SCHOOL OF
CIVIL ENGINEERING

INDIANA

DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-95/1

Final Report

AN EVALUATION OF LANE CLOSURE
STRATEGIES FOR INTERSTATE WORK ZONES

Raktim Pal and Kumares C. Sinha

PURDUE UNIVERSITY

Final Report

**An Evaluation of Lane Closure Strategies
for Interstate Work Zones**

FHWA/IN/JHRP-95/1

by

Raktim Pal
Graduate Research Assistant

and

Kumares C. Sinha
Professor of Civil Engineering

Joint Highway Research Project

Project No: C-36-67HH
File No: 9-10-34

Prepared in cooperation with the
U.S. Department of Transportation Federal Highway Administration

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Purdue University
West Lafayette, IN 47907
November 20, 1995

1. Report No. FHWA/IN/JHRP-95/1	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle An Evaluation of Lane Closure Strategies for Interstate Work Zones		5. Report Date November 20, 1995	
		6. Performing Organization Code	
7. Author(s) Raktim Pal and Kumares C. Sinha		8. Performing Organization Report No. FHWA/IN/JHRP-95/1	
9. Performing Organization Name and Address Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284		10. Work Unit No.	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Indiana Department of Transportation Indiana Government Center North 100 North Senate Avenue Indianapolis, IN 46204		13. Type of Report and Period Covered Final Report September, 1993 to May, 1995	
		14. Sponsoring Agency Code	
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.			
16. Abstract A systematic procedure was developed in the present study that can be used to make a decision regarding the appropriate lane closure strategy at a particular interstate work zone. Four criteria were identified which influence such a decision, namely user travel time and vehicle operating cost, traffic control cost, safety, and contractors' convenience. The influences of these criteria were aggregated using the Analytic Hierarchy Approach. The procedure developed in the present study is systematic in nature, simple to use and sensitive to the policy adopted by a transportation agency. A computer program, LANECLOSE, was developed which can be readily used to select the appropriate lane closure strategy.			
17. Key Words work zone, lane closure, safety, user cost		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Virginia, 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 200	22. Price

IMPLEMENTATION REPORT

There are mainly two lane closure strategies for interstate highway work zones, cross-overs and partial lane closures. There is a trade-off between the two lane closure strategies. The trade-off relationship is location specific and no lane closure strategy can be appropriate for all sites. In some situations a cross-over may be better than a partial lane closure and in some other situations it may be other way around. A systematic procedure was developed in the present study that can be used to make a decision regarding the appropriate lane closure strategy at a particular interstate work zone. Four criteria were identified which influence such a decision, namely user travel time and vehicle operating cost, traffic control cost, safety, and contractors' convenience. A computer program, LANECLOSE, was developed so that the work zone traffic planner can easily use the procedure. It is coded in C language. A special attention was given to the easy availability of the input data for the project site under consideration. The input required are work zone length in miles, traffic volume in vehicles per day, duration of lane closure in days, accident rate (per 10 million vehicle-miles travelled) under normal operating conditions and estimated total project cost in dollars. The project site has to be divided into a number of segments according to the traffic and geometric characteristics and the input data for each segment have to be entered separately. The computer program is self explanatory and the user can easily enter the input data in an interactive manner. The program determines the impact of lane closure strategies on the four factors considered. The ratings for contractors' convenience under the two lane closure strategies are incorporated in the program as default values. However, there is an option for using

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site specific values. The overall evaluation of the lane closure strategy depends on the relative importance of the decision criteria. The user can either assign the relative importance values or can use the default values which are imbedded in the program. A sensitivity analysis may be performed by changing the relative importance of the decision criteria. Finally, the overall weight of each lane closure strategy is determined. The strategy with higher weight is selected as the appropriate lane closure strategy at the given project site. It is recommended that the INDOT personnel involved in work zone traffic planning should use the software extensively to verify its capability.

TABLE OF CONTENTS

	Page
LIST OF TABLES	vi
LIST OF FIGURES	xiv
ABSTRACT	xv
CHAPTER 1 INTRODUCTION	1
1.1 Background	1
1.2 Purpose of the Research	2
1.3 Outline of the Study	4
1.4 Data Types and Sources	7
1.5 Organization of Report	11
CHAPTER 2 ESTIMATION OF USER COSTS	12
2.1 Introduction	12
2.2 Estimation of User Costs	12
2.3 Estimation of User Costs using Regression Model	25
CHAPTER 3 COST OF TRAFFIC CONTROL AT WORK ZONES	31
3.1 Introduction	31
3.2 Traffic Control Cost Data Analysis	31
3.3 Regression Model to Predict Cost of Traffic Control	42
CHAPTER 4 CONTRACTORS' OPINION ON LANE CLOSURE STRATEGY	46
4.1 Introduction	46
4.2 Opinion Survey and Ratings of Contractors' Convenience	47
4.3 Contractors' Preference as Cost Savings	50
4.4 Chapter Conclusion	62
CHAPTER 5 ACCIDENT ANALYSIS AT WORK ZONES	63
5.1 Introduction	63
5.2 Data Collection	64
5.3 Statistical Procedure	65
5.4 Accident Data Analysis	70
5.5 Regression Model to Predict Probable Number of Accidents	89

CHAPTER 6	SYNTHESIS OF STUDY RESULTS	97
	6.1 Introduction	97
	6.2 Selection of Lane Closure Strategy	98
	6.3 Sensitivity Analysis	106
	6.4 Chapter Conclusion	113
CHAPTER 7	SUMMARY AND CONCLUSION	114
	7.1 Summary	114
	7.2 Lane Closure Strategy Selection	114
	7.3 Conclusion	119
LIST OF REFERENCES		120
APPENDICES		
	Appendix A Accident Data	123
	Appendix B Poisson and Negative Binomial Models for Crash Estimation	165
	Appendix C Results of Sensitivity Analysis	169
	Appendix D Computer Program : LANECLOSE	186

LIST OF TABLES

Table	Page
1.1 List of Projects Using Cross-Over : Sites with Two Lanes in Each Direction	8
1.2 List of Projects Using Partial Lane Closure : Sites with Two Lanes in Each Direction	9
1.3 List of Projects Using Cross-Over : Sites with Three Lanes in Each Direction	10
2.1 Average Speeds at Locations Immediately Upstream or Downstream of Work Zones	16
2.2 Average Speeds in Work Zones with Partial Lane Closure	17
2.3 Average Speeds in Work Zones with Cross-Over	18
2.4 Average Speeds on Interstate Highways under Normal Operating Conditions (Speed Limit : 65 mph)	19
2.5 Estimated User Costs in Different Sites with Two Lanes in Each Direction	21
2.6 Estimated User Costs in Different Sites with Three Lanes in Each Direction	24
2.7 Additional User Costs in Cross-Overs and Partial Lane Closures as Percentage of User Costs without Work Zones : Sites with Two Lanes in Each Direction	26
2.8 Additional User Costs in Cross-Overs and Partial Lane Closures as Percentage of User Costs without Work Zones : Sites with Three Lanes in Each Direction	27

Table	Page
2.9 Regression Model for Sites with Two Lanes in Each Direction	29
2.10 Regression Model for Sites with Three Lanes in Each Direction	30
3.1 Cost of Traffic Control for Sites Using Cross-Over : Sites with Two Lanes in Each Direction	33
3.2 Cost of Traffic Control for Sites Using Partial Lane Closure : Sites with Two Lanes in Each Direction	34
3.3 Cost of Traffic Control for Sites Using Partial Lane Closure : Sites with Three Lanes in Each Direction	35
3.4 Summary of Traffic Control Costs under Different Strategies	40
3.5 Summary of Statistical Analysis on Traffic Control Costs under Different Strategies	41
3.6 Explanatory Variables in the Regression Model to Estimate Traffic Control Cost	43
3.7 Statistical Characteristics of the Regression Model to Estimate Traffic Control Cost	44
4.1 Contractors' Ratings on Lane Closure Strategies Concerning Safety	48
4.2 Contractors' Ratings on Lane Closure Strategies Concerning Workability	49
4.3 Grades of Membership for Different Ranges of Safety Related Savings in a Cross-Over (Work Zone Length = 4 miles, ADT = 20000)	58
4.4 Grades of Membership for Different Ranges of Workability Related Savings in a Cross-Over (Work Zone Length = 4 miles, ADT = 20000)	59
5.1 Effect of Cross-Over on Work Zone Accident Rates : Sites with Two Lanes in Each Direction	71
5.2 Effect of Partial Lane Closure on Work Zone Accident Rates : Sites with Two Lanes in Each Direction	72
5.3 Effect of Cross-Over on Work Zone Accident Rates : Sites with Three Lanes in Each Direction	73

Table	Page
5.4 Effect of Partial Lane Closure on Work Zone Accident Rates : Sites with Three Lanes in Each Direction	74
5.5 Overall Accident Rates at Sites Using Cross-Over : Sites with Two Lanes in Each Direction	75
5.6 Overall Accident Rates at Sites Using Partial Lane Closure : Sites with Two Lanes in Each Direction	76
5.7 Overall Accident Rates at Sites Using Cross-Over : Sites with Three Lanes in Each Direction	77
5.8 Overall Accident Rates at Sites Using Partial Lane Closure : Sites with Three Lanes in Each Direction	78
5.9 Average Overall Accident Rates in Different Scenarios	79
5.10 Fatal and Non-Fatal Injury Accident Rates at Sites Using Cross-Over : Sites with Two Lanes in Each Direction	81
5.11 Fatal and Non-Fatal Injury Accident Rates at Sites Using Partial Lane Closure : Sites with Two Lanes in Each Direction	82
5.12 Fatal and Non-Fatal Injury Accident Rates at Sites Using Cross-Over : Sites with Three Lanes in Each Direction	83
5.13 Fatal and Non-Fatal Injury Accident Rates at Sites Using Partial Lane Closure : Sites with Three Lanes in Each Direction	84
5.14 Average Fatal and Non-Fatal Injury Accident Rates in Different Scenarios	85
5.15 Average Accident Rates : With Work Zone Vs. Without Work Zone	86
5.16 Testing the Effect of Work Zone on the Average Accident Rate	86
5.17 Average Overall Accident Rates : Cross-Over Vs. Partial Lane Closure	87
5.18 Testing the Effect of Lane Closure Strategy on the Average Overall Accident Rate	87

Table	Page
5.19 Average Fatal and Non-Fatal Injury Accident Rates : Cross-Over Vs. Partial Lane Closure	88
5.20 Testing the Effect of Lane Closure Strategy on the Average Fatal and Non-Fatal Injury Accident Rate	88
5.21 Explanatory Variables in the Regression Model	91
5.22 Model for Sites using Cross-Over : Sites with Two Lanes in Each Direction	92
5.23 Model for Sites using Partial Lane Closure : Sites with Two Lanes in Each Direction	94
5.24 Model for Sites using Cross-Over : Sites with Three Lanes in Each Direction	95
5.25 Model for Sites using Partial Lane Closure : Sites with Three Lanes in Each Direction	96
6.1 Scale Values Developed by Saaty (1980) to Assign Relative Importance to the Different Decision Criteria	100
6.2 Reciprocal Matrix Showing Relative Importance of Different Components in Contractors' Convenience	104
6.3 Reciprocal Matrix Showing Relative Importance of the Four Decision Criteria	105
6.4 Aggregate Weights of Lane Closure Strategies in AHP : Sites with Two Lanes in Each Direction	107
6.5 Aggregate Weights of Lane Closure Strategies in AHP : Sites with Three Lanes in Each Direction	108
6.6 Summary of results : Sites with Two Lanes in Each Direction	109
6.7 Summary of results : Sites with Three Lanes in Each Direction	110
6.8 Sensitivity Analysis for Contractors' Convenience	112
6.9 Sensitivity Analysis for Safety	112

Table	Page
A.1 Accident Data for R-19484 : Cross-Over at a Site with Two Lanes in Each Direction	123
A.2 Accident Data for R-20370 : Cross-Over at a Site with Two Lanes in Each Direction	124
A.3 Accident Data for R-20368 : Cross-Over at a Site with Two Lanes in Each Direction	125
A.4 Accident Data for R-20369 : Cross-Over at a Site with Two Lanes in Each Direction	126
A.5 Accident Data for R-19972 : Cross-Over at a Site with Two Lanes in Each Direction	129
A.6 Accident Data for R-19847 : Cross-Over at a Site with Two Lanes in Each Direction	131
A.7 Accident Data for R-20384 : Cross-Over at a Site with Two Lanes in Each Direction	132
A.8 Accident Data for R-19112 : Cross-Over at a Site with Two Lanes in Each Direction	133
A.9 Accident Data for R-19113 : Cross-Over at a Site with Two Lanes in Each Direction	134
A.10 Accident Data for R-19113 : Partial Lane Closure at a Site with Two Lanes in Each Direction	135
A.11 Accident Data for R-19979 : Partial Lane Closure at a Site with Two Lanes in Each Direction	136
A.12 Accident Data for R-18301 : Partial Lane Closure at a Site with Two Lanes in Each Direction	138
A.13 Accident Data for R-17425 : Partial Lane Closure at a Site with Two Lanes in Each Direction	140
A.14 Accident Data for R-18572 : Partial Lane Closure at a Site with Two Lanes in Each Direction	141

Table	Page
A.15 Accident Data for R-18831 : Partial Lane Closure at a Site with Two Lanes in Each Direction	144
A.16 Accident Data for R-20502 : Partial Lane Closure at a Site with Two Lanes in Each Direction	148
A.17 Accident Data for R-20503 : Partial Lane Closure at a Site with Two Lanes in Each Direction	150
A.18 Accident Data for R-17424 : Partial Lane Closure at a Site with Two Lanes in Each Direction	151
A.19 Accident Data for R-20511 : Cross-Over at a Site with Three Lanes in Each Direction	153
A.20 Accident Data for R-17992 : Cross-Over at a Site with Three Lanes in Each Direction	154
A.21 Accident Data for R-20511 : Cross-Over at a Site with Three Lanes in Each Direction	155
A.22 Accident Data for R-19394 : Cross-Over at a Site with Three Lanes in Each Direction	156
A.23 Accident Data for R-19396 : Partial Lane Closure at a Site with Three Lanes in Each Direction	158
A.24 Accident Data for R-20060 : Partial Lane Closure at a Site with Three Lanes in Each Direction	161
A.25 Accident Data for R-18806 : Partial Lane Closure at a Site with Three Lanes in Each Direction	162
A.26 Accident Data for R-19482 : Partial Lane Closure at a Site with Three Lanes in Each Direction	163
A.27 Accident Data for B-17737 : Partial Lane Closure at a Site with Three Lanes in Each Direction	164
B.1 Model for Sites using Cross-Over : Sites with Two Lanes in Each Direction	165

Table	Page
B.2 Model for Sites using Partial Lane Closure : Sites with Two Lanes in Each Direction	166
B.3 Model for Sites using Cross-Over : Sites with Three Lanes in Each Direction	167
B.4 Model for Sites using Partial Lane Closure : Sites with Three Lanes in Each Direction	168
C.1 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Convenience is Reduced by 10% : Sites with Two Lanes in Each Direction	169
C.2 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Convenience is Reduced by 10% : Sites with Three Lanes in Each Direction	171
C.3 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Convenience is Reduced by 5% : Sites with Two Lanes in Each Direction	172
C.4 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Convenience is Reduced by 5% : Sites with Three Lanes in Each Direction	173
C.5 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Convenience is Increased by 5% : Sites with Two Lanes in Each Direction	174
C.6 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Convenience is Increased by 5% : Sites with Three Lanes in Each Direction	175
C.7 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Convenience is Increased by 10% : Sites with Two Lanes in Each Direction	176
C.8 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Convenience is Increased by 10% : Sites with Three Lanes in Each Direction	177

Table	Page
C.9 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Reduced by 10% : Sites with Two Lanes in Each Direction	178
C.10 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Reduced by 10% : Sites with Three Lanes in Each Direction	179
C.11 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Reduced by 5% : Sites with Two Lanes in Each Direction	180
C.12 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Reduced by 5% : Sites with Three Lanes in Each Direction	181
C.13 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Increased by 5% : Sites with Two Lanes in Each Direction	182
C.14 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Increased by 5% : Sites with Three Lanes in Each Direction	183
C.15 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Increased by 10% : Sites with Two Lanes in Each Direction	184
C.16 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Increased by 10% : Sites with Three Lanes in Each Direction	185

LIST OF FIGURES

Figures	Page
1.1 Arrangement in a Cross-Over	3
1.2 Arrangement in a Partial Lane Closure	5
1.3 Factors Involved in the Selection of a Lane Closure Strategy	6
4.1 Effect of Traffic Volume on the Safety Related Savings in Cross-Overs	52
4.2 Effect of Work Zone Length on the Safety Related Savings in Cross-Overs	53
4.3 Effect of Traffic Volume on the Workability Related Savings in Cross-Overs	54
4.4 Effect of Work Zone Length on the Workability Related Savings in Cross-Overs	55
4.5 Histogram Showing the Safety Related Savings in Cross-Overs	60
4.6 Histogram Showing the Workability Related Savings in Cross-Overs	61
7.1 Schematic Diagram of the Lane Closure Strategy Selection Process	115

CHAPTER 1

INTRODUCTION

1.1 Background

In the decades of sixties and seventies large amounts of money were spent in the U.S. for the construction of new highways, especially the interstates. With the passage of time, these highways are requiring extensive rehabilitation and maintenance. However, maintenance or rehabilitation activities involve substantial amount of user costs including travel delay, accident and vehicle running cost. Depending on the type of lane closure strategy used, work zones also affect agency costs to a considerable degree. Several studies (Mehmott and Dudek, 1985 ; Cassidy and Han, 1993) have been conducted to find the delay caused by work zone. Safety is also a serious problem. Many researchers (Casteel and Ullman, 1991 ; Pigman and Agent, 1990 ; Hall and Lorenz, 1989) have found that accident rates are significantly higher in work zones than those under normal operation. Several reasons may be attributed to the increase in accident rates because of work zones. First of all, work zones provide a restrictive operating condition affecting the traffic safety and the impact becomes aggravated when the traffic volume is high. Failure to slow down at work zones was found to be a major cause of accidents (Nemeth and Migletz, 1978 ; Faulkner and Richards, 1981 ; Nemeth and Roupail, 1983).

A significant amount of research has been conducted to assess appropriate measures to reduce speed in work zones. Changeable message signs were found to be effective (Richards et al., 1985 ; Hanscom, 1982). The presence of law enforcement officers was also observed to be effective in reducing speed (Levine and Kabat, 1985 ; Richards et al.,1985). Recently the use of radar activated audible messages was studied and found to have some effect on speeding motorists (Benekohal, 1992).

Most of the research conducted so far involved ways and measures for modifying the current lane closure practices in work zones. Not much research, however, has been done to find a systematic method for selecting appropriate lane closure strategies. A notable exception is the work by Dudek et al. (1987) that evaluated lane closure strategies for work zones on four-lane divided highways. However, the study did not provide a conclusive decision regarding the selection of an appropriate lane closure strategy. The present study is intended to fill the gap in current information in evaluating the effectiveness of lane closure strategies for interstate 4R projects.

1.2 Purpose of the Research

There are mainly two lane closure strategies for the work zones on interstate highways : cross-over and partial lane closure. The details of these lane closure strategies are given in the Manual of Uniform Traffic Control Devices (1988). In a cross-over arrangement, as shown in Figure 1.1, all lanes in one direction are closed and two-way traffic is maintained side by side. Cross-overs are constructed to bring the traffic of both directions to one side of the highway. The other side is completely closed for the maintenance or reconstruction activities. In most of the sites in Indiana, bituminous dividers are used to

Figure 1.1 Arrangement in a Cross-Over
(Source : Indiana Manual on Traffic Control Devices, 1988)

separate the traffic moving in opposite directions and drums are used as channelization devices. Thus the drivers have to face the opposing traffic without the protection of sufficient medians. Under heavy traffic and in the night or in bad weather this situation gives rise to safety problem. Moreover, due to the presence of nearby opposing traffic the lane capacity is reduced adding to the delay to the motorists. On the other hand, in a partial lane closure, as shown in Figure 1.2, one or more lanes are closed in one or both directions, but all the lanes in one direction are not closed any time. Traffic cones, drums or concrete barriers are used to close the lanes and maintenance or reconstruction activities are performed on the closed lanes. In such an arrangement traffic is maintained very near to the work zone crew. Due to the proximity of passing vehicles the safety of the work zone crew is endangered and it becomes difficult for construction equipment and other vehicles to go in and out of work zones. Consequently, the work productivity as well as the work quality suffer. Thus, there is a trade-off between the two lane closure strategies. In some situations a cross-over may be better and in some other situations a partial lane closure may be desirable. In this study an attempt was made to identify this trade-off and a systematic procedure was developed that can be used to select an appropriate lane closure strategy for interstate work zones.

1.3 Outline of the Study

An appropriate lane closure strategy can be selected only after evaluating the merits and demerits of the available alternatives. In this study the overall effect of a lane closure strategy in a work zone was evaluated in terms of a number of factors as shown in Figure 1.3. First, the overall impact has two components :

NOTES:

1. Taper Formula:

$$L = SXW \text{ for speeds of 45 or more.}$$

$$L = \frac{WS^2}{60} \text{ for speeds of 40 or less.}$$

Where:

L=Minimum length of taper.

S=Numerical value of posted speed limit prior to work or 85 percentile speed.

W=Width of offset.

2. The maximum spacing between channelizing devices in a taper should be approximately equal in feet to the speed limit.

KEY:

■ ■ Channelizing devices

Figure 1.2 Arrangement in a Partial Lane Closure
(Source : Indiana Manual on Traffic Control Devices, 1988)

Figure 1.3 Factors Involved in the Selection of a Lane Closure Strategy

impact on road users, and

2) impact on the agency.

The impact on road users can be categorized as :

- i) travel time cost,
- ii) vehicle operating cost, and
- iii) safety hazard.

The impact on agency has two components :

- i) cost of traffic control, and
- ii) contractors' convenience.

The factor of contractors' convenience includes worker safety, equipment safety, work productivity, and work quality. As the decision problem here involves multiple criteria, the analytic hierarchy approach (Saaty, 1980) was used to synthesize the study results.

