APPENDICES

APPENDIX A

LITERATURE REVIEW AND BIBLIOGRAPHY OF RELATED RESEARCH

The first task for the project was a literature review, in which articles addressing nighttime construction or maintenance work were reviewed, summarized, and evaluated to provide the basis for further tasks. The articles reviewed were divided into the following categories:

1. Purpose of nighttime work
2. Advantages and disadvantages of nighttime work
3. Crash studies
4. Factors (parameters) affecting nighttime work
5. Comparison of daytime versus nighttime work (decision making system)
6. Guidelines for nighttime work
    6.1. Traffic management and control
    6.2. Lighting
    6.3. Case studies
7. Estimation and analysis
    7.1. Capacity/Delay estimation
    7.2. Cost analysis
    7.3. Productivity/Quality analysis

*Some categories of the literature review are missing from the appendix and are included in Chapter 2 of the report.

Purpose of Nighttime Work

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

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

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

Advantages and Disadvantages of Nighttime work

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

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

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

After the I-40 project, Heine (1989) reported some disadvantages of nighttime work. It was more dangerous to work during the nighttime due to drunken drivers being on the road. Workers were excited when the nighttime work began, but they got tired of performing the nighttime work as the project progressed.

Crash Studies

There were no studies of crashes that occurred as a result of nighttime work. Many studies mentioned the crash frequency during nighttime work, but they did not draw any clear conclusions since they did not have sufficient statistical data. Lee (1969) was the first to address the crash frequency due to nighttime work. The crash records during nighttime work were 12 crahes along the 13-mile length of road work, while 13 nighttime crashes were reported during the same calendar period during the previous year.

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

According to statistical data, the number of night crashes was smaller than that of day crahes, but about 55 percent of all fatal crashes occurred at night (Lum, 1980). Lum collected crash data from 7 states between 1974 and 1975. The results indicated that the total number of crashes during construction and nighttime was higher than before construction, but this study did not draw this conclusion due to the lack of sufficient and reliable data. Only seven states collected data for a year and the data was different from state to state, which prohibited effective comparisons. Since there was no practical and reliable statistical crash study about nighttime work, it will be hard to use the former studies to adapt to the ODOT project.

Guidelines for nighttime work

Guidelines to safely and effectively conduct road construction and maintenance were introduced by the New York State Department of Transportation (1985), Applied Resources, Inc. (1989), and U.S. Department of Transportation (1993). Special guidelines for nighttime work are needed.

Traffic management and control

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

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

Price (1985) established safety by the following instructions:

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

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

Lighting

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

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

Case Studies

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

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

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

Estimation and analysis

In order to evaluate daytime versus nighttime alternatives, many types of estimation and analysis can be utilized. Each identified factor can be expressed as a certain type of quantitative or qualitative value.

Capacity/Delay estimation

All of the capacity and delay estimation studies are based upon the Highway Capacity Manual (HCM) (Transportation Research Board, 1997) or Wang and Abrams's study (1981) to estimate capacity/delay. The first edition of the HCM was published in 1950, the second in 1965, and the third in 1985. The HCM was updated in 1994 and again in 1997.

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

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

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

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

Martinelli and Xu (1996) studied two types of workzone delays, speed-reduction and congestion. Speed-reduction delays result from vehicles moving more slowly in work zones than on an unencumbered freeway. Congestion delays occur when the hourly traffic volume is bigger than the capacity of a work zone for a significant period of time. In order to estimate traffic delay, a mathematical model was developed. A procedure was also established to estimate daily congestion delay under any given conditions. Alternative roadway closures were evaluated in terms of traffic control and additional road user costs. Finally, the optimal work zone length for a project was calculated and procedures were developed. None of the factors discussed in the above study specifically addressed the estimation of capacity and delay due to nighttime operation. Thus, it would be necessary to investigate whether these estimations are appropriate for use in nighttime operations for the ODOT project.

Cost analysis

A manual on user benefit analysis of highway and bus-transit improvements by the American Association of State Highway and Transportation Officials (1977) introduced all mathematical calculation methods to conduct cost analyses related to highways. Dudek et al. (1985) and Shepard and Cottrell (1985) used this manual as the basis of the cost analysis for their study. Price (1985) indicated that the total cost at night for the I-70 resurfacing project between Quebec St. and Colorado Blvd. in Denver was 159% higher after the estimation of all costs, including time and dollar saving to the public due to nighttime work, and personnel and fuel cost due to delays.

Ellis and Kumar (1993) evaluated the Florida Department of Transportation nighttime construction costs. Since all projects are very unique and have unique work tasks, it was very difficult to compare between daytime and nighttime work. In order to solve this problem, eight different types of typical work served as the basis for comparison in this study. The examples of typical work include removal of existing pavement, regular excavation, and bituminous material. All daytime and nighttime FDOT (Florida Department of Transportation) work site data in 1990 was gathered. In addition, all actual nighttime projects were collected and the projects were converted to daytime projects for comparative purposes. The result was that nighttime construction costs (unit costs) were generally lower than daytime costs for FDOT projects. However, this paper drew this conclusion cautiously since eight nighttime projects were insufficient to draw accurate conclusions.

Productivity/Quality analysis

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

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APPENDIX B

SURVEY INSTRUMENT

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

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

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

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

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

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

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

- Do you prefer daytime work or nighttime work?

  ________ Daytime ________ Nighttime

- Why?

____
____
____
____

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

____

____

____

____

____

- Would you like to receive a copy of the results of this survey? ______ Yes ________No

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

Name:____

Address:____

____

____

Phone: ____

e-mail: ____

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

Kimberly D. Douglas, Ph.D., P.E.	541-737-3644	kimberly.d.Douglas@orst.edu
Sang-Bin Park, Graduate Student	541-737-8127	parksa@engr.orst.edu
Andrew Griffith, P.E.	503-986-3538	andrew.s.griffith@odot.state.or.us

Please mail your response to:

Nighttime Construction Project
118 Covell Hall
Oregon State University
Corvallis, OR 97331-24

APPENDIX C

SURVEY RESULTS

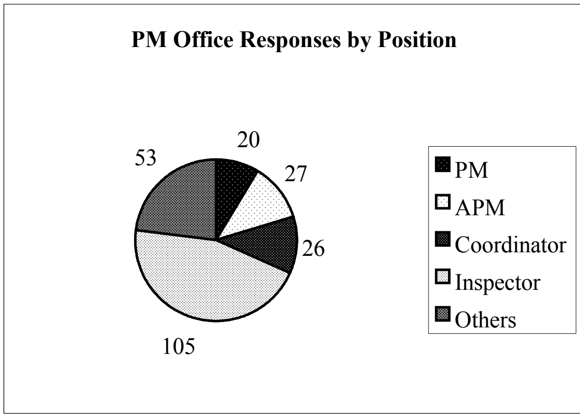
TSRMs and TCPDs Results
Since the number of participants in each category is seven, it is hard to compare with the large numbered categories, such as overall, PMs, and DMs. However, these results can give useful information to support this project because cost factors were relatively low in surveys of PMs and DMs. Where the TSRMs' results are shown, construction cost was ranked highly, but other costs such as maintenance, accident, and user costs are ranked relatively low. The traffic control factor is not consistent between the indicating and ranking factors. Communication supervision and availability of material/equipment repair are ranked very low.

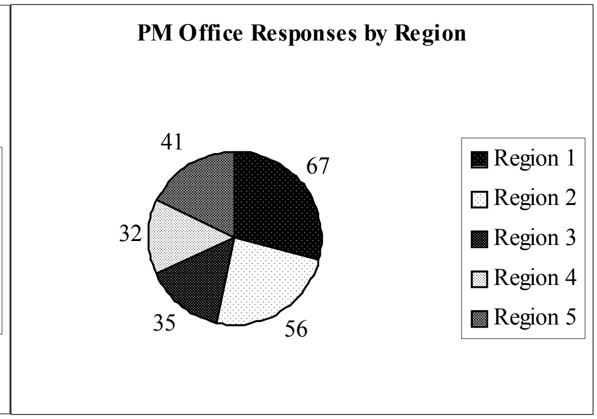
TCPDs' results are provided below. The public relations, quality, and accident cost factors are relatively high. However, communication supervision, maintenance cost, and availability of material/equipment repair factors are relatively low.

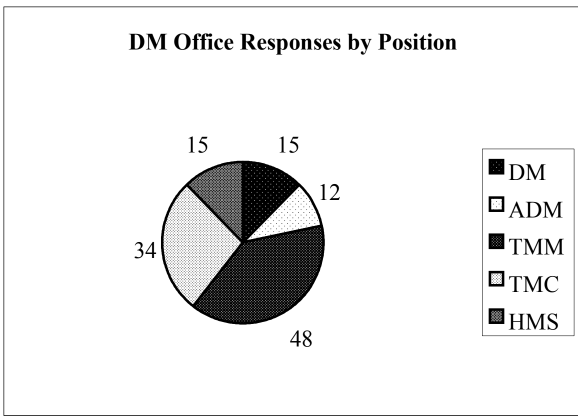
Comparative Analysis of PMs and DMs
Since there were a large number of participants in the PM and DM samples, it is necessary to compare their responses by regions or positions. In addition, any differences between PMs and DMs have to be investigated. In order to compare regions or positions in personnel categories, an ANOVA test was used and a hypothesis test was used to investigate whether there are any differences between the PMs and DMs' responses.

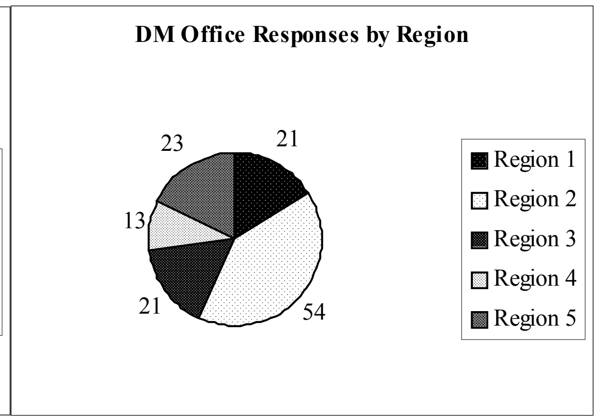
1) Indicating factors by regions in PMs: The noise and public relations factors have significant difference by regions. Noise is relatively important in Region 1, but not important in Region 2. Public relations are important in smaller towns or rural areas, as seen in Regions 3, 4, and 5.
2) Indicating factors by positions in PMs: There are five factors that are significantly different by positions. However, availability of material/equipment repair, air quality, and fuel consumption are ranked in the least important factors in most positions, so these factors can be disregarded. Since the noise factor fluctuated greatly according to position, it is difficult to determine how this factor affects the positions. However, it is an interesting to note that higher positions rank the construction factor lower.
3) Ranking factors by regions in PMs: The only factor to show a significant difference by regions is noise. In Region 1, the noise factor is a relatively important factor compared to other regions. This fact is consistent with the results of the indicating factor by regions and positions.
4) Ranking factors by positions in PMs: Noise, user cost, communication supervision, and availability of material/equipment repair factors are significantly different among positions. These factors are relatively less important factors in these results. Since the factors fluctuated greatly by among positions, it is hard to determine the source of the significant differences.
5) Indicating and ranking factors by regions in DMs: Region 4 has a strong effect on the significant differences. The main reason for the differences was caused when an investigator visited a DM office in Bend, and the meeting was canceled due to a busy schedule without notice to the investigator, so survey forms were left in the office with a request that individuals fill them out and return them by mail. Even though the investigator left enough forms for the staff, they returned only one form that contained responses a CONSENSUS response from four persons - a DM, an ADM, and two TMMs. Thus, the data were used for an average value and the value of the standard deviation is zero. The zero value significantly affects the ANOVA test. The lighting factor is the only factor that was not affected by the Bend district in Region 4. Region 1 ranked the factor relatively lower than other regions.
6) Indicating and ranking factors by positions in DMs: Since there is no significant difference by positions, it is not necessary to show a table.

