

**DEVELOPMENT OF PAVEMENT MAINTENANCE  
MANAGEMENT SYSTEM (PMMS) OF PATIALA CITY  
ROAD NETWORK USING HDM-4 MODEL**

*A Dissertation submitted*  
in partial fulfillment of the requirements  
for the award of degree of

**Master of Engineering**  
in  
**Civil Infrastructure Engineering**

Submitted by

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Under the Supervision of

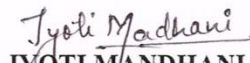
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## DECLARATION

I hereby declare that the thesis titled “**Development of Pavement Maintenance Management System (PMMS) of Patiala City Road Network Using HDM-4 Model**” is an authentic record of my work carried out as requirements for the award of the degree of Master of Engineering in Civil Infrastructure Engineering at Thapar University, Patiala under the supervision of **Tanuj Chopra**, Assistant Professor, Civil Engineering Department, Thapar University, Patiala. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

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## CERTIFICATE

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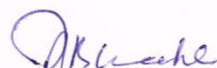
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## **ABSTRACT**

The road transport is in great demand due to its many inbuilt and inherent advantages including its flexibility and reliability. In present scenario, suitable maintenance of highway network is essential for any country for its economic growth. The maintenance of road sections is an essential requirement for the efficiency of highway network.

Indian Road Network is the second largest road network in the world comprising of National Highways, State Highways, Major District Roads, Other District Roads and Urban Roads. To meet the increasing demands of higher pay loads at minimum unit haulage costs, overloading of vehicles has been a common phenomenon on Indian Urban Roads. A rough estimate suggests that more than 50 per cent of the length of Indian Urban Road network is in bad condition needing immediate attention. Allocation of funds for maintenance does not exceed 50 per cent of the normal requirements of roads. Consequently, the gap between the allocation and requirements has been accumulating over the years. So, systematic maintenance of Urban Roads is must.

The focus of the thesis work is mainly on developing Pavement Maintenance Management System (PMMS) for four road sections of Patiala urban road network using HDM-4 model. The Highway Development and Management model (HDM-4) provides a deterministic approach in data input and processing by utilizing data on existing road condition, traffic volume and composition to predict road deterioration as per the urban road conditions in terms of International Roughness Index (IRI) value. This study presents the use of HDM-4 model for the computation of Remaining Service Life (RSL) of all the road sections. Optimum Maintenance and Rehabilitation (M&R) strategy have been determined for each road section using HDM-4 software. Comparative study between Scheduled type and Condition Responsive type M&R strategies has been conducted with the help of HDM-4 model.

The Pavement Maintenance Management System methodology, developed in this study would be useful for the road agencies in planning pavement maintenance strategies in a scientific manner and ensuring rational utilization of limited maintenance funds. Graphical presentations of PMMS results will also be useful for gaining better support from decision-makers, for adequate and timely fund allocations for preservation of the urban road network.

# TABLE OF CONTENTS

<b>DECLARATION</b>	i
<b>ACKNOWLEDGEMENT</b>	ii
<b>ABSTRACT</b>	iii
<b>TABLE OF CONTENTS</b>	iv-vii
<b>LIST OF FIGURES</b>	viii-x
<b>LIST OF TABLES</b>	xi-xiv
<b>LIST OF ABBREVIATIONS</b>	xv
<b>CHAPTER 01: INTRODUCTION</b>	1-8
1.1 General	1
1.2 Statistical Data of Indian Road Network	1-3
1.2.1 Indian Road Network Statistics	1-2
1.2.2 Urban Road Network Statistics in India	2-3
1.3 Road Condition Scenario in India	3-4
1.4 Various Deficiencies and Inadequacies of Urban Roads	4-5
1.5 Classification of Urban Roads	5-6
1.5.1 Arterial Road	5
1.5.2 Sub-arterial Road	5
1.5.3 Collector Street	5
1.5.4 Local Street	6
1.6 Need for Development of PMMS	6
1.7 Objectives of the study	7
1.8 Composition of Thesis	7-8
<b>CHAPTER 02: OVERVIEW OF PMMS AND HDM-4 MODEL</b>	9-17
2.1 Overview of Pavement Maintenance Management System (PMMS)	9-11
2.1.1 Introduction to PMMS	9
2.1.2 Importance of Developing PMMS	10
2.1.3 Components of PMMS	11
2.1.4 Uses of Developing PMMS	11

2.2	Overview of HDM-4 Model	12-17
2.2.1	Introduction to HDM-4 Model	12
2.2.2	Background of HDM-4 Model	12
2.2.3	Role of HDM-4 in Highway Management	13-14
2.2.4	Analytical Framework of HDM-4	14-15
2.2.5	HDM-4 Input Data Modules	15-16
2.2.6	HDM-4 Applications	16-17
<b>CHAPTER 03: LITERATURE REVIEW</b>		18-28
3.1	Literature review	18-27
3.2	Gaps in Existing Literature	27-28
3.3	Objectives of Present Study	28
<b>CHAPTER 04: METHODOLOGY AND REQUIRED DATA COLLECTION</b>		29-67
4.1	General	29
4.2	Methodology for Developing PMMS	29
4.3	Identification and Selection of Patiala City Road Sections	30-31
4.4	Details of Data Required	31-32
4.5	Road Network Data Collection	32-53
4.5.1	General	32
4.5.2	Road Inventory Data	32-35
4.5.3	Traffic Volume Data	35-37
4.5.4	Pavement History Data	38
4.5.5	Structural Evaluation of Pavements	38-44
4.5.6	Functional Evaluation of Pavements	44-53
4.5.6.1	Cracking Measurement	44-46
4.5.6.2	Potholes Measurement	47
4.5.6.3	Rutting Measurement	48-49
4.5.6.4	Roughness Measurement	50-53
4.6	Vehicle Fleet Data	53-56
4.6.1	General	53
4.6.2	Vehicle Fleet Database	54-55

4.6.3	Vehicular Composition and Annual Growth Rate	55-56
4.7	Maintenance and Rehabilitation Works	56-60
4.7.1	Serviceability Levels for Maintenance	56
4.7.2	Maintenance & Rehabilitation (M&R) Treatments and Strategies	57-60
4.7.2.1	Routine maintenance	57
4.7.2.2	Periodic maintenance	58-60
4.8	Costs Data	60-66
4.8.1	Costs of Maintenance and Rehabilitation Works	60-62
4.8.2	Road User Cost (RUC) Data	62-66
4.9	Adaptation of HDM-4 Model to Indian Condition	66-67
 <b>CHAPTER 05: DEVELOPMENT OF PMMS USING HDM-4</b>		 68-109
5.1	General	68
5.2	Use of HDM-4 Application Modules for Pavement Maintenance Management System	68
5.3	Road Network and Vehicle Fleet Data Input in HDM-4	69-76
5.3.1	Road Network	69-73
5.3.2	Vehicle fleet	74-76
5.4	Determination of Remaining Service Life (RSL) of Road Sections	76-84
5.4.1	Input Data	76-77
5.4.2	Selection of Sections and Vehicles	77-78
5.4.3	Define Normal Traffic	78-79
5.4.4	Specify M&R alternative	80
5.4.5	Project Analysis	81
5.4.6	Roughness Progression	81-83
5.4.7	Determination of Remaining Service Life (RSL)	84
5.5	Determination of Optimum M&R Strategy for All the Road Sections	84-105
5.5.1	Input Data	84-85
5.5.2	Selection of Sections and Vehicles	85
5.5.3	Define Normal Traffic	85
5.5.4	Proposed Maintenance and Rehabilitation (M&R)	86

Alternatives	
5.5.5 Specific M&R Alternatives	86-89
5.5.6 Project Analysis	89-90
5.5.7 Road Pavement Deterioration	90-92
5.5.8 Roughness Progression	92-94
5.5.9 M&R Works Report	94-102
5.5.10 Economic Analysis of M&R strategy	102-104
5.5.11 Selection of Optimum M&R Strategy for Each Road	104
Section	
5.5.12 Prioritization of Road Sections based on Optimum M&R	104-105
Strategy	
5.6 Comparative Study of Scheduled type and Condition Responsive	105-109
type M&R Strategy	
5.6.1 Input Data	105
5.6.2 Selection of Sections and Vehicles	106
5.6.3 Define Traffic	106
5.6.4 Proposed Maintenance and Rehabilitation (M&R)	106-107
Alternatives	
5.6.5 Specific M&R Alternatives	107
5.6.6 Project Analysis	108
5.6.7 Roughness Progression	108
5.6.8 M&R Works Report	109
5.6.9 Comparison of M&R Strategies	109
<b>CHAPTER 06: CONCLUSIONS AND RECOMMENDATIONS</b>	110-111
6.1 Conclusions	110-111
6.2 Recommendations for future work	111
<b>REFERENCES</b>	112-114
<b>ANNEXURE A</b>	115-117
<b>ANNEXURE B</b>	118-120
<b>ANNEXURE C</b>	121-128

## **LIST OF FIGURES**

Figure 1.1	Growth Trend in Total Road Length of Indian Road Network	2
Figure 1.2	Growth Trend in Urban Road Network	3
Figure 2.1	Importance of PMMS	10
Figure 2.2	Concept of Life-cycle Analysis in HDM-4	15
Figure 3.1	Roughness Progression for all the Road Sections	27
Figure 4.1	Methodology for Developing PMMS of Patiala Road Sections	29
Figure 4.2	Selected Road Sections Map of Patiala City	30
Figure 4.3	Choked Drain near Petrol Pump on Road Section UR-01	34
Figure 4.4	Still Water on Shoulder near Kababchi Restaurant on Road Section UR-02	34
Figure 4.5	Still Water near Columbia Asia Hospital on Road Section UR-04	35
Figure 4.6	Trend of AADT data for 24-hours for Collector Street Flow type Road sections	36
Figure 4.7	Trend of AADT data for 24-hours for Local Street Flow type Road section	37
Figure 4.8	Different Components of Benkelman Beam Apparatus	39
Figure 4.9	Placement of Beam Probe in between Rear Wheels of Truck	40
Figure 4.10	Benkelman Beam Deflection Test in Progress at Chainage 0.200 km on Section UR-02	41
Figure 4.11	Benkelman Beam Deflection Test in Progress	41
Figure 4.12	Determination of Actual Pavement Temperature on Road Section UR-02	42
Figure 4.13	Cracks on Section UR-03	45
Figure 4.14	Crack Measurement with tape at Chainage 0.100 km on Section UR-02	45
Figure 4.15	Cracks at Chainage 0.050 km on Section UR-04	46
Figure 4.16	Wide Transverse Crack on Section UR-04	46
Figure 4.17	Pothole at Chainage 0.850 km on Section UR-02	47
Figure 4.18	Pothole at Chainage 0.300 km on Section UR-04	47
Figure 4.19	Rut Depth Measurement at chainage 0.200 km on Section UR-01	48
Figure 4.20	Rut Depth Measurement at chainage 0.300 km on Section UR-02	49

Figure 4.21	Rut Depth Measurement at chainage 0.400 km on Section UR-03	49
Figure 4.22	Bump Integrator (Roughometer) Towed with Pick-up	51
Figure 4.23	Bump Integrator Test (Roughness Test) in Progress on Section UR-03	51
Figure 4.24	Bump Integrator Test in Progress on Section UR-03	52
Figure 4.25	Bump Integrator Test in Progress on Section UR-04	52
Figure 5.1	Formation of ‘Collector Street Flow’ Type Traffic Flow Pattern	69
Figure 5.2	Selection of ‘North India Plain’ Climate Zone for the study	70
Figure 5.3	New Section i.e. Bhadson Road, UR-01 Created in ‘Patiala City Road Network’	70
Figure 5.4	Definition Data Input for Bhadson Road Section i.e. UR-01	71
Figure 5.5	Geometry Data Input for Bhadson Road Section i.e. UR-01	71
Figure 5.6	Pavement Data Input for Bhadson Road Section i.e. UR-01	72
Figure 5.7	Condition Data Input for Bhadson Road Section i.e. UR-01	72
Figure 5.8	Calibration Factors Input for Bhadson Road Section i.e. UR-01	73
Figure 5.9	Patiala City Road Network with All the Four Sections Defined	73
Figure 5.10	Definition Data Input for Two-wheeler	74
Figure 5.11	Basic Characteristics Data Input for Two-wheeler	75
Figure 5.12	Economic Unit Costs Data Input for Two-wheeler	75
Figure 5.13	Patiala City Vehicle Fleet with All the Vehicles Defined	76
Figure 5.14	General Input Data for Project: Determination of RSL	77
Figure 5.15	Selection of Sections for Project: Determination of RSL	77
Figure 5.16	Selection of Vehicles for Project: Determination of RSL	78
Figure 5.17	Normal Traffic for the Project: Determination of RSL	78
Figure 5.18	Normal Traffic Details of MT vehicle for Bhadson Road Section i.e. UR-01	79
Figure 5.19	Normal Traffic Details of NMT vehicle for Bhadson Road Section i.e. UR-01	79
Figure 5.20	Defined M&R Alternative for all Selected Pavement Sections	80
Figure 5.21	Intervention Criteria for Selected M&R Work Item	80
Figure 5.22	Run Analysis of Project: Determination of RSL	81
Figure 5.23	Roughness Progression for Bhadson Road Section i.e. UR-01	82
Figure 5.24	Roughness Progression for Bhupinder Road Section i.e. UR-02	82

Figure 5.25	Roughness Progression for Passey Road Section i.e. UR-03	83
Figure 5.26	Roughness Progression for Ghuman Road Section i.e. UR-04	83
Figure 5.27	General Data Input for Project: Determination of Optimum M&R Strategy	85
Figure 5.28	Proposed M&R Alternatives for Project Analysis of Ghuman Road Section	87
Figure 5.29	Work Items Assigned for 'Routine' Work Standard	87
Figure 5.30	General Input Data for 'Patching' Work Item	88
Figure 5.31	Intervention criteria for 'Patching' Work Item	88
Figure 5.32	Costs Data for 'Patching' Work Item	89
Figure 5.33	Set-up Run for Project Analysis	89
Figure 5.34	Roughness Progressions under All Alternatives for Bhadson Road Section	93
Figure 5.35	Roughness Progressions under All Alternatives for Bhupinder Road Section	93
Figure 5.36	Roughness Progressions under All Alternatives for Passey Road Section	94
Figure 5.37	Roughness Progressions under All Alternatives for Ghuman Road Section	94
Figure 5.38	Selection of Bhadson Road Section for Project Analysis	106
Figure 5.39	Data input of M&R Alternatives in Project	107
Figure 5.40	Roughness progression under the three alternatives for Bhadson Road Section	109

## LIST OF TABLES

Table 1.1	Length of Different Categories of Roads (in year 2012)	2
Table 1.2	Design Speed and Recommended RoW for Urban Roads	6
Table 3.1	Inventory Data of All Selected Road Sections	20
Table 3.2	Maintenance and Rehabilitation Strategies for Selected Road Sections	20
Table 3.3	Economic Analysis Summary for Expressway Road Sections	22
Table 3.4	Economic Analysis Summary for National Highway Road Sections	22
Table 3.5	Pavement Condition Data for Each Road Section	24
Table 3.6	Maintenance Alternatives Assigned for the Project	24
Table 3.7	NPV/CAP Ratio for Each Road Section	25
Table 3.8	Inventory and Traffic Data Collection for All Selected Road Sections	26
Table 3.9	Observed Condition Data of All Selected Road Sections	26
Table 3.10	Remaining Service Life (in Years) of all the Road Sections	27
Table 4.1	Section ID and Name of Selected Road Sections	31
Table 4.2	Inventory Data of Selected Road Sections	33
Table 4.3(a)	Relationship Between Drainage Time and Drainage Quality	33
Table 4.3(b)	Drainage Condition of Selected Road Sections	33
Table 4.4	Traffic Volume Data of Road Sections	36
Table 4.5	Road Use and Yearly Flow Distribution Data for Collector Street Flow	37
Table 4.6	Road Use and Yearly Flow Distribution Data for Local Street Flow	37
Table 4.7	Pavement History Data	38
Table 4.8	BB <sub>def</sub> value and SNP value for all Road Sections	44
Table 4.9	Determination of UI and IRI values for all Sections	50
Table 4.10	Functional Evaluation Data of Selected Road Sections	53
Table 4.11	Basic Data of Motorized (MT) Vehicles included in Patiala City Vehicle Fleet	54
Table 4.12	Basic Data of Non-Motorized (NMT) Vehicles in Patiala City Vehicle Fleet	55
Table 4.13	Vehicular Composition and Annual Growth Rate	55

Table 4.14	Maintenance Serviceability Levels for Urban Roads	56
Table 4.15	Price Indices and Fuel Price	61
Table 4.16	Updated Economic Cost Data of M&R works for year 2016	61
Table 4.17	Current Vehicle Operating Cost Inputs (All Prices in Rupees)	63
Table 4.18	Calculation of VOC Components for all types of Vehicle	64
Table 4.19	Calculation of Congestion Factor as per IRC SP: 30-2009	65
Table 4.20	Vehicle Operating Costs data input in per 1,000 vehicle-km unit	66
Table 4.21	Calibration Factors for HDM-4 Deterioration Models	67
Table 5.1	Remaining Service Life of Each Road Section	84
Table 5.2	Proposed Maintenance and Rehabilitation Alternatives	86
Table 5.3	Pavement Deterioration Summary of Section UR-04 for Base Alternative	90
Table 5.4	Pavement Deterioration Summary of Section UR-04 for Alternative 1	91
Table 5.5	Pavement Deterioration Summary of Section UR-04 for Alternative 2	91
Table 5.6	Pavement Deterioration Summary of Section UR-04 for Alternative 3	92
Table 5.7	M&R Works for Bhadson Road Section throughout Intervention Period	95
Table 5.8	Economic Costs of M&R works for Bhadson Road Section	96
Table 5.9	M&R Works for Bhupinder Road Section throughout Intervention Period	96
Table 5.10	Economic Costs of M&R works for Bhupinder Road Section	97
Table 5.11	M&R Works for Passey Road Section throughout Intervention Period	98
Table 5.12	Economic Costs of M&R works for Passey Road Section	99
Table 5.13	M&R Works for Ghuman Road Section throughout Intervention Period	99
Table 5.14	Economic Costs of M&R works for Ghuman Road Section	100
Table 5.15	Year-wise Summary Report of Alternative 1 (Resealing + Thin Overlay) for All the Road sections	101

Table 5.16	Year-wise Summary Report of Alternative 2 (Thick Overlay) for All the Road sections	101
Table 5.17	Year-wise Summary Report of Alternative 3 (Reconstruction) for All the Road sections	102
Table 5.18	Summary of Economic Analysis for Bhadson Road section	102
Table 5.19	Summary of Economic Analysis for Bhupinder Road section	103
Table 5.20	Summary of Economic Analysis for Passey Road section	103
Table 5.21	Summary of Economic Analysis for Ghuman Road section	104
Table 5.22	Optimum M&R Alternative for Each Road Section	104
Table 5.23	Prioritization Ranking of the Road Section	105
Table 5.24	Proposed M&R Alternatives for Project Analysis of Bhadson Road Section	107
Table 5.25	Description of M&R Works with Total Road Agency Costs	109
Table A.1.1	Calculation of Characteristic Deflection for Bhadson Road Section i.e., UR-01	115
Table A.1.2	Calculation of Characteristic Deflection for Bhupinder Road Section i.e., UR-02	116
Table A.1.3	Calculation of Characteristic Deflection for Passey Road Section i.e., UR-03	116
Table A.1.4	Calculation of Characteristic Deflection for Ghuman Road Section i.e., UR-04	117
Table B.1.1	VOC Equations for Two-Wheelers	118
Table B.1.2	VOC Equations for Cars	118
Table B.1.3	VOC Equations for Buses	119
Table B.1.4	VOC Equations for Light Commercial Vehicles (LCV)	119
Table B.1.5	VOC Equations for Heavy Commercial Vehicles (HCV)	120
Table B.2.1	Recommended Equations for Distance-Related Congestion Effects for Different Types of Vehicles	120
Table C.1.1	Pavement Deterioration Summary of Alternative 1 for Bhadson Road Section i.e., UR-01	121
Table C.1.2	Pavement Deterioration Summary of Alternative 2 for Bhadson Road Section i.e., UR-01	121
Table C.1.3	Pavement Deterioration Summary of Alternative 3 for Bhadson	122

	Road Section i.e., UR-01	
Table C.1.4	Pavement Deterioration Summary of Base Alternative for Bhadson Road Section i.e., UR-01	122
Table C.2.1	Pavement Deterioration Summary of Alternative 1 for Bhupinder Road Section i.e., UR-02	123
Table C.2.2	Pavement Deterioration Summary of Alternative 2 for Bhupinder Road Section i.e., UR-02	123
Table C.2.3	Pavement Deterioration Summary of Alternative 3 for Bhupinder Road Section i.e., UR-02	124
Table C.2.4	Pavement Deterioration Summary of Base Alternative for Bhupinder Road Section i.e., UR-02	124
Table C.3.1	Pavement Deterioration Summary of Alternative 1 for Passey Road Section i.e., UR-03	125
Table C.3.2	Pavement Deterioration Summary of Alternative 2 for Passey Road Section i.e., UR-03	125
Table C.3.3	Pavement Deterioration Summary of Alternative 3 for Passey Road Section i.e., UR-03	126
Table C.3.4	Pavement Deterioration Summary of Base Alternative for Passey Road Section i.e., UR-03	126
Table C.4.1	Pavement Deterioration Summary of Alternative 1 for Ghuman Road Section i.e., UR-04	127
Table C.4.2	Pavement Deterioration Summary of Alternative 2 for Ghuman Road Section i.e., UR-04	127
Table C.4.3	Pavement Deterioration Summary of Alternative 3 for Ghuman Road Section i.e., UR-04	128
Table C.4.4	Pavement Deterioration Summary of Base Alternative for Ghuman Road Section i.e., UR-04	128

## **LIST OF ABBREVIATIONS**

AADT	: Annual Average Daily Traffic
BC	: Bituminous Concrete
BM	: Bituminous Macadam
CPI	: Consumer Price Index
CRRRI	: Central Road Research Institute
DBM	: Dense Bituminous Concrete
DBSD	: Double Bituminous Surface Dressing
HDM-4	: Highway Development and Management - 4
IRC	: Indian Road Congress
IRI	: International Roughness Index
MORT&H	: Ministry Of Road Transport & Highways
M&R	: Maintenance and Rehabilitation
MT	: Motorized
NMT	: Non-Motorized
NPV/CAP	: Net Present Value / Capital Cost
PCSE	: Passenger Car Space Equivalent
PCU	: Passenger Car Unit
PMMS	: Pavement Maintenance Management System
RoW	: Right of Way
RSL	: Remaining Service Life
RUC	: Road User Cost
SBSD	: Single Bituminous Surface Dressing
SDBC	: Semi Dense Bituminous Concrete
SNP	: Adjusted Structural Number
UI	: Unevenness Index
UR	: Urban Road
VOC	: Vehicle Operating Cost
WBM	: Water Bound Macadam
WMM	: Wet Mix Macadam
WPI	: Wholesale Price Index

# CHAPTER 01

## INTRODUCTION

---

### 1.1 General

The road transport is perhaps the oldest and undoubtedly, the most widely accepted and adopted mode of transport by the mankind. It is imperative that, for the full and proper development and advancement of a nation, an efficient road transport system is essential.

The road transport is in great demand due to its many inbuilt and inherent advantages including its flexibility and reliability. In the changing scenario of globalization and economic liberalization, a great deal of emphasis is laid on development of this infrastructure through construction of a dependable road network. Consequently, new construction and the upkeep of existing road network have assumed to be of a great significance.

Indian Road Network is the second largest road network in the world. Road transport in India has gained importance over the years despite significant barriers and inefficiencies in inter-state freight and passenger movement compared to railways and air. The Indian government considers road network as critical to the country's development, social integration. The focus of the present study is on the Indian urban road networks and need for their maintenance.

### 1.2 Statistical Data of Indian Road Network

#### 1.2.1 Indian Road Network Statistics

The Indian road network has been developed diversely during the six decades after independence in terms of road length as well as road density. Indian road network comprises of National Highways, Expressways, State Highways, Major District Roads, Village Roads and Urban Roads. The length of different categories of roads as of year 2012 is given in Table 1.1.

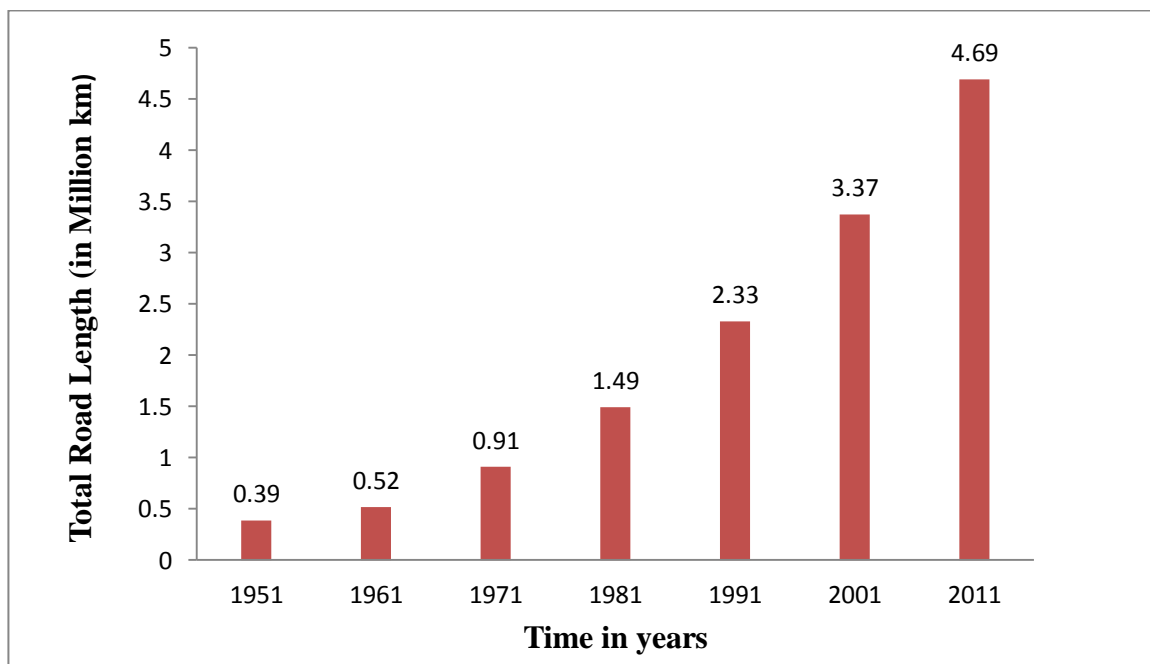
Growth trend in Indian road network has been shown in Figure 1.1. Source for this data is Transport Research Wing, Ministry of Road Transport and Highways (MORT&H). The

total road length (in year 2011) has been increased by 12 times the initial road length (in year 1951) during the decades from 1951 to 2011 (Figure 1.1).

**Table 1.1: Length of Different Categories of Roads (in year 2012)**

Category of Road	Length, Million km
National Highways	0.071
State Highways	0.163
District Roads (MDR, ODR), Village Roads and Rural Roads	3.998
Urban Roads	0.464
<b>Total</b>	<b>4.696</b>

Source: Transport Research Wing, Ministry of Road Transport and Highways (MORT&H)@2012

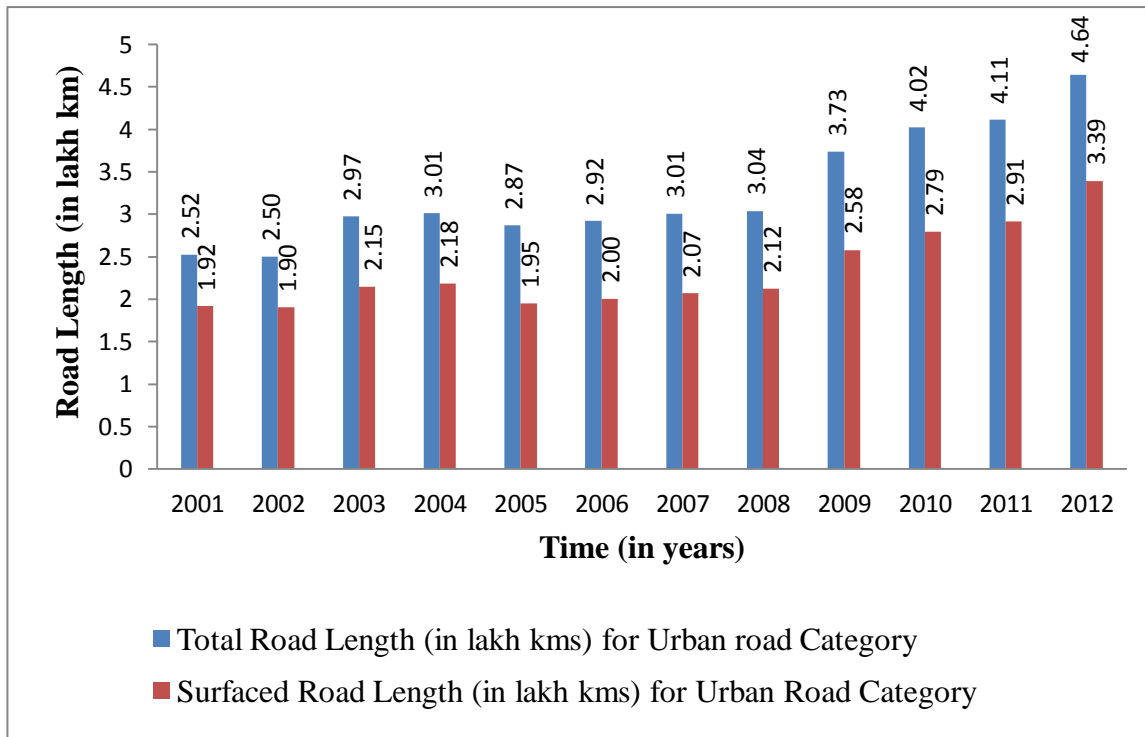


**Figure 1.1: Growth Trend in Total Road Length of Indian Road Network**  
[MORT&H@2012]

### 1.2.2 Urban Road Network Statistics in India

As the focus of the thesis is on urban road network, so the trend growth of urban road network has been studied. The total road length comprises of both surfaced (paved) and unpaved roads. The growth trend in total road length and surfaced road length in lakh km of

urban road network from year 2001 to year 2012 are shown in Figure 1.2. Source for the data is Transport Research Wing, Ministry of Road Transport and Highways (MORT&H). The surfaced road length is approximately 75% of the total road length in each year. The total road length in year 2012 has been increased to 1.84 times the total road length in year 2001. The surfaced road length in year 2012 has been increased to 1.77 times the surfaced road length in year 2001 (Figure 1.2).



**Figure 1.2: Growth Trend in Urban Road Network [MORT&H@2012]**

### 1.3 Road Condition Scenario in India

The construction and maintenance of roads has become a gigantic task for road engineers, with the ever increasing demand for road transport. The existing road network has fallen greatly short of the required capacity and adequacy. To meet the demands, overstraining the existing road infrastructure and the vehicle fleet, is followed and the result is a higher transportation cost. The majority of the roads in the country are deficient with regard to design, standards and geometrics. These reasons are thus responsible for long number of accidents, congestion, delays, and ultimately higher vehicle operating costs. These may end in an irreparable damage to economic growth rate. It is of great concern to note that, the large network established at huge cost is showing signs of accelerated deterioration because of mainly two reasons:

- i) Increased traffic and higher loads than permissible
- ii) Shortfall in funds for construction and maintenance of roads

Due to the poor condition of roads, there is huge annual loss in the form of Vehicle Operating Costs alone. The timely maintenance is missing due to many reasons, which otherwise could have minimized the losses to the exchequer.