1.4 Data Types and Sources

In the present study, data were collected from recent interstate 4R projects in Indiana. Questionnaires were sent to six district offices of Indiana Department of Transportation (INDOT) asking for a list of interstate 4R projects done in previous years or being done currently in their respective districts. In addition, the districts were requested to provide the data regarding the type of lane closure strategy used, duration and length of the road section closed (from mile marker to mile marker) at different phases of the construction period. The list of the projects obtained from the district offices is summarized in Tables 1.1, 1.2 and 1.3. The traffic data, such as ADT, hourly variation in volume, directional split and vehicle mix for these projects, were obtained from the records maintained by the

Table 1.1 List of Projects Using Cross-Over : Sites with Two Lanes in Each Direction

Contract No.	District	Interstate	Length (mile)	Duration
R-20368	La Porte	I-65	6.22	March,93 -October,93
R-19847	Fort Wayne	I-69	4.77	April,92 -October,93
R-19112	Greenfield	I-70	6.50	February,91 -July,92
R-19515	Greenfield	I-70	10.10	September,91 -August,93
R-19113	Greenfield	I-70	8.00	March,91 -January,92
R-19738	Greenfield	I-69	3.00	April,91 -November,91
R-20970	Crawfordsville	I-70	10.77	May,94 -November,94
R-20906	Crawfordsville	I-70	7.59	May,94 -November,94
R-19484	Crawfordsville	I-65	4.40	March,92 -November,93
R-20370	Crawfordsville	I-70	11.00	April,93 -August,94

Table 1.2 List of Projects Using Partial Lane Closure :
Sites with Two Lanes in Each Direction

Contract No.	District	Interstate	Length (mile)	Duration
R-20381	Seymour	I-275	2.83	June,93 -November,93
R-19979	Vincennes	I-64	12.00	July,92 -December,93
R-19483	Fort Wayne	I-69	9.64	September,91 -May,94
R-18301	Greenfield	I-69	5.50	March,90 -January,91
R-17425	Greenfield	I-70	5.00	May,88 -November,89
R-20974	Crawfordsville	I-65	3.50	May,94 -November,94
R-18831	Crawfordsville	I-70	12.00	August,90 -July,91
R-20502	Crawfordsville	I-70	6.60	April,93 -November,93
R-20503	Crawfordsville	I-70	5.40	April,93 -November,93

Table 1.3 List of Projects Using Partial Lane Closure :
Sites with Three Lanes in Each Direction

Contract No.	District	Interstate	Length (mile)	Duration
R-19396	La Porte	I-94	7.07	April,92 -January,94
R-19620	La Porte	I-80/94	4.53	June,92 -November,93
R-20060	La Porte	I-94	6.23	April,93 -October,94
R-19908	Greenfield	I-465	5.50	April,92 -November,93
R-18806	Greenfield	I-69	6.00	April,90 -November,91
R-19482	Greenfield	I-465	4.50	August,93 -December,94
B-17737	Greenfield	I-65	2.50	December,88 -October,89

Roadway Management Division of INDOT. The costs of these projects were obtained from the construction records maintained by the Operations Support Division of INDOT. The costs of the items used for traffic control were added up to obtain the total traffic control cost.

In order to incorporate the contractors' convenience, several contractors were interviewed. Crash data for the projects included in the study were obtained from the records maintained by the Indiana State Police. Each project site was divided into a number of stretches so that the traffic volume was the same throughout the stretch. The number of accidents on each of these stretches was obtained for several years separately for the restricted condition (during construction period) and for the normal operating condition.

1.5 Organization of Report

The report includes seven chapters. Chapter 2 discusses the computation of user travel time and vehicle operating costs. These costs were estimated using MicroBENCOST, a software developed by NCHRP (1994). The evaluation of traffic control costs is described in Chapter 3. The contractors' opinion about convenience in different lane closure strategies is included in Chapter 4. Chapter 5 presents the accident analysis. The synthesis of the study results is given in Chapter 6, and Chapter 7 provides the summary and conclusion.

CHAPTER 2

ESTIMATION OF USER COSTS

2.1 Introduction

Some lanes are closed to the traffic at work zones. As the number of lanes available to the traffic is less than the number of lanes available in normal condition, the traffic capacity is reduced. The proximity of the work zone equipment and crew in case of partial lane closure and the proximity of opposing traffic in case of cross-over further reduce the capacity. Consequently, the operating speed is adversely affected causing delay to the motorists. Restricted traffic flow through work zones also adds to the vehicle operating cost and increases the chance of accidents. In the present study two components of the user cost were considered, travel time cost and vehicle operating cost. The safety aspect was examined separately, as discussed in Chapter 5. Estimates of the two user cost components were made using the computer software, MicroBENCOST (NCHRP, 1993).

2.2 Estimation of User Costs

Travel time costs give the total monetary amount involved in the time spent by different types of vehicles to cross the work zone at a given speed. Vehicle operating costs include costs of fuel consumption, engine oil consumption, vehicle maintenance and depreciation.

2.2.1 Use of MicroBENCOST

MicroBENCOST primarily follows the procedure recommended by AASHTO Red Book (1977) to calculate the user cost. The values of the unit costs used in the AASHTO manual were updated by the Texas Transportation Institute. In the present study the modified values were used. It should be noted that MicroBENCOST updates the unit cost values for future years. MicroBENCOST was run separately for each of the past or continuing interstate 4R projects (during 1988 through 1994) in Indiana, included in the study. Computations were made to estimate user costs under the actual lane closure strategy as well as under the possible alternative. A data base was developed with the information regarding the road section, duration of lane closure, vehicle mix, average daily traffic, variation of traffic volume in different hours of the day, directional split, and so on, for each of these projects. This data base was used in the input files for MicroBENCOST. For both cross-overs and partial lane closures, traffic flow is affected due to reduced speed limit and because of less number of available lanes. The lane capacity is reduced compared to the normal condition. Moreover, in a partial lane closure the proximity of work zone crew and equipment has some adverse effect on the reduction of single lane capacity. Krammes and Gustavo (1994) have done extensive study to find the single lane capacity in the partial lane closure arrangement. The capacity value (1630 vehicles per hour per lane) recommended by them was used in the present study. But any similar research for the cross-over was not found. It can be assumed that the effect would be more adverse in a cross-over, because of the close presence of opposing traffic. The situation in a cross-over on a four-lane highway very much resembles that in a two-lane

highway. Hence the capacity value recommended by Highway Capacity Manual (1985) for a two-lane highway (1400 vehicles per hour per lane) was used for the cross-over. However, the traffic maneuver in the transition areas (entrance and exit sections) in a cross-over is similar to that in a partial lane closure. Hence, the same capacity value (1630 vehicles per hour per lane) was used for the transition areas for both traffic control strategies.

MicroBENCOST uses average speed at work zones in different hours of the day to calculate the user travel time and vehicle operating cost. It is well known that average speed in a traffic stream is primarily dependent on the traffic volume and the capacity and hence we observe fluctuation in average speed in a road segment due to variation of traffic volume. In the input file, the average speed values corresponding to different (v/c) ratio had to be entered. Traffic studies were therefore undertaken at two work zone sites in Indiana. The first field study was conducted during July 22 through July 24, 1994 at a work zone on I-70 in Morgan and Hendricks counties. Cross-over was being used to maintain traffic at this site. Six temporary stations were set up at different locations (including upstream and downstream of the work zone, transition area and activity area) and traffic counts and speeds of the passing vehicles were noted for 48 hours using pneumatic tubes and sensors and the data were stored in the classifiers. After the field study was over the data were retrieved and analyzed in a computer. A similar study was done at a work zone on I-65 in Jasper and White counties, during August 25 through August 27, 1994. Partial lane closure was being used at this site to maintain traffic. However, in both the studies (v/c) ratios in the middle range could be covered. For lower

values of (v/c) ratio not covered in the study, speed values recommended in Highway Capacity Manual (1985) were used. For higher values not covered in the field studies, speed values recommended by Texas Transportation Institute (NCHRP, 1993) were used. The average speed values used in the present study are shown in Tables 2.1 through 2.4.

Although MicroBENCOST has an option for the work zone application, it was not used, because the computer program cannot explicitly distinguish between a cross-over and a partial lane closure. For the purpose of the analysis, each project site was divided into a number of segments so that the homogeneity with respect to geometric, traffic and operational characteristics could be maintained along the segment. For each of these segments geometric, traffic and operational data such as number of lanes available, segment length, grade, curvature, traffic volume, lane capacity and average speed values were entered separately in the input files.

The preparation of the input data for MicroBENCOST is an involved process. But once the input data are entered, the subsequent analyses are fairly straight forward. This software provides a macroscopic evaluation of user costs. To capture the traffic operation at a microscopic level (including lane changing operation and queue dissipation), a simulation model involving complicated gap acceptance and car following maneuvers would be necessary. However, for an approximate estimation of user costs the results obtained using the software were found to be adequate (Sinha and Williams, 1994).

2.2.2 Results

Using MicroBENCOST, travel time and vehicle operating costs were estimated separately for a partial lane closure and a cross-over for each of the work zone. The costs

Table 2.1 Average Speeds at Locations Immediately Upstream or Downstream of Work Zones

Speed Limit: 45 mph		Speed Limit: 55 mph	
(V/C) Ratio	Average Speed (mph)	(V/C) Ratio	Average Speed (mph)
0.05	53.5	0.05	63.0
0.35	53.5	0.35	63.0
0.60	53.5	0.54	57.0
0.77	53.5	0.77	54.0
0.93	46.0	0.93	46.0
1.00	30.0	1.00	30.0
1.20	25.0	1.20	25.0

Table 2.2 Average Speeds in Work Zones with Partial Lane Closure

Speed Limit: 45 mph		Speed Limit: 55 mph	
(V/C) Ratio	Average Speed (mph)	(V/C) Ratio	Average Speed (mph)
0.05	53.5	0.05	63.0
0.16	53.5	0.16	63.0
0.32	53.5	0.32	63.0
0.57	53.5	0.57	63.0
0.74	53.5	0.74	53.4
1.00	45.0	1.00	45.0
1.20	30.0	1.20	30.0

Table 2.3 Average Speeds in Work Zones with Cross-Over

Speed Limit: 45 mph		Speed Limit: 55 mph	
(V/C) Ratio	Average Speed (mph)	(V/C) Ratio	Average Speed (mph)
0.05	53.5	0.05	53.5
0.16	53.5	0.16	57.5
0.32	53.5	0.32	57.5
0.57	53.5	0.32	57.5
0.61	53.5	0.70	57.5
1.00	45.0	1.00	45.0
1.20	30.0	1.20	30.0

Table 2.4 Average Speeds on Interstate Highways under Normal Operating Conditions
(Speed Limit : 65 mph)

(V/C) Ratio	Average Speed (mph)
0.05	68.0
0.35	68.0
0.60	68.0
0.77	54.0
0.93	46.0
1.00	30.0
1.20	25.0

were added up to get the total user costs. The user costs in different projects are shown in Tables 2.5 and 2.6. In most cases the travel time cost was higher in a cross-over and vehicle operating cost was higher in a partial lane closure. This is because of the fact that in case of a cross-over, the (v/c) ratio is higher than that in a partial lane closure for the same traffic volume due to a comparatively lower single lane capacity in the activity area in a cross-over and the corresponding value of average speed is also lower. Hence, more time is required to cover the same distance in case of a cross-over resulting in higher travel time cost. On the other hand, vehicle operating cost is a function of average speed. When the average speed is in the range 30-35 mph, the vehicle operating cost is the minimum, (AASHTO, 1977) and at lower and higher ranges of speed it monotonically increases. Under moderate and heavy traffic, the average speed in a work zone under a cross-over would be lower than that under a partial lane closure, because of the lower single lane capacity of the activity area under a cross-over. In most of the sites included in the present study, the traffic volumes were moderate and the average speed at these sites was more than 35 mph. So the estimated vehicle operating costs under cross-overs were slightly less than those under partial lane closures. However, the savings in vehicle operating costs in cross-overs were less than the savings in travel time costs in partial lane closures. Hence, the total user costs under cross-overs, including both travel time costs and vehicle operating costs, were higher than those under partial lane closures for all the projects included in the present study.

Percent increases in user costs under cross-overs and partial lane closures at different sites, included in the present study, compared to the user costs without work zones are

Table 2.5 Estimated User Costs in Different Sites with Two Lanes in Each Direction

Project	Traffic Control Strategy	Travel Time Cost (x 1000 \$)	Vehicle Operating Cost (x 1000 \$)	Total User Cost (x 1000 \$)
R-20368	CS	11042	9997	21039
	PLC	10563	10076	20639
	WWZ	8686	10884	19570
R-19847	CS	4649	4137	8786
	PLC	4408	4235	8643
	WWZ	3539	4432	7971
R-19112	CS	17019	16529	33548
	PLC	16226	16705	32931
	WWZ	13271	17830	31101
R-19515	CS	66046	40183	106229
	PLC	57828	40047	97875
	WWZ	37525	39204	76729
R-19113	CS	16870	16164	33034
	PLC	16349	16254	32603
	WWZ	13273	17494	30767
R-19738	CS	6890	5869	12759
	PLC	6225	6082	12307
	WWZ	5337	6388	11725
R-20970	CS	16962	15064	32026
	PLC	16185	15339	31524
	WWZ	13344	16575	29919
R-20906	CS	12722	11307	24029
	PLC	11935	11665	23600
	WWZ	10038	12481	22519

R-19484	CS	13817	12582	26399
	PLC	13040	12907	25947
	WWZ	10871	13925	24796
R-20370	CS	14142	12639	26781
	PLC	13505	12848	26353
	WWZ	11126	13847	24973
R-20381	CS	5745	4647	10392
	PLC	5304	4798	10102
	WWZ	4434	5149	9583
R-19979	CS	13988	11104	25092
	PLC	13504	11318	24822
	WWZ	11008	12544	23552
R-19483	CS	85872	70940	156812
	PLC	80038	69285	149323
	WWZ	63138	74626	137764
R-18301	CS	22360	18124	40484
	PLC	20057	17957	38014
	WWZ	15921	18669	34590
R-17425	CS	13098	12290	25388
	PLC	12717	12645	25362
	WWZ	10466	13618	24084
R-20974	CS	12808	11890	24698
	PLC	12124	12122	24246
	WWZ	10073	12978	23051
R-18831	CS	22099	20941	43040
	PLC	21602	20960	42562
	WWZ	17349	22756	40105
R-20502	CS	14062	13300	27362

	PLC	13577	13416	26993
	WWZ	11062	14499	25561
R-20503	CS	12820	12179	24999
	PLC	12335	12303	24638
	WWZ	10084	13240	23324

Note :

CS : Cross-over

PLC : Partial lane closure

WWZ : Without work zone

User costs were estimated for the entire duration of the project.

Table 2.6 Estimated User Costs in Different Sites with Three Lanes in Each Direction

Project	Traffic Control Strategy	Travel Time Cost (x 1000 \$)	Vehicle Operating Cost (x 1000 \$)	Total User Cost (x 1000 \$)
R-19396	CS	43356	38759	82115
	PLC	40731	39729	80460
	WWZ	33929	43127	77056
R-19620	CS	45291	40328	85619
	PLC	42629	41065	83694
	WWZ	34540	44532	79172
R-20060	CS	35901	31842	67743
	PLC	34264	32490	66754
	WWZ	28246	35459	63705
R-19908	CS	53565	41713	95278
	PLC	50116	41974	91910
	WWZ	40640	45179	85819
R-18806	CS	88827	52734	141561
	PLC	74432	51801	126233
	WWZ	45564	50397	95961
R-19482	CS	185167	77012	262179
	PLC	170065	76871	246936
	WWZ	122141	74642	196783
B-17737	CS	69948	30727	100675
	PLC	61160	30682	92022
	WWZ	42893	29871	72764

Note : CS : Cross-over

PLC : Partial lane closure

WWZ : Without work zone

User costs were estimated for the entire duration of the project.

shown in Tables 2.7 and 2.8. The percent increase in user costs under a cross-over can be obtained as :

$$[(UCCS - UCWWZ) \times 100] / UCWWZ$$

where, UCCS denotes the user costs under a cross-over and UCWWZ denotes the user costs without a work zone. Similarly, percent increase in user costs under a partial lane closure can be obtained as

$$[(UCPLC - UCWWZ) \times 100] / UCWWZ$$

where, UCPLC denotes the user costs under a partial lane closure. It can be observed from Tables 2.7 and 2.8 that the percent increase in user costs under a cross-over was higher than that under a partial lane closure for all the sites included in the present study. Thus it can be concluded that total user travel time and vehicle operating costs at any site would be less if a partial lane closure is used instead of a cross-over, although the difference in user costs under the two strategies may not be high.

2.3 Estimation of User Costs Using Regression Model

The preparation of input data for MicroBENCOST takes much effort and in many cases, the data may not be readily available. Therefore, regression models were developed that can be used to estimate user costs for work zones using a cross-over or a partial lane closure. It should be noted that the estimated user travel time and vehicle operating costs under the two lane closure strategies are deterministic and are functions of traffic volume and work zone length. In addition, the estimated user costs under cross-overs were consistently higher than under partial lane closures for all the sites included in the present study. Hence a separate regression line was fitted for each lane closure strategy, although

Table 2.7 Additional User Costs in Cross-Overs and Partial Lane Closures as Percentage of User Costs without Work Zone : Sites with Two Lanes in Each Direction

Project	% Increase in User Cost for Cross-Overs	% Increase in User Cost for Partial Lane Closures	Difference of % Increase in User Cost under Two Strategies
R-20368	7.51	4.08	3.43
R-19847	10.22	8.43	1.79
R-19112	7.57	5.88	1.69
R-19515	38.45	27.56	10.89
R-19113	7.37	5.97	1.40
R-19738	8.82	4.96	3.86
R-20970	7.04	5.36	1.68
R-20906	6.71	4.80	1.91
R-19484	6.46	4.64	1.82
R-20370	7.24	5.53	1.71
R-20381	8.44	5.42	3.02
R-19979	6.54	5.39	1.15
R-19483	13.83	8.39	5.44
R-18301	17.04	9.90	7.14
R-17425	5.41	5.31	0.10
R-20974	7.15	5.18	1.97
R-18831	7.32	6.13	1.19
R-20502	7.05	5.60	1.45
R-20503	7.18	5.63	1.55
Mean	9.86	7.06	2.80
Sample Standard Deviation	7.46	5.17	2.56

Table 2.8 Additional User costs in Cross-Overs and Partial Lane Closures as Percentage of User Costs without Work Zone : Sites with Three Lanes in Each Direction

Project	% Increase in User Cost for Cross-Overs	% Increase in User Cost for Partial Lane Closures	Difference of % Increase in User Cost under Two Strategies
R-19396	6.57	4.42	2.15
R-19620	8.14	5.71	2.43
R-20060	6.34	4.79	1.55
R-19908	11.02	7.10	3.92
R-18806	47.52	31.55	15.97
R-19482	33.23	25.49	7.74
B-17737	38.36	26.47	11.89
Mean	21.60	15.07	6.53
Sample Standard Deviation	17.51	12.11	5.58

there was no significant difference in estimated user costs under the two strategies. It can also be observed from Tables 2.7 and 2.8 that the average percent increase in user cost under both strategies at the sites with three lanes in each direction was higher than that at the sites with two lanes in each direction. So two different sets of models were developed for the two types of sites. Initially traffic volume, project length and their interaction were used as explanatory variables. But the effect of length was not found to be significant. So this variable was dropped. The final models, presented in Tables 2.9 and 2.10, showed very good fit and the regression coefficients were also intuitively interpretable. These models can then be used to estimate user costs associated with future projects on interstates in Indiana. Once the traffic volume and the length of the work zone are known, the regression equations would give an estimate of the total yearly user cost at the work zone under both cross-over and partial lane closure strategies.

Table 2.9 Regression Model for Sites with Two Lanes in Each Direction

Cross-Over :

Dependent Variable : Total user travel time and vehicle operating cost
(in thousand dollar) in a year

Independent Variables	Estimated Coefficients	T-statistic
Constant	- 1.15154e+004	- 7.86500
Traffic volume (vehicles per day)	0.38584	4.83086
Interaction between length and traffic volume	0.22979	18.11764

Number of observations : 37

R^2 : 0.97327

Corrected R^2 : 0.97169

Partial Lane Closure :

Dependent Variable : Total user travel time and vehicle operating cost
(in thousand dollar) in a year

Independent Variables	Estimated Coefficients	T-statistic
Constant	- 8.44611e+003	- 7.03053
Traffic volume (vehicles per day)	0.27207	4.15160
Interaction between length and traffic volume	0.22333	21.45947

Number of observations : 37

R^2 : 0.97872

Corrected R^2 : 0.97747

Table 2.10 Regression Model for Sites with Three Lanes in Each Direction

Cross-Over :

Dependent Variable : Total user travel time and vehicle operating cost
(in thousand dollar) in a year

Independent Variables	Estimated Coefficients	T-statistic
Constant	- 1.77001e+004	- 6.42878
Traffic volume (vehicles per day)	0.25544	6.72030
Interaction between length and traffic volume	0.24072	11.17015

Number of observations : 38

R^2 : 0.92528

Corrected R^2 : 0.92101

Partial Lane Closure :

Dependent variable : Total user travel time and vehicle operating cost
(in thousand dollar) in a year

Independent Variables	Estimated Coefficients	T-statistic
Constant	- 1.63948e+004	- 6.03431
Traffic volume (vehicles per day)	0.21849	5.82500
Interaction between length and traffic volume	0.23637	11.11515

Number of observations : 38

R^2 : 0.91798

Corrected R^2 : 0.91329

CHAPTER 3

COST OF TRAFFIC CONTROL AT WORK ZONES

3.1 Introduction

Traffic control costs at work zones include costs of installing signs, markings, lightings, barricades and channelizing devices and other personnel and material costs. In addition, if a cross-over is used, the cost of constructing a cross-over facility is also involved. The data for traffic control cost in twenty eight interstate 4R projects in different parts of Indiana were collected. Twelve of them were for sites using cross-over on four lane interstate highways, nine of them for sites using partial lane closure on four lane interstate highways and the rest were for the sites using partial lane closure on six lane interstate highways. The data were statistically analyzed to determine the significance in the difference in traffic control costs under different strategies. Finally, a linear regression model was developed that can be used to estimate such costs in the future given the characteristics of a project site.

3.2 Traffic Control Cost Data Analysis

As mentioned earlier, questionnaires were sent to six district offices of Indiana Department of Transportation (INDOT) requesting information of recent interstate 4R projects. Total project costs for these projects were obtained from the microfilms and files

maintained by the Operations Support Division of INDOT. The costs of different items involved in these projects are included separately in the records. The costs of the items used in traffic control at a site (as per the guidelines of Standard Specifications (1993) of INDOT) were added up to get the total traffic control cost. The traffic control cost for each project was expressed as a percentage of the total project cost. The traffic control cost was also normalized in terms of lane-mile basis. This way, the effect of project size could be minimized. The computed traffic control costs are presented in Tables 3.1 through 3.3.

3.2.1 Statistical Procedure

An analysis of variance (ANOVA) was used to compare the computed traffic control costs. However, two conditions had to be satisfied prior to the use of such a technique. The conditions include the normality of sample data about the sample mean as well as the homogeneity of the variances. When the assumption of normality is not valid but the assumption of equal variances still holds good, Kruskal-Wallis test may be used. When both the assumptions are not valid, a non-parametric test, such as Wilcoxon test, can be used (Neter et al., 1990).