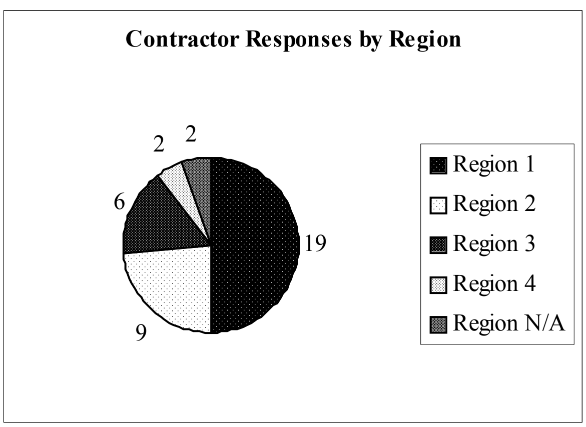
RESPONDED PERSONNEL

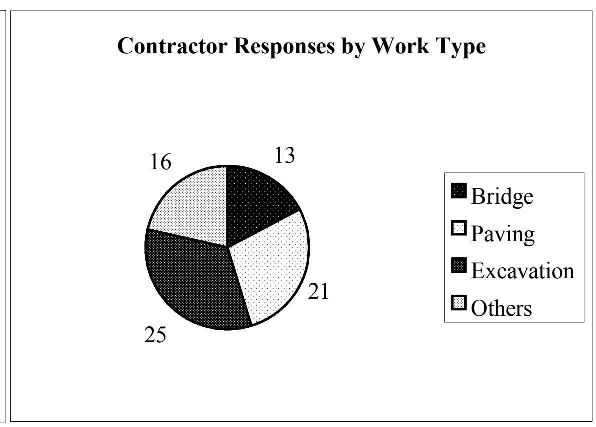












SURVEY RESULTS (Continued)

TSRMs' results

TSRM (n=7)			
Indicating		*Ranking*	
Factor	Average	Factor	Average
Congestion	**6.14**	**Congestion**	**2.14**
Safety	**6.14**	**Safety**	**3.86**
Construction Cost	6.14	**Traffic Control**	**5.43**
Noise	5.57	Construction Cost	6.14
Lighting	5.29	Quality	6.43
Public Relations	5.14	Productivity	7.14
Scheduling	5.00	Scheduling	8.71
Traffic Control	**4.86**	Noise	9.00
Productivity	4.86	Public Relations	9.29
Quality	4.86	Lighting	10.14
Worker Condition	4.67	Worker Condition	10.43
User Cost	4.57	Driver Condition	11.14
Accident Cost	4.43	Accident Cost	11.29
Driver Condition	4.00	User Cost	11.43
Maintenance Const	3.86	Maintenance Cost	13.86
Communication Supervision	3.86	Communication Supervision	14.29
Availability of Mat'/Equip' Repair	3.57	Availability of Mat'/Equip' Repair	15.00
Air Quality	3.17	Fuel Consumption	16.86
Fuel Consumption	2.67	Air Quality	17.43

TCPDs' results

TCPD (n=7)			
Indicating		*Ranking*	
Factor	Average	Factor	Average
Congestion	**6.29**	**Congestion**	**2.86**
Safety	**6.00**	**Safety**	**4.14**
Traffic Control	**5.29**	**Traffic Control**	**4.29**
Public Relations	5.29	Quality	7.29
Quality	5.14	Public Relations	8.14
Accident Cost	5.14	Accident Cost	8.43
Noise	5.14	Productivity	8.86
Scheduling	5.14	Noise	8.86
Lighting	5.00	Construction Cost	9.43
Construction Cost	4.86	Lighting	9.71
Driver Condition	4.80	Driver Condition	9.83
User Cost	4.71	User Cost	10.29
Worker Condition	4.60	Worker Condition	10.33
Productivity	4.57	Scheduling	11.29
Communication Supervision	4.00	Availability of Mat'/Equip' Repair	14.14
Maintenance Cost	3.71	Maintenance Cost	14.29
Availability of Mat'/Equip' Repair	3.71	Air Quality	14.29
Air Quality	2.71	Fuel Consumption	15.29
Fuel Consumption	2.29	Communication Supervision	15.86

COMPARISON BETWEEN OVERALL AND PERSONNEL

PM (n=231)			
Indicating		*Ranking*	
Factor	Average	Factor	Average
Safety	6.55	Safety	1.90
Traffic Control	6.13	Traffic Control	3.94
Congestion	5.89	Congestion	5.06
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
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
Communication Supervision	4.51	User Cost	12.21
User Cost	4.37	Communication Supervision	12.34
Availability of Mat'/Equip' Repair	4.25	Maintenance Cost	13.39
Maintenance Cost	4.17	Availability of Mat'/Equip' Repair	13.54
Air Quality	3.53	Air Quality	14.89
Fuel Consumption	3.02	Fuel Consumption	16.12

DM (n=132)			
Indicating		*Ranking*	
Factor	Average	Factor	Average
Safety	6.41	Safety	1.89
Traffic Control	6.21	Traffic Control	3.68
Congestion	6.10	Congestion	4.80
Lighting	5.99	Productivity	7.48
Public Relations	5.60	Quality	7.61
Quality	5.48	Worker Condition	7.67
Availability of Mat'/Equip' 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 Mat'/Equip' 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
Communication Supervision	4.85	User Cost	12.41
User Cost	4.69	Communication Supervision	12.73
Noise	4.42	Noise	13.22
Air Quality	3.06	Air Quality	15.66
Fuel Consumption	2.91	Fuel Consumption	16.93

COMPARISON BETWEEN OVERALL AND PERSONNEL (Continued)

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 Mat'/Equip' 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 Mat'/Equip' 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

DOTs (n=31)			
Indicating		*Ranking*	
Factor	Average	Factor	Average
Congestion	6.57	Safety	2.41
Safety	6.07	Congestion	2.93
Traffic Control	6.03	Traffic Control	4.66
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
Communication Supervision	4.40	Driver Condition	11.21
Quality	4.38	Construction Cost	11.25
Construction Cost	4.24	Availability of Mat'/Equip' Repair	12.93
Availability of Mat'/ Equip' Repair	4.24	Maintenance Cost	13.43
Maintenance Cost	3.74	Communication Supervision	14.36
Air Quality	3.46	Air Quality	16.29
Fuel Consumption	2.68	Fuel Consumption	17.00

COMPARISON BETWEEN OVERALL AND PERSONNEL (Continued)

TSRM (n=7)			
Indicating		*Ranking*	
Factor	Average	Factor	Average
Congestion	6.14	Congestion	2.14
Safety	6.14	Safety	3.86
Construction Cost	6.14	Traffic Control	5.43
Noise	5.57	Construction Cost	6.14
Lighting	5.29	Quality	6.43
Public Relations	5.14	Productivity	7.14
Scheduling	5.00	Scheduling	8.71
Traffic Control	4.86	Noise	9.00
Productivity	4.86	Public Relations	9.29
Quality	4.86	Lighting	10.14
Worker Condition	4.67	Worker Condition	10.43
User Cost	4.57	Driver Condition	11.14
Accident Cost	4.43	Accident Cost	11.29
Driver Condition	4.00	User Cost	11.43
Maintenance Const	3.86	Maintenance Cost	13.86
Communication Supervision	3.86	Communication Supervision	14.29
Availability of Mat'/Equip' Repair	3.57	Availability of Mat’/Equip’ Repair	15.00
Air Quality	3.17	Fuel Consumption	16.86
Fuel Consumption	2.67	Air Quality	17.43

TCPD (n=7)			
Indicating		*Ranking*	
Factor	Average	Factor	Average
Congestion	6.29	Congestion	2.86
Safety	6.00	Safety	4.14
Traffic Control	5.29	Traffic Control	4.29
Public Relations	5.29	Quality	7.29
Quality	5.14	Public Relations	8.14
Accident Cost	5.14	Accident Cost	8.43
Noise	5.14	Productivity	8.86
Scheduling	5.14	Noise	8.86
Lighting	5.00	Construction Cost	9.43
Construction Cost	4.86	Lighting	9.71
Driver Condition	4.80	Driver Condition	9.83
User Cost	4.71	User Cost	10.29
Worker Condition	4.60	Worker Condition	10.33
Productivity	4.57	Scheduling	11.29
Communication Supervision	4.00	Availability of Mat'/Equip' Repair	14.14
Maintenance Cost	3.71	Maintenance Cost	14.29
Availability of Mat'/Equip' Repair	3.71	Air Quality	14.29
Air Quality	2.71	Fuel Consumption	15.29
Fuel Consumption	2.29	Communication Supervision	15.86

<PM> INDICATING FACTORS BY REGIONS

Region 1		Region 2		Region 3		Region 4		Region 5	
Factor	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*
Safety	6.58	Safety	6.57	Safety	6.31	Safety	6.53	Safety	6.68
Traffic Control	6.18	Traffic Control	6.02	Traffic Control	6.06	Traffic Control	6.28	Congestion	6.27
Lighting	5.81	Lighting	5.89	Congestion	6.06	Lighting	6.19	Traffic Control	6.12
Congestion	5.72	Congestion	5.76	Lighting	5.69	Congestion	5.78	Lighting	5.95
Quality	5.42	Quality	5.43	Public Relations	5.66	Quality	5.78	Quality	5.44
Worker Cond'	5.28	Worker Cond'	5.43	Quality	5.37	Public Relations	5.72	Public Relations	5.15
Productivity	5.21	Driver Condition	5.14	Productivity	5.06	Accident Cost	5.37	Worker Cond'	5.10
Noise	5.14	Productivity	5.02	Scheduling	4.94	Driver Condition	5.16	Productivity	4.98
Public Relations	5.12	Public Relations	4.98	Driver Condition	4.91	Scheduling	5.13	Accident Cost	4.89
Scheduling	5.07	Accident Cost	4.80	Noise	4.76	Worker Cond'	5.03	Constr' Cost	4.89
Driver Condition	5.00	Constr' Cost	4.61	Constr' Cost	4.69	Constr' Cost	5.03	Driver Condition	4.88
Constr' Cost	4.90	Scheduling	4.55	Worker Cond'	4.62	Productivity	4.81	Scheduling	4.83
Accident Cost	4.84	Com' Supervi'	4.43	Accident Cost	4.48	Noise	4.75	Noise	4.68
Com' Supervi'	4.62	User Cost	4.24	Com' Supervi'	4.44	Com' Supervi'	4.75	Com' Supervi'	4.44
User Cost	4.56	Noise	4.15	A' of M'/E' Rep'	4.26	User Cost	4.55	A' of M'/E' Rep'	4.37
Maintenance C'	4.43	A' of M'/E' Rep'	4.09	Maintenance C'	4.22	Maintenance C'	4.30	User Cost	4.32
A' of M'/E' Rep'	4.35	Maintenance C'	4.07	User Cost	4.09	A' of M'/E' Rep'	4.29	Maintenance C'	3.76
Air Quality	3.56	Air Quality	3.33	Air Quality	3.70	Air Quality	3.77	Air Quality	3.44
Fuel Consum'	3.05	Fuel Consum'	2.89	Fuel Consum'	2.84	Fuel Consum'	3.63	Fuel Consum'	2.82

<Note>

(shaded): a factor has a p-value lower than 0.05

A' of M'/E' Rep': Availability of Material/Equipment
Constr' Cost: Construction Cost
Com' Supervi': Communication Supervision
Maintenance C': Minatenance Cost
Fuel Consum': Fuel Consumption
Worker Cond': Worker Condition

<PM> INDICATING FACTORS BY POSITIONS

PM		APM		Coordinator		Inspector		Others	
Factor	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*
Safety	6.60	Safety	6.11	Safety	6.46	Safety	6.57	Safety	6.62
Traffic Control	6.05	Traffic Control	5.96	Congestion	6.12	Traffic Control	6.26	Traffic Control	6.04
Public Relations	5.90	Congestion	5.56	Traffic Control	5.73	Lighting	6.14	Lighting	5.92
Congestion	5.75	Lighting	5.48	Lighting	5.40	Congestion	5.99	Quality	5.74
Quality	5.40	Quality	5.19	Public Relations	5.36	Quality	5.41	Congestion	5.65
Lighting	5.35	Accident Cost	5.00	Scheduling	5.28	Public Relations	5.29	Productivity	5.37
Noise	5.20	Public Relations	4.96	Quality	5.23	Worker Cond'	5.15	Worker Cond'	5.32
Worker Cond'	5.10	Worker Cond'	4.93	Productivity	5.00	Productivity	5.08	Constr' Cost	5.08
Scheduling	5.10	Driver Condition	4.78	Driver Condition	4.96	Driver Condition	5.06	Driver Condition	4.98
Driver Condition	5.00	Scheduling	4.78	Worker Cond'	4.85	Constr' Cost	4.92	Public Relations	4.98
Productivity	4.75	Com' Supervi'	4.74	Constr' Cost	4.84	Scheduling	4.88	Noise	4.96
User Cost	4.60	Constr' Cost	4.48	Noise	4.84	Accident Cost	4.84	Accident Cost	4.96
Accident Cost	4.53	Productivity	4.44	Accident Cost	4.52	Com' Supervi'	4.75	Scheduling	4.64
Com' Supervi'	4.20	A' of M'/E' Rep'	4.41	Maintenance C'	4.04	Noise	4.69	User Cost	4.58
Constr' Cost	3.63	User Cost	4.11	Com' Supervi'	3.84	A' of M'/E' Rep'	4.62	Maintenance C'	4.38
Maintenance C'	3.44	Maintenance C'	3.74	User Cost	3.64	User Cost	4.40	Com' Supervi'	4.37
A' of M'/E' Rep'	3.05	Noise	3.52	A' of M'/E' Rep'	3.64	Maintenance C'	4.29	Air Quality	4.22
Air Quality	2.47	Air Quality	3.15	Air Quality	2.44	Air Quality	3.69	A' of M'/E' Rep'	4.20
Fuel Consum'	2.20	Fuel Consum'	2.70	Fuel Consum'	2.29	Fuel Consum'	3.01	Fuel Consum'	3.78