#### **1.4 Various Deficiencies and Inadequacies of Urban Roads**

Various deficiencies and inadequacies of urban roads of India are as follow:

- The number of motor vehicles has witnessed a spectacular increase from nearly 0.3 million to 48 millions in a period of 60 years indicating a stunning jump of 150 times. Also, with introduction of new generation vehicles on roads, the load carrying capacity of the commercial vehicles has been enhanced. Further, to meet the increasing demands of higher pay loads at minimum unit haulage costs, overloading of vehicles has been a common phenomenon on Indian urban roads.
- A rough estimate suggests that more than 50 per cent of the length of Indian urban road network is in bad condition needing immediate attention. It should be borne in mind that for achieving the desired economic growth, the foremost requirement is to ensure a good and an effective road network.
- The current maintenance and rehabilitation measures for pavements are based on subjective judgement and past experience of the road engineers only.
- The principal causes of pavement deterioration are left uninvestigated due to lack of data on design, construction and maintenance aspects of pavements.
- Allocation of funds for maintenance does not exceed 50 per cent of the normal requirements of roads. Consequently, the gap between the allocation and requirements has been accumulating over the years.
- Apart from funds, weak planning, poor scheduling and monitoring of maintenance operations, inherent deficiencies in the crust thickness and lack of attention to drainage have contributed much towards accelerated deterioration of urban road network.
- At any given time, the structural and hence the functional condition of a pavement depends on the adverse effect created by ingress and presence of moisture. Water, to

a great extent, can weaken subgrade and overlaying layers. This needs an effective, efficient and well maintained drainage system to minimize the damage to pavements.

## **1.5 Classification of Urban Roads**

Urban roads come under the jurisdiction of Municipal Corporation, Municipal Boards, and Cantonment Boards which are statutory bodies in urban areas. The urban roads are further classified as follow:

### **1.5.1 Arterial Road**

An arterial road is a high-capacity urban road. The key purpose of an arterial road is to deliver traffic from collector roads to freeways, and between urban centers at the highest level of service possible. As such, many arteries are limited-access roads, or feature restrictions on private access. Though the design of arterial roads varies from country to country, city to city, and even within cities, they share a number of common design characteristics. These roads pass through the city limits and carry a large amount of traffic and therefore should be planned as straight as possible, avoiding sharp curves.

### **1.5.2 Sub-arterial Road**

Sub-arterial roads are the city roads which provide lower level of travel mobility than arterial road. Sub-arterial roads are also known as major roads; they run within the limits of the town connecting its important centers. Sub-arterial road's spacing may vary from 0.5 km in central business districts to 3 to 5 km in Sub-urban areas but should normally be not more than 2 km in fully developed areas. Loading and unloading are usually restricted. Pedestrians are allowed to cross these highways at intersections.

### **1.5.3 Collector Street**

Collector Streets are the city roads which are mainly constructed for collecting and distributing the traffic to and from Local Street. Collector Streets are constructed also to provide an access to arterial and sub-arterial streets. These are located in residential, business and industrial areas.

These roads are accessible from the buildings along them. Parking restrictions are few and that too during peak hours.

### 1.5.4 Local Street

Local Streets are the city roads which provide an access to residence, business and other buildings. The traffic carried either originates or terminates along the local streets. Depending upon the importance of the adjoining areas, a local street may be residential, commercial or industrial. Along local streets pedestrians may move freely and parking may be permitted without any restriction.

The Design speeds and space standards for various category of urban road recommended by IRC are given in Table 1.2 [IRC: 86 1983].

**Table 1.2 Design Speed and Recommended RoW for Urban Roads**

<b>Road Classification</b>	<b>Design Speed (kmph)</b>	<b>Recommended Right of Way (RoW) (m)</b>
Arterial Road	80	56-60
Sub-arterial	60	30-40
Collector Street	50	20-30
Local Street	30	10-20

### 1.6 Need for Development of PMMS

Construction of road network involves substantial investment and therefore proper maintenance of these assets is of paramount importance. It is found that the actual maintenance expenditure amount available is much less than what is required for urban roads. The current maintenance practice in India is to provide the maintenance and rehabilitation strategies based on subjective judgement and engineering experience. Ironically, even if the engineer has a significant experience, the presently analytical tools are generally not used in India to assist him in selecting the best strategy based on the economics of life cycle costs.

It is a complex problem of matching of resources, time, materials, labour, equipment, funds, design and most of all decision making. Pavement Maintenance Management System (PMMS) consists of a comprehensive, coordinated, sets of activities associated with the planning, design, construction, maintenance, evaluation and research of pavements. To assist the highway engineer in making consistent and cost effective decisions related to the

construction, maintenance and rehabilitation of pavements, development of Pavement Maintenance Management System (PMMS) is much needed for urban roads. There is a need for development of PMMS for urban roads for scientific planning of maintenance techniques and judicious allocation of maintenance funds.

## **1.7 Objectives of the study**

The focus of the study is mainly on developing Pavement Maintenance Management System (PMMS) for Patiala city urban road network using HDM-4 model. The various objectives of the study are as follows:

- Development of methodology for data collection
- Accomplishment of functional and structural evaluation of Patiala city road sections.
- Study of HDM-4 model.
- Determination of Remaining Serviceable Life (RSL) of Patiala city road sections using Project Analysis in HDM-4 model.
- Determination of optimum Maintenance and Rehabilitation strategy for road sections of Patiala city using Project Analysis in HDM-4 model.
- Prioritization of Patiala city road sections based on optimum M&R strategy.
- Comparative study of Scheduled type and Condition Responsive type M&R Strategy for individual road section using Project Analysis in HDM-4 model.

## **1.8 Composition of Thesis**

The thesis is arranged systematically, exhibiting the objectives of work as defined in the previous section.

**First Chapter** is the introduction chapter. This chapter comprises of statistical data of Indian road network and urban road network, road condition scenario in India, various deficiencies and inadequacies of urban roads. This chapter also covers the classification of urban roads, need for development of PMMS for urban road network and objectives of the present study.

**Second Chapter** presents the overview of Pavement Maintenance Management System (PMMS), role of HDM-4 model for developing the PMMS. This chapter also discusses the overview of HDM-4 model.

**Third Chapter** is the literature review. It discusses the various works done on PMMS using HDM-4 model in India and in abroad.

**Fourth Chapter** incorporates a detailed methodology for the development of PMMS for road sections of Patiala city road network. It comprises of identification and selection of urban road network, required data collection for HDM-4 database such as highway network data, vehicle fleet data, maintenance and rehabilitation standards, cost data of maintenance and rehabilitation work items, road user cost data and adaptation of HDM-4 model for Indian condition.

**Fifth Chapter** describes the application of HDM-4 model for developing PMMS for Patiala city road network. Project Analysis of HDM-4 model has been done to accomplish three objectives i.e. Determination of Remaining Serviceable Life (RSL) of Patiala city road sections, Determination of optimum maintenance and rehabilitation strategy for Patiala city road sections and Comparative study of Scheduled type and Condition Responsive type M&R Strategy for individual road section. Results and discussions of above mentioned objectives have been included in this chapter.

**Sixth Chapter** shows the conclusions of present study and recommendations for future work.

# OVERVIEW OF PMMS AND HDM-4 MODEL

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## 2.1 Overview of Pavement Maintenance Management System (PMMS)

### 2.1.1 Introduction to PMMS

Pavement Maintenance Management System (PMMS) is a technical or operational methodology for managing or directing and controlling maintenance resources, in a scientific manner, for optimum benefits. It is a complex problem of matching of resources, time, materials, labour, equipment, funds, design and most of all decision making, whereas, Pavement Maintenance Management System (PMMS) consists of a comprehensive, coordinated set of activities associated with the planning, design, construction, maintenance, evaluation and research of pavements. The use of this system places continuity emphasis on the economic utilization of personnel, equipment and materials, with the available resources. A major objective of PMMS is to assist the highway engineer in making consistent and cost effective decisions related to the construction, maintenance and rehabilitation of pavements [Guidelines for Maintenance of Primary, Secondary and Urban Roads, MORT&H, 2004].

The Pavement Maintenance Management System performs the following functions:

- To identify projects, in need of M&R and to establish priorities
- Identification of the type of maintenance and/or rehabilitation required
- Requirement of type and timing of future M&R
- To minimize life-cycle costs or maximize benefits
- To predict performance of pavements in future

The prime purpose of maintenance phase in a Pavement Maintenance Management System is to determine the cost associated with providing various level-of-serviceability for any given pavement. This is an important feedback to planning, design and construction. The type and degree of maintenance can also influence the rate and serviceability loss for a pavement. It is clear that Pavement Maintenance Management System requires careful planning and implementation, efficient reporting of maintenance practices and problems.

### 2.1.2 Importance of Developing PMMS

Pavement Maintenance Management System (PMMS) is a scientific tool for managing the pavements so as to make the best possible use of resources available or to maximize the benefit for society. Figure 2.1 shows the importance of developing PMMS for road networks. Existing pavement deteriorates with age or continuous traffic loadings. Pavement deterioration is shown by dashed curve (Figure 2.1). There are two trigger points for showing the periodic maintenance i.e. Treatment 1 and Reconstruction work i.e. Treatment 2. If PMMS is developed, then Treatment 1 is assigned in year A and B at X cost as a periodic maintenance to improve the quality and performance of pavement. If PMMS is not developed, then assignment of periodic maintenance i.e. Treatment 1 is neglected in requisite year. Pavement deteriorates more and reaches to trigger point 2 where reconstruction of pavement becomes essential. Treatment 2 is assigned in year Y at 10X cost for regaining the strength and quality of the pavement. Neglecting development of PMMS results in higher reconstruction cost. So, it is important to develop PMMS for timely and cost effective maintenance of pavement.

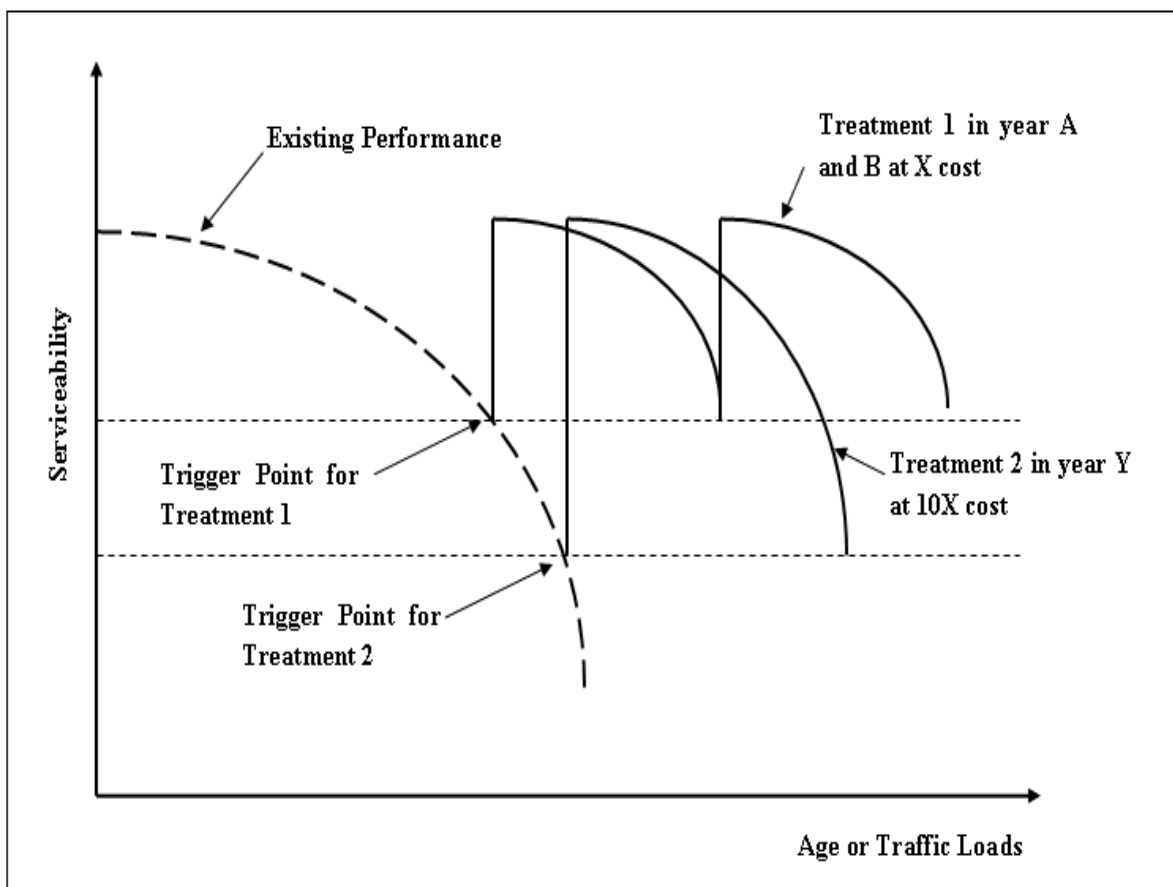


Figure 2.1: Importance of PMMS

### 2.1.3 Components of PMMS

PMMS is divided into two following components:

- ***Database***

PMMS has a database which consists of road inventory data, history data, road condition data and traffic data of that road network.

- ***Pavement Analysis Program (PAP)***

Pavement Analysis Program (PAP) is a set of tools which compute the pavement condition and select the maintenance strategy based on its condition and other criteria. It also helps in making annual work program and required budget. A number of useful reports are generated from this component.

### 2.1.4 Uses of Developing PMMS

With a complete understanding of the database, the typical uses of PMMS are represented as follows:

- ***Pavement Inventory Data***

Once a PMMS is developed for any road network, an entire and readily available inventory data of that road network can be obtained including up-to-date road conditions. This data is essential for routine use in tracing maintenance work and for reference in preparing reports or studies.

- ***Developing Maintenance Budgets***

Instead of preparing the typical one-year maintenance budget, a PMMS allows us to prepare a series of budgets. These budgets can be in the form of a multi-year program, identifying not only short-term (one-year) needs, but outlining needs over the course of many years. Further, alternatives can be prepared and presented to the budget decision makers.

- ***Prioritization***

A PMMS allows us for the prioritization of maintenance projects based on cost and condition ratings and other factors such as traffic. It further can be used for selecting

and ranking of projects for the upcoming budget year, as well as for long term financial planning.

## **2.2 Overview of HDM-4 Model**

### **2.2.1 Introduction to HDM-4 Model**

HDM-4 model (Highway Development and Management model), successor of HDM-III, was introduced by World Bank in year 1996. HDM-4 model is a pavement maintenance management tool which acts as a decision making tool for estimating the economic or engineering entities of road investment projects. HDM-4 software has been developed in such a way that it can be successfully used globally [Kerali et al., 2000]. Calibration factors are used for analysis in the HDM-4 model in case of local conditions to get accurate results.

### **2.2.2 Background of HDM-4 Model**

- First move towards producing a road project appraisal model was made in 1968 by the World Bank i.e. Highway Cost Model (HCM)
- In 1976, World Bank funded further developments of HCM that produced the first version of Highway Design & Maintenance Standard model (HDM).
- In 1987, World Bank developed a more comprehensive model incorporating the findings from all previous studies and this led to HDM-III.
- HDM-III model was in excess of 10 years old by 1995. There was a need to incorporate the results of the extensive research that has been undertaken around the world in intervening period. In the case of vehicle operating costs, it was recognized that vehicle technology has improved dramatically since 1980 with the result that typical vehicle operating cost could be significantly less than cost predicted by HDM-III model.
- It was necessary to update the model. The need of additional capabilities to be included was there such as models for traffic congestion effects, cold climate effects, a wider range of pavement types and structures, road safety, environmental effects (Energy consumption, traffic noise and vehicle emissions).

In this way, Development of HDM-4 model (Highway Development and Management model) was undertaken. In India, concept of HDM-4 came by Central Road Research Institute (CRRI) studies.

### 2.2.3 Role of HDM-4 in Highway Management

HDM-4 model has various roles in highway management in the form of following highway management functions:

- ***Planning***

Planning involves the analysis of the road system as a whole, typically requiring the preparation of medium to long term, or strategic, estimates of expenditure for road development and preservation under various budget and economic scenarios. The physical highway section system is usually characterized at the planning stage by:

- (i) Characteristics of the road network
- (ii) Length of road in each category
- (iii) Characteristics of vehicle fleet which use the road network

- ***Programming***

Programming involves the programme or the preparation, under budget constraints, of multi-year road work and expenditure programmes in which sections of the network likely to require maintenance, improvement or new construction are selected and analyzed. The physical road network is considered at the programming stage on a link-by-link basis, with each link characterized by homogeneous pavement sections defined in terms of physical attributes. The programming activity produces estimates of expenditure in each year for each road section. Budgets are typically constrained, and a key aspect of programming is to prioritize the road works in order to find the best use of the constrained budget.

- ***Preparation***

This is short-term planning stage where road schemes are packaged for implementation. At this stage, designs are prepared in more details; bills of quantities and detailed costing are prepared, together with work instructions and contracts. Detailed specifications and costing are likely to be drawn up, and any cost-benefit analysis may be revised to confirm the feasibility of the final scheme. Works on adjacent road sections may be combined into a package of a size that is cost-effective for work execution. Typical preparation activities are the detailed design of following; an overlay scheme and Road Improvements works.

- ***Operation***

Operation activities cover the on-going operation of an organization. Decisions about the management of operations are made typically on a daily or weekly basis including the schedule of work to be carried out and monitoring in terms of supervisor and labour. Activities are normally focused on individual sections or sub-sections of a road, with measurements often being made at a relatively detailed level.

#### **2.2.4 Analytical Framework of HDM-4**

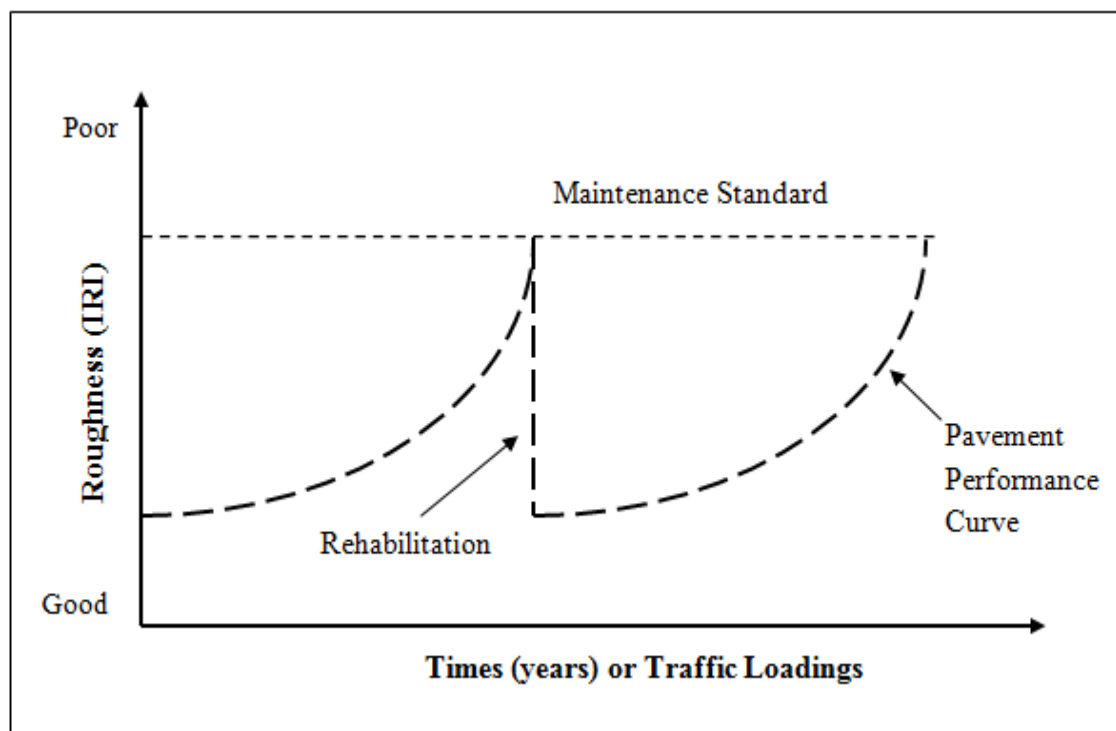
The HDM-4 analytical framework is based on the concept of pavement life cycle analysis. This is applied to predict the following parameters over the life cycle of a road pavement, which is typically 15 to 40 years [Kerali et al. 2000].

- Road Deterioration (RD)
- Road Work Effects (RWE)
- Road User Effects (RUE)
- Socio-Economic and Environmental Effects (SEE)

Once constructed, road pavement deteriorates as a consequence of several factors, most notably traffic loading, environmental weathering and effect of inadequate drainage systems.

Overall long-term condition of the road pavements directly depends on the maintenance or improvement standards assigned to the roads. Figure 2.2 shows predicted trend in pavement performance represented by the riding quality that is often measured in terms of the International Roughness Index (IRI) [Kerali et al. 2000]. When a maintenance standard is defined, it imposes a limit to the level of deterioration that a pavement is permitted to attain.

The impact of the road condition as well as the road design standards, on road users are measured in terms of road user costs. Road user costs comprise of Vehicle Operating Cost (VOC), Cost of Travel Time and Costs to economy of Road Accidents. In HDM-4, Road User Effects can be calculated by predicting physical quantities of resource consumption and then multiplying these quantities by the corresponding user specified unit costs for both motorized vehicles and non-motorized vehicles. HDM-4 is designed to make comparative cost estimates and economic analysis of different investment options.



**Figure 2.2: Concept of Life-cycle Analysis in HDM-4**

### 2.2.5 HDM-4 Input Data Modules

The three analysis tools (Strategy, Programme and Project) operate on data defined in one of four data managers:

- ***HDM-4 Configuration***

Since HDM-4 will be used in a wide range of environments, it provides the facility to customize system operation to reflect the norms. HDM-4 configuration comprises of traffic flow pattern, speed flow pattern, climate zone, currencies and section aggregate data and tables. Default values are supplied with HDM-4, but these are all user-definable and facilities are provided to enable this data to be modified corresponding to the work study environment.

- ***Road Networks***

Road Networks provide the basic facilities for storing the characteristics of one or more road sections. It allows user to define different networks and sub-networks, and to define road sections, which is the fundamental unit of analysis. The data entities supported within the road network are section's definition (section name, ID, length, carriageway width, shoulder, traffic flow in terms of AADT, traffic flow and

speed flow pattern, climate zone, surface class etc.), geometry (rise and fall, speed limit, average horizontal curvature, altitude and drainage type), pavement history (surfacing type, thickness, previous works on road and adjusted structure number (SNP) etc.), condition (condition at the end of year, roughness (IRI), total area of cracking, ravelled area, number of potholes, mean rut depth, drainage etc.). Calibration factors for distresses can be assigned corresponding to work study environment.

- ***Vehicle Fleets***

Vehicle Fleets provide facilities for the storage and retrieval of vehicle characteristics required for calculating vehicle speeds, operating costs, travel time costs and other vehicle effects. Motorized and Non-Motorized vehicles are included with their basic characteristics and economic unit costs. Multiple vehicle fleet data sets can be set up for use in different analysis, with wide range of default data provided.

- ***Work Standards***

Road works standard refer to the targets or levels of condition and response that a road management organization aims to achieve. Road organization set up different standards that can be applied in practical situations in order to meet the specific objective which are related to functional characteristics of road network system.

The work standards folder provides facilities within a flexible framework to define a list of maintenance standards and improvement standards with their default work costs that are followed by road organizations in their network management and development activities.

### **2.2.6 HDM-4 Applications**

- ***Strategy Analysis***

Strategy analysis deals with entire networks or sub-networks managed by one road organization. In order to predict the medium to long term requirements of an entire road network or sub-network, HDM-4 applies the concept of a road network matrix comprising categories of road network defined according to the key attributes that most influence pavement performance and road user costs. A typical road network

matrix could be categorized according to the following: traffic volume or loading, pavement types, pavement conditions, environment or climatic zones, functional classification [Kerali et al., 2000]

- ***Programme Analysis***

This deals primarily with the prioritization of a defined long list of candidate road projects (discrete segments of a road network) into a one-year or multi-year work programme under defined budget constraints. The programme analysis can be used to compare the life cycle costs predicted under the existing regimen of pavement management against the life cycle costs predicted for the periodic maintenance, road improvement or development alternatives.

The main difference between strategy analysis and programme analysis is the way in which road links and sections are physically identified. Programme analysis deals with individual links and sections that are unique physical units throughout the analysis. In strategy analysis, the road system essentially loses its individual link and section characteristics by grouping all road segments with similar characteristics into the road network matrix categories [Kerali et al., 2000].

- ***Project Analysis***

Project analysis is concerned with the following; “Evaluation of one or more road projects or investment options. The application analyses a road link or section with user-selected treatments, with associated costs and benefits, projects annually over the analysis period. Economic indicators are determined for the different investment options.” Project analysis may be used to estimate the economic or engineering viability of road investment projects by considering the issues such as structural performance of road pavements, life cycle predictions of road deterioration, road works effects and costs, road user costs and economic comparisons of project alternatives [Kerali et al., 2000].

#### 3.1 Literature Review

**Kerali et al. [2000]** gave an overview of Highway Development and Management tool (HDM-4). HDM-4, which is the successor to the Highway Design and Maintenance standards Model (HDM-III), was developed by World Bank to provide a harmonized systems approach to road management with adoptable and user-friendly software tools. The scope of HDM-4 has been to present a powerful and systematic system for the analysis of road management and investment alternatives. In HDM-04, additional capabilities such as models for rigid concrete pavement deteriorations, vehicle operating costs, accident costs, traffic congestion effects, cold climatic effects, a wider range of pavement types and structure, road safety and environmental effects have been introduced. The HDM-4 comprises of three dedicated applications tools for project level analysis, road work programming under constrained budgets, and for strategic planning of long term network performance and expenditure needs. Facility for exporting and importing of data has been introduced in HDM-4. Local adaptation and calibration of HDM-4 can be achieved by specifying default data sets which represent pavement performance and vehicle resource consumption in the country where the model is being used.

**Pienaar et al. [2000]** compared HDM-III model with HDM-4 model on a case study conducted in Swaziland. For the study, the Nsoko-Maloma road in Swaziland was selected. Data required for the economic analysis such as road inventory data, condition data, history data, traffic data and cost data were collected on that section. Analysis was done with both models. Then output of HDM-III and HDM-4 models were compared in order to get an insight into the changes and improvements incorporated in HDM-4. The HDM-4 consequently produced lower values for the benefit-cost ratio and internal rate of return on the case study. When compared to the justification level, this reduction did not influence the economic viability of the project. In conclusion, the improvements of HDM-4 as observed in the analysis were summarized. Some of these improvements were a modern-day programming style and wider options with regard to the definition of the vehicle fleet, upgrading choices, pavement types, seal types and other maintenance actions.

**Aggarwal et al. [2005]** developed the Pavement Management System (PMS) for Indian National Highway network using HDM-4 model. For the study, five National Highways, within the boundaries of Dehradun & Haridwar districts of Uttarakhand state and Saharanpur & Muzaffarpur districts of Uttar Pradesh state, comprising of total length of 310 km were selected. The selected network was further divided into 22 road sections. Required data collections were carried out. Using collected road sections data, HDM-4 deterioration models were calibrated for the Indian condition. Under Project Analysis in HDM-4, optimum M&R strategy as well as optimum Improvement strategy was found for the road section on the basis of higher NPV/Cost ratio. The remaining service life of each road sections with no provision of M&R strategy within intervening period was computed. Condition responsive maintenance strategies were compared with the scheduled type of maintenance strategies and it was concluded that the adoption of condition responsive maintenance strategies as compared to scheduled type indicates more than 33% savings in highway agency costs over an analysis period of 20 years. Under Programme Analysis, an unconstrained work programme of whole network was prepared for 10 years.

**Jain et al. [2005]** calibrated the HDM-4 pavement deterioration models for Indian National Highway Network located in the Uttar Pradesh and Uttaranchal states of India. HDM-4 model has been developed for worldwide use. For use of HDM-4 in any country, calibration of model is necessary. For the study, 145 road sections located along National Highways and State Highways of various Indian states were selected. The study continuously monitored and measured performance of the test sections over a period of 3 to 5 years. On the basis of collected data, pavement performance prediction models were developed for the major modes of distress, including cracking, raveling, potholes, and roughness, which are most significant from road maintenance and road user cost considerations. Indian deterioration models were compared with HDM-4 deterioration models. On comparing the observed distresses and predicted HDM-4 distresses, calibration factors were developed for initiation and progression of distresses like cracking, raveling, pothole, roughness. The calibrated HDM-4 pavement deterioration models could be used for prediction of distress and to develop the maintenance management strategies for the Indian National Highway networks.

**Khan et al. [2010]** conducted a study to improve the important features of Pavement Management System (PMS) in Bangladesh. This study dealt with road database analysis of Road and Highway Development (RHD) of Bangladesh for reliability analysis,

development of treatment intervention criteria and optimum maintenance strategies using HDM-4 software. The whole RHD road network was divided into 48 groups of road based on surface type, pavement width and traffic volume for determining the optimum maintenance strategy for each road group. The road inventory data, condition data, history and maintenance strategies with their unit cost were input into HDM-4 software and strategy analysis was performed. Intervention criteria were different for the maintenance strategies of each road group depending upon the road classification. NPV/Cost ratio was the optimization objective function in the analysis. The Maintenance strategy which provided higher NPV/Cost ratio was selected for that road section. Engineering judgment was required when NPV/Cost was approximately same for several maintenance strategies that are applicable to a road group. Engineering judgment was based on the classification of road, importance of the road, pavement performance etc. It was concluded that optimum maintenance strategies for all the road groups would help to develop optimum road maintenance policy for Bangladesh.

**Jain et al. [2013]** developed optimum maintenance and rehabilitation strategy for multilane highways by using programme analysis component of HDM-4 software. For the study, one expressway (from Noida to Greater Noida) divided into five sub-sections and one National Highway (NH-24, Ghaziabad-Hapur) divided into eight sub-sections were selected shown in Table 3.1. Road inventory data and pavement history were collected for all the road sections. Functional as well as structural evaluation (measurement of cracking, potholes, rut depth, roughness and deflection) was performed for each road section.

**Table 3.1: Inventory Data of All Selected Road Sections**

Section ID	Section Name	Length (km)	Carriage-way Width (m)
<b>Expressway: From Noida to Greater Noida</b>			
NGN1	Mahamaya flyover to Bus Stop Ch. 5.0	5.0	10.5
NGN2	Bus Stop Ch. 5.0 to Advit Navis Park	5.0	10.5
NGN3	Advit Navis Business Park to Nr. Brick Kiln	5.0	10.5
NGN4	Brick Kiln to GN Sign Board	5.0	10.5
NGN5	GN Sign Board to GN Roundabout	3.5	10.5
<b>National Highway 24: Ghaziabad to Hapur</b>			
NH-24-01	Km Stone Delhi 11.0 km to 16.0 km	5.0	7.0

NH-24-02	Km Stone Delhi 16.0 km to 21.0 km	5.0	7.0
NH-24-03	Km Stone Delhi 21.0 km to 26.0 km	5.0	7.0
NH-24-04	Km Stone Delhi 26.0 km to 31.0 km	5.0	7.0
NH-24-05	Km Stone Delhi 31.0 km to 36.0 km	5.0	7.0
NH-24-06	Km Stone Delhi 36.0 km to 41.0 km	5.0	7.0
NH-24-07	Km Stone Delhi 41.0 km to 46.0 km	5.0	7.0
NH-24-08	Km Stone Delhi 46.0 km to 51.0 km	5.0	7.0

Keeping in mind the norms for maintenance of National Highways and Expressways [MORT&H, 2004], Maintenance and Rehabilitation (M&R) strategies with the intervention criteria were assigned for each road section considering shown in Table 3.2. M&R works cost data and road user cost data were collected for the economic analysis.

**Table 3.2: Maintenance and Rehabilitation Strategies for Selected Road Sections**

<b>M&amp;R Alternatives</b>	<b>Work Standards</b>	<b>Description of Work</b>	<b>Intervention Criteria</b>
Routine Maintenance	Routine Maintenance	Crack Repairs	> 5%
		Ravel Patching	> 10%
		Pothole Patching	>= 5 %
		Shoulder Repair	Structural crack >= 5 %
Alternative 1	Resealing SDBC	Resealing with 25 mm SDBC	Damage Area >= 5 %
Alternative 2	Thick Overlay	Overlay of 40 mm BC	Roughness >= 2.8 IRI
Alternative 3	Resealing and Overlay	25 mm SDBC Reseal + Overlay of 40 mm BC	Roughness >= 2.8 IRI
Alternative 4	Strengthening	Overlay of 40 mm BC + DBM 50 mm	Roughness >= 2.8 IRI

All the required data were input into HDM-4 and Programme Analysis was performed in HDM-4. While running the analysis, Alternatives 1 to Alternative 4 were compared against Base Alternative. After the completion of programme analysis, the pavement deterioration and M&R works reports were generated. The Economic Analysis Summary for both Expressway and NH-24 road sections have been shown in Table 3.3 and 3.4 respectively.