The ANOVA model can be stated as follows :

$$Y_{ij} = \mu_i + \epsilon_{ij}$$

where, Y_{ij} is the traffic control cost in the j -th project using the i -th lane closure strategy, μ_i is the average traffic control cost for the projects using the same lane closure strategy

**Table 3.1 Cost of Traffic Control for the Sites Using Cross-Over :
Sites with Two Lanes in Each Direction**

Project	Length of Project (mile)	Total Cost of Traffic Control TC (\$)	Total Project Cost PC (\$)	TC as percent of PC (%)	TC per lane mile (\$)
R-20368	6.22	429136	8279028	5.18	17248
R-20369	5.00	868492	15172527	5.72	43425
R-19972	5.21	690063	13760467	5.02	33112
R-19847	4.77	589099	6768702	8.70	30875
R-19112	6.50	572262	9379422	6.10	22010
R-19515	10.10	981165	18674980	5.25	24286
R-19113	8.00	752558	8229611	9.14	23517
R-19738	3.00	810748	4369090	18.56	67562
R-20970	10.771	1837778	14518709	12.66	42656
R-20906	7.588	733242	6583082	11.14	24156
R-19484	4.40	964360	5996956	16.08	54793
R-20370	11.00	1098511	9467444	11.60	24966
Mean				9.60	34051

Table 3.2 Cost of Traffic Control for the Sites Using Partial Lane Closure :
Sites with Two Lanes in Each Direction

Project	Length of Project (mile)	Total Cost of Traffic Control TC (\$)	Total Project Cost PC (\$)	TC as percent of PC (%)	TC per lane mile (\$)
R-20381	2.83	485877	2715593	17.89	42922
R-19979	12.00	761747	10777260	7.07	15870
R-19483	9.64	1287498	12997265	9.90	33389
R-18301	5.50	304766	5846764	5.21	13853
R-17425	5.00	299993	5983186	5.01	15000
R-20974	3.50	265276	4364897	6.08	18948
R-18831	12.00	435793	5898095	7.39	9079
R-20502	6.60	276931	3367766	8.22	10603
R-20503	5.40	356450	3109510	11.46	16502
Mean				8.69	19574

Table 3.3 Cost of Traffic Control for the Sites Using Partial Lane Closure :
Sites with Three Lanes in Each Direction

Project	Length of Project (mile)	Total cost of Traffic Control TC (\$)	Total Project Cost PC (\$)	TC as percent of PC (%)	TC per lane mile (\$)
R-19396	7.07	1863623	17480543	10.66	43939
R-19620	4.53	1797695	12462356	14.43	66140
R-20060	6.23	1004758	12621638	7.96	26880
R-19908	5.50	2303954	24106707	9.56	69817
R-18806	6.00	371402	9769415	3.80	10317
R-19482	4.50	2251510	15213574	14.80	83389
B-17737	2.50	1876349	10239285	18.33	125090
Mean				11.14	60976

and ϵ_{ij} is the difference between them. In the present study, $i = 1$ (cross-over), 2 (partial lane closure) ; and $j = 1, \dots, n_i$ (sample size under the i -th lane closure strategy). The test of equality of the average traffic control costs under two strategies was conducted on the basis of the null hypothesis :

$$H_0 : \mu_1 = \mu_2$$

The test statistic used was :

$$F^* = \frac{MSTR}{MSE}$$

where, MSTR represented the treatment mean square and MSE represented the error mean square.

If $F^* < F(1-\alpha ; 1, n_T-2)$, n_T being the sample size under two strategies, the hypothesis H_0 was accepted ; otherwise it was rejected at a significance level α .

Before using the ANOVA technique, the assumptions of normality and equality of variances were verified. In order to test the normality of the error terms, let the coefficient of correlation between ordered residuals and their expected values be r and the critical value of correlation coefficient for n observations at a significance level α be $cr_n(\alpha)$. If $r > cr_n(\alpha)$, it was concluded at α level that error terms were normally distributed.

Another important assumption in ANOVA was that the variance of the traffic control costs under cross-overs (σ_1^2) and that under partial lane closures (σ_2^2) were not different. To check the validity of this assumption, Bartlett test was used, as discussed below.

Let s_1^2 and s_2^2 denote the sample variances under cross-overs and partial lane closures and df_1 and df_2 represent the corresponding degrees of freedom, respectively. The test of the equality of the variances was conducted on the basis of the null hypothesis :

$$H_0 : \sigma_1^2 = \sigma_2^2$$

The test statistic used was :

$$B = \frac{df_T}{C} [\ln(MSE) - \ln(GMSE)]$$

where,

$$C = 1 + \frac{1}{3 * (2-1)} \left[\left(\sum_{i=1}^2 \frac{1}{df_i} \right) - \frac{1}{df_T} \right]$$

$$MSE = \frac{1}{df_T} \sum_{i=1}^2 (df_i s_i^2)$$

$$GMSE = [(s_1^2)^{df_1} (s_2^2)^{df_2}]^{\frac{1}{df_T}}$$

$$df_T = \sum_{i=1}^2 df_i$$

$$df_i = n_i - 1$$

Let $X^2(1-\alpha ; 1)$ be the chi-square statistic with one degree of freedom at a significance level α . If $B < X^2(1-\alpha ; 1)$, the null hypothesis H_0 was accepted ; otherwise it was rejected at a significance level α .

For the purpose of Kruskal-Wallis Test, the projects under the two strategies were ranked from 1 to n_T in increasing order based on their traffic control costs (Y_{ij}). Let R_i^* be the mean of the ranks of the projects using i -th strategy and R^{**} be the overall mean rank. The test of equality of the average traffic control costs under two strategies was conducted on the basis of the null hypothesis :

$$H_0 : \mu_1 = \mu_2$$

The test statistic used was :

$$X^2_{KW} = \frac{\sum_{i=1}^2 n_i (R_i^* - R^{**})^2}{\frac{n_T(n_T+1)}{12}}$$

If $X^2_{KW} < X^2(1-\alpha ; 1)$, the null hypothesis H_0 was accepted ; otherwise it was rejected at significance level α .

When the assumption of normality was not valid and the two samples had significantly different variances, neither ANOVA technique nor Kruskal-Wallis test could have been applied. In such cases Wilcoxon test was used, as presented below.

The test statistic W_N is the sum of the ranks of the traffic control costs of the projects using a cross-over in the pooled array of m and n observations for cross-overs and partial lane closures, respectively; where the array is sorted in increasing order. The rejection regions for the following hypotheses are :

Hypothesis -----	Rejection Region -----
$\mu_2 - \mu_1 < 0$	$W_N \geq m(N+1)/2 + 0.5 + z_\alpha (mn(N+1)/12)^{1/2}$
$\mu_2 - \mu_1 > 0$	$W_N \leq m(N+1)/2 - 0.5 - z_\alpha (mn(N+1)/12)^{1/2}$
$\mu_2 - \mu_1 = 0$	Both above with $z_{\alpha/2}$

where, $N = (m+n)$; z_α and $z_{\alpha/2}$ are the z-statistics at significance levels α and $\alpha/2$, respectively.

3.2.2 Results of the Significance Tests

The traffic control costs were statistically analyzed to determine the significance in the difference in traffic control costs under different lane closure strategies. All the statistical tests were performed at 5% significance level. As very few observations were available for the sites using cross-over with three lanes in each direction, they were not considered in the statistical analysis. The results for the other sites are summarized in Tables 3.4 and 3.5.

The average percentage of total project cost spent in traffic control was found to be close under both cross-over and partial lane closure strategies. However, the average traffic control cost per lane-mile in case of a cross-over for sites with two lanes in each direction was significantly higher than that in case of a partial lane closure for similar sites. This may be due to the additional cost incurred due to construction of a cross-over. It should be noted that the items included in traffic control cost under a cross-over strategy are approximately same as those under a partial lane closure strategy, except the construction and maintenance of the cross-over arrangement. The additional cost incurred

Table 3.4 Summary of Traffic Control Costs under Different Strategies

Traffic Control Strategy	Traffic Control Cost as Percent of Total Project Cost tcpc (%)	Traffic Control Cost per Lane Mile tcpl (\$)
Cross-over (2 lanes in each direction) CS2	9.60	34051
Partial Lane Closure (2 lanes in each direction) PL2	8.69	19574
Partial Lane Closure (3 lanes in each direction) PL3	11.14	60976

**Table 3.5 Summary of Statistical Analysis on Traffic Control Costs
under Different Strategies
(Testing of Hypothesis with Significance Level = 0.05)**

Hypothesis	Test Used	Test Statistic	Critical Values / Critical Ranges	Conclusion
M(tcpCPL2) = M(tcpCPL3)	F-test	1.44	4.61	Accepted
M(tcpCPL2) = M(tcpCS2)	Kruskal -Wallis	0.25	3.84	Accepted
M(tcpCPL3) = M(tcpCS2)	F-test	0.64	4.46	Accepted
M(tcplPL2) = M(tcplPL3)	Wilcoxon	55	(57.48, 95.52)	Rejected
M(tcplPL2) = M(tcplCS2)	Wilcoxon	63	(70.92, 127.08)	Rejected
M(tcplPL3) = M(tcplCS2)	Wilcoxon	91	(46.31, 93.69)	Accepted

Note :

M(tcpCS2) : Mean traffic control cost as percentage of total project cost for sites with two lanes in each direction using cross-over

M(tcpPL2) : Mean traffic control cost as percentage of total project cost for sites with two lanes in each direction using partial lane closure

M(tcpPL3) : Mean traffic control cost as percentage of total project cost for sites with three lanes in each direction using partial lane closure

M(tcplCS2) : Mean traffic control cost per lane mile for sites with two lanes in each direction using cross-over

M(tcplPL2) : Mean traffic control cost per lane mile for sites with two lanes in each direction using partial lane closure

M(tcplPL3) : Mean traffic control cost per lane mile for sites with three lanes in each direction using partial lane closure

due to the cross-over arrangement constitutes a very small percentage of the total project cost. Thus, when the traffic control cost was expressed as a percentage of the total project cost, it did not show any significant difference under the two different strategies. As it can be expected, the traffic control cost per lane-mile using a partial lane closure was more for sites with three lanes in each direction than for sites with two lanes in each direction.

3.3 Regression Model to Predict Cost of Traffic Control

In order to provide a tool to estimate the expected traffic control cost under a given lane closure strategy, a simple linear regression model was developed. As indicated in Table 3.6, the explanatory variables initially considered were project length, total project cost and two dummy variables representing the two lane closure strategies at sites with two lanes in each direction. Setting these two dummy variables to zero, the traffic control cost under a partial lane closure at a given site with three lanes in each direction can be estimated.

The sign of the regression coefficient corresponding to project length was negative in the initial model. This would indicate that the expected cost of traffic control would decrease with increasing project length. This is not realistic. The negative sign in the estimated coefficient might be attributed to the correlation between the two explanatory variables, project length and total project cost. As the t-statistic for the regression coefficient corresponding to project length was also not significant, it was dropped in the final model. The estimated parameters of the final model are shown in Table 3.7. The corrected R^2 in the new model was higher than that in the initial model. All the regression

Table 3.6 Explanatory Variables in the Regression Model to Estimate Traffic Control Cost

Dependent Variable : Traffic control cost (in dollar) in a project

Explanatory Variables	Mnemonics
1. Intercept term	cnst
2. Dummy variable for cross-over = 1 , if cross-over for sites with two lanes in each direction = 0 , otherwise	bcs
3. Dummy variable for partial lane closure = 1 , if partial lane closure for sites with two lanes in each direction = 0 , otherwise	bplc
4. Total project cost (in dollar)	tpc

Table 3.7 Statistical Characteristics of the Regression Model to Estimate Traffic Control Cost

Dependent Variable : Traffic control cost (in dollar) in a project

Explanatory Variable	Estimated Coefficient	T-statistic
cnst	7.40019 E+005	2.49169
bcs	-5.02813 E+005	-2.52850
bplc	-6.20151 E+005	-2.53355
tpc	6.17230 E-002	3.46563

Auxiliary Statistic :

Number of observations : 28

R^2 : 0.66551

Corrected R^2 : 0.62370

coefficients in the final model were also statistically significant and could be intuitively interpreted.

The regression model can be used to estimate traffic control costs associated with similar interstate 4R projects. Once the approximate total project cost is known, the regression equation can readily be used to estimate the traffic control cost at a work zone under both the lane closure strategies. It should be noted that regression line could not be fitted for traffic control costs at sites with three lanes in each direction using cross-overs due to scarcity of data points. In such cases, an estimate of the additional cost incurred in a cross-over arrangement must be made based on judgement and experience. With more data an appropriate regression equation can be developed in the future.

CHAPTER 4

CONTRACTORS' OPINION ON LANE CLOSURE STRATEGY

4.1 Introduction

Opinions of the contractors regarding lane closure strategies at work zones are very important as they are directly involved with the execution of the job at the site. Consequently, representatives of the contractors involved with interstate 4R projects in Indiana were contacted for a personal interview. Contractors were found to be mainly concerned about two aspects : safety and workability. Safety is a broad category and it includes safety of workers, operating equipment and travellers. Workability can be defined as the ease of work execution affecting work productivity and quality of work. In a partial lane closure strategy, traffic is maintained very close to the work zone crew and equipment, and such an arrangement poses threat to the safety of workers, travellers and equipment. The nearby heavy traffic also creates mental pressure on the workers affecting the productivity and quality of work. In a cross-over strategy, sufficient working spaces are available and it becomes easier for heavy equipment (e.g. trucks, loaders, etc.) to enter and leave the site. Therefore, the contractors interviewed indicated a consistent preference for cross-overs to partial lane closures.

4.2 Opinion Survey and Ratings of Contractors' Convenience

Fifteen construction companies involved with interstate 4R projects in Indiana were contacted for an opinion survey. Eight of them agreed to participate in the survey. Seventeen representatives of these companies were personally interviewed. Each interviewee was asked to rate five factors in a scale of 1-10 for both the cross-over and partial lane closure strategies. These five factors were worker safety, equipment safety, traveller safety, work productivity, and quality of work. The strategy with a higher rating for a particular factor is a more desirable strategy for that factor.

The ratings for the safety related factors are given in Table 4.1. It can be observed that all personnel interviewed rated cross-overs much higher than partial lane closures in all categories of safety. For the safety of workers and equipment, cross-overs received unanimously higher rating, while there was some difference in opinion in the category of traveller safety. Nevertheless, the overwhelming majority (fourteen out of seventeen) preferred cross-overs to partial lane closures for traveller safety. Only three suggested that a cross-over would be worse than a partial lane closure for traveller safety because of the proximity of opposing traffic without a sufficient median.

The ratings of workability related factors are presented in Table 4.2. The respondents were unanimous in rating cross-overs higher than partial lane closures with respect to both work productivity and work quality. However, a significant number (seven out of seventeen) did not want to provide any rating for work quality. The item of work quality is a sensitive issue and it is understandable that contractors do not want to state that the work quality may suffer if a particular type of lane closure is chosen.

Table 4.1 : Contractors' Ratings on Lane Closure Strategies Concerning Safety

Respondent	Worker	Safety	Equipment	Safety	Traveller	Safety
	CS	PLC	CS	PLC	CS	PLC
1	7	2	7	2	6	3
2	9	5	8	6	9	5
3	9	1	7	3	4	6
4	10	1	10	1	8	5
5	10	2	8	5	9	7
6	10	3	10	3	7	7
7	10	3	10	3	8	10
8	8	2	6	3	4	8
9	10	1	7	3	6	4
10	8	3	8	3	5	5
11	9	3	5	5	8	3
12	10	3	10	3	5	6
13	10	5	10	5	9	7
14	10	5	10	5	10	5
15	9	2	9	2	9	2
16	10	5	10	5	10	5
17	8	2	8	2	8	2
Average	9.2	2.8	8.4	3.5	7.4	5.1

Note :

CS : Cross-over

PLC : Partial lane closure

Table 4.2 : Contractors' Ratings on Lane Closure Strategies Concerning Workability

Respondent	Work	Productivity	Work	Quality
	CS	PLC	CS	PLC
1	8	2	8	3
2	5	5	NR	NR
3	7	3	NR	NR
4	10	1	NR	NR
5	7	5	NR	NR
6	10	3	NR	NR
7	10	7	NR	NR
8	9	4	NR	NR
9	7	3	7	3
10	7	3	8	5
11	10	5	9	5
12	8	6	8	7
13	10	7	10	8
14	10	5	10	3
15	9	2	9	2
16	10	5	10	5
17	8	2	8	2
Average	8.5	4.0	8.7	4.6

Note :

CS : Cross-over

PLC : Partial lane closure

NR : No response

4.3 Contractors' Preference as Cost Savings

A procedure was developed in the present study to quantify contractors' preference for cross-overs in terms of cost savings. The results of this approach were not used in the overall evaluation of the lane closure strategies because of the insufficient data. However, the procedure is presented here to illustrate its applicability. With adequate data the procedure can be properly calibrated and the results can then be incorporated in the overall evaluation framework.

The contractors were asked if they had the opportunity of using cross-overs instead of partial lane closures, how much could be saved on average in a year per project due to a reduced number of accidents involving workers and equipment for a given level of traffic volume. The same question was asked for different levels of traffic volume and different project lengths. The responses were recorded in ranges of dollar amount saved. Similar questions were asked for savings due to higher workability in cross-overs and the responses were recorded in ranges of dollar amount saved.

The savings in cross-overs over partial lane closures as perceived by contractors were very subjective and there was a wide variation in the response pattern. Therefore, a procedure based on fuzzy logic approach was developed that can be used to synthesize the opinions. Fuzzy logic approach has been proposed (Zadeh, 1977) to systematically incorporate the subjective information in decision making process and it has been used by many researchers in dealing with public works (Brown and Yao, 1983 ; Tee, 1988).

4.3.1 Computation of Membership Functions

Fuzzy membership functions were developed, from the responses of the contractors, for different ranges of dollar amounts saved in case of cross-overs. The grade of membership of each element in the fuzzy set was computed based on the number of responses favoring that particular element. The procedure for computing the grade of membership can be summarized as follows :

- i) Compute the number of responses n_i , favoring each element i in a given range, representing traffic volume or length of work zone.
- ii) Obtain the highest number of responses ($\max(n_i)$) for the given range of expected savings.
- iii) Normalize the number of responses n_i , for each element i , by dividing it by $\max(n_i)$ to get the grade of membership or membership value of that particular element.
- iv) Plot the membership values against traffic volume or length of work zone and join them by straight lines to get a membership function. Sometimes adjustments may be required to smoothen the membership function.

The physical significance of membership functions can be explained better with the help of the plots shown in Figures 4.1 through 4.4. The membership functions for safety related savings under different levels of traffic volume and length of work zone are shown in Figures 4.1 and 4.2, respectively. Figure 4.1 indicates that higher the traffic volume, higher is the safety related savings in cross-overs. It can be observed that lower ranges of savings have higher membership values at a lower traffic volume. On the other hand, in case of higher ranges of savings, higher membership values correspond to higher traffic

Figure 4.1, Effect of Traffic Volume on the Safety Related Savings in Cross-Overs

Figure 4.2 Effect of Work Zone Length on the Safety Related Savings in Cross-Overs

Figure 4.3 Effect of Traffic Volume on the Workability Related Savings in Cross-Overs

Savings in Workability : Contractors' Perception

Figure 4.4 Effect of Work Zone Length on the Workability Related Savings in Cross-Overs

volumes. For example, in Figure 4.1, the \$ 0-10000 range has a membership value of 1 at ADT of 5000 vehicles per day and a membership value of 0 at ADT of 20000 vehicles per day, while the range \$ 30000-60000 has a membership value of 1 at ADT of 30000 vehicles per day and a membership value of 0 at ADT of 10000 vehicles per day. Figure 4.2 indicates that the longer the work zone, the higher is the safety related savings in using cross-overs. Figures 4.3 and 4.4 present plots of membership functions of savings due to higher workability in cross-overs. It can be noted in Figure 4.3 that the higher the traffic volume, the higher is the savings in cross-overs due to higher workability. Similarly, Figure 4.4 indicates that the longer the work zone, the higher is the savings due to better working environment in cross-overs.

4.3.2 Fuzzy Addition

So far the effects of traffic volume and project size (i.e. length of work zone) on expected cost savings have been separately discussed. Now these effects would be combined so that it will be possible to predict how much savings can be achieved in a year in an interstate 4R project of a particular size if a cross-over is used instead of a partial lane closure when the average daily traffic on that section is given.

Let us first consider the case of perceived safety related savings in a cross-over. Let A represent the safety related savings as a function of traffic volume and B represent the safety related savings as a function of work zone length. The effect of each of them acting separately is obtained from the union of the fuzzy sets A and B ($\mu_{A \cup B}$) and the joint effect is given by the algebraic sum of A and B (μ_{A+B}). Let S denote the fuzzy set representing the total safety related savings for a given project if a cross-over is used

instead of a partial lane closure. The grade of membership for safety related savings is denoted by μ_s and can be bounded by

$$\mu_{A \cup B} \leq \mu_s \leq \mu_{A+B}$$

The same procedure can be used to estimate the grades of membership associated with savings due to workability.

4.3.3 Perceived Cost Savings in an Example Problem

The estimation of the total perceived cost savings is illustrated by the following example. Let the work zone be 4 mile long and the ADT 20000 vehicles per day. Using the membership functions in Figures 4.1 and 4.2, the grades of membership for different ranges of safety related savings can be obtained, as shown in Table 4.3. The lower and upper bounds of the grades of membership for different ranges of safety related savings for the cross-over are graphically represented in Figure 4.5. The first central moment of the area under the histogram gives the possible amount of money that can be saved due to better work zone safety if a cross-over is used instead of a partial lane closure strategy. For the given project the safety related savings would be \$ 33,498. Similarly, the expected workability related savings in a cross-over can be obtained using Figures 4.3 and 4.4. The grades of membership or different ranges of workability related savings are shown in Table 4.4 and the lower and upper bounds are graphically presented in Figure 4.6. The estimated workability related savings for the example problem would be \$ 34,880. The total estimated savings would be \$ 68,378 if a cross-over is used to maintain traffic in the given project.

Table 4.3 Grades of Membership for Different Ranges of Safety Related Savings
in a Cross-Over (Work Zone Length = 4 miles, ADT = 20000)

Ranges of savings (\$)	Effect of traffic volume A	Effect of length of work zone B	A U B	A + B
0 - 10000	0	0.28	0.28	0.28
10000 - 20000	1.0	1.0	1.0	1.0
20000 - 30000	0.75	0.9	0.9	0.975
30000 - 60000	0.66	1.0	1.0	1.0

$$\mu_{A \cup B} (10000-20000) = \max (1.0, 1.0) = 1.0$$

$$\mu_{A + B} (10000-20000) = 1 - (1 - 1) * (1 - 1) = 1.0$$

Table 4.4 Grades of Membership for Different Ranges of Workability Related Savings in a Cross-Over (Work Zone Length = 4 miles, ADT = 20000)

Ranges of savings (\$)	Effect of traffic volume A	Effect of length of work zone B	A U B	A + B
0 - 10000	0	0	0	0
10000 - 20000	0.67	0.375	0.67	0.794
20000 - 30000	1.0	0.86	1.0	1.0
30000 - 60000	0.6	0.64	0.64	0.856

$$\mu_{A \cup B} (10000-20000) = \max (0.67, 0.375) = 0.67$$

$$\mu_{A + B} (10000-20000) = 1 - (1 - 0.67) * (1 - 0.375) = 0.794$$

Figure 4.5 Histogram Showing the Safety Related Savings in Cross-Overs

Figure 4.6 Histogram Showing the Workability Related Savings in Cross-Overs

4.4 Chapter Conclusion

A fuzzy logic approach can be used to incorporate the subjectivity involved in contractors' opinions and variations in response patterns. However, in the present study, not only the number of responses was limited, but also the personnel interviewed did not feel confident in quantifying their preference into dollar amounts. It is felt these factors adversely affected the robustness of the membership functions developed in the study. Thus the estimated savings may not appropriately represent the contractors' convenience in cross-overs.

On the other hand, the personnel interviewed were confident in rating the factors involved in representing the contractors' convenience in a 1-10 scale for both cross-overs and partial lane closures. It was also observed that all the contractors indicated a strong inclination towards cross-overs irrespective of work zone lengths and traffic volumes. Hence, the mean value of the ratings for each factor involved in contractors' convenience was used as the input to the analytical framework of strategy selection discussed in Chapter 6. Estimated dollar savings on the basis of the fuzzy logic approach can be used provided appropriate membership functions can be developed from a more structured interview process than which was possible in the present study.

