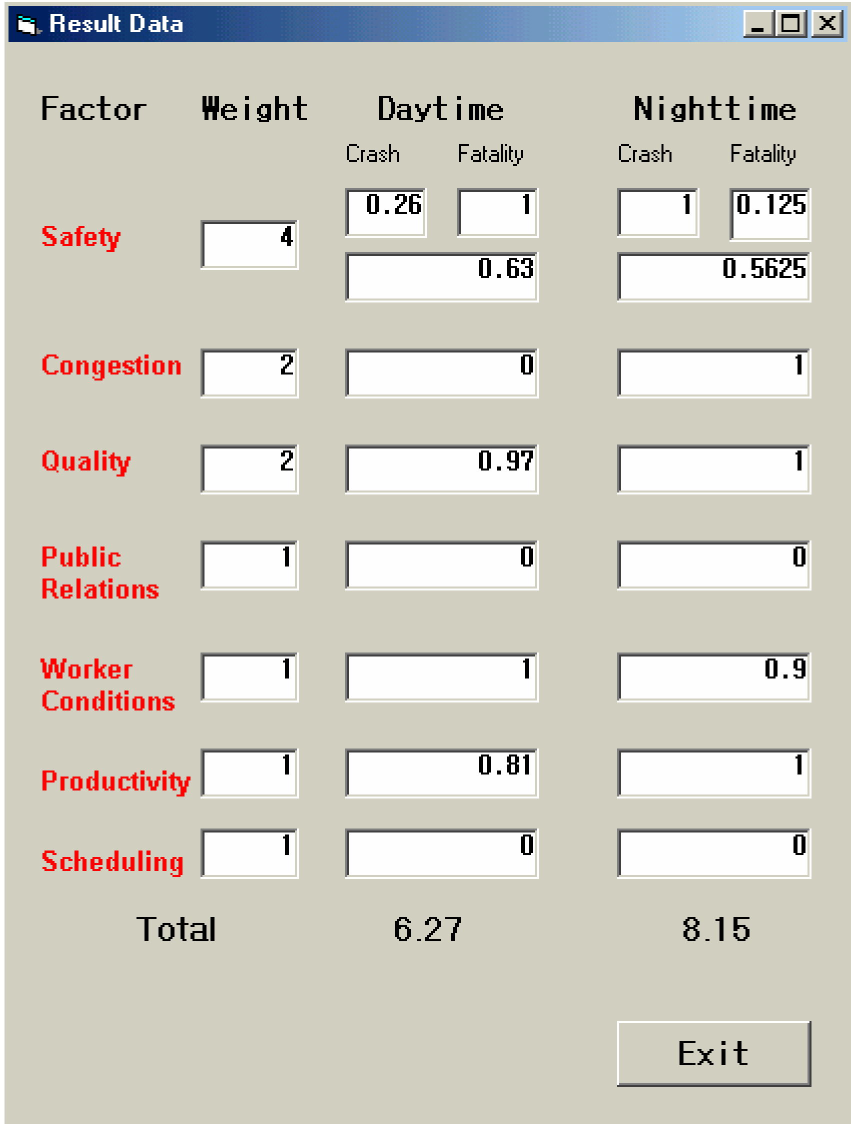

Figure 4.4: An example of detailed information in the decision model's result

Figure 4.5 shows an example of the decision models' recommendation to work either during the daytime or nighttime. If a project's duration is less than 3 days, the decision model recommends it be conducted during the daytime, while if a project results in unacceptable local business access during the daytime, the decision model recommends it be done at night. Because of the projects' duration and the impact to local businesses, the decision model recommends either daytime or nighttime work. A decision maker then may select their preference for conducting the work by considering the higher priority factor for the situation.