<Note>

: a factor has a p-value lower than 0.05

A' of M'/E' Rep': Availability of Material/Equipment
Constr' Cost: Construction Cost
Com' Supervi': Communication Supervision
Maintenance C': Minatenance Cost
Fuel Consum': Fuel Consumption
Worker Cond': Worker Condition

<PM> RANKING FACTORS BY REGIONS

Region 1		Region 2		Region 3		Region 4		Region 5	
Factor	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*
Safety	1.87	Safety	1.64	Safety	2.34	Safety	1.78	Safety	2.02
Traffic Control	3.73	Traffic Control	3.93	Traffic Control	3.86	Traffic Control	3.81	Traffic Control	4.46
Congestion	4.99	Congestion	5.25	Congestion	5.29	Congestion	4.50	Congestion	5.15
Quality	6.28	Quality	6.54	Quality	6.29	Quality	5.53	Quality	5.95
Productivity	7.51	Worker Cond':	6.70	Driver Condition	7.60	Driver Condition	7.31	Productivity	6.98
Worker Cond':	7.67	Productivity	7.50	Worker Cond':	7.86	Worker Cond':	7.31	Lighting	8.20
Driver Condition	8.27	Lighting	7.73	Productivity	8.17	Productivity	7.72	Driver Condition	8.46
Noise	9.48	Driver Condition	8.18	Public Relations	8.86	Constr' Cost:	8.88	Worker Cond':	8.78
Lighting	9.55	Public Relations	9.95	Lighting	9.77	Public Relations	9.22	Public Relations	9.00
Constr' Cost:	9.84	Constr' Cost:	9.96	Scheduling	10.17	Lighting	9.72	Constr' Cost:	9.49
Scheduling	10.18	Scheduling	11.05	Constr' Cost:	10.31	Accident Cost	10.34	Scheduling	10.20
Public Relations	10.33	Accident Cost	11.66	Accident Cost	11.69	Scheduling	11.19	Noise	10.90
User Cost	11.66	Com' Supervi':	11.89	Com' Supervi':	11.77	User Cost	11.94	Accident Cost	11.12
Com' Supervi':	11.69	Noise	12.16	Noise	11.83	Noise	13.06	User Cost	12.51
Accident Cost	11.85	User Cost	12.64	User Cost	12.49	Maintenance C':	13.50	Com' Supervi':	13.39
A' of M'/E' Rep':	13.06	A' of M'/E' Rep':	13.09	Maintenance C':	13.00	Com' Supervi':	13.78	A' of M'/E' Rep':	13.54
Maintenance C':	13.37	Maintenance C':	13.18	A' of M'/E' Rep':	13.51	A' of M'/E' Rep':	15.34	Maintenance C':	13.93
Air Quality	14.48	Air Quality	15.64	Air Quality	14.69	Air Quality	15.53	Air Quality	14.22
Fuel Consum':	16.09	Fuel Consum':	16.48	Fuel Consum':	16.23	Fuel Consum':	16.66	Fuel Consum':	15.17

<Note>

: a factor has a p-value lower than 0.05

A' of M'/E' Rep': Availability of Material/Equipment
Constr' Cost: Construction Cost
Com' Supervi': Communication Supervision
Maintenance C': Minatenance Cost
Fuel Consum': Fuel Consumption
Worker Cond': Worker Condition

<PM> RANKING FACTORS BY POSITIONS

PM		APM		Coordinator		Inspector		Others	
Factor	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*
Safety	1.75	Safety	1.89	Safety	2.42	Safety	2.06	Safety	1.38
Congestion	3.80	Congestion	3.93	Congestion	3.54	Traffic Control	3.50	Traffic Control	4.68
Traffic Control	4.15	Traffic Control	4.07	Traffic Control	3.77	Congestion	5.60	Quality	5.64
Quality	7.00	Quality	5.67	Quality	6.19	Quality	6.41	Congestion	5.70
Public Relations	7.90	Productivity	7.22	Productivity	6.85	Worker Cond':	7.39	Productivity	7.21
Productivity	8.80	Worker Cond':	7.74	Worker Cond':	7.85	Productivity	7.56	Worker Cond':	7.28
Worker Cond':	8.85	Public Relations	8.30	Driver Condition	8.12	Driver Condition	7.63	Lighting	8.11
Driver Condition	9.05	Constr' Cost:	8.44	Constr' Cost:	9.58	Lighting	8.34	Driver Condition	8.13
Scheduling	9.30	Driver Condition	8.52	Public Relations	10.08	Public Relations	9.49	Constr' Cost:	9.89
Lighting	9.65	Accident Cost	9.22	Noise	10.35	Constr' Cost:	9.98	Public Relations	10.72
Constr' Cost:	9.75	Lighting	9.44	User Cost	10.42	Scheduling	10.21	Scheduling	11.38
Noise	10.00	Scheduling	9.67	Lighting	11.31	Noise	10.74	Noise	12.06
User Cost	10.10	A' of M'/E' Rep':	10.78	Accident Cost	11.46	Com' Supervi':	11.44	Accident Cost	12.09
Accident Cost	11.70	User Cost	11.19	Scheduling	11.50	Accident Cost	11.48	User Cost	12.70
Com' Supervi':	12.80	Com' Supervi':	11.22	Maintenance C':	12.96	A' of M'/E' Rep':	12.77	Maintenance C':	13.51
Maintenance C':	13.75	Maintenance C':	12.59	Com' Supervi':	13.15	User Cost	12.98	Com' Supervi':	13.79
A' of M'/E' Rep':	16.60	Noise	13.00	A' of M'/E' Rep':	13.50	Maintenance C':	13.46	Air Quality	14.75
Air Quality	16.65	Air Quality	15.07	Air Quality	14.69	Air Quality	14.54	A' of M'/E' Rep':	15.08
Fuel Consum':	17.30	Fuel Consum':	15.19	Fuel Consum':	15.77	Fuel Consum':	16.05	Fuel Consum':	16.11

<Note>

(shaded): a factor has a p-value lower than 0.05

A' of M'/E' Rep': Availability of Material/Equipment

Constr' Cost: Construction Cost

Com' Supervi': Communication Supervision

Maintenance C': Minatenance Cost

Fuel Consum': Fuel Consumption

Worker Cond': Worker Condition

<DM> INDICATING FACTORS BY REGIONS

Region 1		Region 2		Region 3		Region 4		Region 5	
Factor	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*
Safety	6.24	Safety	6.52	Safety	6.76	Lighting	6.54	Safety	6.70
Congestion	6.14	Congestion	6.20	Traffic Control	6.67	A' of M'/E' Rep':	6.15	Traffic Control	6.57
Traffic Control	5.95	Traffic Control	6.07	Congestion	6.43	Congestion	5.85	Lighting	5.96
Public Relations	5.33	Lighting	6.06	Lighting	6.24	Traffic Control	5.85	Congestion	5.65
Lighting	5.29	Public Relations	5.81	Quality	6.10	Public Relations	5.62	Driver Condition	5.35
Quality	5.15	A' of M'/E' Rep':	5.81	Worker Cond':	5.90	Driver Condition	5.38	Worker Cond':	5.35
Worker Cond':	5.10	Quality	5.70	Maintenance C':	5.75	Maintenance C':	5.38	Public Relations	5.22
Scheduling	5.10	Worker Cond':	5.55	Public Relations	5.71	Scheduling	5.23	Quality	5.14
Com' Supervi':	5.05	Maintenance C':	5.54	Constr' Cost:	5.67	Safety	5.15	Scheduling	5.09
Productivity	4.95	Accident Cost	5.52	Driver Condition	5.62	Noise	4.77	Productivity	4.95
Maintenance C':	4.95	Scheduling	5.35	Productivity	5.43	Constr' Cost:	4.75	Maintenance C':	4.87
Noise	4.86	Productivity	5.28	Scheduling	5.43	Productivity	4.45	Accident Cost	4.83
A' of M'/E' Rep':	4.86	Driver Condition	5.21	A' of M'/E' Rep':	5.38	Quality	4.45	A' of M'/E' Rep':	4.74
Constr' Cost:	4.80	Com' Supervi':	5.08	Accident Cost	5.33	User Cost	4.42	Constr' Cost:	4.68
Driver Condition	4.76	Constr' Cost:	5.06	User Cost	5.05	Accident Cost	4.38	Com' Supervi':	4.52
Accident Cost	4.75	User Cost	4.89	Com' Supervi':	4.86	Com' Supervi':	4.23	User Cost	4.52
User Cost	4.19	Noise	4.41	Noise	4.55	Worker Cond':	3.69	Noise	3.73
Air Quality	2.75	Air Quality	3.57	Fuel Consum':	3.37	Fuel Consum':	1.92	Air Quality	2.68
Fuel Consum':	2.60	Fuel Consum':	3.35	Air Quality	3.26	Air Quality	1.77	Fuel Consum':	2.32

<Note>

: a factor has a p-value lower than 0.05

A' of M'/E' Rep': Availability of Material/Equipment
Constr' Cost: Construction Cost
Com' Supervi': Communication Supervision
Maintenance C': Minatenance Cost
Fuel Consum': Fuel Consumption
Worker Cond': Worker Condition

<DM> RANKING FACTORS BY REGIONS

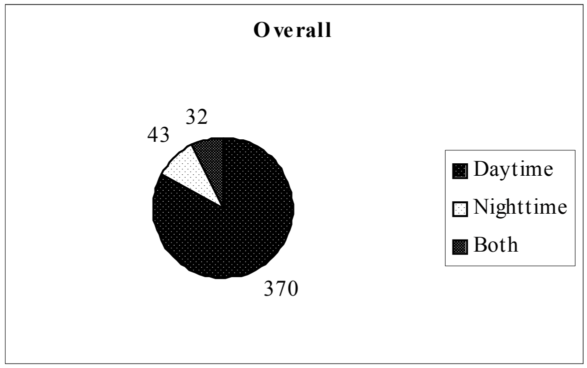
Region 1		Region 2		Region 3		Region 4		Region 5	
Factor	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*	*Factor*	*AVG*
Safety	1.90	Safety	1.46	Safety	1.43	Congestion	5.31	Safety	1.09
Traffic Control	3.90	Traffic Control	3.74	Traffic Control	3.29	Traffic Control	5.31	Traffic Control	2.78
Congestion	4.48	Congestion	4.67	Congestion	4.33	Safety	5.77	Congestion	5.52
Productivity	6.48	Worker Cond':	6.81	Productivity	6.95	Public Relations	6.92	Productivity	7.26
Quality	7.86	Quality	7.11	Quality	7.10	Lighting	6.92	Worker Cond':	7.26
Public Relations	8.43	Productivity	7.61	Lighting	8.38	Maintenance C':	7.15	Quality	7.74
Worker Cond':	8.48	Lighting	7.76	Worker Cond':	8.71	Scheduling	7.69	Driver Condition	8.00
Scheduling	9.33	Driver Condition	9.06	Maintenance C':	9.90	A' of M'/E' Rep':	8.00	Lighting	9.83
Maintenance C':	9.71	Maintenance C':	9.15	Driver Condition	9.95	Driver Condition	8.08	Public Relations	10.39
Driver Condition	9.95	A' of M'/E' Rep':	9.35	Scheduling	10.24	Worker Cond':	8.92	A' of M'/E' Rep':	10.39
A' of M'/E' Rep':	10.67	Public Relations	9.39	Public Relations	10.33	Productivity	9.85	Maintenance C':	10.83
Constr' Cost:	11.29	Scheduling	10.26	Constr' Cost:	10.76	Quality	9.85	Accident Cost	11.00
Noise	11.76	Accident Cost	10.35	A' of M'/E' Rep':	11.33	Com' Supervi':	10.69	Scheduling	11.26
Com' Supervi':	11.86	Constr' Cost:	11.56	User Cost	12.76	Accident Cost	11.00	Constr' Cost:	11.74
Accident Cost	12.33	User Cost	11.89	Accident Cost	13.10	User Cost	12.00	User Cost	13.30
Lighting	12.62	Com' Supervi':	12.19	Noise	13.14	Noise	12.08	Noise	13.57
User Cost	12.67	Noise	13.94	Com' Supervi':	13.86	Constr' Cost:	13.54	Com' Supervi':	14.91
Air Quality	16.38	Air Quality	15.44	Air Quality	16.43	Air Quality	13.85	Air Quality	15.83
Fuel Consum':	16.48	Fuel Consum':	16.65	Fuel Consum':	18.00	Fuel Consum':	16.69	Fuel Consumption	17.17