CHAPTER 5

ACCIDENT ANALYSIS AT WORK ZONES

5.1 Introduction

Safety in highway work zones is a major concern to the contractors, crews, highway agency personnel and the road users. Work zones cause restrictive traffic condition and hence are potentially hazardous. Many researchers (Hall and Lorenz, 1989 ; Casteel and Ullman, 1991 ; Pigman and Agent, 1990 ; Ullman and Krammes, 1990) studied the effect of work zones on traffic safety and all the studies concluded that accident rates in work zones are generally higher than accident rates on comparable highway sections without work zones.

There are many factors which may affect the accident rate on a given highway section including geometry, pavement condition, traffic control strategy, traffic volume, length of the work zone and so on. In this study, the primary area of investigation was the relative safety effects of partial lane closure and cross-over as a lane closure strategy for interstate 4R projects.

In a partial lane closure, the crew have to work very close to the traffic, which is a potentially dangerous situation. On the other hand, in the case of a cross-over, traffic is maintained at a distance from the crew and the equipment, but traffic in two directions travel without a substantial median. This is also not a very desirable situation, particularly

when the traffic volume is high. It thus appears that under both lane closure strategies, sections with work zones are more accident prone than those sections without work zones.

5.2 Data Collection

The crash data associated with the 4R project sites included in this study were obtained from the records maintained by the Indiana State Police. Each site was divided into a number of homogeneous segments with respect to traffic volume. The number of accidents that took place on each of these segments, during the period of the year(s) when the maintenance or reconstruction job was going on, was noted. The number of accidents on each segment under normal operating conditions was also obtained for the same periods in other years. In the statistical analysis, used to find whether the accident rate with a work zone was higher than that without a work zone, accident data for the comparison sections were also needed. The comparison section for a segment in a project was chosen on the same interstate on which the project was done, keeping in mind that geometric features and traffic volumes in the two sections should not be very different. In order to calculate the accident rate, lengths of these sections and the average daily traffic (ADT) on them were also determined.

As an example of the data collection procedure, the project R-20368 in LaPorte district can be considered. At this work zone on I-65, the extent of lane closure was from mile marker 217 to 223 and the traffic was maintained using a cross-over arrangement. The duration of the project in 1993 was from April 19 to November 15. From the State Police Record all crashes reported on the highway section during this period were extracted as accidents under work zone conditions. The number of crashes that took place on this

section during the same period in each of the years of 1988 through 1992 was also retrieved from the data base. The section on I-65 from mile marker 205 to 214 was taken as a comparison section and the number of crashes on this section during April 19 to November 15 in each of the years from 1988 to 1993 was extracted.

The crash data associated with the work zones considered in the present study are presented in Appendix A. Crashes were classified into three broad categories : fatal, non-fatal injury and property damage. Traffic count data were available for 1987, 1990 and 1992. By interpolating these data, the average daily traffic volumes (ADT) in other years were estimated.

5.3 Statistical Procedure

Accidents are random events and it is generally agreed that accident counts follow Poisson distribution. However, the analysis of accident data is complicated due to the following two reasons (Griffin, 1982) : a) regression towards the mean fallacy, and b) post hoc ergo propter hoc fallacy.

The regression towards the mean can be explained by the following example : Suppose a high number of accidents has been observed in an intersection in one year. It is likely that in the following year a less number of accidents may be observed, even if no improvement is made. Hence, if an improvement is made and the number of accidents is reduced in the following year, it is not appropriate to conclude only from the accident counts in the two successive years that the reduction in number of accidents is solely due to the improvement made, because some chance factors may be involved. The post hoc ergo propter hoc (after the fact, therefore because of the fact) fallacy can be illustrated

by the following example : Suppose a highway section is rehabilitated and subsequently the number of wet weather accidents is reduced. This fact does not necessarily indicate that rehabilitation has reduced the wet weather accident rate. Less rainfall in the following year may be the cause of reduction of the wet weather accident rate. In the present study, an effort was made to collect crash data for several years to minimize the two problems associated with accident analyses.

There are two major types of statistical procedures for accident data analysis (Pendleton, 1991) : a) Bayesian approach, and b) Non-Bayesian or Frquentist approach. Bayesian approach can be classified further into two categories : i) Pure Bayesian method, and ii) Empirical Bayesian method. Non-Bayesian approach can be classified into three categories (Griffin, 1982) : i) Before and after study, ii) Before and after study with a comparison group, and iii) Before and after study with a comparison group and a check for comparability.

It has been claimed (Pendleton, 1991) that the empirical Bayesian approach is one of the most desirable statistical methods for analyzing the effect of an activity on accident reduction as it takes care of regression towards the mean to a great extent. However, in the present study this approach could not be used due to the sparsity of data. Moreover, it was assumed that the regression towards the mean would not have a significant effect. The reason behind such assumption was that the highway sections, selected for 4R projects, were not necessarily the sections with high accident rates. In fact the pavement condition rating is the major criterion used in selecting sections for 4R projects. As the Bayesian approach was not suitable for the available data set, the Non-Bayesian approach

was used for the analysis. It has been argued that the " before and after study with a comparison group and check for comparability " is the most desirable method among the Non-Bayesian approaches (Griffin, 1982). This is because it checks the compatibility of the comparison section with the test section, in addition to checking the safety impact of a treatment on the test section. Hence this approach was used in the present study.

5.3.1 Before and After Study with a Comparison Group and a Check for Comparability

This before and after study procedure has been described elaborately by Griffin (1982). For such studies, accident counts for several years (both before and after a treatment) are taken for the affected section and a comparison section. Then it is checked whether the change in the accident rate on the affected section after the treatment is significantly different from that on the comparison section. If the accident rates are significantly different, then it is concluded that the treatment has been effective. The test for comparability is conducted as follows :

Let y_{ij} denote the number of accidents before the treatment on the section j in the year i , $i = 1, \dots, h$; $j = 1, 2$. Similarly, x_{ij} denotes the number of accidents after the treatment on the same section j in the year i , $i = 1, \dots, k$; $j = 1, 2$. In the present study the comparison section and test section (i.e. section with work zone) were denoted as sections 1 and 2, respectively. The test statistic is computed as shown below :

$$G^2_{before} = -2 \sum_{i=1}^h \sum_{j=1}^2 y_{ij} \ln\left(\frac{m_{ij}}{y_{ij}}\right)$$

where,

$$m_{ij} = \frac{y_{i+} y_{+j}}{y_{++}}$$

$$y_{i+} = \sum_{j=1}^2 y_{ij}$$

$$y_{+j} = \sum_{i=1}^h y_{ij}$$

$$y_{++} = \sum_{i=1}^h \sum_{j=1}^2 y_{ij}$$

Degrees of freedom = $h - 1$

Similarly ,

$$G^2_{after} = -2 \sum_{i=1}^k \sum_{j=1}^2 x_{ij} \ln\left(\frac{n_{ij}}{x_{ij}}\right)$$

where,

$$n_{ij} = \frac{x_{i+} x_{+j}}{x_{++}}$$

$$x_{i+} = \sum_{j=1}^2 x_{ij}$$

$$x_{+j} = \sum_{i=1}^k x_{ij}$$

Degrees of freedom = $k - 1$

The decision regarding the comparability is made by checking the following.

$$x_{++} = \sum_{i=1}^k \sum_{j=1}^2 x_{ij}$$

$$G^2_{comparability} = G^2_{before} + G^2_{after}$$

$$\text{If } G^2_{comparability} < \chi^2(1-\alpha; k+h-2) ,$$

the comparison section is comparable with the affected section at a significance level of α .

The test for the effectiveness of the treatment is done by using the following test statistic :

$$z^* = \frac{\ln T}{\sqrt{\frac{1}{X_1} + \frac{1}{X_2} + \frac{1}{Y_1} + \frac{1}{Y_2}}}$$

where,

$$T = \frac{Y_1 X_2}{X_1 Y_2}$$

$$Y_1 = y_{11} + \dots + y_{h1} , \quad Y_2 = y_{12} + \dots + y_{h2} ,$$

$$X_1 = x_{11} + \dots + x_{k1} , \quad X_2 = x_{12} + \dots + x_{k2} .$$

$$\text{If } z^* > z(1 - \frac{\alpha}{2}) ,$$

then the treatment is effective at a significance level of α .

The objective of the statistical analysis in the present study was to find whether the accident rates at interstate work zones at different locations in Indiana were significantly higher than the accident rates on the same sections under normal operating conditions. Accident rates at work zones were higher at most of the sites, but in some cases the

reverse was true. Although this situation seems to be counter-intuitive, it may be possible that these sites already had high accident rates and motorists became extra cautious at work zones on these sites. In addition, it may also be due to various work zone safety programs including increased police patrols. It was therefore decided to capture the variations of accident rates in both directions (i.e. increasing and decreasing). Hence, the two-tailed test ($z(1 - \alpha/2)$) was used to check whether accident rates at work zones were significantly different from accident rates under normal operating conditions.

5.4 Accident Data Analysis

5.4.1 Effect of Work Zone on Accident Rate

It can be intuitively assumed that accident rates under work zone conditions would be different than accident rates under normal operating conditions. In order to validate this assumption, the crash data for the sites included in the present study were analyzed using the procedure described in Section 5.3. Each site was divided into a number of segments to maintain the homogeneity of traffic and geometric characteristics and crash data on each of the segments were analyzed separately. The results of the analysis are shown in Tables 5.1 through 5.4. Eight out of twenty-five highway segments at sites with two lanes in each direction experienced significantly higher numbers of accidents under work zone conditions. On the other hand, in four out of seven highway segments at sites with three lanes in each direction, significantly higher numbers of accidents took place under work zone conditions. The overall accident rates (including fatal, non-fatal injury and property damage accidents) at different sites are presented in Tables 5.5 through 5.8 and the average rates are summarized in Table 5.9. The severe accident rates (including only fatal

Table 5.1 Effect of Cross-Over on Work Zone Accident Rates :
Sites with Two Lanes in Each Direction

Project	Section	G^2_{comp}	Critical Value	Conclusion on Comparability	z^*	Critical Value	Conclusion on Effectiveness
R-19484	A	3.488	9.49	CM	3.744	1.96	S
R-20368	A	10.690	9.49	NCM	-	-	-
R-20369	A	18.636	9.49	NCM	-	-	-
	B	7.410	9.49	CM	3.238	1.96	S
	C	5.464	9.49	CM	-0.567	1.96	NS
R-19972	A	2.714	7.81	CM	-0.300	1.96	NS
	B	3.708	5.99	CM	1.375	1.96	NS
R-19487	A	3.342	9.49	CM	1.908	1.96	NS
R-19112	A	5.908	9.49	CM	2.523	1.96	S

Note : The critical values shown here are for 5% significance level (two sided test)

CM : Comparable NCM : Not Comparable

S : Significant NS : Not Significant

Table 5.2 Effect of Partial Lane Closure on Work Zone Accident Rates :
Sites with Two Lanes in Each Direction

Project	Section	G^2_{comp}	Critical Value	Conclusion on Comparability	z^*	Critical Value	Conclusion on Effectiveness
R-19476	A	1.404	9.49	CM	0.121	1.96	NS
R-19979	A	3.988	5.99	CM	-1.256	1.96	NS
	B	4.578	7.81	CM	-1.012	1.96	NS
R-18301	A	4.370	9.49	CM	1.833	1.96	NS
	B	1.348	9.49	CM	1.443	1.96	NS
R-17425	A	2.243	9.49	CM	-1.055	1.96	NS
R-18572	A	0.666	5.99	CM	4.002	1.96	S
	B	0.736	5.99	CM	0.744	1.96	NS
	C	1.430	5.99	CM	-0.815	1.96	NS
	D	0.908	5.99	CM	0.746	1.96	NS
R-18831	A	0.360	3.84	CM	6.152	1.96	S
	B	2.624	5.99	CM	-0.163	1.96	NS
	C	0.022	3.84	CM	2.846	1.96	S
	D	4.346	5.99	CM	0.474	1.96	NS
	E	1.078	5.99	CM	3.384	1.96	S
	F	12.524	5.99	NCM	-	-	-
R-20502	A	12.244	9.49	NCM	-	-	-
	B	2.658	9.49	CM	1.946	1.96	NS
R-20503	A	4.456	9.49	CM	2.069	1.96	S
R-17424	A	-	-	-	-	-	-
	B	0.210	5.99	CM	1.750	1.96	NS

Note : The critical values shown here are for 5% significance level (two sided test)

CM : Comparable NCM : Not Comparable

S : Significant NS : Not Significant

Table 5.3 Effect of Cross-Over on Work Zone Accident Rates :
Sites with Three Lanes in Each Direction

Project	Section	G^2_{comp}	Critical Value	Conclusion on Comparability	z^*	Critical Value	Conclusion on Effectiveness
R-20511	A	6.052	9.49	CM	4.260	1.96	S
R-17992	A	9.186	5.49	NCM	-	-	-
R-20307	A	28.762	9.49	NCM	-	-	-
R-19394	A	7.568	9.49	CM	-3.651	1.96	S
	B	18.340	9.49	NCM	-	-	-

Note : The critical values shown here are for 5% significance level (two sided test)

CM : Comparable NCM : Not Comparable

S : Significant NS : Not Significant

Table 5.4 Effect of Partial Lane Closure on Work Zone Accident Rates :
Sites with Three Lanes in Each Direction

Project	Section	G^2_{comp}	Critical Value	Conclusion on Comparability	z^*	Critical Value	Conclusion on Effect-iveness
R-19396	A	0.362	7.81	CM	2.803	1.96	S
	B	4.730	7.81	CM	1.638	1.96	NS
	C	0.896	7.81	CM	0.585	1.96	NS
	D	6.132	7.81	CM	2.333	1.96	S
R-19482	A	16.618	9.49	NCM	-	-	-
B-17737	A	5.198	7.81	CM	0.592	1.96	NS

Note : The critical values shown here are for 5% significance level (two sided test)

CM : Comparable NCM : Not Comparable

S : Significant NS : Not Significant

For the projects R-20060 and R-18806 , the accident data of the comparison sections was not available.

Table 5.5 Overall Accident Rates at Sites Using Cross-Over :
Sites with Two Lanes in Each Direction

Contract #	Part of the Project	Accident Rate without Work Zone (per 10 million VMT)	Accident Rate with Work Zone (per 10 million VMT)	Change in Accident Rate
R-19484	A	7.1485	10.9000	3.7515
R-20370	A	4.0416	4.2166	0.1750
	B	6.0863	3.7290	- 2.3546
R-20368	A	6.6200	5.6894	- 0.9306
R-20369	A & B	6.7700	9.5602	2.7902
	C	5.7081	3.9720	- 1.7361
R-19972	A	3.2638	6.5692	3.3054
	B	5.1403	14.5137	9.3734
R-19847	A	8.9307	13.5000	4.5693
R-20384	A	8.5406	9.3700	0.8294
R-19112	A	5.0683	7.1462	2.0779
R-19113	A	5.0767	7.3512	3.2745
Mean		6.0329	8.0431	2.0102
Std. Deviation		1.6842	3.6017	3.2005

Table 5.6 Overall Accident Rates at Sites Using Partial Lane Closure :
Sites with Two Lanes in Each Direction

Contract #	Part of the Project	Accident Rate without Work Zone (per 10 million VMT)	Accident Rate with Work Zone (per 10 million VMT)	Change in Accident Rate
R-19476	A	6.0692	5.4588	- 0.6104
R-19979	A	6.9101	2.3127	- 4.5974
	B	5.2306	2.1753	- 3.0553
R-18301	A & B	3.7458	7.6737	3.9279
R-17425	A	7.5050	10.4068	2.9018
R-18572	A & B	6.5200	9.8724	3.3524
	C & D	5.8815	5.5150	- 0.3665
R-18831	A, B & C	7.6237	9.9774	2.3537
	D, E & F	5.2603	10.3684	5.1081
R-20502	A & B	2.8128	5.9291	3.1163
R-20503	A	5.0620	8.6660	3.6040
R-17424	A & B	4.4786	11.0774	6.5988
Mean		5.5916	7.4528	1.8612
Std. Deviation		1.4645	3.1398	3.3354

Table 5.7 Overall Accident Rates at Sites Using Cross-Over :
Sites with Three Lanes in Each Direction

Contract #	Part of the Project	Accident Rate without Work Zone (per 10 million VMT)	Accident Rate with Work Zone (per 10 million VMT)	Change in Accident Rate
R-20511	A	3.6385	6.2686	2.6301
R-17992	A	6.4083	18.4459	12.0376
R-20307	A	6.6314	8.8106	2.1792
R-19394	A	6.2165	2.4454	- 3.7711
	B	6.2444	10.8015	4.5571
Mean		5.8278	9.3544	3.5266
Std. Deviation		1.2350	5.9645	5.6871

Table 5.8 Overall Accident Rates at Sites Using Partial Lane Closure :
Sites with Three Lanes in Each Direction

Contract #	Part of the Project	Accident rate without Work Zone (per 10 million VMT)	Accident Rate with Work Zone (per 10 million VMT)	Change in Accident Rate
R-19396	A & B	6.5707	10.8514	4.2809
	C & D	6.0753	11.6837	5.6084
R-20060	A & B	7.4273	6.1973	- 1.2300
R-18806	A	6.2413	10.2272	3.9859
R-19482	A	10.3513	7.9131	- 2.4383
B-17737	A	8.4337	13.7311	5.2974
Mean		7.5166	10.1006	2.5840
Std. Deviation		1.6422	2.6940	3.4964

Table 5.9 Average Overall Accident Rates in Different Scenarios

Sites	Accident Rate without Work Zone (per 10 million VMT)	Accident Rate with Work Zone (per 10 million VMT)	Change in Accident Rate
Sites Using Cross-over (2 lanes in each direction)	6.0329	8.0431	2.0102
Sites Using Partial Lane Closure (2 lanes in each direction)	5.5916	7.4528	1.8612
Sites Using Cross-over (3 lanes in each direction)	5.8278	9.3544	3.5266
Sites Using Partial Lane Closure (3 lanes in each direction)	7.5166	10.1006	2.5840

and non-fatal injury accidents) are presented in Tables 5.10 through 5.13 and the average rates of such accidents are summarized in Table 5.14. Finally, the average rates of overall and severe accidents (with work zones as well as without work zones) for all the sites included in the present study are shown in Table 5.15. The test results, as shown in Table 5.16, indicate that average rates of overall accidents as well as severe accidents were significantly higher under work zone conditions.

5.4.2 Average Accident Rates under Different Lane Closure Strategies

It was observed that the overall as well as severe accident rates at work zones were significantly higher than the accident rates under normal operating conditions, irrespective of lane closure strategies. However, one may also be interested to find whether a particular lane closure strategy would be potentially more dangerous than the other. If cross-overs are used, drivers have to face the opposing traffic without the protection of sufficient medians in most cases. Under heavy traffic and in the night or in bad weather, this situation gives rise to safety problem. Hence, it was hypothesized that a site might experience higher number of accidents if a cross-over was used instead of a partial lane closure. In order to verify this assumption, the average overall accident rates under the two lane closure strategies were compared as shown in Table 5.17. The results of the statistical analysis, presented in Table 5.18, indicated that while the average overall accident rate under cross-overs was slightly higher than that under partial lane closures, the rates were not statistically significantly different. Next, the average severe accident rates under the two lane closure strategies were compared as shown in Table 5.19. In this case also, although the average severe accident rate under cross-overs was slightly higher

**Table 5.10 Fatal and Non-Fatal Injury Accident Rates at Sites Using Cross-Over :
Sites with Two Lanes in Each Direction**

Contract #	Part of the Project	Fatal and Non-Fatal Injury Accident Rate without Work Zone (per 10 million VMT)	Fatal and Non-Fatal Injury Accident Rate with Work Zone (per 10 million VMT)	Change in Fatal and Non-Fatal Injury Accident Rate
R-19484	A	1.1968	2.5276	1.3308
R-20370	A	0.9073	0.0000	- 0.9073
	B	1.2173	1.2430	0.0257
R-20368	A	1.2872	1.4223	0.1351
R-20369	A & B	1.4507	1.7382	0.2875
	C	1.6054	0.7944	- 0.8110
R-19972	A	0.3626	0.0000	- 0.3626
	B	0.0000	7.2568	7.2568
R-19847	A	1.5094	3.5001	1.9907
R-20384	A	1.9826	2.1623	0.1797
R-19112	A	1.0308	1.5205	0.4897
R-19113	A	0.9965	2.7305	1.7340
Mean		1.1289	2.0746	0.9457
Std. Deviation		0.5376	1.9380	2.1879

Table 5.11 Fatal and Non-Fatal Injury Accident Rates at Sites Using
Partial Lane Closure : Sites with Two Lanes in Each Direction

Contract #	Part of the Project	Fatal and Non-Fatal Injury Accident Rate without Work Zone (per 10 million VMT)	Fatal and Non-Fatal Injury Accident Rate with Work Zone (per 10 million VMT)	Change in Fatal and Non-Fatal Injury Accident Rate
R-19476	A	0.7586	2.7294	1.9708
R-19979	A	0.3839	0.0000	- 0.3839
	B	0.5411	0.7251	0.1840
R-18301	A & B	1.1411	2.1742	1.0331
R-17425	A	1.6385	1.5768	- 0.0617
R-18572	A & B	1.1410	3.1412	2.0002
	C & D	1.2806	0.3558	- 0.9248
R-18831	A, B & C	1.9344	2.3946	0.4602
	D, E & F	1.0521	3.5641	2.5120
R-20502	A & B	0.9822	0.8746	- 0.1076
R-20503	A	1.1195	2.5488	1.4293
R-17424	A & B	1.1893	4.2880	3.0987
Mean		1.0969	2.0311	0.9342
Std. Deviation		0.4252	1.3405	1.2684

Table 5.12 Fatal and Non-Fatal Injury Accident Rates at Sites Using Cross-Over :
Sites with Three Lanes in Each Direction

Contract #	Part of the Project	Fatal and Non-Fatal Injury Accident Rate without Work Zone (per 10 million VMT)	Fatal and Non-Fatal Injury Accident Rate with Work Zone (per 10 million VMT)	Change in Fatal and Non-Fatal Injury Accident Rate
R-20511	A	0,9217	1.6999	0.7782
R-17992	A	1.8605	5.3032	3.4427
R-20307	A	1.8651	1.9579	0.0928
R-19394	A	1.5349	1.6303	0.0954
	B	1.7602	2.5924	0.8322
Mean		1.5885	2.6367	1.0482
Std. Deviation		0.3961	1.5320	1.3851

Table 5.13 Fatal and Non-Fatal Injury Accident Rates at Sites Using
Partial Lane Closure : Sites with Three Lanes in Each Direction

Contract #	Part of the Project	Fatal and Non-Fatal Injury Accident rate without Work Zone (per 10 million VMT)	Fatal and Non-Fatal Injury Accident Rate with Work Zone (per 10 million VMT)	Change in Fatal and Non-Fatal Injury Accident Rate
R-19396	A & B	1.6165	2.2607	0.6442
	C & D	1.4639	1.7136	0.2497
R-20060	A & B	2.0327	0.5025	- 1.5302
R-18806	A	1.4847	2.5293	1.0446
R-19482	A	2.1215	1.9410	- 0.1805
B-17737	A	1.8655	3.7294	1.8639
Mean		1.7641	2.1128	0.3487
Std. Deviation		0.2829	1.0574	1.1565

Table 5.14 Average Fatal and Non-Fatal Injury Accident Rates in Different Scenarios

Sites	Fatal and Non-Fatal Injury Accident Rate without Work Zone (per 10 million VMT)	Fatal and Non-Fatal Injury Accident Rate with Work Zone (per 10 million VMT)	Change in Fatal and Non-Fatal Injury Accident Rate
Sites Using Cross-over (2 lanes in each direction)	1.1289	2.0746	0.9457
Sites Using Partial Lane Closure (2 lanes in each direction)	1.0969	2.0311	0.9342
Sites Using Cross-over (3 lanes in each direction)	1.5885	2.6367	1.0482
Sites Using Partial Lane Closure (3 lanes in each direction)	1.7641	2.1128	0.3487

Table 5.15 Average Accident Rates : With Work Zone Vs. Without Work Zone

Cases	Without Work Zone [μ_1] (per 10 million VMT)	With Work Zone [μ_2] (per 10 million VMT)	Difference in Accident Rate under Two Scenarios
Overall Accident Rate (Fatal, Non-Fatal Injury and Property Damage)	6.1067	8.3808	2.2741
Severe Accident Rate (Fatal and Non-Fatal Injury Only)	1.2925	2.1465	0.8540

Table 4.16 Testing the Effect of Work Zone on the Average Accident Rate

Hypotheses	T-statistics	Critical Value at 5% Significance Level	P-value (One Sided Test)	Conclusion
All Accidents : $H_0 : \mu_1 = \mu_2$ $H_a : \mu_1 < \mu_2$	3.334	1.669	0.00077	H_0 is rejected at 5% significance level.
Fatal and Non-Fatal Accidents Only : $H_0 : \mu_1 = \mu_2$ $H_a : \mu_1 < \mu_2$	3.178	1.669	0.00123	H_0 is rejected at 5% significance level.