**Table 3.3: Economic Analysis Summary for Expressway Road Sections**

Section ID	Base Alternative	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	NPV/CAP	NPV/CAP	NPV/CAP	NPV/CAP	NPV/CAP
NGN1	0	6.408	7.799	10.269	4.851
NGN2	0	6.900	7.709	10.128	4.727
NGN3	0	8.058	9.633	11.924	5.735
NGN4	0	2.462	3.206	4.491	1.954
NGN5	0	7.230	8.292	10.560	4.922

**Table 3.4: Economic Analysis Summary for National Highway Road Sections**

Section ID	Base Alternative	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	NPV/CAP	NPV/CAP	NPV/CAP	NPV/CAP	NPV/CAP
NH-24-01	0	8.194	12.437	11.919	8.311
NH-24-02	0	9.368	14.198	13.502	9.379
NH-24-03	0	10.434	15.615	14.838	10.308
NH-24-04	0	9.465	14.302	13.591	9.434
NH-24-05	0	7.408	11.292	10.870	7.606
NH-24-06	0	10.787	16.139	15.240	10.517
NH-24-07	0	12.879	19.127	18.013	12.422
NH-24-08	0	7.003	10.730	10.366	7.278

It was seen that M&R strategy which had higher NPV/CAP ratio was considered as optimum for the road section. On the basis of the economic analysis summary, for Expressway sections, the Alternative 3 i.e., '25 mm SDBC Reseal and 40 mm BC overlay' was selected as the optimum M&R strategy having the maximum NPV/Cost among other alternatives. While, for NH- 24 sections, Alternative 2 i.e., 'Thick Overlay of 40 mm BC' was selected as the optimum M&R strategy with maximum NPV/Cost value. Hence, optimum M&R Strategy was selected by using Programme analysis in HDM-4 model. Finally, a complete procedure was represented as a practical guideline to assist road agencies.

**Shah et al. [2013]** evaluated the pavement performance using pavement condition indicator i.e., Pavement Condition Index (PCI), which is the basic component of Pavement Management System. They developed a combined Overall Pavement Condition Index (OPCI) for the selected network of Noida urban roads. For this purpose, ten road sections of Noida city comprising of 29.92 km were selected for the study. Field data like Pavement inventory and history data were collected. Pavement functional evaluation (measurement of cracking, patching, pothole, rutting, raveling, roughness and skid resistance) and structural evaluation (measurement of deflection) were carried out. The four performance indices i.e., Pavement Condition Distress Index ( $PCI_{\text{Distress}}$ ), Pavement Condition Roughness Index ( $PCI_{\text{Roughness}}$ ), Pavement Condition Skid Resistance Index ( $PCI_{\text{Skid}}$ ), Pavement Condition Structural Index ( $PCI_{\text{Structure}}$ ) were developed individually. Then all these indices were combined to form an Overall Pavement Condition Index (OPCI). The proposed OPCI was expected to be a good representative of pavement condition and performance. The condition of the pavement was rated as well as Maintenance and Rehabilitation (M&R) works were assigned to pavement on the basis of OPCI value which ranged from 0 to 100 i.e., OPCI value from 0-10 means Failed section requiring Reconstruction, 10-25 means Very Poor section requiring Reconstruction, 25-40 means Poor section requiring Mill and Replace, 40-55 means Fair section requiring Overlays, 55-70 means Good section requiring Premix Carpet, 70-85 means Very Good section requiring Preventive Maintenance and 85-100 means Excellent section requiring Routine Maintenance.

It was concluded from OPCI values that out of ten sections, five sections were in need of milling and replacing and other five sections were in need of thick overlays.

**Girimath et al. [2014]** carried out Distress (Defects) survey for Bangalore city outer Ring road for identifying optimum maintenance strategy for selected road network using HDM -4 model. The methodology in this study involved five stages. First stage was the selection of urban road network in which twelve road sections were selected. Second stage was the collection of secondary data like history of road maintenance, maintenance strategies existing in the study area, the cost data for maintenance of road network and routine maintenance details. Third stage was to carry out pavement condition evaluation, i.e. measurement of distresses like potholes, patching, ravelling, surface cracking etc. Fourth stage was to analyze the roadway network at Project level and network level by using HDM-4. Final stage was the prioritization of road network based on economic analysis i.e. NPV/CAP ratio.

Road Condition Survey was done for each road sections. Table 3.5 shows Pavement Condition data for each road section.

**Table 3.5: Pavement Condition Data for Each Road Section**

<b>Section</b>	<b>Crack (%)</b>	<b>Ravel (%)</b>	<b>Pothole (%)</b>	<b>Rutting (%)</b>	<b>Roughness (IRI)</b>	<b>Deflection (mm)</b>
AR-11	1	5	10	4	4.50	0.47
AR-12	9.1	7	14	15	3.06	0.59
AR-13	4.4	8	6	9	2.96	0.55
AR-21	3.2	10	5	4	2.79	0.66
AR-22	5.1	11	8	6	3.00	0.89
AR-23	4.5	16	4	8	2.71	0.60
AR-24	4.9	12	3	11	2.87	0.56
AR-31	6.1	15	5	7	3.15	0.71
AR-32	5.5	7	8	10	3.77	0.62
AR-41	8.2	14	13	7	2.88	0.56
AR-42	1.6	18	15	5	2.80	0.78
AR-43	3	11	12	6	2.78	0.74

Project level pavement analysis was carried out using HDM-4 software with various Maintenance and Rehabilitation alternatives. The following maintenance alternatives were considered for the analysis shown in Table 3.6.

**Table 3.6: Maintenance Alternatives Assigned for Project**

<b>Maintenance Alternatives</b>	<b>Maintenance Work</b>	<b>Intervention Criteria</b>
Base Alternative	Do Nothing	-
Alternative 1	Routine Maintenance	Scheduled Annually
Alternative 2	Overlay BC 40 mm	Roughness $\geq$ 6 IRI
Alternative 3	Overlay SDBC 25 mm	Roughness $\geq$ 6 IRI
Alternative 4	Provide DBM 75 mm	Roughness $\geq$ 6 IRI

The Pavement deterioration and M&R works reports were generated. The Economic Analysis summary of each alternative for all the selected road sections was arrived. It was seen that Alternative 2 was yielding maximum NPV/CAP ratio for all the road sections. The NPV/CAP ratios of Base Alternative and Alternative 2 have been shown in Table 3.7.

**Table 3.7: NPV/CAP Ratio for Each Road Section**

Section ID	Do nothing	Routine Maintenance	Alternative 2
AR-1 (00-1.1)	0	0	0.754
AR-2 (10.5-13.8)	0	0	0.554
AR-2 (6.7-10.5)	0	0	0.504
AR-2 (13.8-16.9)	0	0	0.591
AR-2 (16.9-20.4)	0	0	1.499
AR-2 (20.4-22.2)	0	0	0.827
AR-3 (22.2-24)	0	0	0.757

The following conclusions were drawn, from the field study and HDM-4 analysis. HDM-4 was used successfully for economic analysis purpose and Maintenance treatment with 40mm BC overlay was found out to be optimum for the urban roads of Bangalore city.

**Shah et al. [2014]** analyzed and compared the two methods for priority ranking of road maintenance i.e., (i) Subjective rating based ranking (ii) Economic indicator based ranking. For the study, 21 road sections of total length 60 km of Noida city were chosen. Road inventory data, condition data, history and geometric details were collected for identified sections. Subjective ranking method consisted of determining the Maintenance Priority Index (MPI) for each road section which was further dependent upon four factors i.e., Road Condition Index (RCI) [number that indicates the pavement condition based on five distresses i.e. patching, rutting, raveling, potholes, cracks], Traffic Volume Factor (TVF), Special Factor (SF) [depending upon the classification of urban road] and Drainage Factor (DF). Higher the MPI value, higher will be the priority of road section for maintenance work. In Economic indicator based ranking method, Project Analysis option of HDM-4 was run to prioritize the road sections for maintenance. For prioritization from number of road sections, the road section with highest NPV/CAP was selected. When these two methods were compared, it was seen that for few road sections, the priority ranking differed significantly while for other road sections, the priority ranking was close to each other.

**Gupta et al. [2015]** developed optimum maintenance and rehabilitation strategies for urban bituminous concrete surfaced roads using HDM-4 software. For the study, three road sections were chosen in Panchkula, India. Inventory data, pavement history data, traffic volume data (in terms of AADT), maintenance work costs data and road condition data

(measurement of cracking, roughness, potholes, deflection etc.) were collected. Maintenance strategies were assigned with intervention criteria. Project analysis was carried out in HDM-4. Optimum maintenance activity was selected for the road sections based on maximum NPV/Cost ratio. It was concluded that similar kind of optimum maintenance and rehabilitation strategy can be developed for different categories of urban road network.

**Gupta et al. [2015]** determined the remaining service life (RSL) of different road sections. Three road sections of Panchkula city, Haryana were selected for the study. Inventory data, pavement history data, traffic volume data (in terms of AADT), maintenance works cost data and road condition data (measurement of roughness and deflection) were collected. Inventory and Traffic Data collection has been shown in Table 3.8. Observed condition data has been shown in Table 3.9.

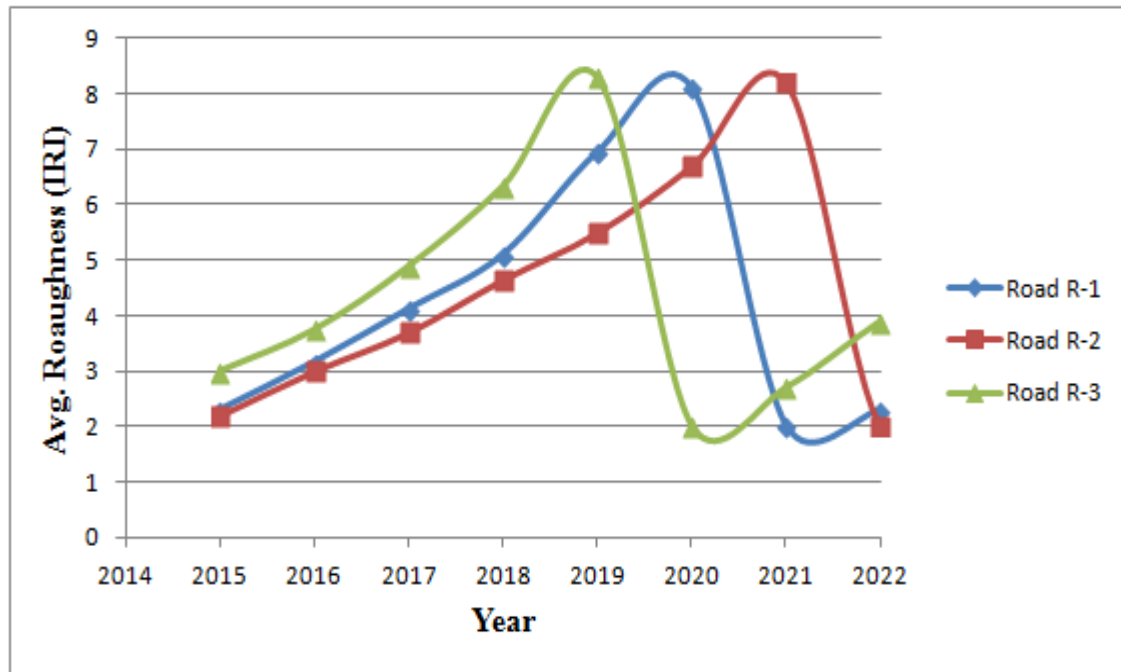
**Table 3.8: Inventory and Traffic Data Collection for All Selected Road Sections**

<b>Section ID</b>	<b>Section Name</b>	<b>Length (m)</b>	<b>Carriage-way Width (m)</b>	<b>AADT</b>	<b>AADT Year</b>	<b>Flow Type</b>
R-1	Amartex Chowk to Sector 15	1.55	9.7	17,140	2014	One Way
R-2	From Sector 14 to Sector 15	1.10	9.7	15,975	2014	One Way
R-3	From Sector 9 to Sector 16	0.960	9.7	22,253	2014	One Way

**Table 3.9: Observed Condition Data of All Selected Road Sections**

<b>Section ID</b>	<b>Condition Year</b>	<b>Roughness IRI (m/km)</b>	<b>Benkelman Beam Deflection (mm)</b>	<b>Adjusted SNP</b>
R-1	2013	2.23	0.42	3.76
R-2	2013	2.19	0.41	3.82
R-3	2013	2.68	0.44	3.65

Project level Analysis in HDM-4 was selected to determine the Remaining Service Life (RSL) of selected road sections. ‘Do Nothing uptill Reconstruction’ Alternative was created with intervention criteria of Roughness  $\geq 8$  IRI. All the data were input and the project was analyzed. Figure 3.1 shows the Roughness Progression for all the road sections.



**Figure 3.1: Roughness Progression of Each Road Section**

The Remaining Service Life (RSL) of each road section was determined as the time period left in years before the reconstruction of pavement was necessitated on the basis of progression of roughness up to the intervention level (i.e. Roughness  $\geq 8$  m/km IRI). Remaining Service Life of each road sections were determined and shown in Table 3.10.

**Table 3.10: Remaining Service Life (in Years) of All Selected Road Sections**

Section ID	Reconstruction Year	Remaining Service Life (RSL in Years)
R-1	2020	5
R-2	2021	6
R-3	2019	4

It was concluded from RSL values that all the three road sections would become candidates for reconstruction within 4 to 6 years without any maintenance work assigned during analysis period.

### 3.2 Gaps in Existing Literature

As, literature review of PMMS using HDM-4 model have been discussed in previous section. There are some gaps in existing literature of developing Pavement Maintenance Management System (PMMS) with the help of HDM-4 model. These gaps are as follows:

- Comparative study of Scheduled type and Condition Responsive type M&R Strategy for Indian National Highways had been conducted. But, comparative study of Scheduled type and Condition Responsive type M&R Strategy for Indian urban road network has not been performed yet.
- The methodology for development of PMMS is complex to understand and needs to be made simpler so that field engineers will be able to understand and utilize it effectively.
- Calibration factors for pavement deterioration model have been developed successfully for Indian National Highways in past. But, there are no specific calibration factors developed till now for pavement deterioration model for Indian urban road network.

### **3.3 Objectives of the Study**

The objectives of the present study are as follows:

- Determination of Remaining Serviceable Life (RSL) of Patiala city road sections using Project Analysis in HDM-4 model.
- Determination of optimum Maintenance and Rehabilitation strategy for road sections of Patiala city using Project Analysis in HDM-4 model.
- Prioritization of Patiala city road sections based on optimum M&R strategy.
- Comparative study of Scheduled type and Condition Responsive type M&R Strategy for individual road section of urban road network using Project Analysis in HDM-4 model.

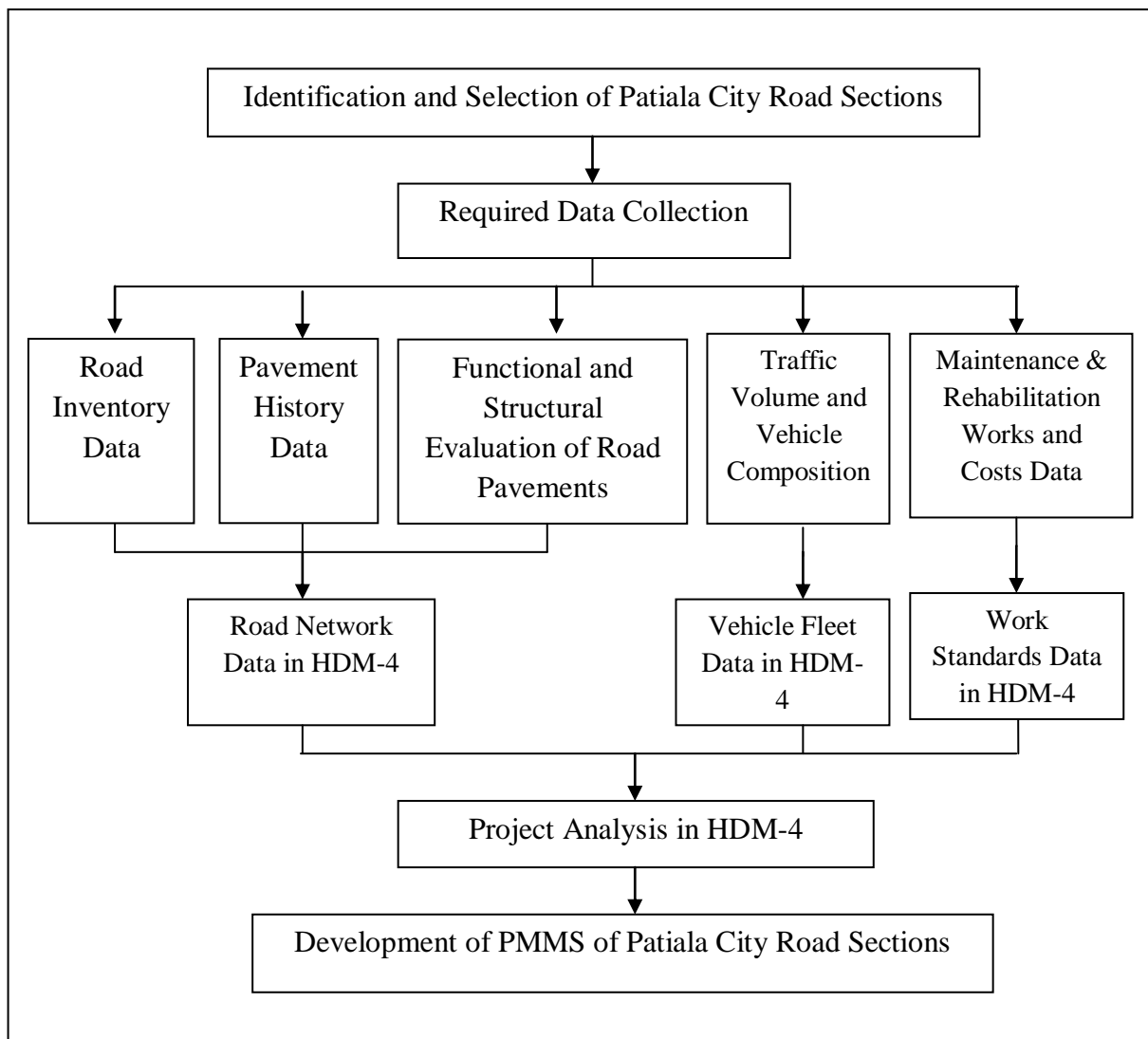
**METHODOLOGY AND REQUIRED DATA COLLECTION**

**4.1 General**

It is important to prepare a systematic methodology which should include all the processes involved in the development of Pavement Maintenance Management System. In this chapter, methodology for developing PMMS has been shown.

**4.2 Methodology for Developing PMMS**

Methodology for developing Pavement Maintenance Management System (PMMS) of Patiala city road sections is shown in Figure 4.1 with the help of flow chart.



**Figure 4.1: Methodology for Developing PMMS of Patiala Road Sections**

### 4.3 Identification and Selection of Patiala City Road Sections

The very first step in developing the Pavement Maintenance Management System (PMMS) is to identify the road network and select the road sections based upon the homogeneity properties. In the present study, Patiala city road network has been identified and four road sections comprising of total length 4 km have been selected for developing Pavement Maintenance Management System. Figure 4.2 shows the road map of selected road sections of Patiala city.

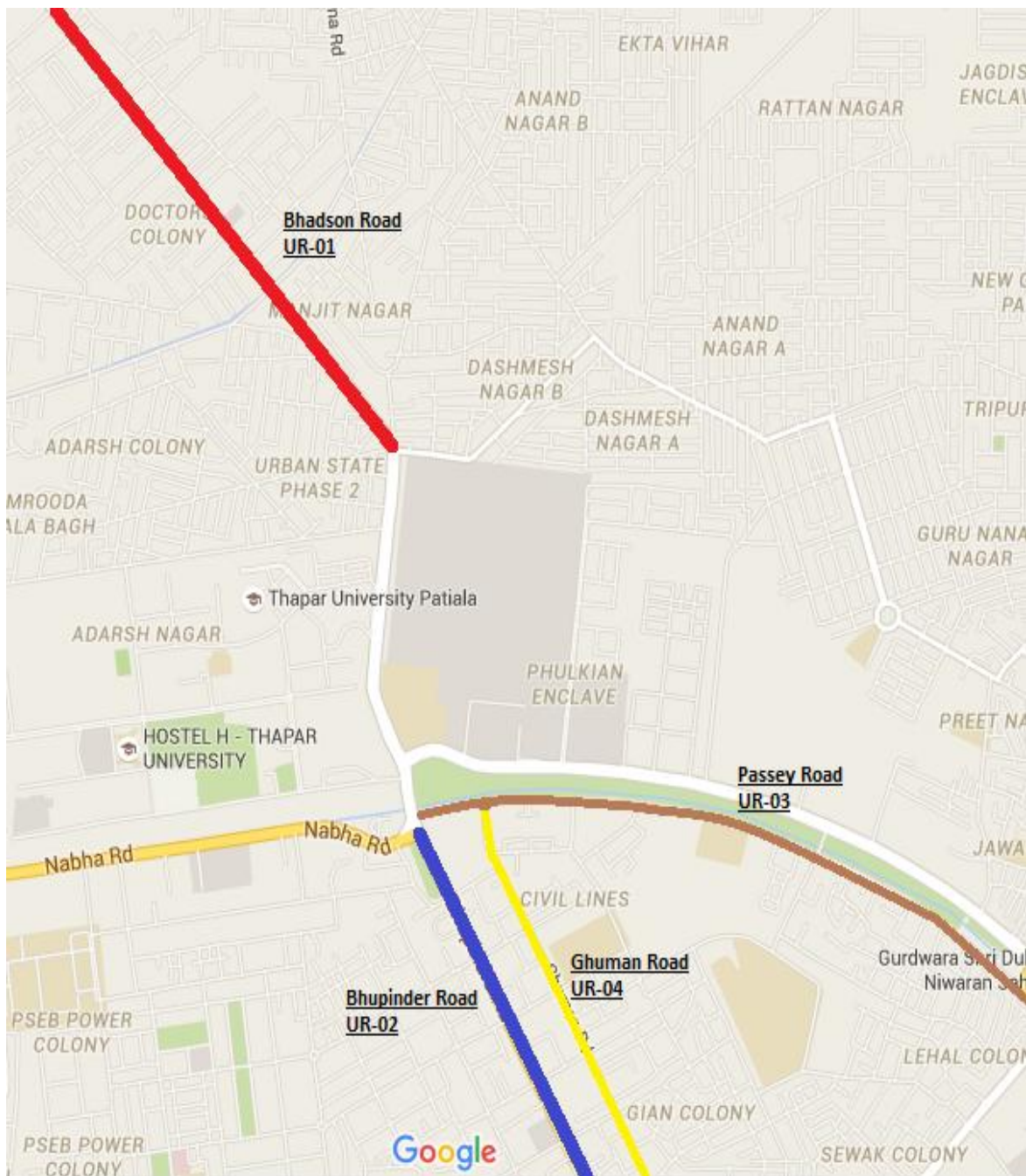


Figure 4.2: Selected Road Sections Map of Patiala City

The selected road sections are homogenous within them, but vary considerably from each other in terms of traffic and pavement width. All the selected pavement sections have been assigned a unique ‘Section ID’ and a ‘Section Name’ for their easy identification as given in Table 4.1.

**Table 4.1: Section ID and Name of Selected Road Sections**

<b>Section ID</b>	<b>Section Name</b>	<b>Description</b>	<b>Classification of Road</b>
UR-01	Bhadson Road	From Central Jail to Sarabha Nagar	Collector Street
UR-02	Bhupinder Road	From Thapar University to Sahni’s Bakery	Collector Street
UR-03	Passey Road	From Thapar University to Charan Bagh	Collector Street
UR-04	Ghuman Road	From Passey Road to Civil Lines	Local Street

#### **4.4 Details of Data Required**

The required data were collected in such a way that they directly or in their derived form should meet the requirements of HDM-4 system.

Data collection required were divided into four categories, which are as follows:

- Road Network Data
- Vehicle Fleet Data
- Maintenance and Rehabilitation Works Data
- Costs Data

Road Network data refer to inventory data, pavement history data, pavement condition data etc. Vehicle Fleet data include representation of vehicles with their basic characteristics. Maintenance and Rehabilitation Works data refer to details of maintenance activities for the road section. Costs data include road use cost data and maintenance works cost data. Detailed description of each data collection category, their procedure for collecting the data and equipments used for the same have been discussed in further sections.

## 4.5 Road Network Data Collection

### 4.5.1 General

According to the data requirements of HDM-4, the road network data collection was carried out for all the sections. The road network data collection was divided into four components.

- Road Inventory Data
- Traffic Volume Data
- Pavement History Data
- Pavement Functional and Structural Evaluation Data

In order to adapt HDM-4 for use in the study area, the various road network elements have been defined as given below:

- *Speed flow type*

In the study, the speed flow type on selected road sections varied from ‘Two Lane Standard’ to Four Lane Standard and the width of the carriageway. Speed flow type has been shown in Table 4.2 for each road sections.

- *Climate zone*

One climate zone namely ‘North India Plain’, has been defined on the basis of temperature (mean annual temperature) and rainfall (mean annual precipitation) characteristics of the study area i.e. Patiala City. Mean annual temperature is 24.5 °C and Mean annual precipitation is 254 mm for Patiala city (source: Climate-Data.org).

### 4.5.2 Road Inventory Data

The inventory data includes the following details about the selected road sections:

- (i) Name and Category of road
- (ii) Carriageway width
- (iii) Shoulder width
- (iv) Drainage condition

The above data was collected from visual inspection of the pavement sections, as well as from the Municipal Corporation, Patiala. The Inventory Data of All Selected Sections of Patiala city is shown in Table 4.2.

**Table 4.2: Inventory Data of Selected Road Sections**

Section ID	Section Length (km)	Carriageway Width (m)	Shoulder Width (m)	Speed Flow Type	Flow Direction	Design Speed (km/hr)
UR-01	1.000	8.4	1.4	Two-Lane Wide Road	Two-way	50
UR-02	1.000	13.4	1.9	Four Lane Divided Road	Two-way	50
UR-03	1.000	6.5	1.6	Two Lane Road	Two-way	50
UR-04	1.000	7.2	1.9	Two Lane Road	Two-way	30

**Drainage Condition Data:** Data regarding side drainage condition on the road sections was collected on the basis of visual inspection and local public opinion. Drainage condition was classified as excellent, good, fair, poor, very poor based on the relationship between drainage time and drainage quality and condition of drains provided shown in Table 4.3(a). Lined drains have been provided in UR-01 and UR-02. There is no provision of drain in UR-03 and also drain is not required in this section. There are choked lined drains in UR-04 road section. Table 4.3(b) shows the drainage condition of selected road sections. Figure 4.3, 4.4 and 4.5 show the drainage condition on different road sections.

**Table 4.3(a): Relationship between Drainage Time and Drainage Quality**

Drainage Quality	Excellent	Good	Fair	Poor	Very Poor
Free water Removed Within	2 hours	12 hours	1 day	3 day	> 3 days

**Table 4.3(b): Drainage Condition of Selected Road Sections**

Section ID	Section Name	Drainage Condition
UR-01	Bhadson Road	Good
UR-02	Bhupinder Road	Good
UR-03	Passey Road	Excellent
UR-04	Ghuman Road	Poor



**Figure 4.3: Choked Drain near Petrol Pump on Road Section UR-01**



**Figure 4.4: Still Water on Shoulder near Kababchi Restaurant on Road Section UR-02**



**Figure 4.5: Still Water near Columbia Asia Hospital on Road Section UR-04**

#### **4.5.3 Traffic Volume Data**

Traffic volume counts are conducted manually for 72 hours consecutively by engaging adequate number of enumerators in individual road section. In this study, Traffic volume data was collected from Municipal Corporation, Patiala.

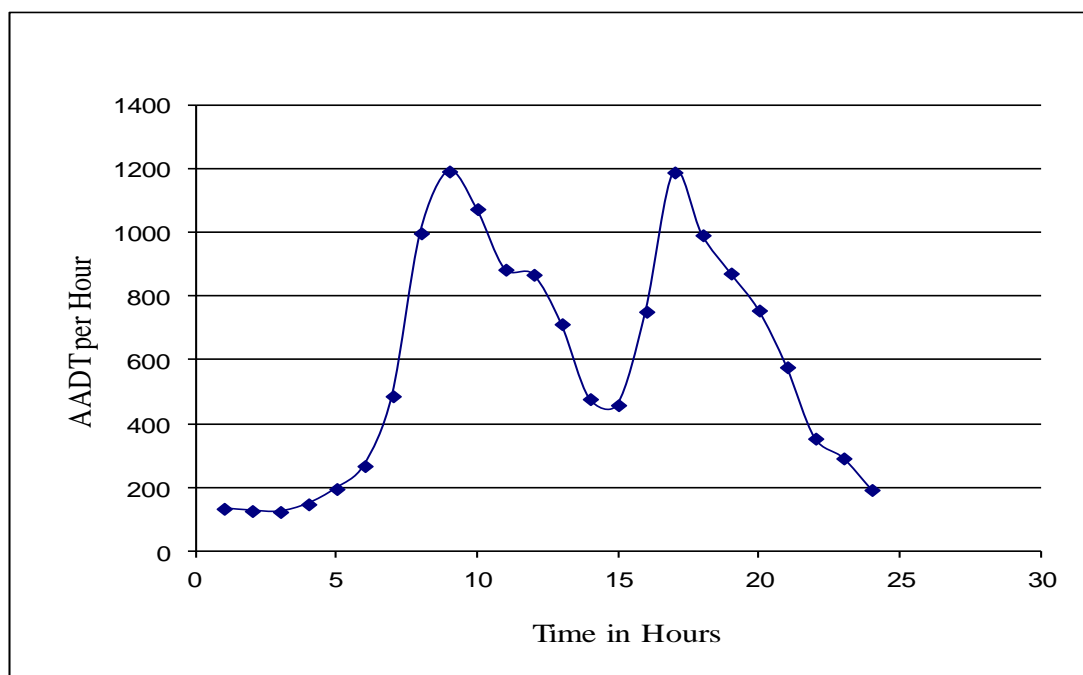
In HDM-4 model, Traffic data is entered in the form of Annual Average Daily Traffic (AADT). Instead of expressing AADT in PCU unit, AADT is expressed in PCSE unit in HDM-4. PCSE (Passenger Car Space Equivalent) is termed as the differences in space occupied by each vehicle based on its size (length of vehicle) as compared with that of standard vehicle (car).

AADT for each section were calculated by summing up the products of number of individual vehicle and its PCSE factor. Table 4.4 shows the traffic volume of each road section in terms of AADT. As per HDM-4 model, section having traffic volume more than 10,000 AADT is considered as High traffic volume section, section having in between 6,000 to 10,000 AADT as Medium traffic volume section and less than 6,000 AADT as Low traffic volume section.