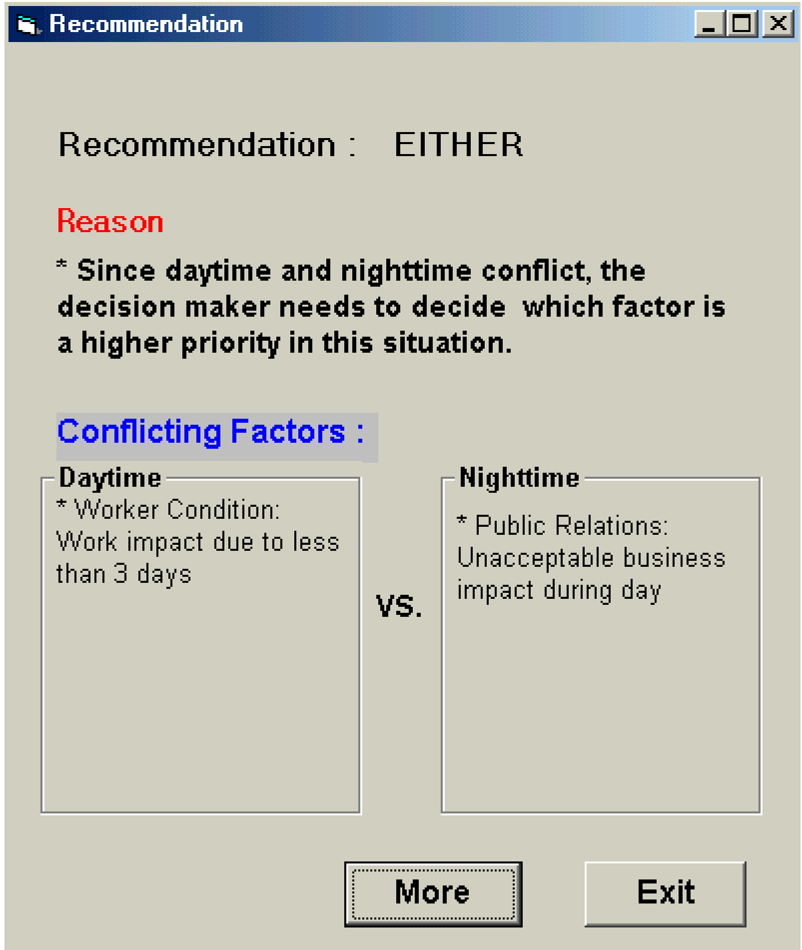

Figure 4.5: An example of both recommendations in the decision model

5.0 PHASE III: TESTING AND ANALYSIS

The decision model was tested using real construction and maintenance projects in Oregon to check whether the recommendations made by the decision model are consistent with current decision makers' subjective decisions. Representative projects were tested using the decision model. In addition, the weights of the safety and congestion factors were modified and tested with the selected projects in a sensitivity analysis. Since safety and congestion are the two most important factors and have different weights within the model, the sensitivity analysis is necessary to determine whether the decision would change with different weights.

5.1 DETERMINATION OF THE SIZE OF CASE STUDIES AND SAMPLING STRATEGIES

It was necessary to first determine the proper number of sample projects to be included in the 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). Yin 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) 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.

The focus of this test was to identify, select and test at least ten former and/or future construction or maintenance projects that were/will be conducted during the day or night. 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 of when to conduct a project in the future.

Table 5.1 shows the selection strategies applied for testing projects using the decision model. Based upon the strategies used, various types of projects conducted within Oregon were selected. A total of 12 projects were identified, 11 were tested using the decision model (one was not included because the work was performed during a complete closure). Detailed information for each project is provided in Appendix G.

Table 5.1: Selection strategies for testing projects

Strategy	Category
Type of Work	Construction and Maintenance
Type of Work Duration	Less and More than 3 days
Type of Work Status	Former, Current, and Future Projects
Type of Scheduled Work	Daytime and Nighttime
Type of Region	Region 1, 2, 3, 4, and 5
Type of Workplace	Interstate-Urban, Interstate-Rural, Arterial-Urban, and Arterial-Rural

5.2 TESTING AND RESULTS OF THE DECISION MODEL

Using information obtained about the 11 projects, user costs for daytime versus nighttime performance of each project were estimated and a total score of the two alternatives was computed using the decision model. Table 5.2 shows the test results for the 11 projects using the decision model.