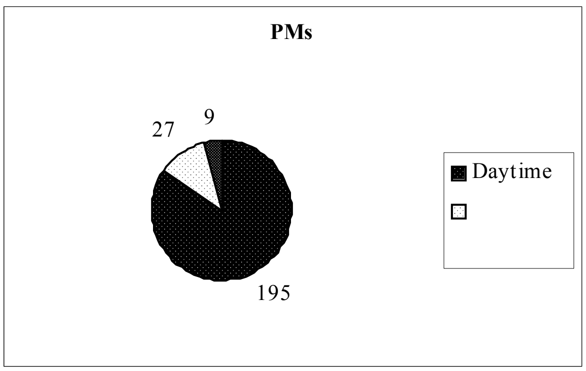
<Note>

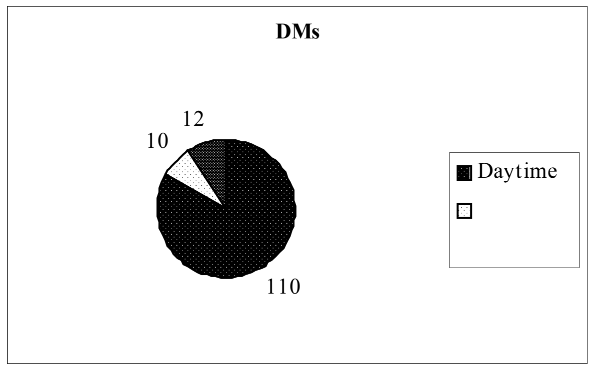
: a factor has a p-value lower than 0.05

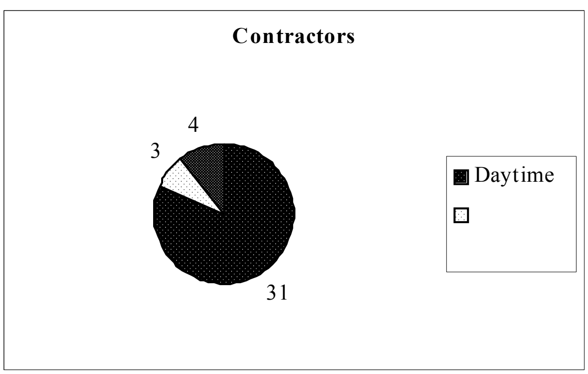
A' of M'/E' Rep': Availability of Material/Equipment
Constr' Cost: Construction Cost
Com' Supervi': Communication Supervision
Maintenance C': Minatenance Cost
Fuel Consum': Fuel Consumption
Worker Cond': Worker Condition

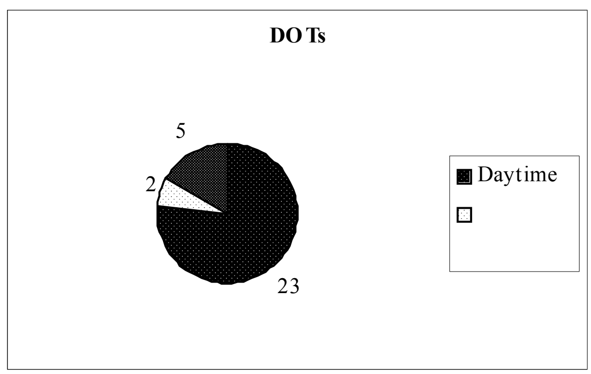
PREFERENCE OF WORK TIME

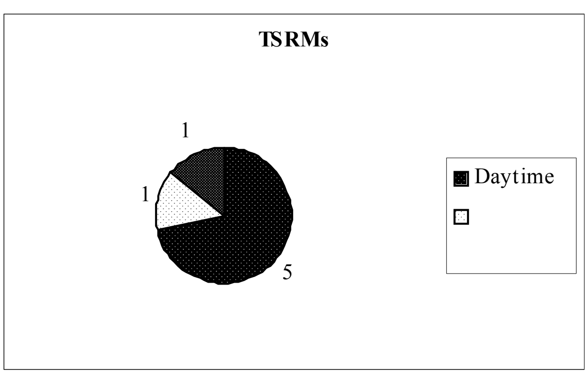


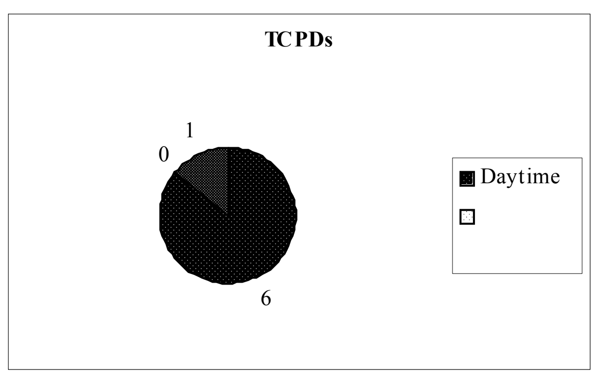












APPENDIX D

OREGON CRASH ANALYSIS

Findings
Since the objective of the investigation of the crash data is to determine when it is safer to conduct construction or maintenance work, this analysis will focus on the accident rate of daytime versus nighttime. For each area of interest, the accident data was separated by daytime versus nighttime in work zones and non-work zones. This enables us to understand accidents in two different times in a work zone versus a non-work zone.

Crash Results
After analyzing the data, it was obvious that crashes occurred more often in the daytime both for work zone and a non-work zone. Figure D.1 and Table D.1 show the results of the crash analysis. The ratio values are the values of daytime crashes compared to nighttime crashes (=1.00) in a work zone versus a non-work zone. A value < 1.00 represents more nighttime crashes and a value > 1.00 indicates less nighttime crashes. In the overall result, there are two work zone values, Work I and Work II. Work I includes all the overall results: region 1, 2, 3, 4, and 5 highways, Portland (Po), Salem (S), Medford (M), Bend (B), Pendleton (Pe), while Work II excludes the data of Medford, Bend, and Pendleton since for these cities it was unclear whether construction or maintenance operations were conducted at night or not.

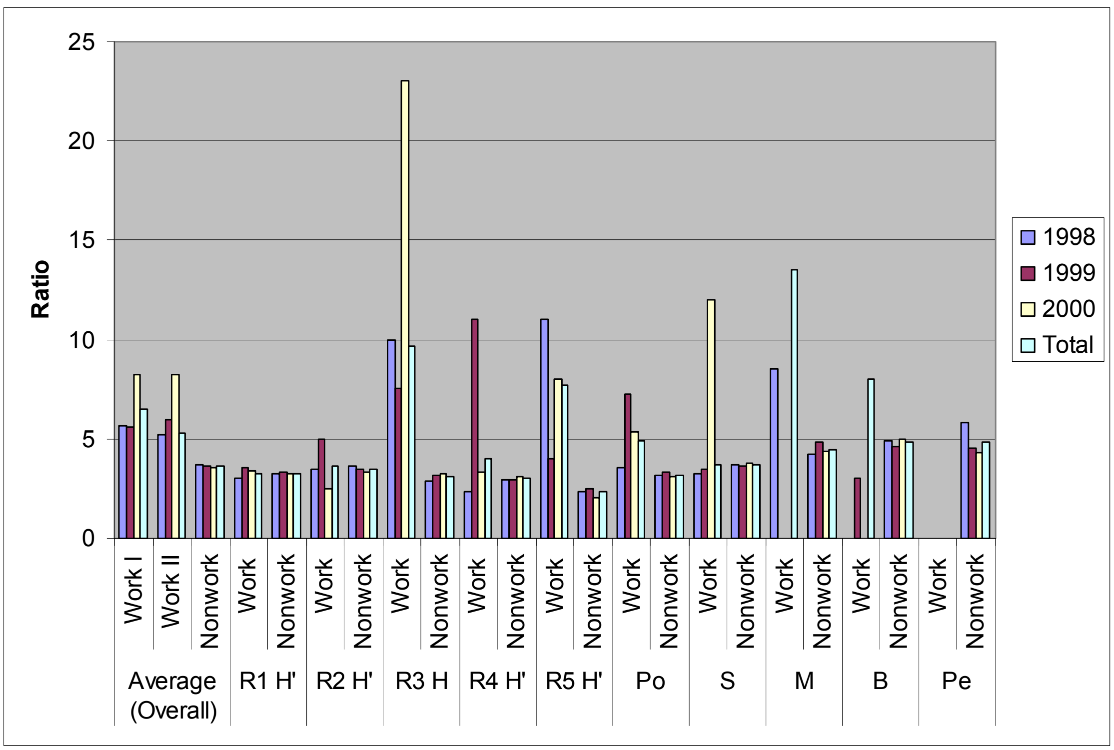


Figure D.1: Crash Frequency of Nighttime versus Daytime (Daytime/Nighttime)

Table D.1: Overall Crash Ratio of Daytime vs. Nighttime (Daytime/Nighttime)

Workzone Crashes in Daytime vs. Nighttime

Year	**R1 High'**	**R2 High'**	**R3 High'**	**R4 High'**	**R5 High'**		
1998	3.00	3.45	10.00	2.33	11.00		
1999	3.57	5.00	7.57	11.00	4.00		
2000	3.38	2.46	23.00	3.33	8.00		
Total	3.28	3.63	9.67	4.00	7.67		
Year	**Portland**	**Salem**	**Medford**	**Bend**	**Pendleton**	**Average I**	**Average II**
1998	3.56	3.23	8.50	N/A	N/A	**5.63**	**5.22**
1999	7.25	3.5	N/A	3.00	N/A	**5.61**	**5.98**
2000	5.33	12	N/A	N/A	N/A	**8.22**	**8.22**
Total	4.89	3.71	13.50	8.00	N/A	**6.48**	**5.26**

NonWorkzone Crashes in Daytime vs. Nighttime

Year	R1 High'	R2 High'	R3 High'	R4 High'	R5 High'	
1998	3.24	3.64	2.87	2.94	2.37	
1999	3.32	3.50	3.15	2.93	2.52	
2000	3.25	3.32	3.23	3.09	2.07	
Total	3.27	3.49	3.07	2.99	2.31	
Year	**Portland**	**Salem**	**Medford**	**Bend**	**Pendleton**	**Average**
1998	3.20	3.72	4.26	4.94	5.81	**3.70**
1999	3.31	3.66	4.84	4.61	4.56	**3.64**
2000	3.09	3.8	4.41	5	4.28	**3.55**
Total	3.20	3.72	4.48	4.84	4.87	**3.62**

The reason the ratio value of daytime versus nighttime crashes is used is that it is difficult to analyze crash data in the two different time frames considering traffic volume data. Traffic volumes in cities or highways are not consistent. It depends on the specific location and traffic volume data is not available in sufficient detail. In addition, this study needs to judge by quantitative values when it is safer, daytime or nighttime. Thus, the obtaining ratio value of daytime versus nighttime crashes is the most appropriate technique to achieve the objective.

According to Table D.1 and Figure D.1, the overall average ratio value for crashes in a work zone is 6.48 and the value for crashes in a non-work zone is 3.62. This means that the number of crashes during the daytime is 6.48 times bigger than the number of crashes during the nighttime during construction or maintenance operations. The number of crashes during the day in a non-work zone is 3.62 times bigger than the number of crashes during the night. In addition, it is clear that the frequency of daytime crashes is significantly higher than the frequency of nighttime crashes in a work zone rather than a non-work zone. Figure D.2 shows clearly the overall results.