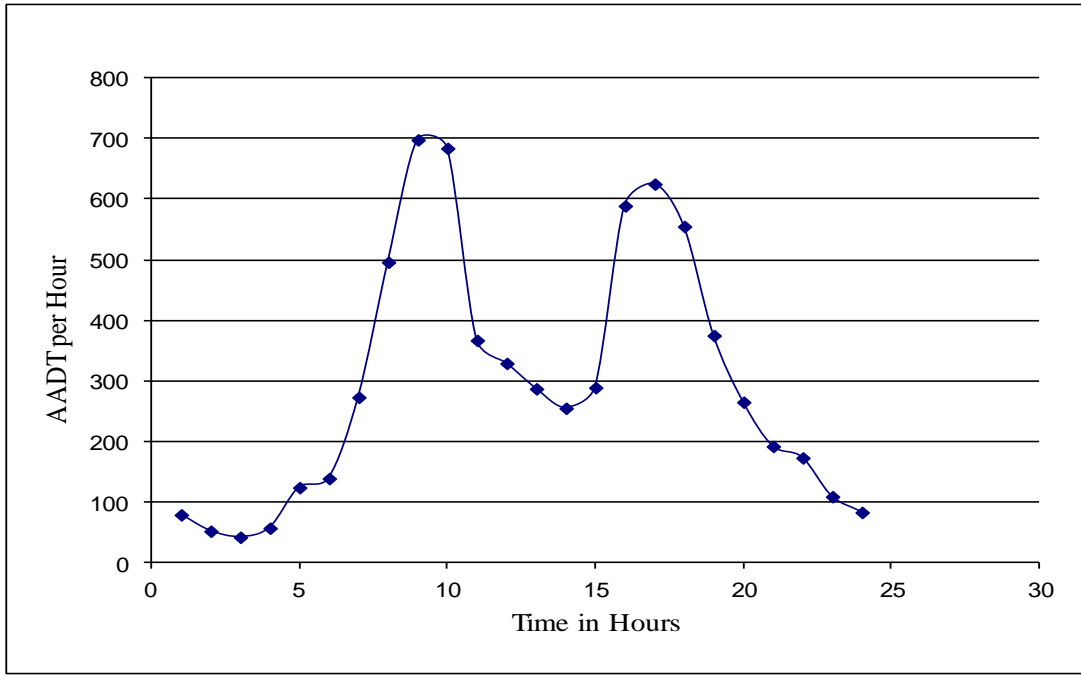
**Table 4.4: Traffic Volume Data of Road Sections**

Section ID	Motorized AADT (in PCSE)	Non-Motorized AADT	AADT year	Traffic Volume
UR-01	14,232	2,019	2016	High
UR-02	16,550	3,320	2016	High
UR-03	11,856	2,247	2016	High
UR-04	6,120	1,885	2016	Medium

**Traffic Flow Pattern:** In the study, new traffic flow patterns were defined for the road sections. For UR-01, UR-02 and UR-03, traffic flow pattern named as ‘Collector Street Flow’ was defined depending upon road use and flow distribution data. For UR-04, traffic flow pattern named as ‘Local Street Flow’ was defined. Figure 4.6 and 4.7 show the trend of AADT for 24-hours for Collector and Local Street flow respectively. An entire day has been distributed into four periods i.e. Peak, Average, Below Average and Lean with their assigned range of traffic volume (AADT). The road use and yearly flow distribution data for Collector Street and Local Street have been shown in Table 4.5 and 4.6 respectively. Yearly traffic flow for Collector and Local Street flow have been distributed among those four periods and Percentage of Average Daily Traffic (PCNADT) have been determined.



**Figure 4.6: Trend of AADT Data for 24-hours for Collector Street Flow type Road Sections**



**Figure 4.7: Trend of AADT Data for 24-hours for Local Street Flow type Road Section**

**Table 4.5: Road Use and Yearly Flow Distribution Data for Collector Street Flow**

Period	Range	Mid Value	Hours	Total (Mid Value * Hours)	PCNADT (%)
Peak	900-1200	1050	1825	19,16,250	39.77
Average	600-900	750	2190	16,42,500	34.09
Below Average	300-600	450	1825	8,21,250	17.04
Lean	0-300	150	2920	4,38,000	9.09
		<b>Sum</b>	8760	48,18,000	100

**Table 4.6: Road Use and Yearly Flow Distribution Data for Local Street Flow**

Period	Range	Mid Value	Hours	Total (Mid Value * Hours)	PCNADT (%)
Peak	500-700	600	1825	10,95,000	44.28
Average	300-500	400	1460	5,84,000	23.61
Below Average	150-300	225	2555	5,74,875	23.25
Lean	0-150	75	2920	2,19,000	8.86
		<b>Sum</b>	8760	24,72,875	100

#### 4.5.4 Pavement History Data

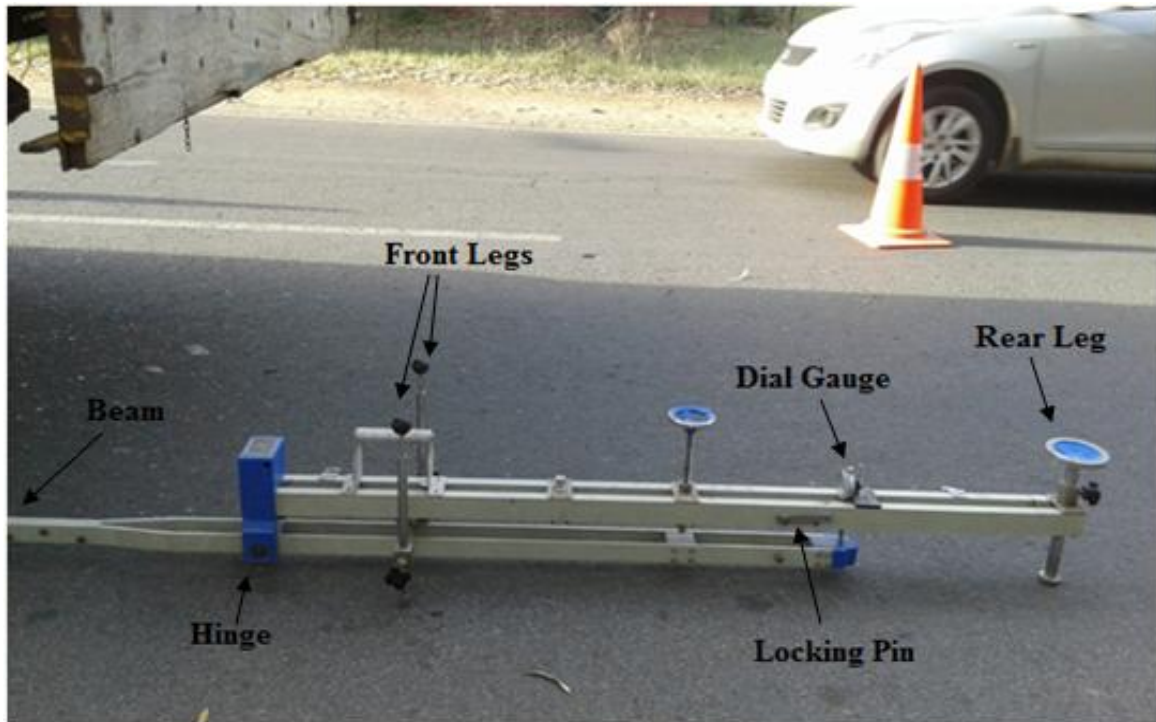
Pavement History data as given in Table 4.7 such as pavement type, year of last construction, surfacing and maintenance were collected from PWD and Municipal Corporation of Patiala.

**Table 4.7: Pavement History Data**

Section ID	Surfacing Material Type	Current Surface Thickness (mm)	Previous Surface Thickness (mm)	Last Construction Year	Last Rehabilitation Year	Last Surfacing Year	Last Preventive Treatment Year
UR-01	Bituminous Concrete (BC)	75	50	2003	2008	2013	2014
UR-02	Bituminous Concrete (BC)	75	50	2003	2009	2013	2014
UR-03	Bituminous Concrete (BC)	75	50	2004	2010	2014	2014
UR-04	Bituminous Concrete (BC)	75	50	2004	2009	2012	2012

#### 4.5.5 Structural Evaluation of Pavements

The structural evaluation was undertaken to assess the pavement's structural ability to receive wheel loads plying over it. Measurement of rebound deflection comes under this category. Higher the rebound deflection, poor will be the structural capacity and performance. The normal practice is to use the Benkelman Beam deflection method for evaluating the structural condition of the flexible pavement as per the procedure laid down in IRC: 81-1997. Figure 4.8 shows the different components of Benkelman Beam apparatus. The next section outlines the detailed procedure for measurement of rebound deflection as per IRC: 81 – 1997.



**Figure 4.8: Different Components of Benkelman Beam Apparatus**

***Procedure for Deflection Measurement:***

The Procedure for deflection measurement using Benkelman Beam Deflection method [IRC: 81-1997] has been mentioned below:

- For every one km stretch, 21 points are selected in such a way that 11 points lie on outer wheel path of one side (at every 100 m interval) and 10 points on other side (at every 100 m interval). The points marked on adjacent lanes should be staggered in such a way that interval between each point should be 50 m.
- The points on the pavement to be tested are selected and marked. For highways, the point should be located at a distance of 60 cm from the pavement edge if the lane width is less than 3.5 m and at 90 cm distance from the pavement edge for wider lanes. For divided four lane highway, the measurement points should be at a distance of 1.5 m from the pavement edge.
- The dual rear wheels of the truck are centered above the selected point. The probe of the Benkelman beam is inserted between the duals and placed on the selected point.
- The locking pin is removed from the beam and the legs are adjusted so that the plunger of the beam is in contact with the stem of the dial gauge. The beam pivot arms are checked for free movement.

- The dial gauge is set at approximately 1 cm. The initial reading ( $D_o$ ) is recorded when the rate of deformation of the pavement is equal or less than 0.025 mm/min.
- The truck is slowly driven a distance of 2.70 m. An intermediate reading ( $D_i$ ) is recorded when the rate of recovery of the pavement is equal or less than 0.025 mm/min.
- The truck is driven forward a further 9 m. The final reading ( $D_f$ ) is recorded when the rate of recovery of pavement is equal to or less than 0.025 mm/min.
- Pavement temperature is recorded at least once every hour inserting thermometer in the standard hole and filling up the hole with glycerol.
- The tyre pressure is checked at two or three hour intervals during the day and adjusted to the standard, if necessary.

Figure 4.9 to Figure 4.11 show the test being performed at various road sections.



**Figure 4.9: Placement of Beam Probe in between Rear Tyres of Truck**



**Figure 4.10: Benkelman Beam Deflection Test in Progress at Chainage 0.200 km, Section UR-02**



**Figure 4.11: Benkelman Beam Deflection Test in Progress at Chainage 0.350 km, Section UR-02**

The three following types of data were required for evaluating the pavement deflection:

***(i) Truck specifications for conducting the test:***

Rear axle weight of the truck = 8170 kg, Tyre pressure = 5.6 kg/cm<sup>2</sup>

Spacing between the tyre walls = 30 - 40 mm.

***(ii) Temperature data:***

The standard temperature for performing the experiment is 35°C. Since it is not always possible to conduct the test at the standard temperature, a correction factor has to be applied for the deflection. The correction factor is determined by knowing the temperature at the time of testing. The procedure for determining the temperature is as given below.

- A hole was drilled into the pavement with the help of a mandrel. The depth of the hole was 45 mm and the diameter of the hole was 1.25 cm at the top and 1 cm at the bottom.
- The hole was filled with glycerol and the temperature was recorded after 5 minutes with the thermometer (range of temperature between 0 - 100° with 1° division).
- The temperature readings were measured for every hour during the survey.

Figure 4.12 shows the actual pavement temperature determination on Passey Road (UR-03).



**Figure 4.12: Determination of Actual Pavement Temperature on Road Section UR-03**

**(iii) Soil data:**

Deflection measurements should be made during the monsoons when the pavement is in its weakest condition. Hence a correction for seasonal variation has to be applied for the deflection which is a function of the soil subgrade. The data required were: a) Average annual rainfall in that area, (b) Soil classification – sandy / gravelly, clayey with low plasticity and clayey with high plasticity. (c) Field moisture content.

Hence the soil tests to be conducted were Moisture content test, Sieve analysis (for soil classification) and Atterberg limit tests (for Determination of PI value). The procedure for soil collection is given below:

- A test pit in the shoulder was excavated to a depth up to 15 cm below the surface level for each road section. The soil samples were collected for moisture content test and Atterberg limit tests.

**Calculations for the Characteristic Deflection ( $D_c$ ):** The Characteristic deflections were calculated for all the sections by noting the initial, intermediate and final deflections readings of the Benkelman Beam Deflection test.

- If  $D_i - D_f \leq 0.025$  mm  
Rebound Deflection, (RD) =  $2 (D_o - D_f)$
- If  $D_i - D_f > 0.025$  mm,  
Rebound Deflection =  $2(D_o - D_f) + 2.91 [2(D_i - D_f)]$ .
- Correction for Temperature: for every  $1^\circ\text{C}$ , correction of 0.01 mm must be applied. If temp is more than  $35^\circ\text{C}$ , Correction will be negative. If temp is less than  $35^\circ\text{C}$ , Correction will be positive.
- Correction for Seasonal Variation: The correction for seasonal variation is determined using graphs of IRC: 81-1997.
- The deflection values corrected for temperature shall be multiplied by the appropriate values of seasonal correction factors to obtain corrected values of deflection.
- Mean deflection,  $X_m = \sum \text{Corrected deflections} / n$ . Here, n is no. of observations
- Standard deviation,  $\sigma = \sqrt{\sum (X_i - X_m)^2 / (n-1)}$
- Characteristic Deflection,  $D_c = X_m + 2 \sigma$  ; for NH and SH

$$D_c = X_m + \sigma \quad ; \text{ for Other Roads}$$

The calculation details for determining characteristic deflection for all the road sections have been mentioned in Annexure A. Characteristic deflections for all the road sections obtained from Benkelman Beam deflection values have been shown in Table 4.8.

**Calculation of Adjusted Structural Number (SNP):**

From the BB deflection values determined as above, the Adjusted Structural Number (SNP) for all the pavement sections has been calculated as per the relationships given by Odoki and Kerali, 2000.

For granular base courses, such as WBM/WMM

$$BB_{def} = 6.5 * (SNP)^{-1.6}$$

For bituminous base courses, such as BM/BUSG

$$BB_{def} = 3.5 * (SNP)^{-1.6}$$

Table 4.8 shows adjusted structural number (SNP) for each road section.

**Table 4.8: BB<sub>def</sub> Value and SNP value for all Road Sections**

Section ID	Benkelman Beam Deflection Value (BB <sub>def</sub> )	Adjusted Structural Number (SNP)
UR-01	0.43	5.46
UR-02	0.48	5.09
UR-03	0.44	5.38
UR-04	0.51	4.91

**4.5.6 Functional Evaluation of Pavements**

Functional evaluation of pavements consists of collection of road condition data related to surface distress (crack area and cracking pattern, ravelled area, pothole area), rut depth, surface roughness, skid resistance and type of surface texture. In this study, cracking, potholes, rutting, and roughness have been measured for each road section. Table 4.10 shows functional evaluation of each road section.

**4.5.6.1 Cracking Measurement**

A number of representative test sections of length 100 m were chosen for cracking measurements for each pavement section. Cracking (Alligator, Longitudinal & Transverse) were visually inspected. In case of alligator cracking, the area covered under the distress was marked in the form of rectangular box with chalk on ground and measured with tape. In

case of longitudinal and transverse cracks, effective width was taken as 50 cm and actual length was measured. Cracked area was expressed as percentage of total pavement area. Figure 4.13 to Figure 4.16 show the cracks present on road section and measurement of cracks.



**Figure 4.13: Cracks on Road Section UR-03**



**Figure 4.14: Crack Measurement with tape at chainage 0.100 km on Section UR-02**



**Figure 4.15: Cracks at chainage 0.050 km on Section UR-04**



**Figure 4.16: Wide Transverse Crack on Section UR-04**

#### **4.5.6.2 Pothole Measurement**

Pothole means open cavity on the pavement. Measurement of potholes for each road section was visually done. One unit Standard Pothole equals to  $0.1 \text{ m}^2$ . Minimum diameter of 150 mm and minimum depth of 25 mm pothole has been taken. Figure 4.17 and Figure 4.18 show the potholes on section UR-02 and section UR-04 respectively.



**Figure 4.17: Pothole at Chainage 0.850 km on Section UR-02**



**Figure 4.18: Pothole at Chainage 0.300 km on Section UR-04**

The pothole area was measured in terms of  $m^2$ , and the depth of each pothole was also measured to convert into volume of potholes. The volume was then converted into number of standard pothole units of ten litre volume each. The pothole measurements were finally expressed as number of pothole units per km length of the pavement section, as per HDM-4 data requirements.

#### ***4.5.6.3 Rutting Measurement***

Rutting refers to permanent deformation on pavement surface in the wheel path. Permanent deformation is commonly defined as distortions within individual layers of the pavement structure. Rutting is caused by structural and/or material failure that can lead to hazardous driving conditions. It is very common in flexible pavements. So, for the safety concern, the collection of accurate transverse profile data is critical for pavement management.

The rut depth was measured with 2 m straight edge placed in transverse direction. Twelve observations randomly selected were carried out for each road section. The maximum rut depth in mm was noted down in each observation. The rut depths were averaged to get the mean rut depth of the road section. Figure 4.19 to Figure 4.21 show the rut depth measurement on different road sections.



**Figure 4.19: Rut Depth Measurement at chainage 0.200 km on Section UR-01**



**Figure 4.20: Rut Depth Measurement at chainage 0.300 km on Section UR-02**



**Figure 4.21: Rut Depth Measurement at chainage 0.400 km on Section UR-03**

#### 4.5.6.4 Roughness Measurement

Road Roughness refers to surface irregularities in the longitudinal direction. Roughness is an important pavement evaluation parameter because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs. Roughness was measured with Fifth Wheel Bump Integrator or simply known as Roughometer. The specifications for test are as follow: operational speed of the vehicle should be  $32 \pm \frac{1}{2}$  km/hr. The tyre pressure should be  $2.1 \text{ kg/cm}^2$ .

The equipment was towed by Pick-up and operated with speed 32 kmph. The equipment towed by Pick-up was made to run over wheel path (0.9 m distance from lane edge for two-lane and 1.5 m distance from lane edge for four-lane). Figure 4.22 to 4.25 shows the photos of Bump Integrator test performed on various road sections.

Accumulated Bumps (in cm) were noted down corresponding to length travelled (in km) for each road section from display panel board connected with equipment. Unevenness Index (in cm/km) was calculated for each section by following equation.

$$\text{Unevenness Index (UI)} = \text{Bumps in cm} / \text{Length travelled (km)}$$

In HDM-4, Roughness is inputted in the form of International Roughness Index (IRI, m/km). Above Unevenness Index (UI) value was converted into International Roughness Index (IRI in m/km) by using the following equation [Odoki and Kerali, 2000].

$$UI = 630 * IRI^{1.12}$$

Where, UI is Unevenness Index in mm/km. IRI is International Roughness Index in m/km unit. Table 4.9 shows the calculated values of Unevenness Index (UI) and International Roughness Index (IRI) for each road section.

**Table 4.9: Determination of UI and IRI values for all Sections**

<b>Section ID</b>	<b>Bumps (cm)</b>	<b>Length Travelled (km)</b>	<b>Unevenness Index in (cm/km)</b>	<b>International Roughness Index (IRI)</b>
UR-01	136	1.000	136	1.99
UR-02	157	1.000	157	2.25
UR-03	149	1.000	149	2.16
UR-04	285	1.000	285	3.85



**Figure 4.22: Bump Integrator (Roughometer) Towed with Pick-up**



**Figure 4.23: Bump Integrator Test (Roughness Test) in Progress on Section UR-03**



**Figure 4.24: Bump Integrator Test in Progress on Section UR-03**



**Figure 4.25: Bump Integrator Test in Progress on Section UR-04**

**Table 4.10: Functional Evaluation Data of Selected Road Sections**

<b>Section ID</b>	<b>Condition Year</b>	<b>Roughness IRI (m/km)</b>	<b>Cracking Area (%)</b>	<b>Potholes (no./km)</b>	<b>Rut Depth (mm)</b>
UR-01	2016	1.99	2.86	01	3.8
UR-02	2016	2.25	3.69	02	5.2
UR-03	2016	2.16	3.32	00	4.3
UR-04	2016	3.85	4.05	12	3.32

## **4.6 Vehicle Fleet Data**

### **4.6.1 General**

A typical traffic flow in Indian urban roads comprises of both Motorized vehicles (MT) and Non-Motorized vehicles (NMT). Both vehicles contribute in traffic flow of Patiala city. A typical vehicle fleet in India may be considered to be comprised of the following vehicles for the purpose of economic analysis to be conducted in PMMS. The same set of vehicles has also been identified as representative vehicle fleet for Indian conditions [Archondo et al., 2003]. These vehicles are:

#### *Motorized (MT) Vehicles*

- Two Wheeler
- Car/Jeep/Van
- Bus(Medium)
- Mini Truck
- Mini Bus
- Truck
- Auto Rickshaw
- Tractor/Trolley

#### *Non-Motorized Vehicles*

- Cycle
- Man Driven Rickshaw
- Cart

#### 4.6.2 Vehicle Fleet Database

The basic vehicle fleet data items [Archondo et al., 2003], which are required to be specified such as Passenger Car Space Equivalent (PCSE), Number of wheels, Number of axles, Annual number of kilometers driven, Vehicle service life, Operating weight, Equivalent Standard Axle Load Factor (ESALF) etc. for each vehicle type, are given in Table 4.11 and Table 4.12. All these data items are incorporated in the vehicle fleet database created in HDM-4. This vehicle fleet database has been named as ‘Patiala City Vehicle Fleet’ for all future references and uses.

**Table 4.11: Basic Data of Motorized (MT) Vehicles included in Patiala City Vehicle Fleet**

<b>Vehicle Characteristics</b>	<b>Two-wheeler</b>	<b>Trucks (Medium)</b>	<b>Mini Truck</b>	<b>Bus (Medium)</b>	<b>Mini Bus</b>	<b>Car/Jeep/ Van</b>	<b>Tractor /Trolley</b>
PCSE	0.5	1.4	1.3	1.5	1.2	1	1.3
Number of Wheels	2	6	4	6	4	4	4
Number of Axles	2	2	2	2	2	2	2
Annual no. of kilometers Driven	6000	85000	60000	100000	60000	30000	60000
Annual no. of Working Hours	150	2300	2000	2250	2000	1200	2000
Vehicle Service Life (Years)	7	9	9	8	9	10	9
No. of Passengers	1	0	0	40	20	4	0
Operating Weight (Tonnes)	0.25	16.2	7.75	13.5	7.75	1.20	7.75
ESALF	0	6.44	0.34	0.55	0.02	0.0	3.6

**Table 4.12: Basic Data of Non-Motorized (NMT) Vehicles in Patiala City Vehicle Fleet**

Vehicle Characteristics	Cycle	Man-Driven Rickshaw	Cart
PCSE	-	-	-
Number of Wheels	2	3	2
Number of Axles	2	2	1
Annual no. of kilometers Driven	2500	7200	7200
Annual no. of Working Hours	150	500	500
Vehicle Service Life (Years)	10	6	6
No. of Passengers	0	2	2
Operating Weight (Tonnes)	0.1	.30	0.4
ESALF	0	0	0

#### 4.6.3 Vehicular Composition and Annual Growth Rate

The vehicular composition for both Motorized (MT) and Non-Motorized (NMT) vehicles was found out from volume count data provided by Municipal Corporation, Patiala. The average annual growth rate of vehicles in Patiala has been taken as per the Master Plan of Patiala District, 2011 [PUDA 2011]. Table 4.13 shows vehicular composition and annual average growth rate.

**Table 4.13: Vehicular Composition and Annual Growth Rate**

Vehicle Type	Composition of Traffic Flow (%)								Annual Average Growth Rate (%)
	UR-01		UR-02		UR-03		UR-04		
	MT	NMT	MT	NMT	MT	NMT	MT	NMT	
Car/Jeep/Van	29.8	-	32.4	-	35.4	-	33.3	-	8.5
Mini Bus	3.9	-	0.6	-	0.6	-	-	-	3.7
Bus	3.6	-	0.8	-	0.8	-	-	-	4.0
Two Wheeler	39.8	-	43.9	-	41.0	-	49.1	-	4.2
Mini Truck	2.1	-	1.5	-	1.5	-	1.5	-	12.5
Truck (Medium)	3.4	-	0.8	-	-	-	-	-	5.0
Tractor/	2.6	-	1.5	-	1.5	-	1.5	-	5.9

Trolley									
Auto Rickshaw	14.8	-	18.5	-	19.2	-	14.6	-	5.4
Cycle	-	46	-	49	-	56	-	60	3.4
Man-Driven Rickshaw	-	52	-	50	-	43	-	39	3.4
Cart	-	2		1	-	1	-	1	3.4
<b>Total</b>	100	100	100	100	100	100	100	100	

## 4.7 Maintenance and Rehabilitation Works

### 4.7.1 Serviceability Levels for Maintenance

The maintenance quality levels, which have been acknowledged in most of the developed countries, comprises of measuring the service conditions of roads in terms of some surface defects such as roughness, potholes, cracking, rutting, and skid resistance etc., to determine a “Serviceability Index” which varies from country to country.

The maintenance serviceability levels for urban roads as per “Guidelines for Maintenance of Primary, Secondary and Urban Roads”, [MORT&H, 2004], are given in Table 4.14.

**Table 4.14: Maintenance Serviceability Levels for Urban Roads**

S. No.	Serviceability Indicator	Serviceability Levels		
		Arterial Roads	Sub-Arterials Roads	Other Roads
1.	Roughness by Bump Integrator (max. permissible) Equivalent IRI*	2000 mm/km 2.8 m/km	3000 mm/km 4.0 m/km	4000 mm/km 5.2 m/km
2.	Potholes per km (max. number)	Nil	2-3	4-8
3.	Cracking and patching area (max. permissible)	5 percent	10 percent	10-15 percent
4.	Rutting – 20 mm (maximum permissible)	5mm	5-10 mm	10-20 mm
5.	Skid number (minimum desirable)	50 SN	40 SN	35 SN

\*As per Odoki and Kerali [2000]

In the present study, all the road sections belong to Other Roads category (Collector Street and Local Street), so Serviceability Level as required for Other Roads has been adopted.

#### **4.7.2 Maintenance & Rehabilitation (M&R) Treatments and Strategies**

A Maintenance & Rehabilitation (M&R) strategy is a course of activity to be done over the analysis period for keeping the road section in good condition. Maintenance activities are usually grouped according to planning managerial and funding engagements. These have been categorized as Ordinary Repairs (Routine Maintenance) and Periodic Renewals (Periodic Maintenance) as per the 'Report of the Committee on Norms for Maintenance of Roads in India' [MORT&H 2001b].

##### **4.7.2.1 Routine Maintenance**

Routine maintenance actions consist of works that may need to be undertaken each year or at intervals during the course of a year. The routine maintenance works on bituminous pavements, whose effects on the pavement performance are mainly comprised of the following two operations: Crack Sealing and Pothole Patching.

- ***Crack Sealing***

This is a scheduled type of routine maintenance treatment, which is used to treat wide structural cracking. Crack sealing has several effects on future deterioration modeling. Crack sealing will not improve initial pavement ride ability. However, crack sealing is not applicable if area of wide structural cracking exceeds 20%. This treatment comprises of application of a slurry seal [Specifications clause 516 of MORT&H 2001d].

- ***Patching***

This is also a scheduled type, which is used to repair the following surface distresses: potholing, wide structural cracking, and ravelling. The treatment for pothole patching consists of placing a bituminous mix, either of the same quality as the existing bituminous surface or a superior mix after trimming the potholes to proper shape and depth, and side painting with tack coat. This is followed by compaction [Specifications clause 3004.1 of MORT&H 2001d]. Patching of ravelled area only prevents the formation of potholes from those areas. It has no effect on future pavement deterioration.

#### **4.7.2.2 Periodic Maintenance**

Periodic maintenance of road pavements is defined as works that are planned to be undertaken at intervals of several years. These are normally on a large scale and require specialized equipments and skilled resources. The periodic maintenance works on bituminous roads comprise the following: Preventive Treatment, Resealing or Resurfacing, Overlay, Mill and Replace, and Reconstruction.

- **Preventive Treatment**

The purpose of preventive treatment is to delay the initiation or progression of structural cracking and ravelling. Preventive treatment refers to addition of a thin film of surfacing to improve road quality and waterproofing. This is applied at the first signs of cracking or ravelling distress, but it is not applied once the area of all cracking and ravelling exceed 5% and 10% respectively. Preventive treatment generally consists of a Rejuvenation and Fog seal. Rejuvenation is a light application of solvents, oils or plasticizers sprayed onto the pavement surface. Fog seal is a light sprayed application of bitumen, which covers an oxidized binder with a fresh, less viscous material [Specifications clause 3004.2 of MORT&H 2001d].

- **Resealing**

Resealing can be used for low levels of surface distress such as cracking and ravelling, or roughness. For bituminous pavements, it consists of thin surfacing such as Bituminous Surface Dressing (BSD) to seal the entire road surface against the ingress of water and to improve skid resistance. It neither increases the strength of the pavement considerably nor improves the riding quality significantly. A single coat bituminous surface dressing (SBSD) consists of a single application of bituminous binder material followed by aggregate spreading and rolling [Specifications clause 508 of MORT&H 2001d]. When the surface dressing is similarly done in two layers it is termed as Double Bituminous Surface Dressing (DBSD). Resealing works reset surface distresses to zero and thereafter the pavement condition is considered to be new. The default effects of all types of resealing on some distresses [Morosiuk et al., 2001] are specified as follow:

(i) Roughness resets to 2.0 m/km IRI

(ii) Texture depth resets to 2.5 mm

(iii) Skid resistance resets to 0.6 SFC50

- ***Overlay***

For bituminous pavements, it refers to the addition of thick surfacing such as Bituminous Concrete (BC) to restore or improve the structural integrity and to increase the strength of the pavement [Specifications clause 512 of MORT&H 2001d]. Bituminous Concrete is a thoroughly compacted, dense graded bituminous mix. The Semi-dense Bituminous Concrete (SDBC) has comparatively lower binder content and the aggregate used are less dense-graded [Specifications clause 511 of MORT&H 2001d]. Apart from these, lesser quality mix Premix Carpet (PC) [Specifications clause 509 of MORT&H 2001d] can also be used depending upon the relative importance and traffic volume carried by the road.

The default effects of bituminous concrete overlays on distresses [Morosiuk et al., 2001] are specified as follows:

- (i) The rut depth gets reduced to 15 % of the original value
- (ii) Roughness resets to 2.0 m/km IRI
- (iii) Texture depth resets to 0.7 mm
- (iv) Skid resistance resets to 0.5 SFC50

- ***Mill and Replace***

This treatment involves the removal of all or part of the existing bituminous surfacing and replacing it with a new bituminous surfacing. It is usually performed to correct defects that have occurred mainly due to poor construction quality or where the road surface levels need to comply with some requirements related to kerb height and drainage facilities in urban roads.

Mill and Replace works resets surface distresses and rut depth to zero, and thereafter it is assumed that the pavement behaves as if new. The default effects of bituminous concrete overlays on roughness, texture depth and skid resistance [Morosiuk et al., 2001] are specified as follows:

- (i) Roughness resets to 2.0 m/km IRI
- (ii) Texture depth resets to 2.5 mm
- (iii) Skid resistance resets to 0.5 SFC50

- **Reconstruction**

Pavement reconstruction refers to all works that requires the re-specification of the surfacing and road base types. Reconstruction as a maintenance standard is specified using the following: New pavement type, surface material, base material, surfacing thickness, base thickness, structural number (SN) of pavement of the layers above the subgrade, relative compaction and construction defect indicators. After reconstruction, the pavement type is reset to new type as specified. Surface distresses (i.e. edge break, potholing, cracking and ravelling) and mean rut depth are all reset to zero. The roughness, texture depth and skid resistance values are specified to reset in accordance with those for Mill and Replace.

## 4.8 Costs Data

### 4.8.1 Costs of Maintenance and Rehabilitation (M&R) Works

The “Committee for Maintenance Norms for Roads in India”, has suggested the total costs for carrying out various types of maintenance and rehabilitation (M&R) works on bituminous pavements situated in various price zones of the country. This zoning has been done on the basis of cost of stone metal (stone chips) in that particular region. For this study, the costs specified for Zone-IV have been taken because it is applicable for urban Roads [MORT&H 2001b].

#### *Cost Updating*

The costs given in [MORT&H 2001b] are relevant for the base year 1999-2000. For including the effect of inflation, these costs are necessitated to be updated for application in consequent years. This has been made possible by provision of a mathematical model for annual updation of costs by linking labour component of the costs with Consumer Price Index (CPI), material component with Wholesale Price Index (WPI) and machinery component with average price of fuel [MORT&H 2001b]. As per this model, percentage increase in cost for the subsequent years is given by following equation.

$$\text{Percentage Increase in cost} = [F_L (I_1 - I_0)/I_0 + F_M (W_1 - W_0)/W_0 + F_F (f_1 - f_0)/f_0] * 100$$

Where,  $F_L$ ,  $F_M$  and  $F_F$  are the labour component, material component and machinery component of the cost respectively.  $I_1$ ,  $W_1$  and  $f_1$  are the annual average CPI, WPI and fuel

price respectively for the stated year (2015-16 in the present study) and  $I_0$ ,  $W_0$  and  $f_0$  are the annual average CPI, WPI and fuel price respectively for the base year 1999-2000. The values of these components are given in Table 4.15.