Table 5.2: Test results of the decision model

Project / Name / Contract No.	User Costs		Total Score in the Decision Model		Recommendation of the Decision Model	Reason	Status
	Daytime	Nighttime	Daytime	Nighttime			
I-5 Medford / Joseph Thomas PM / 12746	$346,504	$274	5.99	8.15	Nighttime	6.27 < 8.15	Both
I-84 / Marge West PM / 12708	$5,051,372	$18,602	6.27	8.15	Nighttime	6.27 < 8.15	Nighttime
US 97 / Jon Heacock PM / 12394	$572	$128	N/A	N/A	Nighttime	Local Business	Nighttime
I-84 / Patrick Cimmioyotti PM / 12776	$312	$310	7.79	8.15	Nighttime	8.07 < 8.15	Nighttime
The Port of Entry / Tom Feeley PM / 12576	$220	$104	7.59	8.15	Nighttime	7.87 < 8.15	Nighttime
I-5 North Portland / Earl Mershon PM / 12460	$2,682,818	$3,864	6.27	8.15	Nighttime	6.27 < 8.15	Nighttime
Pendleton / Terry Mcartor DM	$328	$110	N/A	N/A	Daytime	2 day project	Nighttime
OR 8 Beaverton / Ron Kroop DM	$626	$144	N/A	N/A	Nighttime	Local Business	Nighttime
OR 8 Forest Grove / Ron Kroop DM	$230	$52	N/A	N/A	Nighttime	Local Business	Not Decided yet
OR 43 / Ron Kroop DM	$298	$72	N/A	N/A	Either	2 day project & Local Business	Daytime
Bridge Project / Larry Olson DM	$3,130,540	$416	6.27	8.15	Nighttime	6.27 < 8.15	Nighttime

Most project and district managers planned their projects for the nighttime due to heavy traffic congestion during the day. Operation schedules in the status column of Table 5.2 are current decisions made by project and/or district managers. When they did not provide a project's alternative schedule for the daytime, an assumption was made that the work would be conducted from 9 a.m. to 5 p.m.

The following are facts produced throughout testing of the decision model:

1) **Consistency of decision-making**: In 11 projects tested, the recommendations for seven projects in the decision model were consistent with current decision makers' decisions. This shows that the model is consistent with current decision makers' actual decisions and is reliable for use as a decision-making tool. Three projects had different decision model recommendations than what the actual decisions were: a) the I-5 project in Medford is being conducted both during the day and at night, while the decision model recommended only nighttime work, b) the as-yet to be started project in Pendleton is planned to be done at night, whereas the decision model recommended it be done during the day, and c) the District Manager for the OR Highway 43 project conducted the work during the day. The decision model however recommended either daytime or nighttime work based on a two day work schedule (daytime recommendation), and the impact to local businesses would be minimized if the project were done at night. Thus, the decision maker in situation (c) would select the higher priority (work schedule vs. business impact) and perform the work accordingly. One project could not be compared with the actual decision because the district manager had not yet made a decision.

2) **High feasibility of nighttime operations**: The decision model recommended that work be conducted during the daytime for only one of the projects, as this was the only project that could be accomplished in a short duration. The remaining projects were recommended for nighttime work because congestion and negative impacts on local businesses would thus be minimized. The recommendation of the decision model means that nighttime operations are more economical and also lessen the impacts to local residents and businesses within the work zones. This result supports current decision makers' choices for nighttime operations in order to reduce congestion and the impact on local businesses.

3) **High adaptation of Go and No-Go logic**: Six projects' recommendations were based upon the magnitude of total scores in the daytime versus nighttime alternatives, while the other five projects' recommendations depended on Go and No-Go logic. In the decision model, there are four criteria of 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.

4) **Feasibility of either daytime or nighttime**: The OR Highway 43 project received a recommendation of working either during the daytime or nighttime because of the conflict between work duration and the impact on local businesses. Thus, the decision maker would need to decide (subjectively) when to conduct the work, based upon a priority hierarchy for the project.

5) **Impact of congestion in the decision model**: There are two aspects of the impact of congestion within the decision model. First, the differences of user cost during the daytime and nighttime are tremendous for the major highways of large urban areas. Generally, the score for the daytime is zero, but the score for the nighttime is two. This difference results in a recommendation of working at night instead of in the day.

   Secondly, project manager Patrick Cimmiyotti decided that the I-84 project could be conducted at night. The decision model also recommended nighttime work due to the negligible difference in user costs between the two time frames ($1.00). If this difference is disregarded, the decision model recommends daytime rather than nighttime work.

   In addition, the Port of Entry project was conducted at night. The decision model concluded that the project could have been conducted during both the day and night. The result was due to the small amount of dollar difference in user cost, pending that the real decision maker did not mind the user costs associated with both schedules.

6) **Impact on 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 areas with low traffic volumes. Even though the amount of user cost in both daytime and nighttime work is not great, the decision model recommends conducting operations at night.