Table 5.17 Average Overall Accident Rates : Cross-Over Vs. Partial Lane Closure

Cases	Under Cross-Over [μ_1] (per 10 million VMT)	Under Partial Lane Closure [μ_2] (per 10 million VMT)	Difference under Two Scenarios
Overall Accident Rate (Fatal, Non-Fatal Injury and Property Damage)	8.4288	8.3354	0.0934
Increase in Overall Accident Rate Compared to Normal Condition	2.4562	2.1021	0.3541

Table 4.18 Testing the Effect of Lane Closure Strategy on the Average Overall Accident Rate

Hypotheses	T-statistics	Critical Value at 5% Significance Level	P-value (One Sided Test)	Conclusion
Overall Accident Rate : $H_0 : \mu_1 = \mu_2$ $H_a : \mu_1 > \mu_2$	0.074	1.693	0.4711	H_0 is not rejected at 5% significance level.
Increase in Overall Accident Rate Compared to Normal Condition : $H_0 : \mu_1 = \mu_2$ $H_a : \mu_1 > \mu_2$	0.288	1.693	0.3886	H_0 is not rejected at 5% significance level.

Table 5.19 Average Fatal and Non-Fatal Injury Accident Rates :
Cross-Over Vs. Partial Lane Closure

Cases	Under Cross-Over [μ_1] (per 10 million VMT)	Under Partial Lane Closure [μ_2] (per 10 million VMT)	Difference under Two Scenarios
Severe Accident Rate (Fatal and Non-Fatal Injury Only)	2.2400	2.0583	0.1817
Increase in Severe Accident Rate Compared to Normal Condition	0.9759	0.7390	0.2369

Table 4.20 Testing the Effect of Lane Closure Strategy on the Average Fatal and Non-Fatal Injury Accident Rate

Hypotheses	T-statistics	Critical Value at 5% Significance Level	P-value (One Sided Test)	Conclusion
Accident Rate : $H_0 : \mu_1 = \mu_2$ $H_a : \mu_1 > \mu_2$	0.3511	1.693	0.3665	H_0 is not rejected at 5% significance level.
Increase in Accident Rate Compared to Normal Condition : $H_0 : \mu_1 = \mu_2$ $H_a : \mu_1 > \mu_2$	0.4336	1.693	0.3375	H_0 is not rejected at 5% significance level.

than that under partial lane closures, the results of the statistical analysis, presented in Table 5.20, indicated that these rates were not significantly different.

The data available for the present study were not sufficient to confirm conclusively the hypothesis that a cross-over may be potentially more hazardous. A possible reason for this result was the fact that the crash data were unmatched as the sites for the crash data for two strategies were not the same. Nevertheless, it can be observed that P-values in Table 5.18 were higher than the corresponding P-values in Table 5.20. This indicates that the probability of average accident rates under two strategies being different is higher in case of severe crashes. Therefore, there is some evidence that there may be a higher chance of having a severe crash in a cross-over than in a partial lane closure. However, more data would be necessary to make a statistically significant conclusion.

5.5 Regression Model to Predict Probable Number of Accidents

The number of crashes experienced at a project site indicates the degree of safety hazard at that site. Depending on the lane closure strategy used, the impact on safety may vary. In order to find the effect of a lane closure strategy on work zone accident rates, it is necessary to estimate the probable number of accidents that would be experienced at the project site under a given lane closure strategy. Regression lines were fitted to predict the number of crashes at work zones. It was found by a number of researchers (Frome et al., 1973 ; Hausmann et al., 1986 ; Cameron and Trivedi, 1990) that Poisson or negative binomial models are appropriate for count data. As crash data also fall in the same category, Poisson and negative binomial models were developed as shown in Appendix B. But the predictive power of these models was very low (as indicated by R^2

values in Tables B.1 through B.4). Consequently, the possibility of using normal regression models was explored as such models are simple and easy to use. Residuals obtained from normal regression models were in straight line on normal probability plots. This indicated that the assumption of normality of the error terms was valid. Therefore, the use of normal regression models was justifiable.

It can be hypothesized that the number of crashes is likely to be higher in longer sections and/or with higher traffic volumes. Similarly, the number of crashes would increase with longer durations of the project. It is also likely that in sections with high crash rates under normal conditions, the number of crashes under restricted conditions would also be relatively higher. All these factors were used in the regression models as explanatory variables. Several combinations of the explanatory variables were considered and the best combination was selected to predict the probable number of accidents. The following criteria were used to select the "best" model :

- 1) It should have a fairly high corrected R^2 . The purpose of using corrected R^2 values was to consider the loss of degrees of freedom caused by the increase in the number of independent variables.

- 2) The regression coefficients should not be counter-intuitive, i.e. the signs of these coefficients should be compatible with the physical interpretation.

- 3) The values of the regression coefficients should be significantly different from zero, i.e. the corresponding t-statistic should lie beyond the critical value.

After various trials the final model for cross-overs at sites with two lanes in each direction was obtained, as shown in Table 5.22. All the regression coefficients of the

Table 5.21 Explanatory Variables in the Regression Model

Dependent Variable : Number of accidents at work zone

Explanatory Variables	Mnemonics
1. Intercept term	cnst
2. Duration of project (in days)	dur
3. Interaction between traffic volume and length of the project	vml
4. Accident rate under normal condition (per 10 million vehicle miles travelled)	acrnrm

Table 5.22 Model for Sites Using Cross-Over :
Sites with Two Lanes in Each Direction

Dependent Variable : Expected number of accidents at work zone

Explanatory Variables	Estimated Coefficients	T-statistic
cnst	-24.50332	-3.1949
dur	0.1272	4.0043
vml	1.03101 E-004	3.04811
acnm	1.44057	1.38428

Auxiliary Statistics :

Number of observations : 13

R^2 : 0.87028

Corrected R^2 : 0.82704

model were physically interpretable and were statistically significant at 5% significance level except the one for the accident rate under normal conditions. However, with the exclusion of this variable, the corrected R^2 decreased from 0.82704 to 0.81120. At the same time, the computed P-value was very close to the desired significance level (5%). If the significance level (value of α) was slightly increased, the regression coefficient would have been statistically significant. Hence, it was not dropped from the model.

The model for partial lane closures at sites with two lanes in each direction is presented in Table 5.23. The regression coefficients were statistically significant at 5% level and none of them was counter-intuitive. The model for cross-overs at sites with three lanes in each directions is presented in Table 5.24. The regression coefficients in this model were also significant at 5% level and could be physically interpreted. In the model shown in Table 5.25 for partial lane closures at sites with three lanes in each direction, all the regression coefficients were statistically significant and were intuitively interpretable. Initially, the accident rate under normal conditions was included in the model, but the corresponding t-statistic was very low. Hence, it was dropped from the model.

From these regression equations, the expected number of accidents in a work zone under both lane closure strategies can be estimated with considerable accuracy, given that the information is provided concerning the length, the traffic volume, the accident rate under normal conditions, and the duration of the project.

Table 5.23 Model for Sites Using Partial Lane Closure :
Sites with Two Lanes in Each Direction

Dependent Variable : Expected number of accidents at work zone

Explanatory Variables	Estimated Coefficients	t-statistic
cnst	-25.97956	-3.09197
dur	7.84678 E-002	3.33815
vml	1.91737 E-004	5.52625
acnm	1.19706	1.98513

Auxiliary Statistics :

Number of observations : 21

R^2 : 0.73515

Corrected R^2 : 0.68841

Table 5.24 Model for Sites Using Cross-Over :
Sites with Three Lanes in Each Direction

Dependent Variable : Expected number of accidents at work zone

Explanatory Variables	Estimated Coefficients	t-statistic
cnst	-3.18971 E+002	-9.94938
dur	0.29211	5.42998
vml	4.92368 E-004	14.99333
acnm	32.42671	9.74726

Auxiliary Statistics :

Number of observations : 5

R^2 : 0.99610

Corrected R^2 : 0.98441

Table 5.25 Model for Sites Using Partial Lane Closure :
Sites with Three Lanes in Each Direction

Dependent Variable : Expected number of accidents at work zone

Explanatory Variables	Estimated Coefficients	t-statistic
cnst	-69.2807	-2.022
dur	0.35295	2.75317
vml	1.65543 E-004	3.50836

Auxiliary Statistics :

Number of observations : 9

R^2 : 0.70131

Corrected R^2 : 0.60174

CHAPTER 6

SYNTHESIS OF STUDY RESULTS

6.1 Introduction

The main objective of this study was to develop an analytical framework to determine a cost-effective lane closure strategy for an interstate work zone. There are mainly two types of lane closure strategies for interstate construction work zones, cross-overs and partial lane closures. Each type has certain merits and demerits. For example, in case of cross-overs, when two-way two-lane traffic is maintained, night driving is very uncomfortable. The cost of traffic control is also typically higher as additional cost is incurred in constructing the cross-over. The safety of the work zone crew is affected in case of partial lane closures as the traffic is maintained close to the work area and the productivity also decreases. Obviously there is a trade-off. Under certain conditions a cross-over may be better than a partial lane closure and under some other conditions it may be the other way around. A well defined procedure needs to be followed to make a judgement regarding a particular strategy selection. In this chapter, a procedure is presented that combines various factors in assessing the appropriateness of a lane closure strategy at an interstate work zone.

6.2 Selection of Lane Closure Strategy

There are mainly four components involved in the selection procedure of the lane closure strategy, namely user travel time and vehicle operating cost, traffic control cost, safety, and contractors' convenience. The combined effect of these components dictates the selection of an appropriate lane closure strategy. There are several ways of combining the effect of different components. In the present study, two separate approaches were initially considered. First, an effort was made to monetize all component factors and a cost minimization approach was explored. However, no reliable set of accident cost data could be determined and the factor of contractors' convenience could not be effectively translated into dollar amounts. Consequently, an approach was sought that could combine various noncommensurable factors represented by different dimensions. The analytic hierarchy approach (AHP) suggested by Saaty (1980) was found to be more appropriate, particularly because this procedure is most direct and it allows the incorporation of the experience and judgement of agency personnel and contractors.

6.2.1 Analytic Hierarchy Approach

6.2.1.1 Methodology

In a multi-objective decision making process, each objective has a certain level of importance and can be placed in a hierarchical order depending on its relative importance. The attributes of each alternative are then evaluated with respect to each of the objectives and the attribute values are aggregated to reach the final decision. This process is called analytic hierarchy process (AHP) as it recognizes the hierarchical structure in the decision making mechanism (Saaty, 1980).

A technique involving the experience and mutual agreement of knowledgeable agency personnel may be used to set up the hierarchical order among the objectives and among the attribute values under each objective. In the AHP it is done by consistent pair-wise comparisons. The qualitative judgement from pair-wise comparisons is translated into absolute numbers by using the scale values presented in Table 6.1.

There are mainly two goals in an analytic hierarchy process : i) to decide the relative importance of each of the objectives involved in the decision making, and ii) to insure that the qualitative judgement regarding each alternative to fulfill a certain objective is properly quantified.

The steps involved in the analytic hierarchy process is described as follows. Let $C_1, C_2, \dots, C_n$ be the set of objectives. The relative importance of the objective C_i compared to the objective C_j is obtained from the agency personnel's opinions and is expressed in a 1-9 scale developed by Saaty (1980) and is denoted by a_{ij} . For all the pairs of objectives, such values are obtained and these are stored in a $(n \times n)$ matrix as follows:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & \dots & a_{2n} \\ \vdots & \vdots & \dots & \dots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & \dots & 1 \end{bmatrix}$$

A is called the reciprocal matrix. Two interesting features of this matrix are :

i) If $a_{ij} = K$, then $a_{ji} = 1/K$, $K > 0$; and

Table 6.1 Scale Values Developed by Saaty (1980) to Assign Relative Importance to the Different Decision Criteria

Intensity of Importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally
3	Weak importance	Experience or judgement slightly favor one criterion over another
5	Essential or strong importance	Experience and judgement strongly favor one criterion over another
7	Very strong or demonstrated importance	One criterion is favored very strongly over another ; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one criterion over another is of highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent scale values	When compromise is needed

ii) If C_i has equal importance as C_j , then $a_{ij} = 1$.

Let $\underline{w}$ be the column vector representing the relative weights ($w_1, w_2, \dots, w_n$) of the n objectives. These weights can be estimated as follows. There are n numbers of eigen values in a $(n \times n)$ matrix. As all the diagonal elements in the reciprocal matrix are 1, the sum of all the eigen values would be n , i.e., $\sum e_i = n$, where e_i is the i -th eigen value. In a perfectly consistent matrix the highest eigen value would be n as the other eigen values are zero. Thus, from a perfectly consistent matrix, the relative weights can be obtained from the following relationship :

$$[A].\underline{w} = n.\underline{w}$$

where, $\underline{w}$ is the eigen vector corresponding to the eigen value n . But in most cases, the reciprocal matrices are not perfectly consistent as subjectivity is involved in the experts' opinions used to develop these matrices. The degree of inconsistency is reflected by the maximum eigen value ($e_{\max}$) obtained from the reciprocal matrix. More consistent the reciprocal matrix, the closer is $e_{\max}$ to n . When $e_{\max}$ is not very different from n , the relative weights ($\underline{w}$) can be estimated with sufficient accuracy as follows :

$$[A].\underline{w} = e_{\max}.\underline{w}$$

where, $\underline{w}$ is the eigen vector corresponding to $e_{\max}$.

Let w_i be the i -th weight in $\underline{w}$ and $\alpha = \sum w_i$. Then the corresponding normalized weight would be (w_i/α) .

The lack of consistency can be measured by the consistency index (CI). For a $(n \times n)$ matrix, it is defined as $(e_{\max} - n)/(n - 1)$. It is compared with the average consistency index of randomly generated reciprocal matrices (Saaty, 1980). The consistency index computed

in such a way is called random index (RI). The consistency ratio (CR) is obtained by dividing the consistency index by the random index and it measures the degree of inconsistency. The lower the value of this ratio, the higher is the consistency. It has been suggested by Saaty (1980) that the consistency ratio of each of the reciprocal matrix should be lower than 0.10 to ensure the accuracy in the estimation.

Relative performances of the available alternatives under each of the objectives considered can be determined following the steps described above. Say $u_{1k}, u_{2k}, \dots, u_{mk}$ are the relative weights of the m available alternatives under the objective k . Let

$$\beta_k = \sum_{j=1}^m u_{jk}$$

The normalized weights under the objective k are obtained as (u_{jk}/β_k) . In order to reach a decision under the multi-objective decision criteria, these weights should be aggregated.

The aggregated weights $\underline{v}$ for the alternatives can be determined as

$$\begin{bmatrix} v_1 \\ \cdot \\ \cdot \\ \cdot \\ v_m \end{bmatrix} = \begin{bmatrix} \frac{1}{\beta_1} u_{11} & \cdot & \cdot & \frac{1}{\beta_n} u_{1n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \frac{1}{\beta_1} u_{m1} & \cdot & \cdot & \frac{1}{\beta_n} u_{mn} \end{bmatrix} * \begin{bmatrix} \frac{1}{\alpha} w_1 \\ \cdot \\ \cdot \\ \cdot \\ \frac{1}{\alpha} w_n \end{bmatrix}$$

The alternative with the highest weight should then be chosen as the most desirable alternative.

6.2.1.2 Application of Analytic Hierarchy Approach in Selection of Lane Closure Strategy

As mentioned earlier, there are four broad components for the selection of a lane closure strategy. These are user travel time and vehicle operating cost, traffic control cost, safety, and contractors' convenience. Further, from the opinion survey of the contractors four sub-components involved in contractors' convenience were identified : worker safety, equipment safety, work productivity, and quality of work. Although the contractors also rated the lane closure strategies with respect to traveller safety, this factor was not included in the overall evaluation, because the traveller safety aspect was explicitly considered as a separate item represented by expected number of crashes. At first, the relative importance of each of the four sub-components of the contractors' convenience factor was obtained from their pair-wise comparisons using the contractors' opinions, and the reciprocal matrix was constructed, as shown in Table 6.2. On the basis of the ratings given by contractors, as mentioned in Chapter 4, the relative weights of the two lane closure strategies with respect to these sub-components were obtained. These weights were aggregated using AHP to estimate the relative convenience of the contractors under the two lane closure strategies. At the second stage, the relative importance of the four major components (e.g. user travel time and vehicle operating cost, traffic control cost, safety, and contractors' convenience) was determined from the opinions of the INDOT district personnel. The corresponding reciprocal matrix was constructed, as shown in Table 6.3. The user travel time and vehicle operating costs as well as traffic control costs under cross-overs as well as partial lane closures were estimated for all the projects included in the study using the regression models developed in Chapters 2 and 3,

Table 6.2 Reciprocal Matrix Showing Relative Importance of Different Components in Contractors' Convenience

	Worker Safety	Equipment Safety	Work Productivity	Quality of Work
Worker Safety	1	9	5	7
Equipment Safety	1/9	1	1/5	1/4
Work Productivity	1/5	5	1	3
Quality of Work	1/7	4	1/3	1

$$e_{\max} = 4.2347$$

$$\text{Consistency Index (CI)} = 0.0782$$

$$\text{Random Index (RI)} = 0.9$$

$$\text{Consistency Ratio (CR)} = \text{CI} / \text{RI} = 0.0782/0.9 = 0.0869 < 0.1$$

Table 6.3 Reciprocal Matrix Showing Relative Importance of the Four Decision Criteria

	User Cost	Traffic Control Cost	Safety	Contractor's Convenience
User Cost	1	7	1/5	1/5
Traffic Control Cost	1/7	1	1/9	1/9
Safety	5	9	1	1
Contractor's Convenience	5	9	1	1

$$e_{\max} = 4.2389$$

$$\text{Consistency Index (CI)} = 0.0796$$

$$\text{Random Index (RI)} = 0.9$$

$$\text{Consistency Ratio (CR)} = \text{CI} / \text{RI} = 0.0796/0.9 = 0.0884 < 0.1$$

respectively. The issue of safety was considered by predicting the probable number of accidents under both strategies and these numbers were estimated using the regression equations developed in Chapter 5. From pair-wise comparisons of these estimated values, the relative weights of the lane closure strategies for each of these components were obtained. In all pair-wise comparisons, the 1-9 scale, as shown in Table 6.1, was used.

In the present study, weights were defined such that higher weights indicated better performance. The estimated weights for projects on 4-lane and 6-lane interstates are shown in Tables 6.4 and 6.5, respectively. The lane closure strategies selected by the AHP procedure were compared with the actual strategies used for the projects. The results are summarized in Tables 6.6 and 6.7. It can be noted that in seven out of twenty-six projects, the AHP procedure indicated a different strategy than the actual one used at the project site.

6.3 Sensitivity Analysis

The selection of a suitable lane closure strategy for a work zone is influenced by the relative weights assigned to the four decision criteria. In the example application in the present study, safety and contractors' convenience were given the same weights and both of them were assigned higher priorities than the other two (user travel time and vehicle operating cost and traffic control cost). User travel time and vehicle operating costs as well as traffic control costs were not significantly different under the two lane closure strategies for the projects considered in the study. However, all contractors interviewed indicated a very strong preference for cross-overs over partial lane closures. Thus, for the projects in which the estimated probable number of accidents under the partial lane closure

Table 6.4 Aggregate Weights of Lane Closure Strategies in AHP :
Sites with Two Lanes in Each Direction

Project	Weight for Cross-over	Weight for Partial Lane Closure	Selected Lane Closure Strategy
R-20368	0.6448	0.3552	CS
R-19487	0.5019	0.4981	CS
R-19112	0.6448	0.3552	CS
R-19515	0.7549	0.2451	CS
R-19113	0.7508	0.2492	CS
R-19738	0.4810	0.5190	PLC
R-20970	0.5389	0.4611	CS
R-20906	0.5019	0.54981	CS
R-19484	0.5019	0.4981	CS
R-20370	0.6448	0.3552	CS
R-20381	0.4899	0.5101	PLC
R-19976	0.5150	0.4850	CS
R-19483	0.4859	0.5141	PLC
R-18301	0.4821	0.5179	PLC
R-17425	0.4843	0.5157	PLC
R-20974	0.5008	0.4992	CS
R-18831	0.4737	0.5263	PLC
R-20502	0.4831	0.5169	PLC
R-20503	0.6420	0.3580	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table 6.5 Aggregate Weights of Lane Closure Strategies in AHP :
Sites with Three Lanes in Each Direction

Project	Weight for Cross-over	Weight for Partial Lane Closure	Selected Lane Closure Strategy
R-19396	0.8171	0.1829	CS
R-19620	0.4583	0.5417	PLC
R-20060	0.7990	0.2010	CS
R-19908	0.4765	0.5235	PLC
R-18806	0.7973	0.2027	CS
R-19482	0.4583	0.5417	PLC
B-17737	0.4583	0.5417	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

Table 6.6 Summary of Results : Sites with Two Lanes in Each Direction

Project	Lane Closure Strategy Used in the Project	Strategy Selected by AHP Approach
R-20368	CS	CS
R-19847	CS	CS
R-19112	CS	CS
R-19515	CS	CS
R-19113	CS	CS
R-19738	CS	PLC
R-20970	CS	CS
R-20906	CS	CS
R-19484	CS	CS
R-20370	CS	CS
R-20381	PLC	PLC
R-19476	PLC	CS
R-19483	PLC	PLC
R-18301	PLC	PLC
R-17425	PLC	PLC
R-20974	PLC	CS
R-18831	PLC	PLC
R-20502	PLC	PLC
R-20503	PLC	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table 6.7 Summary of Results : Sites with Three Lanes in Each Direction

Project	Lane Closure Strategy Used in the Project	Strategy Selected by AHP Approach
R-19396	PLC	CS
R-19620	PLC	PLC
R-20060	PLC	CS
R-19908	PLC	PLC
R-18806	PLC	CS
R-19482	PLC	PLC
R-17737	PLC	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

was not very different from that under the cross-over, the preferred strategy selected was a cross-over. It should be noted that if the relative importance of these criteria are changed, the decision about the lane closure strategy may not be the same.

