SCHOOL OF CIVIL ENGINEERING

INDIANA DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-88/18 -1

Final Report

ASSESSMENT OF ROUTINE MAINTENANCE NEEDS AND OPTIMAL USE OF MAINTENANCE FUNDS: FINAL REPORT

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FINAL REPORT

ASSESSMENT OF ROUTINE MAINTENANCE NEEDS AND OPTIMAL USE OF ROUTINE MAINTENANCE FUNDS

TO: H. L. Michael, Director
Joint Highway Research Project

August 31, 1988

Project No: C-36-63K

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

File: 9-7-11

Attached is the Final Report on the HPR Part II Study entitled, "Assessment of Routine Maintenance Needs and Optimal Use of Routine Maintenance Funds." This report presents the results of all phases of the study including recommendations for implementation. The draft dated August 31, 1988 was submitted to the members of the Advisory Committee for review and the comments of the IDOH representative in the Committee have been incorporated in the current version. This report was prepared by me and the research work was conducted by Messrs. F. M. Montenegro, K. J. Feighan, R. P. Tandon, K. Ksaibati and T. Al-Suleiman and Drs. T. F. Fwa and J. D. N. Riverson under my direction.

The report is forwarded for review, comment and acceptance by the IDOH and FHWA as fulfillment of the objectives of the research.

Respectfully submitted,

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Final Report

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. Abstract

This report presents the findings of a research work on the development of optimal strategies for highway routine maintenance management. A procedure based on a condition survey was developed for the assessment of maintenance needs at the subdistrict level. An expert system was developed to illustrate how the procedure can be programmed to facilitate easy implementation. A possible design of an integrated routine maintenance data base system was prepared so that data related to pavement roughness and rehabilitation schedules could be integrated with highway characteristics, traffic and other data for maintenance management. In order to ascertain what type of surface condition data to be included in the data base, an analysis was performed to investigate the relationship between routine maintenance and surface roughness. Two separate surveys of maintenance personnel were conducted to estimate information on cost and service life of various maintenance activities as well as to determine perceived priorities for these activities. An optimization model was then developed that can be used for programming and periodic scheduling of maintenance activities within the constraints of budget and other resources. The report also includes recommendations for implementation.

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TABLE OF CONTENTS

	Page
CHAPTER 1 - INTRODUCTION	1
1.1 Background Information	1
1.2 Scope of the Study	2
1.3 Report Organization	4
CHAPTER 2 - PROCEDURE TO ASSESS ROUTINE MAINTENANCE NEEDS	6
2.1 Introduction	6
2.1.1 Maintenance Management Systems	7
2.1.2 Condition Evaluation Procedures	8
2.2 Development of the Proposed Approach and Design of Experiment	8
2.2.1 Development of the Condition Survey Form	8
2.2.2 Design of Experiment	8
2.2.3 Statistical Selection of the Maintenance Units Surveyed	12
2.2.4 Objective Measurement of Highway Distresses	12
2.3 Analysis of the Validity of the Proposed Approach	15
2.3.1 Work Load and Subjective Evaluation of Distresses	18
2.3.2 Analysis of the Field Survey Data	22
2.3.3 Proposed Quantity Standards	22
2.4 Proposed Plan for Implementation	26
2.5 Chapter Conclusions	30
CHAPTER 3 - ESTIMATION OF SERVICE LIFE AND COST OF MAINTENANCE ACTIVITIES	32
3.1 Introduction	32
3.2 Background	32
3.3 Need for Data	33
3.4 Definition of Parameters Estimated	34
3.4.1 Service Life Estimates	34
3.4.2 Cost Information	36
3.5 Structure of Questionnaire	36
3.6 Description of Survey Methodology	38
3.7 Analysis of Results	40

3.7.1 Shallow Patching 40
3.7.2 Premix Leveling 48
3.7.3 Full Width Shoulder Seal 49
3.7.4 Seal Coating 49
3.7.5 Sealing Longitudinal Cracks and Joints 51
3.7.6 Sealing Cracks 51
3.7.7 Spot Repair of Unpaved Shoulders 52
3.7.8 Blading Shoulders 52
3.7.9 Clipping Shoulders 53
3.7.10 Recondition Unpaved Shoulders 53
3.7.11 Clean and Reshape Ditches 54
3.7.12 Motor Patrol Ditching 55

3.8 Chapter Conclusions 55

CHAPTER 4 - EFFECT OF ROUTINE MAINTENANCE ON PAVEMENT ROUGHNESS 57

4.1 Introduction 57
4.2 Development of Data Base 57

4.2.1 Design of Experiment 58
4.2.2 Selection of Contract Sections 60
4.2.3 Routing Maintenance Quantities 60
4.2.4 Routing Maintenance Amount by Contract Sections 61
4.2.5 Routine Maintenance Expenditure 62

4.3 Data Analysis 62
4.4 Regression Models for Routing Maintenance Expenditure and Regional Effects 67
4.5 Implications of the Models 73
4.6 Chapter Conclusions 79

CHAPTER 5 - THE CONFIGURATION OF A PAVEMENT ROUTINE MAINTENANCE DATA BASE SYSTEM 81

5.1 Introduction 81
5.2 Development of a Microcomputer Database 82

5.2.1 Work Plan 84
5.2.2 Data Base Elements 85
5.2.3 The IDOH Roughness Computer Files 85
5.2.4 Future Programmed Major Activities 85
5.2.5 Condition Survey Information 87
5.2.6 Uses of the Data Base 87

5.3 An Example Application of the Data Base System 88

5.3.1 Data File Structure 88
5.3.2 Input Format 89

5.3.3 Output Description 92
5.3.4 Software 93
5.3.5 System Programs 97
5.3.6 Application Programs 97
5.3.7 Error Messages 97
5.3.8 System Configuration 97
5.3.9 Information Updating 98

5.4 Implementation and Evaluation of the RMDBS 99
5.5 Chapter Conclusions 100

CHAPTER 6 - AN EXPERT SYSTEM TO ESTIMATE HIGHWAY PAVEMENT ROUTINE MAINTENANCE WORK LOAD 102

6.1 Introduction 102
6.2 Proposed Approach 103
6.3 Selection of Distress Types and Maintenance Activities 104
6.4 Knowledge Acquisition 106
6.5 Details of the Proposed Expert System 109

6.5.1 Justification for Using LISP 110

6.6 Description of the Program Modules 111

6.6.1 Task Specific Data or Input Module 111
6.6.2 Knowledge-Base 114
6.6.3 Output Module 118
6.6.4 Procedure to Use the Package 119

6.7 An Example Problem 119
6.8 Limitation of the Expert System and Recommendations for Improvement 121
6.9 Chapter Conclusions 123

CHAPTER 7 - PRIORITY RATING OF ROUTINE MAINTENANCE ACTIVITIES 125

7.1 Introduction 125
7.2 Considerations in Priority Rating Assessment 126

7.2.1 Advantages and Disadvantages of the Proposed Approach 126
7.2.2 Factors Affecting Priority Ratings 128

7.3 The Survey Procedure 130

7.3.1 Statistical Sampling 130
7.3.2 Priority Rating Procedure 132

7.4 Analysis of Survey Data 136

7.4.1 Computation of Final Priority Ratings 136
7.4.2 Analysis of Priority Rating Data 139

7.5 Summary of Findings 148
7.6 Chapter Conclusions 149

CHAPTER 8 - OPTIMAL PROGRAMMING OF MAINTENANCE ACTIVITIES ... 151

8.1 Introduction 151
8.2 Background 152
8.3 Formulation of Proposed Model 153

8.3.1 Integer Programming Model 154
8.3.2 Objective Function 157
8.3.3 Production Requirements 159
8.3.4 Resources Constraints 159
8.3.5 Rehabilitation Constraints 160

8.4 Data Requirements 162

8.4.1 Performance Standards 163
8.4.2 Unit Cost Data 164
8.4.3 Resource Inventory Data 164
8.4.4 Maintenance Needs Assessment 165
8.4.5 Priority Ranking of Routine Maintenance Work ... 166
8.4.6 Schedules of Rehabilitation Activities 166

8.5 Numerical Illustrative Example 167
8.6 Role of the Model in Maintenance Management 174
8.7 Chapter Conclusions 176

CHAPTER 9 - CONCLUSIONS 178

9.1 Major Results of the Study 178
9.2 Recommendations for Implementation 179

REFERENCES 182

LIST OF TABLES

Table		Page
2.1	Routine Maintenance Activities Included in the Study	9
2.2	Highway Distresses Included in the Survey	10
2.3	Tests for the Significance of the Approach and Subdistrict and Individual Estimator's Effects	17
2.4	Variables Considered in the Development of Predictive Models	20
2.5	Models for Prediction of Work Load	21
2.6	Proposed "Present" Quantity Standards	23
3.1	Production Units and Costs	37
3.2	Service Life and Daily Accomplishments Roadway Condition; POOR	41
3.3	Service Life and Daily Accomplishments Roadway Condition; FAIR	42
3.4	Service Life and Daily Accomplishments Roadway Condition; GOOD	43
3.5	Service Life and Daily Accomplishments Shoulder/Ditch Condition; POOR	44
3.6	Service Life and Daily Accomplishments Shoulder/Ditch Condition; FAIR	45
4.1	Distribution of Contract Sections by Climatic Region by Routine Maintenance Category for Each Pavement Type	64
4.2	Statistical Characteristics of Covariance Analysis by Pavement Type	66
4.3	Statistical Characteristics of Patching and Joint and Crack Sealing Models	71
4.4	Statistical Characteristics of Patching Models	72
7.1	List of Maintenance Activities Investigated	133
7.2	Results from Part 1 of Priority Rating Survey	140
7.3	Results from Part 2 of Priority Rating Survey	141

7.4 Priority Ratings of Routine Maintenance Activities by Highway Class and Distress Severity Level 142

8.1 Work Measurement Units of Some Routine Maintenance Activities in Indiana 168

8.2 Daily Production Rate Data 169

8.3 Unit Cost Data 169

8.4 Manpower and Equipment Requirements 170

8.5 Maintenance Priority Weighting Factors 170

8.6 Data on Maintenance Needs and Rehabilitation Constraint Factors 171

8.7 Resource Constraints and Other Input Information 172

8.8 Integer Programming Solution to Example Problem 173

LIST OF FIGURES

Figure		Page
1.1	Schematic Diagram Showing Basic Elements of the Study	3
2.1	Asphalt Pavement Condition Survey Form Used by the Foremen in the Study	13
2.2	Concrete Pavement Condition Survey Form Used by the Foremen in the Study	14
2.3	Form Used to Record Typical Distresses During Field Measurements	16
2.4	Asphalt Pavement Form Proposed for Implementation	27
2.5	Concrete Pavement Form Proposed for Implementation	28
4.1	Locations of Subdistricts Included in the Study	59
4.2	Effect of Patching and Joint & Crack Sealing Expenditure Level on Interstate Rigid Pavement Roughness	74
4.3	Effect of Patching and Joint & Crack Sealing Expenditure Level on Interstate Overlaid Pavement Roughness	74
4.4	Effect of Patching and Joint & Crack Sealing Expenditure Level on OSH Flexible Pavement Roughness	75
4.5	Effect of Patching Expenditure Level on OSH Flexible Pavement Roughness	75
4.6	Effect of Patching and Joint & Crack Sealing Expenditure Level on OSH Overlaid Pavement Roughness	76
4.7	Effect of Patching Expenditure Level on OSH Rigid Pavement Roughness	76
4.8	Effect of Expenditure Level of Two Maintenance Policies on Interstate Overlaid Pavement Roughness	78
4.9	Effect of Expenditure Level of Two Maintenance Policies on OSH Flexible Pavement Roughness	78
5.1	Routine Maintenance Activities as Affected by Major Activities	82
5.2	Data Base Elements	86
5.3	A Hierarchical Sequential Structure	90

5.4 RMDBS Main Menu 91

5.5 RMDBS Information Menu 94

5.6 RMDBS Roughness and Traffic Menu 95

5.7 An Example of the Roughness Report Produced by the RMDBS . 96

6.1 Relationships between Activities and Distresses 107

6.2 Grouping of Distresses 108

6.3 Flow Chart for the Expert System 112

6.4 Flow Chart for the Input Module 113

7.1 Highway Districts in Indiana as Stratification Basis for Survey Sampling 131

7.2 Activity Flow Chart for the Partitioned Two-Stage Survey Procedure 135

7.3 Priority Rating Scale and Rater Instruction 137

7.4 Activity Flow Chart for Alternative Survey Procedure 138

7.5 Comparison of North and South Region Priority Ratings for Routine Maintenance Activities on Interstate 144

7.6 Comparison of North and South Region Priority Ratings for Routine Maintenance Activities on High Volume OSH 145

7.7 Comparison of North and South Region Priority Scores for Routine Maintenance Activities on Low Volume OSH 146

8.1 Computation of Rehabilitation Constraint Factor Y_{ijk} for Highway Section i 161

CHAPTER 1

INTRODUCTION

1.1 Background Information

An area of major concern for most highway agencies today is routine maintenance. In recent years, due to the impact of high inflation and fiscal restraint, most state highway agencies cannot afford to maintain their highways to the standard practiced in the 1960s when the highway system was relatively new. Today, as more and more of the highways built during the 1950s and 60s are reaching and passing their original design life, the need for maintenance and rehabilitation is growing more rapidly.

With the view of combating the problem of deteriorating highway system, the Federal 3-R (Resurfacing, Restoration and Rehabilitation) Program was launched in 1976. In 1982, a fourth R, Reconstruction, was added with a substantial increase in Federal funding. Also, there was a significant increase in Federal matching grant for several states due to "the 85 percent floor" clause of the STAA of 1982. Despite these efforts to increase highway funds, the basic problem of needs exceeding available revenues still remains. Most importantly, the use of Federal grant requires state matching money. Furthermore, there is no Federal money available for routine maintenance. Consequently, the need to allocate optimally the fund available for routine maintenance is ever present.

The emphasis in highway activity is now on protecting as well as prolonging the service life of existing facilities. Under a situation where available resources are limited, and insufficient to meet total funding needs to match Federal grants, as well as to finance entirely state supported activities, an effective management approach performs a vital role. Most states and numerous other agencies have installed separate maintenance management and pavement management systems. A pavement management system (PMS) generally involves the preservation of physical condition of existing pavements, while a maintenance management system (MMS) involves the management of resources for routine maintenance of pavement, shoulder, drainage and other highway elements. An effective highway management approach would be to integrate maintenance aspects in pavement management and to widen the role of MMS so as to consider facility management approach in routine maintenance decisions.

1.2 Scope of the Study

The purpose of the present research was to develop a systematic methodology that can provide optimal strategies for a highway routine maintenance management. The optimality was to be measured in terms of the level of preservation of the condition of various highway elements. In this effort, several tasks were undertaken as depicted in Figure 1.1. There were two major tasks, the assessment of maintenance needs and the development of an optimization model for programming of maintenance activities. A procedure based on a condition survey was developed for the assessment of maintenance needs at the subdistrict level. An expert system was developed to illustrate how the procedure can be programmed to facilitate easy implementation. A possible design of an integrated routine maintenance data base system was prepared so that data related to pavement roughness and rehabilitation schedules could be integrated with highway characteristics, traffic and other data for

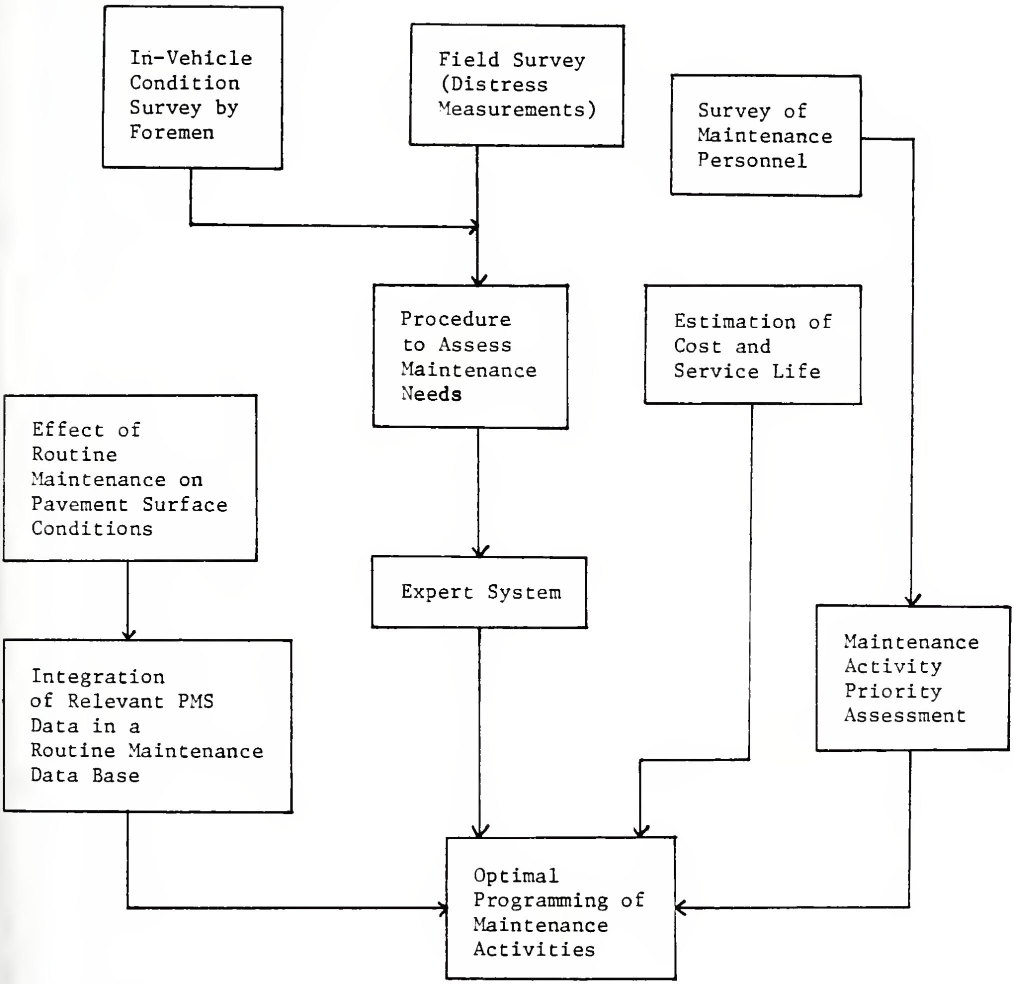


Figure 1.1 Schematic Diagram Showing Basic Elements of the Study

maintenance management. In order to ascertain what type of surface condition data to be included in the data base, an analysis was performed to investigate the relationship between routine maintenance and surface roughness. Two separate surveys of maintenance personnel were conducted to estimate information on cost and service life of various maintenance activities as well as to determine perceived priorities for these activities. An optimization model was then developed that can be used for programming and periodic scheduling of maintenance activities within the constraints of budget and other resources.

1.3 Report Organization

In Chapter 2 is described the procedure used to develop appropriate standards for maintenance need assessments. Chapter 3 presents the results of the survey to generate estimates of costs and service lives of maintenance activities by roadway condition, by type of material and equipment. Chapter 4 discusses the analysis performed to ascertain the effect of routine maintenance expenditure level on pavement roughness. Pavement roughness data, the only routinely collected pavement performance data at the IDOH, could then be used to help in making maintenance decisions. In Chapter 5 a possible design of an integrated routine maintenance data base system is discussed. The use of an expert system to perform the task of estimating routine maintenance needs is illustrated in Chapter 6. Chapter 7 presents a procedure for determining priority ratings of maintenance activities by highway class and by distress level. These ratings, along with the other information generated in the study, are used to develop an optimization model, as discussed in Chapter 8, for determining amounts of different maintenance activities to be performed over a given time period under the constraints of production requirements, budget allocation, manpower, material and equipment availability, and rehabilitation schedule. Chapter 9 presents conclusions and recommendations for implementation of the study results.

CHAPTER 2

A PROCEDURE TO ASSESS ROUTINE MAINTENANCE NEEDS

2.1 Introduction

One of the most important functions of a maintenance management system is to estimate the amount of maintenance work to be performed on various highway sections within a maintenance unit during a coming year or season. For the state highway system in Indiana, the budgeting for routine maintenance work is established primarily by subdistrict foremen on the basis of historical quantity standards and their judgment [Sharaf et al. 1982]. The procedure, used in most states, is based on Roy Jorgensen's work in the 1960s [Mahone et al. 1980; RJA 1972]. However, this historical-empirical approach may not provide an assessment of actual needs by specific highway sections for scheduling of activities in the field.

A system is proposed in the present study for assessing routine maintenance work load based on a condition survey of roadways by unit foremen. It is believed that the proposed system can provide a tool to assist in the assessment of work loads by highway section. There can be several added benefits of the proposed procedure. Subdistricts and districts will be able to have a systematically gathered and uniformly defined maintenance needs data. Maintenance management at all levels can thus have another tool to check the maintenance levels-of-service throughout the state allowing maintenance policies to be consistent.

2.1.1 Maintenance Management Systems

The present version of the maintenance management systems in most states is primarily based on the development of appropriate standards. These standards are then used to control and plan various maintenance activities.

1. Quality standards are used to represent maintenance levels of service.

2. Quantity standards are the means by which inventory units are converted into work load. For example, if a certain network has 10 miles of bituminous road, multiplying this by the quantity standard for shallow patching - such as 2 tons per mile of bituminous road - will lead to the expected amount of shallow patching: 20 tons. Quantity standards are developed primarily from historical data as well as from input from the unit foremen. They are averages of past requirements per unit of inventory for each maintenance activity. Some standards are based on management policy, such as that for mowing.

3. Performance standards help to translate expected work load per activity to man-hours, material and equipment requirements per activity. They provide the average requirement of manpower, materials and equipment to accomplish one unit of a maintenance activity. Thus, having the work load per activity, we can multiply these quantities by their respective performance standards and arrive at the requirements of labor, materials and equipment.

The Indiana Department of Highways (IDOH) Field Operations Manual provide a good insight into the maintenance management system in use in Indiana [IDOH 1985]. The procedure is based on the sets of standards described earlier.

2.1.2 Condition Evaluation Procedures

The currently available condition survey procedures were developed primarily for pavement management systems, and they are directed to decisions regarding rehabilitation needs. However, in the present study it was necessary to develop a survey procedure that can identify conditions triggering routine maintenance needs. The proposed procedure is to conduct a visual condition survey by unit foremen on a periodic basis.

2.2 Development of the Proposed Approach and Design of Experiment

2.2.1 Development of the Condition Survey Form

A simple survey form was developed on the basis of current procedures and consultation with the unit foremen and subdistrict personnel. The selection of maintenance activities and condition distresses to be included in the survey procedure was based on maintenance personnel's opinion and information available in the literature on highway maintenance management. Table 2.1 shows the list of maintenance activities included in the study, and the highway distresses considered in the survey are presented in Table 2.2.

2.2.2 Design of Experiment

The proposed approach was tested in field as to its validity and accuracy as well as to check if the survey form developed represented the actual typical condition of the roadways. The work elements included:

1. Collection of the highway physical condition information through a visual inspection by unit foremen. The type of visual inspection was

Table 2.1 Routine Maintenance Activities Included in the Study

Pavement	Unpaved Shdrs.	Drainage
201 Shallow Patching	210 Spot Repair Unpaved Shdrs.	231 Clean and Reshape Ditches
202 Deep Patching	211 Blading Shdrs.	234 Motor Patrol Ditching
203 Premix Leveling	212 Clipping Unpaved Shdrs.	
204 Full Width Shdr. Seal	213 Reconditioning Unpaved Shdrs.	
205 Seal Coating		
206 Sealing Long. Cracks and Joints		
207 Sealing Cracks		

Table 2.2 Highway Distresses Included in the Survey

Flexible Pavements	Rigid Pavements
	Blow Ups
Blow Ups	Bumps
Bumps	Condition of Long. Joints
Depressions	Condition of Transv. Joints
Ditch Condition	Ditch Condition
Linear Cracks	Linear Cracks
Potholes	Potholes.
Raveling	Raveling in Bit. Shldr
Rutting	Shdr. Build Up
Shdr. Build Up	Shdr. Drop-Off
Shdr. Drop-Off	Shdr. Potholes
Shdr. Potholes	Spalling
Surface Failures	Surface Failures

the same as that currently used by the IDOH. The units were selected in a stratified random sampling. The unit foremen were asked to generate two types of data: a subjective opinion about the degree of several deficiency conditions in the roadway stretch being analyzed and an estimate of the expected amount of work in the selected maintenance activities currently needed, based on the condition of the roadway they are evaluating.

2. Objective measurements of different deficiency conditions by the research team on the same highway stretches surveyed by the unit foremen.

3. Statistical correlation and analysis of the data collected in Steps 1 and 2.

4. Development of the criteria that would relate the unit foremen's evaluation of a deficiency condition to a certain level of routine maintenance activity.

5. Analysis of the variability of the subjective opinions about the roadway condition. This analysis can then assist in improving the consistency of future maintenance decisions.

The forms used included information on both the roadway condition as well as estimated maintenance needs. Foremen were required to estimate the work load so that the information could be used to analyze the validity of the proposed approach. This part of the survey form was designed to generate appropriate data to translate road condition information to maintenance work load.

2.2.3 Statistical Selection of the Maintenance Units Surveyed

The study used a stratified random sampling scheme. A stratified random scheme is a restricted randomization design in which the experimental units are first sorted into homogeneous groups or blocks and then the required number of experimental units is randomly selected within each group [Neter et al. 1985].

The study considered the northern, central and southern part of the State of Indiana as blocks, from which the units to be surveyed were selected. In this way, variations in climate and regional maintenance practices could be taken into account when analyzing the validity of the proposed approach. Three subdistricts were randomly selected in each of these three regions. Within each of these subdistricts, two randomly selected maintenance units were surveyed. In such a way, the variations associated with both unit foreman and subdistrict could be analyzed when assessing the accuracy of the proposed condition survey method. A total of eighteen maintenance units were included in the study. The survey covered asphalt and concrete highways in both interstate and state highway systems. A total of 965 lane miles was surveyed. The forms used to conduct the foremen's survey are shown in Figures 2.1 and 2.2.

2.2.4 Objective Measurement of Highway Distresses

The highway stretches surveyed by the unit foremen were also surveyed by the research team and the highway distresses observed were physically measured. This measurement took place within no more than two days from the foremen's survey. Every highway stretch that a foreman evaluated was

DISTRICT__________ HIGHWAY S | US | IS No.________

SUBDISTRICT__________ FROM__________

UNIT NO.__________ TO__________

DATE__________ TRAFFIC LOW | MED | HIGH

DIRECTION N | S | E | W

ASPHALT PAVEMENTS						
TRAFFIC LANES AND PAVED SHOULDERS						
M	S	F	N	SLIGHT	POTHOLES	SHALLOW PATCHING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	CRACKS	CRACK SEALING .... gals
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		FULL WIDTH SHOULDER SEAL ...... ft. miles
M	S	F	N	SLIGHT	RAVELING	
M	S	F	N	MODERATE		SEAL COATING ...... lane miles
M	S	F	N	SEVERE		
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES		DEEP PATCHING .... tons
M	S	F	N			
M	S	F	N			
M	S	F	N	SLIGHT	RUTTING, DIPS	LEVELING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
UNPAVED SHOULDERS						
M	S	F	N	SLIGHT	BUILD-UP	CLIPPING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	POTHOLES	SPOT REPAIR (210) .... tons of agg.
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	DROP-OFF	BLADING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		RECONDTING .... shldr. miles
DRAINAGE						
P	F	G		DITCHES		DITCHING (231) ...... linear ft
						MOTOR PATROL DITCHING (234) .... ditch miles

Figure 2.1 Asphalt Pavement Condition Survey Form Used by the Foremen in the Study

DISTRICT ____________ HIGHWAY [S | US | IS] No. ____________

SUBDISTRICT ____________ FROM ____________ ____________

UNIT NO. ____________ TO ____________

DATE ____________ TRAFFIC [LOW | MED | HIGH]

DIRECTION [N | S | E | W]

CONCRETE PAVEMENTS						
TRAFFIC LANES AND PAVED SHOULDERS						
M	S	F	N	SLIGHT	POTHOLES	SHALLOW PATCHING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES		DEEP PATCHING .... tons
M	S	F	N			
M	S	F	N			
P	F	G		LONGITUD. JOINTS		SEALING LONG. CRACKS & JOINTS ..... linear miles of cracks & joints
P	F	G		TRANSVERSE JOINTS		CRACK SEALING .... gals.
M	S	F	N	SLIGHT	CRACKS	
M	S	F	N	MODERATE		FULL WIDTH SHOULDER SEAL ...... ft miles
M	S	F	N	SEVERE		
M	S	F	N	RAVELING IN BITUMINOUS SHLDR		
UNPAVED SHOULDERS						
M	S	F	N	SLIGHT	BUILD-UP	CLIPPING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	POTHOLES	SPOT REPAIR .... tons of agg.
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	DROP-OFF	BLADING .... shldr. miles
M	S	F	N	MODERATE		RECONDTNG .... shldr. miles
M	S	F	N	SEVERE		
DRAINAGE						
P	F	G		DITCHES		DITCHING (231) ...... linear ft
						MOTOR PATROL DITCHING (234) .... ditch miles

Figure 2.2 Concrete Pavement Condition Survey Form Used by the Foremen in the Study

subsequently evaluated by measuring objectively its distresses. As the measurement took place within a short period of foremen's survey, the possibility of occurrence of any changes in the highway condition between the two evaluations was minimized. The form used to record the physical measurements of distress is shown in Figure 2.3.

2.3 Analysis of the Validity of the Proposed Approach

The subjective condition rating data were converted into a numerical scale so that quantitative statistical analysis methods could be used. A point estimation technique was applied for the conversion of the subjective category scale used during the field survey to a 0-10 numerical scale.

To analyze the data gathered, regression analyses were performed. Table 2.3 presents a summary of the results obtained. It shows the significance of the proposed approach in explaining the variability of maintenance work load for eight of the nine maintenance activities considered. The lack of significance in the case of Sealing Longitudinal Cracks and Joints can be attributed to the small sample size.