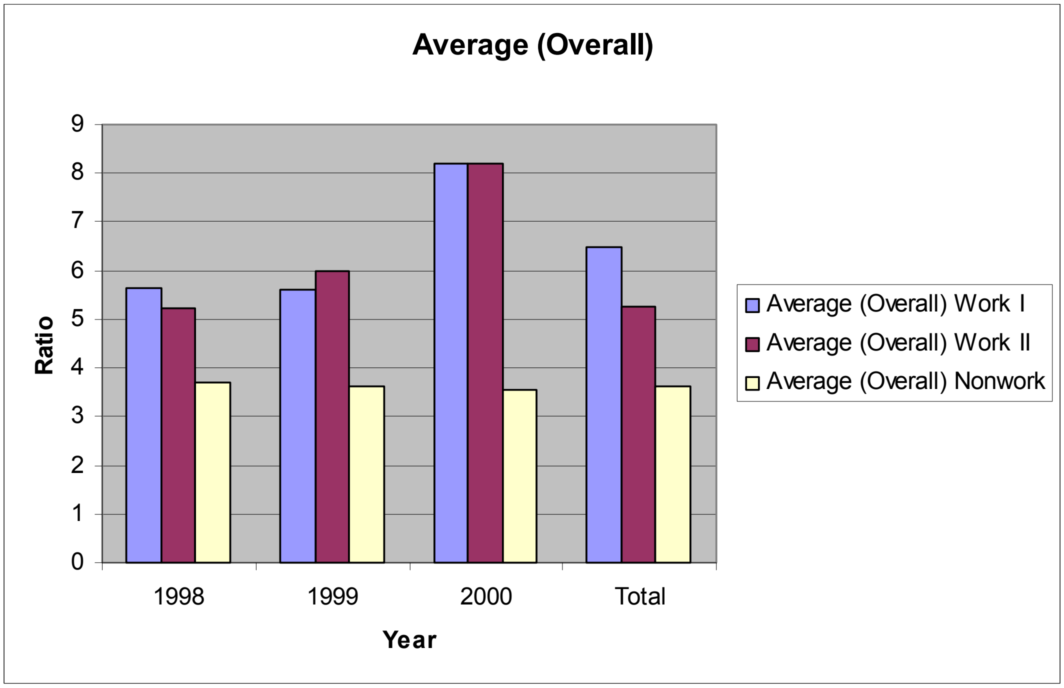


Figure D.2: The Overall Results

In Figure D.1, it is clear that the results of Region 1 Highways are consistently equivalent in ratio values for all 3 years in a work zone and a non-work zone, but the results of Region 3 Highways had the biggest differences between years in a work zone versus a non-work zone. However, the actual number of crashes in daytime in a work zone is 143 and the number in nighttime is 47, meanwhile the number in daytime in a non-work zone is 13,094 and the number in nighttime is 3,821 in Region 1. In Region 3 Highways, the actual crash number in daytime in a work zone is 23; meanwhile the number in nighttime is 1.

In Table D.1, the ratio value Medford in 1998 is 8.50, but the total ratio value for the city is 13.50. The reason why the total value increased is that there were some crashes during the daytime in 1999 and 2000, but there were no crashes in those years at nighttime so the ratio values in 1999 and 2000 are not applicable and this influences the increase in the total ratio value.

If the results of Table D.1 are re-sorted by higher versus lower traffic volume areas, new interesting results can be obtained and these are shown in Table D.2. In higher traffic volume areas, the ratio values in a work zone and a non-work zone are very similar, while in lower traffic volume areas, the ratio values in a work zone and a non-work zone are significantly different. With these facts, the following two conclusions can be established: 1) construction or maintenance operations do not significantly affect the increase of accidents in the higher traffic volume areas (16% increase), and 2) in the lower traffic volume areas, there are many more crashes at daytime in a work zone (128% increase). This conclusion may not be reliable if nighttime operations are not frequently conducted in lower traffic volume areas.

Table D.2: Crash Results by Higher vs. Lower Traffic Volume Areas

Higher Traffic Volume Areas

	Year	**R1 High'**	**R2 High'**	**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	Year	R1 High'	R2 High'	Portland	Salem	**Average**
	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**

Lower Traffic Volume Areas

	Year	R3 High'	R4 High'	R5 High'	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	Year	R3 High'	R4 High'	R5 High'	Medford	Bend	Pendleton	**Average**
	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**

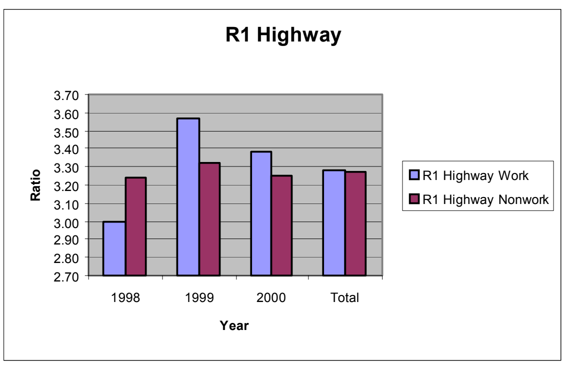
Results of Fatal Crashes

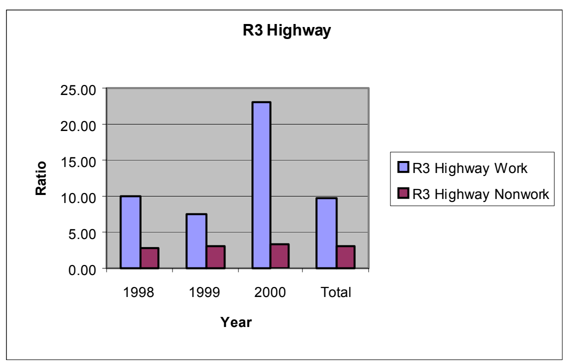
Table D.3 shows the results of fatal crashes and only three areas are analyzed because other areas did not have any fatal crashes in a work zone and therefore, it was not applicable to obtain the ratio value. Overall, the percentage of fatal crashes against the total number of crashes is very low (e.g., lower than 1% of total accidents). However, it is necessary to consider the fatal crashes because a fatal crash has huge costs for road users, workers, as well as ODOT, and people's lives are in jeopardy.

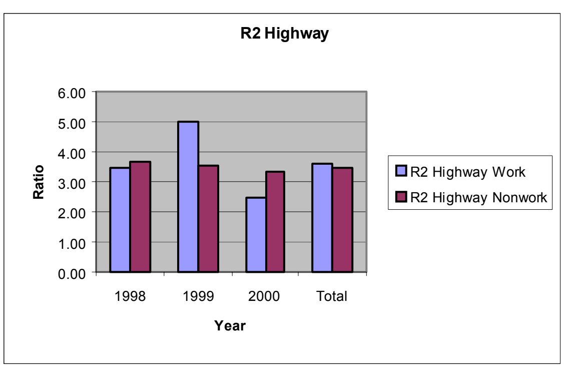
Table D.3: Result of Fatal Crash

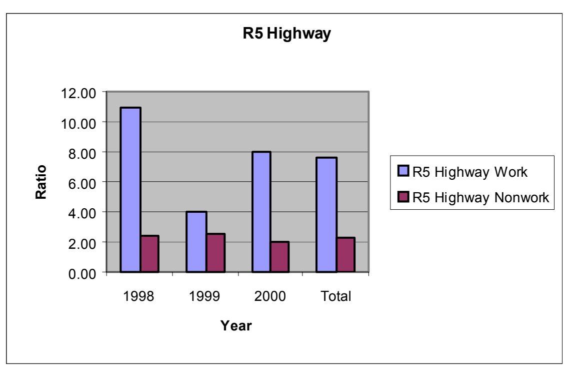
Year	Work					Nonwork					Night crash ratio of work vs. nonwork (=1.00)
	Daytime		Nighttime		D vs. N	Daytime		Nighttime		D vs. N	
	# of Fatal	% against total crash	# of Fatal	% against total crash	Ratio of % in D vs. N (D=1.00)	# of Fatal	% against total crash	# of Fatal	% against total crash	Ratio of % in D vs. N (D=1.00)	
R1 Highway											
1998	0	0.00	0	0.00	#DIV/0!	32	0.41	30	1.24	3.02	#DIV/0!
1999	1	1.22	2	8.70	7.13	32	0.44	20	0.90	2.05	3.49
2000	0	0.00	1	3.85	#DIV/0!	26	0.37	24	1.10	2.97	#DIV/0!
Total	1	0.38	3	3.70	9.74	90	0.40	74	1.08	2.70	3.61
R5 Highway											
1998	0	0.00	0	0.00	#DIV/0!	27	2.68	12	3.46	1.29	#DIV/0!
1999	1	25.00	0	0.00	0.00	17	1.85	11	3.01	1.63	0.00
2000	0	0.00	1	100.00	#DIV/0!	12	1.43	8	1.97	1.38	#DIV/0!
Total	1	4.35	1	33.33	7.66	51	1.98	31	2.77	1.40	5.48

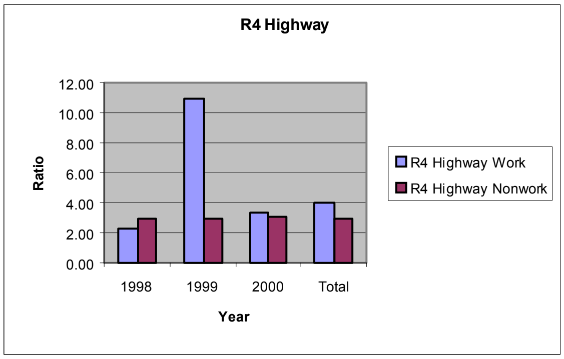
According to Table D.3, the fatal crash ratios of nighttime against daytime in a non-work zone are 2.70 for Region 1 Highways, and 1.40 for Region 5 Highways. The average value of the two areas is 2.05. However, the ratio values in a work zone are 9.74 for Region 1 Highways and 7.66 for Region 5 Highways. The average value is 8.70 and it is about 4.2 times higher than that of a non-work zone. Therefore, it is concluded that fatal crash rate at nighttime in a work zone is about 8 times higher than the rate for daytime.

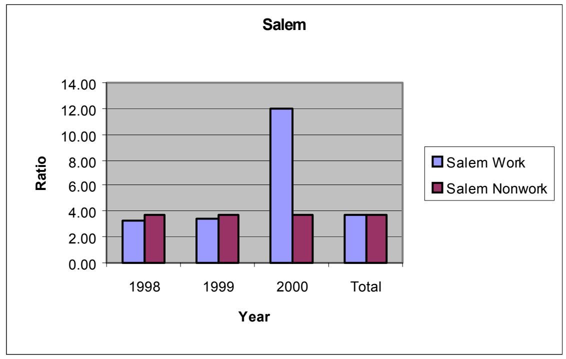









R4 Highway
Ratio
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1998
1999
2000
Total
Year
R4 Highway Work
R4 Highway Nonwork


Salem
Ratio
14.00
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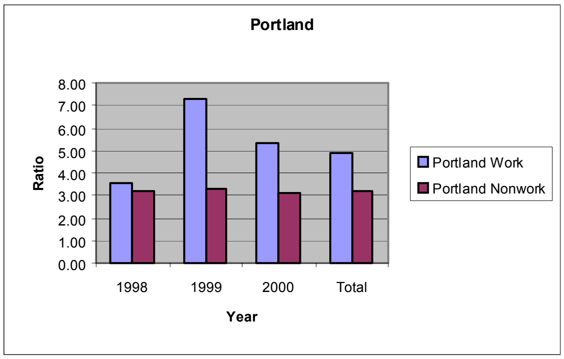
1998
1999
2000
Total
Year
Salem Work
Salem Nonwork


Portland
Ratio
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1998
1999
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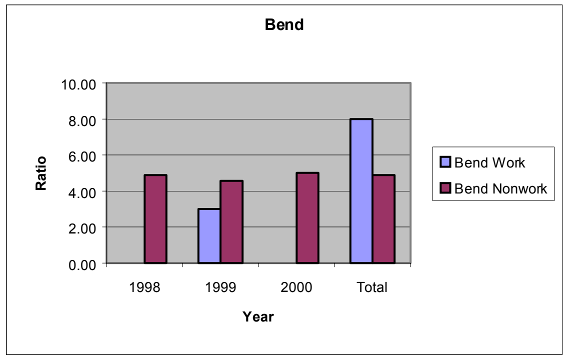
Total
Year
Portland Work
Portland Nonwork


Bend
Ratio
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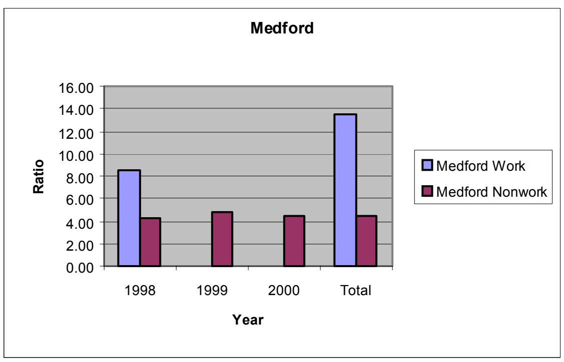
1998
1999
2000
Total
Year
Bend Work
Bend Nonwork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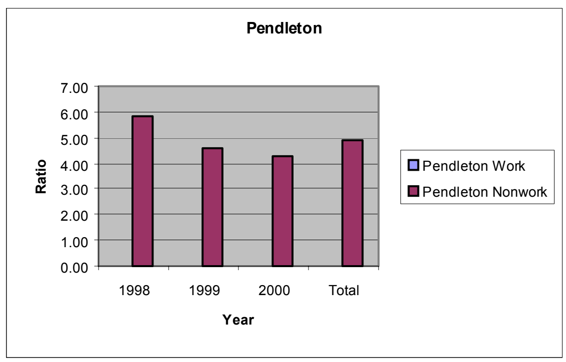
Total
Year
Medford Work
Medford Nonwork


Pendleton
Ratio
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2.00
1.00
0.00
1998
1999
2000
Total
Year
Pendleton Work
Pendleton Nonwork

APPENDIX E

USERGUIDE TO ESTIMATE ROAD USER COSTS

Background

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

Structure of the Spreadsheet

The spreadsheet consists of four separate sheets:

1) Information and Instructions: This section describes the background of the spreadsheet and lists the instructions for its use.