**Table 4.15: Price Indices and Fuel Price**

Item	Year	
	1999-2000	2015-16
Consumer Price Index (CPI)	425	689
Wholesale Price Index (WPI)	145	322
Fuel Price in Rupees	10	59

The sources for CPI, WPI and fuel price values are Labour Bureau, Office of Economic Adviser and Ministry of Petroleum and Natural Gas, Government of India respectively.

On the basis of the above model, the percentage increase in costs for the year 2015-16 over the base year costs has been calculated as follow:

- Routine maintenance costs = 125.26%,
- Periodic maintenance costs = 205.40%

Costs data for stated year 2016 over the base year 1999-2000 has been updated. Table 4.16 shows updated cost data of maintenance and rehabilitation works and drainage works as per the discussions held with field engineer, in-charge of the maintenance of the pavement sections under study.

**Table 4.16: Updated Economic Cost Data of M&R Works for year 2016**

S. No.	Type of M&R Work	Cost per sq. m of Surface Area (in Rupees)
<b>Routine Maintenance</b>		
1.	Crack Sealing (All Cracks)	66.4
2.	Pothole Patching	84.7
3.	Patch Repair	84.7
4.	Rutting and Undulation Repair	117.7
5.	Tack Coat	13.5

6.	Liquid Seal Coat	68.8
<b>Periodic Maintenance</b>		
1.	Single Bituminous Surface Dressing (SBSD)	178.5
2.	Double Bituminous Surface Dressing (DBSD)	282.7
3.	Premix Carpet (20mm PC)	223.2
4.	Mix Seal Surfacing (20 mm MSS)	230.6
5.	Semi Dense Bituminous Concrete (25mm SDBC)	208.3
6.	Bituminous Concrete (25mm BC)	230.6
7.	Bituminous Concrete (40mm BC)	369.0
8.	Bituminous Macadam (50mm BM)	370.5
9.	Dense Bituminous Macadam ( 75mm DBM)	614.5
10.	Mill 90mm and Replace with ( BM 50mm + BC 40mm)	739.4
11.	200 mm Wet Mix Macadam + 75 mm Dense Bituminous Macadam + 40mm Bituminous Concrete	1429.8

#### 4.8.2 Road User Cost (RUC) Data

Road User Cost (RUC) is one of the most important parameters for analysis of life-cycle cost of road project. Road User Cost is defined as costs incurred by the vehicle operators and by the travelling public at large [Jain, 2013]. Total Transport Cost comprises of two costs i.e. Road Costs (10 – 30%) and Road User Costs (70 -90%). From the RUC range, it can be stated that RUC plays major role during life cycle cost analysis of road projects.

Road User Costs consists of three components i.e. Vehicle Operating Costs (VOC), Travel Time Costs (TTC) and Accident Costs (AC).

$$\text{Road User Cost (RUC)} = \text{VOC (55 - 70\%)} + \text{TTC (20 - 40\%)} + \text{AC (5 - 10\%)}$$

Amongst the above, VOC is the dominating component in RUC. VOC is defined as the price, the user has to spend to move the vehicle per unit distance. RUC mostly depends upon VOC. In this study, only Vehicle Operating Costs component has been considered. Vehicle Operating Costs data has been calculated as per IRC SP: 30-2009. Economic cost (exclusive of tax) has been considered for this study.

Table 4.17 shows the current vehicle operating cost inputs i.e., of year 2016.

**Table 4.17: Current Vehicle Operating Cost Inputs (All Prices in Rupees)**

<b>S. No.</b>	<b>VOC Input</b>	<b>Economic Cost in Rupees (Exclusive of Tax)</b>
<b>A. Cost of New Vehicle</b>		
1.	Two-wheeler	45,850
2.	Car/Jeep/Van	6,46,900
3.	Bus (Medium)	9,34,500
4.	Mini Bus	5,53,300
5.	Truck (Medium)	9,67,900
6.	Mini-Truck	5,53,300
7.	Tractor/Trolley	5,53,300
8.	Auto Rickshaw	1,80,000
<b>B. Costs of Petroleum Products</b>		
1.	Petrol (per litre)	24.50
2.	Diesel (per litre)	23.6
3.	Engine Oil (per litre)	73.5
<b>C. Cost of New Tyres</b>		
1.	Two-wheeler	850
2.	Car/Jeep/Van	2500
3.	Bus (Medium)	8500
4.	Mini Bus	3950
5.	Truck (Medium)	8000
6.	Mini-Truck	3950
7.	Tractor/Trolley	3950
8.	Auto Rickshaw	1500

Vehicle Operating Costs components like fuel consumption, lubricating oil consumption, maintenance labour etc. have been calculated using the equations given in section B.1 of Annexure B of this report referred from clause 6.6, Annex C of IRC SP: 30-2009. In this study, three road sections are of two-lane type and one road section is of four-lane type. So, calculations have been made corresponding to two-lane type. Average roughness value has been taken as 3000 mm/km. Rise and Fall (RF) has been taken as 5 m/km. Rise has been taken as 3 m/km and fall has been taken as 2 m/km. For the calculation purpose, Mini-truck, Mini-bus and Tractor/trolley have been considered as Light commercial vehicle. Truck has been considered as Heavy commercial vehicle. Table 4.18 shows the calculated values of VOC components for all types of vehicle.

**Table 4.18: Calculated Values of VOC Components for All Types of Vehicle**

<b>VOC Components</b>	<b>Two-Wheeler</b>	<b>Car/Jeep /Van</b>	<b>Bus</b>	<b>Light Commercial Vehicle</b>	<b>Heavy Commercial Vehicle</b>
Free Speed (km/hr)	42.63	67.88	51.19	53.83	50.00
Fuel Consumption (litre/1000 km)	25.47	56.54	173.52	141.33	183.95
Lubricating Oil Consumption (litre/1,000 km)	0.45	2.10	2.07	1.27	2.07
Spare Parts Cost (Rs./km)	7.39	11.64	46.34	25	76.56
Maintenance Labour (Rs./km)	4.06	6.40	25.5	9.22	28.27
Utility (km/day)	90.33	420	804	147	326
Crew Wages (Rs./km)	-	-	1.17	4.08	2.20
Annual Overhead (Rs./km)	0.25	0.87	0.62	3.41	1.97

**Congestion Effect:** VOC components calculated in Table 4.8 with the help of Annexure B (section B.1) equations are for uncongested free flow conditions. In case of urban traffic,

congestion usually occurs. So, it is important to take account for congestion effect [Clause 6.9, IRC SP: 30-2009]. Equations for Congestion Factors are provided in section B.2 of Annexure B referred from table 10 of IRC SP: 30-2009. Table 4.19 shows the calculated values of congestion factors for each type of vehicle.

**Table 4.19: Calculated Values of Congestion Factor as per IRC SP: 30-2009**

Section ID	Volume/ Capacity Ratio	Two-wheeler	Car/Jeep/ Van	Bus	Light Commercial Vehicle	Heavy Commercial vehicle
UR-01	0.9	1.02	1.13	1.79	1.8	1.34
UR-02	0.30	1.00	1.08	1.17	1.11	1.07
UR-03	0.38	1.00	1.00	1.22	1.28	1.43
UR-04	0.38	1.00	1.00	1.22	1.28	1.43
<b>Average Congestion Factor</b>		1.00	1.05	1.35	1.37	1.32

Average Congestion Factors have been multiplied with above VOC components to get the VOC components for congested flow condition. The congested VOC components have been multiplied with current VOC inputs to get the Vehicle Operating Cost (VOC) values of each vehicle. Table 4.20 shows the Vehicle Operating Costs data which are directly going to be entered in HDM-4. All the quantities are in per 1,000 vehicle-km unit.

Economic costs of new cycle, Man-Driven Rickshaw and Cart have been taken as Rs. 2000, 4500 and 6,000. In the present study, Auto Rickshaw is one of the influencing vehicles for each road section. In vehicle fleet part of HDM-4 model, representation of three-wheeler type vehicle i.e. Auto Rickshaw has not been covered. So, to take account for this vehicle type in HDM-4 model, the Vehicle Operating Cost relationship between Auto Rickshaw and Car (Medium) has been anticipated as given below based on author's interviews with owners/drivers of both categories of vehicles [Prakash, 2009].

$$\text{VOC of two numbers of Auto Rickshaw} = \text{VOC of 1 Medium Car}$$

So, on the basis of above relationship, vehicle operating costs of Auto Rickshaw have been calculated.

**Table 4.20: Vehicle Operating Costs Data Input per 1,000 vehicle-km**

Parameter	Vehicle Type						
	Two-wheeler	Car/Jeep/Van	Bus (Medium)	Mini Bus	Trucks (Medium)	Mini Truck	Tractor/Trolley
Cost of Fuel (Rupees/ litre)	620	1400	5530	4570	5730	4570	4570
Cost of Lubricants (Rupees/litre)	4	16	13	13	20	13	13
Maintenance Labour (Rupees/hour)	4.06	6.40	25.5	9.22	28.27	9.22	9.22
Crew Wages (Rupees/hour)	-	-	1.17	4.08	2.20	4.08	4.08
Annual Overhead	0.25	0.91	0.84	4.67	2.60	4.67	4.67
Annual Interest (%)	8	8	8	8	8	8	8

#### 4.9 Adaptation of HDM-4 Model to Indian Condition

Since, HDM-4 has been designed to be used in a wide range of environments, it is important that prior to using HDM-4 the system should be configured and calibrated for local use. The use of appropriate calibration factors in HDM-4 pavement deterioration models will facilitate more reliable and rational prediction of pavement deterioration for the highway network under study. The pavement deterioration models incorporated in HDM-4 were developed from results of large field experiments conducted in several countries. Consequently, the default equations in HDM-4 if used without calibration, would predict pavement performance that may not accurately match that observed on specific road sections [Bennett and Paterson, 2000].

Jain et al. developed the calibration and adaptation of HDM-4 bituminous road deterioration models for Indian Conditions. In that study calibration factors were proposed for National

Highway network within the SNP range of 3.0 - 5.5. As in the present study, SNP range is 4.8 – 5.46. So, the same calibration factors have been used in the present study as given in Table 4.21 [Jain et al., 2005].

**Table 4.21: Calibration Factors for HDM-4 Deterioration Models**

<b>Model Description</b>	<b>Average Calibration Factor</b>
Cracking Initiation Model	$K_{cia} = 0.43$
Cracking Progression Model	$K_{cpa} = 1.25$
Ravelling Initiation Model	$K_{vi} = 0.37$
Ravelling Progression Model	$K_{vp} = 0.52$
Pothole Initiation Model	$K_{pi} = 0.45$
Pothole Progression Model	$K_{pp} = 0.95$
Roughness Progression Model	$K_{gp} = 0.85$
Rutting Progression Model	$K_{rst} = 1.0$
Skid Resistance Progression Model	$K_{sfc} = 1.0$

### DEVELOPMENT OF PMMS USING HDM-4 MODEL

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#### 5.1 General

The methodology for developing Pavement Maintenance Management System (PMMS) of Patiala city road network using HDM-4 model has been discussed in the previous chapter. The pavement maintenance and management at the project level deals with detailed maintenance management decisions for an individual project. Project level work incorporates detailed engineering applications to address individual pavement sections and their specific problems. Application of HDM-4 software at project level for developing PMMS of Patiala road sections i.e. achieving the objectives of the present study has been discussed in this chapter.

#### 5.2 Use of HDM-4 Application Modules for Pavement Maintenance Management System

There are three main application modules of HDM-4 for the purpose of pavement management at various levels out of which two modules Project Analysis and Program Analysis are applicable for Pavement Maintenance Management System. In this study, the project level maintenance management analysis has been carried out by using the 'Project Analysis' application module of HDM-4.

In the present study, the following types of objectives have been undertaken for the project level analysis of four road sections of Patiala city road network.

- Determination of Remaining Service Life (RSL) of selected road sections of Patiala city road network.
- Determination of Optimum Maintenance and Rehabilitation (M&R) Strategy for all the selected road sections.
- Prioritization of the selected road sections for maintenance work based on optimum M&R strategy.
- Comparative Study of Scheduled type and Condition Responsive type M&R strategy for individual road section.

### 5.3 Road Network and Vehicle Fleet Data Input in HDM-4

The basic data input in HDM-4 are Road Network and Vehicle Fleet Data. Road Network refers to the network having number of road sections with their characteristics. Vehicle Fleet Data refers to representation of vehicles and their characteristics.

#### 5.3.1 Road Network

For the study, Road Network named as ‘Patiala City Road Network’ has been created. Four road sections with section ID UR-01, UR-02, UR-03 and UR-04 have been included in this network. Each road section with its definition, geometry, pavement and condition data (mentioned in previous chapter) has been inputted. Prior to this, Traffic Flow patterns named as ‘Collector Street Flow’ (Figure 5.1) for section UR-01, UR-02 and UR-03 and ‘Local Street Flow’ for section UR-04 have been created in Configuration part. Climate Zone ‘North India Plain’ has been selected for the study (Figure 5.2). Snapshots of entering all the data for Bhadson Road section i.e. UR-01 have been shown from Figure 5.3 to Figure 5.9. This road network has been further used for determining the objectives.

**Traffic Flow Pattern: Collector Street Flow**

Definition

Name: Collector Street Flow

Road use: Inter-urban

Flow distribution data

Select method:  HV  PCNADT

Period	Description	Hrs per year (HRYRp)	Hourly Volume (HVp)	% of AADT (PCNADTp)
1	Peak	1825.00	1.657	39.77
2	Average	2190.00	0.355	34.09
3	Below Average	1825.00	0.101	17.04
4	Lean	2920.00	0.011	9.10
		8760.00		100.00

NB. HRYRp must equal 8760, and PCNADTp must equal 100

The name of this Traffic Flow Pattern

**Figure 5.1: Formation of ‘Collector Street Flow’ Type Traffic Flow Pattern for UR-01, UR-02 and UR-03**

**Climate Zone: North India Plain**

Climate

Name: North India Plain

Moisture Classification: Sub-humid

Moisture Index: -40

Duration of dry season: 0.67 (as a fraction of a year)

Mean monthly precipitation: 90 mm

Temperature Classification: Subtropical - hot

Mean temperature: 30 °C

Avg. Temperature Range: 12 °C

Days T > 32°C: 120 days

Freeze Index: 0 C-days

Percentage Of Time Driven

on snow covered roads: 0 0<=PCTDS<=100

on water covered roads: 10 0<=PCTDW<=100

OK

Cancel

Defaults...

The name of this Climate Zone

**Figure 5.2: Selection of 'North India Plain' Climate Zone for the study**

**New Section from Aggregate Data**

Section Name: Bhadson Road

Section ID: UR-01

Link Name: Central Jail End Road- Sarabha Nagar f

Link ID: PUR-01

Speed flow type: Two Lane Wide

Traf flow pattern: Collector Street Flow

Climate zone: North India Plain

Road Class: Secondary or Main

Traffic: High

Geometry: Mostly straight and gently undulating

Length: 1 km

Carriageway width: 8.40 m

Shoulder width: 1.4 m

Traffic flow direction: Two-way

Number of Lanes: 2

Last surfacing: 2013 year

Surface class: Bituminous

Pavement type: Asphalt Mix on Asphalt Pavement

Ride quality: Good

Structural adequacy: Good

Surface condition: Good

Construction quality: Good

Surface texture: Good

OK

Cancel

Name of section

**Figure 5.3: New Section i.e. Bhadson Road, UR-01 Created in 'Patiala City Road Network'**

Section: Bhadson Road

Definition | Geometry | Pavement | Condition

Section Name:  Length:  km

Section ID:  Carriageway width:  m

Link Name:  Shoulder width:  m

Link ID:  Number of Lanes:

Speed flow type:

Traffic flow pattern:

Climate zone:

Road class:

Surface class:

Pavement Type:

Traffic

Motorised:  AADT

NMT:  AADT

Year:

Flow direction:

Details... OK Cancel

Name of section

**Figure 5.4: Definition Data Input for Bhadson Road Section i.e. UR-01**

Section: Bhadson Road

Definition | Geometry | Pavement | Condition

Rise + Fall:  m/km

Avg horiz curvature:  deg/km

Speed limit:  km/h

Altitude:  m

Drain type:

Details... OK Cancel

Average road rise plus fall (in m/km)

**Figure 5.5: Geometry Data Input for Bhadson Road Section i.e. UR-01**

Section: Bhadson Road

Definition | Geometry | Pavement | Condition

Surfacing

Material type: Asphaltic Concrete

Most recent surfacing thickness: 75 mm

Previous/old surfacing thickness: 50 mm

Previous works (HDM-4 Work Types)

Last reconstruction or new construction: 2003 year

Last rehabilitation (overlay): 2008 year

Last resurfacing (resealing): 2013 year

Last preventative treatment: 2014 year

Strength

Calculated Dry season model parameters

SNP: 5.45 DEF: 0.43 mm

[1]  Structural Number: 4.29

Subgrade CBR: 5.2 %

Dry Season  Wet Season

[2]  Calculated SNP: Calculate SNP...

Road base (for stabilised base only)

Base thickness: mm

Resilient modulus: GPa

Details... OK Cancel

Surface material

Figure 5.6: Pavement Data Input for Bhadson Road Section i.e. UR-01

Section: Bhadson Road

Definition | Geometry | Pavement | Condition

Condition at end of year	2016
Roughness (IRI - m/km)	1.99
Total area of cracking (%)	2.86
Ravelled area (%)	0.00
Number of Potholes (No./km)	1.00
Edge break area (m <sup>2</sup> /km)	0.00
Mean rut depth (mm)	3.80
Texture depth (mm)	0.70
Skid resistance (SCRIM 50km/h)	0.40
Drainage	Good

Add New Year

Delete Year

Sort Years

Details... OK Cancel

Yearly condition data

Figure 5.7: Condition Data Input for Bhadson Road Section i.e. UR-01

Section Calibration: Bhadson Road

Speed Related | Drainage, Shoulders, and NMT Lanes | History

Surface Distress | Surface Texture | Structural Defects

Calibration factors

	Initiation	Progression
All structural cracking:	0.43	1.25
Wide structural cracking:	0.43	1.25
Transverse thermal cracking:	0.43	1.25
Ravelling:	1	1
Pothole:	0.45	0.95
Edge break:	1	

Distribution of cracking

All structural cracking: 75.5 %

Transverse thermal cracking: 24.5 %

Total: 100 %

Wide structural cracking as a percentage of All structural cracking: 0 %

Patching

Time lapse to patching: Twelve months

Surface Distress Retardation

Cracking retardation time: 0 years

Ravelling retardation factor: 1

OK Cancel

Average number of rises and falls (per km)

Figure 5.8: Calibration Factors Input for Bhadson Road Section i.e. UR-01

Road Network: Patiala City Road Network - All Sections/Definition Data

ID	Description	Data Last Modified	Surface Class	Pavement Type	Length (km)
UR-01	Bhadson Road	13-06-16	Bituminous	Asphalt Mix on Asphalt Pavement	1.1
UR-02	Bhupinder Road	13-06-16	Bituminous	Asphalt Mix on Asphalt Pavement	1.1
UR-03	Passey Road	13-06-16	Bituminous	Asphalt Mix on Asphalt Pavement	1.1
UR-04	Ghuman Road	13-06-16	Bituminous	Asphalt Mix on Asphalt Pavement	1.1

Add New Section...
 Delete
 Edit...
 Save
 Close

Name of section

Figure 5.9: Patiala City Road Network with All the Four Sections Defined

### 5.3.2 Vehicle Fleet

For the study, Vehicle Fleet named as ‘Patiala City Vehicle Fleet’ has been created. Eight types of Motorized Vehicle (MT) i.e. Two-wheeler, Car/Jeep/Van, Auto-Rickshaw, Bus (Medium), Mini-Bus, Truck, Mini-Truck and Tractor/Trolley and three types of Non-Motorized Vehicle (NMT) i.e. Cycle, Man-Driven Rickshaw and Cart have been included in this vehicle fleet.

All the vehicles with their basic characteristic data and economic unit costs (mentioned in previous chapter) are entered as inputs into vehicle attributes under vehicle fleet section in HDM-4 software. Snapshots of entering vehicle fleet data for Two-wheeler have been shown from Figure 5.10 to Figure 5.13. This vehicle fleet has been used further for determining the objectives of this study.

The screenshot shows a software window titled "Vehicle Attributes: Two-wheeler". It contains three tabs: "Definition", "Basic Characteristics", and "Economic Unit Costs". The "Definition" tab is selected. The fields are as follows:

- Name: Two-wheeler
- Base Type: Motorcycle
- Class: Motorcycles
- Category: Motorised
- Description: motorcycle or scooter
- Life Method:  Constant Life  Optimal Life

Buttons on the right side include "Calibration...", "Reset Defaults", "OK", and "Cancel". A "View vehicle attributes" link is located at the bottom left of the window.

**Figure 5.10: Definition Data Input for Two-wheeler into Patiala City Vehicle Fleet**

Vehicle Attributes: Two-wheeler

Definition | Basic Characteristics | Economic Unit Costs

Physical

Passenger Car Space Equiv: 0.5

No. of Wheels: 2

No. of Axles: 2

Tyres

Tyre type: Bias-ply

Base no. of recaps: 1.3

Retread cost: 15 %

Utilisation

Annual km: 6000 km

Working hours: 150 hrs

Average life: 7 years

Private use: 100 %

Passengers: 1 persons

Work related passenger-trips: 75 %

Calculate...

Loading

ESALF: 0

Operating weight: 0.25 tonnes

Calculate...

Calibration...

Reset Defaults

OK

Cancel

Passenger Car Space Equivalents factor (PCSE)

**Figure 5.11: Basic Characteristics Data Input for Two-wheeler**

Vehicle Attributes: Two-wheeler

Definition | Basic Characteristics | Economic Unit Costs

Vehicle resources

New vehicle: 45850

Replacement tyre: 850

Fuel: 620 per litre

Lubricating oil: 4 per litre

Maintenance labour: 4.06 per hour

Crew wages: 0 per hour

Annual overhead: 0.25

Annual interest: 8 %

Time Value

Passenger: 0 per hour working time

Cargo: 0 per hour

Passenger: 0 per hour non-working time

All costs should be expressed in the fleet currency - Rupees

Calibration...

Reset Defaults

OK

Cancel

The average purchase cost of a new vehicle of this type

**Figure 5.12: Economic Unit Costs Data Input for Two-wheeler**

Name	Class	Data Last Modified	Base Type	Category
Two-wheeler	Motorcycles	13-06-16	Motorcycle	Motorised
Car/Jeep/Van	Passenger Cars	13-06-16	Car Medium	Motorised
Bus (medium)	Buses	13-06-16	Bus Medium	Motorised
Mini Bus	Buses	13-06-16	Mini-bus	Motorised
Truck (Medium)	Trucks	13-06-16	Truck Medium	Motorised
Mini - Truck	Trucks	13-06-16	Truck Light	Motorised
Tractor / Trolley	Trucks	13-06-16	Truck Light	Motorised
Auto-Rickshaw	Passenger Cars	13-06-16	Car Small	Motorised
Cycle	Bicycle	13-06-16	Bicycle	NMT
Man-Driven Rickshaw	Rickshaw	13-06-16	Rickshaw	NMT
Cart	Animal Cart	13-06-16	Animal Cart	NMT

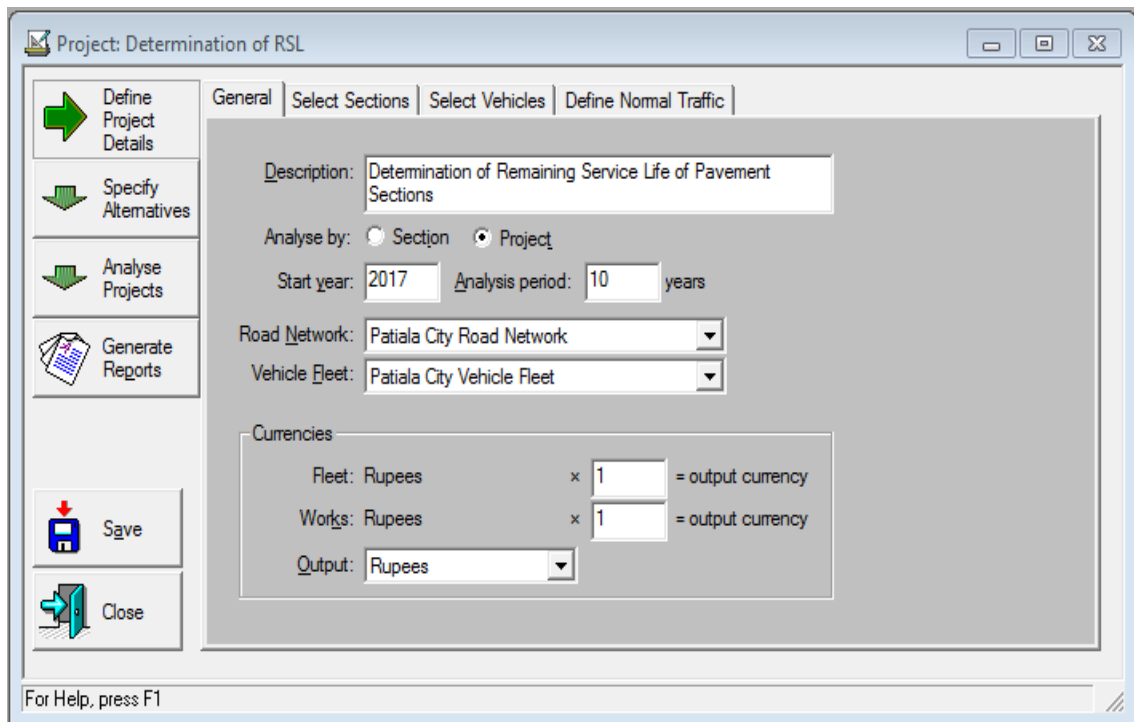
**Figure 5.13: Patiala City Vehicle Fleet with All the Vehicles Defined**

## 5.4 Determination of Remaining Service Life (RSL) of Road Sections

The aim of the very first objective was to compute Remaining Serviceable Life (RSL) of each road section. Remaining Serviceable Life (RSL) of a road section means the time left in years, till it becomes necessary to reconstruct the road pavement, providing no Maintenance and Rehabilitation (M&R) works throughout the intervening period [Gupta and Kumar, 2015]. ‘Project Analysis’ in HDM-4 has been selected for determining this parameter.

### 5.4.1 Input Data

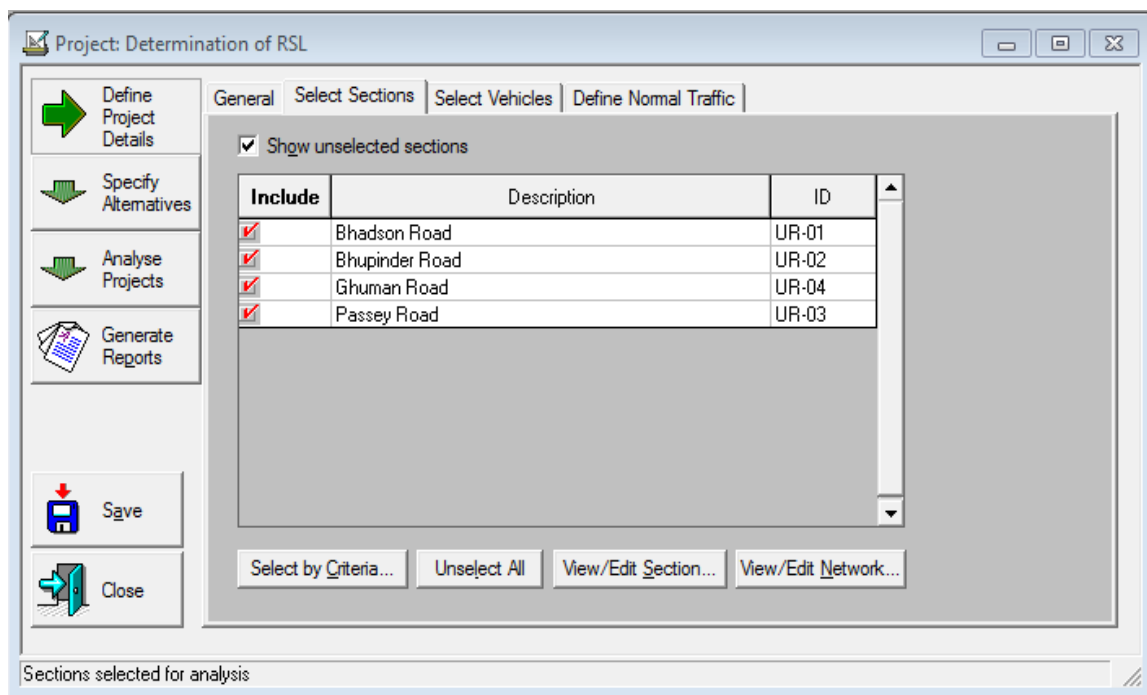
A new project named as ‘Determination of RSL’ was created which consisted of ‘Patiala City Road Network’ and ‘Patiala City Vehicle Fleet’ as inputs. The intervening period (analysis period) for the analysis of the project was taken as 10 years keeping in mind that all the selected road sections will become the candidates for reconstruction work within next ten years when no maintenance work is provided during the intervening period. Analyse by project was chosen for analysis. Figure 5.14 shows general input data for Project: Determination of RSL.



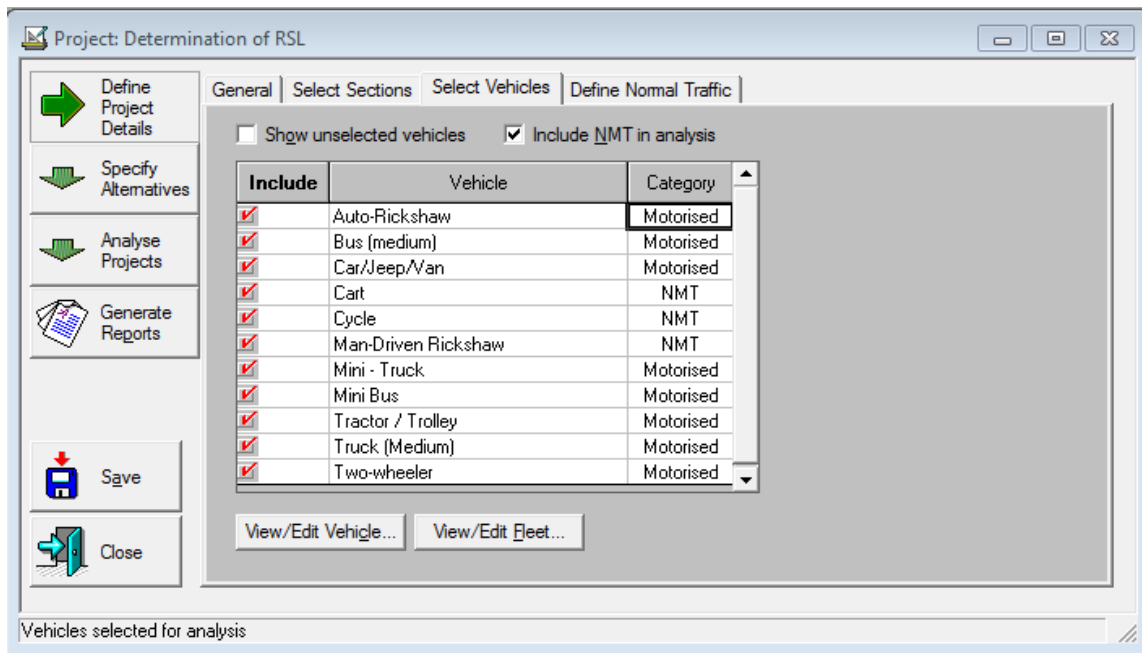
**Figure 5.14: General Input Data for Project: Determination of RSL**

#### 5.4.2 Selection of Sections and Vehicles

All the four sections from Patiala City Road Network and all the types of vehicles from Patiala City Vehicle Fleet were selected for the analysis purpose. Figure 5.15 and Figure 5.16 show the snapshots of selection of sections and selection of vehicles respectively.