It can be seen in Table 2.3 that maintenance subdistricts showed a significant influence in the estimation of the work load of Shallow Patching, Crack Sealing and Premix Leveling at a level of significance of 0.05. Individual estimator's influences were found significant in assessing the needs of Spot Repair Unpaved Shoulders, Blading Unpaved Shoulders and Cleaning and Reshaping Ditches. These results suggest that the amount of work in Spot Repair Unpaved Shoulders, Blading Unpaved Shoulders and Cleaning and Reshaping Ditches is particularly influenced by the personal judgment of unit foremen, while the

HIGHWAY CLASS & No : Typical sample unit No: length dist:

HIGHWAY FEATURE/ DISTRESS	TRAFFIC LANES	PAVED SHOULDER
WIDTH	1 | 2 | 3 | ___ft	No | Yes ___ft ___ft
SURFACE TYPE	ASPHALT | CONCRETE	ASPHALT | CONCRETE
POTHOLES	lth | wth | depth	length | width | depth
LINEAR CRACKS	sealed | lth ___ wth ___ unsealed | lth<1/8 | wth	sealed | lth ___ wth ___ unsealed | lth<1/8 ..... wth .....
ALLIGATOR CRACKING	seal | patch | L | M | H | sealed unsealed ft2	seal | patch | L | M | H | sealed unsealed ft2
RAVELING	L | M | H | ft2	L | M | H | ft2
RUTTING	inside wheel in | outside wheel in	___in
DIPS CORRUG.	DEPTH | FT2	DEPTH | FT2
BLOW UPS	L | M | H | No FT2	L | M | H | No FT2
SPALLING	L | M | H | No FT2	L | M | H | No FT2
SURFACE FAILURE	L | M | H | depth FT2 edge?	L | M | H | depth FT2
BUMPS	L | M | H | depth FT	L | M | H | FT
LONG JOINTS	fault | L | M | H | No | sldge LMH No	fault | L | M | H | No | sldge LMH No
TRANSVERSE JOINTS	fault | L | M | H | No | sldge LMH No	fault | L | M | H | No | sldge LMH No
PATCHED SURFACE	L M H FT2	L M H FT2
LANE/SDR DROP OFF	length FT depth IN	out shder width ft
PAVSHDR/UNPSHDR DROP OFF	length FT depth IN	med shder width ft
BUILD UP	length FT depth IN dist from pav.shder	
POTHOLES	LENGTH WIDTH DEPTH	sod L M H length shape P F G lth depth
DITCH	WIDTH FT DEPTH FT	REMARKS
DIRT DEBRIS	N F S M NO DITCH	
CLOGGED(SED.)	N F S M CEMENT DITCH	
VEGETATION	N F S M DITCH IN PRIVATE YARD	
EROSION	N F S M	
CROSS SECTION	GOOD (TRIANG.) BAD (SQ.)	

DAY: DISTRICT: SUBDISTRICT: UNIT:

Figure 2.3 Form Used to Record Typical Distresses During Field Measurements

Table 2.3 Tests for the Significance of the Approach and Subdistrict and Individual Estimator's Effects

Maintenance Activity	Approach (Related "Assessed" Distresses)			Subdistrict Effect			Individual Estimator's Effect		
	Significant at α = 0.05	F	α	Significant at α = 0.05	F	α	Significant at α = 0.05	F	α
Shallow Patching	yes	6.98603 (4,41)*	<0.001	yes	2.9448 (8,50)	0.01 - 0.025	no	1.2666 (9,41)	> 0.1
Crack Sealing	yes	4.6951 (4,41)	0.001-0.005	yes	2.5729 (8,50)	0.01-0.025	no	1.7119 (9,41)	> 0.1
Deep Patching	yes	2.9663 (7,38)	0.01 - 0.025	no	0.8495 (8,47)	> 0.1	no	1.0688 (9,38)	>0.1
Premix Leveling	yes	2.9248 (3,32)	0.01 - 0.025	yes	2.3576 (8,41)	0.025-0.05	no	1.7193 (9,32)	>0.1
Sealing Longitudinal Cracks and Joints	no	49.3049** (3,1)	> 0.1	no	3.5725 (4,2)	> 0.1	no	4.3236 (1,1)	>0.1
Clipping Unpaved Shdrs	yes	25.8952 (2,43)	< 0.001	no	1.6044 (8,52)	>0.1	no	1.3799 (9,43)	>0.1
Spot Repair Unpaved Shdrs.	yes	5.9417 (4,41)	< 0.001	no	1.9063 (8,50)	0.05 - 0.1	yes	2.4455 (9,41)	0.025-0.05
Blading Shdrs	yes	4.2549 (4,41)	0.005 - 0.01	no	1.7162 (8,50)	>0.1	yes	4.0648 (9,41)	0.001 - 0.005
Clean and Reshape Ditches	yes	26.7146 (1,44)	< 0.001	no	1.4627 (8,53)	> 0.1	yes	3.782 (9,44)	0.001 - 0.005

* Degrees of freedom

** Remember that the sample size is much smaller in this case, thus, the power of the tests is lower amount of Shallow Patching, Crack Sealing and Premix Leveling are more subject to regional differences in maintenance materials, practices or standards. The influences of subdistricts and foremen should be further studied in order to achieve consistency in maintenance needs assessment.

2.3.1 Work Load and Subjective Evaluation of Distresses

A set of regression analyses was performed to relate routine maintenance work load with the subjective evaluation of distresses by unit foremen. The purpose of these analyses were:

1. To develop models that can be used to estimate routine maintenance work loads on the basis of subjective evaluation of roadway distresses.

2. To form the basis of the calculation of "present" quantity standards.

3. To know how much of the variability of estimated maintenance work loads can be explained by foremen´s survey.

These points were addressed by a stepwise regression procedure that gives "best" models for each of the analyzed maintenance activities. The following was the model adopted.

$$y_i = a + \sum_{j=1}^{n_i} b_j X_{ij} \qquad (2.1)$$

where,

y_i = square root of expected work load per activity per lane-mile, shoulder-mile or ditch-mile;
a = constant;
b_j = regression parameters, $j=1,2,\ldots,n_i$;
x_{ij} = subjectively rated distresses (pothole frequency, pothole size, etc).

The variables listed in Table 2.4 were included in Equation 2.1 in the process of developing models to predict work load per activity. The "best" models arrived at are presented in Table 2.5.

The values of the coefficients of determination, R^2, represent the proportion of the variability of estimated work loads that can be explained by foremen's evaluation of distresses. Except for blading shoulders, the R^2 values are generally reasonable. Some factors that might have lowered the R^2 values obtained are: (1) the lack of full understanding by some foremen of the meaning of some distresses, like raveling, when rating the roads; (2) the lack of consistency in the speed at which the foremen evaluated the roads (10 to 55 mph); (3) some foremen might have rated the extent of certain distresses influenced by "non-typical" spots rather than based on the overall extent of those distresses over the highway stretches; (4) maintenance standards for certain activities may be based on usage and experience rather than on established maintenance level-of-services (for example, unpaved shoulders may be clipped once every few years instead of being clipped whenever the buildup is greater than a determined height); (5) some of the distresses evaluated trigger two or more maintenance options; for example, bumps may trigger either "Bumps Burning" or "Deep Patching", depending on severity; and (6) altogether different maintenance activities may be triggered only for a certain extent of a particular distress type and not always (for example, raveling can trigger either sealing or patching or major maintenance, depending on the extent and severity of raveling). It is believed that many of these items can be improved by training and thus the resulting future R^2 values can be increased.

Table 2.4 Variables Considered in the Development of Predictive Models

Maintenance Activity	"Assessed" Distresses Considered	
Shallow Patching	Frequency of Potholes (X_1) Severity of Potholes (X_2)	Frequency of Cracks (X_3) Severity of Cracks (X_4)
Crack Sealing	Frequency of Cracks (X_3) Severity of Cracks (X_4)	Frequency of Raveling (X_5) Severity of Raveling (X_6)
Deep Patching	Frequency of Potholes (X_1) Severity of Potholes (X_2) Frequency of Cracks (X_3) Severity of Cracks (X_4)	Frequency of Raveling (X_5) Severity of Raveling (X_6) Frequency of Bumps, Blow Ups, and Surface Failures (X_7)
Premix Leveling	Frequency of Ruts and Dips (X_8) Severity of Ruts and Dips (X_9)	Frequency of Bumps, Blow Ups, and Surface Failures (X_7)
Sealing Longitudinal Cracks and Joints	Frequency of Cracks (X_3) Severity of Cracks (X_4)	Condition of Longitudinal Joints (X_{10})
Clipping Unpaved Shrds.	Frequency of Build-Ups (X_{11})	Severity of Build-Ups (X_{12})
Spot Repair Unpaved Shrds.	Frequency of Potholes in Unpaved Shdr. (X_{13}) Severity of Potholes in Unpaved Shdr. (X_{14})	Frequency of Dropoff (X_{15}) Severity of Dropoff (X_{16})
Blading Shdrs.	Frequency of Potholes in Unpaved Shdr. (X_{13}) Severity of Potholes in Unpaved Shdr. (X_{14})	Frequency of Dropoff (X_{15}) Severity of Dropoff (X_{16})
Clean and Reshape Ditches	Condition of Roadside Ditches (X_{17})	

Table 2.5 Models for Prediction of Work Load

Maintenance Activity	"Best" Suited Models	R^2 (%)
Shallow Patching	$y' = 0.157 + 0.09253 X_1 + 0.10865 X_2$	37.15
Crack Sealing	$y' = 3.243 + 1.409 X_4$	36.54
Deep Patching	$y' = -0.362 + 0.1176 X_1 + 0.15267 X_7$	30.66
Premix Levelling	$y' = -1.339 + 0.219 X_8 + 0.459 X_9$	58.00
Sealing Long. Cracks and Joints	No significant model was developed due to the lack of sufficient sample size	–
Chipping Unpaved Shdrs.	$y' = -0.067 + 0.06746 X_{11} + 0.05793 X_{12}$	55 43
Spot Repair Unpaved Shdrs.	$y' = -0.004 + 0.21536 X_{13} + 0.26212 X_{16}$	31.30
Blading Shdrs.	$y' = 0.239 + 0.08648 X_{13}$	12.71
Clean and Reshape Ditches	$y' = 34.845 - 4.26425 X_{17}$	47.98

The variables X_1, X_2, ..., X_{17} are defined in Table 4

* y'= y transformed = y ** 0.5 = Square root of expected work load per lane mile, shoulder mile or ditch mile.

A note of caution should be given. The models developed in this section are statistical in nature. No mechanistic or cause-effect relationship between work load and "assessed" distresses was established.

2.3.2 Analysis of the Field Survey Data

This section presents a regression of maintenance work load per activity on related measured distresses. The objective was to highlight major distresses that need to be included in the survey form proposed for implementation. It should be noted that the extent of patched surface was found to be the only additional significant highway feature that contributed to the explanation of the variation in estimated needs of Premix Leveling.

2.3.3 Proposed Quantity Standards

On the basis of the models developed in this study "present" quantity standards (QS) were computed for various combinations of highway distress frequency and severity. As an illustration, the following example can be considered. The QS for Shallow Patching in roadways assessed as having of "Many" "Slight" potholes was calculated using the model for Shallow Patching. In that model, expected shallow patching per lane mile is a function of the assessed frequency (x_1) and severity of potholes (x_2). The model was solved with the numerical values associated with the categories "Many" and "Slight" potholes, 8.01 and 1.79, respectively. The resulting QS-value can thus be computed as 1.20 tons per lane mile. Similar computations were done for other activities under various combinations of distress frequency and severity. The resulting QS-values are presented in Table 2.6.

Table 2.6 Proposed "Present" Quantity Standards

Shallow Patching
(Tons per Lane Mile)

"Assessed" Pothole Severity \ "Assessed" Pothole Frequency	N	S	M
Sl	0.20	0.50	1.20
Mo	0.60	1.10	2.10
Se	1.20	1.90	3.10

Crack Sealing
(Gallons per Lane Mile)

"Assessed" Severity of Cracks

Sl	33.23
Mo	103.24
Se	212.73

Deep Patching
(Tons per Lane Mile)

"Assessed" Bumps, Blow-Ups and Surface Failure Frequency \ "Assessed" Pothole Frequency	N	S	M
N	0.0	0.04	0.50
S	0.10	0.50	1.30
M	0.90	1.70	3.25

Table 2.6 (Continued)

		Blading Shdrs. (Shdr. Miles per Shdr. Mile)
"Assessed" Frequency of Potholes in Unpaved Shdrs	N	0.10
	S	0.30
	M	0.90

		Clean and Reshape Ditches (Ft per Ditch Mile)
"Assessed" Condition of Roadside Ditch	P	693.0
	F	190.0
	G	2.0

Table 2.6 (Continued)

Premix Leveling
(Tons per Lane mile)

"Assessed" Severity of Rutting and Dips	"Assessed" Frequency of Rutting and Dips: N	S	M
Sl	0.13	0.34	1.53
Mo	1.13	4.07	7.12
Se	6.27	11.96	16.89

Clipping Unpaved Shdrs.
(Shdr. Miles per Shdr. Mile)

"Assessed" Severity of Buildups	"Assessed" Frequency of Buildups: N	S	M
Sl	0.01	0.10	0.33
Mo	0.07	0.25	0.60
Se	0.20	0.45	0.90

Spot Repair Unpaved Shdrs.
(Tons per Shdr. Mile)

"Assessed" Severity of Dropoff	"Assessed" Frequency of Potholes in Unpaved Shdr: N	S	M
Sl	0.40	1.70	4.80
Mo	2.00	4.45	9.10
Se	5.10	8.60	14.70

The procedure proposed for use in estimating future routine maintenance work loads appears to be conceptually sound; as it involves an assessment of maintenance needs based on present needs (evaluation of distresses that trigger those needs) rather than past experience or arbitrary guesses.

2.4 Proposed Plan for Implementation

The different steps that can be followed to implement the proposed approach are listed below.

1. Unit foremen would perform the condition survey in early fall and early spring each year. Condition data would be recorded for each highway stretch within the boundaries of a maintenance unit. One form should be filled for each highway stretch. Figures 2.4 and 2.5 show the proposed forms for asphalt and concrete pavements. These forms are modified versions of the forms used in the study. Unlike the forms used in the study, the proposed forms include "patched area" as one of the distress indicators and a three-category scale is used for the frequency of distresses. The analysis conducted in the study indicated these changes would improve the survey results.

2. Unit foremen would drive along the entire stretch of a roadway at a reduced speed of about 30 mph before rating. It should be noted that the proposed survey was designed to be fast enough so that an entire highway stretch could be surveyed without resorting to sampling sections. In this manner, the foremen would base their judgment on the overall condition of the stretch. Only one combination of frequency and severity of particular deficiency conditions should be selected. For

DISTRICT ____________ HIGHWAY [S | US | IS] No ____________

SUBDISTRICT ____________ FROM ____________

UNIT NO. ____________ TO ____________

DATE ____________ TRAFFIC [LOW | MED | HIGH]

DIRECTION [N | S | E | W]

ASPHALT PAVEMENTS				
TRAFFIC LANES AND PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	RAVELING
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, BUMPS AND SURFACE FAILURES	
M	S	N	SLIGHT	RUTTING, DIPS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	PATCHED SURFACE
M	S	N	MODERATE	
M	S	N	SEVERE	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

Figure 2.4 Asphalt Pavement Form Proposed for Implementation

DISTRICT ______________ HIGHWAY | S | US | IS | No ______________

SUBDISTRICT ______________ FROM ______________

UNIT NO. ______________ TO ______________

DATE ______________ TRAFFIC | LOW | MED | HIGH |

DIRECTION | N | S | E | W |

CONCRETE PAVEMENTS				
TRAFFIC LANES AND PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, SPALLING, BUMPS AND SURFACE FAILURES	
P	F	G	LONGITUD. JOINTS	
P	F	G	TRANSVERSE JOINTS	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	RAVELING IN BITUMINOUS SHLDR	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

Figure 2.5 Concrete Pavement Form Proposed for Implementation

example, if a unit foreman thinks that there is extensive cracking of low severity in a highway stretch, he will mark the cell corresponding to "Many" "Slight" cracks.

3. An estimation of maintenance work load for each activity and for each highway stretch can be made by matching the condition data recorded on the forms in Figures 2.4 and 2.5 during the spring survey with the appropriate "present" quantity standards given in Table 2.6. These quantity standards are a function of the "assessed" levels of frequency and severity of distresses. For example, when a stretch has "Many" "Moderate" potholes, 2.05 tons of Shallow Patching for each lane mile of the stretch would be considered. Multiplying the corresponding "present" quantity standards by the number of lane miles, shoulder miles or ditch miles of the highway stretch, various maintenance work loads for each highway stretch would be obtained. The maintenance needs for any maintenance unit, subdistrict, district, or the state, can be computed by adding the needs for each road stretch within that area. The estimated work loads by highway sections can then be used to determine the actual work loads within a budget constraint.
4. The aggregation of the evaluation data per maintenance subdistrict would provide a periodic indication of the overall condition of the highways within the subdistrict. These data can be used to check the effectiveness of different maintenance policies related to field work.

Since the proposed procedure enables the estimation of quantities of needed routine maintenance, it can be applied at the time of budget estimation. It can also be employed as appropriate during the year as an assessment of maintenance needed (as currently done with Form MM-236) for periodic scheduling. The approach developed in this study can be implemented in various phases.

In the first phase, the proposed procedure can be applied on a trial basis in selected subdistricts. The average characteristics for different subjective assessment of distresses are given in Tables 4.9 and 4.10 of the report by Montenegro and Sinha [1986]. The values in the tables can be considered as limits for defining various distress levels with corresponding quantity standards given in Table 2.6. The procedure can be implemented for about two years to ensure familiarity. Further review of quantity standards can then be used in the present study to reconcile differences in estimation, if any. By this approach, the new procedures can be gradually incorporated into the current maintenance management system as desired.

2.5 Chapter Conclusions

The principal objective of this part of the study was to develop an approach that can be used primarily to determine how much of a routine maintenance activity to be performed on a highway section during a given time period subject to a given budgetary constraint. This approach is based on the subjective rating of highway distresses by maintenance unit foremen. Routine maintenance needs are connected to their immediate cause, highway deficiencies. It is envisioned that the implementation of this approach would give a more structured approach to maintenance planning, since maintenance needs estimation would be based on present needs rather than historical averages or arbitrary guesses.

This study developed both the methodology to perform the proposed foremen's surveys and the criteria to relate the subjective data obtained to certain levels of routine maintenance activities. In this connection, regression analyses allowed the development of estimation models for expected work load based on foremen's subjective evaluation of distresses. Finally, the concept of "present" quantity standards were introduced. It should be noted, however, that before the procedure can be fully implemented, further work is necessary to establish increased consistency in foremen's evaluation of distress conditions and subsequent work load estimation.

The use of this approach can provide decision-makers with the information and tools to monitor the condition of the highway network. This can help not only to assess maintenance needs but also to check the efficiency and quality of maintenance field work.

CHAPTER 3

ESTIMATION OF SERVICE LIFE AND COST OF MAINTENANCE ACTIVITIES

3.1 Introduction

Interest in highway maintenance has been largely motivated by a desire to obtain a greater degree of control and standardization of approach in order to achieve ultimately a better return per dollar invested in the construction and maintenance of highways. However, most of the research that has been undertaken to date has been in the area of major maintenance or rehabilitation. Consequently, there is limited published information on techniques and data concerning routine maintenance activities and management. This chapter describes research into service life and costs of some of the routine maintenance activities in Indiana as these values were deemed to be essential inputs for an effective maintenance management program.

3.2 Background

The major features of the current maintenance management system in Indiana Department of Highways that are relevant to this research are the Field Operations Manual [IDOH 1983-84] and Crew Day Cards. The Field Operations Manual basically consists of a set of performance standards for each designated maintenance activity. Each activity is identified by a number. The performance standard gives a description of the activity in question and a recommended maintenance procedure as well as a standard crew size, equipment complement and a range of expected average daily production.

The Crew Day Cards provide a means of authorizing work to be done and recording work completed. One crew day card is given to each crew leader every morning with details of the nature and location of the work as well as assignment of employees and equipment. At the end of the day, the crew leader fills in the number of accomplishment units achieved that day as well as the manhours worked and the equipment and materials used. Thus it is possible to subsequently determine average manhours, material usage and other information, per production unit.

This management system has been in operation in Indiana since 1975 and a large amount of data has been accumulated over this time. The system has produced a relatively high degree of uniformity in maintenance procedures.

3.3 Need for Data

A variety of treatment alternatives exist for different types and levels of pavement and shoulder distress within the field of routine maintenance. All of these treatments will be effective to one degree or another, but a need exists to evaluate which methods produce the best solution to a given problem. In order to determine such an optimal solution, regardless of the nature of the deficiency, it is essential that two parameters be known; the service life and the cost of each of the alternatives.

The following uses have been put forward as justification for research into the estimation of expected service life and costs [TRB 1981; Mahone et al. 1980].

1. To estimate and allocate funds available.

2. To identify the most cost-effective solutions.

3. To monitor if change in work practices or materials significantly increases service life and to evaluate whether or not such changes are cost-effective.

4. To identify locations which consistently underscore the expected life of a given treatment.

5. To justify a change in emphasis at the network level, e.g. advocating sealing (preventive maintenance) over patching (corrective maintenance).

6. To anticipate when necessary expenditure will re-occur.

7. To co-ordinate with PMS and other management systems in working out the most cost-effective "holding" action until major rehabilitation or reconstruction can take place.

3.4 Definition of Parameters Estimated

Having established the need for the data, the next step is to determine how best to obtain the necessary information. A review of routine maintenance activities conducted by IDOH indicated that not all activities were of equal importance. Consequently, in the initial work a number of activities were selected from the general areas of pavement, shoulder and highway drainage. The criteria applied in selecting the activities were annual expenditure per activity and annual volume of work performed per activity.

3.4.1 Service Life Estimates

The expected service life of any treatment may vary with the degree of deficiency of any particular distress type as well as from distress type to distress type. There are also unique influences peculiar to each general category of pavements, shoulders and drainage.

A distinction between actual and effective service life must be made as it is crucial to understanding the uses to which the data accumulated can be put. An actual service life of a given treatment is regarded as the time elapsed from when the treatment is applied to the point in time when its condition falls below a prescribed, measurable value. In the present research, rather than the actual service life of a treatment, an estimate of the effective service life was made to represent the time elapsed from when the treatment is applied until the time when, in the opinion of the field personnel, it needs to be replaced.

In the establishment of a maintenance management program, what is of ultimate concern is the amount of money spent on any given activity and the way that available monies can be spent to produce the maximum good. In the area of routine maintenance, the operation and implementation of available funds is basically carried out by field personnel. In the IDOH organization, geographic areas of responsibility are broken down into districts, subdistricts and units. On a road mileage basis, a unit averages approximately 140 miles. The unit foremen are responsible for deciding in the first instance when and where work needs to be carried out. Hence, it is relevant and is finally useful, to obtain an estimate of how long a treatment lasts based on the opinion of the unit foreman.

This approach to service life estimation is not new or unique. Ontario has already carried out such a survey as part of its Routine Maintenance Program (RMP) and has incorporated the results, both service life estimates and costs, into its overall RMP system [OMTC 1982].

There is no doubt that a need exists for research to be carried out into actual service lives. However, as such specific information becomes available in the future, the appropriate service life functions can be inserted in the proposed Routine Maintenance Management Program.

3.4.2 Cost Information

A large amount of research has been undertaken in recent years at Purdue into the overall and specific costs of routine maintenance activities in Indiana [Sharaf et al. 1982; IDOH 1985-86]. As a consequence of this prior research, it was possible to obtain a unit cost per production unit for each activity. In Table 3.1, a summary of the unit cost data is presented for each of the activities considered in the study. It was previously mentioned that Crew Day Cards were required to be filled in each day and that daily accomplishment was one of the values listed. Thus, maintenance personnel are familiar with the concept of production units and with the variation in production caused by changing roadway or climatic conditions. It is also believed that using production units as an indirect measure of cost yields greater potential for transferability of results for comparison purposes.

3.5 Structure of Questionnaire

A questionnaire was used to acquire service life estimates. This ques-

Table 3.1
Production Units and Costs

ACTIVITY	PRODUCTION UNIT	TOTAL COST PER PROD. UNIT
Shallow Patching	Tons of Aggregate	$114.17
Premix Levelling	Tons of Premix	$41.46
Full Width Shoulder Seal	Foot Miles	$177.50
Seal Coating	Lane Miles	$1352.60
Long. Joint And Crack Sealing	Lineal Miles	$108.50
Crack Sealing	Lane Miles	$290.00
Spot Repair Of Unpaved Shoulders	Tons of Aggregate	$13.64
Blading Shoulders	Shoulder Miles	$13.73
Clipping Shoulders	Shoulder Miles	$205.50
Reconditioning Unpaved Shoulders	Shoulder Miles	$885.60
Clean and Reshape Ditches	Linear Feet of Ditch	$0.61
Motor Patrol Ditching	Ditch Miles	$377.80

tionnaire is laid out in a tabular/matrix type format. There are three categories of condition for each activity which generally conform to the overall descriptors of poor, fair and good although there is some variation in definition depending on the particular activity in question.

The condition input is further sub-divided into cells consisting of three components. These roughly correspond to minimum, average and maximum. All refer to service life estimates currently given by the unit foremen with available manpower, equipment, materials, and so on. A decision was made to look for minimum and maximum values as well as an average value because it was felt that the average value alone could be misleading in terms of the overall range of performance.

Minimum service life values are not intended to be the single worst case in the experience of the unit foreman but rather an indication of what is considered to be a realistic, poor service life value. Similarly, the maximum value is considered to reflect a generally high service life value as opposed to the longest service life history known to the unit foreman.

In a survey such as this, a decision must be made as to the detail and accuracy of results which can be reasonably expected. A necessary tradeoff must be made between amount of data acquired and the consequent error induced in the respondent's estimates through boredom, desire to complete the survey rapidly, and so on. It is believed that the questionnaire used struck a reasonable compromise in this regard.

3.6 Description of Survey Methodology

Implementation of the survey questionnaire involved consideration of where and how many interviews should be conducted. The State is divided into six administrative districts, each of which is comprised of a number of subdistricts. To interview personnel in all 37 of the subdistricts would have been extremely costly, time-consuming and difficult to arrange.

A decision was made to choose subdistricts to take part in the survey by a process of stratified random sampling. In using this technique two subdistricts were selected at random from each district. When the individual strata contain relatively homogenous elements, the variability for a given stratified random sample will be less than in a simple random sample of the same size, i.e. the stratified sample is more efficient [Neter et al. 1988].

Homogenity for each stratum is considered reasonable in that each subdistrict within a district is subject to much the same climatic and topographic conditions and usually has the same source of maintenance materials and equipment. In addition, meetings of all subdistrict supervisors and general foremen occur on a regular basis and consequently repair strategies and methods would be expected to be fairly consistent.

Discernible patterns in the service life estimates for a number of the activities were anticipated due to the large difference in climate and topography between Northern and Southern Indiana. The use of stratified sampling made it possible to examine and identify such patterns as well as estimate the overall population characteristics. From the point of view of feasibility, the fact that two subdistricts from each district were chosen meant that it was generally possible to interview in two subdistricts each day, thus reducing time and travel costs. The entire survey was carried out in a two-week period at the end of June, 1985.

Generally, at each subdistrict office a meeting was held with the general foreman and two unit foremen. Throughout the state a total of 33 maintenance personnel were interviewed. A personal interview approach was utilized to obtain data as opposed to mailed questionnaire to both reduce ambiguous responses and increase the response rate. It should be noted that the field personnel were extremely co-operative and knowledgeable in every instance. Care was taken to avoid asking leading questions and generally very little prompting was required to get numerical estimates with accompanying justification for the values given.

3.7 Analysis of Results

The results of the service life estimation survey are summarized in Tables 3.2 through 3.4 for pavement related activities and Tables 3.5 and 3.6 for shoulder and drainage related activities. A discussion of individual activities is presented below.

3.7.1 Shallow Patching

There are four sub-divisions within this activity corresponding to the different possible materials used in patching. They are hot mix, cold mix, winter or fibre mix and fibre mix heated in a Portapatcher. Each of these materials was treated as a separate subject of interest with service life and accomplishments being recorded for all four types.