2) Lane Rental (LR) Input sheet: The user needs to enter the required information in the yellow cells. After entering the necessary information, the user costs for each hour for that project will be calculated.

3) LR Table sheet: This sheet enables the user to estimate road user costs based on specific traffic volumes for a particular area, instead of using the AADT (Annual Average Daily Traffic). User defined K-factors instead of standard K-factors as defined by the Highway Capacity Manual may also be used in the sheet. If the user enters the site specific information the accuracy of the estimate will be higher. If the user does not have this information then this sheet may be disregarded.

4) LR Calculation sheet: This sheet shows the detailed calculation of the user costs estimated in the LR input sheet or the LR table sheet.

The Lane Rental Input sheet may be used for a general estimate of user costs. If site specific traffic volumes or a user defined K-factor is available, then the Lane Rental Table Sheet may be used to estimate a more specific user cost.

Required Information

1. Project name
2. Analysis code: There are six codes total: Four codes for the type of road in a project: interstate urban (IU), interstate rural (IR), arterial urban (AU), and arterial rural (AR). If a user has a user defined K-factor or specific traffic volumes two additional codes may be used: user defined factors (UF), and user defined volumes (UV).
3. AADT: Enter AADT for both directions.
4. Percent of trucks
5. Number of lanes (one direction)
6. Free flow speed (mph): This is the posted speed for the road.
7. Maximum queue length limit (miles): The queue length limit is the first practical diversion point for traffic to take an alternate route around the congestion. If a user does not want to limit the queue length or wants to make the cost estimate conservative, enter the largest number (99) in this cell.
8. Confidence level (%): This is not a statistical confidence interval. It is a percentage of sites where the measured capacity equaled or exceeded the value given based on the lane capacity and the lane distribution. Figure 6-12 in the 1997 Highway Capacity Manual presents the cumulative distribution of observed work-zone capacities. (Zimmerman recommended that the 50th percentile was about the best a user could reasonably expect.)
9. Delay (\$/hour) passenger car: This study used 12.85.
10. Fuel cost (\$/gal): This study used 1.55.
11. Average # people per vehicle: This study used 1.25.
12. # of Lanes closed (one direction): Enter the number of lanes closed during work in each hour.

Special Cases

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

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

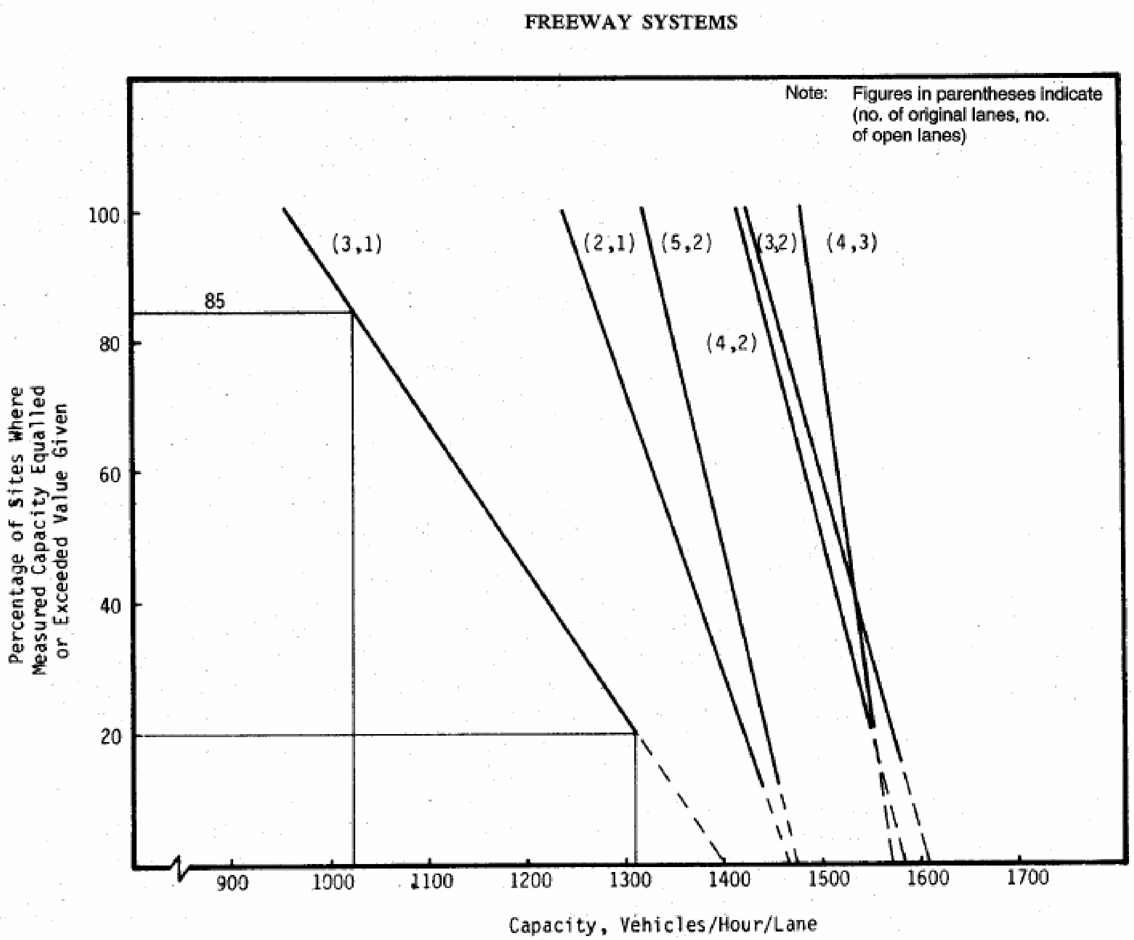

Figure 6-12. Cumulative distribution of observed work-zone capacities (9).

APPENDIX F

THE STUDY OF WORKER CONDITION

Background
Since worker condition is one of the major factors in making a decision of when to conduct nighttime construction and maintenance roadwork, the factor will be included in the decision model for this research. However, this factor is a qualitative factor and is necessary to quantify it for the decision model. In this memo, the process to quantify worker condition will be discussed.

In this research, it is impossible to conduct experiments to measure worker conditions in different shifts due to the limitation of time and budget. Thus, investigation of the published literature is the next best approach to gather information about worker conditions in different shifts and to quantify the factor.

There are several references concerning shift work in industry and the studies addressed various physiological issues related to shift work (Folkard et al., 1985, Fraser, 1989, Grandjean, 1988, and Kroemer et al., 1994 & 1997). They addressed circadian (diurnal) rhythms, sleep, and the scheduling of shift work. For circadian rhythms, typical variations in body functions over the day by body temperature, heart rate, blood pressure, and K^+ excretion were discussed. For sleep, sleeping stages, quantity, and quality of sleeping were addressed. In addition, some examples were provided to schedule the shift work. However, most studies found that it is difficult to conclude how much there is for workers during the night shift since 1) it is difficult to measure, 2) all individuals have different physiological conditions and 3) there were very few studies to investigate it.

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

Findings
After reviewing the literature, important facts used to quantify worker conditions are summarized in this section.

The Impacts of Nighttime Work
Costa (1996) addressed several negative impacts on health and the well being of workers due to shift work, especially night work:

1) Biological: coming from disturbances of normal circadian rhythms of the psychophysiological functions, beginning with the sleep/wake cycle
2) Working: producing errors and accidents due to fluctuations in work performance and efficiency over the 24-hour span.
3) Social: difficulties in maintaining the proper relationships with family and social levels and negative consequences on martial relations, caring of children and social contacts.
4) Medical: potential disorders such as gastrointestinal (colitis, gastroduodenitis and peptic ulcer), neuro-psychic (chronic fatigue, anxiety, depression) and cardiovascular (hypertension, ischemic heart diseases) functions due to disturbances of sleeping and eating habits.

Costa reviewed 19 former studies related to accident rates during daytime versus nighttime. Only 8 studies had a higher frequency of accidents at nighttime.

Kroemer et al. (1997) mentioned that on the average, night-shift workers have about half an hour less sleep time than permanent day-shift workers. No differences have been found in the mortality of night shift workers compared to workers in other shifts. However, it was fairly clear that night shift workers have suffered from health disturbances with greater frequency than other shift workers. Also, Fraser (1989) mentioned that two-thirds of the shift workers suffer from some form of demonstrable ill-health and one quarter abandon shift work altogether.

Shipley (1980) addressed that night-shift workers have a smaller amount of sleep than day-shift workers who have more uninterrupted blocks of sleep. However, for the implications for health, it is yet unknown. Kroemer et al. (1994) can support Shipley's argument with their finding that young adults sleep 7.5 hours with a standard deviation of about one hour on the average. Some adults are well rested after 6.5 hours of sleep, or less, while others take habitually 8.5 hours or more.

Accidents in Nighttime Work

In a comprehensive analysis of truck driver accident data, James & Robert (1980) found that a comparison between the percentage of accidents and the percentage of trucks on the road by time of day showed that only 19% of truck traffic occurred between midnight and 8:00 a.m., and about 81% in the other 16 hours. When the ratio of the percentage of accidents to percentage of trucks on the road by the time of day were considered, it was noted that an accident involving a dozing driver was about 7 times more likely to occur, on the average, in one of the early morning hours than in one of the other hours of the day.

Folkard, Monk, and Lobban (1978) collected all accidents and unusual incidents involving patients during their stay in hospitals from 1970 to 1975 to determine whether there was any circadian variation in the incidence of minor accidents. This study mentioned that the incidence of minor accidents decreased over the nurses' early and late day shifts and increased over their night shift. However, it is difficult to make a conclusion that only the nurses' circadian rhythms affect to the circadian variation in the frequency of accidents without considering those of the patients.

The Performance Level (Productivity) of Nighttime Work

The Study by Vidaček, Radošević-Vidaček, & Folkard, (1986)

Vidaček et al. conducted an experiment with 186 female shift workers at an electronics component factory. The workers were rotated in a three-shift system: morning (06:00-14:00), afternoon (14:00-22:00) and night (22:00-06:00) involving five successive workdays and two rest days. According to statistical analysis, there was a significant difference of the type of shifts since the productivity gap of afternoon and night shift was 50 (Table F.1). In Figure F.1, the productivity on Monday was the lowest in afternoon and night shift and increased until Wednesday, but decreased again. However, the productivity of morning shift workers was stable from Monday to Wednesday, but decreased on Thursday and slightly increased on Friday. The productivity (performance level) of night shift workers was at a 95.96% level of that of morning shift workers. In other words, productivity of night shift workers had a 4% decrease than that of morning shift workers. In addition, the productivity of night shift workers had a 4.5% decrease from that of a combination of morning and afternoon shifts.