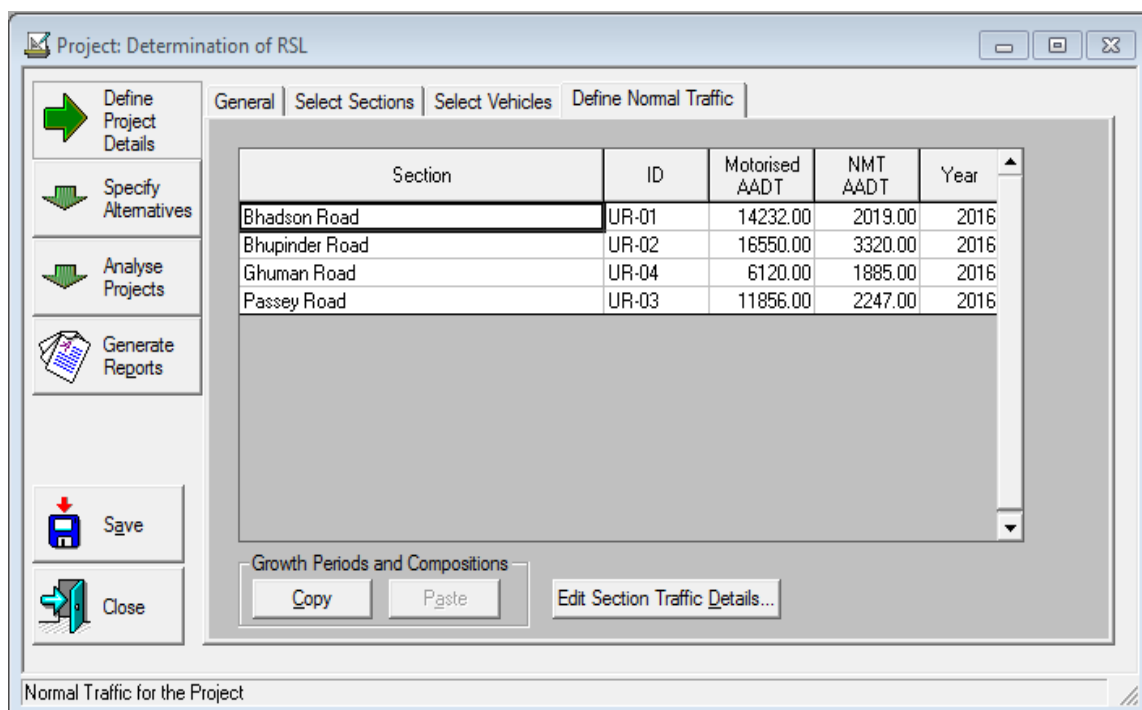
**Figure 5.15: Selection of Sections for Project: Determination of RSL**



**Figure 5.16: Selection of Vehicles for Project: Determination of RSL**

### 5.4.3 Define Normal Traffic

Normal traffic details such as Vehicular compositions with their annual average growth rate for both MT and NMT vehicles have been inputted for each section. Figure 5.17 Normal Traffic for the Project: Determination of RSL. Figure 5.18 and Figure 5.19 show the normal traffic details for MT and NMT vehicles for Bhadson Road section i.e. UR-01 respectively.



**Figure 5.17: Normal Traffic for the Project: Determination of RSL**

Normal Traffic Details

Motorised | **NMT**

Section Details

Name: Bhadson Road

AADT: 14232 Year: 2016

Growth Periods

Vehicle	Initial Composition (%)	Annual % increase from 2017
Two-wheeler	39.80	4.20
Car/Jeep/Van	29.80	8.50
Bus (medium)	3.60	4.00
Mini Bus	3.90	3.70
Truck (Medium)	3.40	5.00
Mini - Truck	2.10	12.50
Tractor / Trolley	2.60	5.90

Add New Period  
Delete Period  
Edit Period...

OK Cancel

Normal traffic growth periods

Figure 5.18: Normal Traffic Details of MT vehicle for Bhadson Road Section i.e. UR-01

Normal Traffic Details

Motorised | **NMT**

Section Details

Name: Bhadson Road

AADT: 2019 Year: 2016

Growth Periods

Vehicle	Initial Composition (%)	Annual % increase from 2017
Cycle	46.00	3.40
Man-Driven Rickshaw	52.00	3.40
Cart	2.00	3.40

Add New Period  
Delete Period  
Edit Period...

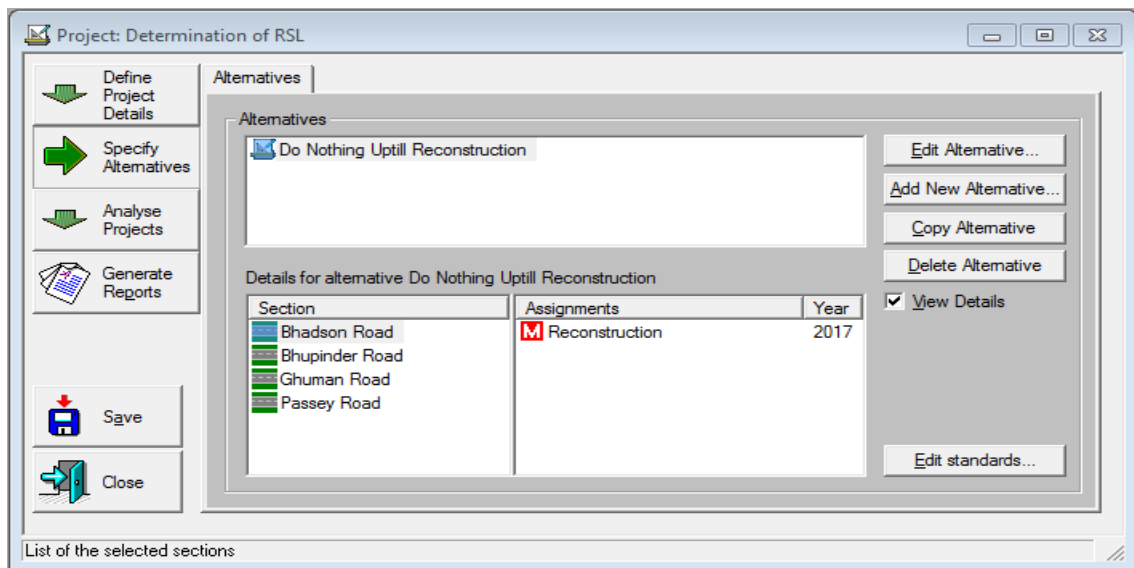
OK Cancel

Normal traffic growth periods

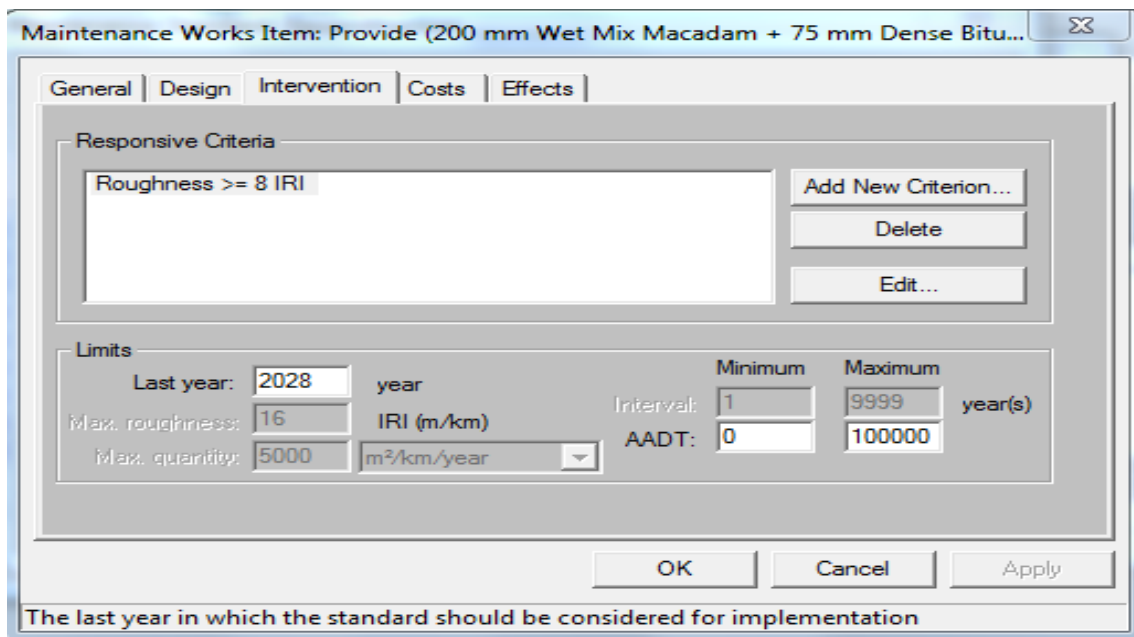
Figure 5.19: Normal Traffic Details of NMT vehicle for Bhadson Road Section i.e. UR-01

### 5.4.4 Specify M&R alternative

The condition responsive M&R alternative named as ‘Do Nothing uptill Reconstruction’ was defined for the project in which ‘Reconstruction’ maintenance work standard was assigned along with intervention criteria to each road section. As road roughness plays a vital role in PMMS, Roughness  $\geq 8$  m/km IRI has been taken as intervention criteria for reconstruction work. Figure 5.20 and Figure 5.21 show the specification of M&R alternative.



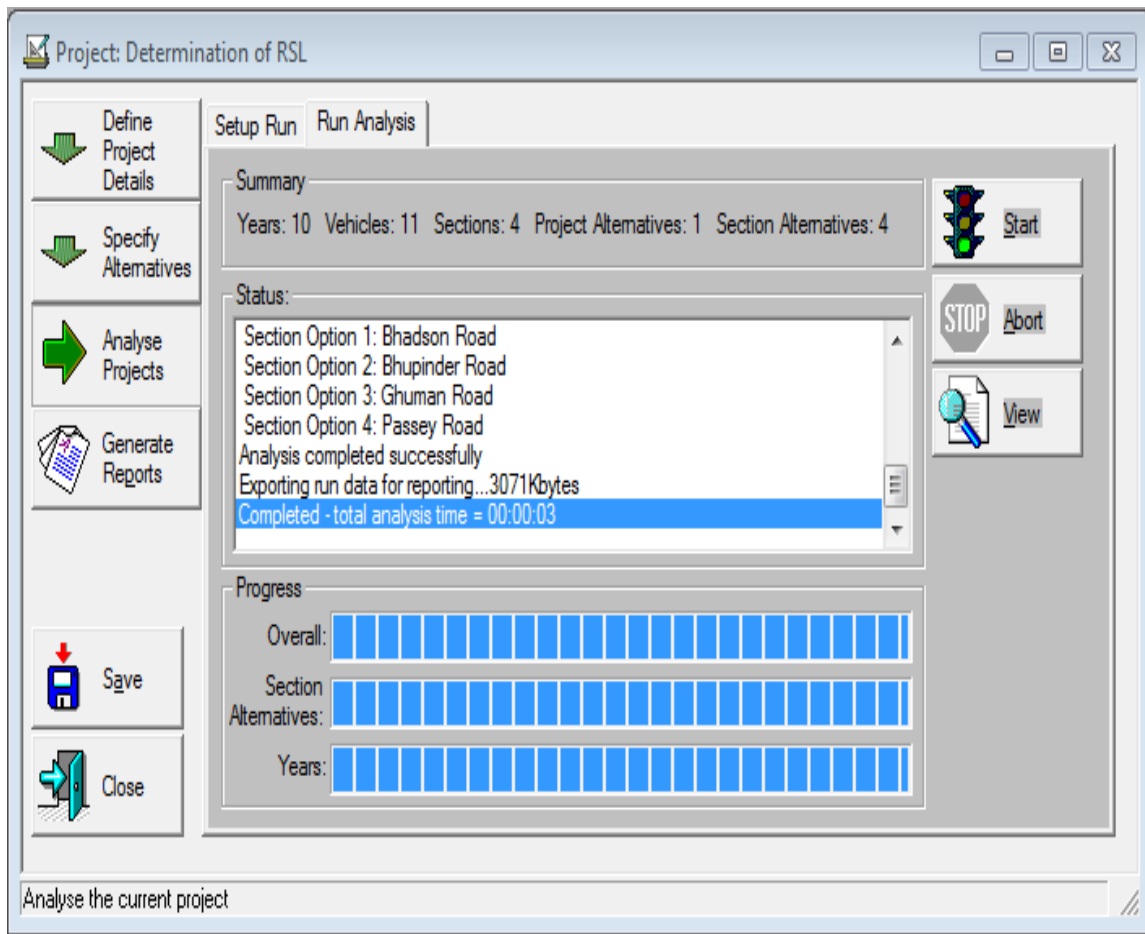
**Figure 5.20: Defined M&R Alternative for all Selected Pavement Sections**



**Figure 5.21: Intervention Criteria for Selected M&R Work Item**

### 5.4.5 Project Analysis

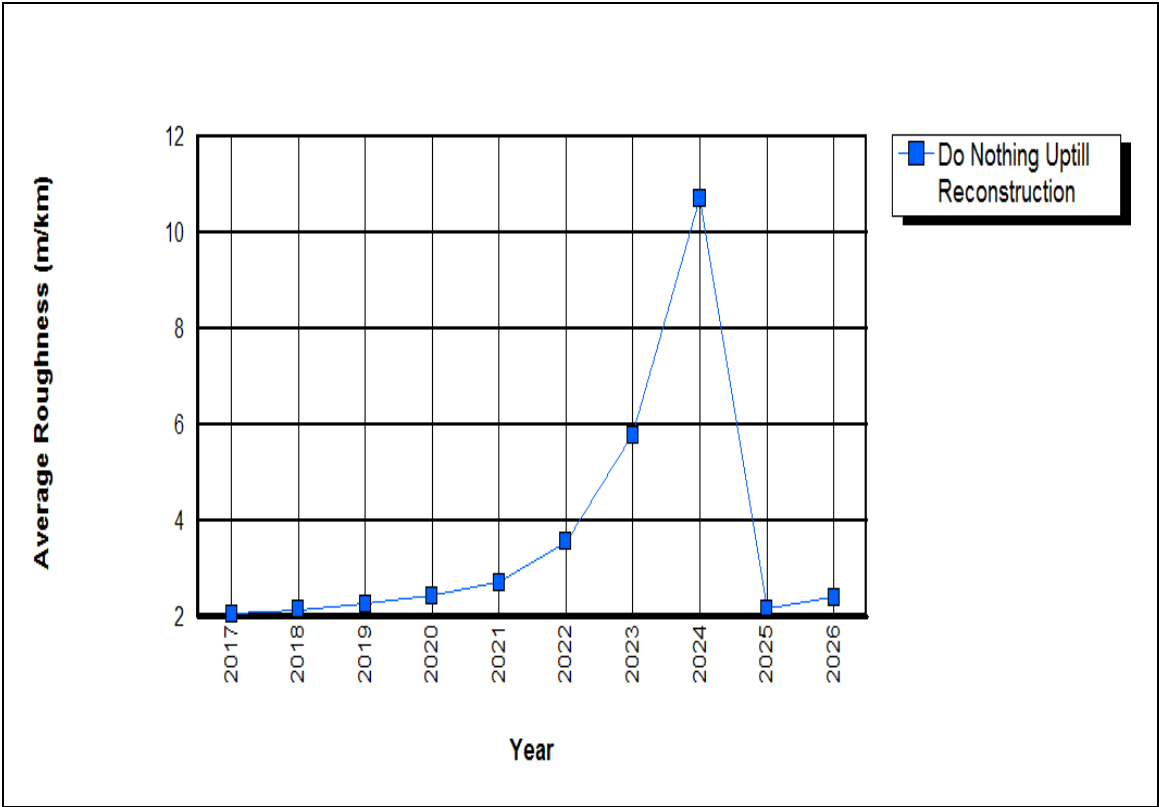
No economic analysis was required to be conducted for this objective because no other alternative was assigned for comparison purpose. The project analysis application was run for analyzing the pavement future condition (pavement deterioration) of all the selected road sections under assigned M&R alternative. Figure 5.22 shows the run analysis of the project.



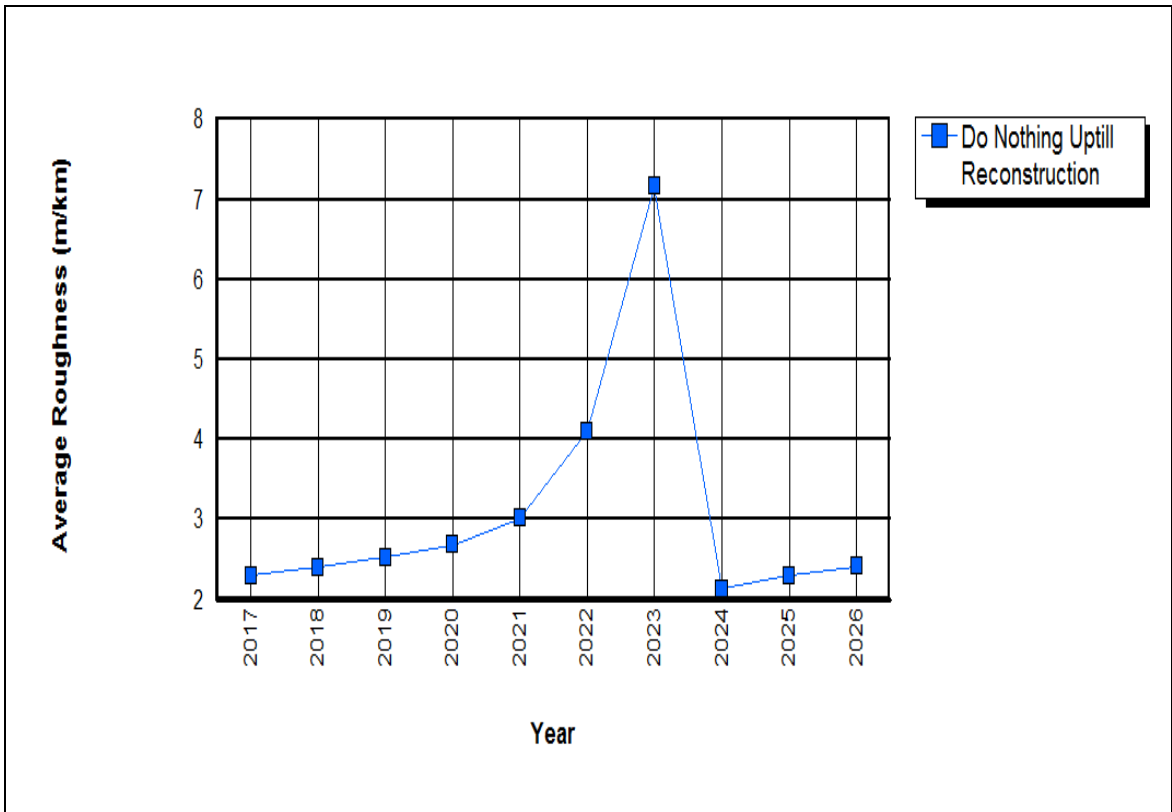
**Figure 5.22: Run Analysis of Project: Determination of RSL**

### 5.4.6 Roughness Progression

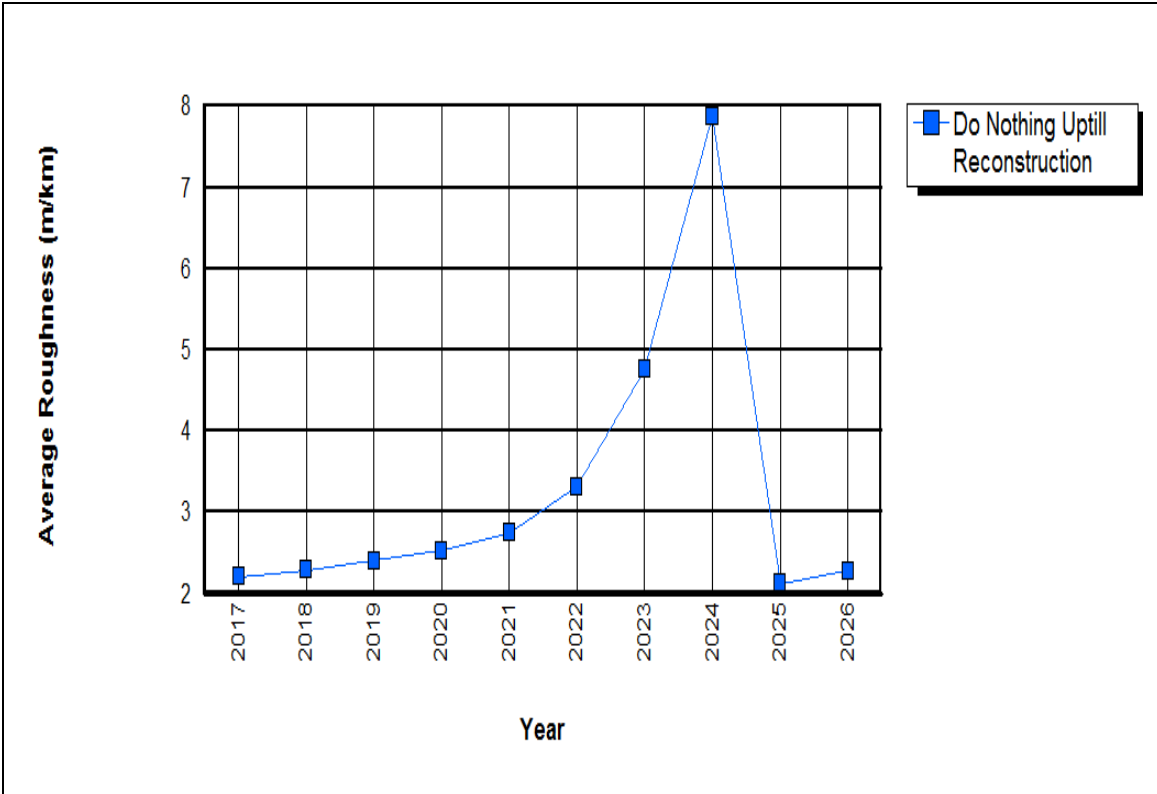
The Roughness progresses with each year (start year - 2017). If it exceeds intervention value i.e.  $\geq 8$  IRI in a certain year, Reconstruction alternative shall be triggered for that year. Figure 5.23 to Figure 5.26 show average roughness progression graph for all the selected road sections i.e. UR-01, UR-02, UR-03 and UR-04 respectively. The sharp fall in average roughness values indicates the reconstruction work of the road section in that certain year.



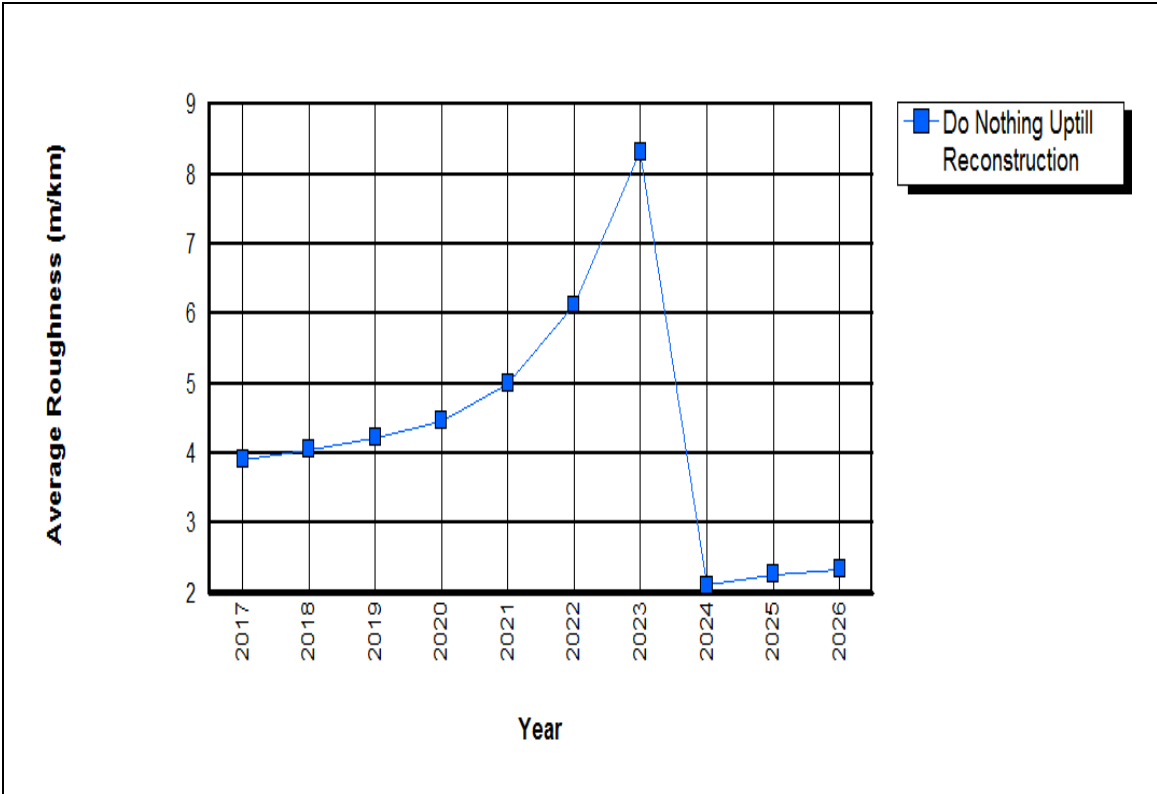
**Figure 5.23: Roughness Progression for Bhadson Road Section i.e. UR-01**



**Figure 5.24: Roughness Progression for Bhupinder Road Section i.e. UR-02**



**Figure 5.25: Roughness Progression for Passey Road Section i.e. UR-03**



**Figure 5.26: Roughness Progression for Ghuman Road Section i.e. UR-04**

### 5.4.7 Determination of Remaining Service Life (RSL)

The Remaining Service Life (RSL) in respect of all pavement sections is determined as the time period left in years before the reconstruction of pavement is necessitated on the basis of progression of roughness up to the intervention level. Remaining Serviceable Life of all the road sections were computed from the above mentioned roughness progression graphs and road work summary report of the road sections. Table 5.1 shows the computed RSL values of each road section.

**Table 5.1: Remaining Service Life of Each Road Section**

Section ID	Section Name	Reconstruction Year	Remaining Service Life (RSL), in years
UR-01	Bhadson Road	2024	7
UR-02	Bhupinder Road	2023	6
UR-03	Passey Road	2024	7
UR-04	Ghuman Road	2023	5

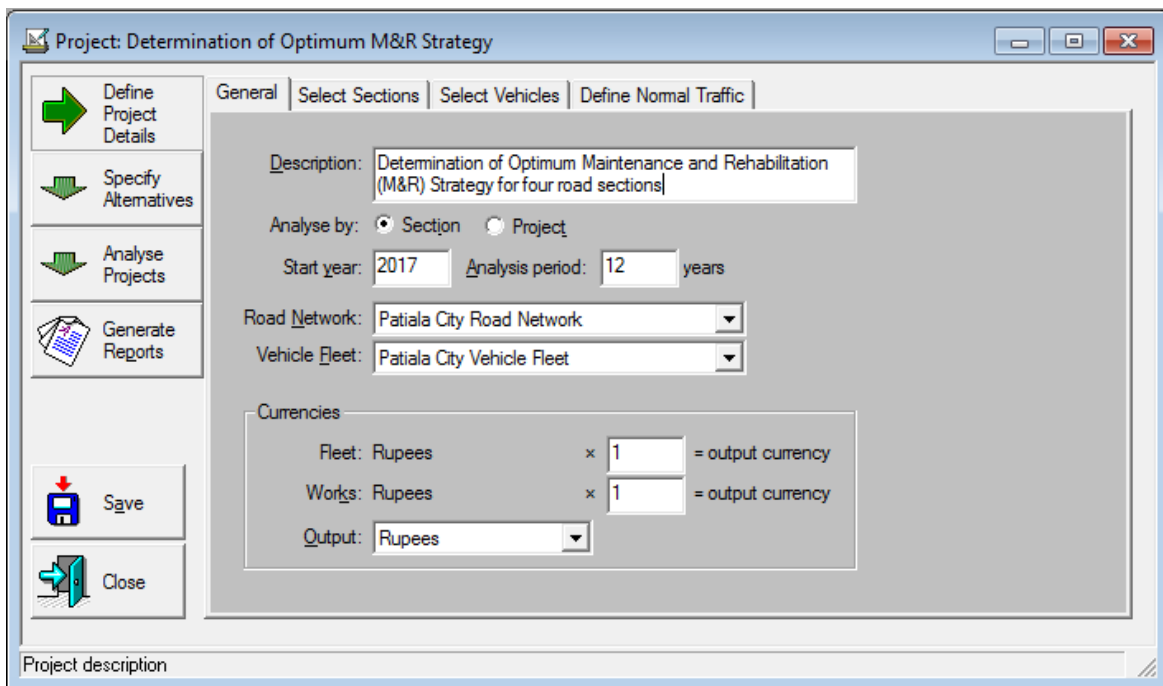
**Comments:** It can be seen that all the four road sections will be needing reconstruction work within 5 to 7 years if no maintenance and rehabilitation work is assigned to the road sections throughout the intervening period. Remaining Service Life (RSL) value of the road section will help the road agency to know the imperative time for reconstruction work prior to the failure of entire road. Budgeting and funding for reconstruction work can be done accordingly.

### 5.5 Determination of Optimum M&R Strategy for All the Road Sections

The aim of this objective is to determine the optimum Maintenance and Rehabilitation (M&R) strategy for all the four Road Sections i.e., Bhadson Road section (UR-01), Bhupinder Road section (UR-02), Passey Road (UR-03) and Ghuman Road section (UR-04). This objective shows the economic analysis of Maintenance and Rehabilitation (M&R) strategies for road sections. The importance of this objective is to evaluate the cost-effective benefits resulting from investing in M&R works of a road section at the appropriate time, as compared against carrying out minimum routine maintenance annually. The optimum M&R strategy has been selected on the basis of economic indicators, such as NPV/Cost Ratio. Project Analysis in HDM-4 has been adopted for this objective.

### 5.5.1 Input Data

A new project named as ‘Determination of Optimum M&R Strategy’ was created which consisted of ‘Patiala City Road Network’ and ‘Patiala City Vehicle Fleet’ as inputs. Analysis period (intervening period for analysis of the project) was taken as 12 years. Analyse by section has been chosen. Input and output currencies are taken as Rupees. Figure 5.27 shows general data input for Project: Determination of Optimum M&R Strategy.



**Figure 5.27: General Data Input for Project: Determination of Optimum M&R Strategy**

### 5.5.2 Selection of Sections and Vehicles

For this objective, all the four road sections i.e., UR-01, UR-02, UR-03 and UR-04 mentioned earlier have been selected from Patiala City Road Network. All the eleven types of vehicle have been marked and selected from Patiala City Vehicle Fleet for the analysis of this project.

### 5.5.3 Define Normal Traffic

Normal traffic details such as Vehicular compositions with their annual average growth rate for both MT and NMT vehicles have been inputted for individual road section.

### 5.5.4 Proposed Maintenance and Rehabilitation (M&R) Alternatives

Four Maintenance and Rehabilitation (M&R) alternatives have been proposed for this objective and given in Table 5.2 keeping in mind the serviceability level of Other Roads (mentioned in previous chapter). The first strategy i.e., 'Base Alternative' indicates the provision of minimum routine maintenance in terms of crack sealing and patching. Three other alternative M&R strategies have been proposed in this study to compare with the base alternative for the economic analysis of the project. All the maintenance standards assigned in the below mentioned table are applicable from the very first year of the analysis period, i.e. year 2017.