Table 3.2
Service Life and Daily Accomplishments
Roadway Condition; POOR

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=2.8 APD =7.7	S.L.=8.5 APD =7.2	S.L.=12.5 APD =6.7
Shallow Patching Cold Mix	S.L.=0.2 APD =8.9	S.L.=0.3 APD =7.1	S.L.=0.7 APD =5.5
Shallow Patching Winter Mix	S.L.=1.0 APD =8.0	S.L.=3.7 APD =6.7	S.L.=3.8 APD =5.4
Shallow Patching Portapatcher	S.L.=1.3 APD =6.5	S.L.=5.3 APD =5.4	S.L.=7.3 APD =4.3
Premix Levelling (Wedging)	S.L.=17.1 APD =151	S.L.=24.9 APD =120	S.L.=30.9 APD =88
Seal Coat Chip Seal	S.L.=24.6 APD =5.0	S.L.=26.4 APD =6.3	S.L.=32.4 APD =7.8
Seal Coat Sand Seal	S.L.=0 APD =0	S.L.=0 APD =0	S.L.=0 APD =0
Sealing Long. Cracks & Joints	S.L.=17.7 APD =5.9	S.L.=22.5 APD =6.3	S.L.=26.2 APD =6.7
Sealing Cracks	S.L.=8.2 APD =1.2	S.L.=13.1 APD =1.5	S.L.=17.4 APD =1.8

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 3.1)

Table 3.3
Service Life and Daily Accomplishments
Roadway Condition; FAIR

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=9.9 APD =4.4	S.L.=17.2 APD =4.2	S.L.=23.7 APD =4.2
Shallow Patching Cold Mix	S.L.=0.2 APD =4.7	S.L.=0.6 APD =3.9	S.L.=1.0 APD =3.3
Shallow Patching Winter Mix	S.L.=3.1 APD =4.6	S.L.=5.0 APD =4.0	S.L.=5.9 APD =3.3
Shallow Patching Portapatcher	S.L.=6.6 APD =4.8	S.L.=8.9 APD =3.8	S.L.=11.6 APD =2.8
Premix Levelling (Wedging)	S.L.=29.1 APD =105	S.L.=34.3 APD =89	S.L.=41.1 APD =69
Seal Coat Chip Seal	S.L.=31.8 APD =5.5	S.L.=37.4 APD =6.8	S.L.=45.6 APD =8.5
Seal Coat Sand Seal	S.L.=14.4 APD =6.2	S.L.=15.6 APD =8.2	S.L.=20.4 APD =10.8
Sealing Long. Cracks & Joints	S.L.=25.6 APD =8.0	S.L.=29.5 APD =8.4	S.L.=33.3 APD =9.1
Sealing Cracks	S.L.=13.6 APD =2.8	S.L.=19.9 APD =3.0	S.L.=24.5 APD =3.1

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 3.1)

Table 3.4
Service Life and Daily Accomplishments
Roadway Condition; GOOD

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=36.0 APD =3.0	S.L.=53.4 APD =2.8	S.L.=54.2 APD =2.5
Shallow Patching Cold Mix	S.L.=0.3 APD =3.2	S.L.=0.7 APD =2.6	S.L.=1.2 APD =2.2
Shallow Patching Winter Mix	S.L.=3.3 APD =3.3	S.L.=5.8 APD =2.7	S.L.=6.8 APD =2.4
Shallow Patching Portapatcher	S.L.=14.7 APD =3.1	S.L.=23.1 APD =2.7	S.L.=24.1 APD =2.3
Premix Levelling (Wedging)	S.L.=36.0 APD =65.7	S.L.=47.1 APD =55	S.L.=49.7 APD =48
Seal Coat Chip Seal	S.L.=37.8 APD =6.2	S.L.=48.0 APD =7.5	S.L.=55.2 APD =9.1
Seal Coat Sand Seal	S.L.=19.2 APD =6.2	S.L.=21.6 APD =8.2	S.L.=28.8 APD =10.8
Sealing Long. Cracks & Joints	S.L.=31.6 APD =9.8	S.L.=34.9 APD =10.2	S.L.=38.2 APD =10.9
Sealing Cracks	S.L.=20.7 APD =4.1	S.L.=26.5 APD =4.5	S.L.=31.6 APD =4.9

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 3.1)

Table 3.5
Service Life and Daily Accomplishments
Shoulder/Ditch Condition; POOR

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Full Width Shoulder Seal	S.L.=0 APD =0	S.L.=0 APD =0	S.L.=0 APD =0
Spot Repair Of Unpaved Shoulders	S.L.=3.0 APD =51.4	S.L.=4.7 APD =46.4	S.L.=6.2 APD =41.8
Blading Shoulders	S.L.=2.7 APD =10.2	S.L.=4.4 APD =10.6	S.L.=4.8 APD =11.3
Clipping Shoulders	S.L.=33.3 APD =1.5	S.L.=37.1 APD =1.9	S.L.=42.5 APD =2.3
Recondition Shoulders	S.L.=36.0 APD =3.3	S.L.=38.0 APD =3.4	S.L.=38.0 APD =3.4
Clean and Reshape Ditches	S.L.=28.6 APD =546	S.L.=30.8 APD =696	S.L.=34.4 APD =846
Motor Patrol Ditching	S.L.=28.9 APD =1.0	S.L.=29.8 APD =1.3	S.L.=30.5 APD =1.7

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 3.1)

Table 3.6
Service Life and Daily Accomplishments
Shoulder/Ditch Condition; FAIR

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Full Width Shoulder Seal	S.L.=24.0 APD =65.0	S.L.=30.6 APD =73.5	S.L.=37.2 APD =83.5
Spot Repair Of Unpaved Shoulders	S.L.=6.3 APD =32.7	S.L.=8.3 APD =30.5	S.L.=10.9 APD =27.7
Blading Shoulders	S.L.=5.7 APD =12.4	S.L.=7.2 APD =13.2	S.L.=7.8 APD =14.4
Clipping Shoulders	S.L.=39.3 APD =2.8	S.L.=43.1 APD =3.2	S.L.=47.5 APD =3.7
Recondition Shoulders	S.L.=46.0 APD =4.5	S.L.=46.0 APD =4.5	S.L.=46.0 APD =4.5
Clean and Reshape Ditches	S.L.=42.7 APD =1082	S.L.=45.3 APD =1255	S.L.=48.0 APD =1436
Motor Patrol Ditching	S.L.=36.0 APD =1.7	S.L.=38.3 APD =2.0	S.L.=42.8 APD =2.5

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 3.1)

The effective service life of a patch was taken to be the time elapsed until more work was necessitated at the location where the patch was placed. This approach was taken as it was pointed out by the maintenance personnel that, although the material in the patch itself may remain in place for a considerable length of time, cracking and break-up at the edges of the patch may require early repair with additional patching. Patching accomplishments per day (a.p.d.) vary in an expected way, decreasing as the roadway condition improves and decreasing as the service life increases. This pattern is consistent for all four types of shallow patching.

Patching a.p.d. decreases with improving roadway condition simply because there is less severe distress at any one location and distressed locations are further apart on a road in good condition as opposed to a road in poor condition. There are two reasons why the service life and a.p.d. vary inversely for a given road condition. Firstly, a location which yields a high a.p.d. generally exhibits a large amount of distress. The source of this distress may be poor drainage, heavy traffic volumes etc., and undoubtedly this source will cause failure around the newly- patched surface. Thus there is no cause-and-effect relationship between service life and a.p.d. per se here; both simply reflect the effect of the distress source. Secondly, if more care and thoroughness is practised in placing the patch mix, the daily accomplishment will go down but this care will be reflected in an increased effective service life. These two factors combined, explain the difference in a.p.d. between minimum, average and maximum for any given roadway condition.

<u>Hot Mix Patch</u>: Hot mix patching has consistently the highest estimate of effective service life. There are a number of reasons why this is so.

Firstly, the material is usually of superior quality and therefore is easier to place and compact than the other three types of patching material. Also, hot mix is generally only available between April and October as plant production is limited to these months. Consequently, the climatic and road-base conditions are usually favorable for placement of the patch which naturally leads to greater longevity.

It was generally considered that a hot mix patch placed on a good road should function effectively throughout the surface life of the road. This roadlife, represented by the resurfacing cycle, was taken to be 60 months for the purposes of calculation.

Cold Mix Patch: Cold mix patching material was considered by all personnel surveyed to be the poorest performer of the four types of patch material. The results in Table 3.2 indicates that most service life estimates were given in days rather than months. The primary factor for this low service life is that the conditions under which the cold mix is placed make it difficult for the patch to hold. Cold mix is generally used in winter when no hot mix is available and consequently is placed in poor weather conditions that often includes a wet road-base.

The combination of water and traffic loads can lead to early patch failure and if snow plows are being used the patches can be removed over night. Additionally, cold patch material as used is not adequate, being prone to shoving.

Winter Mix Patch: Winter mix patching material is essentially a cold mix with fibres added to produce greater stability and resistance to shoving and is used under the same conditions as cold mix. Almost all personnel interviewed believed that the winter patch material was significantly better than cold mix in its ability to stay in position and this opinion is reflected in the service life estimates obtained.

Winter Mix Patch Using Portapatcher: A Portapatcher provides the facility to heat patching material. Heating patching material improves its workability for placement and compaction. Patches made with material heated in a Portapatcher were estimated to have a longer service life than patches made with cold mix. Two of the four northern subdistricts of IDOH expressed the opinion that the performance of winter mix heated in a portapatcher was as good as patches made with hot mix.

In locations where flexibility and elasticity are important, e.g. on bridge decks, the heated fibre mix patch appeared to perform better than a hot mix patch. One drawback to using the portapatcher is that a larger crewsize is required.

3.7.2 Premix Leveling

Premix leveling or wedging involves placement of bituminous mixtures to correct depressions and rutting. Several subdistricts indicated that this activity is now primarily carried out by contract rather than by IDOH personnel. However, most subdistricts had sufficient experience to estimate service life and daily accomplishments.

The estimates follow an expected pattern for similar reasons to those mentioned in the discussion on patching. The primary reason given for early failure of wedging was the roadway surface not being tacked properly prior to application of the bituminous mixture.

In the case of premix leveling, a distinction was frequently made between the service life when material was placed using a grader as opposed to using a paving machine. Also, the opinion prevailed that the paver produces a more uniform, better-riding and longer-lasting surface.

3.7.3 Full Width Shoulder Seal

Shoulder sealing specifically involves seal coating of an existing paved shoulder. When the paved shoulder condition is poor, the general consensus of opinion was that a shoulder seal was not an appropriate treatment as no additional structural support is provided. The appropriate treatment of a paved shoulder in poor condition was deemed to be rebuilding.

Survey results indicate that the service life and a.p.d. vary directly in shoulder sealing. The explanation for this relation is that the unit of accomplishment is foot-miles. Thus, a shoulder at the lower end of the fair shoulder range will require more work (and hence less miles covered) and yet will break up faster than a shoulder at the upper end of the range. Consequently, as in previous relations, the source of the deficiency establishes the relationship between accomplishments and service life. The major factor that influences the a.p.d. obtained is the width of the shoulder to be sealed as the unit of accomplishment is foot-miles. Obviously a much higher a.p.d. will be obtainable on a 10 foot shoulder than on a 3 foot one.

3.7.4 Seal Coating

There are two sub-divisions which fall under the general headings of seal coating. These are chip seal treatments and sand seal treatments. As the name implies, they differ primarily in the aggregate coating used in the seal coating operation.

Chip Seal: Chip Sealing consists of coating full width roadway sections with hot bituminous material and covering with #11 or #12 stone. One factor that can influence the service life obtained is the type of stone used in the surfacing operation; limestone chips were believed to be preferable to pea gravel.

The service life and a.p.d. pattern of seal coating is similar to that seen in the discussion of Full Width Shoulder Seal. The major factor governing the a.p.d. was the haulage distance for bituminous material and aggregate rather than the roadway surface itself.

Sand Seal: The cover aggregate in sand seal is, as implied, sand rather than stone. From the survey a total of 5 subdistricts believed they had sufficient experience to estimate sand seal values, although a number of the other subdistricts have begun to utilize this activity in the last 2 to 3 years. An opinion in general was that the sand seal was not effective on a poor roadway condition. On such a surface, the sand seal would not prevent further deterioration or correct cracking for any appreciable length of time. On roads in fair or good condition, the consensus of opinion was that a sand seal is effective in sealing cracks and will contribute substantially to the longevity of the road life. One subdistrict reported that the sand seal was effective when placed over a "fatted" surface, i.e. a pavement surface with flushed asphalt whereas the chip seal was better suited to dried-out pavements. The same trends in service life and a.p.d. observed in the shoulder seal activity are again evident here, namely a direct relationship between daily accomplishment and service life.

3.7.5 Sealing Longitudinal Cracks and Joints

Sealing longitudinal cracks and joints is accomplished by cleaning the cracks and joints and then filling them with liquid bituminous sealant. The usual method of crack and joint cleaning is to use a stream of compressed air to blow out the accumulated debris. An alternative method of cleaning the cracks and joints is to use a crack router attached to a tractor but this operation is not considered here.

An examination of Tables 3.2, 3.3 and 3.4 shows that there is not a large difference between maximum and minimum service life estimates of crack and joint sealing for any given roadway condition. However, the a.p.d. estimates for sealing do vary substantially as the roadway condition changes. This is to be expected as the accomplishment unit is in linear miles and less sealing is required on a road in good condition compared to a road in poor condition.

3.7.6 Sealing Cracks

The purpose of this activity is to clean and seal cracks in both bituminous and concrete roadways. An examination of the values obtained shows a marked difference between maximum and minimum service life for each roadway condition in contrast with the previous activity.

A definite relation exists between a.p.d. and the roadway condition which is to be expected as a workman will cover fewer lane miles as the amount of cracking increases.

3.7.7 Spot Repair of Unpaved Shoulders

Spot repair involves the repair of small areas of unpaved shoulders with addition of aggregate and reshaping. Little significant difference exists overall in service life estimates given by various subdistricts except for the minimum values of service life in the southern region of the state. An explanation of this lower value may be explained by the topography in Southern Indiana which is hilly.

A strong influence on the service life of unpaved shoulder spot repair was believed to be rainfall in combination with high gradients. These factors, reinforced by traffic encroachment onto the shoulder at curves, provided the lowest estimate of service life. Service life and a.p.d. vary inversely in this activity because the accomplishment unit is tons of aggregate and the worst locations require more aggregate.

3.7.8 Blading Shoulders

Blading shoulders involves the redistribution of material and reshaping of unpaved shoulders. As the daily accomplishment unit is in shoulder miles, there is a direct relationship between service life and a.p.d. with the poorest locations yielding the lowest service life and lowest a.p.d. The preferred equipment for this activity was a dump truck with scraper or underblade attached.

3.7.9 Clipping Shoulders

In shoulder clipping excess growth is removed from unpaved shoulders to restore adequate shoulder drainage. For a given shoulder condition, the southern subdistricts' estimates of service life are significantly under the overall average while the northern subdistricts' estimates of service life are significantly above the overall average. The milder climate in Southern Indiana which encourages vegetation growth may explain the difference.

A number of subdistricts distinguished between the a.p.d. using a front-end loader and what was variously described as a dirt loader, belt loader or travel loader. The latter type of loader significantly increased the a.p.d. Factors which influence the a.p.d. include the amount of 500 to be cut and loaded and the haulage distance to a disposal site.

3.7.10 Recondition Unpaved Shoulders

Unpaved shoulder reconditioning involves addition of aggregate and reshaping of unpaved shoulders for continuous sections of shoulder as opposed to spot repair which is carried out at isolated spots. None of the four southern subdistricts sampled had sufficient experience to estimate service life or a.p.d. However, in comparing service life and a.p.d., the central region was substantially lower than the northern region. A possible explanation to this difference is that the northern subdistricts tend to seal or oil the rebuilt shoulder in the same year that it is rebuilt which should lead to a longer service life.

An examination of the results shows that in general there was little variation in the service life or a.p.d. for a given shoulder condition. The main variable influencing accomplishment was generally felt to be the aggregate haulage distance.

3.7.11 Clean And Reshape Ditches

Cleaning and reshaping ditches comprises the excavation of dirt and debris from roadside ditches using a gradall which restores the ditch efficiency for adequate drainage. Geography plays a major role in the estimates of both service life and a.p.d. The central and northern subdistricts did not vary excessively in their estimates but the southern subdistricts were much lower in estimates of both service life and a.p.d. In fact, even within the southern region the subdistricts furthest south were significantly lower in their estimation.

The above results indicate topography and soil conditions play an important role in the rapidity and extent of ditch blockage; in areas with steep hills, heavy rainfall and poor soil conditions, the effective service life is low. For the same reason, the a.p.d., measured in linear feet of ditch, is also low in such areas. Another factor that influences a.p.d. obtained is the distance necessary to haul material removed from the ditch for disposal. An interesting point that was often repeated in discussion with the maintenance personnel was that the daily production can be very misleading. In a ditch that is badly clogged with debris, it may be necessary to make two or three passes with the excavator to restore an adequate cross-section. However, this extra work does not show up in the daily record. This is the basic reason why an examination of Tables 3.4 and 3.5 shows such a large variation in a.p.d.

for ditch condition.

3.7.12 <u>Motor Patrol Ditching</u>

Motor patrol ditching, as the name implies, involves cleaning of ditches using a motor patrol rather than a gradall. There was much discussion as to the merits and de-merits of one versus the other. In one southern subdistrict, motor patrol ditching is not carried out at all because of the difficultly of operating such equipment on the hilly terrain with heavily blocked ditches. Other limitations on using motor patrols for cleaning ditches include difficulty of operation in wet weather and in areas of claying soils with steep ditches. Conditions favorable to motor patrol ditching include operation in dry weather and in areas with sandy soil and on flat, wide ditches. The consensus of opinion was also that the use of the gradall in cleaning and reshaping produces a better, more rounded and longer-lasting ditch cross-section than the motor patrol. A comparison of the a.p.d. shows that motor patrol ditching, measured in ditch miles, has a higher production rate than gradall ditching which is measured in feet. The principal explanation for this is that motor patrol ditching is limited to wide areas where few obstructions are present. The main factor that governs the a.p.d. attained is the distance required to haul the debris from the ditch to a designated dump site.

3.8 Chapter Conclusions

The overall goal of this research is to further evolve a functioning system for Routine Maintenance Management in Indiana. Results reported in this report provide a first, meaningful estimate of service life for a major portion of the routine maintenance activities engaged in by the IDOH. Drawing on records and prior research, both a.p.d. and costs for the various activities are tabulated. With maintenance activity service life, a.p.d. and cost, the basic information is available to establish the framework of a maintenance management system that will address optimal allocation of maintenance resources. Specifically, the data reported here will give initial estimates for parameters that are necessary to make an efficient management system possible. Periodic study needs to be conducted in this area that will, over a period of time, provide more definitive functional relations for maintenance activity service life. In the meantime, the information generated in the survey can furnish a reasonable set of input data for the optimization of maintenance decisions.

CHAPTER 4

EFFECT OF ROUTINE MAINTENANCE ON PAVEMENT ROUGHNESS

4.1 Introduction

In the present study an effort was made to study the effect of various routine maintenance expenditure levels on pavement condition in terms of surface roughness. Pavement roughness was used as a direct quantitative measure of pavement surface condition instead of Present Serviceability Index (PSI). This was based on the results of several studies [Yoder and Milhous 1964; Paterson 1982] which concluded that in many instances the use of roughness measurements alone is sufficient for predicting the serviceability index.

To accomplish the objective, a data base was developed for pavement routine maintenance, roughness number and pavement characteristics. The appropriate data were collected based on construction contract sections. A contract section is that portion of a highway pavement that is contracted out to one contractor for a specific activity such as resurfacing. The pavement characteristics within a contract section are generally uniform. In contrast, a highway section may stretch from county line to county line and may include a series of different contract sections with different pavement characteristics.

4.2 Development of Data Base

Two regions, two highway classes and three pavement types were considered. The two highway classes include Interstate and Other State Highways (OSH). The three pavement types are flexible pavements, rigid pavements, and rigid pavements with bituminous overlay. The data base was developed from three sources of information: routine maintenance records, roughness measurement records, and road life records.

4.2.1 Design of Experiment

The IDOH has six districts. Five districts have six subdistricts, and one district has seven subdistricts for a total of thirty-seven subdistricts. In each subdistrict, there are three to four units which actually perform the field maintenance work. In this phase of the study, the subdistrict was considered the appropriate management unit. Information had to be extracted from several thousands of Crew Day Cards recorded by subdistricts. Ten subdistricts were selected for the analysis based on the following considerations:

1. To include sufficient sections from Interstate highways.
2. To represent the administrative system so that at least one subdistrict was selected from each district.
3. To represent the entire state geographically.
4. To cover both climatic regions in the State (North and South)
5. To avoid subdistricts which have dense highway network such as the Indianapolis Subdistrict.

Finally, six subdistricts were selected from the South region and four subdistricts from the North region. Figure 4.1 shows the locations of the selected subdistricts.

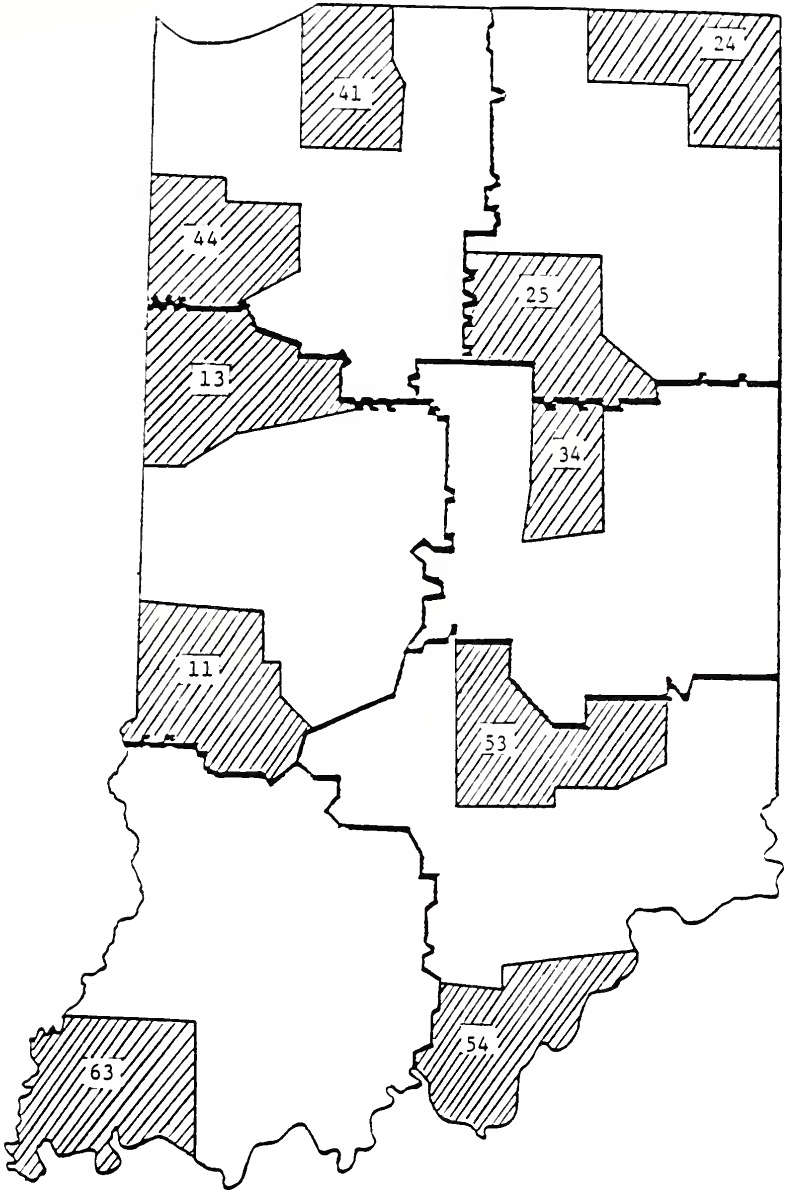


Figure 4.1 Locations of Subdistricts Included in the Study.

4.2.2 Selection of Contract Sections

The two most recent roughness measurements (1984, 1985) in counts/mile were used. Only those contract sections that did not receive any major maintenance or resurfacing between two roughness measurements were selected. The data on roughness measurement on each contract section for 1984 and 1985 along with other information such as contract number, contract length, surface type, landmarks, number of lanes in each direction and date of construction or last major maintenance were recorded in a newly created "roughness file." A total of 550 contract sections were selected including 126 sections in Interstate and the remaining sections in Other State Highways (OSH).

4.2.3 Routine Maintenance Quantities

The amount of routine maintenance applied between two dates of roughness measurements were determined from Crew Day Cards obtained from each subdistrict considered. A total of about ten thousand Crew Day Cards were analyzed. Cards with missing information such as highway number, county number or location of the work were excluded.

Pavement routine maintenance activities considered in this paper were combined into two groups: (i) patching which consists of shallow patching (Activity 201) and deep patching (Activity 202); (ii) joint and crack sealing which consists of sealing longitudinal cracks and joints (Activity 206) and sealing cracks (Activity 207).

The relevant information extracted from the Crew Day Cards included activity type, date of work, location of work, and the number of production units accomplished. The information was recorded in a newly created "routine maintenance file".

4.2.4 Routine Maintenance Amount by Contract Sections

Both roughness and routine maintenance records have generally the same inventory data which include the following information common to both files:

1. Highway class and number

2. County number

3. Subdistrict number

4. District number

Using this information, it was possible to determine the amount of routine maintenance work done on a contract section. Two location demarcation scales were established for each highway in each subdistrict. The first scale was called the "Contract Section Scale". It used the identified mile-posts and determined contract length in lane-miles. The second scale called "land-marks scale" used mile-posts and the distance between two successive land-marks. Land-marks included intersections, bridges, county lines, and rivers.

Having established the two scales, routine maintenance quantity on each card was distributed according to the contract length by activity. In most cases, the location of routine maintenance was recorded between land-marks containing more than one contract section. In such cases, the "land-marks scale" was applied and the routine maintenance work was distributed in proportion to the length of the different contract sections. If the location of routine maintenance work was defined by mile-posts within a contract section, then the quantity of the work was assigned directly to the corresponding contract section. This occurred mainly with Interstate highways because in Indiana only Interstates have mile posts.

Finally, the routine maintenance quantities were summed for each contract section and recorded along with roughness measurement and other information in a single file containing routine maintenance and roughness data. Information on Average Daily Traffic (ADT) and percent of trucks obtained from the Division of Planning of the IDOH was added to the data base.

4.2.5 Routine Maintenance Expenditure

Having determined the quantity of each routine maintenance activity on each contract section, the dollar values of maintenance activities performed on contract sections were obtained by multiplying the quantities by appropriate unit costs developed by Sharaf et al. [1982] and IDOH [1985-86]. The routine maintenance expenditure was calculated in dollars/lane-mile/year. The cost items considered were labor, materials, and the cost of motor fuel consumed by maintenance equipment and vehicles. These costs did not include overhead and equipment depreciation costs. Cutting relief joints (Activity 209), joint and bump burning (Activity 214), and others (Activity 219) were not considered because it was found that very few Crew Day Cards had these activities for the selected subdistricts during the study period.

4.3 Data Analysis

A statistical test was conducted to determine whether the data in north and south regions can be analyzed as one data set or not. The two southernmost subdistricts (numbers 54 and 63) were selected to be tested against the two northernmost subdistricts (numbers 24 and 41) as shown in Figure 4.1. Since sufficient Interstate sections were not available in these subdistricts, only Other State Highways were considered in the analysis. Pavement sections were grouped based on the type of routine maintenance which was applied during the study period. Table 4.1 shows the distribution of pavement contract sections by region and by routine maintenance category for each pavement type. The number of sections that received only sealing or no maintenance was very few and in some cells no observations were available. Therefore, it was decided to consider in the analysis two sets of sections, one set that received only patching and the other that received both patching and sealing.

Analysis of covariance technique was used for data analysis. Pavement age and cumulative Equivalent Single Axle Load (ΣESAL) were considered as quantitative variables and climatic region and routine maintenance category as qualitative variables. Pavement roughness in 1985 was used as dependent variable. As recommended by Anderson and McLean [1974] and in order to develop the covariance models for different pavement types, the normality and homogeneity of variance tests were made on the dependent variables. Having met the normality and homogeneity tests, the following covariance model was adopted.

$$\text{Log}_{10}\ (RN_{85}) = \mu + R + RM + R * RM + Age + \Sigma ESAL + \varepsilon \qquad (4.1)$$

where,

RN_{85} = roughness measurement in 1985 in counts/mile

μ = overall mean

Table 4.1 Distribution of Contract Sections by Climatic Region by Routine Maintenance Category for Each Pavement Type.

Pavement Type	Routine Maintenance Category	Northern Region			Southern Region		
		Subdistricts		Total Data Points	Subdistricts		Total Data Points
		Angola (24)[1]	Laporte (41)[1]		New Albany (54)[1]	Evansville (63)[1]	
Flexible	Patching	10	9	19	11	4	15
	Patching and Jt. & Crack Sealing	5	1	6	4	10	14
	Jt. & Crack Sealing	1	1	2	2	1	3
	None	-	4	4	1	-	1
Rigid	Patching	2	8	10	6	4	10
	Patching and Jt. & Crack Sealing	-	3	3	-	12	12
	Jt. & Crack Sealing	-	-	-	-	8	8
	None	-	1	1	-	-	-
Overlaid	Patching	10	7	17	1	4	5
	Patching and Jt. & Crack Sealing	1	7	8	1	11	12
	Jt. & Crack Sealing	-	5	5	-	-	-
	None	-	-	-	-	-	-

[1] Code Number of subdistrict.

R = climatic region

RM = routine maintenance category

R*RM = interaction between region and routine maintenance

Age = pavement age since construction or last major maintenance in years

ΣESAL = total accumulated ESAL

ε = random error component

Table 4.2 shows the statistical characteristics of covariance analysis for each pavement type. The major findings of this analysis are summarized below.

1. The regional effect was significant in all cases at level of $\alpha < .10$. Based on this major finding, regression models were developed in the next section, and regional effect was considered as a main factor in these models.

2. Routine maintenance category (RM) was found to be not significant with respect to roughness measurements in 1985. This was because there were only two categories of maintenance considered and the measurements were only for one year. However, the interaction between climatic region and routine maintenance category was significant at $\alpha < .25$. This level of α was chosen because the recording of the location of routine maintenance work in most of the Crew Day Cards is not precise. In addition, the initial data analysis was conducted as an overall test. Regression models were used to specify the trend of this interaction. The significance of the interaction between climatic region and routine maintenance

Table 4.2 Statistical Characteristics of Covariance Analysis by Pavement Ty

Variables	Flexible Pavements (54)[1]		Rigid Pavements (35)[1]		Overlaid Pavements (42)[1]	
	F-Value	α-Level	F-Value	α-Level	F-Value	α-Level
Region	3.70	0.060	4.02	0.054	5.66	0.023
RM	0.15	0.702*	0.36	0.551*	0.15	0.701*
Region*RM	1.61	0.211	6.19	0.019	2.48	0.124
Age	19.06	0.000	0.94	0.341*	4.52	0.040
ΣESAL	2.69	0.108	0.07	0.796*	4.48	0.041

[1] Number of observations.

* The variable is not significant at $\alpha < 0.25$

Note: $\mathrm{Log}_{10}(RN_{85})$ was used as the dependent or response variable.

category implies that effects of RM category differed between North and South regions.

3. The effects of pavement age and ΣESAL were significant at $\alpha < .10$, except for rigid pavements. A part of the reason can be that most rigid pavement sections are very old in both regions.

The above conclusions cannot be generalized because the analysis was conducted with only 4 out of 10 subdistricts in the data base.

4.4 Regression Models for Routine Maintenance Expenditure and Regional Effects

Based on the results of the covariance analysis, regression analysis was performed to study the effects of routine maintenance expenditure level and region on pavement roughness. Rate of change in pavement roughness was used as the dependent variable in these models. Pavement sections with both negative and positive changes in roughness were considered in the analysis. Rate of change in pavement roughness was calculated as follows:

$$RRN = \frac{RN_{85} - RN_{84}}{RN_{84}} \tag{4.2}$$

where,

RRN = rate of change in pavement roughness

RN_{84} = roughness measurement in 1984 (counts/mile)

RN_{85} = roughness measurement in 1985 (counts/mile)

In Equation 4.2, (RN_{84}) can be assumed to represent the cumulative effect of past maintenance on pavement condition, while (RN_{85} - RN_{84}) represents the effect of routine maintenance that was applied between the two roughness measurements, assuming all other factors remaining the same during the period.