Table F.1: The trend in productivity over a week of morning, afternoon and night shifts

Shift	Mon	Tue	Wed	Thru	Fri	Total	Average
Morning Shift	960	958	962	934	942	4756	951.2
Afternoon Shift	944	958	980	967	962	4811	962.2
Night Shift	855	898	952	946	913	4564	912.8

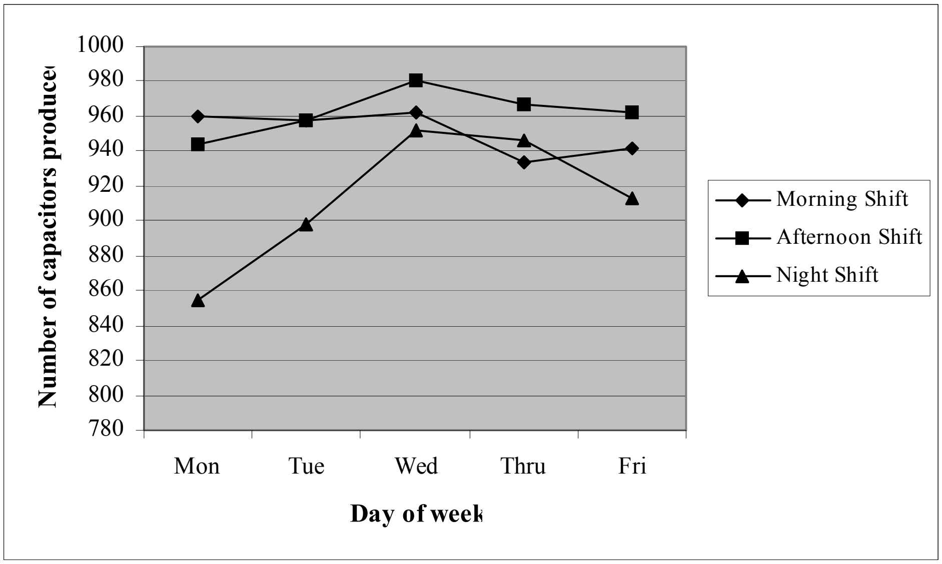

Figure F.1: The trend in productivity

The Study by Tilley, et al., (1982)
Tilley et al. conducted an experiment with two groups of six workers who were a mean age of 43 with a range from 30 to 60 years old from Cadbury Schweppes, Limited in Cambridge for 2 years. The workers in the group were divided into three sections: morning, afternoon, and night. Each had two workers working on the same shift.

First, this study measured the quantity of sleep and the result was workers for the night shift had 1.5 hours less sleep than the nighttime sleep periods for the afternoon-shift of which the average sleeping time was 7 hours. This represents a 25% reduction in sleeping time.

In order to measure the performance level of shift workers, this study measured simple unprepared reaction time. Figure F.2 and F.3 show the results. Figure F.2 is the result of the first half of the test and Figure F.3 is the second half of the test. The results indicate that simple reaction time of night-shift workers was poorer with successive nights on the night shift as the task duration increases.

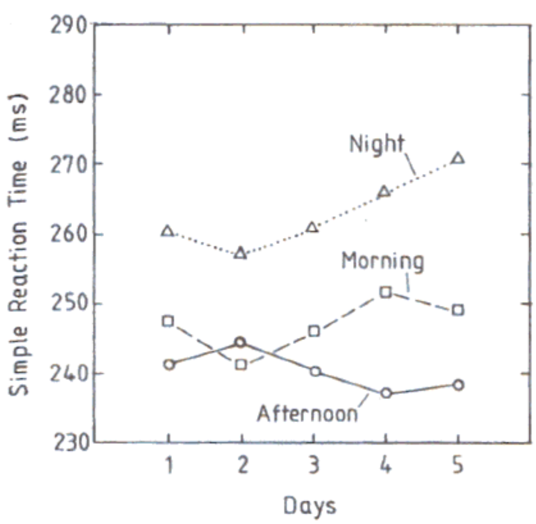

Figure F.2: Reaction time I (Tilley, et al., 1982)

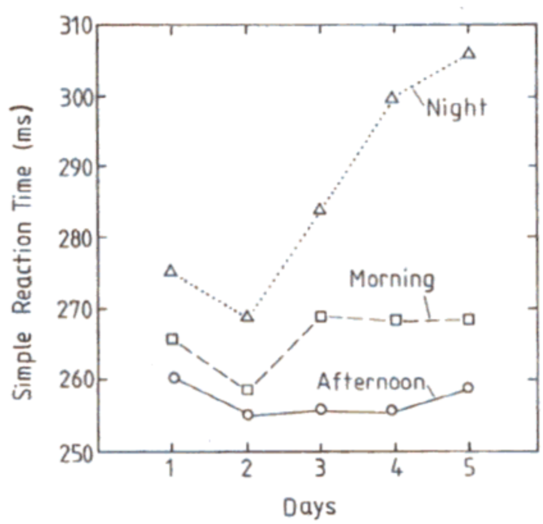

Figure F.3: Reaction time II (Tilley, et al., 1982)

By using the above data, Table F.2 can be created to compare the performance level of nighttime versus daytime. It is possible to conclude that the performance level of nighttime shift is 7 or 9 % lower than that of the morning shift or the combination of the morning and afternoon shifts.

Table F.2: Performance levels in different shifts

Shift	Total
Morning Shift	2568.50
Afternoon Shift	2491.00
Night Shift	2754.00
(Morning + Afternoon)/2	2529.75
Morning vs. Night Shift	0.07
(Morning + Afternoon)/2 vs. Night Shift	0.09

<u>The Study by Brown, (1949)</u>
Brown studied how the performance of teleprinter operators, especially female switchboard operators in the Royal Air Force Medical Service, during the war varies at different times of the day and night. He measured the waiting time per call of the operators.

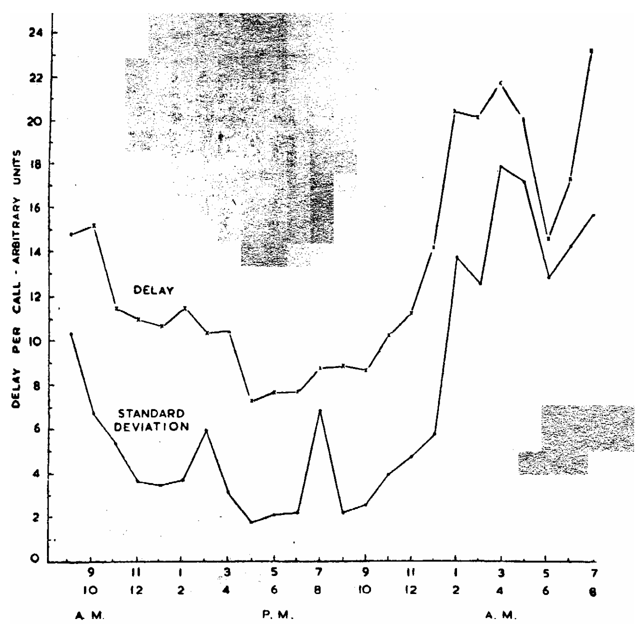

Figure F.4: Delay at various times (Brown, 1949)

With collected data, Figure F.4 can be obtained and Table F.3 shows the analysis of Figure 4. It could be concluded that the delay per call rate in night shift was 52% higher.

Table F.3: The performance levels of shift operators

Shift	SUM	AVG
Daytime Delay/Call	128.20	10.68
Nighttime Delay/Call	194.50	16.21
Comparison of Day vs. Night		0.52

The Study by Hildebrandt, Rohmert, & Rutenfranz, (1974)
This study investigated the frequency of errors made during the daily rhythms by locomotive drivers of the Federal German Railway. Figure F.5 shows the result of 2238 automatic compulsive braking caused from the drivers omitting to operate an attention switch when passing a pre-signal set in the warning position.

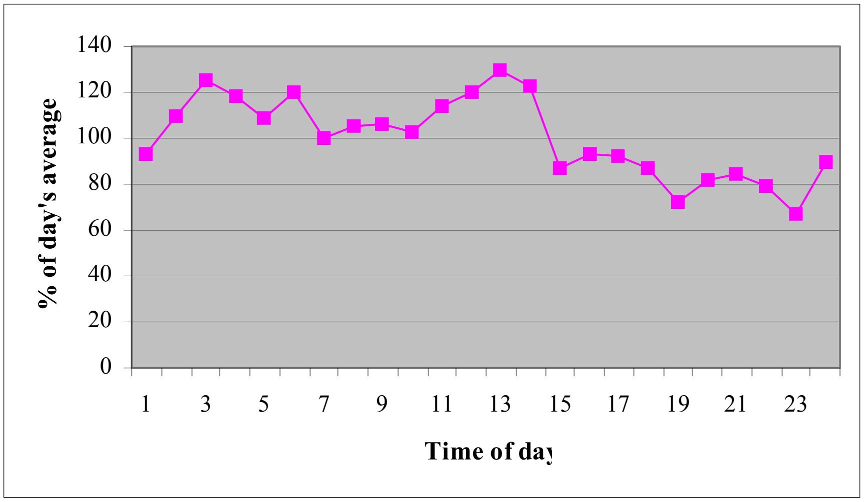

Figure F.5: Relative frequency of automatic compulsive braking

Figure F.5 shows that the time of the post-lunch dip hours such as 3 PM or 3 AM had the highest level of errors in a day. After calculation with the given figure in the paper, it can be concluded that daytime had a 10 % higher rate of the errors. Since performance levels of nighttime workers were generally lower because of the circadian rhythms, this study had a reverse result. However, this study did not clearly show how shift work divided into 24 hours.

The Study by Bjerner & Swensson, (1953 & 1955)
This study investigated shift workers' errors to read meters in a gas company in Sweden. Three workers, who were rotated on every week, were studied from 1912 to 1931. Figure F.6 shows the total number of errors at different times (24 hour cycles).

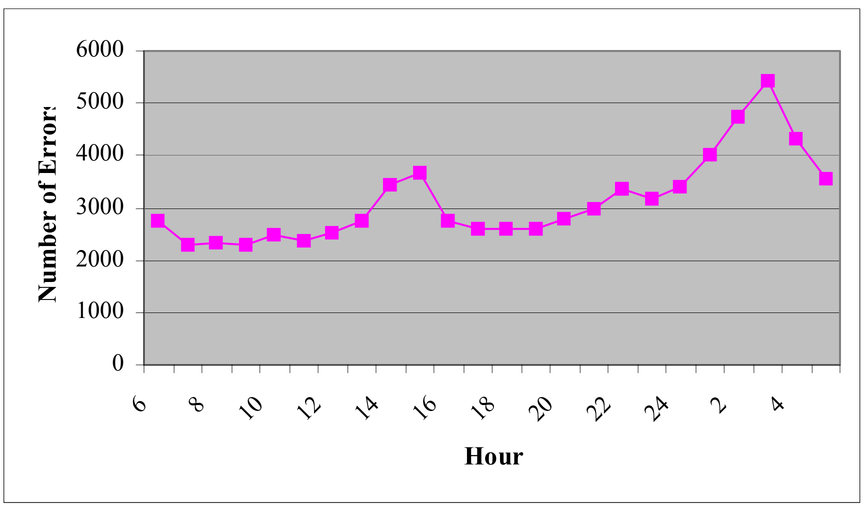

Figure F.6: The total number of errors at different times

Table F.4: The comparison of errors between daytime and nighttime

Sum of daytime	32290.00
Sum of nighttime	42920.00
Difference Between Nighttime and Daytime	10630.00
	0.33

With the data in Figure F.6, Table F.4 shows that the workers had the 32.92% higher rate of error during nighttime (6 PM – 5 AM). In addition, this study analyzed the above data by each worker in 6 weeks and 6 days. Six figures were provided in the paper, but it was very difficult to obtain exact data with the figures for further investigation. However, it is clear that the shapes of the figures are very similar to Figure F.6. In addition, since the length of daylight differs by the season, this study conducts statistical analysis about the difference of daylight lengths, but there is no significant difference between the lengths of daylight among seasons.

This study mentioned that other studies did similar types of research at different gas companies and the study had a similar curve to Figure F.6. Also, this study showed another study that was an experiment with rats to measure the performance level between daytime and nighttime had similar results, but this study concluded that it is difficult to make a conclusion with the experiments with rats because humans have social relations and it deeply affected nighttime work.

Wojtczak-Jaroszowa & Pawlowska-Skyba, (1967)

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

Table F.5 shows the time schedule of shift work in both companies. Figures F.7 and F.8 show the measured speed of work in each time period by different shifts. For example, period I covers 5:30-6:30 for morning shift, 13:30-14:30 for afternoon shift, and 21:30-22:30 for night shift in the clothing fabrication company in figure F.7. Table F.6 is the result of hypotheses tests to compare different shifts in both companies. According to the results, there is only significant difference between morning shift and night shift in a clothing industry. Other shifts did not have any significant differences between them.