5.3 SENSITIVITY ANALYSIS

The safety and congestion factors are the critical factors within the decision model, with weights of 4 and 2, respectively. Through sensitivity analysis, the decision model was examined as to how sensitive it is to fluctuations in different weight values for the safety and congestion factors. Fluctuations in different weight values of the two factors are important to see just how much deviation there is in the decision-making. Table 5.3 shows the total scores of the daytime and nighttime alternatives, the different weights of the two factors, and the weights of the two factors modified from 2 to 4.

Table 5.3: Sensitivity analysis of the decision model

		S4C2		S4C3		S4C4	
No.	**Project**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
1	I-5 Medford	5.99	8.15	5.99	9.15	5.99	10.15
2	I-84 (West)	6.27	8.15	6.27	9.15	6.27	10.15
3	I-84 (Cimmiyotti)	7.79	8.15	8.69	9.15	9.59	10.15
4	The Port of Entry	7.59	8.15	8.39	9.15	9.19	10.15
5	I-5 North Portland	6.27	8.15	6.27	9.15	6.27	10.15
6	Bridge Project	6.27	8.15	6.27	9.15	6.27	10.15
		S3C2		S3C3		S3C4	
No.	**Project**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
1	I-5 Medford	5.43	7.59	5.43	8.59	5.43	9.59
2	I-84 (West)	5.64	7.59	5.64	8.59	5.64	9.59
3	I-84 (Cimmiyotti)	7.23	7.59	8.13	8.59	9.03	9.59
4	The Port of Entry	7.03	7.59	7.83	8.59	8.63	9.59
5	I-5 North Portland	5.64	7.59	5.64	8.59	5.64	9.59
6	Bridge Project	5.64	7.59	5.64	8.59	5.64	9.59
		S2C2		S2C3		S2C4	
No.	**Project**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
1	I-5 Medford	4.87	7.03	4.87	8.03	4.87	9.03
2	I-84 (West)	5.01	7.03	5.01	8.03	5.01	9.03
3	I-84 (Cimmiyotti)	6.67	7.03	7.57	8.03	8.47	9.03
4	The Port of Entry	6.47	7.03	7.27	8.03	8.07	9.03
5	I-5 North Portland	5.01	7.03	5.01	8.03	5.01	9.03
6	Bridge Project	5.01	7.03	5.01	8.03	5.01	9.03

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

Six projects were tested using sensitivity analysis, namely those that had recommended operation schedules based upon the differences of their total scores, rather than the Go and No-Go gauge. The modification of weights in this analysis focused on inserting a higher weight for congestion compared to safety. After checking all of the total scores in the table, one might conclude that the total scores in the nighttime are always superior to those in the daytime. Therefore, decisions are not changed regardless of the higher weights of the congestion factor.

With the computed scores in Table 5.3, the differences between nighttime and daytime scores can be obtained. These are shown in Table 5.4 and Figure 5.1, which demonstrates that a nighttime schedule is always superior to a daytime schedule no matter the weights of the safety and congestion factors.

Table 5.4: Difference of nighttime and daytime scores in the decision model in sensitivity analysis

		Nighttime-Daytime								
No.	**Project**	**S4C2**	**S4C3**	**S4C4**	**S3C2**	**S3C3**	**S3C4**	**S2C2**	**S2C3**	**S2C4**
1	I-5 Medford	2.16	3.16	4.16	2.16	3.16	4.16	2.16	3.16	4.16
2	I-84 (West)	1.88	2.88	3.88	1.95	2.95	3.95	2.02	3.02	4.02
3	I-84 (Cimmiyotti)	0.36	0.46	0.56	0.36	0.46	0.56	0.36	0.46	0.56
4	The Port of Entry	0.56	0.76	0.96	0.56	0.76	0.96	0.56	0.76	0.96
5	I-5 North Portland	1.88	2.88	3.88	1.95	2.95	3.95	2.02	3.02	4.02
6	Bridge Project	1.88	2.88	3.88	1.95	2.95	3.95	2.02	3.02	4.02