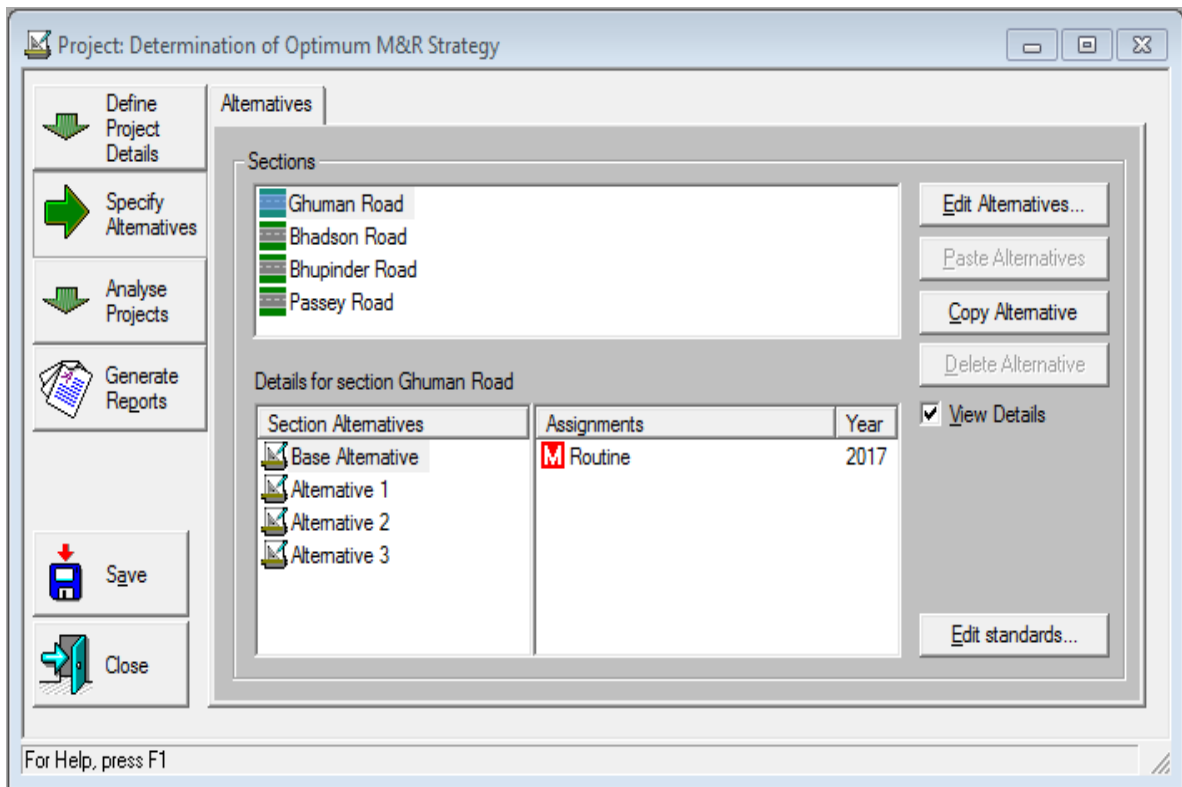
**Table 5.2: Proposed Maintenance and Rehabilitation Alternatives**

<b>M&amp;R Strategy</b>	<b>Works Standard</b>	<b>Description of Work</b>	<b>Intervention Level</b>
Base Alternative	Routine	Crack Sealing	Scheduled annually
		Patching	Scheduled annually
Alternative 1	Resealing + Thin Overlay	Provide 25 mm DBSD	Total damage area* > 8% of total area
		Provide 25 mm BC	Roughness $\geq 4$ , $\leq 5.8$ IRI
Alternative 2	Thick Overlay	Provide 40 mm BC	Roughness $\geq 5.8$ , $\leq 8$ IRI
Alternative 3	Reconstruction	Provide (200 mm Wet Mix Macadam + 75 mm Dense Bituminous Macadam + 40mm Bituminous Concrete)	Roughness $\geq 8$ IRI

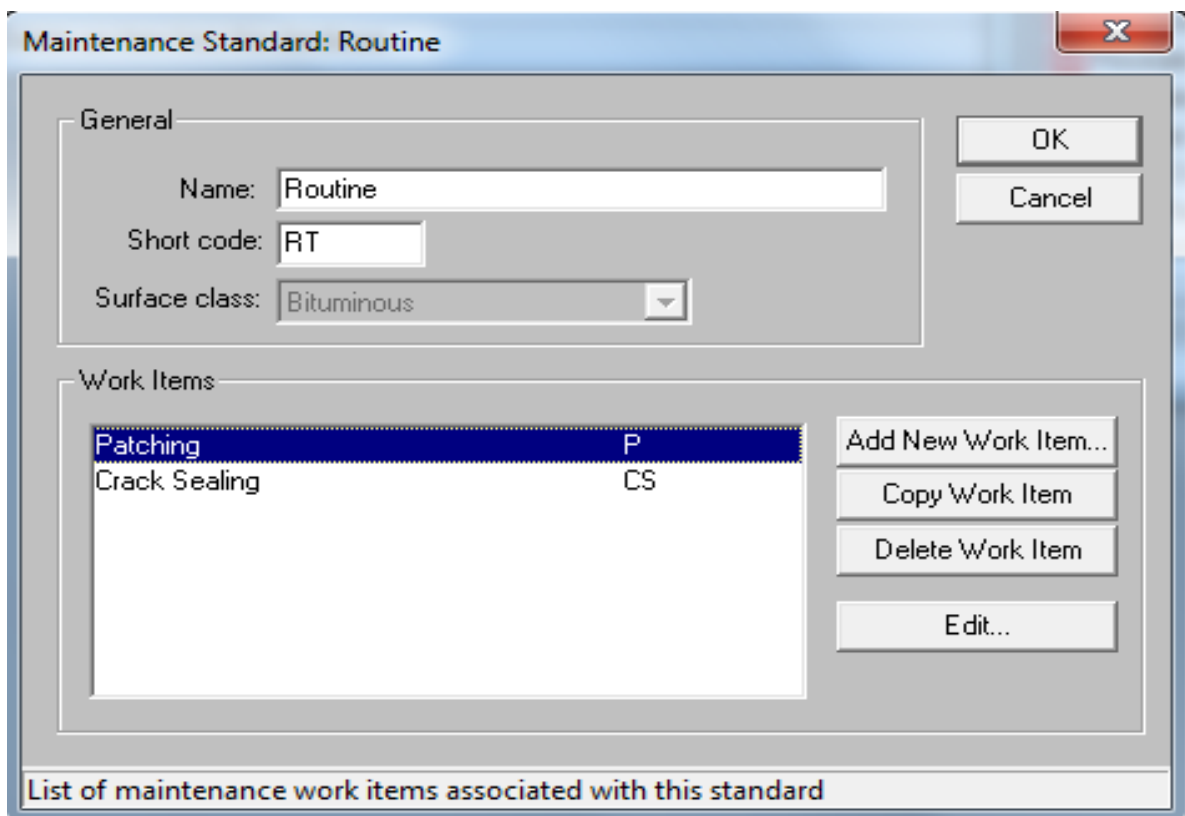
\*Total Damage Area comprises of cracked, ravelled and potholed area

### 5.5.5 Specify M&R Alternatives

Proposed Maintenance and Rehabilitation (M&R) alternatives have been specified in the project. Corresponding to these alternatives, M&R work items with their economic costs have been assigned with the required intervention levels. Figure 5.28 shows all the Proposed M&R alternatives for analysis of this project. Figure 5.29 shows work items assigned for 'Routine' work standard. Figure 5.30 to Figure 5.32 show the data input for Patching work item.



**Figure 5.28: Proposed M&R Alternatives for Project Analysis of Ghuman Road Section i.e., UR-04**



**Figure 5.29: Work Items Assigned for 'Routine' Work Standard**

Maintenance Works Item: Patching

General | Intervention | Costs | Effects

Name: Patching

Short code: P

Surface: Bituminous

Feature type: Carriageway

Operation: Patching

Intervention type:  Scheduled  
 Responsive

OK Cancel Apply

The name of this works item

**Figure 5.30: General Input Data for ‘Patching’ Work Item**

Maintenance Works Item: Patching

General | Intervention | Costs | Effects

Intervention criteria

Time Interval: 1 Years

Limits

Last year: 2030 year

Max. roughness: 6 IRI (m/km)

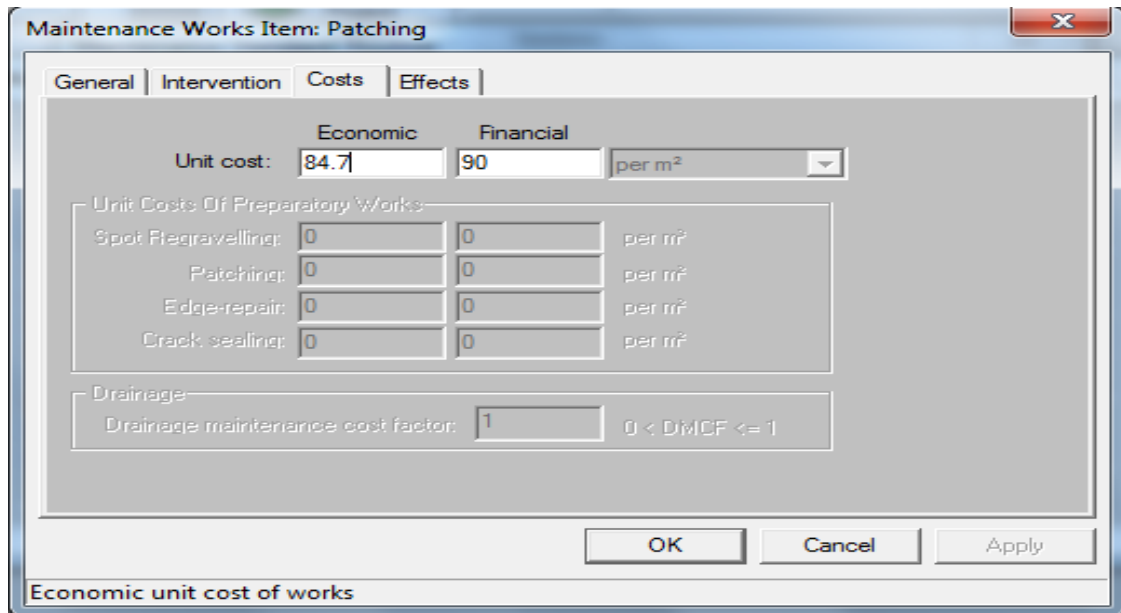
Max. quantity: 5000 m<sup>2</sup>/km/year

	Minimum	Maximum
Interval:	1	9999 year(s)
AADT:	0	100000

OK Cancel Apply

Frequency at which the work item will be performed (ie. every X years/days)

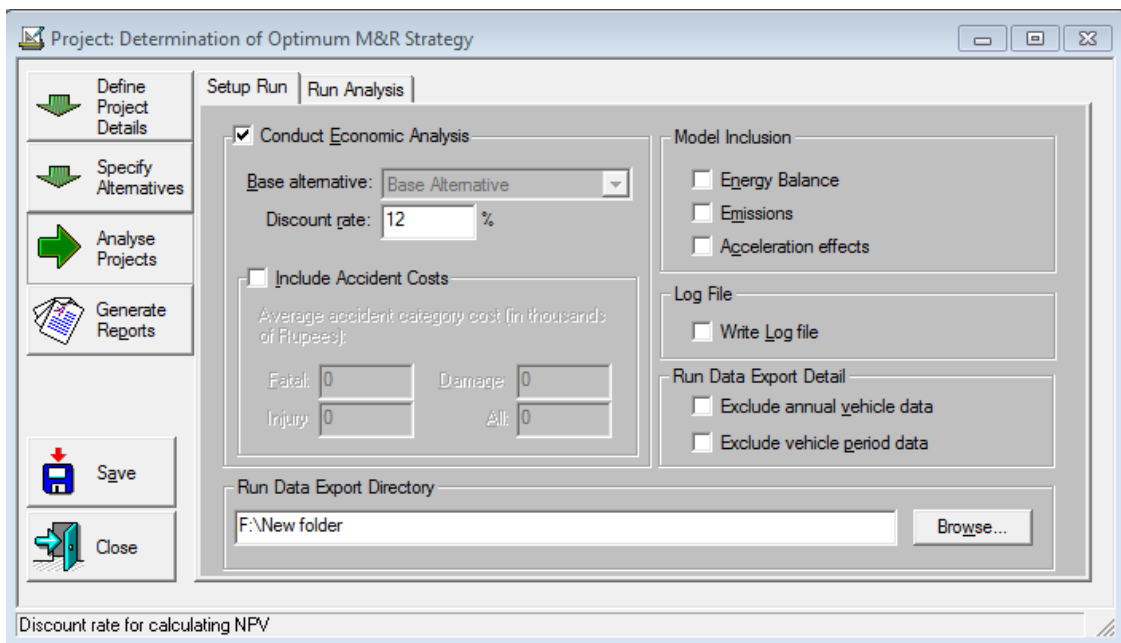
**Figure 5.31: Intervention criteria for ‘Patching’ Work Item**



**Figure 5.32: Costs Data for ‘Patching’ Work Item**

### 5.5.6 Project Analysis

As the economic analysis for the selected sections has to be done, so in Set-up Run of Project Analysis, ‘Conduct Economic Analysis’ was selected. Base Alternative was chosen for comparison purpose by default. A discount rate of 12 % was taken as shown in Figure 5.33. The choice of discount rate is governed by various factors such as future availability of finance, various opportunities for its use etc. A discount rate of 12 % can be taken for economic analysis in developing country like India [Clause 7.8, IRC: SP: 30-2009].



**Figure 5.33: Set-up Run for Project Analysis**

Project Run Analysis has been carried for all the selected road sections. As a result of this analysis, the road pavement deterioration/works reports and Maintenance & Rehabilitation works reports have been generated corresponding to each M&R alternative considered above. These two types of reports are described in the following sections.

### 5.5.7 Road Pavement Deterioration

The pavement deterioration summary reports for all the road sections have been given in detail in Annexure C. The pavement deterioration summary reports of the Ghuman Road Section i.e., UR-04, as obtained under proposed M&R strategies over the analysis period of 12 years, are given in Table 5.3 to Table 5.6 taken from section C.4 of Annexure C. From the deterioration reports, it was seen that as the analysis period started, traffic volume on pavement i.e., Motorized AADT increased with each incremental year. Adjusted Structural Number (SNP) of the pavement started decreasing until some M&R alternative was assigned. Detailed pavement deterioration i.e. progression of defects such as roughness, cracks, potholes, rut depth etc. with each incremental year corresponding to each alternative have been shown.

**Table 5.3: Pavement Deterioration Summary of Section UR-04 for Base Alternative**

Year	MT AADT	ESAL Million / Lane	SNP	Roughness , IRI (m/km)	All Structural Cracks (% area)	No. of Pothole	Mean Rut Depth (mm)
2017	6,494	0.07	4.59	3.91	3.19	7.17	3.48
2018	6,892	0.07	4.61	3.98	0.86	0.00	3.64
2019	7,318	0.08	4.60	4.11	2.27	15.82	3.79
2020	7,773	0.08	4.58	4.25	4.87	23.69	3.96
2021	8,259	0.09	4.55	4.41	9.13	29.83	4.12
2022	8,779	0.10	4.49	4.59	13.77	33.81	4.29
2023	9,334	0.10	4.45	4.76	17.85	33.33	4.46
2024	9,929	0.11	4.40	4.95	23.61	33.68	4.64
2025	10,566	0.12	4.31	5.15	31.52	33.22	4.82

2026	11,247	0.13	4.20	5.37	42.14	31.56	5.01
2027	11,977	0.13	4.03	5.61	55.24	28.21	5.21
2028	12,760	0.14	3.82	5.85	6650	22.99	5.43

**Table 5.4: Pavement Deterioration Summary of Section UR-04 for Alternative 1**

<b>Year</b>	<b>MT AADT</b>	<b>ESAL Million / Lane</b>	<b>SNP</b>	<b>Roughness , IRI (m/km)</b>	<b>All Structural Cracks (% area)</b>	<b>No. of Pothole</b>	<b>Mean Rut Depth (mm)</b>
2017	6,494	0.07	4.59	3.91	3.19	7.17	2.00
2018	6,892	0.07	4.77	2.55	0.00	0.00	0.67
2019	7,318	0.08	4.77	2.62	0.00	0.00	0.83
2020	7,773	0.08	4.77	2.70	0.50	0.00	0.98
2021	8,259	0.09	4.77	2.79	1.77	0.00	1.13
2022	8,779	0.10	4.76	2.88	4.54	0.00	1.29
2023	9,334	0.10	4.73	2.99	4.81	0.00	0.84
2024	9,929	0.11	4.95	2.46	0.00	0.00	0.37
2025	10,566	0.12	4.95	2.53	0.00	0.00	0.52
2026	11,247	0.13	4.95	2.60	0.00	0.00	0.68
2027	11,977	0.13	4.95	2.69	1.20	0.00	0.83
2028	12,760	0.14	4.94	2.77	3.37	0.00	0.99

**Table 5.5: Pavement Deterioration Summary of Section UR-04 for Alternative 2**

<b>Year</b>	<b>MT AADT</b>	<b>ESAL Million / Lane</b>	<b>SNP</b>	<b>Roughness , IRI (m/km)</b>	<b>All Structural Cracks (% area)</b>	<b>No. of Pothole</b>	<b>Mean Rut Depth (mm)</b>
2017	6,494	0.07	4.59	3.91	6.37	14.34	3.48
2018	6,892	0.07	4.50	4.05	11.45	17.30	3.64
2019	7,318	0.08	4.41	4.22	18.95	52.46	3.81
2020	7,773	0.08	4.28	4.47	29.45	111.40	3.99
2021	8,259	0.09	4.08	5.00	21.74	145.47	2.41

2022	8,779	0.10	4.65	2.92	0.60	0.00	0.79
2023	9,334	0.10	4.64	3.01	2.02	0.00	0.95
2024	9,929	0.11	4.63	3.11	5.03	0.00	1.12
2025	10,566	0.12	4.60	3.22	10.46	0.00	1.28
2026	11,247	0.13	4.54	3.36	19.28	0.00	1.46
2027	11,977	0.13	4.44	3.52	32.56	0.00	1.64
2028	12,760	0.14	4.28	3.80	51.23	132.62	1.85

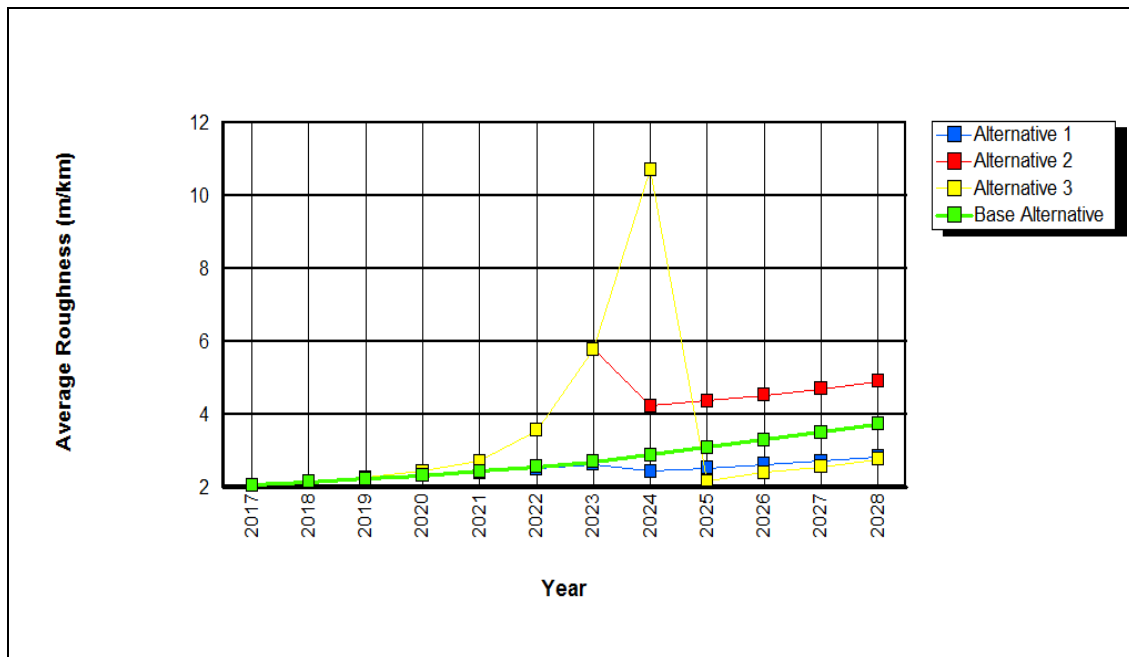
**Table 5.6: Pavement Deterioration Summary of Section UR-04 for Alternative 3**

<b>Year</b>	<b>MT AADT</b>	<b>ESAL Million/ Lane</b>	<b>SNP</b>	<b>Roughness, IRI (m/km)</b>	<b>All Structural Cracks (% area)</b>	<b>No. of Pothole</b>	<b>Mean Rut Depth (mm)</b>
2017	6,494	0.07	4.59	3.91	6.37	14.34	3.48
2018	6,892	0.07	4.50	4.05	11.45	17.30	3.64
2019	7,318	0.08	4.41	4.22	18.95	52.46	3.81
2020	7,773	0.08	4.28	4.47	29.45	111.40	3.99
2021	8,259	0.09	4.08	5.00	43.47	290.94	4.19
2022	8,779	0.10	3.82	6.14	29.98	284.90	2.53
2023	9,334	0.10	4.42	4.93	0.83	0.00	0.83
2024	9,929	0.11	4.41	5.07	2.55	0.00	1.00
2025	10,566	0.12	4.40	5.23	6.04	0.00	1.18
2026	11,247	0.13	4.37	5.40	12.18	0.00	1.36
2027	11,977	0.13	4.32	5.60	21.94	0.00	1.55
2028	12,760	0.14	4.22	5.83	36.43	0.00	1.75

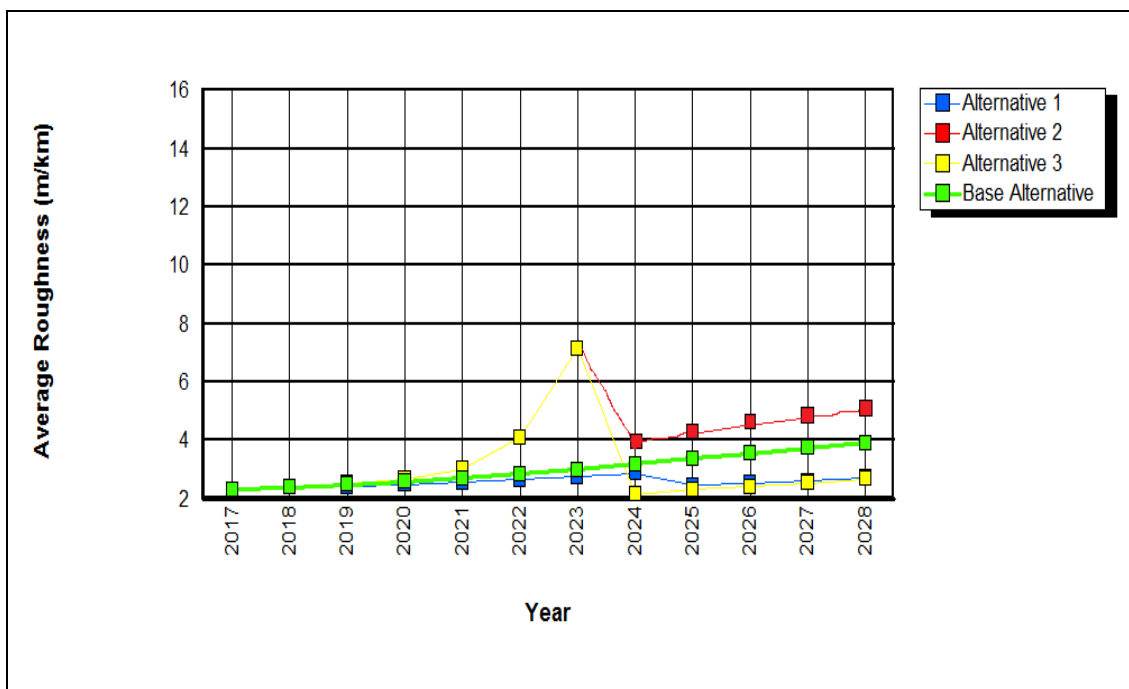
### 5.5.8 Roughness Progression

The Roughness progression graphs of all the four alternatives for all the four road sections are shown individually from Figure 5.34 to Figure 5.37. The roughness progression has

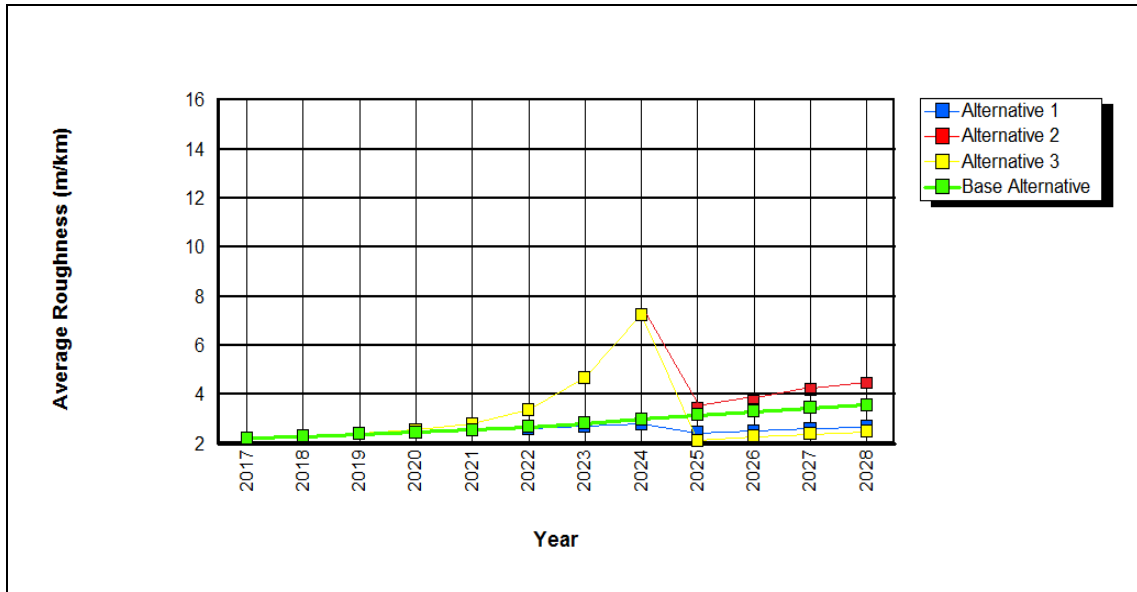
been traced to know whether the works have been correctly triggered according to the specified intervention criteria or not.



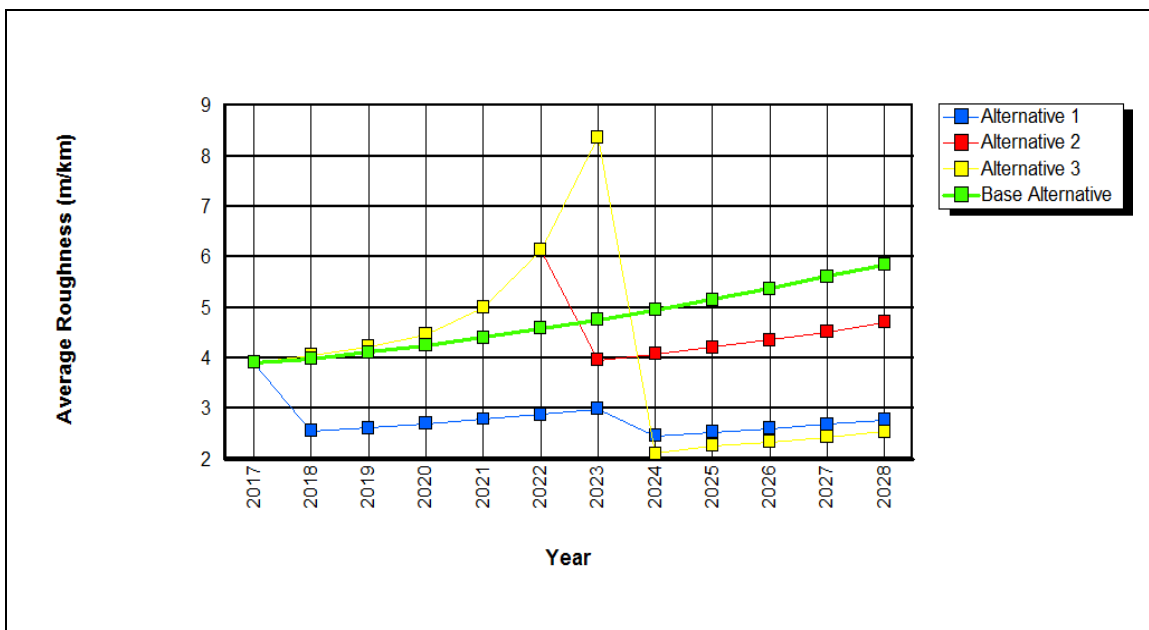
**Figure 5.34: Roughness Progressions under All Alternatives for Bhadson Road Section i.e. UR-01**



**Figure 5.35: Roughness Progressions under All Alternatives for Bhupinder Road Section i.e. UR-02**



**Figure 5.36: Roughness Progressions under All Alternatives for Passey Road Section i.e. UR-03**



**Figure 5.37: Roughness Progressions under All Alternatives for Ghuman Road Section i.e. UR-04**

### 5.5.9 M&R Works Report

The various works resulting from application of all the specified M&R strategies (as triggered by the respective intervention parameters), timings of their application and associated cost of each work item are given in the M&R works report of all the four road

sections from Table 5.7 to Table 5.14. The year-wise summary report of each alternative for all the road sections have been mentioned in Table 5.15 to Table 5.17. This works report gives description of the works that would be implemented in each year of the analysis period (2017-2028), under each M&R strategy.