In order to find the effect of the change in the relative importance of the decision criteria on the selection of lane closure strategies, a sensitivity analysis was done. It was found that user cost, traffic control cost, contractors' convenience and safety were assigned initially with weights 0.7274, 0.2049, 2.59, and 2.59 respectively and the corresponding normalized relative weights were 0.1190, 0.0336, 0.4237, and 0.4237 respectively. As the contractors' convenience and safety were given the higher priorities, these two factors were chosen for the sensitivity analysis. If the weight of any of these factors is changed the normalized relative weights of all the four factors would also change. For example, if the weight of contractors' convenience is increased by 10%, the normalized relative weights of user cost, traffic control cost, contractors' convenience and safety would be 0.1142, 0.0321, 0.4472, and 0.4065 respectively.

The results of the sensitivity analysis of the criterion of contractors' convenience is presented in Table 6.8. It can be noted that as the initial weight was increased, cross-overs were preferred in more projects. For example, for seventeen out of twenty-six projects cross-overs were chosen when the initial weight for contractors' convenience was increased by 10%. On the other hand, when the importance of contractors' convenience was reduced, the number of projects favoring cross-overs was reduced, but not in the same proportion as that for the weight increase. The results of the sensitivity analysis on safety are shown in Table 6.9. As the weight of safety was increased, partial lane closures

Table 6.8 Sensitivity Analysis for Contractors' Convenience

Weight of Contractors' Convenience Changed By	10% Decrease	5% Decrease	Initial Value (no change)	5% Increase	10% Increase
Number of Projects Favoring Cross-over	10	11	15	15	17
Number of Projects Favoring Partial Lane Closure	16	15	11	11	9

Table 6.9 : Sensitivity Analysis for Safety

Weight of Safety Changed By	10% Decrease	5% Decrease	Initial Value (no change)	5% Increase	10% Increase
Number of Projects Favoring Cross-over	18	15	15	11	10
Number of Projects Favoring Partial Lane Closure	8	11	11	15	16

were preferred. Because contractors' convenience and safety were given the same initial weights, the effect of weight changes had similar but opposite trends. The relative weights of cross-overs and partial lane closures in each of the twenty-six projects included in this study are shown in Appendix C for various degrees of importance of contractors' convenience and safety. It should be noted that the selection of a lane closure strategy is highly location specific and it will vary from site to site.

6.4 Chapter Conclusion

The analytic hierarchy approach (AHP) is a powerful technique for making a decision under multi-objective decision environments. One advantage in this approach is that it can convert performances of various alternatives expressed in different units into a consistent set of dimensionless weights. In the present study while user travel time and vehicle operating costs and traffic control costs are expressed in dollars, safety is represented in terms of number of crashes and contractors' convenience in terms of subjective ratings. There are other approaches available to obtain commensurable values of various factors. However, an important aspect of AHP is that it can assure a certain level of consistency of ratings. The sensitivity analysis indicated that the weights of alternatives would change with the change of the relative importance of the decision criteria and the subsequent selection of an alternative would be affected. The pair-wise comparisons included in the study reflect the experience and judgement of INDOT district personnel and contractors interviewed in the study. A separate set of comparisons should be made and weights estimated if these values do not represent the preference of particular decision-makers.

CHAPTER 7

SUMMARY AND CONCLUSION

7.1 Summary

A methodology was developed for the estimation of road user travel time and vehicle operating cost, traffic control cost, safety, and the extent of contractors' convenience associated with lane closure strategies at a given work zone. A procedure based on the analytic hierarchy approach was used to combine these effects. The methodology was applied to select a desirable strategy for the twenty-six projects included in the present study. The steps involved in the proposed methodology are summarized in this chapter.

7.2 Lane Closure Strategy Selection

The work zone lane closure strategy selection methodology is presented in the schematic diagram shown in Figure 7.1. Further discussions are presented below.

7.2.1 Input Requirements

The project site should be divided into a number of segments so that the homogeneity with respect to traffic and geometric characteristics is maintained along the segment. On interstate highways the traffic volume remains the same along a section between two consecutive interchanges. Such a section can be treated as a single segment. Depending on the location of interchanges, the work zone should be divided into a number of

Figure 7.1 Schematic Diagram of the Lane Closure Strategy Selection Process

segments, and the length, AADT, and the duration of the lane closure on each of the segments should also be known. Average accident rates on these segments should be estimated in terms of accidents per 10 million vehicle-miles travelled (VMT). The approximate total project cost must also be estimated and used as input data.

7.2.2 Estimation of User Travel Time and Vehicle Operating Cost

The user travel time and vehicle operating cost in each of the segments under both lane closure strategies can be estimated from the regression models presented in Tables 2.9 and 2.10. The dependent variable is the user travel time and vehicle operating cost (in thousand dollars) in a year (365 days) and is a function of the length of the segment (in miles) and the traffic volume (in number of vehicles per day). Depending on the duration of a lane closure the estimated cost should be adjusted. The adjusted cost for each segment should be added to obtain the total user travel time and vehicle operating cost for the project. MicroBENCOST, a software developed by NCHRP (1993), can also be used to estimate the user travel time and vehicle operating cost. But extensive input data have to be collected to prepare the input files. Moreover, the linear regression models, developed in the present study, had very high goodness of fit and the errors in estimation would not be critical, if the regression equations were used.

7.2.3 Estimation of Traffic Control Cost

The traffic control cost under both strategies can be estimated using the regression model given in Table 3.7. This cost is expressed as a percentage of total project cost. If

available, the transportation agency may use estimates of project specific traffic control cost under both strategies.

7.2.4 Contractors' Convenience

All the contractors interviewed showed a strong preference for cross-overs over partial lane closures, irrespective of project size. The average ratings, as shown in Tables 4.1 and 4.2, may be used as indicators of contractors' convenience under both lane closure strategies. However, site specific values can be used, if available.

7.2.5 Estimation of Expected Number of Crashes

The expected number of crashes on each of the segments under both lane closure strategies can be estimated from the regression models shown in Tables 5.22 through 5.25. The independent variables are the work zone length (in miles), the lane closure duration (in days), the average daily traffic volume (in number of vehicles per day) and the average crash rate (in number of crashes per 10 million vehicle-miles travelled) under normal operating conditions. The crash rate at each segment under normal operating conditions can be obtained by dividing the number of crashes recorded on the segment in previous years (in the absence of the work zone) by vehicle-miles travelled in those years. The estimated expected number of crashes on each segment should be added to obtain the total expected number of crashes at the project site. In case the data on recorded number of crashes are not available, the crash rate can be estimated from acceptable average values for the type of road and land use.

7.2.6 Synthesis of Impacts and Selection of Lane Closure Strategy

An overall index can be estimated by combining the impacts of the four factors. A procedure based on the analytic hierarchy approach was suggested. The relative importance of the four factors was determined on the basis of the judgement of district personnel using a 1-9 scale shown in Table 6.1. The weights of the four factors, as shown in Table 6.3, may be used as default values. The two lane closure strategies should be rated using the scale shown in Table 6.1 according to the values obtained for individual factors. Finally, the overall impact of using a partial lane closure or a cross-over can be estimated and expressed in terms of dimensionless weights. The strategy with a higher weight is to be selected as the appropriate lane closure strategy. If the relative weights for both strategies are close to each other, a sensitivity analysis may be conducted before reaching the final decision by changing the relative weights of the impacts of the four factors.

A computer program, LANECLOSE, was developed which can be readily used to select the appropriate lane closure strategy at an interstate 4R project site. The program is listed in Appendix C. It is coded in C language. The input required are work zone length, traffic volume, duration of project, accident rate under normal operating conditions and estimated total project cost. It is assumed that both cross-over and partial lane closure strategies can be physically accomplished at the given site. If partial lane closure is used, for many types of resurfacing jobs restrictions may only be in place while the contractor is paving. In such a case, the percentage of project duration the lane is actually closed has to be specified. The program is self-explanatory and the user can easily enter the input

data in an interactive manner. The program determines the impacts of lane closure strategies on user travel time and vehicle operating cost, traffic control cost, contractors' convenience, and safety. The user can either assign the relative importance of the impacts or can use the default values which are imbedded in the program. Finally, the overall weight of each lane closure strategy is determined. The strategy with higher weight is selected as the appropriate lane closure strategy at the given project site.

7.3 Conclusion

In the present study, linear regression models were used to estimate user travel time and vehicle operating costs, traffic control costs, and expected number of crashes. Although the data available to develop these models were limited, the goodness of fit in the models developed was sufficient. However, more comprehensive models can be developed with a larger data set. Although Poisson and negative binomial models were developed for crash estimation, they were not used in the framework because of very low predictive power. However, the normal regression models had fairly good fit and were selected particularly for their simplicity and ease of use.

The procedure presented in the study can be used to estimate the overall impact of a work zone under a cross-over as well as under a partial lane closure with sufficient accuracy. As more data are available, the models can be redefined and the procedure can be finely tuned.

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APPENDICES

APPENDIX A
ACCIDENT DATA

Table A.1 Accident Data for R-19484 : Cross-Over at a Site with Two Lanes
in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	178-183	244	1988	24164	0	3	22	25
		From	1989	23222	1	5	22	28
		Apr 01	1990	22280	0	2	21	23
		To	1991	22065	0	5	15	20
		Dec 01	1992*	21620	1	6	28	35
			1993*	21620	0	9	25	34

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	188-192	244	1988	25143	0	1	13	14
		From	1989	24877	0	5	11	16
		Apr 01	1990	24610	1	7	12	20
		To	1991	23895	0	6	8	14
		Dec 01	1992	23180	0	1	4	5
			1993	23180	0	4	6	10

Table A.2 Accident Data for R-20370 : Cross-Over at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	11-15	183	1988	23677	0	1	8	9
		From	1989	26356	0	2	8	10
		Apr 01	1990	29030	0	6	6	12
		To	1991	27490	0	1	10	11
		Sep 30	1992	25950	0	1	6	7
			1993*	25950	0	0	10	10

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	16-20	62	1988	23677	0	2	5	7
		From	1989	26356	0	0	4	4
		Oct 01	1990	29030	0	1	4	5
		To	1991	27490	0	2	3	5
		Dec 01	1992	25950	0	0	4	4
			1993*	25950	0	1	2	3

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.3 Accident Data for R-20368 : Cross-Over at a Site with Two Lanes
in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	217-223	211 From Apr 19 To Nov 15	1988	20394	1	3	14	18
			1989	21227	0	2	13	15
			1990	22150	1	7	20	28
			1991	22975	0	2	20	22
			1992	23800	0	5	20	25
			1993*	23800	0	5	15	20

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	205-214	211 From Apr 19 To Nov 15	1988	19600	1	11	31	43
			1989	21765	0	9	32	41
			1990	23930	0	8	26	34
			1991	25320	0	10	26	36
			1992	26710	1	11	46	58
			1993	26710	1	7	43	51

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.4 Accident Data for R-20369 : Cross-Over at a Site with Two Lanes
in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	228-229	102	1988	20304	0	1	3	4
		From	1989	21227	0	1	2	3
		May 05	1990	22150	0	1	0	1
		To	1991	22975	0	0	1	1
		Aug 14	1992	23800	0	1	2	3
			1993*	23800	0	0	1	1

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	230-236	102	1988	22420	0	2	15	17
		From	1989	21580	0	3	10	13
		May 05	1990	20740	1	0	9	10
		To	1991	23085	0	1	7	8
		Aug 14	1992	25430	0	4	6	10
			1993*	25430	0	4	17	21

Table A.4, continued

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	240-246	102 From May 05 To Aug 14	1988	24577	0	7	8	15
			1989	24728	0	1	9	10
			1990	24880	0	7	17	24
			1991	26090	0	4	11	15
			1992	27300	1	1	16	18
			1993	27300	0	0	6	6

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	235-239	99 From Aug 15 To Nov 21	1988	22420	0	3	3	6
			1989	21580	0	1	3	4
			1990	20740	0	0	8	8
			1991	23085	0	2	3	5
			1992	25430	0	3	6	9
			1993*	25430	0	1	4	5

Table A.4, continued

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	240-246	99	1988	24577	0	0	8	8
		From	1989	24728	0	3	7	10
		Aug 15	1990	24880	0	6	17	23
		To	1991	26090	0	1	3	4
		Nov 21	1992	27300	0	1	10	11
			1993	27300	0	1	9	10

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.5 Accident Data for R-19972 : Cross-Over at a Site with Two Lanes
in Each Direction

Section with Work Zone :

Inter -state	Section (mile marker to mile marker)	Project Dura- tion (days)	Year	ADT	# of Fatal Acci- dents	# of Non- Fatal Injury Acci- dents	# of Pro- perty Damage Acci- dents	Total # of Acci- dents
I-69	55-56	148	1988	16748	0	1	0	1
		From	1989	17669	0	0	2	2
		Mar 29	1990	18590	0	0	3	3
		To	1991	19580	0	0	2	2
		Aug 23	1992	20570	0	0	1	1
			1993*	20570	0	0	4	4

Comparison Section :

Inter -state	Section (mile marker to mile marker)	Project Dura- tion (days)	Year	ADT	# of Fatal Acci- dents	# of Non- Fatal Injury Acci- dents	# of Pro- perty Damage Acci- dents	Total # of Acci- dents
I-69	41-45	148	1988	15767	0	1	3	4
		From	1989	17893	0	3	6	9
		Mar 29	1990	20020	0	0	2	2
		To	1991	20220	0	1	2	3
		Aug 23	1992	20420	0	3	11	14
			1993	20420	0	2	8	10

Table A.5, continued

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	57-58	67	1988	16748	0	0	2	2
		From	1989	17669	0	0	1	1
		Aug 30	1990	18590	0	0	0	0
		To	1991	19580	0	0	2	2
		Nov 04	1992	20570	-	-	-	-
			1993*	20570	0	2	2	4

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	41-45	148	1988	15767	0	0	5	5
		From	1989	17893	0	1	4	5
		Aug 30	1990	20020	0	1	2	3
		To	1991	20220	0	0	2	2
		Nov 04	1992	20420	0	0	3	3
			1993	20420	0	0	4	4

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.6 Accident Data for R-19847 : Cross-Over at a Site with Two Lanes
in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	59-65	186	1988	16358	0	4	10	14
		From	1989	17614	0	3	14	17
		May 18	1990	18870	0	1	17	18
		To	1991	18395	1	3	18	22
		Nov 19	1992*	17190	0	7	20	27

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	73-78	186	1988	14164	0	0	6	6
		From	1989	14992	0	1	11	12
		May 18	1990	15820	0	3	8	11
		To	1991	16505	0	1	6	7
		Nov 19	1992	17190	0	1	6	7

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.7 Accident Data for R-20384 : Cross-Over at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	99-101	166	1988	20490	0	1	9	10
		From	1989	25030	0	1	7	8
		Apr 21	1990	29570	0	1	10	11
		To	1991	28715	0	6	6	12
		Oct 03	1992	27860	1	3	11	15
			1993*	27860	0	3	10	13

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	102-105	166	1988	27267	0	4	14	18
		From	1989	30609	0	0	10	10
		Apr 21	1990	33950	0	3	9	12
		To	1991	32420	1	2	16	19
		Oct 03	1992	30890	1	4	17	22
			1993	30890	1	9	25	35

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.8 Accident Data for R-19112 : Cross-Over at a Site with Two Lanes
in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Acci-dents	# of Non-Fatal Injury Acci-dents	# of Pro-erty Damage Acci-dents	Total # of Acci-dents
I-70	115-122	275	1988	21588	0	3	28	31
		From	1989	24449	0	4	21	25
		March	1990	27310	0	9	18	27
		To	1991*	29895	0	10	37	47
		Nov	1993	32480	1	8	26	35

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Acci-dents	# of Non-Fatal Injury Acci-dents	# of Pro-erty Damage Acci-dents	Total # of Acci-dents
I-70	104-115	275	1988	25338	2	23	44	69
		From	1989	27644	0	25	65	90
		March	1990	29950	1	18	44	63
		To	1991	30910	0	16	51	67
		Nov	1993	31870	1	9	54	64

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.9 Accident Data for R-19113 : Cross-Over at a Site with Two Lanes
in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	137-144	214	1988	21944	0	9	14	23
		From	1989	26177	0	1	17	18
		May	1990	30140	0	3	17	20
		To	1991*	27810	1	12	22	35
		Nov	1992	25210	0	3	13	16
			1993	25210	0	6	7	13

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.10 Accident Data for R-19476 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-64	39-46	246	1988	9472	0	2	7	9
		From	1989	10391	1	2	9	12
		Mar 01	1990	11310	0	0	18	18
		To	1991	11240	0	1	8	9
		Nov 01	1992*	11170	1	5	6	12
			1993	11170	1	1	14	16

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-64	29-38	246	1988	10550	0	1	10	11
		From	1989	11565	0	0	10	10
		Mar 01	1990	12580	0	1	12	13
		To	1991	11310	0	0	10	10
		Nov 01	1992	10040	0	2	7	9
			1993	10040	0	2	11	13

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.11 Accident Data for R-19979 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-64	74-79	153	1988	9347	0	0	4	4
		From	1989	9459	0	0	7	7
		July	1990	9570	0	1	6	7
		To	1991	9495	-	-	-	-
		Dec	1992*	9420	0	0	2	2

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-64	80-85	153	1988	10434	0	0	5	5
		From	1989	10572	0	4	4	8
		July	1990	10710	0	1	2	3
		To	1991	10985	0	2	2	4
		Dec	1992	11260	0	0	5	5

Table A.11, continued

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-64	74-79	244	1988	9347	0	0	6	6
		From	1989	9459	0	1	9	10
		April	1990	9570	0	1	8	9
		To	1991	9495	0	1	3	4
		Dec	1993*	9420	0	1	2	3

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-64	80-85	244	1988	10434	0	0	9	9
		From	1989	10572	0	6	9	15
		April	1990	10710	0	2	2	4
		To	1991	10985	0	2	4	6
		Dec	1993	11260	0	1	7	8

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.12 Accident Data for R-18301 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	6-9	306	1988	33617	0	3	10	13
		From	1989	34933	0	3	15	18
		March	1990*	36250	0	8	23	31
		To	1991	39095	0	6	7	13
		Dec	1992	41940	1	7	6	14
			1993	41940	1	6	12	19

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	10-12	306	1988	32627	0	4	15	19
		From	1989	34734	0	4	14	18
		March	1990*	36840	0	9	20	29
		To	1991	38015	0	6	7	13
		Dec	1992	39190	0	3	9	12
			1993	39190	1	1	10	12

Table A.12, continued

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	14-19	306 From March To Dec	1988	27494	0	10	22	32
			1989	30217	2	5	24	31
			1990	32940	1	9	32	42
			1991	39095	0	4	27	31
			1992	45250	0	13	25	38
			1993	45250	0	9	23	32

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.13 Accident Data for R-17425 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	151-156	214	1988*	24696	0	5	28	33
		From	1989	25508	0	8	20	28
		April	1990	26320	0	10	24	34
		To	1991	26780	0	1	10	11
		Nov	1992	27240	0	5	7	12
			1993	27240	1	3	13	17

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	145-148	214	1988	20620	0	8	14	22
		From	1989	25880	0	7	12	19
		April	1990	31140	0	7	12	19
		To	1991	28715	0	2	4	6
		Nov	1992	26290	0	1	6	7
			1993	26290	0	2	12	14

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.14 Accident Data for R-18572 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	164-167	213	1988	25827	0	8	14	22
		From	1989	27334	0	3	11	14
		Apr 17	1990*	28840	1	7	24	32
		To	1992	35390	0	2	12	14
		Nov 15	1993	35390	0	1	11	12

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	168-172	213	1988	31904	0	1	22	23
		From	1989	35802	0	3	22	25
		Apr 17	1990*	39700	1	12	21	34
		To	1992	31780	0	7	18	25
		Nov 15	1993	31780	0	3	22	25

Table A.14, continued

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	148-157	213	1988	26952	1	8	21	30
		From	1989	27191	0	7	23	30
		Apr 17	1990	27430	0	4	22	26
		To	1992	28700	0	7	21	28
		Nov 15	1993	28700	0	8	18	26

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	164-167	183	1988	25827	0	8	10	18
		From	1989	27334	0	2	9	11
		Apr 01	1991*	32115	0	0	7	7
		To	1992	35390	0	2	8	10
		Sep 30	1993	35390	0	1	8	9

Table A.14, continued

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	168-172	183	1988	31904	0	2	17	19
		From	1989	35802	0	3	13	16
		Apr 01	1991*	35740	0	2	22	24
		To	1992	31780	0	7	14	21
		Sep 30	1993	31780	0	2	18	20

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	148-157	183	1988	26952	2	5	19	26
		From	1989	27191	0	8	16	24
		Apr 01	1991	28065	0	9	14	23
		To	1992	28700	0	5	21	26
		Sep 30	1993	28700	0	8	18	26

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.15 Accident Data for R-18831 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	1-2	94	1988	15529	0	3	7	10
		From	1989	17355	0	1	4	5
		Aug 14	1990*	19180	0	4	4	8
		To	1992	21200	0	0	2	2
		Nov 15	1993	21200	0	1	1	2

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	3-6	94	1988	19717	0	0	3	3
		From	1989	23294	0	1	3	4
		Aug 14	1990*	26870	0	2	7	9
		To	1992	19310	0	1	6	7
		Nov 15	1993	19310	0	3	6	9

Table A.15, continued

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	7-10	94	1988	24991	0	2	5	7
		From	1989	27586	0	0	2	2
		Aug 14	1990*	30180	0	0	8	8
		To	1992	30940	0	1	3	4
		Nov 15	1993	30940	0	4	8	12

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	1-2	122	1988	15529	0	3	7	10
		From	1989	17355	0	0	4	4
		Apr 01	1991*	20190	1	1	3	5
		To	1992	21200	0	1	5	6
		Jul 31	1993	21200	0	1	3	4

Table A.15, continued

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	3-6	122	1988	19717	0	1	7	8
		From	1989	23294	0	0	4	4
		Apr 01	1991*	22590	0	2	9	11
		To	1992	19310	0	1	3	4
		Jul 31	1993	19310	0	2	3	5

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	7-10	122	1988	24991	0	3	3	6
		From	1989	27586	0	0	2	2
		Apr 01	1991*	30560	0	7	9	16
		To	1992	30940	0	0	6	6
		Jul 31	1993	30940	0	0	1	1

Table A.15, continued

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	41-50	260	1988	24632	0	2	21	23
		From	1989	28331	0	2	16	18
		Apr 01	1990	32030	2	7	21	30
		To	1991	29540	0	9	16	25
		Nov 15	1992	27050	1	4	24	29
			1993	27050	0	12	15	27

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.16 Accident Data for R-20502 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	34-36	260	1988	19255	0	3	0	3
		From	1989	19438	0	3	4	7
		Apr 01	1990	19620	0	1	4	5
		To	1991	22120	0	3	1	4
		Nov 15	1992	24620	0	1	4	5
			1993*	24620	0	2	7	9

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	37-40	260	1988	23125	0	2	5	7
		From	1989	27513	0	2	6	8
		Apr 01	1990	31900	0	2	5	7
		To	1991	28525	1	1	5	7
		Nov 15	1992	25510	0	3	7	10
			1993*	25510	0	2	12	14