The analysis included data from all the selected subdistricts in both regions. Only those pavement sections that received Patching (P) or Patching and Joint & Crack Sealing (PS) were analyzed. Five categories of highway class - pavement type were included: Interstate rigid pavement; Interstate overlaid pavement; OSH flexible pavement; OSH rigid pavement; and OSH overlaid pavement. Three criteria were considered in selecting the best model: (i) the general goodness-of-fit represented by the coefficient of multiple determination (R^2); (ii) the general linearity test for the model through the application of the general F test and (iii) the significance of individual coefficients of the model through the t or F tests. These criteria were applied and an attempt was made to have the same model type for the five categories in order to facilitate the consideration of the effects of different factors.

After several trials, the following regression model appeared to satisfy most of the required conditions.

$$RRN = a + b \text{ Log}_{10} (RM) + c (R) + d \text{ Log}_{10} (RM) * (R) \qquad (4.3)$$

where,

RRN = rate of change in pavement roughness

RM = routine maintenance expenditure level (\$/lane-mile/year). This variable takes the symbol (P) for pavement sections that received patching and (PS) for sections that received patching and joint and crack sealing.

R = dummy variable to represent the region in which the pavement section is located: 0 for northern region and 1 for southern region.

a,b,c,d = regression parameters.

A high level of confidence with $\alpha = .05$ was used to test the significance of all regression models. The following models were found significant.

For Interstate rigid pavements:

$$RRN = 1.0 - 0.37 \text{ Log}_{10} (PS) - 0.07 R \qquad (4.4)$$

For Interstate overlaid pavements:

$$RRN = 1.83 - 0.81 \text{ Log}_{10} (PS) + 0.11 R \qquad (4.5)$$

$$RRN = 0.27 - 0.20 \text{ Log}_{10} (P) + 0.26 R \qquad (4.6)$$

For OSH flexible pavements:

$$RRN = 1.5 - 0.49 \text{ Log}_{10} (PS) + 2.19 R - 0.79 \text{ Log}_{10} (PS) * R \qquad (4.7)$$

$$RRN = 1.65 - 0.65 \text{ Log}_{10} (P) - 0.94 R + 0.43 \text{ Log}_{10} (P) * R \qquad (4.8)$$

For OSH overlaid pavements:

$$RRN = 5.44 - 2.04 \text{ Log}_{10} (PS) - 3.8 R + 1.5 \text{ Log}_{10} (PS) * R \qquad (4.9)$$

For OSH rigid pavements:

$$RRN = 0.62 - 0.15 \text{ Log}_{10} (P) - 0.13 R \qquad (4.10)$$

Only Equations 4.7, 4.8 and 4.9 included the interaction term (between routine maintenance expenditure level and region). This is because the routine maintenance expenditure level on OSH had a wider range. For example, the expenditure level of PS on OSH overlaid pavements varies between 100 and 750 $/lane-mile/year, while on Interstate overlaid it varies between 150 and 400 $/lane-mile/year.

A summary of the characteristics of the regression models are given in Tables 4.3 and 4.4, respectively. As shown in these tables, a relatively higher R^2 was obtained for Interstate than OSH models. This may be due to the fact that Interstate highways are mile posted; so, it was easier and more accurate to match routine maintenance locations with roughness measurements. Furthermore, the significance test for the coefficient "b" for the variable RM (routine maintenance expenditure level) showed a high level of confidence. The levels of significance of the region and interaction term were lower than that of the expenditure level. However, these variables could be considered significant at 90% level of confidence as shown in Tables 4.3 and 4.4.

Two observations can be made regarding the insignificant models: (i) number of available sections in the northern region in some cases was very small and (ii) routine maintenance records in southern region were less organized and the location of maintenance on these records was less accurate. Therefore, regression models were developed separately for northern and southern regions. In general, higher R^2 was obtained for all category models in the North. Most of the category models in the southern region were insignificant. However, in all these insignificant models, there was a consistent trend indicating the significance at a higher level of α. The primary reason

Table 4.3 Statistical Characteristics of Patching and Joint and Crack Sealing Models.

Criterion	Interstate Rigid (27)[1]	Interstate Overlaid (10)[1]	OSH Flexible (44)[1]	OSH Rigid (43)[1]	OSH Overlaid (47)[1]
Coefficient of Determination (R^2)	0.30	0.86	0.46	0.07	0.32
Adjusted Coefficient (adj. R^2)	0.27	0.84	0.43	0.05	0.30
Linearity Test					
F-Value	5.14	20.96	11.23	1.48	8.37
α Level	0.014	0.001	0	0.24*	0
Significant Test for Coefficients					
Log_{10} (PS)					
F-Value	9.78	23.06	3.66	2.95	14.82
α Value	0.005	0.002	0.063	0.093	0
Region					
F-Value	1.15	7.71	6.20	0	7.86
α Value	0.29**	0.028	0.017	0.95**	0.007
Log_{10} (PS) * Region					
F-Value	—	—	5.24	—	7.27
α Value	—	—	0.027	—	0.009

[1] Number of observations

* The model is not significant at α > 0.05

** The coefficient is not significant at α > 0.10.

Table 4.4 Statistical Characteristics of Patching Models.

Criterion	Interstate Rigid (29)[1]	Interstate Overlaid (21)[1]	OSH Flexible (78)[1]	OSH Rigid (44)[1]	OSH Overla (47)[1]
Coefficient of Determination (R^2)	0.13	0.61	0.21	0.25	0.09
Adjusted Coefficient (adj. R^2)	0.06	0.59	0.18	0.23	0.07
Linearity Test					
F-Value	1.20	14.07	6.33	6.70	2.07
α Level	0.33*	0	0.001	0.003	0.14
Significant Test for Coefficients					
Log_{10} (P)					
F-Value	1.27	10.88	16.17	6.37	3.71
α Value	0.27**	0.004	0	0.02	0.06
Region					
F-Value	1.20	18.49	3.87	3.94	0.57
α Value	0.28**	0	0.053	0.05	0.45
Log_{10} (P) * Region					
F-Value	1.26	--	3.12	--	--
α Value	0.27**	--	0.082	--	--

[1] Number of observations

* The model is not significant at $\alpha > 0.05$

** The coefficient is not significant at $\alpha > 0.10$.

of these results is the inaccuracy in determining the exact location and amount of maintenance activity.

4.5 Implications of the Models

The effects of routine maintenance expenditure level and region on rate of change in pavement roughness can be best demonstrated through the examination of the graphical presentations in Figures 4.2 to 4.7. The RRN is positive in most cases indicating that roughness increases regardless of maintenance expenditure level. However, the amount of this increase varies. It is clear that in most of the cases, RRN in the northern region is higher than that in southern region, especially at low expenditure level of routine maintenance. This may be because of longer cold period and higher amount of snowfall in the northern region requiring a higher level of maintenance. The validity of this conclusion can be supported by the fact, as reported by Fwa and Sinha [1985], that the non-load-related damage responsibility in the northern region is significantly higher than that in the southern region. In some cases as shown in Figures 4.3 and 4.4, RRN is higher in the southern region. In these cases, it was found that the average pavement age of the analyzed sections in the southern region was more and the average ESAL on these sections was also higher. For example, the average age of OSH flexible pavement sections in the southern region that received patching and sealing was about 12 years while it was 9 years in the northern region. The corresponding average traffic levels were 209,000 and 151,000 accumulated ESAL, respectively.

It is obvious in Figures 4.2 to 4.7, that as routine maintenance expendi-

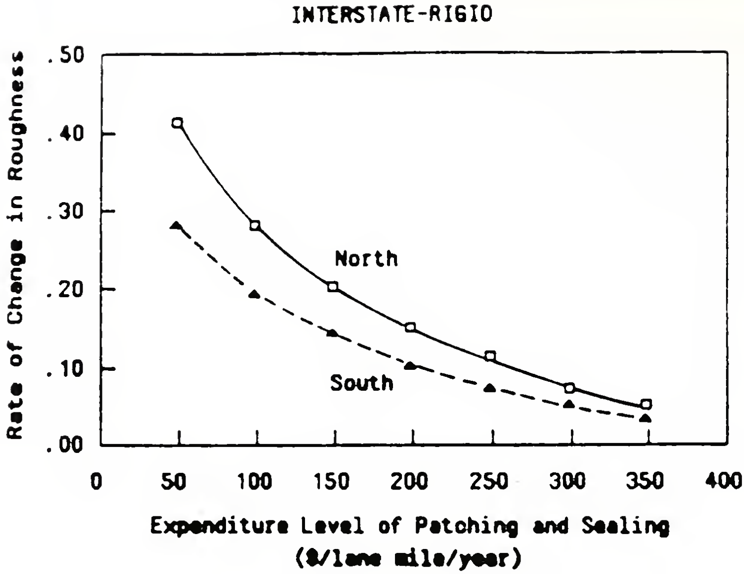


Figure 4.2 Effect of Patching and Joint & Crack Sealing Expenditure Level on Interstate Rigid Pavement Roughness

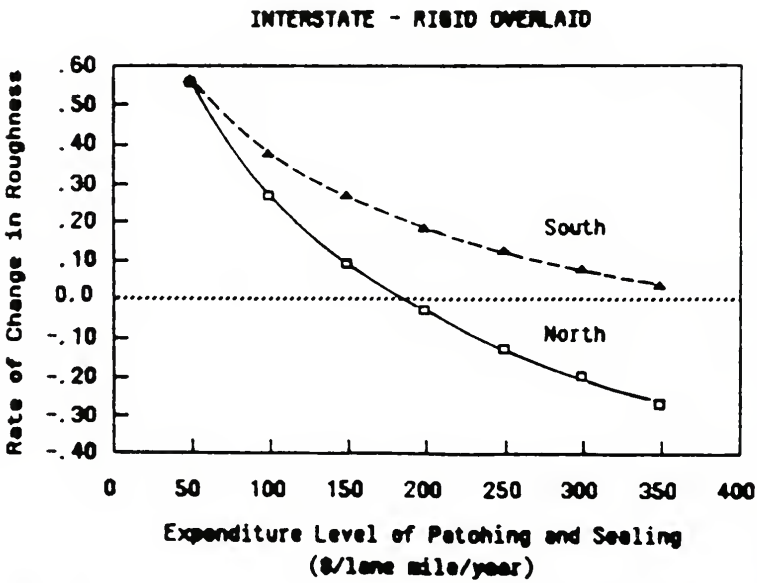


Figure 4.3 Effect of Patching and Joint & Crack Sealing Expenditure Level on Interstate Overlaid Pavement Roughness

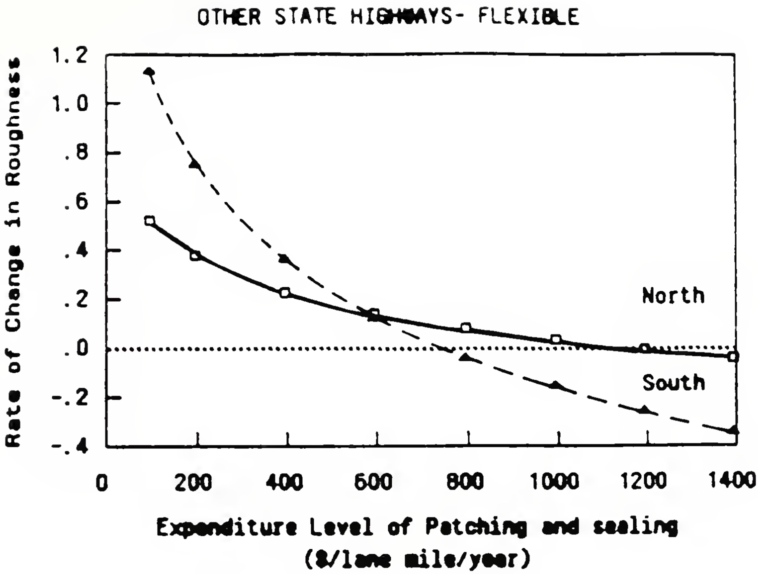


Figure 4.4 Effect of Patching and Joint & Crack Sealing Expenditure Level on OSH Flexible Pavement Roughness

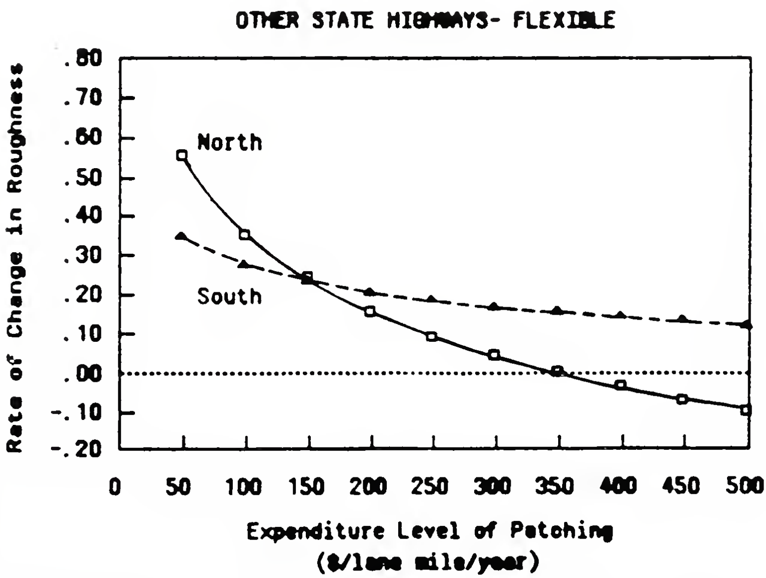


Figure 4.5 Effect of Patching Expenditure Level on OSH Flexible Pavement Roughness.

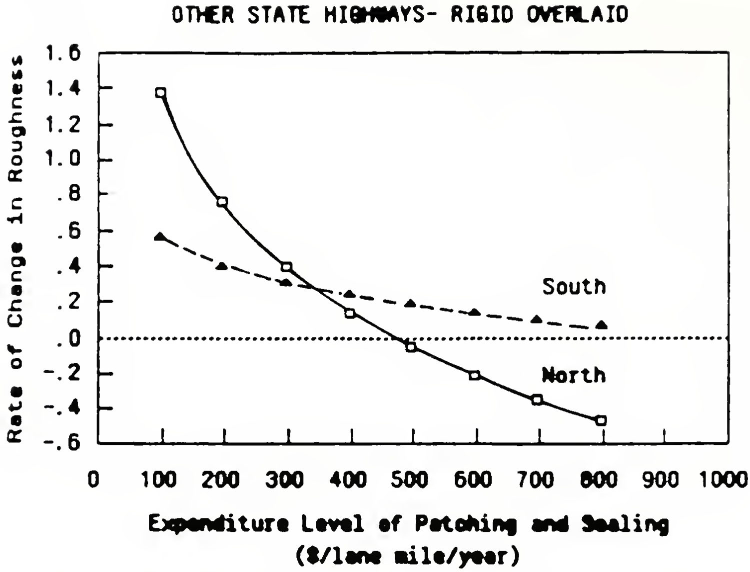


Figure 4.6 Effect of Patching and Joint & Crack Sealing Expenditure Level on OSH Overlaid Pavement Roughness.

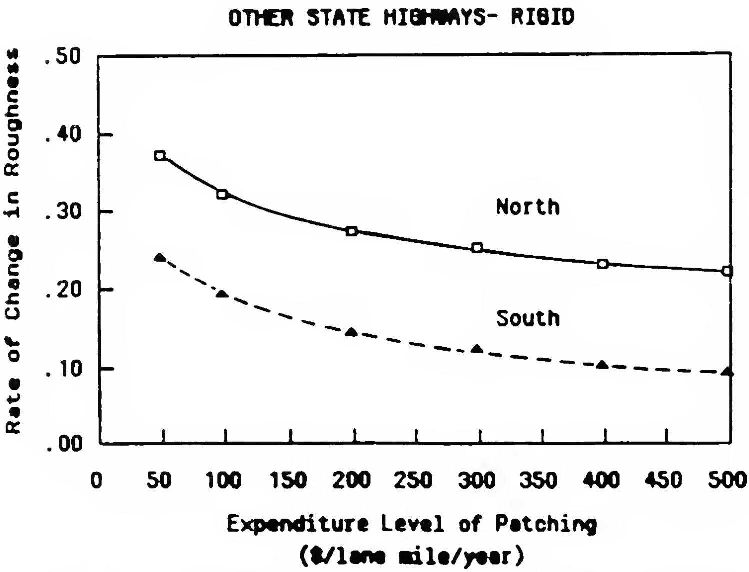


Figure 4.7 Effect of Patching Expenditure Level on OSH Rigid Pavement Roughness.

ture level increases, RRN decreases and the difference in pavement surface deterioration between the two regions becomes less. In some cases, as shown in Figures 4.5 and 4.6, at higher expenditure levels RRN in the northern region is lower than that in southern region. In some cases, in the North, pavement roughness decreased even at lower expenditure levels. These results may possibly reflect the higher maintenance quality and degree of supervision in the subdistricts selected in the northern region.

The discussion of the results in this paper leads to the concept of routine maintenance cost-effectiveness. One measure of maintenance cost-effectiveness can be represented by the reduction in RRN as routine maintenance increased from one expenditure level to another. In general, the reduction in RRN in the northern region was more than that in the southern region if maintenance increased from one expenditure level to another, regardless of pavement type or maintenance activity. Furthermore, this reduction was noticeable or higher when the increase in expenditure took place at lower levels of maintenance.

Figures 4.8 and 4.9 show the effect of expenditure level of two maintenance categories (P and PS) on RRN for Interstate rigid and OSH flexible pavements in the southern region, respectively. It is clear in these figures that regardless of highway class or pavement type, the effectiveness (slope of the curve) of using patching and sealing is higher than that of patching alone. The results show that adding joint and crack sealing to patching increases the maintenance effectiveness in reducing RRN. Hence, joint and crack sealing may have an important role as a preventive maintenance activity in improving pavement surface condition.

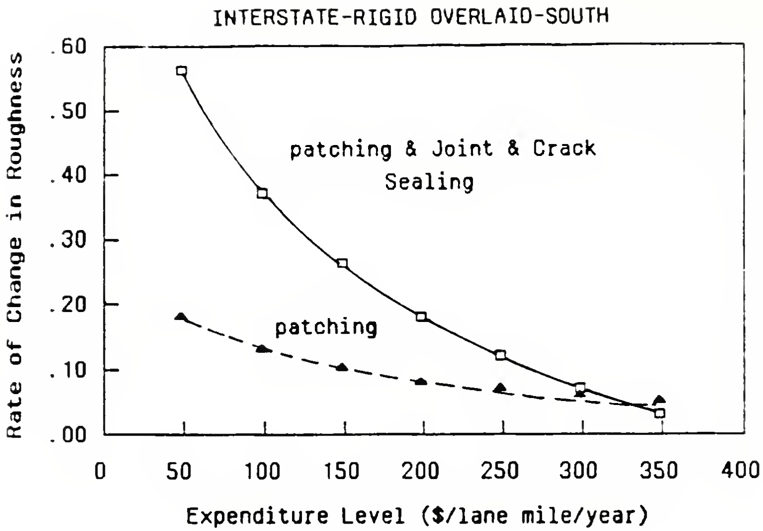


Figure 4.8 Effect of Expenditure Level of Two Maintenance Policies on Interstate Overlaid Pavement Roughness.

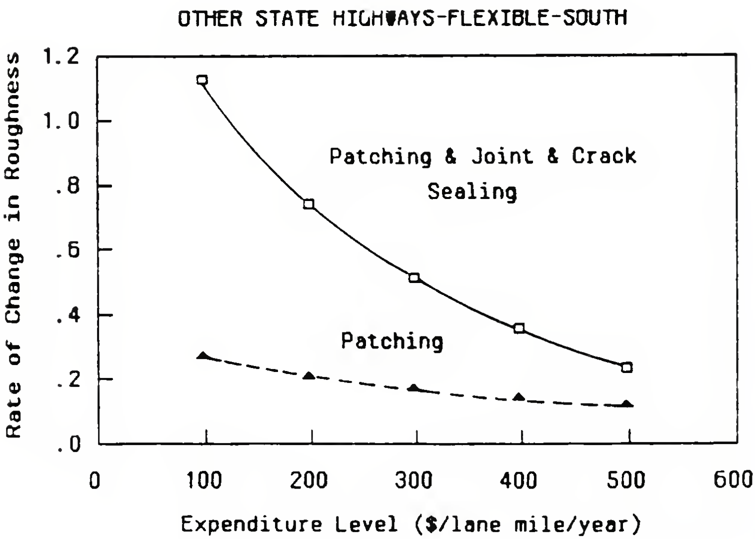


Figure 4.9 Effect of Expenditure Level of Two Maintenance Policies on OSH Flexible Pavement Roughness.

An important application of the results of this analysis is in assessment of the effect of climatic region, routine maintenance expenditure level and their interaction on pavement performance in terms of surface roughness. The results can be used to help the management at the central office monitor the surface condition of the highway network within a subdistrict on a periodic basis. In addition, knowing the surface roughness of pavement sections, the models can be used by maintenance managers to determine the required increase in maintenance expenditure level in order to achieve a specified level of improvement in overall pavement condition. It should be noted, however, that these models do not conclusively describe the relationship between rate of change in roughness and routine maintenance expenditure level since the statistical significance was not always high.

Since most of the regression models in this study have low R^2, it is recommended to apply these models for typical ranges of maintenance expenditure levels. To improve, it is necessary to introduce other factors such as pavement age and traffic level as well as to obtain maintenance expenditure data on a wider range.

4.6 Chapter Conclusions

The main objective of this part of the research was to study the effect of routine maintenance expenditure level on pavement roughness. An integrated data base for pavement routine maintenance and pavement characteristics for the state highway system in Indiana was compiled. Contract section instead of countywide highway section was used as a pavement section unit to develop this data base. As a result of covariance analysis it was found that the effect climatic of region was significant. Therefore, regression models for the effect of routine maintenance expenditure level on rate of change in pavement roughness were developed and the region was considered a main factor in these models. The effect of expenditure level was found significant in most of the developed models.

Based on these models, it was concluded that the rate of change in pavement roughness was more in the northern region especially at low expenditure levels. The results reflect not only the possible effect of maintenance quality but also the importance of organizing and classifying the maintenance records as noticed in the northern region. Furthermore, it was found that the sections receiving patching and sealing had higher cost-effectiveness than the sections receiving patching alone. However, because the data were not obtained through controlled experiments and sample sizes were limited, the results cannot be considered conclusive.

CHAPTER 5

THE CONFIGURATION OF A PAVEMENT ROUTINE MAINTENANCE DATA BASE SYSTEM

5.1 Introduction

Like in many other states, routine maintenance program in Indiana is not effectively coordinated with major activity programs. This lack of coordination stems from the fact that the philosophy behind the development of major activity programs is different from that of routine maintenance programs.

Major activity programs identify highway sections which are at or near a prescribed structural failure level and then allocate resources to upgrade these sections within the available funds. On the other hand, routine maintenance programs consider only the apparent condition of a highway element (pavement surface condition of a highway) and tries to keep the serviceability as high as possible, regardless of the structural adequacy of the highway element.

Although the criteria for the development of major activity programs may differ from those of the routine maintenance programs, both programs have a common goal of preserving the condition of the highway system. An effective coordination between the two programs may result in considerable savings. For instance, sometimes expensive routine maintenance activities, such as seal coating, get applied on sections that have been scheduled to receive resurfacing within a few months [Sharaf and Sinha 1984; Sinha et al. 1984]. Such a situation arises in the absence of a coordination. An effective exchange of information between two programs is thus essential. Figure 5.1 is a schematic

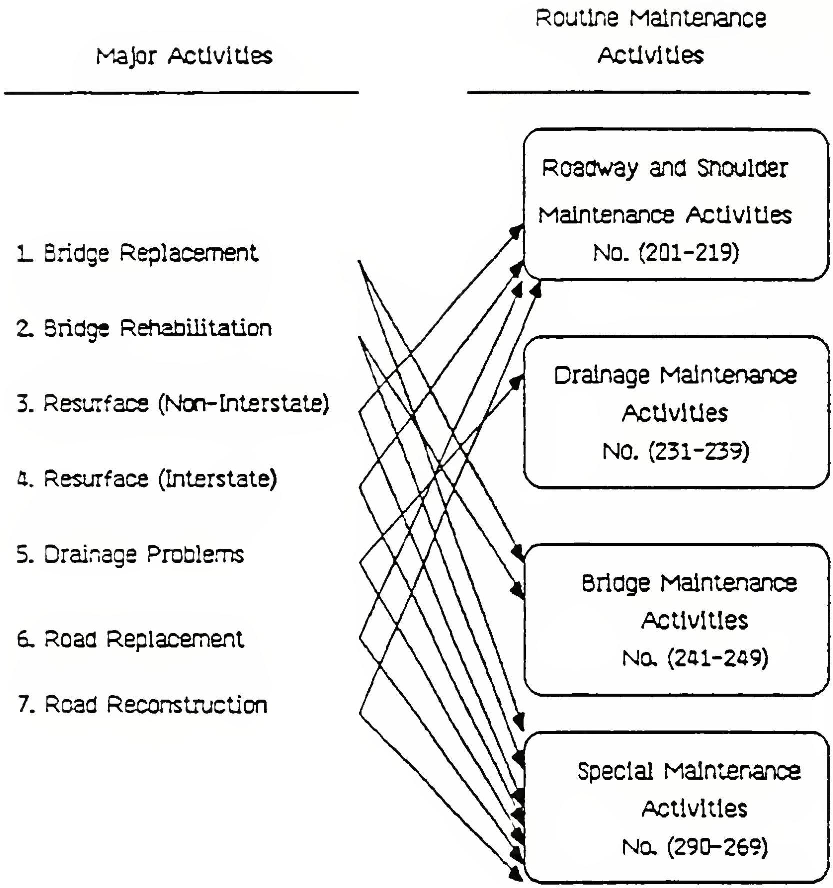


Figure 5.1 Routine Maintenance Activities as Affected by Major Activities.

presentation showing an example of how information on seven major activities can relate to routine maintenance activities. In Table 2.1 is presented a list of routine maintenance activities included in the roadway and shoulder group.

The purpose of this phase of the present research effort was to develop a computerized information system which can transfer the available information on highway elements' current condition and programmed improvement activities to different levels of routine maintenance mangement (central office, district and subdistrict). It is believed that the availability of such information can result in substantial savings in maintenance expenditure and in the development of an effective maintenance program.

A Routine Maintenance Data Base System (RMDBS) is a procedure for collecting, storing, processing, and retrieving the information required in a maintenance management system. It represents the basis for a maintenance management system since all pavement decisions must be made according to a common, integrated source of information derived from reliable, good quality data.

5.2 Development of a Microcomputer Database

When developing the proposed data base, the following points were taken into consideration.

1. Use currently available data.

2. Structure the data base to permit future modifications and improve-

ments.

3. Provide a data base that can provide the management with timely access to the routine maintenance and capital programs information base at a reasonable cost.

4. Simplify the use, maintenance, and updating of the data base.

5.2.1 <u>Work Plan</u>

The general approach followed to develop the data base is summarized as follows:

1. Review of the existing maintenance computer files.

2. Transformation of the available highway information sources, such as highway inventory, roughness and skid resistance files, to a form suitable for use in the current organizational structure. For example, routine maintenance data are currently recorded by highway section in Indiana. A highway section refers to the stretch of a highway within the boundaries of a county. However, in order to be compatible with the other information, the records had to be reorganized so that they represent subdistrict boundaries.

3. Development of a computer file for the future highway improvement programs.

4. Development of a computer program to prepare several information reports. These reports would serve the purpose of informing various management units of actions taken by other units. For example,

subdistricts would be able to identify sections with high roughness values and sections that are scheduled for future improvement activities in a specific location.

5.2.2 Data Base Elements

With the growth of available data and the increasing power of modern computers, managers are practically flooded with information. The problem is to discriminate between all the data available and the data which the manager needs and can use. In the proposed integrated data base, only the data that can assist the managers to identify maintenance needs are included. The data base would be compromised of the following three elements:

1. The IDOH roughness computer files,
2. Future programmed major activities,
3. Results of condition survey.

These data base elements are shown in Figure 5.2.

5.2.3 The IDOH Roughness Computer Files

The Indiana Department of Highways (IDOH) Roughness Computer Files form the backbone of the proposed data base. The following information was taken from these computer files: highway number, county, year resurfaced, mileage, landmarks, contract number, current roughness, roughness of previous year, current ADT, and the ADT of previous year.

5.2.4 Future Programmed Major Activities

The future programmed major activities were taken from the Biennial High-

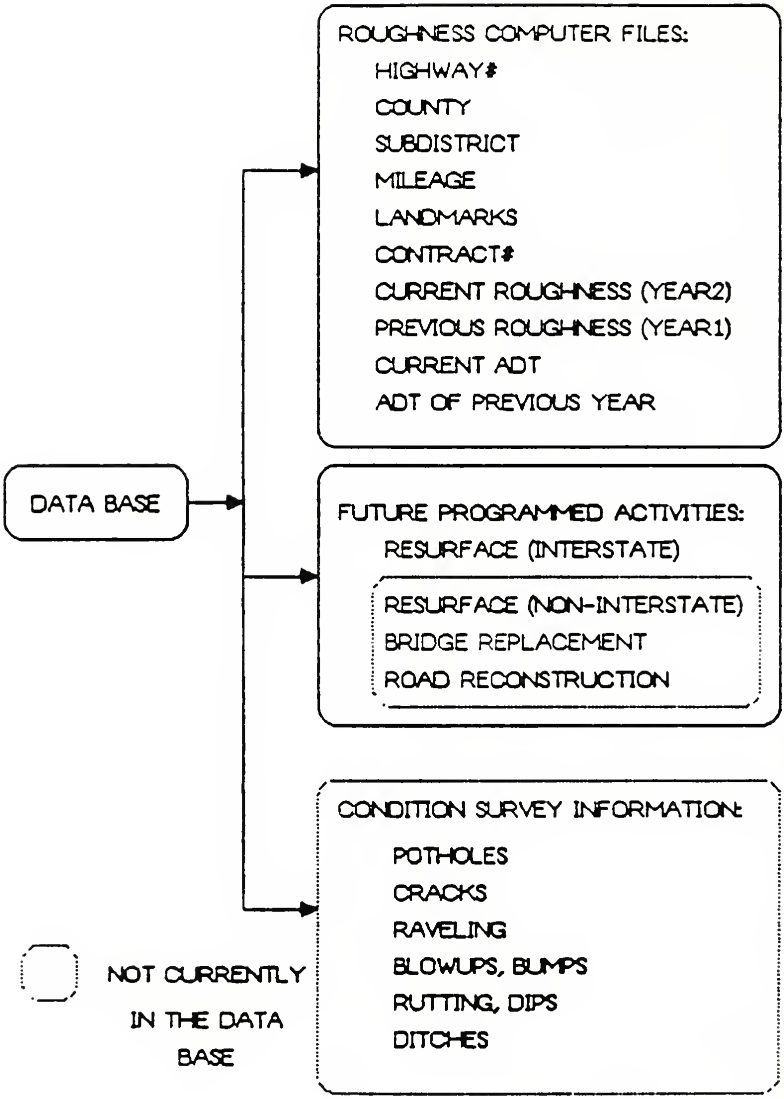


Figure 5.2 Data Base Elements.

way Improvement Program (HIP) [IDOH 1984-86]. In the HIP, projects are arranged in the following categories: Bridges, Resurfacing, Safety Improvements, Roadside Improvements, New Facilities, Park Facilities, and Toll Facilities. Information from the 1984-1986 Biennial Highway Improvement Program was used in the data base developed in this study.