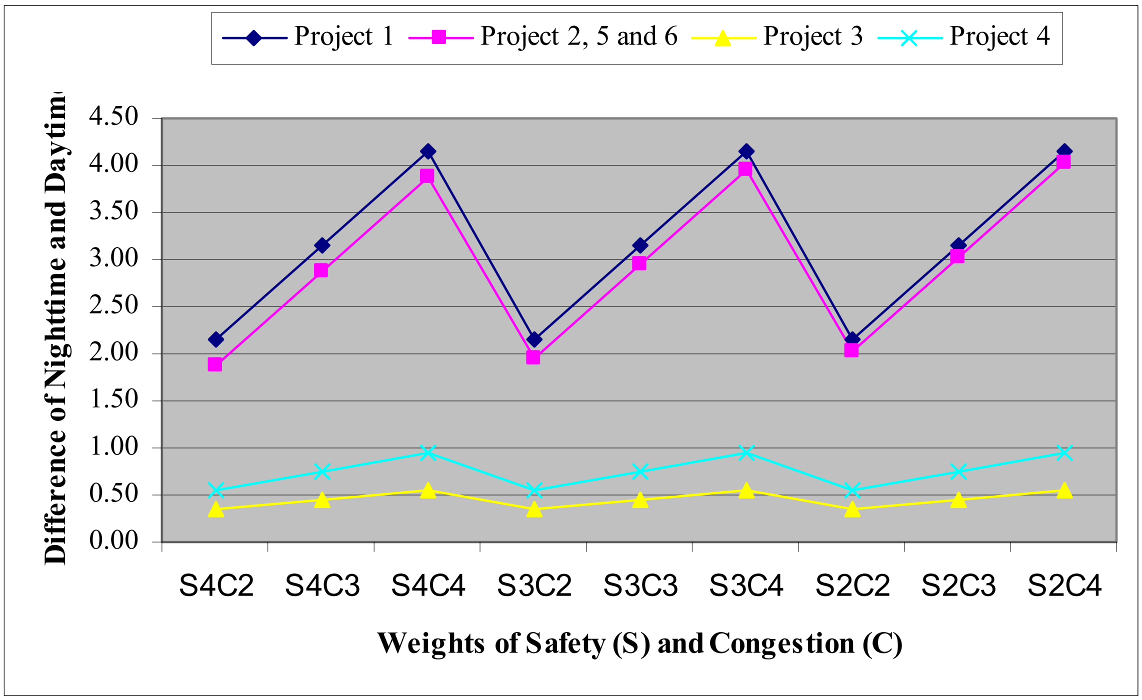

Figure 5.1: Sensitivity analysis of the decision model

5.4 THE CONGESTION FACTOR IN THE DECISION MODEL

After sensitivity analysis, the congestion factor in the decision model was investigated in depth. Table 5.5 shows the calculated scores in the decision model without the consideration of the congestion factor. There are two types of daytime crash scores in the safety factor: 0.26 and 0.12. In Regions 1 and 2 the crash value in the daytime is 0.26. For Regions 3, 4 and 5 the crash value is 0.12. However, the congestion factor is heavily considered for the cities in Region 1 and 2, so only one score value was used (0.26) in Table 5.5.

Table 5.5: Factor scores in the decision model without congestion factor

Factor	Weight	Day	Day Score	Night	Night Score
Safety	4	0.6300	2.5200	0.5625	2.2500
Quality	2	0.9700	1.9400	1.0000	2.0000
Public Relations	1	0.0000	0.0000	0.0000	0.0000
Worker Conditions	1	1.0000	1.0000	0.9000	0.9000
Productivity	1	0.8100	0.8100	1.0000	1.0000
Scheduling	1	0.0000	0.0000	0.0000	0.0000
SUM			6.2700		6.1500
Daytime - Nighttime = 0.12					

Without considering the congestion factor, the sum of the score in the decision model is consistent with various projects, and the daytime alternative is superior to the nighttime alternative. The score difference is 0.12. This difference means that nighttime scores are always higher if the congestion factor is added into the decision model and the daytime user cost is larger, regardless of the ratio. Table 5.6 and Figure 5.2 show the deviation of the total scores in the decision model by the congestion factor in ratios of daytime and nighttime user costs. This result shows that the congestion factor critically affects the decision of when to conduct nighttime operations within Oregon, provided that worker conditions, scheduling, and public relations do not influence the decision.