Table A.16, continued

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	41-50	260	1988	24632	0	2	21	23
		From	1989	28331	0	2	16	18
		Apr 01	1990	32030	2	7	21	30
		To	1991	29540	0	9	16	25
		Nov 15	1992	27050	1	4	24	29
			1993	27050	0	12	15	27

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.17 Accident Data for R-20503 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	28-33	260	1988	23677	0	4	15	19
		From	1989	26354	1	3	17	21
		Apr 01	1990	29030	0	6	11	17
		To	1991	27490	0	6	16	22
		Nov 15	1992	25150	1	2	22	25
			1993*	25150	0	10	24	34

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	51-58	260	1988	24632	0	2	16	18
		From	1989	28331	0	1	14	15
		Apr 01	1990	32030	0	3	12	15
		To	1991	29540	0	7	15	22
		Nov 15	1992	27050	0	3	9	12
			1993	27050	0	4	10	14

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.18 Accident Data for R-17424 : Partial Lane Closure at a Site with Two Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	145-148	214	1988*	20621	0	8	14	22
		From	1990	31140	0	7	12	19
		May	1991	28715	0	2	4	6
		To Nov	1992	26290	0	1	6	7

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	149-150	214	1988*	24143	0	4	5	9
		From	1990	28630	0	0	4	4
		May	1991	27780	0	1	5	6
		To Nov	1992	26930	0	2	5	7

Table A.18, continued

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	131-136	214	1988	20691	0	3	10	13
		From	1990	28630	1	3	10	14
		May	1991	26415	0	5	13	18
		To Nov	1992	24200	0	5	13	18

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.19 Accident Data for R-20511 : Cross-Over at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	73-77	246	1988	69420	0	8	15	23
		From	1989	77550	0	11	26	37
		March	1990	85680	0	8	29	37
		To	1991	90665	0	8	14	22
		Nov	1992	95650	0	3	28	31
			1993*	95650	1	15	43	59

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-70	85-89	246	1988	85826	0	17	62	79
		From	1989	89417	0	25	62	87
		March	1990	93205	1	9	52	62
		To	1991	104735	0	13	53	66
		Nov	1992	116265	0	19	70	89
			1993	116265	1	20	50	71

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.20 Accident Data for R-17992 : Cross-Over at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-465	41-45	145	1990*	74775	0	23	57	80
		From	1991	96634	0	13	25	38
		Jul 24	1992	118492	0	8	31	39
		To Dec 15	1993	118492	0	15	32	47

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-465	46-47	145	1990	56100	0	3	8	11
		From	1991	64580	0	0	9	9
		Jul 24	1992	73060	0	0	10	10
		To Dec 15	1993	73060	0	3	18	21

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.21 Accident Data for R-20511 : Cross-Over at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-465	1-3	109	1988	57139	1	4	8	13
		From	1989	57497	0	0	8	8
		Mar 15	1990	57857	0	2	6	8
		To	1991	60167	0	10	17	27
		Jul 01	1992	62477	0	2	6	8
			1993*	62477	0	4	14	18

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-465	4-7	109	1988	53777	0	0	6	6
		From	1989	51053	0	1	7	8
		Mar 15	1990	48330	0	7	11	18
		To	1991	53065	0	1	4	5
		Jul 01	1992	57800	0	7	11	18
			1993	57800	0	4	10	14

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.22 Accident Data for R-19394 : Cross-Over at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-465	52-53	167	1988	76977	1	7	10	18
		Apr 23	1989	79603	0	3	9	12
		-Aug 15	1990	82230	0	5	11	16
		&	1991	77845	0	1	15	16
		Sep 01	1992*	73460	1	3	2	6
		-Oct 22	1993	73460	0	3	16	19

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-465	49-51	167	1988	68358	1	8	10	19
		Apr 23	1989	70764	0	10	19	29
		-Aug 15	1990	73170	0	5	25	30
		&	1991	70805	0	5	12	17
		Sep 01	1992	68440	0	6	5	11
		-Oct 22	1993	68440	0	4	16	20

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.22, continued

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	105-108	220	1988	65028	0	12	23	35
		Mar 03	1989	72211	0	6	22	28
		-Aug 02	1990	79393	0	7	16	23
		&	1991	74765	0	10	31	41
		Aug 15	1992*	70137	1	11	38	50
		-Oct 20	1993	70137	0	7	15	22

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	109-111	220	1988	93159	0	12	37	49
		Mar 03	1989	103762	0	22	69	91
		-Aug 02	1990	114365	0	25	83	108
		&	1991	105998	0	17	67	84
		Aug 15	1992	97630	0	21	61	82
		-Oct 20	1993	97630	0	9	35	44

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.23 Accident Data for R-19396 : Partial Lane Closure at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-94	19-21	167	1988	41103	0	5	10	15
		From	1989	45012	0	1	5	6
		June 19	1990	48920	0	4	6	10
		To	1991	47305	0	1	11	12
		Dec 02	1992*	45690	0	5	17	22

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-94	22-25	167	1988	33871	1	5	17	23
		From	1989	37805	0	5	13	18
		June 19	1990	41740	1	3	12	16
		To	1991	36845	0	5	21	26
		Dec 02	1992*	31950	1	4	21	26

Table A.23, continued

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-94	26-33	167	1988	32509	0	18	44	62
		From	1989	34290	1	7	21	29
		June 19	1990	36070	0	8	33	41
		To	1991	35045	0	11	33	44
		Dec 02	1992	34020	1	8	37	46

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-94	19-21	238	1988	41103	0	6	15	21
		From	1989	45012	0	1	7	8
		Mar 29	1990	48920	0	7	9	6
		To	1991	47305	0	1	13	14
		Nov 21	1993*	45690	1	1	23	25

Table A.23, continued

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-94	22-25	238	1988	33871	1	6	21	28
		From	1989	37805	0	5	18	23
		Mar 29	1990	41740	2	6	15	23
		To	1991	36845	0	5	28	33
		Nov 21	1993*	31950	0	9	41	50

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-94	26-33	238	1988	32509	0	15	57	72
		From	1989	34290	1	8	26	35
		Mar 29	1990	36070	0	9	48	57
		To	1991	35045	1	13	40	54
		Nov 21	1993	34020	0	19	59	78

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.24 Accident Data for R-20060 : Partial Lane Closure at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-94	38-39	248 From April 05 To Dec 08	1988	29395	0	2	2	4
			1989	29683	0	1	5	6
			1990	29970	0	1	11	12
			1991	35090	0	6	8	14
			1992	40210	0	3	2	5
			1993*	40210	0	1	6	7

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-94	40-45	248 From Apr 05 To Dec 08	1988	19704	0	1	15	16
			1989	21727	1	12	20	33
			1990	23750	1	8	24	33
			1991	25235	1	6	27	34
			1992	26720	2	7	24	33
			1993*	26720	0	2	28	30

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.25 Accident Data for R-18806 : Partial Lane Closure at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-69	1-7	244	1988	52495	1	11	42	54
		From	1989	55994	0	15	42	57
		April	1990*	59493	0	16	51	67
		To	1991*	64733	0	30	89	119
		Nov	1992	69973	1	12	44	57
			1993	69973	0	14	45	59

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.26 Accident Data for R-19482 : Partial Lane Closure at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-465	34-39	122	1988	79898	0	8	36	44
		From	1989	80859	0	15	41	56
		Aug	1990	81820	0	14	56	70
		To	1991	95809	1	12	33	46
		Nov	1992	109798	0	9	58	67
			1993*	109798	0	13	40	53

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-465	25-27	122	1988	48881	1	7	22	30
		From	1989	49516	0	6	19	25
		Aug	1990	50150	0	5	23	28
		To	1991	59345	0	7	25	32
		Nov	1992	68540	0	4	17	21
			1993	68540	0	4	19	19

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

Table A.27 Accident Data for B-17737 : Partial Lane Closure at a Site with Three Lanes in Each Direction

Section with Work Zone :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	112-113	304	1989*	97025	0	22	59	81
		From	1990	104955	0	13	41	54
		Jan	1991	105630	0	12	41	53
		To	1992	106305	0	10	37	47
		Oct	1993	106305	0	13	50	63

Comparison Section :

Inter-state	Section (mile marker to mile marker)	Project Duration (days)	Year	ADT	# of Fatal Accidents	# of Non-Fatal Injury Accidents	# of Property Damage Accidents	Total # of Accidents
I-65	114-115	304	1989	95513	0	5	26	31
		From	1990	105050	0	6	20	26
		Jan	1991	108513	0	3	23	26
		To	1992	111975	0	7	22	29
		Oct	1993	111975	0	4	14	18

* indicates the year(s) in which the repair, rehabilitation or reconstruction activities were going on at the site.

APPENDIX B

POISSON AND NEGATIVE BINOMIAL MODELS FOR CRASH ESTIMATION

Table B.1 Model for Sites Using Cross-Over :
Sites with Two Lanes in Each Direction

Negative Binomial Model :

Dependent Variable : $\log(\text{number of accidents at work zone}) = \log(Y)$

Explanatory Variables	Estimated Coefficients	T-statistic
Intercept term	0.71163	2.345
Duration of project (days)	0.79231 E-02	5.559
Interaction between traffic volume and work zone length	0.495 E-05	3.081
α where, $\text{Var}(Y) = E(Y) \cdot [1 + \alpha \cdot E(Y)]$	0.48097 E-01	2.041

Auxiliary Statistics :

Number of observations : 13

$L(0) = -106.94$, $L(B) = -70.29$, $\lambda^2 = 0.343$

Table B.2 Model for Sites Using Partial Lane Closure :
Sites with Two Lanes in Each Direction

Poisson Model :

Dependent Variable : $\log(\text{number of accidents at work zone}) = \log(Y)$

Explanatory Variables	Estimated Coefficients	T-statistic
Intercept term	0.78576	3.272
Duration of project (days)	0.41872 E-02	4.752
Interaction between traffic volume and work zone length	0.10052 E-02	8.114

Auxiliary Statistics :

Number of observations : 21

$L(0) = -124.81$, $L(\beta) = -72.09$, $R^2 = 0.422$

Table B.3 Model for Sites Using Cross-Over :
Sites with Three Lanes in Each Direction

Truncated Regression Model :

Dependent Variable : Accident rate under normal operating conditions (z)

Truncation : $Z| (Z > 0)$

Explanatory Variables	Estimated Coefficients	T-statistic
Intercept term	-16.239	-4.653
Traffic volume (vehicles per day)	0.30001 E-03	6.331
Length of section (miles)	8.0681	8.416
Interaction between traffic volume and length of section	-0.10739 E-03	-8.399
σ (correction term for truncation)	0.86708 E-01	3.162

Poisson Model :

Dependent Variable : Expected number of accidents at work zone

Explanatory Variables	Estimated Coefficients	T-statistic
Intercept term	-7.103	-4.464
Duration of project (days)	0.91905 E-02	3.845
Interaction between traffic volume and work zone length	0.14531 E-04	8.306
Predicted value of accident rate under normal operating conditions (per 10 million vehicle miles travelled)	0.91992	6.420

Auxiliary Statistics :

Number of observations : 5

$L(0) = -63.51$, $L(B) = -14.29$, $\lambda^2 = 0.775$

Table B.4 Model for Sites Using Partial Lane Closure :
Sites with Three Lanes in Each Direction

Truncated Regression Model :

Dependent Variable : Accident rate under normal operating conditions (z)

Truncation : $Z| (Z > 0)$

Explanatory Variables	Estimated Coefficients	T-statistic
Intercept term	-0.4244	-0.135
Traffic volume (vehicles per day)	0.89205 E-04	1.830
Length of section (miles)	1.3975	1.929
Interaction between traffic volume and length of section	-0.13421 E-04	-1.192
σ (correction term for truncation)	1.3427	4.239

Poisson Model :

Dependent Variable : Expected number of accidents at work zone

Explanatory Variables	Estimated Coefficients	T-statistic
Intercept term	0.44029	-1.147
Duration of project (days)	0.66322 E-02	4.478
Interaction between traffic volume and work zone length	0.24061 E-04	2.979
Predicted value of accident rate under normal operating conditions (per 10 million vehicle miles travelled)	0.17027	2.136

Auxiliary Statistics :

Number of observations : 9

$L(0) = -101.39$, $L(\beta) = -44.17$, $\lambda^2 = 0.564$

APPENDIX C

RESULTS OF SENSITIVITY ANALYSIS

Table C.1 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Inconvenience is Reduced by 10% : Sites with Two Lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-20368	0.6532	0.3648	CS
R-19487	0.4860	0.5140	PLC
R-19112	0.6352	0.3648	CS
R-19515	0.7502	0.2498	CS
R-19113	0.7459	0.2541	CS
R-19738	0.4641	0.5359	PLC
R-20970	0.5246	0.4754	CS
R-20906	0.4860	0.5140	PLC
R-19484	0.4860	0.5140	PLC
R-20370	0.6352	0.3648	CS
R-20381	0.4735	0.5265	PLC
R-19476	0.4997	0.5003	PLC
R-19483	0.4693	0.5307	PLC
R-18301	0.4653	0.5347	PLC
R-17425	0.4676	0.5324	PLC
R-20974	0.4848	0.5152	PLC
R-18831	0.4565	0.5435	PLC

R-20502	0.4664	0.5336	PLC
R-20503	0.6323	0.3677	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.2 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Inconvenience is Reduced by 10% : Sites with Three Lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-19396	0.8152	0.1848	CS
R-19620	0.4405	0.5595	PLC
R-20060	0.7962	0.2038	CS
R-19908	0.4594	0.5406	PLC
R-18806	0.7944	0.2056	CS
R-19482	0.4405	0.5595	PLC
B-17737	0.4405	0.5595	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.3 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Inconvenience is Reduced by 5% : Sites with Two Lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-20368	0.6401	0.3599	CS
R-19487	0.4941	0.5059	PLC
R-19112	0.6401	0.3599	CS
R-19515	0.7526	0.2474	CS
R-19113	0.7484	0.2516	CS
R-19738	0.4727	0.5273	PLC
R-20970	0.5319	0.4681	CS
R-20906	0.4941	0.5059	PLC
R-19484	0.4941	0.5059	PLC
R-20370	0.6401	0.3599	CS
R-20381	0.4819	0.5181	PLC
R-19476	0.5075	0.4925	CS
R-19483	0.4778	0.5222	PLC
R-18301	0.4739	0.5261	PLC
R-17425	0.4761	0.5239	PLC
R-20974	0.4930	0.5070	PLC
R-18831	0.4653	0.5347	PLC
R-20502	0.4750	0.5250	PLC
R-20503	0.6373	0.3627	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.4 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Inconvenience is Reduced by 5% : Sites with Three Lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-19396	0.8162	0.1838	CS
R-19620	0.4496	0.5504	PLC
R-20060	0.7976	0.2024	CS
R-19908	0.4681	0.5319	PLC
R-18806	0.7959	0.2041	CS
R-19482	0.4496	0.5504	PLC
B-17737	0.4496	0.5504	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.5 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Inconvenience is Increased by 5% : Sites with Two Lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-20368	0.6493	0.3507	CS
R-19487	0.5094	0.4906	CS
R-19112	0.6493	0.3507	CS
R-19515	0.7571	0.2429	CS
R-19113	0.7531	0.2469	CS
R-19738	0.4889	0.5111	PLC
R-20970	0.5456	0.4544	CS
R-20906	0.5094	0.4906	CS
R-19484	0.5094	0.4906	CS
R-20370	0.6493	0.3507	CS
R-20381	0.4976	0.5024	PLC
R-19476	0.5222	0.4778	CS
R-19483	0.4937	0.5063	PLC
R-18301	0.4900	0.5100	PLC
R-17425	0.4921	0.5079	PLC
R-20974	0.5083	0.4917	CS
R-18831	0.4817	0.5183	PLC
R-20502	0.4910	0.5090	PLC
R-20503	0.6466	0.3534	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.6 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Inconvenience is Increased by 5% : Sites with Three Lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-19396	0.8180	0.1820	CS
R-19620	0.4667	0.5333	PLC
R-20060	0.8003	0.1997	CS
R-19908	0.4845	0.5155	PLC
R-18806	0.7986	0.2014	CS
R-19482	0.4667	0.5333	PLC
B-17737	0.4667	0.5333	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.7 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Inconvenience is Increased by 10% : Sites with Two Lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-20368	0.6537	0.3463	CS
R-19487	0.5165	0.4835	CS
R-19112	0.6537	0.3463	CS
R-19515	0.7593	0.2407	CS
R-19113	0.7553	0.2447	CS
R-19738	0.4964	0.5036	PLC
R-20970	0.5520	0.4480	CS
R-20906	0.5165	0.4835	CS
R-19484	0.5165	0.4835	CS
R-20370	0.6537	0.3463	CS
R-20381	0.5050	0.4950	CS
R-19476	0.5291	0.4709	CS
R-19483	0.5012	0.4988	CS
R-18301	0.4975	0.5025	PLC
R-17425	0.49996	0.5004	PLC
R-20974	0.5155	0.4845	CS
R-18831	0.4894	0.5106	PLC
R-20502	0.4985	0.5015	PLC
R-20503	0.6510	0.3490	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.8 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Contractors' Inconvenience is Increased by 10% : Sites with Three Lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-19396	0.8189	0.1811	CS
R-19620	0.4747	0.5253	PLC
R-20060	0.8015	0.1985	CS
R-19908	0.4921	0.5079	PLC
R-18806	0.7999	0.2001	CS
R-19482	0.4747	0.5253	PLC
B-17737	0.4747	0.5253	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.9 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Reduced by 10% : Sites with Two lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-20368	0.6512	0.3488	CS
R-19487	0.5168	0.4832	CS
R-19112	0.6512	0.3488	CS
R-19515	0.7529	0.2471	CS
R-19113	0.7508	0.2492	CS
R-19738	0.4949	0.5051	PLC
R-20970	0.5517	0.4483	CS
R-20906	0.5168	0.4832	CS
R-19484	0.5168	0.4832	CS
R-20370	0.6512	0.3488	CS
R-20381	0.5053	0.4947	CS
R-19476	0.5334	0.4666	CS
R-19483	0.5019	0.4981	CS
R-18301	0.4960	0.5040	PLC
R-17425	0.5002	0.4998	CS
R-20974	0.5156	0.4844	CS
R-18831	0.4902	0.5098	PLC
R-20502	0.4990	0.5010	PLC
R-20503	0.6483	0.3517	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.10 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Reduced by 10% : Sites with Three lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-19396	0.8135	0.1865	CS
R-19620	0.4742	0.5258	PLC
R-20060	0.7964	0.2036	CS
R-19908	0.4912	0.5088	PLC
R-18806	0.7927	0.2073	CS
R-19482	0.4742	0.5258	PLC
B-17737	0.4742	0.5258	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.11 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Reduced by 5% : Sites with Two lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-20368	0.6480	0.3520	CS
R-19487	0.5092	0.4908	CS
R-19112	0.6480	0.3520	CS
R-19515	0.7539	0.2461	CS
R-19113	0.7508	0.2492	CS
R-19738	0.4878	0.5122	PLC
R-20970	0.5452	0.4548	CS
R-20906	0.5092	0.4908	CS
R-19484	0.5092	0.4908	CS
R-20370	0.6480	0.3520	CS
R-20381	0.4974	0.5026	PLC
R-19476	0.5240	0.4760	CS
R-19483	0.4938	0.5062	PLC
R-18301	0.4889	0.5111	PLC
R-17425	0.4920	0.5080	PLC
R-20974	0.5080	0.4920	CS
R-18831	0.4818	0.5182	PLC
R-20502	0.4909	0.5091	PLC
R-20503	0.6451	0.3549	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.12 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Reduced by 5% : Sites with Three lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-19396	0.8153	0.1847	CS
R-19620	0.4661	0.5339	PLC
R-20060	0.7977	0.2023	CS
R-19908	0.4837	0.5163	PLC
R-18806	0.7951	0.2049	CS
R-19482	0.4661	0.5339	PLC
B-17737	0.4661	0.5339	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.13 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Increased by 5% : Sites with Two lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-20368	0.6418	0.3582	CS
R-19487	0.4950	0.5050	PLC
R-19112	0.6418	0.3582	CS
R-19515	0.7559	0.2441	CS
R-19113	0.7508	0.2492	CS
R-19738	0.4744	0.5256	PLC
R-20970	0.5329	0.4671	CS
R-20906	0.4950	0.5050	PLC
R-19484	0.4950	0.5050	PLC
R-20370	0.6418	0.3582	CS
R-20381	0.4827	0.5173	PLC
R-19476	0.5064	0.4936	CS
R-19483	0.4785	0.5215	PLC
R-18301	0.4755	0.5245	PLC
R-17425	0.4768	0.5232	PLC
R-20974	0.4939	0.5061	PLC
R-18831	0.4659	0.5341	PLC
R-20502	0.4757	0.5243	PLC
R-20503	0.6391	0.3609	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.14 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Increased by 5% : Sites with Three lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-19396	0.8188	0.1812	CS
R-19620	0.4509	0.5491	PLC
R-20060	0.8002	0.1998	CS
R-19908	0.4695	0.5305	PLC
R-18806	0.7994	0.2006	CS
R-19482	0.4509	0.5491	PLC
B-17737	0.4509	0.5491	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.15 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Increased by 10% : Sites with Two lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-20368	0.6390	0.3610	CS
R-19487	0.4883	0.5117	PLC
R-19112	0.6390	0.3610	CS
R-19515	0.7568	0.2432	CS
R-19113	0.7507	0.2493	CS
R-19738	0.4682	0.5318	PLC
R-20970	0.5272	0.4728	CS
R-20906	0.4883	0.5117	PLC
R-19484	0.4883	0.5117	PLC
R-20370	0.6390	0.3610	CS
R-20381	0.4758	0.5242	PLC
R-19476	0.4981	0.5019	PLC
R-19483	0.4713	0.5287	PLC
R-18301	0.4693	0.5307	PLC
R-17425	0.4697	0.5303	PLC
R-20974	0.4872	0.5128	CS
R-18831	0.4585	0.5415	PLC
R-20502	0.4686	0.5314	PLC
R-20503	0.6363	0.3637	CS

Note :

CS : Cross-over

PLC : Partial lane closure

Table C.16 Aggregate Weights of Lane Closure Strategies in AHP when the Importance of Safety is Increased by 10% : Sites with Three lanes in Each Direction

Project	Weight for cross-over	Weight for partial lane closure	Selected traffic control strategy
R-19396	0.8205	0.1795	CS
R-19620	0.4437	0.5563	PLC
R-20060	0.8013	0.1987	CS
R-19908	0.4629	0.5371	PLC
R-18806	0.8015	0.1985	CS
R-19482	0.4437	0.5563	PLC
B-17737	0.4437	0.5563	PLC

Note :

CS : Cross-over

PLC : Partial lane closure

APPENDIX D

COMPUTER PROGRAM : LANE CLOSE

```

/** Work Zone Lane Closure Strategy Selection */
/** Raktim Pal and Kumares C. Sinha */
/** School of Civil Engineering */
/** West Lafayette, IN 47907. */