5.2.5 Condition Survey Information

The current pavement data collection program in Indiana does not include any kind of statewide condition surveys. In Chapter 2 a periodic condition survey procedure proposed to be carried out by unit foremen has been discussed. The foremen would be responsible for filling out standard forms evaluating the condition of road sections within their respective units. If implemented, this information would be entered into the computer and would be a part of the proposed data base developed in the present study.

5.2.6 Uses of the Data Base

The possible uses of the proposed data base are:

1. Provide timely information to managers in an understandable and easily applicable form.

2. Provide coordination between major maintenance and routine maintenance programs.

3. Provide an uniform method for the use of surface condition data.

4. Provide information for the central office and district in setting priorities in the allocation of funds by activity and by subdistrict. This may be accomplished by using the results of the proposed condition survey which may be included in the proposed data base.

5. Allow the subdistrict foremen to identify routine maintenance needs, set priorities on these needs and program the work in accordance with the resulting priorities.

5.3 An Example Application of the Data Base System

Personal computers are now in common use and have proven highly cost effective for information system applications. Therefore, the IBM personal computer was chosen to accommodate the proposed Routine Maintenance Data Base System for Indiana. The data base system includes a series of programs which interact with the users and produce simple reports about any specific highway section. For the purpose of this study, only the Interstate system was considered.

5.3.1 Data File Structure

Due to the large size of the data file and the slow speed of the personal computer, the indexed sequential technique was used to access information quickly. An index file developed was named INDEX. This file is composed of 37 numbers, each number assigned to one of the 37 subdistricts in Indiana. Then the large data file was divided into 37 subfiles, so that each subfile includes the records of one subdistrict. A record can be defined as the set of information which describes a specific segment of the road within a subdistrict. When the computer program needs to access a specific record in a subdistrict, a search is made in the index file for the subdistrict, then a search for the record will be made only inside the subfile which includes the records for this specific subdistrict, as shown in Figure 5.3. This technique saves a great deal of computer time during the execution of the RMDBS, and it can help the managers to obtain reports easily and quickly from the data base.

5.3.2 Input Format

Communication between user and computer is perhaps the most difficult aspect of an information system. Therefore, the RMDBS was created as a tool which can be learned quickly by users of any level of computer background. The inputs and outputs of the program were made simple. Friendly interactive programs were developed to produce different menus which show the user the different available options from which he may choose. When the user selects an option, the program will automatically show a submenu, ask for information, or produce an informational report that matches the selected option. There are eight different menus, and Figure 5.4 shows the Main Menu.

The program is set up so the user sees what input is typed, then the program checks the input and gives an error message if there is any input error. This kind of input is simple even for an inexperienced program user.

A carriage return locks the input to the indicated item and automatically advances to the next item for input. The item that is ready to receive an input is identified by underlining.

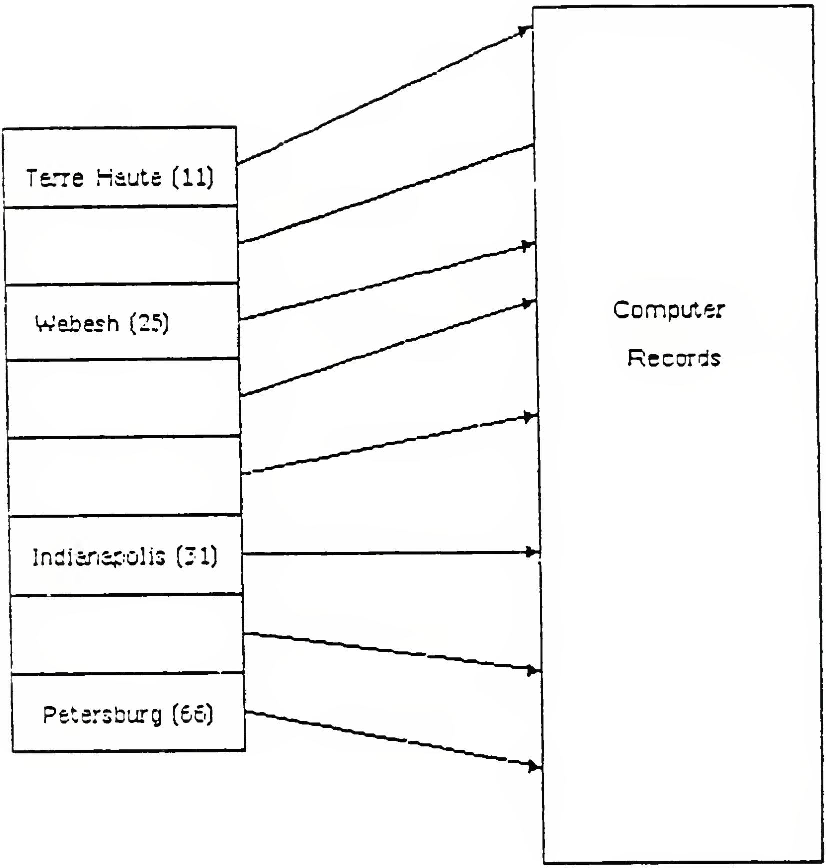


Figure 5.3 A Hierarchical Sequential Structure.

I N D I A N A   D E P A R T M E N T   O F   H I G H W A Y S

R O U T I N E   M A I N T E N A N C E   D A T A   B A S E

M A I N   M E N U

1) ADD HIGHWAY SECTIONS

2) MODIFIY EXISTING INFORMATION

3) REPORT AND REVIEW INFORMATION

4) QUIT

SELECT A NUMBER: _

Figure 5.4 RMDBS Main Menu.

5.3.3 Output Description

The RMDBS produces ten different reports:

a. Roughness report: The report gives the roughness measurements for the current and previous year. The roughness measurements are given between mileposts.

b. Increase in roughness report: This report shows the rate of increase in roughness between the current and the previous year for the specified section.

c. Mileage report: This report gives the milepost reading of the start and the end of the specified section.

d. Contract number report: This report shows the contract number of the specified section.

e. Date report: This report gives the date when the section was opened to traffic.

f. Traffic report: This report shows the ADT for the current and previous years.

g. Landmarks reports: The landmarks which are within the boundaries of the section are shown in this report.

h. Surface type report: This report will show whether the specified section is rigid or flexible.

i. Resurfacing project report: This report will show the anticipated future resurfacing projects and the cost of these projects.

j. Highway section report: This report will list all the highway sections within a subdistrict.

More reports would be generated after condition survey information is added to the data base. These reports would indicate the type and extent of distresses on each segment of the highway system.

If the user wants to get one of the above reports, roughness report for example, he has to operate the program to get the main menu (Figure 5.4). The menu consists of 4 options and option number 3 will provide information and reports. After this procedure has been completed, the computer will present the user with the list of the subdistricts and the user will choose the relevant subdistrict. The computer will then show all the highway sections within this subdistrict and once again the user will select the appropriate section. Next, the user will select option number 1 from the menu shown in Figure 5.5 to get the available reports on roughness. The final step will be to choose option number 1 in the roughness and traffic information menu shown in Figure 5.6. Figure 5.7 is a presentation of the roughness report for a section in Terre Haute (Subdistrict 11).

5.3.4 Software

Software is defined as computer programs, procedures, and associated documentation used in the operation of computer hardware. The two major categories of software are systems programs and application programs.

I N D I A N A   D E P A R T M E N T   O F   H I G H W A Y S

R O U T I N E   M A I N T E N A N C E   D A T A   B A S E

1) ROUGHNESS AND TRAFFIC INFORMATION

2) GENERAL INFORMATION

3) CONDITION SURVEY INFORMATION

4) BACK TO THE PREVIOUS MENU

5) QUIT

Enter option # _

Figure 5.5 RMDBS Information Menu.

I N D I A N A D E P A R T M E N T O F H I G H W A Y S

R O U T I N E M A I N T E N A N C E D A T A B A S E

1) ROUGHNESS FOR CURRENT AND PREVIOUS YEAR

2) ADT FOR CURRENT AND PREVIOUS YEAR

3) RATIO OF CURRENT ROUGHNESS TO PREVIOUS ROUGHNESS

4) BACK TO THE PREVIOUS MENU

5) QUIT

Enter action # _

Figure 5.6 RMDBS Roughness and Traffic Menu.

H.W.:70 Direction:e

Subdistrict:11 County:84

Mileage From	To	Year1 Roughness	Year2 Roughness
0	1	378	423
1	2	431	497
2	3	376	336
3	4	425	337
4	5	490	461
5	6	385	694
6	7	417	970
7	8	406	1168
8	9	382	989
9	10	344	437
10	11	413	443
11	12	416	804
12	13	1906	399
13	14	1668	311
14	15	1582	291
15	16	1636	727
16	17	1878	433

Figure 5.7 An Example of the Roughness Report Produced by the RMDBS.

5.3.5 System Programs

System programs are a collection of computer programs used to coordinate and control the overall operation of a computer system. The PC. DOS 2.1 and KnowledgeMan 1.07 were the system programs used in the RMDBS.

5.3.6 Application Programs

Application programs are written for specific applications. These programs depend on the system programs during execution. The RMDBS consists of 36 application programs. The operation of the RMDBS program is dependent on all the available options and all the programs are therefore interrelated. The RMDBS programs serve four different purposes:

1. Show different menus with available options.
2. Show the input menu to identify a section or to input the condition survey data.
3. Produce reports according to the selected option of the user.
4. Confirm input information and detect input errors.

5.3.7 Error Messages

Due to the simplicity of the input format, the user of the RMDBS can commit very few input errors. The program prints error messages in response to the kind of errors detected. After printing the error message, the program will give user the opportunity to change the input.

5.3.8 System Configuration

The following computer components are essential for the use of the RMDBS:

1. system unit, containing a minimum of: IBM personal computer family with hard disk or true compatibles, monochromatic or color video monitor (25 lines * 80 characters), keyboard, and a printer (80 column).

2. Pc-DOS 2.1 or later version.

3. KnowledgeMan software 1.07 or later version.

5.3.9 Information Updating

When creating the RMDBS, the need for continued updating of the data base was taken into consideration. The data of each record were divided into two parts:

1. The first part includes the result of the condition survey. These data are proposed to be collected by the foremen. It is suggested that this part of the data base should be updated by the subdistrict management. Then the information can be transferred to other management levels by computer instead of the condition survey forms. The updating of this part of the data base should be done twice each year because the condition survey data are proposed to be collected bi-annually.

2. The second part includes the following: roughness, ADT, future programmed activities, and surface type. This part of the data should be updated by the central computing facilities in Indianapolis because all these data are located in computer files there. The updating of this part should be done yearly because the roughness measurements are

collected on a yearly basis.

5.4 Implementation and Evaluation of the RMDBS

The following steps may be involved in implementation of the proposed information system on a pilot basis.

1. Selection of Management Units: For pilot implementation two separate districts should be selected with two subdistricts from each district. Four subdistricts, two districts and the central office should then be supplied with the necessary hardware and software.

2. User Training: Training is critical for the successful implementation of an information system. Users must be informed as to the formats and contents of reports and terminal displays and how to request reports. The personnel from the management units selected for pilot implementation should be given appropriate training for the use of the RMDBS.

3. Data Collection: All necessary data except the condition survey information already exist in computer files. The condition survey data, if available, should be added to the data base.

4. Evaluation: Evaluation provides the feedback necessary to assess the value of information included in the system. This feedback provides direction for adjustments to the information system that may be necessary. First, the adequacy of the software should be

evaluated. The ease of use can be taken as an indication of software adequacy. Next, the RMDBS should be evaluated in terms of the information provided. The objective of the RMDBS is to generate information to support maintenance decision making. Therefore, the extent to which information is relevant or not for decision making is the area of concern in evaluating the performance of the RMDBS. This evaluation can be accomplished by systematically interviewing the users in the management units selected for pilot implementation. If the management is satisfied with the information system, it is reasonable to assume that the system meets the requirements. If management is not satisfied, modifications ranging from minor adjustments to complete redesign may be required [Llewellyn 1976].

5. Statewide Implementation: After modification , the RMDBS can be generalized for use by all maintenance management units in Indiana.

5.5 Chapter Conclusions

The most difficult task in the development of an information system is to determine the information requirements of the users. This was done by examining the available data with respect to the functions that were to be performed by determining who should be interested in different combinations of these data. The major findings of the study are summarized below.

1. When considering the relationship between level of maintenance and roughness, it was found that the rate of increase in roughness

varies inversely with the level of routine maintenance. Because of this relationship, roughness measurements were included in the data base. These measurements could be used by the subdistrict management to determine necessary surface treatments.

2. Information on future programmed resurfacing activities was included in the data base. This would help to identify highway sections which are scheduled to be resurfaced. In this way, spending on routine maintenance for these sections could be eliminated or decreased.

3. Data collected from condition surveys, as suggested in Chapter 2 should be a part of the data base. This information can help the management at the central office monitor the surface condition of the highway network within a subdistrict on a periodic basis. The same data could be used by the subdistrict management to set priorities for performing routine maintenance activities.

CHAPTER 6

AN EXPERT SYSTEM TO ESTIMATE HIGHWAY PAVEMENT ROUTINE MAINTENANCE WORK LOAD

6.1 Introduction

The Indiana Department of Highways (IDOH) has six districts, each district having six or seven subdistricts. Each subdistrict is again divided into 3 to 4 units. Estimation of routine maintenance workload is performed at the unit level. The IDOH current practice for the estimation of routine maintenance needs is to use primarily quantity standards developed on the basis of historical records. This work load estimation procedure does not explicitly relate to the current condition of the roads.

A possible improved procedure based on condition surveys has been developed in the present study, as discussed in Chapter 2. The approach calls for a periodic survey of highway sections by unit foremen who would subjectively rate the observed distresses. The observed distresses are translated to their immediate cause and appropriate corrective maintenance measures and their amounts are estimated through a series of steps. The methodology was developed through statistical correlation of distress measurements with foremen's estimates of expected workloads. In this procedure the considerable experience and collective know-how of unit foremen were tapped to develop a set of quantity standards that would depend on present condition of roads.

The proposed approach is particularly useful to new or relatively inexperienced unit foremen. Although the foremen can be trained to undertake to identify the type and extent of distresses through proper instructions, there is an inherent uncertainty involved on the part of unit foremen in translating the distress information into the type and amount of activities to be performed. A knowledge-based expert system would be a good application to minimize the uncertainty involved in the estimation process. It provides a base to estimate the activities in the absence of an expert. The knowledge-base can be tested and altered over a period of time to improve its performance. Since the computer is used to store an expert system, it can very well become a part of a larger cost estimation system for the entire road network within the jurisdiction of a given management unit. In this chapter is discussed how the data generated by the periodic condition survey procedure can be utilized to develop a knowledge-based expert system that can be incorporated in the maintenance management system of the Indiana Department of Highways.

6.2 Proposed Approach

Three approaches can be taken to estimate routine maintenance work load: a) charts or figures relating activities to distresses; b) statistically developed equations; and c) computer based expert system. The expert system approach has the following advantages.

1. Charts are easily understandable when at most three independent variables are involved. But that may not be the case for many activities, where more than three types of distresses may be responsible.

2. Equation forms require the user to be able to interpret each variable involved in the equation. However, the package is expected to be used by the field personnel, and it is necessary to have the results in direct

and easily understandable forms.

3. With new information, the updating of charts and equations may not be an easy task. On the other hand, any new information can be readily incorporated in the knowledge-base of an expert system as this part is kept separate from the entire program.

4. Computer based program can be used as a part of a bigger program for cost estimation for the district wide or statewide maintenance needs. Charts and equations may not be efficiently used for this purpose.

6.3 Selection of Distress Types and Maintenance Activities

Since the unit foremen estimate maintenance needs by surveying the road condition, pavement distresses are input to the process. The type of activities and their amount and cost are the output.

The expert system developed in the present study only takes into account of the activities performed on asphalt pavement and shoulder. The Indiana Department of Highways has 14 different activities related to roadway and shoulder [IDOH 1984]. The procedure used to select the activities for the present study is discussed below:

1. Activities were chosen based on the level of expenditure during the three year period of 1982-84 fiscal years. Higher the money spent on any activity, higher was the priority for inclusion in the study [Sinha et al. 1985].

2. Effort was made to select those activities that can be related to

pavement distresses. In other words, activities can be judged or measured by a few but visible and distinct distress conditions.

3. Activities selected were those that are generally estimated by unit foremen based on their experience and knowledge.

Taking the above three factors into account, six activities were finally chosen for the study: shallow patching, crack sealing, full width shoulder sealing, seal coating, deep patching, and leveling.

The input part of the expert system includes the pavement distress conditions. The judicious choice of these conditions is vital for the success of the system. Frequently, there may be more than one of these surface distresses on a highway section. Sometimes one type of distress may progress to a more serious type of distress or may progress to failure when not properly and timely remedied. This argument brings another factor into light that although these are distinct distress conditions, the underlying causes behind them can create separate distress type in due course of time.

The maintenance personnel have a variety of materials and correcting actions that may be used for various types of distresses. These may be used singularly or in combination with others. Furthermore, very few activities are performed for one exclusive distress. In fact, most of the maintenance activities are performed for more than one surface distress. For example, shallow patching can be performed to correct potholes, edge failures, and other potential surface hazards. Leveling can be performed to correct surface failure caused by settlement at pipe replacements, and deep patches. Similarly, seal coating can be performed to correct extensive cracking, raveling, spalling, and for preventing deterioration of the surface. A review of the literature [Montenegro et al. 1986; Byrd et al. 1975; Asphalt Institute 1967; Asphalt Institute 1981] indicated a set of possible relationships between the types of activities and the distresses they can correct, as shown in Figure 6.1.

In order to minimize the ambiguity involved in the identification of detailed nature of several distresses, aggregated distress types were considered. For example, alligator cracks, edge joint cracks, reflection cracks and shrinkage cracks were all put into a general category of cracks only. Consequently, the field survey considered the following five categories of distresses for observation by the unit foremen [Montenegro et al.1986]. A diagram showing the grouping of distresses is presented in Figure 6.2.

* Potholes
* Cracks
* Raveling
* Blow ups, Bumps, and Surface Failures
* Rutting and Dips

6.4 Knowledge Acquisition

Maintenance unit foremen interviewed in the survey,discussed in Chapter 2, had many years of experience with intimate knowledge of the highways within their jurisdiction. The proposed expert system attempts

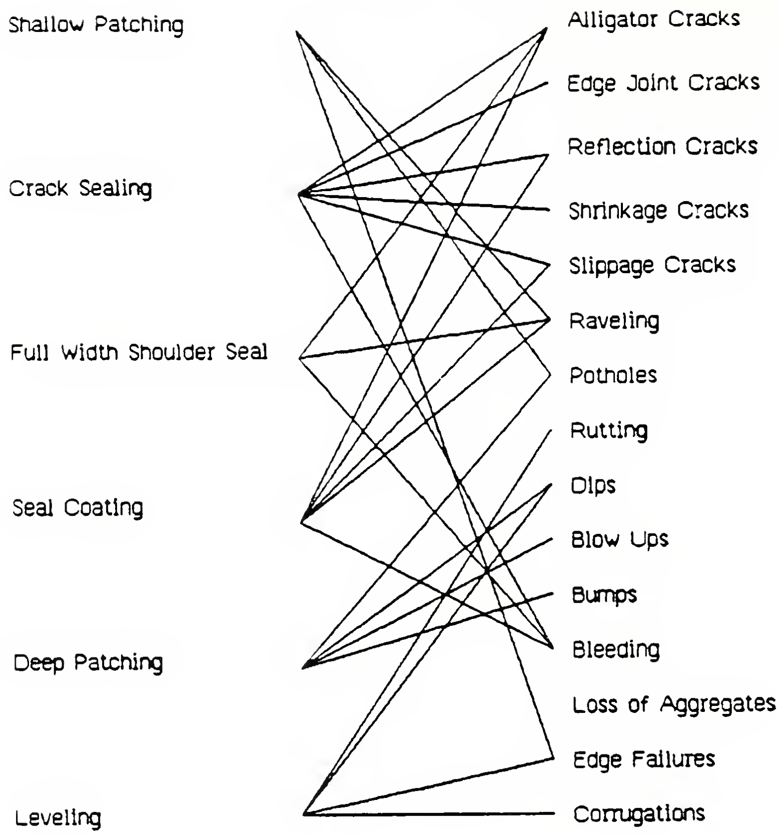


Figure 6.1 Relationships between activities and distresses

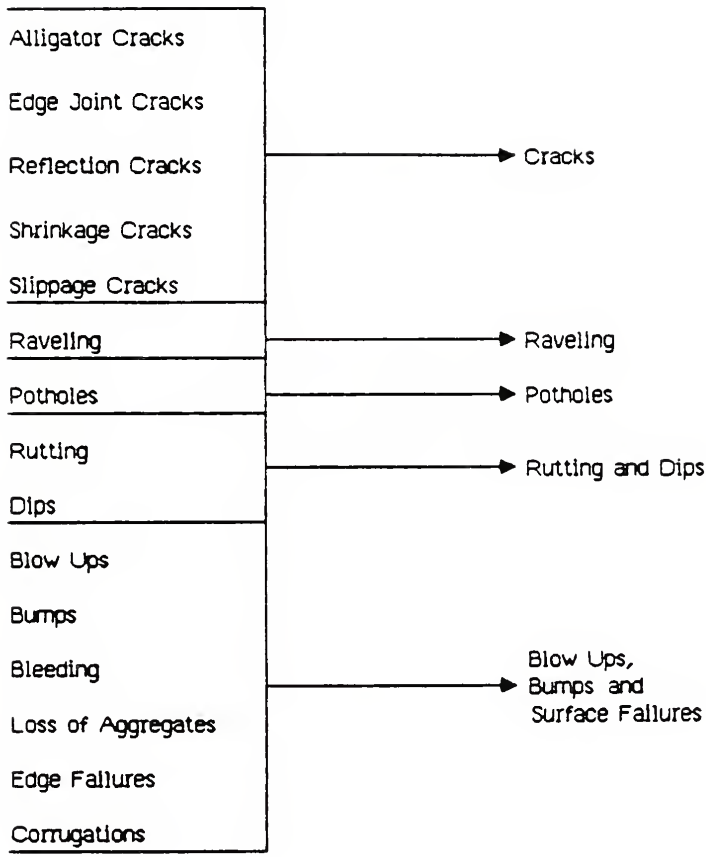


Figure 6.2 Grouping of distresses

to simulate the reasoning of the unit foremen surveyed. The unit foremen were requested not only to give their opinion of the roadway conditions in terms of the extent and severity. The severity was considered in three categories, "slight," "moderate" and "severe." The extent of a distress was identified as "many" (m), "some" (s), "few" (f) and "none" (n). The unit foremen were also requested to provide an estimation of the work load per maintenance activity during the coming fiscal year.

Quantitative statistical methods were used to derive regression equations between required work load for an activity and roadway distresses on the basis of foremen survey data. For that purpose, qualitative distress categories were converted into numerical values by using point estimation technique [Montenegro and Sinha 1986].

A multivariable regression analysis, based on least square fit, was used to develop the necessary equations. This approach served two purposes: (1) It provided a way to estimate activity work loads depending upon the level of distresses. (2) It also ensured that only those variables that are significant at a given level of confidence (α value) were included in the equation. While doing the regression analysis, it was ensured that only those distresses were included that have logical relationship to the activity in consideration.

6.5 Details of the Proposed Expert System

An interactive computer program written in LISP [Wilensky 1984] language was developed that can be used by unit foremen to estimate maintenance needs on the basis of field observations of pavement distresses. It requires the user to answer a set of questions about the physical properties of the highway section including distress information and then it gives recommendations about maintenance activities.

6.5.1 Justification for Using LISP

LISP is largely used as a programming language for artificial intelligence purposes. It has several capabilities such as pattern matching which other structured languages like PASCAL and FORTRAN do not have. Since the program requirements of the present study are simple and do not need any exceptional features of LISP, it could have been written in PASCAL or FORTRAN as well. But there are few points that made the use of LISP desirable. First, the maintenance work load estimation involves a lot of variables and since no declaration statements for the variables are required for them, a lot of space is saved with the LISP and the program becomes compact . Second, in LISP the same variable can have a numerical value or a character string attached to it, so no type clash is involved and at different stages of the program, the same variable can have either type of value. It is therefore easy to avoid a situation where a variable might take a character string value instead of a numerical value. This situation may arise in providing input information when the user is asked to give section length in miles, he/she may give the answer in text as "ten" instead of "10". This kind of mistake is difficult to be checked in PASCAL or FORTRAN. Third, since a lot of input is required in text form, reading the whole character string is easier in LISP than in other packages. Next, the order in which the functions are put does not matter in LISP, thus making it easy to separate the components of the expert system. Finally, LISP allows easy manipulation of the knowledge base which might be changed in future with the acquisition of new information.

6.6 Description of the Program Modules

The flow chart for the overall program is shown in Figure 6.3. It has three major components : input module, knowledge base, and output module. The knowledge base comprises of two modules, conversion and rules modules. The component modules are explained in the following sections.

6.6.1 Task Specific Data or Input Module

The input module fetches all the information from the user after the initiation of the program as shown in Figure 6.4. It has two distinct parts : (1) general features of the highway section and (2) information on distresses. The program starts with a brief description of the problem of maintenance needs estimation and explains how the program functions. Only one question is asked of the user at a time. The first part requires the user to give section length, lane width, number of lanes in one direction, and whether the section has any paved shoulders. If there are no paved shoulders, the program moves to the second part, otherwise it asks the user to give inside and outside shoulder widths. Answer to each of these questions is to be given numerically, such as 10 for section length, and not in text form such as "ten". A check is inserted in each of the functions for this purpose. If the answer is given in text form, the original question is repeated. This procedure

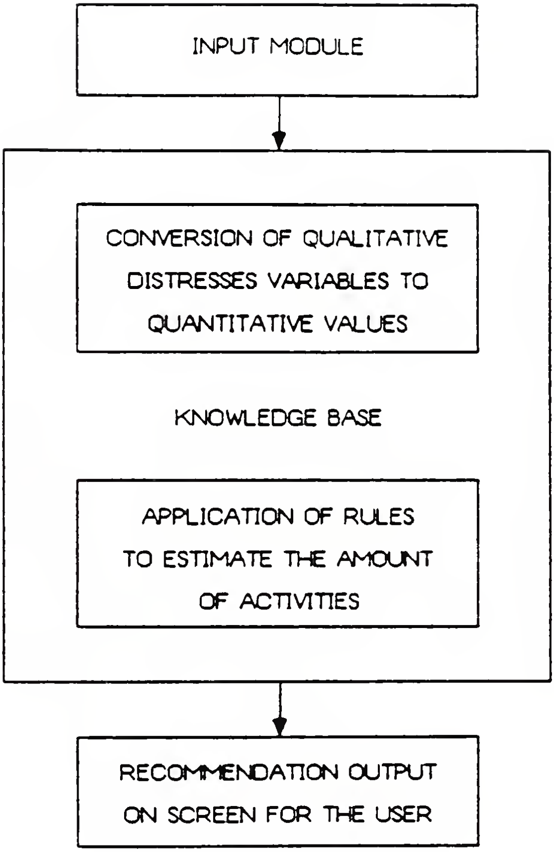


Figure 6.3 Flow chart for the expert system

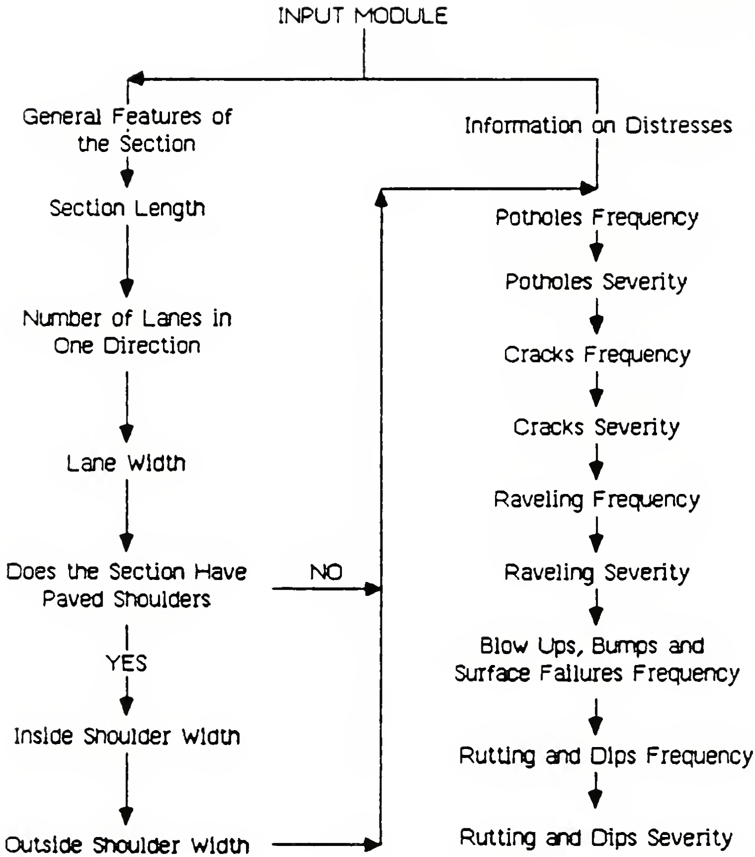


Figure 6.4 Flow chart for the input module

was used to make the input consistent with the nature of the program.