Table 5.6: Total scores' deviation in the decision-making by congestion factor

User Cost Ratio	Daytime Total Score	Nighttime Total Score
X/Y=1	8.27	8.15
1<X/Y<2	8.07	8.15
2<=X/Y<3	7.87	8.15
3<=X/Y<4	7.67	8.15
4<=X/Y<5	7.47	8.15
5<=X/Y<6	7.27	8.15
6<=X/Y<7	7.07	8.15
7<=X/Y<8	6.87	8.15
8<=X/Y<9	6.67	8.15
9<=X/Y<10	6.47	8.15
10<=X/Y	6.27	8.15

Note: X is daytime user cost
Y is nighttime user cost

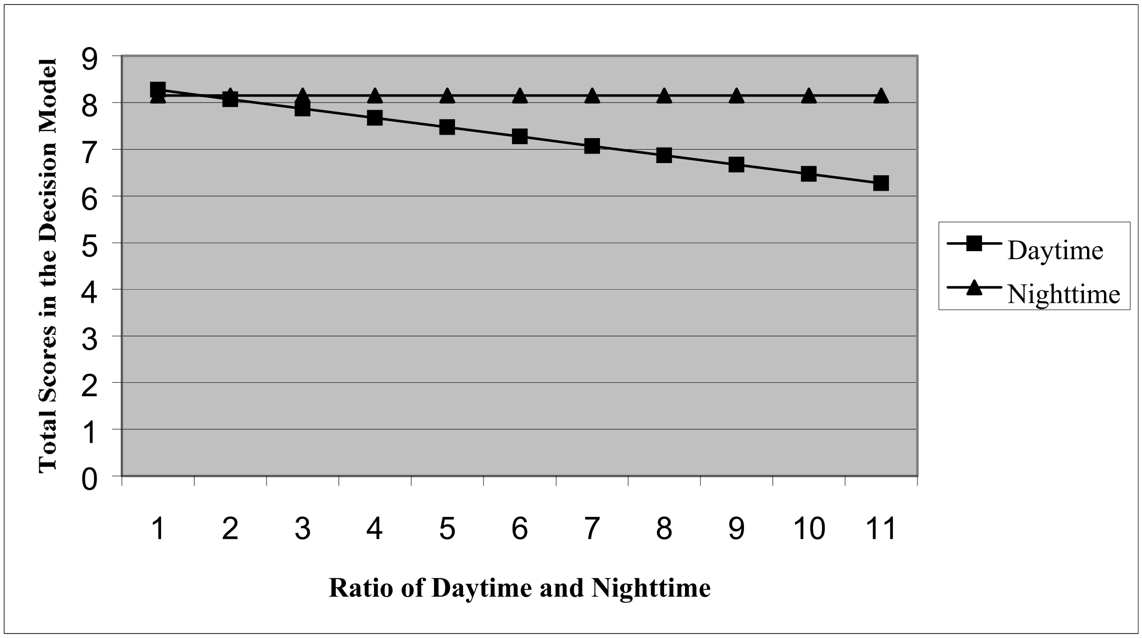

Figure 5.2: Deviation in decision-making by congestion factor

6.0 CONCLUSION

6.1 SUMMARY

Like other DOTs, the Oregon Department of Transportation (ODOT) has emphasized preservation of existing highways and bridges rather than constructing new facilities. Also, 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 Oregon 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 applicable to ODOT decision makers because of the absence of a practical decision model available to actual decision makers. Therefore, a decision model that facilitates the determination of when to conduct nighttime road construction and maintenance work was developed. In order to create the decision model, it was necessary to identify and prioritize the factors of importance to this decision making model.

After a thorough literature review, 19 factors were identified that affect the decision-making process and that were sufficiently well established to utilize in the development of the model for ODOT. All 19 factors were then used to create a survey that was administered to key ODOT staff, contractors, and representatives from other DOTs.

The survey in this study characterized the importance of the factors related to daytime versus nighttime decision-making. After analyses 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 the 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 then 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 ODOT projects and comparing its recommendations of when to conduct the projects with actual decision makers' decisions. The overall testing results were consistent with the current decision makers' judgments due to the impact of the congestion factor in the decision model. In addition, sensitivity analysis showed the deviations of the decision-making in the model. The analysis concluded that the decision-making did not change, regardless of differing weights of the safety and congestion factors.

This study developed what should be a practical and useful tool to help decision makers analyze when to conduct nighttime work. In addition, the decision model will be useful for making decisions consistently, and provides a means to explain the decision to the stakeholders.

6.2 IMPLEMENTATION

The authors, with assistance from the Research Technical Advisory Committee, have developed an implementation strategy that will engage and inform ODOT senior management about the decision model and the results of this study. This will include formal presentations to key ODOT management groups, key construction and maintenance personnel, and the ODOT Standing Committee on Construction.

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