Table F.3: The performance levels of shift operators

Shift	Clothing	Glass
Morning	5:30-13:30	6:00-14:00
Afternoon	13:30-21:30	14:00-22:00
Night	21:30-5:30	22:00-6:00

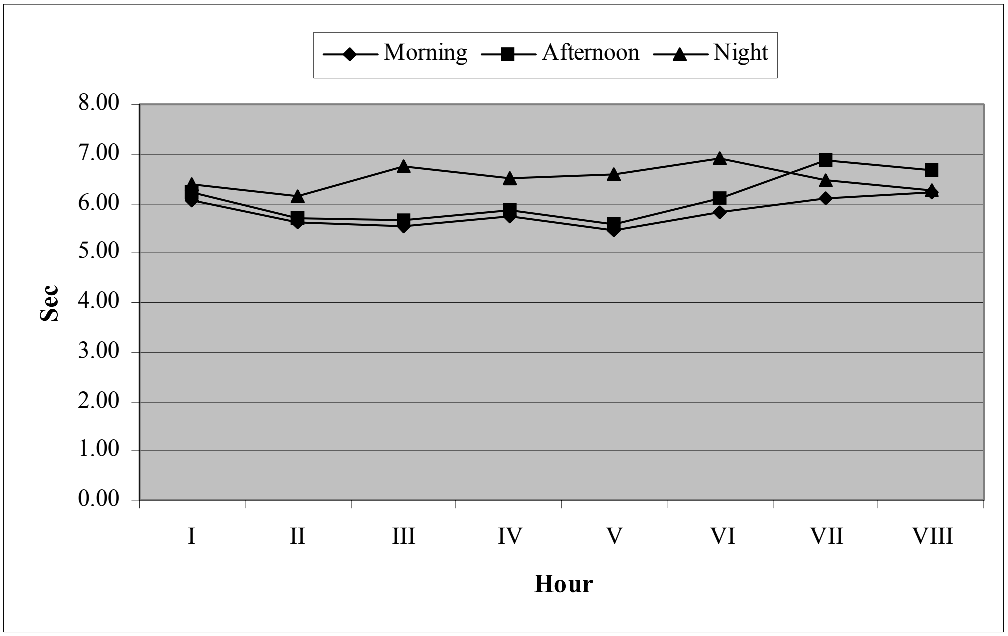

Figure F.7: The speed of work in different shifts in the clothing industry

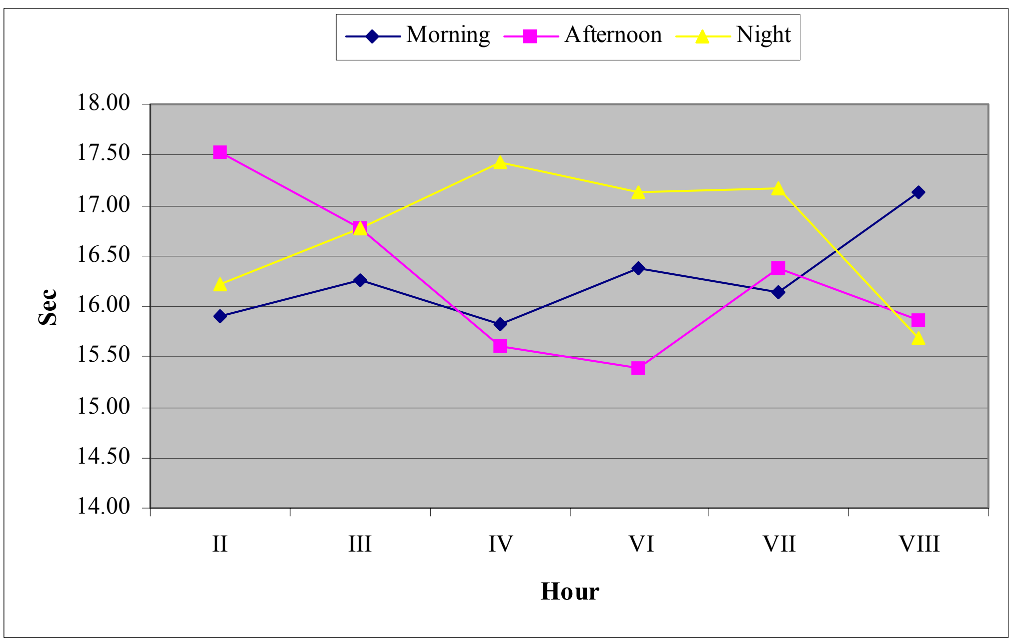

Figure F.8: The speed of work in different shifts in the glass industry

Table F.6: Hypotheses tests: p-value

	Clothing	Glass
Morning vs. Afternoon	0.234	0.690
Morning vs. Night	0.006	0.396
Afternoon vs. Night	0.110	0.283

Table F.7: Comparison of performance levels in different shifts in a clothing industry

Shift	I	II	III	IV	V	VI	VII	VIII	Average
M vs. N	5.28	9.07	21.70	13.61	20.66	18.73	6.24	0.80	11.73
A vs. N	2.41	7.92	18.69	11.09	18.49	13.09	-5.55	-6.14	6.89
M+A vs. N	3.82	8.50	20.18	12.34	19.57	15.84	0.00	-2.79	9.26

Table F.8: Comparison of performance levels in different shifts in a glass industry

Shift	II	III	IV	VI	VII	VIII	Average
M vs. N	1.95	3.20	10.11	4.52	6.39	-8.46	2.82
A vs. N	-7.47	0.00	11.60	11.24	4.83	-1.20	2.90
M+A vs. N	-2.99	1.57	10.85	7.77	5.60	-4.97	2.86

With the data provided in the paper, the analysis of the comparison of performance levels in different shifts in both companies could be obtained in Tables F.7 and F.8. In the clothing industry, it can be concluded that the performance level of female workers at night is 11.73% lower than that of the morning, 6.89% lower than that of the afternoon, and 9.26% lower than that of a combination of morning and afternoon. Also, in the glass industry, the performance level of male workers at night is 2.82% lower than that of the morning, 2.90% lower than that of the afternoon, and 2.86% lower than that of a combination of the morning and afternoon.

Female workers' performance level in the clothing company had a bigger difference between shifts than the performance level of male workers' in the glass company. However, the measured data from the glass company did not include all 8 working hours since the first and fifth time periods were excluded due to no working processes during the periods. This fact may affect the decrease in the gap of the performance level between shifts. Moreover, there is only a significant difference between morning and night shifts in a clothing industry with the result of hypotheses tests. It is possible to conclude that the performance level of night shifts is about 11.73% lower that that of the morning shift.

Other Studies

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

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

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

In this research, all six studies were reviewed, but it was concluded that the overall analysis using six studies by Monk et al. was not applicable to this research since two studies were not done using real measurements of shift work performance. Prokop and Prokop (1955) surveyed truck drivers in Germany to investigate when it was difficult to drive on the road for 24-hour cycles instead of measuring real performance of the truck drivers. Also, the study by Folkard, Monk and Lobban (1978) is not applicable since the relationship between the patients' accident and nurses' circadian rhythms is ambiguous.

Conclusion

After reviewing the literature of shift work, it was determined that a very low number of studies measure the performance levels of shift work. Only five studies had the applicable quantitative values of worker conditions in shift work and four of them were very old studies:

1) Vidaček, Radošević-Vidaček, & Folkard, (1986)
2) Tilley, Wilkinson, Warren, Watson, & Drud, (1982)
3) Brown, (1949)
4) Bjerner & Swensson, (1953 & 1955)
5) Wojtczak-Jaroszowa & Pawlowska-Skyba, (1967)

Table F.9 shows the detailed quantitative values of worker condition in shift work by each study. It can be carefully concluded that simple reaction time and speed of work are very close to worker condition, and the values are 7, 9, and 11.73% lower in night shift. Therefore, worker condition at nighttime is about 10% lower compared to daytime.

Table F.9: Overall results of worker condition

Study #	Subject	Result of Night Shift	
		Morning vs. Night	M+Afternoon vs. Night
1	Productivity	4% low	4.5% low
2	Simple reaction time	7% low	9% low
3	Delay per call	52% longer	N/A
4	Reading errors	32.92% higher	N/A
5	Speed of work	11.73% lower	N/A

APPENDIX G

PROJECT DETAILS

Project Name	I-5 Medford
Contract Number	12746
Name of PM/DM	Joseph Thomas
Project Type	Construction
Project Status	Current
Decision of Project Schedule	Both
Is the project a paving project?	Yes
If it is yes, is the pavement temperature below 21 degrees C or the humidity is higher than 75%?	No
Is the project duration less than 3 days?	No
If it is yes, can other nighttime project be done-back-to with this project to make the duration of work greater than 3 days?	N/A
Do you have workers who can be scheduled for night work?	Yes
Is this project on the State Highway System?	Yes
What region is this project in?	3
Will noise levels prevent this work being done at night due to current local ordinances?	No
If it is yes, would a noise variance be possible?	N/A
If it is no, can work be scheduled such that nosiest portions of the work can be done and meet local ordinances?	N/A
Will the project result in unacceptable local business access during daytime?	No
Information for estimation of user cost:	
What location category is this project?	Interstate-Rural
Which direction plans to be worked?	Both
What is the AADT (both directions) in the project area?	40600
What is the percentage of trucks?	15%
What is the number of lanes (one direction)?	2
What is the free flow speed (mph)?	55
If the project will be conducted (or was conducted) at daytime, what are the starting and ending times in each day? How many lanes will be closed (or was closed) in each direction during working?	Both day and night
If the project will be conducted (or was conducted) at nighttime, what are the starting and ending times in each day? How many lanes will be closed (or was closed) in each direction during working?	Both day and night

I-84 Resurfacing	US 97 Bend Resurfacing	I-84 Resurfacing
12708	12394	12776
Marge West	Jon Heacock	Patrick Cimmiyotti
Construction	Construction	Construction
Current	Former	Future
Nighttime	Nighttime	Nighttime
Yes	Yes	Yes
No	No	No
No	No	No
N/A	N/A	N/A
Yes	Yes	Yes
Yes	Yes	Yes
1	4	4
Yes	Yes	No
Yes	Yes	N/A
N/A	N/A	N/A
No	Yes	No
Interstate-Urban	Arterial Urban	Interstate-Rural
Both	Both	Both
160000	24000-30000	10700
15%	12%	15%
3	2	Two
55	35-45	65
No lane closure between 5 AM - 8 PM and weekends 9 AM - 9 PM	Could not be done during the day in this city.	Anticipated work schedule will be 7AM-7PM with one lane being closed.
One lane closure between 9PM-6AM (Eastbound), One lane closure between 8PM-5AM (Westbound), Two lane closure between 11PM-5AM (Both)	9PM-6AM and 2 travel lanes closed during operation	7PM-7AM and one lane would be closed.

The Port of Entry	I-5 Pavement Preservation in North Portland	Pendleton Viaduct Seal Project
12576	12460	Maintenance
Tom Feeley	Earl Mershon	Terry Mcartor
Construction	Construction	Maintenance
Former	Current	Future
Nighttime	Nighttime	Nighttime
Yes	Yes	
No	No	
No	No (2 years)	Yes (2 days)
N/A	N/A	
Yes	Yes	Yes
Yes	Yes	Yes
4	1	5
No	Yes	No
N/A	Yes	N/A
N/A	N/A	N/A
No	No	No
Interstate-Rural	Interstate-Urban	Arterial-Urban
Both	Both	Both
6900	130000	14600
33%	9%	
One	2 and 3 lanes in each	1
55	55	35
No	No daytime lane closures.	Too much traffic during the day to safely do this project
One lane was closed at night the night shift was 6PM to 6AM.	Sunday through Thursday nights in 3-lane sections: close 1 lane at 8PM, 2 at 10:30PM. Reopen by 5:30 AM.	7PM-4:30AM, one lane closed in one direction, the turn lane will be coned off and used for travel around the work zone.

OR 8 Grind Inlay Beaverton	OR 8 Grind Inlay Forest Grove	OR 43 Overlay (West Linn)	Straightening of steel bridge beam damaged by an over height truck
N/A	N/A	N/A	N/A
Ron Kroop	Ron Kroop	Ron Kroop	Larry Olson
Maintenance	Maintenance	Maintenance	Maintenance
Former	Future	Former	Former
Nighttime	Not Yet	Daytime	Nighttime
			No
			N/A
No	No	Yes (I day)	No (3day Project)
N/A	N/A	No	N/A
Contract	Contract	Yes	Yes
Yes	Yes	Yes	Yes
1	1	1	1
Yes	Yes	Yes	No
Yes	Yes	Yes	N/A
N/A	N/A	N/A	N/A
Yes	Yes	Yes	No
Arterial-Urban	Arterial-Urban	Arterial-Urban	Interstate-Urban
Both	Both	Both	Inbound
40000	15000	20000	157200
5%	3%	3%	20%
2	2	2	4
35-45	23-35	35	55
	Not Yet	7AM-3PM, 1 lane closure in each direction	Impossible to close lanes due to traffic congestion
9PM-5AM, 1 lane closure in each direction	Not Yet		11PM-5AM, 2 lane closed