Once all the information for the first part is given, it is output on the screen for the user to make a final check for any typing mistakes. At this time the user has the option of going back to any information given earlier and make a correction. Once the user is satisfied, he/she can invoke the second part of the input module.

In the second part, information on distresses is requested to be given by the user. "Potholes", "cracks", "raveling", and "rutting and dips" have two items : severity and frequency. "Blowups, bumps and surface failures" is represented only by frequency. For each of the distress types, there are three severity levels, "Slight", "Moderate", and "Severe". On the other hand, there are four levels of frequency, "None", "Few", "Some", and "Many". Similar to part one, the user is asked to answer one question at a time. However, in this case, answers are given in qualitative terms. Immediate checks are made for any typing mistakes.

After the second part is completed, all the input values are printed for the final check. The user has the option to go back and change any of the values. Once the user is done with this task, no more information is required. The expert system then explicitly gives the recommendation regarding the maintenance needs on the screen. In the process it goes through several parts that are explained in the following sections.

6.6.2 Knowledge-Base

Knowledge-base is the component which stores all the rules. This is where the expert system applies its own knowledge to the facts provided by the user to come up with the conclusions. It has two distinct subdivisions. The first subdivision, conversion module, contains the rules for qualitative values of distresses to be converted into numerical values. A typical function is as shown below:

```
(cond
     ((equal *ravf* ´no) (setq X5 0.68))
     ((equal *ravf* ´fe) (setq X5 2.57))
     ((equal *ravf* ´so) (setq X5 5.04))
     ((equal *ravf* ´my) (setq X5 8.01)))
(cond
     ((equal *ravs* ´sl) (setq X6 1.79))
     ((equal *ravs* ´mo) (setq X6 4.91))
     ((equal *ravs* ´se) (setq X6 8.05))))
```

The construct shown above is just a case of multiple IF-THEN situations. The numerical values shown in the construct are the average numerical values for the levels of distresses as explained in the previous section. The first "cond" corresponds to the rules for the conversion of frequency levels to respective numerical values. For example, the second line of the construct means that if the frequency of raveling is given by the user as "none", the variable X5 is to be set equal to 0.68 (X5 is the variable representing raveling frequency in numerical terms).

The second "cond" corresponds to the rules for the conversion of severity levels to respective numerical values. The first line of the construct means that if the severity of raveling is given by the user as "slight", the variable X6 is to be set equal to 1.79 (X6 is the variable representing raveling severity in numerical terms). All these IF constructs correspond to the levels of frequency and severity. These conditions are tested sequentially and once any one of these is satisfied, the execution is halted.

The construct shown here is for "raveling" distress. Similar constructs are included in the knowledge-base for other distresses such as potholes, cracks, and so on. This type of architecture comes under a broad heading of "production system" where knowledge is represented in terms of IF-THEN rules. It is apparent here that this part of the knowledge base is a major source of variation in the estimation process. Different foremen´s perception of "none" frequency of potholes may be different. However the model uses the average value.

The second part of the knowledge-base, rules module, which can also be called the inference engine, includes the rules to estimate the amount of activities, once the quantitative equivalents of distress levels are known. One typical example for crack sealing is shown as follows:

```
(defun crsea ()
     (let
          ((temp 0))
          (setq temp (add  0.7475
```

```
                    (times 0.361 X4)
                    (times 0.132 X7)))
          (setq Y2 (times temp temp))))

(defun scrsea ()
    (let
       ((temp 0))
       (setq temp
          (add
               (add 0.1331
                    (times (minus 0.0183) X4)
                    (times (minus 0.0077) X7))
               (times
                  (add (minus 0.0183)
                       (times 0.0051 X4)
                       (times (minus 0.0019) X7)) X4)
               (times
                  (add (minus 0.0077)
                       (times (minus 0.0018) X4)
                       (times 0.0054 X7)) X7)))
           (setq Y2ST (sqrt (times (abs temp) 1.52)))))

(defun rcrsea ()
     (setq *U2* (diff Y2 (times 2.02 Y2ST)))
     (setq *H2* (add  Y2 (times 2.02 Y2ST)))
     (cond
```

```
((lessp *U2* 0.0) (setq *U2* 0.0))))
```

The first function "crsea" shown above gives the point estimation of the activity crack sealing based on the quantitative values of distress variables. The variables Y2, X4, and X7 are amount of crack sealing in tons * 1000/ ft-mile, cracks severity and frequency of blowups, bumps, and surface failures, respectively.

Since the output of the expert system is in the form of range of values for each activities, standard deviation is needed for each point estimation of work load. The second function "scrsea" shown above calculates the standard deviation for work load of crack sealing. The last function "rcrsea" shown above uses the values obtained by previous two functions and calculates the lower and upper bounds of 95% confidence interval for estimated value of amount of work load for crack sealing. The variables *U2* and *H2* represent the lower and upper bounds, respectively.

Similar functions are used for each of the six activities. Thus the first part converts the qualitative values of distresses into corresponding numerical values and the second part computes the amount of activities.

6.6.3 Output Module

This module controls the execution of the entire program. It calls input module and later on uses the knowledge-base to estimate the maintenance work loads. It has two functions. First, it converts all the values calculated in the second part of the knowledge-base to standard units for all activities, such as ton for shallow patching and gallon for crack sealing, and so on. These quantities are the estimated work loads for the highway section under consideration. The second function simply outputs all the values with proper titles and units.

6.6.4 Procedure to Use the Package

The procedure to use the package is given in Reference [Tandon 1986]. A version of FRANZ LISP is available on several personal computers and thus the package can be transferred to a floppy disc. This would make it possible to be readily used by personnel at the subdistrict level and the use of language LISP would not limit its application and usage.

6.7 An Example Problem

Following is an example which shows the input and output information. The values given by the user for the first part of the input module are as follows:

```
ROAD SECTION LENGTH (in miles)    :- 10
NUMBER OF LANES -- ONE WAY ONLY   :- 1
LANE WIDTH (in feet)              :- 11.5
INSIDE SHOULDER WIDTH (in feet)   :- 3
OUTSIDE SHOULDER WIDTH (in feet)  :- 6
```

The values given by the user for the second part of the input module are as follows:

CRACKS	SEVERITY	:- MODERATE
	FREQUENCY	:- MANY
POTHOLES	SEVERITY	:- SLIGHT
	FREQUENCY	:- FEW
RAVELING	SEVERITY	:- SLIGHT
	FREQUENCY	:- NONE
BLOW UPS, BUMPS and SURFACE FAILURES		
	FREQUENCY	:- MANY
RUTTING and DIPS	SEVERITY	:- SEVERE
	FREQUENCY	:- MANY

The 95% confidence range of estimated work loads on this highway section and the associated costs given by the expert system are as follows:

<u>Amount of Work</u>

SHALLOW PATCHING	5.2 - 6.1 tons
CRACK SEALING	1359 - 1584 gallons
FULL WIDTH SHOULDER SEALING	0 - 7 ft-miles
SEAL COATING	0 - 1.7 lane-miles
DEEP PATCHING	8.6 - 9.8 tons
LEVELING	161 - 162 tons

<u>Estimated Costs</u>

SHALLOW PATCHING	$ 596 - 701

CRACK SEALING	$ 2,827 - 3,294
FULL WIDTH SHOULDER SEALING	$ 0 - 832
SEAL COATING	$ 0 - 2,858
DEEP PATCHING	$ 575 - 655
LEVELING	$ 7,411 - 7,477

6.8 Limitation of the Expert System and Recommendations for Improvement

The most important part of the development of an expert system is the testing process. It improves the system's performance over a period of time as new information is incorporated in the knowledge-base. The present system, when tested with the available data, performs reasonably well. However, the variation in the amount of activities reported in the field for a given level of distress is high. There are several areas that need attention and further study to make the use of the expert system more effective.

1. In the present approach, the distress conditions are defined by levels of frequency and severity. These levels are then given numerical values on the basis of expert opinions. Only four levels of frequency and three levels of severity were included. This situation creates inflexibility as the user is allowed to select from a limited set of options representing a large variation in distress conditions. This shortcoming can be minimized by increasing the number of levels and thus reducing the variability. Another possible way to tackle the problem could be to ask the

user to rate the distress condition on a numerical scale directly as is done in the pavement serviceability rating procedure [Yoder et al. 1975]. This would eliminate the subjective judgment involved in transferring foremen's opinions to a numerical scale.

2. In the data collection process, assessment forms are filled by different foremen for different road sections, and thus there is a possible loss in consistency. It will be beneficial to expose the foremen to other parts of the state and also to opinions of other foremen as to the condition of a road section. This procedure could minimize individual variability of the foremen's responses.

3. In the expert system developed in the study, climatic variations have not been considered. Originally the data were collected by dividing the Indiana state highway system into three regions: north, central, and south. But due to very few data collected per region, all data were grouped together for analysis purpose. It may be so that routine maintenance needs are perceived differently at the northern part of the state as opposed to the southern part due to substantial difference in the weather. It is therefore necessary to survey more road sections per region, so that climatic variations can be reflected into the estimation process.

4. One of the major causes for the large variation in the reported amount of estimated maintenance needs is due to the choice of different activities by foremen for the same type of distress. Same type of distress can trigger different activities and an activity

can be prescribed to correct more than one distress type. Furthermore, different practices may be expected in different parts of the state. The reasons might be unavailability of materials for a particular activity, or one activity being less expensive due to proximity of the site from a mixing plant, and so on. More research is needed in this area so that information about the regional practices can be included in the input module before the estimation process.

6.9 Chapter Conclusions

One of the key components of routine maintenance management is the identification and estimation of the type and amount of activities to be performed in the field. The estimation is done by foremen who have extensive experience and know-how in the area of routine maintenance. Foremen observe road conditions and convert the information into the type and amount of activities, depending upon the severity of distresses. An expert system has been developed in the present study that attempts to simulate the knowledge and experience of foremen in the estimation process. The knowledge-base of the expert system has been prepared by analyzing the results of a field survey by maintenance unit foremen.

The expert system is written in LISP and it includes only routine maintenance activities for asphalt pavement with or without paved shoulders. It is interactive in nature and it asks the user simple questions about general features of the highway section under consideration and information about pavement and shoulder distresses. Questions are asked in a user friendly language and are easy to interpret. It has immediate checks for any typing mistakes while answering a question. The knowledge-base in the expert system is kept separate from the main program and can be improved as more research is done on the subject.

CHAPTER 7

PRIORITY RATING OF ROUTINE MAINTENANCE ACTIVITIES

7.1 Introduction

Efficient programming and scheduling of routine maintenance activities is vital to the success of maintenance management at both project and network levels. More and more agencies are now using, or looking into possibility of using computer mathematical models to perform the work of programming and scheduling maintenance activities [Stein et al. 1987; Burke 1984; Theberge 1987; Carnahan et al. 1987; Bell 1984].

While mathematical programming of routine maintenance activities using computer undoubtedly has great potential in improving efficiency and saving costs, one must realize that the applicability and usefulness of the results obtained from such analysis depend very much on the accuracy and reasonableness of input and constraint factors [Stein et al. 1987; Bell 1984]. The priority ratings of various routine maintenance activities are without doubt one of the most important input factors that has a great impact on the final outcome of a mathematical programming analysis. Unfortunately, complete priority information which is required for a meaningful programming and scheduling analysis, are very often not available.

Due to the lack of priority information on routine maintenance activities, a survey was conducted in Indiana to acquire the necessary data. This chapter describes the rating procedure adopted and the steps involved in arriving at the final priority ratings for different routine maintenance activity by highway class and severity level of road distress condition. Using the Indiana data collected, analyses were performed to illustrate how other useful information on routine maintenance practice could be derived from this form of study. Finally, the need for each highway agency to establish its own maintenance priority ratings appropriate for its program is stressed.

7.2 Considerations in Priority Rating Assessment

There are a number of different priority assessment schemes reported in the literature [Stein et al. 1987; Theberge 1987; Kilareski et al. 1983; Schoenberger 1986; Snaith et al. 1984]. Practically all of these schemes rely on defining certain numeric indices such as pavement condition index, maintenance needs index, and defect rating value etc, which are computed using data obtained from pavement condition surveys. These indices form the basis for priority assessment purposes. The key difference between these schemes and the scheme proposed in this study is that, instead of using an aggregated index to represent maintenance needs and to set priority, the present study developed maintenance activity specific priority ratings. In other words, priority ratings are assigned explicitly to routine maintenance activity types.

7.2.1 Advantages and Disadvantages of the Proposed Approach

The form of priority ratings generated by the scheme described here has been incorporated in a highway routine maintenance optimization programming model discussed in the next chapter. The experience shows that the advantages of this approach are:

1. Maintenance activity specific priority ratings have a clear-cut physical meaning easily understood by both planning and field maintenance personnel. In contrast, using a numeric index to represent different distress conditions involves data transformation and subjective judgement which may not be shared by the maintenance personnel at different levels.

2. Specific routine maintenance activities can be easily matched up with labor, material, equipment, construction productivity and time requirements. This link is particularly useful in programming and scheduling of routine maintenance activities for agencies directly involved with planning and execution of field maintenance. The establishment of such links is not straight forward in schemes where aggregate pavement condition indices are used as the basis for priority rating.

3. Data collected in the maintenance activity specific priority rating scheme can be further processed, as illustrated in a later section of this chapter, to extract useful information on routine maintenance practice. Much of this information would be lost if maintenance needs data collected are aggregated into a common numeric index.

The disadvantage of the proposed approach is with the acquisition of priority rating data. The number of entries to be priority rated is much bigger and more difficult to handle as compared to a single index variable in most condition index priority based setting schemes.

7.2.2 Factors Affecting Priority Ratings

The relative priorities of various routine maintenance activities are influenced by a number of factors. The following possible factors were identified in the present study:

1. Routine maintenance activity type. Highway routine maintenance encompasses activities undertaken on a regular or continual basis to serve as preventive measures or as corrective measures. Each of these activities has a different impact on restoring condition and lengthening of service life.

2. Highway class. Highways of different classification receive different degrees of attention from highway agencies. A highway with a higher degree of importance will receive maintenance earlier than another highway needing the same type of maintenance.

3. Road distress condition. Considering the severity level of road distress condition, it appears logical to state that a highway section with a more severe distress would be repaired sooner than one with a less severe distress condition.

4. Seasonal effect. Not all maintenance activities would be performed throughout the year. For instance, certain activities may have to be suspended in the winter due either to weather constraint or repair effectiveness consideration. These activities

would therefore not be given any priority during the winter months, even though they might have high priorities in the other seasons of the year.

5. Climatic and environmental factors. It is a well recognized fact that pavements in regions with different climate and environmental conditions behave differently. The prevailing types of pavement distresses in different regions are not likely to be the same. The priority ratings for different maintenance activities would therefore be different.

6. Maintenance practice and policy. Highway agencies with different maintenance practices and policies place different emphases on different aspects of maintenance, and their priority ratings for various routine maintenance activities would not be the same.

7. Miscellaneous factors. Priority ratings of maintenance activities may also be affected by safety consideration, environmental concern, political influence and other factors.

In theory, if n_1, n_2, n_3, n_4, n_5, n_6 and n_7 represent respectively the number of variables in each of the 7 factors above, one would have to rate in priority order a total of $(n_1 x n_2 x n_3 x n_4 x n_5 x n_6 x n_7)$ combinations. This is however, rarely the case in practice. For example, factors 5 and 6 are likely to be location specific, and would not vary greatly over a relatively large area. To account for factor 4, one may opt to produce different sets of priority list for different seasons.

In the present study, factors 1, 2 and 3 were considered explicitly. Factors 5 and 6 were taken care of in the survey sampling stage where areas with different conditions in the two factors were identified and sampled separately. The survey was conducted in the summer, the results may not be applicable to winter months due to seasonal effects. Factor 7 was not included. However, it is very likely that some of the miscellaneous factors could have influenced individual raters in arriving at their priority scores.

7.3 The Survey Procedure

The survey began with a statistical sampling of surveyed units, followed by field interview of maintenance personnel in the selected units. Details of the two phases are described below.

7.3.1 Statistical Sampling

The survey units in this study was selected from a stratified random sampling process [Neter et al. 1985; Montenegro et al. 1986]. A stratified random sampling is a restricted randomization sampling design in which the experimental units are first sorted into homogeneous groups or blocks. The required number of experimental units is then randomly selected within each group.

There are three levels of maintenance management in the IDOH (Indiana Department of Highways): central office level, district level and subdistrict level. Figure 7.1 shows the district locations in Indiana. The six districts clearly provide a logical basis for stratification.

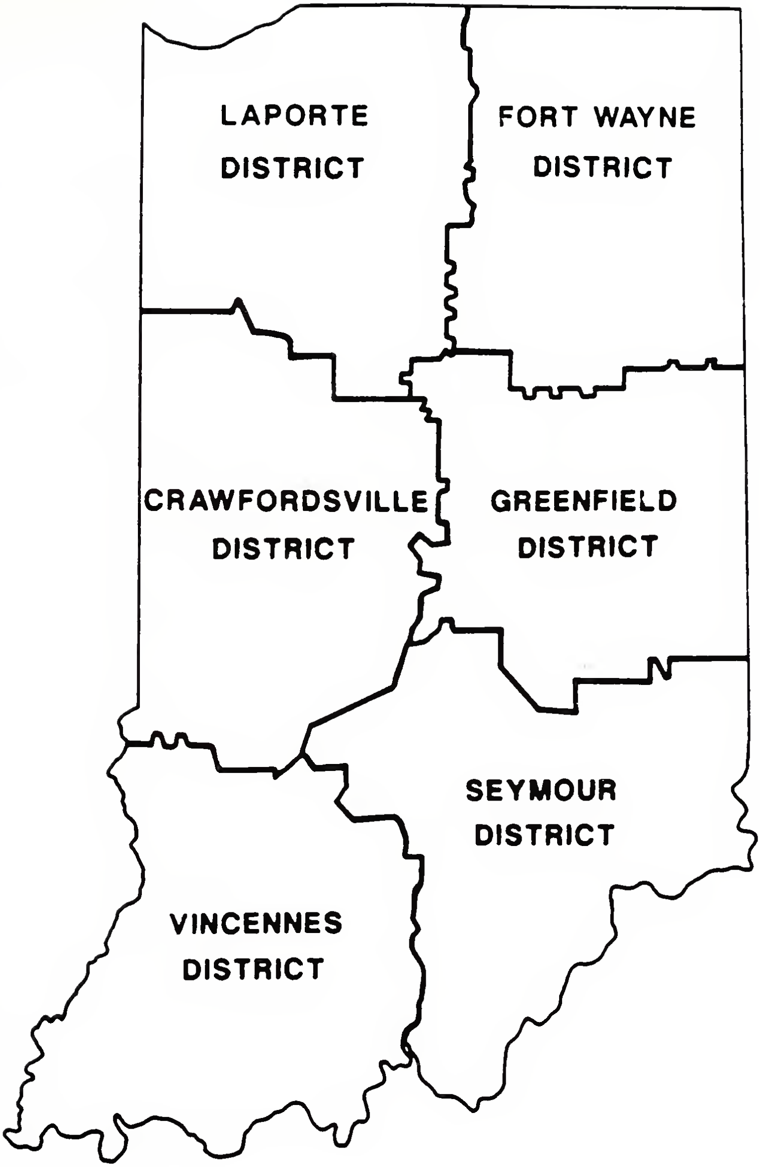


Figure 7.1 Highway Districts in Indiana As Stratification Basis for Survey Sampling

Two subdistricts were randomly selected from each district to form the survey units.

The stratification by district also serves well to represent two distinct climatic conditions found in Indiana. Past studies in Indiana [Yoder et al. 1980; Sharaf and Sinha 1984; Fwa et al. 1986] have indicated the presence of the following two climatic regions: the colder North region represented by the two northern-most districts, and the relatively warmer South region which includes the remaining four districts. A total of 36 representatives of maintenance staff were surveyed. Sixteen of the staff surveyed were from the North region and twenty from the South region.

7.3.2 Priority Rating Procedure

The factors included in the survey were maintenance activity type, highway class, and distress severity level of the road needing the activity. Fourteen routine maintenance activities involving pavement, shoulder and drainage were investigated. Table 7.1 shows the list of maintenance activities investigated.

The highway classes defined were Interstate and Other State Highways (OSH). OSH was further broken into two categories: high traffic volume OSH with more than 400 vehicles per day (vpd), and low traffic volume OSH with less than 400 vpd. The traffic volume classification was chosen to provide broad guidelines for differentiating maintenance priorities of the various highways. For road conditions, three levels of distress severity were considered, namely, severe, moderate and

Table 7.1 List of Maintenance Activities Investigated.

Code	Description
201	Shallow Patching
202	Deep Patching
203	Premix Leveling
204	Full Width Shoulder Seal
205	Seal Coating- Chip Seal
206	Sealing Longitudinal Cracks and Joints
207	Crack Sealing
208	Sand Seal
210	Spot Repair of Unpaved Shoulders
211	Blading of Unpaved Shoulders
212	Clipping Unpaved Shoulders
213	Reconditioning Unpaved Shoulders
231	Clean and Reshape Ditches
234	Motor Patrol Ditching

slight.

A simple calculation shows that there are 14x3x3 = 126 entries to be priority rated. Simultaneous rating of all 126 entries is out of question as it is beyond the capability of a normal human. Pairwise comparison is theoretically possible but practically infeasible due to the large number of possible combinations. To reduce the problem to a manageable size, the contributing factors were partitioned into two parts and carried out independently. Figure 7.2 shows the flow diagram of the survey. Part 1 of the survey dealt with assigning priority scores to individual routine maintenance activities in accordance with their relative importance in preserving highway pavement conditions at a desired level. In Part 2, priority scores were assigned to different pavements of various highway classes by road distress severity level according to their relative urgency of need for maintenance work.

To aid raters in arriving at the priority scores of their choice more quickly and efficiently, the following measures were taken: (a) A two-stage rating procedure was adopted. Raters were first asked to rank the entries with all potential ties considered. Keeping the order of the ranks, the raters were next asked to assign priority score to each on a 10-point scale. (b) Instead of using tables or forms, a set of cards with a different maintenance activity written on each, was given to each rater. By allowing each rater to place the cards in rank order and then move them into relative positions above or below each other along the 10-point scale, realistic priority scores could be assigned fairly quickly. The experience of the survey indicated that the rating

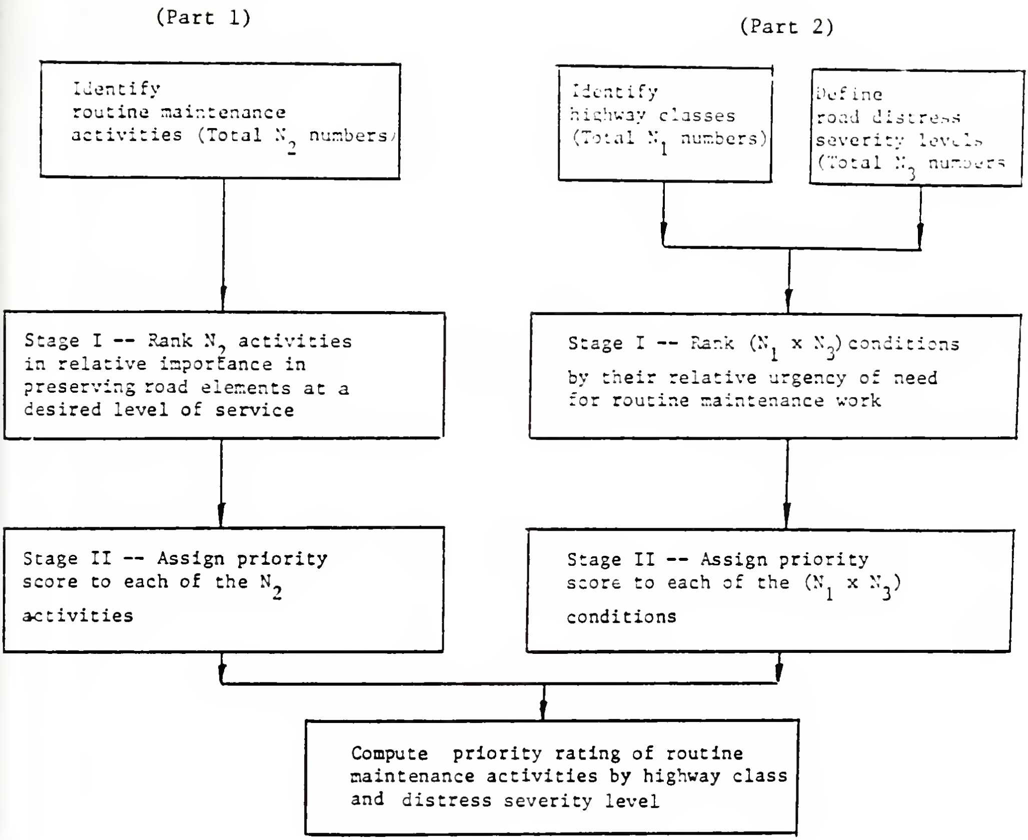


Figure 7.2 Activity Flow Chart for the Partitioned Two-Stage Survey Procedure.

procedure was well received by raters, and satisfactory results were obtained in an unambiguous manner. Figure 7.3 shows the priority rating scale along with rater instructions used for Part 1 of the survey. Identical scale and similar rater instructions were used for Part 2 of the survey.

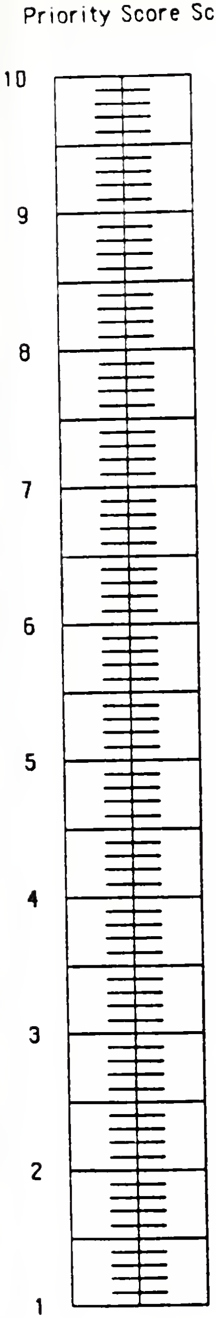
An alternative procedure would have been to adopt a tree-like survey structures as shown in Figure 7.4. The raters would first rate all maintenance activities as in Part 1 of the survey in Figure 7.2, then proceed to repeat N_1 number of times the Part 2 rating process in Figure 7.2. However, this procedure is highly time consuming. Consequently, the survey procedure in Figure 7.2 was used in this study. The computational and analysis techniques discussed in the subsequent sections of this paper are, however, applicable to both procedures.

7.4 Analysis of Survey Data

This section presents the results and computes the final priority ratings of routine maintenance activities by highway class and road condition severity level. In addition to this, it is shown that the data gathered in this form of study can be analyzed further to provide other useful information on routine maintenance practice. As an illustration, an analysis is presented which compares the maintenance practice of the North and South regions of Indiana.

7.4.1 Computation of Final Priority Ratings

The data collected from Parts 1 and 2 of the survey (see Figure



Instruction for Rater

Step 1. You are given 14 routine maintenance activity types, each written on a small card. Go through and read the activity types carefully.

Step 2. (Ranking Assignment) Rank the cards on your desk in accordance with the importance of each activity type in preserving road condition at a desired level. Put the most important activity at the top, followed by other activities in the order of decreasing importance. Ties are allowed.

Step 3. Carefully review the ranking in Step 2. Make changes if necessary.

Step 4. Move the top priority card to the top (i.e. a score of 10) of the scale on this instruction sheet. Next, move one card at a time, in sequence of decreasing importance, to the score and assign a score to each by comparing with the activity immediately above it. Continue until all the cards are placed on the scale.

Step 5. If the last card does not have a score of 1, adjust the scores (except the top score) so that the lowest priority activity has a score of 1.

Step 6. Carefully review the priority scores assigned. Make changes if necessary.

Figure 7.3 Priority Rating Scale and Rater Instruction.

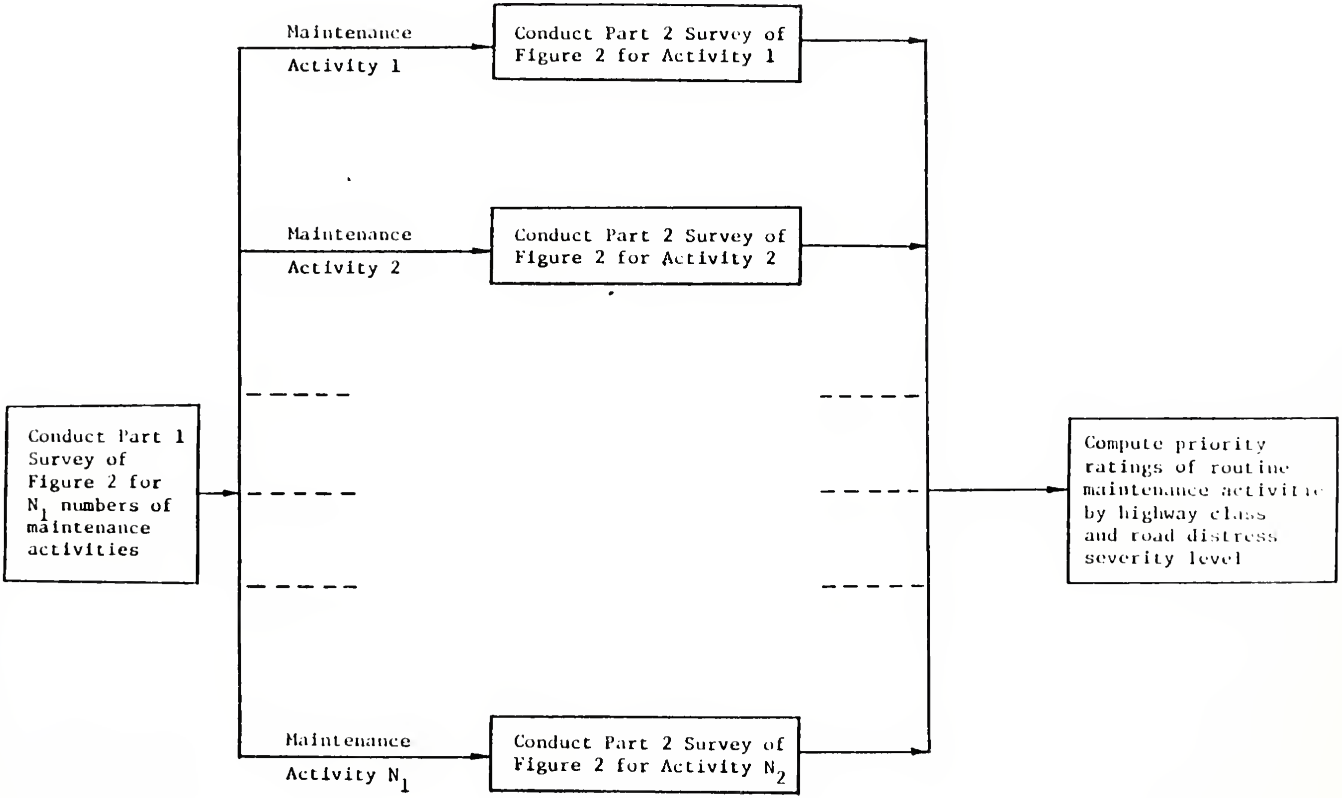


Figure 7.4 Activity Flow Chart for Alternative Survey Procedure.