```

```

#include <stdio.h>
#include <math.h>

```

```

main()
{

```

```

    int i, nseg, ch1, ch2, ch3 ;
    float tpc ;
    float csuc, cstc, cssf, cscn, plcuc, plctc, plesf, plecn ;
    float wsuc, wstc, wssf, wscn, wplcuc, wplctc, wplcsf, wplecn ;
    float nscuc, nstc, nssf, nscn, nplcuc, nplctc, nplcsf, nplecn ;
    float nuc, ntc, nsf, ncn ;
    float eig, ci, cr ;
    float rcs, rplc ;
    float temp1, temp2, temp3, temp4 ;
    float max1, max2, max3, max4 ;
    float per1, per2, per3, per4 ;
    float x1, x2, x3, x4, x5, x6, x7, x8 ;
    float x9, x10, x11, x12, x13, x14, x15, x16 ;
    float r1, r2, r3, r4, g1, g2, g3, g4, c1, c2, c3, c4 ;
    double d1, d2, d3, d4 ;
    float vol[20], dur[20] ;
    float len[20], acnm[20] ;
    float csuca[20], cssfa[20], plcuca[20], plcsfa[20] ;
    float csucb[20], cssfb[20], plcucb[20], plcsfb[20] ;
    float prcn[20] ;

```

```
/** Input Data **/
```

```
printf("The project site should be divided\n") ;
printf("into a number of segments according to\n") ;
printf("traffic and geometric characteristics\n") ;
printf("of each segment.\n\n") ;

printf("Number of segments :\n") ;
scanf("%d",&nseg) ;

for (i=1; i<(nseg+1); i++) {
    printf("Input data for segment # ") ;
    printf("%d\n\n",i) ;
    printf("Length of the segment (in miles) :\n") ;
    scanf("%f",&len[i]) ;
    printf("Traffic volume (ADT) :\n") ;
    scanf("%f",&vol[i]) ;
    printf("Duration of lane closure on the segment (in days) :\n") ;
    scanf("%f",&dur[i]) ;
    printf("If partial lane closure is used, for many types of resurfacing jobs \n") ;
    printf("restrictions may only be in place while the contractor is paving. \n") ;
    printf("In such a case, give the percentage of time the lane is actually closed :\n");
    scanf("%f",&prcn[i]) ;
    printf("Accident rate under normal conditions (per 10 million VMT) :\n") ;
    scanf("%f",&acrm[i]) ;
    printf("\n\n") ;
}

printf("Estimated total project cost (in dollars) :\n") ;
scanf("%f",&tpc) ;
printf("\n\n") ;
```

```
/** Contractors' Convenience **/
```

```
printf("Ratings for contractors' convenience :\n\n") ;
printf("If you want to use default values, please print 1\n") ;
printf("If you want to use site specific values, please print 2\n") ;

scanf("%d",&ch1) ;

switch(ch1) {

    case 1:                /* Default values */
        printf("Using default values :\n") ;
```

```
wscn = 0.8616 ;
wplccn = 0.1384 ;
ncscn = wscn / (wscn+wplccn) ;
nplccn = 1.0 - ncscn ;
break ;
```

```
case 2:                /* Site specific values */
```

```
printf("Using site specific values :\n\n") ;
```

```
printf("Give higher weight to the strategy which can be\n") ;
printf("expected to be preferred by the contractors\n") ;
printf("at this particular project site.\n\n") ;
```

```
printf("Give weight on a 1-10 scale.\n") ;
printf("Magnitudes of the weights should represent\n") ;
printf("the relative advantage of one strategy over the other.\n\n") ;
```

```
printf("Give the weight for cross-over :\n") ;
scanf("%f", &wscn) ;
printf("Give the weight for partial lane closure :\n") ;
scanf("%f", &wplccn) ;
ncscn = wscn / (wscn+wplccn) ;
nplccn = 1.0 - ncscn ;
break ;
```

```
default :
printf("ERROR IN PREVIOUS DATA ENTRY\n") ;
}
```

```
printf("\n\n") ;
```

```
/** User Cost, Traffic Control Cost and Accident **/
```

```
printf("Type of project site :\n\n") ;
printf("If two lanes in each direction, print 1\n") ;
printf("If three lanes in each direction, print 2\n") ;
```

```
scanf("%d",&ch2) ;
```

```
switch(ch2) {
```


case 1: /* Two lanes in each direction */

printf("Two lanes in each direction\n") ;

csuc = 0.0 ;

plcuc = 0.0 ;

cssf = 0.0 ;

plcsf = 0.0 ;

for (i=1; i<(nseg+1); i++) {

csuca[i]=(dur[i]/365.0)*(-11515.4 + 0.38584*vol[i] + 0.22979*len[i]*vol[i]) ;

plcuca[i]=(dur[i]*(prcn[i]/100.0)/365.0)*(-8446.11 + 0.27207*vol[i]
+ 0.22333*len[i]*vol[i]);

cssfa[i] = -24.50332 + 0.1272*dur[i] + (1.03101/10000.0)*vol[i]*len[i]
+ 1.44057*acrn[i] ;

plcsfa[i] = -25.97956 + (7.84678/100.0)*dur[i]*(prcn[i]/100.0)
+ (1.91737/10000.0)*vol[i]*len[i] + 1.19706*acrn[i] ;

csuc += csuca[i] ;

plcuc += plcuca[i] ;

cssf += cssfa[i] ;

plcsf += plcsfa[i] ;

}

temp1 = csuc ;

if (temp1 < plcuc) {

max1 = plcuc ;

wplcuc = 1.0 ;

per1 = ((max1 - csuc)*100.0)/csuc ;

if ((per1 >= 0.0) && (per1 < 5.0))

wcsuc = 1.0 ;

else if ((per1 >= 5.0) && (per1 < 10.0))

wcsuc = 2.0 ;

else if ((per1 >= 10.0) && (per1 < 20.0))

wcsuc = 3.0 ;

else if ((per1 >= 20.0) && (per1 < 30.0))

wcsuc = 4.0 ;

else if ((per1 >= 30.0) && (per1 < 40.0))

wcsuc = 5.0 ;

else if ((per1 >= 40.0) && (per1 < 50.0))

```

        wcsuc = 6.0 ;
    else if ( (per1 >= 50.0) && (per1 < 100.0) )
        wcsuc = 7.0 ;
    else if (per1 >= 100.0)
        wcsuc = 9.0 ;
}

```

```

else {
    max1 = csuc ;
    wcsuc = 1.0 ;
    per1 = ((max1 - plcuc)*100.0)/plcuc ;
    if ( (per1 >= 0.0) && (per1 < 5.0) )
        wplcuc = 1.0 ;
    else if ( (per1 >= 5.0) && (per1 < 10.0) )
        wplcuc = 2.0 ;
    else if ( (per1 >= 10.0) && (per1 < 20.0) )
        wplcuc = 3.0 ;
    else if ( (per1 >= 20.0) && (per1 < 30.0) )
        wplcuc = 4.0 ;
    else if ( (per1 >= 30.0) && (per1 < 40.0) )
        wplcuc = 5.0 ;
    else if ( (per1 >= 40.0) && (per1 < 50.0) )
        wplcuc = 6.0 ;
    else if ( (per1 >= 50.0) && (per1 < 100.0) )
        wplcuc = 7.0 ;
    else if (per1 >= 100.0)
        wplcuc = 9.0 ;
}

```

```

ncsuc = wcsuc / (wcsuc + wplcuc) ;
nplcuc = 1.0 - ncsuc ;

```

```

cstc = 740019.0 - 502813.0 + 0.061723*tpc ;
plctc = 740019.0 - 620151.0 + 0.061723*tpc ;

```

```

temp2 = cstc ;

```

```

if (temp2 < plctc) {
    max2 = plctc ;
    wplctc = 1.0 ;
}

```

```

per2 = ((max2 - cstc)*100.0)/cstc ;
if ( (per2 >= 0.0) && (per2 < 5.0) )
    wstc = 1.0 ;
else if ( (per2 >= 5.0) && (per2 < 10.0) )
    wstc = 2.0 ;
else if ( (per2 >= 10.0) && (per2 < 20.0) )
    wstc = 3.0 ;
else if ( (per2 >= 20.0) && (per2 < 30.0) )
    wstc = 4.0 ;
else if ( (per2 >= 30.0) && (per2 < 40.0) )
    wstc = 5.0 ;
else if ( (per2 >= 40.0) && (per2 < 50.0) )
    wstc = 6.0 ;
else if ( (per2 >= 50.0) && (per2 < 100.0) )
    wstc = 7.0 ;
else if (per2 >= 100.0)
    wstc = 9.0 ;
}

else {
    max2 = cstc ;
    wstc = 1.0 ;
    per2 = ((max2 - plctc)*100.0)/plctc ;
    if ( (per2 >= 0.0) && (per2 < 5.0) )
        wplctc = 1.0 ;
    else if ( (per2 >= 5.0) && (per2 < 10.0) )
        wplctc = 2.0 ;
    else if ( (per2 >= 10.0) && (per2 < 20.0) )
        wplctc = 3.0 ;
    else if ( (per2 >= 20.0) && (per2 < 30.0) )
        wplctc = 4.0 ;
    else if ( (per2 >= 30.0) && (per2 < 40.0) )
        wplctc = 5.0 ;
    else if ( (per2 >= 40.0) && (per2 < 50.0) )
        wplctc = 6.0 ;
    else if ( (per2 >= 50.0) && (per2 < 100.0) )
        wplctc = 7.0 ;
    else if (per2 >= 100.0)
        wplctc = 9.0 ;
}

ncstc = wstc / (wstc + wplctc) ;
nplctc = 1.0 - ncstc ;

```

```

temp3 = cssf ;

if (temp3 < plcsf) {
    max3 = plcsf ;
    wplcsf = 1.0 ;
    per3 = ((max3 - cssf)*100.0)/cssf ;
    if ( (per3 >= 0.0) && (per3 < 5.0) )
        wcssf = 1.0 ;
    else if ( (per3 >= 5.0) && (per3 < 10.0) )
        wcssf = 2.0 ;
    else if ( (per3 >= 10.0) && (per3 < 20.0) )
        wcssf = 3.0 ;
    else if ( (per3 >= 20.0) && (per3 < 30.0) )
        wcssf = 4.0 ;
    else if ( (per3 >= 30.0) && (per3 < 40.0) )
        wcssf = 5.0 ;
    else if ( (per3 >= 40.0) && (per3 < 50.0) )
        wcssf = 6.0 ;
    else if ( (per3 >= 50.0) && (per3 < 100.0) )
        wcssf = 7.0 ;
    else if (per3 >= 100.0)
        wcssf = 9.0 ;
}

else {
    max3 = cssf ;
    wcssf = 1.0 ;
    per3 = ((max3 - plcsf)*100.0)/plcsf ;
    if ( (per3 >= 0.0) && (per3 < 5.0) )
        wplcsf = 1.0 ;
    else if ( (per3 >= 5.0) && (per3 < 10.0) )
        wplcsf = 2.0 ;
    else if ( (per3 >= 10.0) && (per3 < 20.0) )
        wplcsf = 3.0 ;
    else if ( (per3 >= 20.0) && (per3 < 30.0) )
        wplcsf = 4.0 ;
    else if ( (per3 >= 30.0) && (per3 < 40.0) )
        wplcsf = 5.0 ;
    else if ( (per3 >= 40.0) && (per3 < 50.0) )
        wplcsf = 6.0 ;
    else if ( (per3 >= 50.0) && (per3 < 100.0) )
        wplcsf = 7.0 ;
    else if (per3 >= 100.0)
        wplcsf = 9.0 ;
}

```

```

    }
    ncssf = wcssf / (wcssf + wplcsf) ;
    nplcsf = 1.0 - ncssf ;

    break ;

    case 2:                /* Three lanes in each direction */

        printf("Three lanes in each direction\n") ;

        csuc = 0.0 ;
        plcuc = 0.0 ;
        cssf = 0.0 ;
        plcsf = 0.0 ;

        for (i=1; i<(nseg+1); i++) {

            csuca[i]=(dur[i]/365.0)*(-17700.1 + 0.25544*vol[i] + 0.24072*len[i]*vol[i]) ;
            plcuca[i]=(dur[i]*(prcn[i]/100.0)/365.0)*(-16394.8 + 0.21849*vol[i]
                + 0.23637*len[i]*vol[i]);

            cssfa[i] = -318.971 + 0.29211*dur[i] + (4.92368/10000.0)*vol[i]*len[i]
                + 32.42671*acrn[i] ;
            plcsfa[i] = -69.2807 + 0.35295*dur[i]*(prcn[i]/100.0) + (1.65543/10000.0)*vol[i]*len[i];

            csuc += csuca[i] ;
            plcuc += plcuca[i] ;
            cssf += cssfa[i] ;
            plcsf += plcsfa[i] ;
        }

        temp1 = csuc ;

        if (temp1 < plcuc) {
            max1 = plcuc ;
            wplcuc = 1.0 ;
            per1 = ((max1 - csuc)*100.0)/csuc ;
            if ( (per1 >= 0.0) && (per1 < 5.0) )
                wcsuc = 1.0 ;
            else if ( (per1 >= 5.0) && (per1 < 10.0) )
                wcsuc = 2.0 ;
            else if ( (per1 >= 10.0) && (per1 < 20.0) )
                wcsuc = 3.0 ;

```

```

else if ( (per1 >= 20.0) && (per1 < 30.0) )
    wcsuc = 4.0 ;
else if ( (per1 >= 30.0) && (per1 < 40.0) )
    wcsuc = 5.0 ;
else if ( (per1 >= 40.0) && (per1 < 50.0) )
    wcsuc = 6.0 ;
else if ( (per1 >= 50.0) && (per1 < 100.0) )
    wcsuc = 7.0 ;
else if (per1 >= 100.0)
    wcsuc = 9.0 ;
}

else {
    max1 = csuc ;
    wcsuc = 1.0 ;
    per1 = ((max1 - plcuc)*100.0)/plcuc ;
    if ( (per1 >= 0.0) && (per1 < 5.0) )
        wplcuc = 1.0 ;
    else if ( (per1 >= 5.0) && (per1 < 10.0) )
        wplcuc = 2.0 ;
    else if ( (per1 >= 10.0) && (per1 < 20.0) )
        wplcuc = 3.0 ;
    else if ( (per1 >= 20.0) && (per1 < 30.0) )
        wplcuc = 4.0 ;
    else if ( (per1 >= 30.0) && (per1 < 40.0) )
        wplcuc = 5.0 ;
    else if ( (per1 >= 40.0) && (per1 < 50.0) )
        wplcuc = 6.0 ;
    else if ( (per1 >= 50.0) && (per1 < 100.0) )
        wplcuc = 7.0 ;
    else if (per1 >= 100.0)
        wplcuc = 9.0 ;
}

ncsuc = wcsuc / (wcsuc + wplcuc) ;
nplcuc = 1.0 - ncsuc ;

cstc = 740019.0 + (620151.0 - 502813.0) + 0.061723*tpc ;
plctc = 740019.0 + 0.061723*tpc ;

temp2 = cstc ;

```

```

if (temp2 < plctc) {
    max2 = plctc ;
    wplctc = 1.0 ;
    per2 = ((max2 - cstc)*100.0)/cstc ;
    if ( (per2 >= 0.0) && (per2 < 5.0) )
        wcstc = 1.0 ;
    else if ( (per2 >= 5.0) && (per2 < 10.0) )
        wcstc = 2.0 ;
    else if ( (per2 >= 10.0) && (per2 < 20.0) )
        wcstc = 3.0 ;
    else if ( (per2 >= 20.0) && (per2 < 30.0) )
        wcstc = 4.0 ;
    else if ( (per2 >= 30.0) && (per2 < 40.0) )
        wcstc = 5.0 ;
    else if ( (per2 >= 40.0) && (per2 < 50.0) )
        wcstc = 6.0 ;
    else if ( (per2 >= 50.0) && (per2 < 100.0) )
        wcstc = 7.0 ;
    else if (per2 >= 100.0)
        wcstc = 9.0 ;
}

else {
    max2 = cstc ;
    wcstc = 1.0 ;
    per2 = ((max2 - plctc)*100.0)/plctc ;
    if ( (per2 >= 0.0) && (per2 < 5.0) )
        wplctc = 1.0 ;
    else if ( (per2 >= 5.0) && (per2 < 10.0) )
        wplctc = 2.0 ;
    else if ( (per2 >= 10.0) && (per2 < 20.0) )
        wplctc = 3.0 ;
    else if ( (per2 >= 20.0) && (per2 < 30.0) )
        wplctc = 4.0 ;
    else if ( (per2 >= 30.0) && (per2 < 40.0) )
        wplctc = 5.0 ;
    else if ( (per2 >= 40.0) && (per2 < 50.0) )
        wplctc = 6.0 ;
    else if ( (per2 >= 50.0) && (per2 < 100.0) )
        wplctc = 7.0 ;
    else if (per2 >= 100.0)
        wplctc = 9.0 ;
}

```



```

ncstc = westc / (westc + wplctc) ;
nplctc = 1.0 - ncstc ;

temp3 = cssf ;

if (temp3 < plcsf) {
    max3 = plcsf ;
    wplcsf = 1.0 ;
    per3 = ((max3 - cssf)*100.0)/cssf ;
    if ( (per3 >= 0.0) && (per3 < 5.0) )
        wcssf = 1.0 ;
    else if ( (per3 >= 5.0) && (per3 < 10.0) )
        wcssf = 2.0 ;
    else if ( (per3 >= 10.0) && (per3 < 20.0) )
        wcssf = 3.0 ;
    else if ( (per3 >= 20.0) && (per3 < 30.0) )
        wcssf = 4.0 ;
    else if ( (per3 >= 30.0) && (per3 < 40.0) )
        wcssf = 5.0 ;
    else if ( (per3 >= 40.0) && (per3 < 50.0) )
        wcssf = 6.0 ;
    else if ( (per3 >= 50.0) && (per3 < 100.0) )
        wcssf = 7.0 ;
    else if (per3 >= 100.0)
        wcssf = 9.0 ;
}

else {
    max3 = cssf ;
    wcssf = 1.0 ;
    per3 = ((max3 - plcsf)*100.0)/plcsf ;
    if ( (per3 >= 0.0) && (per3 < 5.0) )
        wplcsf = 1.0 ;
    else if ( (per3 >= 5.0) && (per3 < 10.0) )
        wplcsf = 2.0 ;
    else if ( (per3 >= 10.0) && (per3 < 20.0) )
        wplcsf = 3.0 ;
    else if ( (per3 >= 20.0) && (per3 < 30.0) )
        wplcsf = 4.0 ;
    else if ( (per3 >= 30.0) && (per3 < 40.0) )
        wplcsf = 5.0 ;
    else if ( (per3 >= 40.0) && (per3 < 50.0) )
        wplcsf = 6.0 ;
    else if ( (per3 >= 50.0) && (per3 < 100.0) )

```

```

        wplcsf = 7.0 ;
    else if (per3 >= 100.0)
        wplcsf = 9.0 ;
    }

    ncssf = wcssf / (wcssf + wplcsf) ;
    nplesf = 1.0 - ncssf ;

    break ;

    default :
        printf("ERROR IN PREVIOUS DATA ENTRY\n") ;
    }
    printf("\n\n") ;

    /*** Relative Importance of Factors and Overall Weight ***/

    printf("Relative importance of factors :\n\n") ;
    printf("Four factors are considered : user cost, traffic control cost,\n") ;
    printf("safety, and contractors' convenience.\n\n") ;
    printf("If you want to use default ratings, print 1\n") ;
    printf("If you want to use new ratings, print 2\n") ;

    scanf("%d",&ch3) ;

    switch(ch3) {

        case 1:                /* Default ratings */

            printf("Using default ratings :\n") ;

            nuc = 0.1190086 ;
            ntc = 0.0335268 ;
            nsf = 0.4237323 ;
            ncn = 0.4237323 ;

            rcs = nuc*ncsuc + ntc*ncstc + nsf*ncssf + ncn*ncscn ;
            rplc = nuc*nplesuc + ntc*nplesc + nsf*nplesf + ncn*nplescn ;

```

```
printf("Overall weight of cross-over : %f\n", rcs) ;
printf("Overall weight of partial lane closure : %f\n", rplc) ;
printf("Choose the strategy with higher overall weight.\n") ;
```

```
break ;
```

```
case 2:                /* New ratings */
printf("Using new ratings :\n\n") ;
```

```
check: printf("In order to provide new ratings for different factors\n") ;
printf("pairwise comparisons of these factors should be made\n") ;
printf("using the standard scale (see page 100 of the report)\n") ;
printf("according to the following guidelines :\n\n") ;
```

```
printf("In a pair-wise comparison of two factors\n") ;
printf("the less important factor is assumed to have\n") ;
printf("a weight of 1, and the other factor should be\n") ;
printf("assigned a weight of\n") ;
printf("1, if it is equally important as the first one\n") ;
printf("3, if it is slightly more important than the first one\n") ;
printf("5, if it is essentially more important than the first one\n") ;
printf("7, if it is very strongly more important than the first one\n") ;
printf("9, if it is absolutely more important than the first one\n") ;
printf("2,4,6,8 are the intermediate values.\n\n") ;
```

```
printf("How important is user cost compared to traffic control cost ?\n") ;
scanf("%f",&x2) ;
printf("How important is safety compared to user cost ?\n") ;
scanf("%f",&x9) ;
printf("How important is safety compared to traffic control cost ?\n") ;
scanf("%f",&x10) ;
printf("How important is safety compared to contractors' convenience ?\n") ;
scanf("%f",&x12) ;
printf("How important is contractors' convenience compared to user cost ?\n") ;
scanf("%f",&x13) ;
printf("How important is contractors' convenience compared to\n") ;
printf("traffic control cost ?\n") ;
scanf("%f",&x14) ;
```

```
x1 = 1.0 ;
x6 = 1.0 ;
x11 = 1.0 ;
x16 = 1.0 ;
```

```

x5 = 1.0 / x2 ;
x3 = 1.0 / x9 ;
x7 = 1.0 / x10 ;
x15 = 1.0 / x12 ;
x4 = 1.0 / x13 ;
x8 = 1.0 / x14 ;

d1 = x1*x2*x3*x4 ;
d2 = x5*x6*x7*x8 ;
d3 = x9*x10*x11*x12 ;
    d4 = x13*x14*x15*x16 ;

r1 = sqrt(sqrt(d1)) ;
r2 = sqrt(sqrt(d2)) ;
r3 = sqrt(sqrt(d3)) ;
r4 = sqrt(sqrt(d4)) ;

nuc = r1 / (r1+r2+r3+r4) ;
ntc = r2 / (r1+r2+r3+r4) ;
nsf = r3 / (r1+r2+r3+r4) ;
ncn = 1.0 - (nuc+ntc+nsf) ;

g1 = x1+x5+x9+x13 ;
    g2 = x2+x6+x10+x14 ;
g3 = x3+x7+x11+x15 ;
g4 = x4+x8+x12+x16 ;

eig = nuc*g1 + ntc*g2 + nsf*g3 + ncn*g4 ;
ci = (eig - 4.0) / 3.0 ;
cr = ci / 0.9 ;
printf("\n") ;
if ((cr >= 0.0) && (cr < 0.1)) {
    printf("Ratings are consistent.\n\n") ;
}
else {
    printf("Ratings are not consistent, please try again.\n\n") ;
    goto check ;
}

res = nuc*ncsuc + ntc*ncstc + nsf*ncssf + ncn*ncscn ;
rplc = nuc*nplcuc + ntc*nplctc + nsf*nplcsf + ncn*nplccn ;

printf("Overall weight of cross-over : %f\n", rcs) ;

```

```
printf("Overall weight of partial lane closure : %f\n", rplc) ;  
printf("Choose the strategy with higher overall weight.\n") ;
```

```
break ;
```

```
default :
```

```
printf("ERROR IN PREVIOUS DATA ENTRY\n") ;
```

```
}
```

```
printf("\n\n") ;
```

```
return ;
```

```
}
```


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