7.2) are presented in Tables 7.2 and 7.3. Let f_1 and f_2 represent the priority scores obtained from the two parts. The final priority ratings of all routine maintenance activities can be computed as follows:

$$F_{ijk} = (f_1)_i \times (f_2)_{jk} \qquad i=1,2,\ldots N_1,\ j=1,2,\ldots N_2,\ k=1,2,\ldots N_3 \qquad (7.1)$$

where,

F_{ijk} = priority rating for routine maintenance activity i on highway class j with distress severity level k, $1 \leq F_{ijk} \leq 100$

$(f_1)_i$ = priority score for routine maintenance activity type i in relation to all other routine maintenance activity types, $1 \leq (f_1)_i \leq 10$

$(f_2)_{jk}$ = priority score for combination of highway class j and distress severity level k, in relation to all other combinations of the two factors, $1 \leq (f_2)_{jk} \leq 10$

N_1 = total number of routine maintenance activity type

N_2 = total number of highway class

N_3 = total number of distress severity level

In Equation (7.1), the rating score $(f_2)_{jk}$ can be considered to be a weighting factor applied to each maintenance activity. The priority ratings thus computed are recorded in Table 7.4. Priority scores for both the North and South regions are presented in the same table. These priority ratings provide the necessary information on the relative importance of various maintenance activities by highway class and distress severity level.

7.4.2 Analysis of Priority Rating Data

An analysis is presented to compare the maintenance practice of the

Table 7.2 Results from Part 1 of Priority Rating Survey.

Maintenance Activity Code	North Region			South Region		
	Average Rank	Priority Score		Average Rank	Priority Score	
		Average	95% Conf. Interval		Average	95% Conf. Interval
201	1	9.9	9.8 - 10.0	2	9.4	8.8 - 10.1
202	2	9.6	9.2 - 10.0	1	9.6	9.1 - 10.0
203	6	7.2	5.5 - 8.9	8	5.4	2.9 - 7.9
204	10	4.9	3.2 - 6.6	12	3.5	2.1 - 5.0
205	8	6.4	5.4 - 7.3	11	4.4	2.8 - 6.0
206	7	6.7	5.3 - 8.1	8	5.7	4.1 - 7.3
207	7	6.8	5.3 - 8.4	7	6.5	4.6 - 8.4
208	9	5.6	3.8 - 7.3	12	2.9	1.7 - 4.2
210	5	7.8	6.1 - 9.6	7	7.1	5.8 - 8.4
211	6	7.0	5.1 - 8.8	9	5.9	4.2 - 7.5
212	10	4.6	2.8 - 6.4	8	5.8	4.2 - 7.4
213	11	4.2	2.7 - 5.6	7	6.5	4.4 - 8.6
231	10	3.7	1.6 - 5.9	5	7.8	6.7 - 8.8
234	3	1.9	0.3 - 3.5	7	6.6	4.9 - 8.4

Table 7.3 Results from Part 2 of Priority Rating Survey.

Highway Class	Distress Severity Level	North Region Average Rank	North Region Priority Score Average	North Region Priority Score 95% Conf. Interval	South Region Average Rank	South Region Priority Score Average	South Region Priority Score 95% Conf. Interval
Interstate	Severe	1	10.0	10.0 - 10.0	1	10.0	10.0 - 10.0
	Moderate	3	8.7	8.2 - 9.2	4	8.1	7.3 - 8.6
	Slight	6	6.3	4.7 - 7.8	7	4.1	2.8 - 5.4
High Volume OSH	Severe	2	9.4	8.9 - 9.9	2	9.5	9.5 - 9.7
	Moderate	5	7.8	7.2 - 8.3	5	7.3	6.8 - 7.9
	Slight	8	4.3	3.0 - 5.6	7	3.7	2.2 - 5.1
Low Volume OSH	Severe	5	7.4	6.4 - 8.3	4	7.6	6.0 - 9.3
	Moderate	7	4.9	3.6 - 6.4	7	3.8	2.2 - 5.5
	Slight	9	1.0	1.0 - 1.0	9	1.0	1.0 - 1.0

Table 7.4 Priority Ratings of Routine Maintenance Activities by Highway Class and Distress Severity Level.

Routine Maintenance Activity Code	Interstate			High Volume OSH			Low Volume OSH		
	Distress Severity Lev.			Distress Severity Lev.			Distress Severity Lev.		
	Severe	Moderate	Slight	Severe	Moderate	Slight	Severe	Moderate	Sligh
201	99 (N)	86 (N)	62 (N)	93 (N)	77 (N)	43 (N)	73 (N)	49 (N)	10 (N)
	94 (S)	76 (S)	39 (S)	90 (S)	70 (S)	35 (S)	71 (S)	36 (S)	9 (S)
202	96 (N)	84 (N)	60 (N)	90 (N)	75 (N)	41 (N)	71 (N)	47 (N)	10 (N)
	96 (S)	78 (S)	40 (S)	92 (S)	70 (S)	36 (S)	73 (S)	35 (S)	10 (S)
203	72 (N)	63 (N)	45 (N)	68 (N)	56 (N)	31 (N)	53 (N)	35 (N)	7 (N)
	54 (S)	44 (S)	22 (S)	52 (S)	39 (S)	20 (S)	38 (S)	21 (S)	5 (S)
204	49 (N)	43 (N)	31 (N)	46 (N)	38 (N)	21 (N)	36 (N)	24 (N)	5 (N)
	35 (S)	28 (S)	14 (S)	34 (S)	26 (S)	13 (S)	27 (S)	13 (S)	4 (S)
205	64 (N)	56 (N)	40 (N)	60 (N)	50 (N)	28 (N)	47 (N)	31 (N)	6 (N)
	44 (S)	36 (S)	18 (S)	42 (S)	32 (S)	16 (S)	33 (S)	16 (S)	4 (S)
206	67 (N)	58 (N)	42 (N)	63 (N)	52 (N)	29 (N)	50 (N)	33 (N)	7 (N)
	57 (S)	46 (S)	23 (S)	55 (S)	42 (S)	21 (S)	43 (S)	22 (S)	6 (S)
207	68 (N)	59 (N)	43 (N)	64 (N)	53 (N)	29 (N)	50 (N)	33 (N)	7 (N)
	65 (S)	53 (S)	27 (S)	62 (S)	47 (S)	24 (S)	50 (S)	25 (S)	7 (S)
208	56 (N)	49 (N)	35 (N)	53 (N)	44 (N)	24 (N)	41 (N)	27 (N)	6 (N)
	29 (S)	23 (S)	12 (S)	28 (S)	21 (S)	11 (S)	22 (S)	11 (S)	3 (S)
210	78 (N)	68 (N)	49 (N)	73 (N)	61 (N)	34 (N)	58 (N)	38 (N)	8 (N)
	71 (S)	58 (S)	29 (S)	68 (S)	52 (S)	26 (S)	54 (S)	27 (S)	7 (S)
211	70 (N)	61 (N)	44 (N)	67 (N)	55 (N)	30 (N)	52 (N)	34 (N)	7 (N)
	59 (S)	48 (S)	24 (S)	57 (S)	43 (S)	22 (S)	46 (S)	12 (S)	6 (S)
212	46 (N)	40 (N)	29 (N)	43 (N)	36 (N)	20 (N)	34 (N)	23 (N)	5 (N)
	58 (S)	46 (S)	23 (S)	55 (S)	42 (S)	21 (S)	43 (S)	22 (S)	6 (S)
213	42 (N)	37 (N)	26 (N)	39 (N)	33 (N)	18 (N)	31 (N)	21 (N)	4 (N)
	65 (S)	53 (S)	27 (S)	62 (S)	47 (S)	24 (S)	50 (S)	25 (S)	7 (S)
231	37 (N)	32 (N)	23 (N)	35 (N)	29 (N)	16 (N)	27 (N)	18 (N)	4 (N)
	78 (S)	63 (S)	32 (S)	75 (S)	57 (S)	29 (S)	59 (S)	30 (S)	8 (S)
234	19 (N)	17 (N)	12 (N)	18 (N)	15 (N)	8 (N)	14 (N)	9 (N)	2 (N)
	66 (S)	53 (S)	27 (S)	63 (S)	48 (S)	24 (S)	50 (S)	32 (S)	7 (S)

Note: (N) stands for North Region, and (S) stands for South Region.

North and South regions of Indiana. Plotted in Figures 7.5, 7.6 and 7.7 are data obtained from Table 7.4 for routine maintenance activities on Interstate, high traffic volume OSH and low traffic volume OSH, respectively. Due to the large number of data points in the table, three plots instead of one were prepared for clarity of presentation.

In a priority rating comparison analysis, as mentioned in the preceding section, one is interested in the relative magnitudes of priority values within each set of ratings. For instance, rating panel A may award priority values of 20, 30, 40 and 50 to four different maintenance activities, while rating panel B awards 40, 50, 60 and 70, and panel C awards 30, 20, 50, 40 to the same activities. It is clear that there is no difference between panels A and B scores for the purpose of routine maintenance programming, and that panel C scores are quite different from those of the two sets. The statistical coefficient of correlation [Neter et al. 1985], "r," would again be an appropriate parameter to measure this difference. Panels A and B would give a "r" value of 1.0, which means a perfect linear association between the two sets of priority scores. Panels A and C or B and C produce a much lower "r" value equal to 0.60, indicating a relatively poor association between the two sets compared.

Using all the 126 pairs of priority scores in Table 7.4, computation gives a value of "r" equal to 0.74. This shows that the agreement between the priority ratings of the North and South regions was only fair. However, a closer examination of the plots in Figures 7.5, 7.6

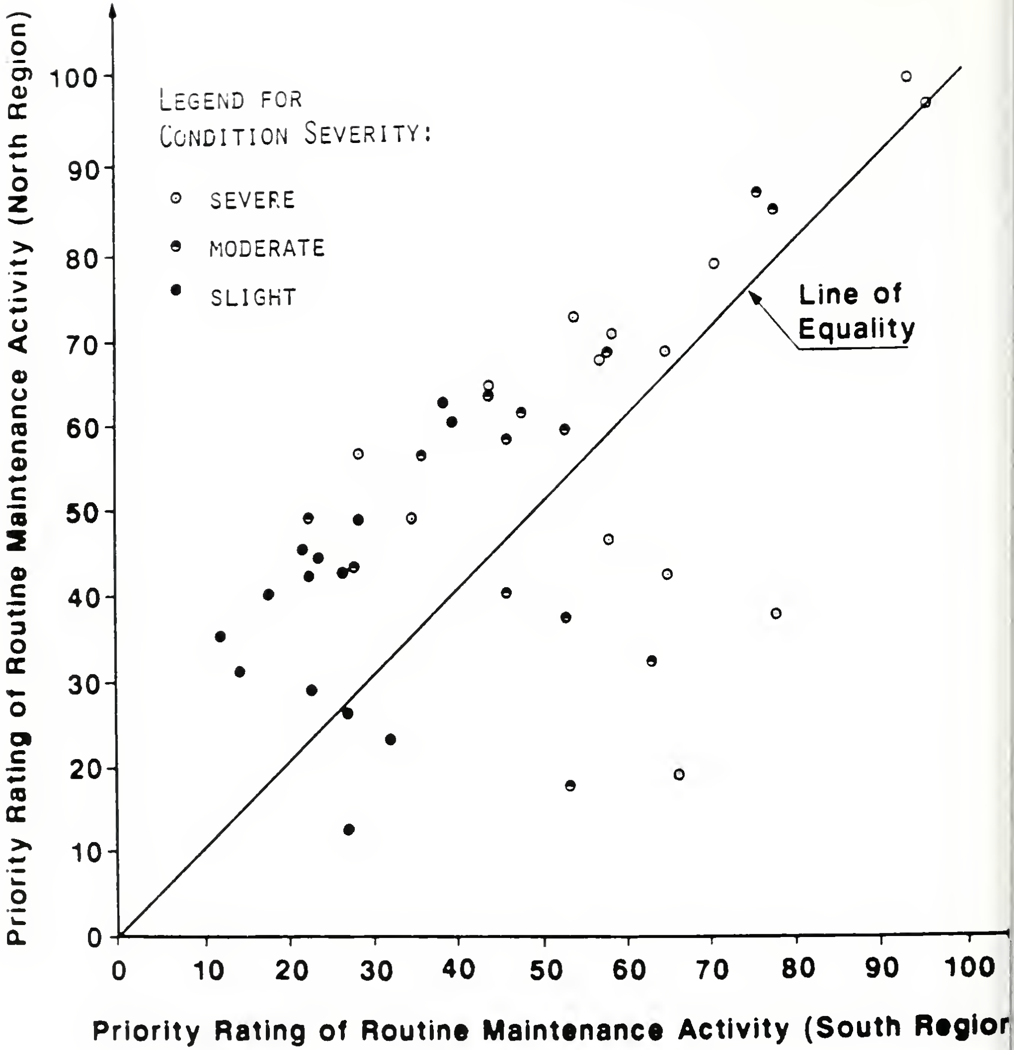


Figure 7.5 Comparison of North and South Region Priority Ratings for Routine Maintenance Activities on Interstate.

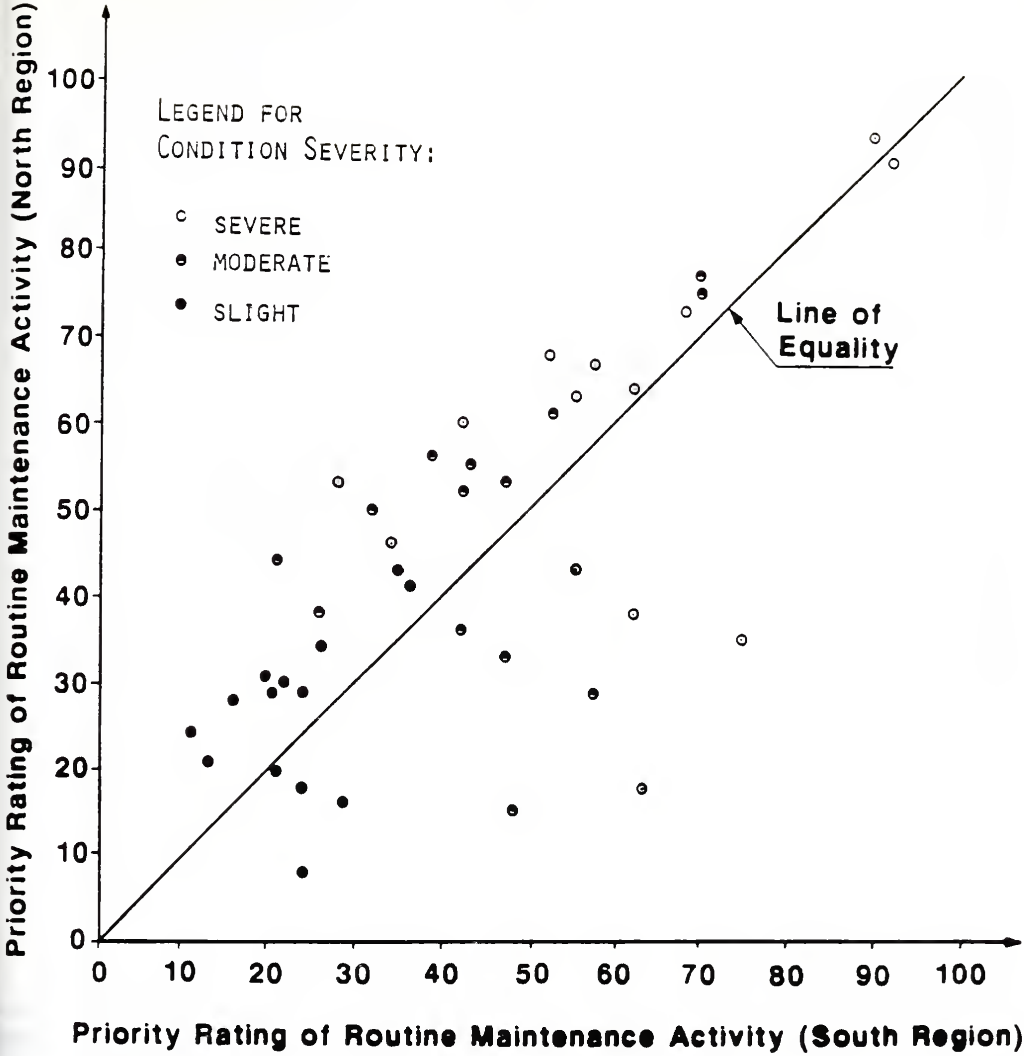


Figure 7.6 Comparison of North and South Region Priority Ratings for Routine Maintenance Activities on High Volume OSH.

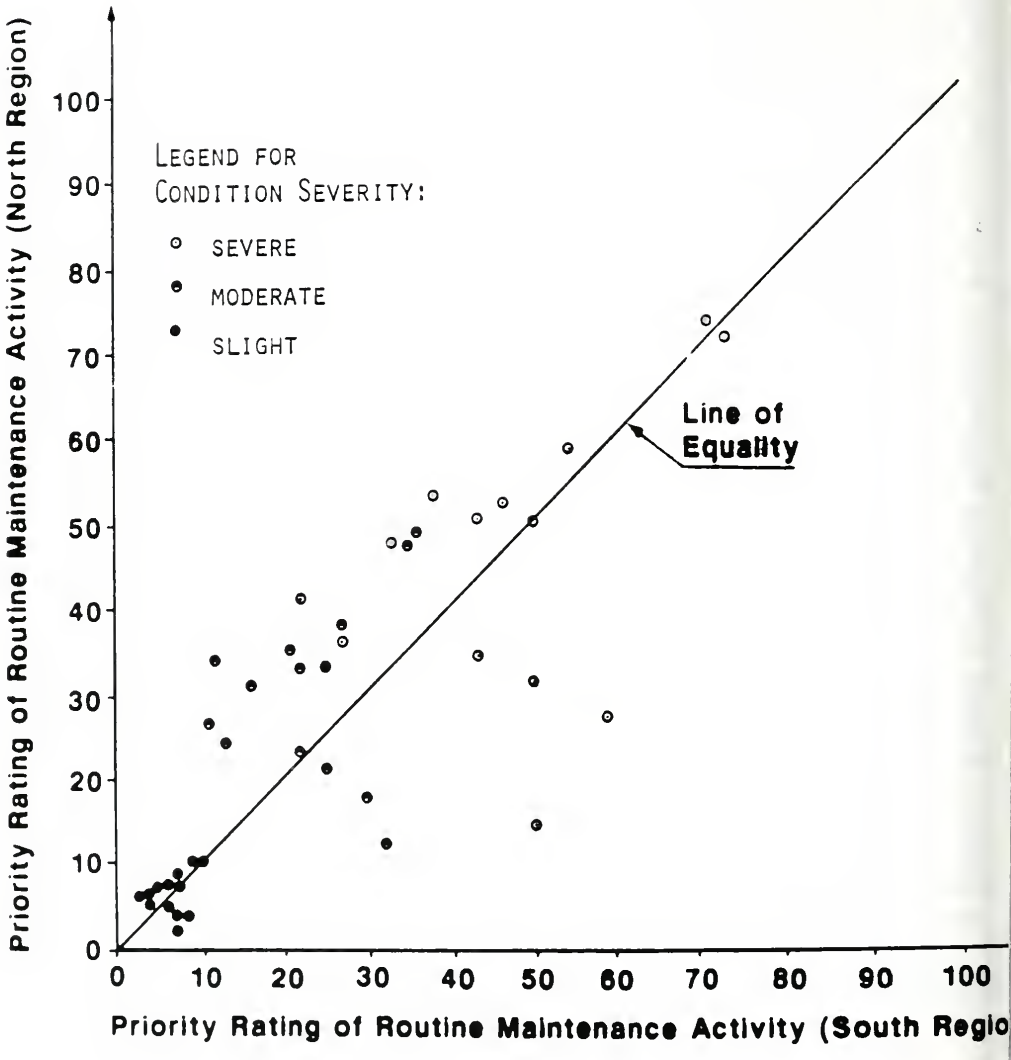


Figure 7.7 Comparison of North and South Region Priority Scores for Routine Maintenance Activities on Low Volume OSH.

and 7.7 shows that (i) all the points that lie below the line of equality belong to the following four maintenance activities: 212, 213, 231 and 234; and (ii) all other data points tend to cluster relatively closely within a straight band.

A revised computation confirms the above observation. Considering only the first 10 maintenance activities in Table 7.4, a "r" value of 0.95 was obtained. For the last four maintenance activities, i.e. activities 212, 213, 231 and 234, the "r" value computed was 0.69. These results reveal that the North and South maintenance personnel were in excellent agreement over the priority ratings of most maintenance activities, except for the four activities mentioned above. These four activities are mainly drainage-related maintenance work. The South region personnel placed more priority on these activities as compared to their counterpart in the North region. This is possibly due to climatic and topographical differences between the two regions. The South has steeper and more rolling to hilly terrain. It also has more rainfall, with an annual average of more than 40 in. compared to about 35 in. in the North.

A study of the priority rankings in Table 7.2 indicates that both the North and South region maintenance personnel gave highest priorities to pavement-related activities such as shallow and deep patching, premix leveling and crack sealing. The main discrepancy arose when the South region maintenance personnel assigned appreciably higher priorities to the last four drainage-related activities. Taking these four activities aside, the two groups of maintenance personnel appeared to be quite agreeable upon the relative priority rankings of the remaining activities. These observations concurs with the comments made in the preceding paragraph.

It can be noticed that the pattern of comparison plot seen in Figure 7.5 for Interstate was repeated very closely in the plot in Figure 7.6 for high volume OSH, and again in Figure 7.7 for low volume OSH. This reflects indirectly a measure of consistency in the rating results. The partitioning technique and the two-stage procedure used in the survey process appeared to have produced logical realistic ratings from the raters. The three plots also show a trend of the position of general data points to shift toward the low priority area at the lower left-hand corner of the plots, as one moves from Interstate to high volume OSH, and then to low volume OSH. This roughly reflects the priority rankings of various highway classes depicted in Table 7.3.

7.5 Summary of Findings

The main findings of the Indiana study are summarized below:

1. The partitioned two-stage survey procedure was well received by raters. The process was found to be quick, easily understood, and easily implemented by maintenance personnel with different levels of knowledge and experience. Analyses of the data showed that logical realistic ratings were obtained from raters. The results provided consensus view of unwritten but important daily decision making process governing routine maintenance practices of the highway maintenance agencies in Indiana.

2. The priority ratings from the North and South regions of Indiana showed in overall a fair degree of agreement, although a distinct difference was found where the South region maintenance personnel placed significantly higher priorities on drainage-related activities compared to their northern counterparts. The two parties showed excellent agreement on the relative priorities of other routine maintenance activities. Both assigned highest priorities to pavement-related activities on Interstate and high volume OSH, and lowest priorities to activities on low volume OSH with moderate and low distress severity levels.

3. The difference in the priority ratings between the two regions is believed to be related to the differences in their climatic and topographical conditions. One would therefore expect variations in priority ratings of maintenance activities among regions with different climatic and environmental conditions.

7.6 Chapter Conclusions

A partitioned two-stage survey scheme was implemented and found to be effective in assessing priority ratings of routine maintenance activities by highway class and road distress severity. The maintenance activity specific priority data were informative and useful in providing meaningful insight into the routine maintenance practices of highway agencies.

Since the priority ratings are influenced by seasonal factors, climatic and environmental conditions, highway maintenance policy emphasis, and pavement maintenance and repair technology, there is a need for each highway agency to develop its own set of routine maintenance priority ratings, and to periodically update it as a part of the continuing process of highway routine maintenance management.

CHAPTER 8

OPTIMAL PROGRAMMING OF MAINTENANCE ACTIVITIES

8.1 Introduction

Timing, frequency, extent and type of routine maintenance work have a significant impact on the performance of highway pavements and other elements [Haas et al. 1978; Fwa et al. 1986] One of the important functions of a maintenance management system is therefore to provide maintenance managers an effective tool to formulate a good routine maintenance program so as to maintain and preserve the road network under their charge at or above a desired standard.

Unfortunately, there exist many factors which make the task of working out a good routine maintenance program difficult. A highway maintenance unit very often has to perform diverse routine maintenance activities on a large number of highway routes over extended areas. These activities are not equally important in terms of their possible consequences. The highways in question may vary from six-lane Interstate highways to light traffic two-lane roads. Furthermore, due to constraints of resources, not all maintenance needs can be attended to as and when required. To be cost-effective, a routine maintenance program must also be planned in coordination with highway rehabilitation programs.

It is apparent that an appropriate optimization model would be useful in determining what routine maintenance activities should be performed, given a schedule of resurfacing or rehabilitation activities and subject to the constraints of total budget, manpower, material, equipment and other constraints related to maintenance system operations. The purpose of the last phase of the research was to develop such a model for programming routine maintenance activities at network level on the basis of the findings of the earlier phases of the study. This chapter describes an integer programming optimization model and discusses the input data requirements. The model can be applied at the unit, subdistrict, district or even at the statewide level. A numerical example is worked out to illustrate the salient features of the programming procedure.

8.2 Background

As mentioned in earlier chapters,the existing Indiana highway maintenance management system has three basic management levels, namely the central office level, district level, and subdistrict level. Each subdistrict is further subdivided into two to four maintenance units which are directly responsible for performing maintenance work in the field.

Annual maintenance work programs for the entire state are developed at the central office level. Separate programs are prepared for each district and subdistrict in accordance with their respective maintenance inventory data. These work programs identify the types and total amounts of work to be performed during the following fiscal year. Annual maintenance budgets are then computed on the basis of these annual maintenance work programs.

The workload for each maintenance activity is computed from quantity standards which are established largely on the basis of engineering judgment and past experience. It should also be noted that the workloads so determined are estimated average annual quantities of total work needed to attain a desired uniform level of service statewide. They do not reflect the needs of a system or class of highways having similar characteristics.

To identify highway sections that require maintenance, subdistrict unit foremen are to inspect roads periodically for maintenance needs and record in a Maintenance Needed Report [IDOH 1985-86]. Based on the record of Maintenance Needed Reports, subdistrict general foremen would prepare a semi-monthly work schedule for each maintenance unit.

The assignment of routine maintenance activities for the Semi-Monthly Schedule is an area where improvements can be made. Possible improvement that can be made in estimating maintenance needs on the basis of foremen's survey has been presented in Chapter 2. Once the needs are assessed, work schedules can be prepared using an optimization programming procedure to select the best combination of routine maintenance activities. Beside enhancing effective and efficient utilization of resources, the use of optimization programming procedure could help to ensure uniformity and consistency in developing work schedules.

8.3 Formulation of Proposed Model

Six forms of constraints are considered in the model. They are production requirements, budget constraints, manpower availability, equipment availability, material availability, and rehabilitation schedule constraint. The mathematical model is presented below. This is followed by a discussion of the basis and rational of the formulation.

8.3.1 Integer Programming Model

Maximize
$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk} F_{ijk} \tag{8.1}$$

where, W_{ijk} is an integer for $i=1,2,\ldots N_1$, $j=1,2,\ldots N_2$ and $k=1,2,\ldots,N_3$.

Subject to

(a) Production requirements

$$0 < W_{ijk} < \frac{T_{ijk}\, \gamma_{ijk}}{U_{ijk}} \qquad i=1,2,\ldots,N_1 \quad j=1,2,\ldots,N_2 \quad k=1,2,\ldots,N_3 \tag{8.2}$$

(b) Budget constraint

$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk}\, U_{ijk}\, C_{ijk} < B \tag{8.3}$$

(c) Manpower availability

$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk} h_j < H \qquad = 1,2,\ldots,L \qquad (8.4)$$

(d) Equipment availability

$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk} q_{jr} < Q_r \qquad r = 1,2,\ldots,R \qquad (8.5)$$

(e) Material availability

$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk} m_{js} < M_s \qquad s = 1,2,\ldots,S \qquad (8.6)$$

(f) Rehabilitation constraints

$$Y_{ijk} = \frac{D - d_{ijk}}{D} \qquad i=1,2,\ldots,N_1 \quad j=1,2,\ldots,N_2 \quad k=1,2,\ldots,N_3 \qquad (8.7)$$

where, W_{ijk} = equivalent workload units in number of work-days of routine maintenance activity j of need urgency level k selected to be performed on highway i,

F_{ijk} = priority weighting factor for routine maintenance activity j of need urgency level k on highway i,

N_1 = total number of highways considered,

N_2 = total number of routine maintenance activities considered,

N_3 = total number of need urgency levels considered,

T_{ijk} = total workload of routine maintenance needs in work measurement units (see Table 7.1) for routine maintenance activit j of distress severity level k on highway i,

Y_{ijk} = rehabilitation constraint factor for routine maintenance activity j of distress severity level k on highway i, $0 < Y_{ijk}$

U_{ijk} = work productivity for routine maintenance activity j of distress severity level k on highway i,

C_{ijk} = cost per production unit of routine maintenance activity j of distress severity level k on highway i,

B = total budget amount allocated for the analysis period considered

h_j = number of man-days of maintenance crew type required for each production day of routine maintenance activity j,

H = total available number of man-days of maintenance crew type,

L = total number of maintenance crew types,

q_{jr} = number of equipment-days of equipment type r required for each production day of routine maintenance activity j,

Q_r = total available number of equipment-days of equipment type r,

R = total number of equipment types,

m_{js} = quantity of material type s required for each production day of routine maintenance activity j,

M_s = total available quantity of material type s,

S = total number of material types,

d_{ijk} = interference period in number of working days during which no maintenance activity type j would be performed on highway i with distress severity level k,

D = total number of working days in analysis period.

8.3.2 Objective Function

The objective function in Equation (8.1) is the sum of equivalent work-day units of routine maintenance activities each weighted by an appropriate priority factor. Work quantities of routine maintenance activities are generally expressed in terms of their respective work measurement units as illustrated in Table 7.1. It is necessary to convert these work quantity measurements into a common basis of reference. Equivalent work-day is chosen because routine maintenance tasks are typically assigned to field crews on a daily basis. In the Indiana maintenance management system, such tasks are authorized daily at subdistrict level by general or unit foreman to each crew by means of crew day cards [IDOH 1985-86]. There is one card per crew, per activity. Each card contains information on what is to be done, when, how, and the manpower and equipment assigned. Expressing work quantity of a routine maintenance type in terms of equivalent work-days therefore has a direct practical meaning easily understood by both field and planning personnel.

Another good reason for using equivalent work-days is that the performance standards of Indiana maintenance management system are all expressed in terms of daily production rate. There is hence a well-defined relationship between amounts of workload and equivalent work-days:

$$P_{ijk} = W_{ijk}\, U_{ijk} \qquad i=1,2,\ldots,N_1 \quad j=1,2,\ldots,N_2 \quad k=1,2,\ldots,N_3 \qquad (8.8)$$

where, P_{ijk} = amount of workload for routine maintenance activity type j of distress severity level k on highway i, expressed in appropriate work measurement unit specified in Table 7.1.

W_{ijk} and U_{ijk} are as defined in Equations (8.1) and (8.2).

Multiplied to each term of the decision variables, W_{ijk}, in Equation (8.1) is a priority weighting factor F_{ijk}. Each routine maintenance activity is identified by activity type, level of distress severity, and highway type. All things being equal, sections with a higher severity of distresses tend to require maintenance more urgently, and vice versa. The need for the detailed identification of routine maintenance activity is apparent because each combination of activity type - distress severity - highway type has a different priority ranking in the importance to maintain and preserve the overall state of network highway conditions. An activity with a higher priority ranking will be assigned a bigger value of weighting factor in Equation (8.1).

It is significant to note that the maximization process of the integer programming procedure would move in the direction of selecting higher priority activities first. Since priority weighting factors reflect relative importance in maintaining overall state of highway conditions, the integer programming solution would therefore provide the best selection of maintenance activities from the standpoint of highway condition preservation. The objective function in Equation (8.1) can thus be viewed as a measure of effectiveness of routine maintenance strategy. A poor selection of low priority maintenance activities, leading to a low objective function value, would not be effective in preserving highway conditions, and vice versa.

8.3.3 Production Requirements

These production constraints simply state that the amount of maintenance work assigned for each activity type should not exceed the need for it. This is logical because any maintenance work done beyond what is necessary would not be effective. Better return could be achieved by spending the resources on other needy activities. Since the decision variables W_{ijk} cannot take on negative values, non-negativity constraints are also included in the production requirement constraints. The rehabilitation factor, γ_{ijk}, will be discussed under the heading of rehabilitation constraint.

8.3.4 Resources Constraints

Equations (8.3) though (8.6) specify constraints on resources including funding, manpower, equipment and material. It is noted that the existing maintenance management practice in Indiana allocates annual budget amounts to management units by routine maintenance activity types based generally on pre-established quantity standards [ISHC 1975]. To account for these fund allocation constraints, Equation (8.3) should be modified as follows:

$$\sum_{j=1}^{N_2} \sum_{i=1}^{N_1} \sum_{k=1}^{N_3} W_{ijk} U_{ijk} C_{ijk} \leq B \qquad j=1,2,\ldots N_2 \qquad (8.9)$$

where, B = budgeted fund for routine maintenance during the analysis period.

The amount of budget available, B, during an analysis period less than a year can be estimated on the basis of historical records. Also, the budget constraints can be set by activity type, if the information is available.

8.3.5 Rehabilitation Constraints

Effective coordination between routine maintenance programming and scheduling of rehabilitation activities, such as resurfacing and reconstruction, is essential for a successful pavement management system. Lack of coordination between the two forms of operations has been identified as a problem in Indiana [Sharaf and Sinha 1984; Ksaibati 1986] Rehabilitation constraints are included in the formulation in this study to ensure proper coordination between the two operations.

The constraint factors γ_{ijk} in Equations (8.2) and (8.7) each represents the proportion of maintenance needs of a routine maintenance activity required to be satisfied after taking into consideration the constraints imposed by rehabilitation work. Figure 8.1 shows schematically how the correction factor for an individual highway section would be computed.

Values of γ_{ijk} may vary from highway type to highway type, depending upon their structural and material characteristics, volumes of traffic carried, and highway classification. They may also be different for different routine maintenance activity types. For instance, seal coating would probably not be scheduled within 1-3 years preceding a major resurfacing work. On the other hand, shallow patching work may be

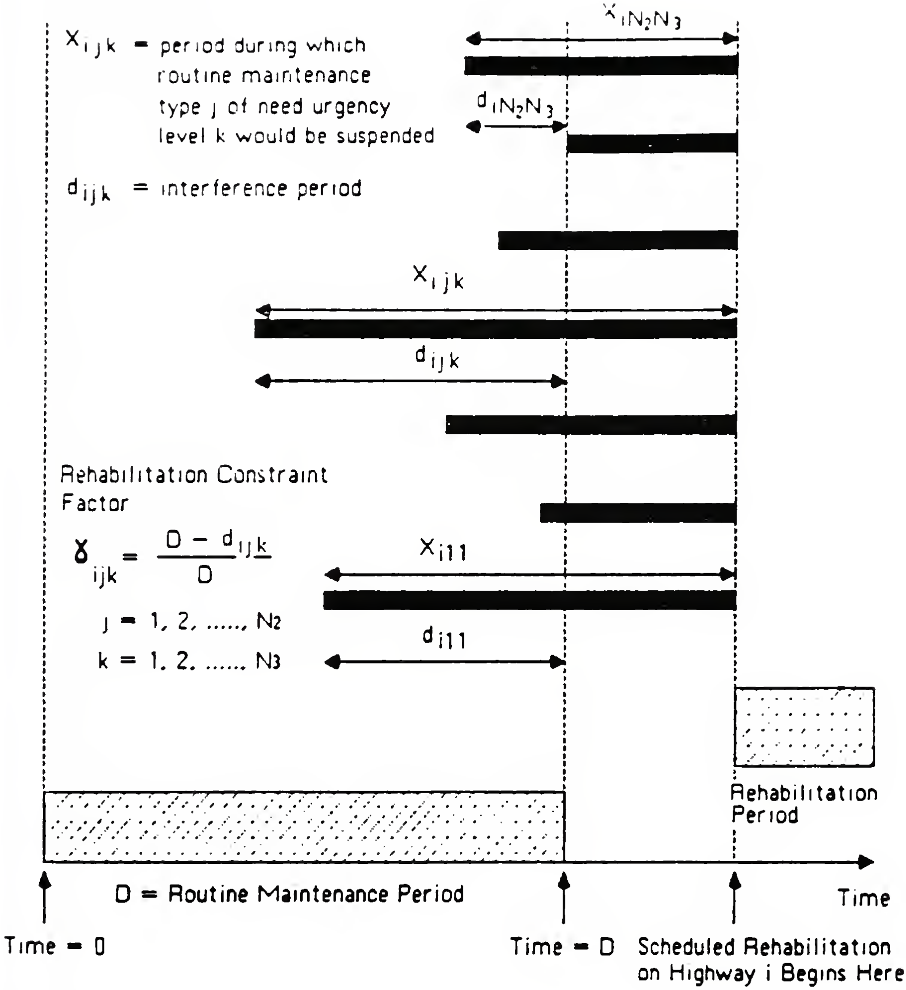


Figure 8.1 Computation of Rehabilitation Constraint Factor γ_{ijk} for Highway Section i.

required weeks or even days before a scheduled rehabilitation to maintain adequate level of service to the traveling public prior to the rehabilitation work. Similarly, due to cost-effectiveness, safety and level of service considerations, the need urgency level of a given routine maintenance type would also have an influence on the length of interference period d_{ijk}, and hence, the value of γ_{ijk}.

Instead of individual highway sections, the programming model can also be applied to highways grouped under a number of highway classes or types. In that case, the rehabilitation constraint factor γ_{ijk} is computed preferably in terms of equivalent work-day units and Equation (8.7) should be replaced by:

$$\gamma_{ijk} = \frac{T_{ijk} - \Sigma(T_{ijk})_d}{T_{ijk}} \quad i=1,2,\ldots,N_1 \quad j=1,2,\ldots,N_2 \quad k=1,2,\ldots,N_3 \tag{8.10}$$

where the term $\Sigma(T_{ijk})_d$ refers to the maintenance workload associated with the interference periods (see Figure 8.1) of all the highway sections in highway class i. A zero value of γ_{ijk} represents a case with $d_{ijk} = D$ where there is a complete interference from rehabilitation work. A γ_{ijk} value of unity implies $d_{ijk} = 0$, indicating no interference from rehabilitation.

8.4 Data Requirements

The data required for the model may be classified into the following main categories:

a. Performance standards

b. Unit costs

c. Resource inventory data

d. Maintenance needs assessment

e. Priority ranking of routine maintenance work

f. Schedule of rehabilitation activities

A description of the specific forms of data required in each of the above categories is presented below. Also described are their respective acquisition procedures currently in use or proposed for use in Indiana.

8.4.1 Performance Standards

Performance standards define the way in which each routine maintenance activity should be performed. They provide guidance to the planning, supervisory and field personnel in the following areas: (i) size and composition of field crew, (ii) number of units and types of equipment, (iii) types and amounts of materials, (iv) step by step procedures for performing the work, and (v) expected daily production.

Specifically, performance standards provide input information for the following coefficients in the routine maintenance programming model: U_{ijk} in Equation (8.3), h_j in Equation (8.4), q_{jr} in Equation (8.5), and m_{js} in Equation (8.6). Performance standards used in the maintenance management of Indiana are found in IDOH Field Operations Handbook.

The proposed programming model requires information on daily production rate, U_{ijk}, on the basis of road condition. Such information is not currently available in the Indiana maintenance performance standards. However, the present research study specifically developed average daily production data that are suitable for use in the model. This work was discussed in Chapter 3, where estimates of daily production rates of various routine maintenance activities for different roadway conditions can be found.

8.4.2 Unit Cost Data

Unit cost in the form of cost per unit production for each routine maintenance activity is required. More desirably, as indicated by the coefficient C_{ijk} in Equation (8.3), cost data by routine maintenance activity type for different roadway conditions should be available. Such detailed cost information would greatly enhance the usefulness of the proposed programming model.

A large amount of research has been undertaken in recent years at Purdue University on routine maintenance costs in Indiana [Sharaf and Sinha 1984; Feighan et al. 1986; Sharaf et al. 1982]. As a consequence of this prior research, it is possible to obtain a unit cost per production unit of each activity for different roadway conditions as required by Equation (8.3) of the programming model.

8.4.3 Resource Inventory Data

Available resources in terms of budget funding, manpower, equipment and materials are necessary input information to the proposed programming model. Budget, manpower and equipment data are easily obtainable from the District or Subdistrict offices of IDOH. Information on material availability is however not as clear.

The requirements for major materials are usually calculated according to routine maintenance work performance, and purchase orders are made for "the right kinds and quantities of materials at the right time to make sure they are available when required" [ISHC 1975]. It therefore appears appropriate to assume that material availability constraints would not be the governing factor in the programming analysis. Consequently, the budget constraint in Equation (8.3) was appropriately adjusted to exclude the amount of material costs.

8.4.4 Maintenance Needs Assessment

The amounts of maintenance need by highway section or highway class and by activity type form the upper bound constraints to the decision variables W_{ijk} in Equation (8.2). The current practice of formulating maintenance workload needs in Indiana relies upon quantity standards which were established largely on the basis of past experience and engineering judgment. The quantity standards enable workload need of each subdistrict to be computed according to its available inventory units. Quantity standards are currently available for each routine maintenance activity by two highway classes, Interstate and Other State Highways.

In the first phase of the present study, a procedure was developed for assessing highway routine maintenance needs based on a condition survey of roadways by unit foremen at the subdistrict level, as discussed in Chapter 7. This procedure would provide maintenance personnel at district and subdistrict levels with realistically defined maintenance needs data. It identifies maintenance needs by highway route, routine maintenance activity type, and degree of distress severity. These maintenance needs data would be input into the programming model proposed in this study.

8.4.5 Priority Ranking of Routine Maintenance Work

The significance of the priority weighting factors, F_{ijk}, in Equation (8.1) has been discussed in an earlier section where the formulation of the objective function was explained. Equation (8.1) requires that all the routine maintenance work items, a total of $(N_1 \times N_2 \times N_3)$ in number, be ranked in accordance with their relative importance in contributing towards preserving the overall network roadway conditions. These values can be obtained, for the fourteen maintenance activities considered in the study, from Chapter 7 of this report. It should be mentioned that absolute values of F_{ijk} factors have no direct effect on the solution of decision variables W_{ijk} in Equation (8.1). It is their relative magnitudes or ranks that makes the difference.

8.4.6 Schedules of Rehabilitation Activities

Lack of coordination between routine maintenance and rehabilitation operations usually arises due to the fact that the philosophy behind scheduling of major rehabilitation activities is different from that for routine maintenance programming. The longterm and predictive nature of the data required for rehabilitation planning does not provide sufficient information to the routine maintenance personnel.

Since effective coordination between the two forms of operation could result in substantial savings in both, it is desirable to have a routine maintenance data base which contains schedule information of relevant rehabilitation activities. A data base system of this nature has been developed in the present study, as discussed in Chapter 5 of this report. Such a system would provide the necessary information for the rehabilitation constraints in Equations (8.7) and (8.10).

8.5 Numerical Illustrative Example

Presented in this section is a numerical example based on routine maintenance data obtained from the Indiana Department of Highways. For illustration purpose, four highway classes, four routine maintenance activity types and three levels of need urgency were considered. Tables 8.1 through 8.7 describe the necessary input data to the problem. Material availability constraints, as explained earlier, were assumed to be satisfied and hence not included.

The solution to the problem is shown in Table 8.8(a) where the value of each decision variable W_{ijk} is given. It was solved using the branch and bound algorithm of MPOS [Cohen et al. 1978]. The optimal workload quantity selected for each routine maintenance item as given in Table 8.8(b) was computed by multiplying W_{ijk} by its corresponding unit production value, U_{ijk}. Table 8.8(c) presents the results by highway class and routine maintenance activity type.

Table 8.1 Work Measurement Units of Some Routine Maintenance Activities in Indiana

Activity Code	Activity Type	Work Measurement Unit
201	Shallow Patching	Tons of Premix
202	Deep Patching	Tons of Premix
203	Premix Leveling	Tons of Premix
204	Full Width Shoulder Seal	Foot Miles
205	Seal Coating	Lane Miles
206	Sealing Longitudinal Cracks & Joints	Linear Miles
207	Sealing Cracks	Lane Miles
208	Sand Seal	Lane Miles
210	Spot Repair of Unpaved Shoulders	Tons of Aggregates
211	Blading Shoulders	Shoulder Miles
212	Clipping Unpaved Shoulders	Shoulder Miles
213	Reconditioning Unpaved Shoulders	Shoulder Miles
231	Clean & Reshape Ditches	Linear Feet
234	Motor Patrol Ditching	Ditch Miles

Table 8.2 Daily Production Rate Data.

Distress Severity Level, k	Maintenance Activity Type, j			
	j=1 (Code 201)	j=2 (Code 202)	j=3 (Code 203)	j=4 (Code 206)
Severe (k=1)	7.2	19.8	120.0	6.3
Moderate (k=2)	4.2	10.4	88.6	8.4
Slight (k=3)	2.8	6.8	55.0	10.2

Note: 1. Description and production measurement unit of each maintenance activity type are given in Table 8.1

2. Values in the table represent U_{ijk} in Equation (8.3) in appropriate measurement units.

3. U_{ijk} values for given indices of j and k are constant regardless highway class i.

Table 8.3 Unit Cost Data.

Distress Severity Level, k	Maintenance Activity Type, j			
	j=1 (Code 201)	j=2 (Code 202)	j=3 (Code 203)	j=4 (Code 206)
Severe (k=1)	85.2	77.4	36.3	131.0
Moderate (k=2)	119.0	121.0	38.1	113.0
Slight (k=3)	159.0	165.0	42.4	103.0

Note: 1. Description and production measurement unit of each maintenance activity type are given in Table 8.1

2. Values in table represent C_{ijk} in Equation (8.3) in dollars per production measurement unit.

3. C_{ijk} values for given indices of j and k are constant regardless of highway class i.

Table 8.4 Manpower and Equipment Requirements.

Maintenance Activity, j	Manpower Requirement, $h_{j\ell}$				Equipment Requirement, q_{jr}					
	$\ell=1$	$\ell=2$	$\ell=3$	$\ell=4$	r=1	r=2	r=3	r=4	r=5	r=6
j=1	0	2	4	0	1	0	1	0	0	0
j=2	1	1	5	1	1	1	0	0	0	1
j=3	1	3	5	2	3	1	1	1	0	1
j=4	1	2	2	4	2	1	0	1	0	0

Note: 1. Manpower and equipment requirement values are in man-days and equipment-days respectively

2. Manpower types 1 to 4 represent respectively supervisors, drivers, laborers and equipment operators

3. Equipment types 1 to 6 represent respectively dump trucks, pickup trucks, crew cabs, distributors, loaders and rollers.

Table 8.5 Maintenance Priority Weighting Factors.

Highway Class, i	Distress Severity Level, k	Maintenance Activity Type, j			
		j=1	j=2	j=3	j=4
i=1 (Urban Interstate)	k=1 (Severe)	90	100	70	50
	k=2 (Moderate)	63	90	63	45
	k=3 (Slight)	54	60	42	30
i=2 (Urban Arterial)	k=1 (Severe)	72	80	56	40
	k=2 (Moderate)	54	70	49	35
	k=3 (Slight)	45	50	35	25
i=3 (Rural Interstate)	k=1 (Severe)	76.5	85	59.5	42.5
	k=2 (Moderate)	58.5	75	52.5	37.5
	k=3 (Slight)	40.5	45	31.5	22.5
i=4 (Rural Primary)	k=1 (Severe)	70.5	65	45.5	32.5
	k=2 (Moderate)	36	40	28	20
	k=3 (Slight)	18	20	14	10

Note: Values in the table represent F_{ijk} in Equation 8.1

Table 8.6 Data on Maintenance Needs and Rehabilitation Constraint Factors.

Highway Class, i	Distress Severity Level, k	Amount of Maintenance Needs: Maintenance Activity Type, j: j=1	j=2	j=3	j=4	Rehabilitation Constraint Factors: Maintenance Activity Type, j: j=1	j=2	j=3	j=4
i=1 (Urban Interstate)	k=1 (Severe)	4	6	8	2	0.82	0.83	1.00	0.80
	k=2 (Moderate)	6	4	2	3	0.70	0.90	0.90	1.00
	k=3 (Slight)	3	25	13	18	1.00	1.00	1.00	1.00
i=2 (Urban Arterial)	k=1 (Severe)	2	6	9	2	0.93	1.00	1.00	0.92
	k=2 (Moderate)	2	10	8	8	0.84	1.00	1.00	0.96
	k=3 (Slight)	4	20	15	15	0.81	1.00	1.00	0.90
i=3 (Rural Interstate)	k=1 (Severe)	5	8	6	5	0.92	1.00	1.00	0.83
	k=2 (Moderate)	5	2	10	10	0.78	1.00	1.00	0.91
	k=3 (Slight)	5	15	15	10	0.80	1.00	1.00	0.96
i=4 (Rural Primary)	k=1 (Severe)	3	4	8	4	1.00	1.00	1.00	1.00
	k=2 (Moderate)	4	16	12	20	1.00	1.00	1.00	1.00
	k=3 (Slight)	15	15	18	15	1.00	1.00	1.00	1.00

Note: Amounts of maintenance needs are expressed in terms of equivalent work-days, each representing directly the quantity $(\frac{T_{ijk}}{U_{ijk}})$ in Equation 8.2

Table 8.7 Resource Constraints and Other Input Information.

Item		Value
1. Analysis period	D	45 working days
2. Budget allocation	b_1	18,000 dollars
	b_2	20,000 dollars
	b_3	13,000 dollars
	b_4	9,000 dollars
3. Manpower availability	H_1	90 man-days
	H_2	135 man-days
	H_3	270 man-days
	H_4	90 man-days
4. Equipment availability	Q_1	135 equipment-days
	Q_2	45 equipment-days
	Q_3	45 equipment-days
	Q_4	45 equipment-days
	Q_5	45 equipment-days
	Q_6	45 equipment-days

Note: Symbols used in table are defined in Equations (8.1) to (8.10)

Table 8.8 Integer Programming Solution to Example Problem.

(a) Output in Equivalent Work-Days

$W_{111} = 3$	$W_{133} = 4$	$W_{222} = 6$	$W_{341} = 4$
$W_{112} = 4$	$W_{141} = 1$	$W_{241} = 1$	$W_{342} = 1$
$W_{113} = 3$	$W_{142} = 3$	$W_{311} = 4$	$W_{411} = 3$
$W_{121} = 4$	$W_{211} = 1$	$W_{312} = 3$	$W_{412} = 4$
$W_{122} = 3$	$W_{212} = 1$	$W_{313} = 4$	$W_{413} = 1$
$W_{132} = 1$	$W_{213} = 3$	$W_{322} = 2$	

Note: All other W_{ijk} have values equal to zero.

(b) Workload in Work Measurement Units

W_{111} = 21.6 tons of premix	W_{222} = 62.4 tons of premix
W_{112} = 16.8 tons of premix	W_{241} = 6.3 linear miles
W_{113} = 8.4 tons of premix	W_{311} = 28.8 tons of premix
W_{121} = 79.2 tons of premix	W_{312} = 12.6 tons of premix
W_{122} = 31.2 tons of premix	W_{313} = 11.2 tons of premix
W_{132} = 88.6 tons of premix	W_{322} = 20.8 tons of premix
W_{133} = 55.0 tons of premix	W_{341} = 25.2 linear miles
W_{141} = 6.3 linear miles	W_{342} = 8.4 linear miles
W_{142} = 25.2 linear miles	W_{411} = 21.6 tons of premix
W_{211} = 7.2 tons of premix	W_{412} = 16.8 tons of premix
W_{212} = 4.2 tons of premix	W_{413} = 2.8 tons of premix
W_{213} = 8.4 tons of premix	

(c) Workload by Highway Class and Routine Maintenance Activity Type

	Shallow Patching (Tons of Premix)	Deep Patching (Tons of Premix)	Premix Leveling (Tons of Premix)	Seal Long. Cracks (Linear Miles)
Urban Interstate	46.8	110.4	143.6	31.5
Urban Arterial	19.8	62.4	0	6.3
Rural Interstate	52.6	20.8	0	33.6
Rural Primary	41.2	0	0	0

The most dominating influence on the final solution appears to come from priority weighting factors. Urban and rural Interstates received most maintenance due to their high priority rankings. The same holds true for shallow and deep patching when routine maintenance activities are compared. These results are within expectation because priority weighting factors directly reflect the sequence in which routine maintenance needs should be carried out. This desired sequence would only be affected to certain extent by resource availability and other constraints.

8.6 Role of the Model in Maintenance Management

The proposed programming model was developed particularly for application at subdistrict levels in Indiana. A detailed discussion of the model and a guide to using it are given in an earlier report [Fwa, Riverson and Sinha 1988]. The applicability and usefulness of such a model can be recognized by examining its potential impacts on the maintenance management system in Indiana.

1. The current bi-monthly subjective selection of routine maintenance activities can be enhanced by the proposed programming procedure without making any changes in the existing management structure. The proposed procedure is able to formulate a program for a more effective and economical utilization of resources.

2. Adoption of the proposed procedure will help to eliminate non-uniform and inconsistent decision-making which is inevitable with the present subjective routine maintenance programming procedure.

By promoting uniformity and consistency across the state at the subdistrict level, it will greatly facilitate planning, monitoring and evaluation of routine maintenance performance on a statewide basis.

3. The model can be easily expanded and modified for use at other network levels. Also, program periods other than the two-week period currently used in Indiana can be analyzed to provide longer-term information which may be useful for planning purposes.

4. Shortfalls and surpluses of resources can be analyzed using the proposed programming model. The possible benefits of re-allocating resources can be investigated by performing parameter sensitivity analysis. These analyses are useful because certain parameters might have been set as a result of managerial policy decisions, and these decisions could be reviewed after examining their consequences on what can be achieved. The amount of certain resources to be made available to a given activity may be adjusted to achieve better results. For instance, the number of temporary laborers to be hired over a given period of the year could be determined by means of such analyses.

The programming model presented has been developed specifically for application in Indiana. Changes are likely needed when applied in other regions due to differences in management systems, maintenance strategy and technology, and data structures.

An extensive amount of data is needed for successful application of the proposed model. All these data, however, should be already available in a fully operational maintenance management system. The value and usefulness of the output information depend very much upon the accuracy and exhaustiveness of the acquired data. The establishment of an appropriate routine maintenance data base is a certain prerequisite to a meaningful routine maintenance programming analysis.

8.7 Chapter Conclusions

There exists a need for the use of mathematical programming to select routine maintenance activities at the subdistrict level of Indiana maintenance management system. An integer programming model was developed to arrive at an optimal combination of routine maintenance activities for achieving the goal of preserving highway systems under a given set of constraints. The constraints considered included maintenance need requirements, budget allocation, manpower, material and equipment availability, and pavement rehabilitation schedule. A priority weighting factor is assigned to each maintenance work so that higher priority work would be selected for execution. The assignment of priority weighting factors takes into consideration (i) the relative importance of each routine maintenance activity in preserving highway systems at a desired level of service conditions, (ii) the urgency of need for a maintenance work in relation to the severity of distresses, and (iii) the type of highway section or highway class.

A considerable amount of routine maintenance data is required for a routine maintenance programming analysis to produce useful results. The importance of setting up a good routine maintenance data base is stressed. Discussed are the types and forms of data needed and the ways in which such data are acquired and processed in Indiana. A numerical example illustrates the procedure of data computation involved in a routine maintenance programming analysis using the proposed model. The proposed programming procedure has great potential in further enhancing the efficiency and effectiveness of the existing maintenance system in Indiana.

CHAPTER 9

CONCLUSIONS

9.1 Major Results of the Study

The study produced several major results. It developed a systematic procedure for estimating maintenance needs based on roadway conditions. This procedure, if properly implemented, can assist in a statewide consistent maintenance budgeting program. An expert system was developed for estimating maintenance needs for flexible pavements. The system can be easily expanded to include other activities. The study established the possible role of maintenance in preserving pavement surface condition indicating that surface roughness data may be used in making certain maintenance decisions. An initial design of an integrated routine maintenance data base system was developed combining several separate data bases so that the information on highway condition, traffic, rehabilitation schedule and other items can be readily obtained by maintenance managers. The research also produced detailed data on service life and cost of various maintenance activities by roadway condition, by material and equipment used. This information can be effectively used to determine the cost-effectiveness of maintenance activities. Next, the study assessed the perceived priorities used by maintenance personnel throughout the state in undertaking maintenance activities. The last major product of the study was the development of an optimization model that can be used to determine the type, amount and location of maintenance activities to be performed so that the overall condition of the roadway would be optimized subject to budget and other resource constraints.

9.2 Recommendations for Implementation

The study dealt with several elements of maintenance management systems. Not all of these can be immediately implemented. Nor can some of them be implemented without further developmental work. Again, some of the items may require additional manpower and accessibility to computers. Therefore, the implementation should take place in an incremental manner. First, the needs assessment procedure using the standards developed in the study can be implemented immediately in a selected set of subdistricts. A series of carefully planned training sessions will be necessary to acquaint the subdistrict personnel with the procedure. The results obtained from the proposed procedure should be used as a complement to the currently used procedure to estimate maintenance needs. Once the procedure appears to produce useful results, more subdistricts can be included. At some point, the standards will have to be updated and a larger sample of subdistricts can be used to estimate the updated standards. As the unit foremen become used to the idea of the condition survey based procedure, the variation in opinion among unit foremen would be minimized and a highly consistent set of standards can be developed. It is believed that the implementation of the procedure using the standards developed in the study would require very little additional manpower, because a periodic condition survey is already a part of the current maintenance management practice in Indiana. The only additional effort would be to record the information in a systematic manner and to make the necessary need estimates. The estimates can be made using the expert system (for flexible pavements) or using the charts provided in the interim report [Montenegro and Sinha 1986].

An immediate use can be made of the information on service life and cost of maintenance activities [Feighan et al. 1986]. By examining the relative cost and effectiveness of performing maintenance alternatives using various materials and equipment under different roadway conditions, the current practices can be evaluated in terms of their cost-effectiveness. Possible changes can then be instituted, if necessary, in maintenance practices of various subdistricts.

The next item that can be implemented, in the short term, is the optimization model [Fwa et al. 1988]. The present version of the model will require the use of the mainframe computer. Although the model requires a large amount of data, they are currently available within the IDOH or as a result of the present study. Once implemented, most of the required data would be fixed and the variable data would include such items as production requirements, budget and other constraints. Initially, it is recommended that the model be implemented in a selected district in order to verify the usefulness of the model and to acquaint the prospective users with the model operation. Although the model will be run at a district office, the data can be specific to a number of selected subdistricts within a district. The results generated by the model can be compared with the manually prepared schedules for monitoring the performance of the model. At some future date, when an integrated routine maintenance data base is implemented, most of the necessary input data for the optimization model would be directly available from the data base.

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