**Table 5.7: M&R Works for Bhadson Road Section (UR-01) During Analysis Period**

Year	M&R Works			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2017	Patching & Crack Sealing	****	****	****
2018	Patching & Crack Sealing	25 mm DBSD	****	****
2019	Patching & Crack Sealing	****	****	****
2020	Patching & Crack Sealing	****	****	****
2021	Patching & Crack Sealing	****	****	****
2022	Patching & Crack Sealing	****	****	****
2023	Patching & Crack Sealing	25 mm DBSD	40 mm BC	****
2024	Patching & Crack Sealing	****	****	200 mm WMM +75 mm DBM + 40 mm BC
2025	Patching & Crack Sealing	****	****	****
2026	Patching & Crack Sealing	****	****	****
2027	Patching & Crack Sealing	****	****	****
2028	Patching & Crack Sealing	25 mm DBSD	****	****

\*\*\*\* means no M&R work assigned in the certain year

**Table 5.8: Economic Costs of M&R Works for Bhadson Road Section (UR-01)**

Year	M&R Work Economic Costs (in Million Rupees)			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2017	0.00391	0.00	0.00	0.00
2018	0.02531	2.369	0.00	0.00
2019	0.02531	0.00	0.00	0.00
2020	0.02531	0.00	0.00	0.00
2021	0.02531	0.00	0.00	0.00
2022	0.02531	0.00	0.00	0.00
2023	0.02531	2.369	3.099	0.00
2024	0.02531	0.00	0.00	12.012
2025	0.02531	0.00	0.00	0.00
2026	0.02531	0.00	0.00	0.00
2027	0.02531	0.00	0.00	0.00
2028	0.02531	2.369	0.00	0.00
<b>Total Cost in Million Rupees</b>	0.282	7.11	3.099	12.012

**Table 5.9: M&R Works for Bhupinder Road Section (UR-02) throughout Analysis Period**

Year	M&R Works			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2017	Patching & Crack Sealing	****	****	****
2018	Patching & Crack Sealing	25 mm DBSD	****	****
2019	Patching & Crack Sealing	****	****	****
2020	Patching & Crack Sealing	****	****	****
2021	Patching & Crack	****	****	****

	Sealing			
2022	Patching & Crack Sealing	****	****	****
2023	Patching & Crack Sealing	****	****	200 mm WMM +75 mm DBM + 40 mm BC
2024	Patching & Crack Sealing	25 mm DBSD	****	****
2025	Patching & Crack Sealing	****	****	****
2026	Patching & Crack Sealing	****	****	****
2027	Patching & Crack Sealing	****	****	****
2028	Patching & Crack Sealing	****	****	****

\*\*\*\* means no M&R work assigned in the certain year

**Table 5.10: Economic Costs of M&R Works for Bhupinder Road Section (UR-02)**

Year	M&R Work Economic Costs (in Million Rupees)			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2017	0.00985	0.00	0.00	0.00
2018	0.04037	3.778	0.00	0.00
2019	0.04037	0.00	0.00	0.00
2020	0.04037	0.00	0.00	0.00
2021	0.04037	0.00	0.00	0.00
2022	0.04037	0.00	0.00	0.00
2023	0.04037	0.00	0.00	19.162
2024	0.04037	3.778	0.00	0.00
2025	0.04037	0.00	0.00	0.00
2026	0.04037	0.00	0.00	0.00
2027	0.04037	0.00	0.00	0.00

2028	0.04037	0.00	0.00	0.00
<b>Total Cost in Million Rupees</b>	0.454	7.557	0.00	19.162

**Table 5.11: M&R Works for Passey Road Section (UR-03) throughout Analysis Period**

Year	M&R Works			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2017	Patching & Crack Sealing	****	****	****
2018	Patching & Crack Sealing	25 mm DBSD	****	****
2019	Patching & Crack Sealing	****	****	****
2020	Patching & Crack Sealing	****	****	****
2021	Patching & Crack Sealing	****	****	****
2022	Patching & Crack Sealing	****	****	****
2023	Patching & Crack Sealing	****	****	****
2024	Patching & Crack Sealing	25 mm DBSD	****	200 mm WMM +75 mm DBM + 40 mm BC
2025	Patching & Crack Sealing	****	****	****
2026	Patching & Crack Sealing	****	****	****
2027	Patching & Crack Sealing	****	****	****
2028	Patching & Crack Sealing	****	****	****

\*\*\*\* means no M&R work assigned in the certain year

**Table 5.12: Economic Costs of M&R Works for Passey Road Section (UR-03)**

Year	M&R Work Economic Costs (in Million Rupees)			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2017	0.00344	0.00	0.00	0.00
2018	0.01958	3.778	0.00	0.00
2019	0.01958	0.00	0.00	0.00
2020	0.01958	0.00	0.00	0.00
2021	0.01958	0.00	0.00	0.00
2022	0.01958	0.00	0.00	0.00
2023	0.01958	0.00	0.00	9.295
2024	0.01958	3.778	0.00	0.00
2025	0.01958	0.00	0.00	0.00
2026	0.01958	0.00	0.00	0.00
2027	0.01958	0.00	0.00	0.00
2028	0.01958	0.00	0.00	0.00
<b>Total Cost in Million Rupees</b>	0.218	3.666	0.00	9.295

**Table 5.13: M&R Works for Ghuman Road Section (UR-04) throughout Analysis Period**

Year	M&R Works			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2017	Patching & Crack Sealing	25 mm DBSD	****	****
2018	Patching & Crack Sealing	****	****	****
2019	Patching & Crack Sealing	****	****	****

2020	Patching & Crack Sealing	****	****	****
2021	Patching & Crack Sealing	****	****	****
2022	Patching & Crack Sealing	****	40 mm BC	****
2023	Patching & Crack Sealing	25 mm DBSD	****	200 mm WMM +75 mm DBM + 40 mm BC
2024	Patching & Crack Sealing	****	****	****
2025	Patching & Crack Sealing	****	****	****
2026	Patching & Crack Sealing	****	****	****
2027	Patching & Crack Sealing	****	****	****
2028	Patching & Crack Sealing	****	****	****

\*\*\*\* means no M&R work assigned in the certain year

**Table 5.14: Economic Costs of M&R Works for Ghuman Road Section (UR-04)**

Year	M&R Work Economic Costs (in Million Rupees)			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2017	0.03484	2.030	0.00	0.00
2018	0.00	0.00	0.00	0.00
2019	0.00027	0.00	0.00	0.00
2020	0.00040	0.00	0.00	0.00
2021	0.00051	0.00	0.00	0.00
2022	0.01792	0.00	2.657	0.00
2023	0.01791	2.030	0.00	10.296
2024	0.01792	0.00	0.00	0.00

2025	0.01791	0.00	0.00	0.00
2026	0.01788	0.00	0.00	0.00
2027	0.01778	0.00	0.00	0.00
2028	0.01773	0.00	0.00	0.00
<b>Total Cost in Million Rupees</b>	0.161	4.060	2.657	10.296

Year-wise summary reports for all the four road sections corresponding to each alternative are mentioned in Table 5.15 to Table 5.17. Considering Table 5.15, Alternative 1 i.e., Resealing + Thin Overlay will be required in year 2018, 2023 and 2028 for Bhadson Road (UR-01), in year 2018 and 2024 for Bhupinder Road (UR-02) and Passey Road (UR-03) and in year 2017 and 2023 for Ghuman Road (UR-04) during the analysis period of 12 years (2017 - 2028).

**Table 5.15: Year-wise Summary Report of Alternative 1 (Resealing + Thin Overlay) for All the Road Sections**

Year	Alternative 1			
	Bhadson Road (UR-01)	Bhupinder Road (UR-02)	Passey Road (UR-03)	Ghuman Road (UR-04)
2017	****	****	****	25 mm DBSD
2018	25 mm DBSD	25 mm DBSD	25 mm DBSD	****
2023	25 mm DBSD	****	****	25 mm DBSD
2024	****	25 mm DBSD	25 mm DBSD	****
2028	25 mm DBSD	****	****	****

\*\*\*\* means no M&R work assigned in the certain year

**Table 5.16: Year-wise Summary Report of Alternative 2 (Thick Overlay) for All the Road Sections**

Year	Alternative 2			
	Bhadson Road (UR-01)	Bhupinder Road (UR-02)	Passey Road (UR-03)	Ghuman Road (UR-04)
2022	****	****	****	40 mm BC
2023	40 mm BC	40 mm BC	****	****
2024	****	****	40 mm BC	****

**Table 5.17: Year-wise Summary Report of Alternative 3 (Reconstruction) for All the Road Sections**

Year	Alternative 3			
	Bhadson Road (UR-01)	Bhupinder Road (UR-02)	Passey Road (UR-03)	Ghuman Road (UR-04)
2023	****	200 mm WMM +75 mm DBM + 40 mm BC	****	200 mm WMM +75 mm DBM + 40 mm BC
2024	200 mm WMM +75 mm DBM + 40 mm BC	****	200 mm WMM +75 mm DBM + 40 mm BC	****

\*\*\*\* means no M&R work assigned in the certain year

#### 5.5.10 Economic Analysis of M&R Strategy

Selection of optimum M&R strategy by economic analysis is based on any of the economic indicators i.e. Net Present Value/Cost (NPV/Cost) Ratio, Internal Rate of Return (IRR) or Net Benefits. In this study, economic indicator NPV/Cost ratio has been considered for selection of optimum M&R strategy for all the road sections. The summaries of economic analysis for all the road sections are shown in Table 5.18 to Table 5.21. Internal Rate of Return (IRR) was determined by trial and error method in HDM-4. Both costs and benefits are discounted at different rates till both get balanced in trial and error method.

**Table 5.18: Summary of Economic Analysis for Bhadson Road Section i.e., UR-01**

Alternative (Alt)	Present value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Costs (B)	Net Present Value, NPV = B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	(2)	(3)	(4)	(5) = (4) - (3)	(6) = (5) / (2)	(7)
Base Alt.	0.154	0.000	0.000	0.000	0.000	0.000
Alt 1	3.996	3.842	26.092	22.250	5.568	51.5

Alt 2	1.570	1.416	2.918	1.502	0.957	21.03
Alt 3	5.434	5.279	8.186	2.907	0.535	16.8

**Table 5.19: Summary of Economic Analysis for Bhupinder Road Section i.e., UR-02**

Alternative (Alt)	Present value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Costs (B)	Net Present Value, NPV = B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	(2)	(3)	(4)	(5) = (4) – (3)	(6) = (5) / (2)	(7)
Base Alt.	0.250	0.000	0.000	0.000	0.000	0.000
Alt 1	5.083	4.834	22.358	17.525	3.448	46.1
Alt 2	4.945	4.698	7.344	2.646	0.535	16.8
Alt 3	9.708	9.458	15.389	5.931	0.611	17.2

**Table 5.20: Summary of Economic Analysis for Passey Road section i.e., UR-03**

Alternative (Alt)	Present value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Costs (B)	Net Present Value, NPV = B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	(2)	(3)	(4)	(5) = (4) – (3)	(6) = (5) / (2)	(7)
Base Alt.	0.120	0.000	0.000	0.000	0.000	0.000
Alt 1	2.466	2.346	7.504	5.158	2.092	33.0
Alt 2	2.399	2.279	3.452	1.173	0.489	14.7
Alt 3	4.205	4.085	6.216	2.131	0.507	15.3

**Table 5.21: Summary of Economic Analysis for Ghuman Road section i.e., UR-04**

Alternative (Alt)	Present value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Costs (B)	Net Present Value, NPV = B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	(2)	(3)	(4)	(5)= (4)–(3)	(6) = (5)/(2)	(7)
Base Alt.	0.088	0.000	0.000	0.000	0.000	0.000
Alt 1	3.059	2.972	29.157	26.186	8.560	129.6
Alt 2	1.508	1.420	3.513	2.093	1.389	22.2
Alt 3	5.216	5.129	8.977	3.848	0.738	20.4

### 5.5.11 Selection of Optimum M&R Strategy for Each Road Section

On the basis of economic analysis of each alternative for all the road sections, optimum M&R strategy or alternative has been selected. The alternative which has higher NPV/Cost ratio for any road section compared to the other predefined alternatives, is selected as optimum M&R strategy for that section. Table 5.22 shows the optimum M&R alternative selected for each road section.

**Table 5.22: Optimum M&R Alternative for Each Road Section**

Section ID	Section Name	Optimum M&R Strategy
UR-01	Bhadson Road	Alternative 1
UR-02	Bhupinder Road	Alternative 1
UR-03	Passey Road	Alternative 1
UR-04	Ghuman Road	Alternative 1

### 5.5.12 Prioritization of Road Sections based on Optimum M&R Strategy

Based on optimum M&R strategy of the road sections, prioritization of all the road sections has been done. Higher the NPV/Cost ratio of optimum M&R strategy of the road section, higher will be the prioritization ranking of that road. Table 5.23 shows the prioritization ranking of road sections based on optimum M&R strategy.

**Table 5.23: Prioritization Ranking of the Road Section**

<b>Section ID</b>	<b>Section Name</b>	<b>Optimum M&amp;R Strategy</b>	<b>NPV/Cost Ratio</b>	<b>Prioritization Ranking</b>
UR-04	Ghuman Road	Alternative 1	8.560	1
UR-01	Bhadson Road	Alternative 1	5.568	2
UR-02	Bhupinder Road	Alternative 1	3.448	3
UR-03	Passey Road	Alternative 1	2.092	4

**Comments:** On the basis of the economic analysis, Alternative 1 i.e., Resealing + Thin Overlay, having the maximum NPV/Cost ratio has been selected as the optimum M&R strategy for all the road sections. IRR value is also higher for Alternative 1 for each road section. Prioritization of the road sections for maintenance work has been done based on optimum M&R strategy. Prioritization ranking has been allotted to each road section. In case of budget constraints, prioritization ranking will help road agency to choose which road section has to be maintained first. For example, Alternative 1 is scheduled to be done in year 2018 for sections UR-01, UR-02 and UR-03. In case of constrained budget, maintenance of road sections will be done based on prioritization ranking of road sections i.e. first preference will be given to UR-01, second to UR-02 and last preference will be UR-03 for maintenance work.

## **5.6 Comparative Study of Scheduled type and Condition Responsive type M&R Strategy**

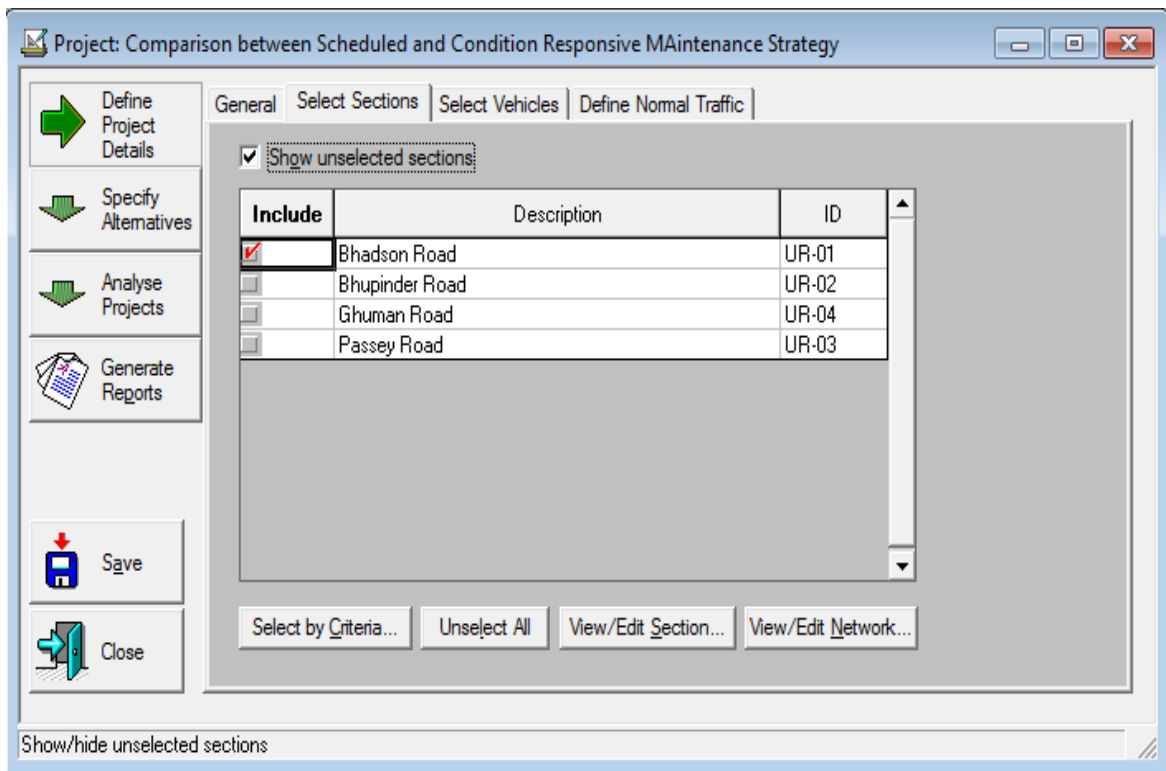
The aim of this objective is to compare the Scheduled type and Condition Responsive type Maintenance and Rehabilitation strategy for Bhadson Road section i.e. UR-01. Comparison of adopting a scheduled type M&R strategy against a condition responsive M&R strategy for individual road section throughout the analysis period has been done in this objective.

### **5.6.1 Input Data**

New Project named as ‘Comparison between Scheduled and Condition Responsive M&R Strategy’ was created which consisted of ‘Patiala City Road Network’ and ‘Patiala City Vehicle Fleet’. Analysis period was taken as 12 years. Start year is 2017. Analyse by project has been chosen for analysis. Input and output currencies are in Rupees.

### 5.6.2 Selection of Section and Vehicles

For this objective, Bhadson Road Section with section ID: UR-01 has been selected from Patiala City Road Network. All the types of vehicle have been selected from Patiala City Vehicle Fleet for the analysis purpose. Figure 5.38 shows the selection of Bhadson Road section for project analysis.



**Figure 5.38: Selection of Bhadson Road Section (UR-01) for Project Analysis**

### 5.6.3 Define Traffic

Normal traffic details such as Vehicular compositions with their annual average growth rate for both MT and NMT vehicles have been inputted for Bhadson Road Section i.e. UR-01.

### 5.6.4 Proposed Maintenance and Rehabilitation (M&R) Alternatives

The Scheduled M&R strategy has been chosen as per the current maintenance norms provided in MORT&H [2001b], whereas the Condition Responsive M&R strategy has been selected as per the serviceability levels up to which the respective pavement section is to be maintained [“Guidelines for Maintenance of Primary, Secondary and Urban Roads”, MORT&H, 2004]. Proposed M&R Alternatives have been given in Table 5.24.

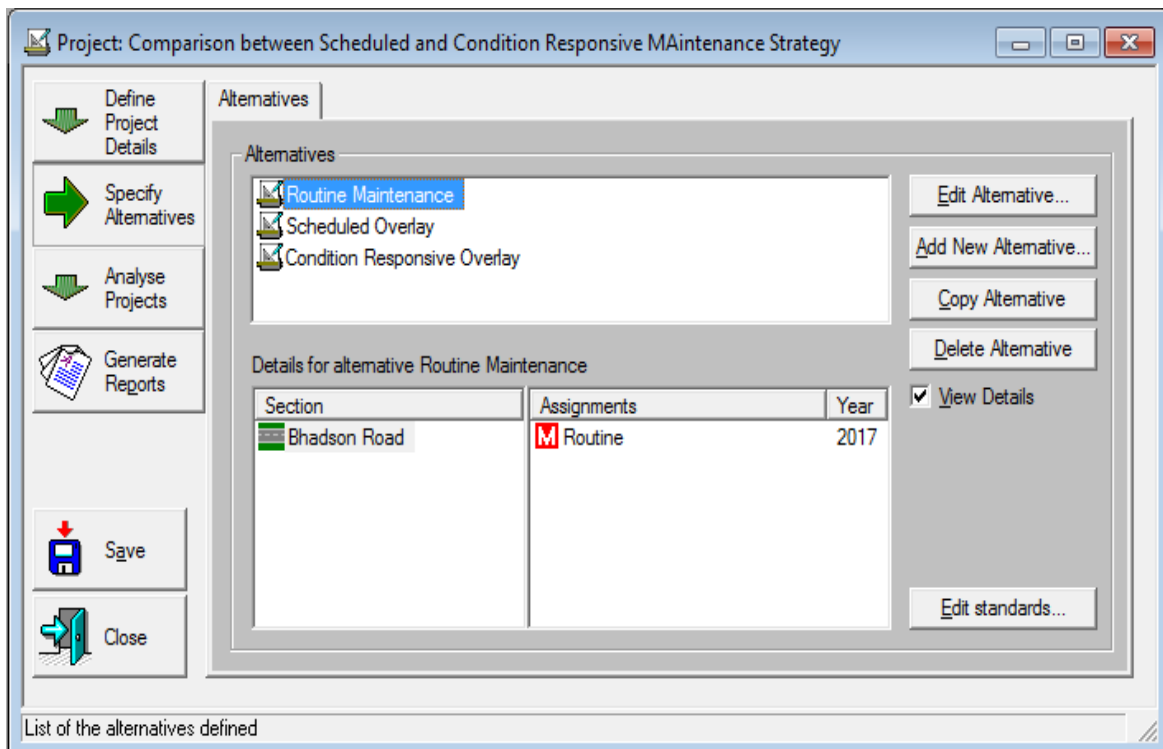
Bhadson Road Section comes under Other Roads category of Indian Urban Roads. Serviceability levels for Other Roads have been kept in mind before proposing the Condition Responsive type M&R strategy for this project.

**Table 5.24: Proposed M&R Alternatives for Project Analysis of Bhadson Road Section**

M&R Alternative	M&R Work	Work Item	Intervention Criteria
Routine Maintenance	Routine	Patching	Scheduled Annually
		Crack Sealing	Scheduled Annually
Scheduled Overlay	Bituminous Concrete (BC) 25 mm Thick	Provide BC 25 mm	Scheduled every Five years
Condition Responsive Overlay	Bituminous Concrete (BC) 25 mm Thick	Provide BC 25 mm	Roughness $\geq$ 4.0 m/km IRI

### 5.6.5 Specify M&R Alternatives

Proposed Maintenance and Rehabilitation (M&R) alternatives mentioned in above table have been specified in the project. Corresponding to these alternatives, M&R work items with their economic and financial unit costs have been assigned with the required intervention level. Figure 5.39 shows the Data input of M&R Alternatives in project.



**Figure 5.39: Data input of M&R Alternatives in Project**

### 5.6.6 Project Analysis

As the economic analysis for the selected section has to be done, so in Set-up Run of Project Analysis, 'Conduct Economic Analysis' was selected. Base Alternative was chosen for comparison purpose by default. Discount rate of 12 % was taken. The application was run for simulating the road condition of Bhadson Road section under three defined Maintenance and Rehabilitation (M&R) alternatives throughout the analysis period of 12 years for this objective.

### 5.6.7 Roughness Progression

The Roughness progression graph of all the three alternatives for Bhadson Road Section has been shown in Figure 5.40. The roughness progression has been traced to know whether the works have been correctly triggered corresponding to the specified intervention criteria. In case of 'Condition Responsive Overlay' alternative, Overlay work has been triggered as soon as the roughness value reaches 4 IRI. But in case of 'Scheduled Overlay' alternative, Overlay work has been triggered in every five years, but at roughness value of IRI = 2.4 m/km or even less, which is well below the limiting value of IRI = 4 m/km (serviceability level for Other Roads).

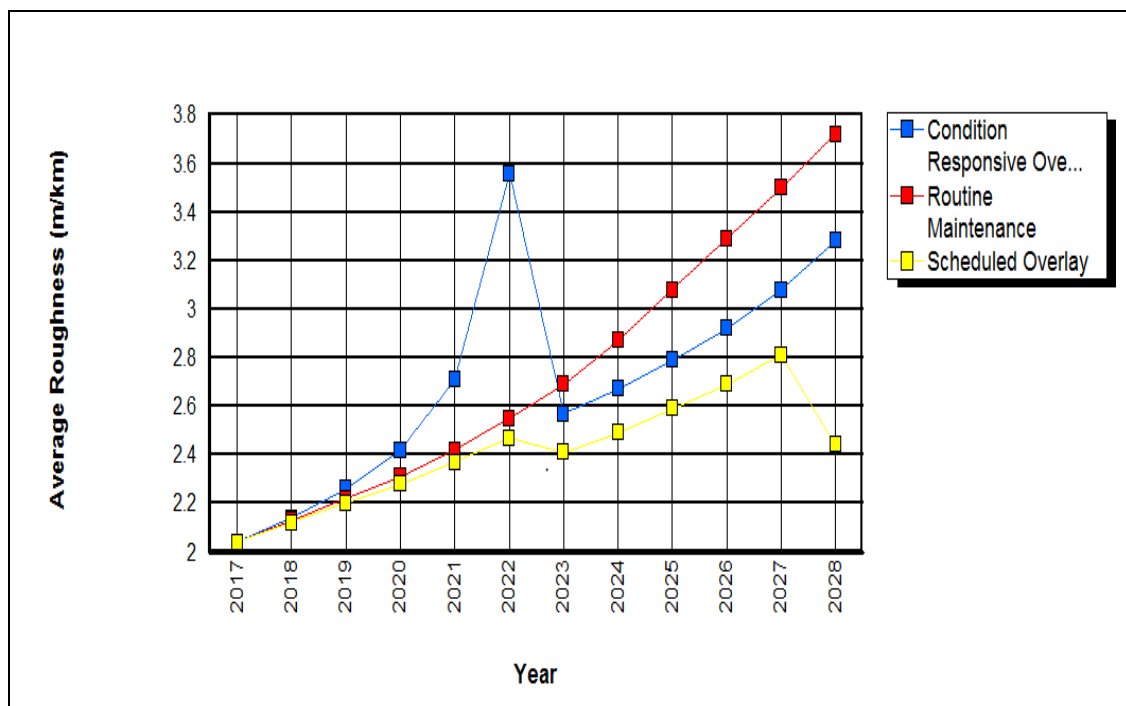


Figure 5.40: Roughness progression under the three alternatives for Bhadson Road Section

### 5.6.8 M&R Works Report

The various work items resulting from the two M&R alternatives specified, as triggered by the respective intervention parameters and timings of their application are shown in Table 5.25. Total road agency costs for both M&R alternatives have been shown.

**Table 5.25: Description of M&R Works with Total Road Agency Costs**

<b>M&amp;R Alternative</b>	<b>M&amp;R Work</b>	<b>Applicable Years</b>	<b>Frequency of Application</b>	<b>Total Road Agency Costs in Million Rupees</b>
Scheduled Overlay	Bituminous Concrete 25 mm Thick	2017, 2022, 2027	3	5.811
Condition Responsive Overlay	Bituminous Concrete 25 mm Thick	2022	1	1.937

### 5.6.9 Comparison of M&R Strategies

The cost comparison of the two defined M&R alternatives clearly shows that in case of adopting Scheduled type M&R strategy, road agency will have to spend Rupees 5.811 Millions on overlaying the road section three times throughout the period of 12 years. However, in case they adopt Condition Responsive type M&R strategy, the agency may have to spend only Rupees 1.937 Million on overlaying the road section one time through the same period. In adopting the Scheduled type M&R strategy, the road agency will have to spend about 3 times more than the cost of Condition Responsive M&R strategy. Hence, there will be huge net saving in cost in case of Condition Responsive type M&R strategy as compared to scheduled type M&R strategy. The Condition Responsive M&R strategy can hence be affirmed as cost effective M&R strategy.

# CONCLUSIONS AND RECOMMENDATIONS

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## 6.1 Conclusions

The following conclusions have been drawn on the basis of the present study:

- Functional and structural evaluations of four road sections of Patiala city have been conducted effectively.
- Globally recognized HDM-4 model has been successfully used for the development of Pavement Maintenance Management System (PMMS) of four road sections of Patiala city road network.
- The determination of Remaining Service Life (RSL) of selected road sections of Patiala city has been successfully carried out using Project level Analysis in HDM-4 software. The remaining service life (RSL) of all the four sections is in the range of 5 to 7 years, depicting that these road sections will be requiring reconstruction work in coming 5 to 7 years. RSL value will help road agency to know imperative time for reconstruction before the entire road failure. Budgeting and funding for reconstruction work can be done accordingly.
- Under Project level analysis in HDM-4, the optimum maintenance and rehabilitation (M&R) strategy for all road section of Patiala city road network has been determined successfully based on highest NPV/Cost ratio, amongst a number of defined M&R strategies. Alternative 1 i.e. 'Resealing + Thin Overlay' has been selected as optimum M&R strategy for all the road sections.
- On the basis of optimum M&R strategy, prioritization of road sections for maintenance works has been successfully done for all the road sections.
- Comparative study of Scheduled type and Condition Responsive type M&R strategies has been successfully carried out for Bhadson Road section. Throughout the analysis period of 12 years, Scheduled type M&R strategy has been triggered three times with total road agency cost of 5.81 Million Rupees and Condition Responsive type M&R strategy has been triggered one time with total road agency cost of 1.937 Million Rupees. The cost comparison of the two defined M&R alternatives clearly show that in adopting the Scheduled type M&R strategy, the

road agency will have to spend about 3 times higher than the cost of Condition Responsive M&R strategy. Condition Responsive M&R strategy is hence chosen as the cost effective M&R strategy.

## **6.2 Recommendations for Future Work**

The recommendations for future work are as follows:

- The need for development of Pavement Maintenance Management System (PMMS) is extremely necessary for urban roads in developing country like India, due to lack of available maintenance funds. So, the methodology for development of PMMS needs to be made simpler so that field engineers will be able to understand and utilize it effectively.
- In the present study, only vehicle operating cost was considered to be road user cost. In future, study of accident costs data can be conducted to get more accurate road user costs data.
- Calibration factors for pavement deterioration model in HDM-4 software can be developed for Patiala city road sections based on the local conditions by conducting pavement condition survey periodically. This will help in getting accurate results for pavement deterioration model for Patiala city road sections.
- Calibration factors for each vehicle type can be developed for Patiala city road sections by conducting the vehicle operating survey periodically, which will help in getting accurate results for road user cost data. This will directly lead to development of successful Pavement Maintenance Management System (PMMS) for Patiala city road sections.

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## A.1 Calculation Details of Benkelman Beam Deflection Readings for All the Four Road Sections

Table A.1.1: Calculation of Characteristic Deflection for Bhadson Road Section i.e., UR-01

Chainage (km)	Initial Reading (mm)	Inter-mediate Reading (mm)	Final Reading (mm)	RD (mm)	Actual Pavement Temperature	Std Temp	Temp. Correction	Corrected RD (mm)	FMC	SCF	Corrected RD (mm)	Mean	SD	Char. Deflection, D <sub>C</sub> (mm)	
0.000	4.44	4.25	4.24	0.40	40	35	-0.05	0.35	4%	1.32	0.46	0.33	0.10	D <sub>C</sub> = (Mean + SD) = (0.33 + 0.10) = 0.43	
0.100	5.23	5.11	5.11	0.24	40		-0.05	0.19			0.25				
0.200	4.56	4.45	4.43	0.26	40		-0.05	0.21			0.28				
0.300	5.56	5.40	5.39	0.34	40		-0.05	0.29			0.38				
0.400	4.63	4.49	4.49	0.28	40		-0.05	0.23			0.30				
0.500	3.89	3.82	3.81	0.16	40		-0.05	0.11			0.15				
0.600	4.46	4.29	4.28	0.36	40		-0.05	0.31			0.41				
0.700	5.35	5.19	5.19	0.32	40		-0.05	0.27			0.36				
0.800	6.31	6.14	6.12	0.38	40		-0.05	0.33			0.44				
0.900	5.28	5.17	5.15	0.26	40		-0.05	0.21			0.28				
1.000	5.36	5.22	5.22	0.28	40		-0.05	0.23			0.30				
0.950	4.64	4.52	4.50	0.28	39		-0.04	0.24			0.31				
0.850	5.22	5.12	5.11	0.22	39		-0.04	0.18			0.24				
0.750	3.66	3.58	3.57	0.18	39		-0.04	0.14			0.18				
0.650	4.78	4.62	4.62	0.32	39		-0.04	0.28			0.37				
0.550	4.92	4.73	4.72	0.40	39		-0.04	0.36			0.48				
0.450	5.21	5.10	5.09	0.24	39		-0.04	0.20			0.26				
0.350	4.23	4.05	4.04	0.38	39	-0.04	0.34	0.44							
0.250	4.56	4.49	4.48	0.16	39	-0.04	0.12	0.16							
0.150	4.31	4.09	4.09	0.44	39	-0.04	0.40	0.53							
0.050	4.95	4.84	4.84	0.22	39	-0.04	0.18	0.24							
														<b>D<sub>C</sub></b>	<b>0.43 mm</b>

Where, RD = Rebound Deflection; FMC = Field Moisture Content; SCF = Seasonal Correction Factor; SD = Standard Deviation

Table A.1.2: Calculation of Characteristic Deflection for Bhupinder Road Section i.e., UR-02

Chainage (km)	Initial Reading (mm)	Inter-mediate Reading (mm)	Final Reading (mm)	RD (mm)	Actual Pavement Temperature	Std Temp	Temp. Correction	Corrected RD (mm)	FMC	SCF	Corrected RD (mm)	Mean	SD	Char. Deflection, D <sub>C</sub> (mm)
0.000	4.37	4.28	4.27	0.20	27		+0.08	0.28			0.37			
0.100	5.91	5.81	5.81	0.20	27		+0.08	0.28			0.37			
0.200	8.75	8.62	8.61	0.28	27		+0.08	0.36			0.48			

0.300	5.72	5.61	5.61	0.22	27	35	+0.08	0.30	4%	1.32	0.40	0.39	0.09	D <sub>C</sub> = (Mean + SD) = (0.39 + 0.09) = 0.48
0.400	6.93	6.84	6.83	0.20	27		+0.08	0.28			0.37			
0.500	7.51	7.38	7.38	0.26	27		+0.08	0.34			0.45			
0.600	4.29	4.18	4.18	0.22	27		+0.08	0.30			0.40			
0.700	8.87	8.80	8.80	0.14	27		+0.08	0.22			0.29			
0.800	4.81	4.70	4.69	0.24	27		+0.08	0.32			0.42			
0.900	3.42	3.32	3.31	0.22	27		+0.08	0.30			0.40			
1.000	6.12	6.01	6.00	0.24	27		+0.08	0.32			0.42			
0.950	5.38	5.29	5.27	0.22	31		+0.04	0.26			0.34			
0.850	7.79	7.69	7.69	0.20	31		+0.04	0.24			0.32			
0.750	4.59	4.48	4.48	0.22	31		+0.04	0.26			0.34			
0.650	3.88	3.75	3.74	0.28	31		+0.04	0.32			0.42			
0.550	6.57	6.47	6.47	0.20	31		+0.04	0.24			0.32			
0.450	5.71	5.61	5.61	0.20	31		+0.04	0.24			0.32			
0.350	4.37	4.24	4.24	0.26	31		+0.04	0.30			0.40			
0.250	6.72	6.59	6.58	0.28	31		+0.04	0.32			0.42			
0.150	4.79	4.69	4.68	0.22	31	+0.04	0.26	0.34						
0.050	5.11	5.00	5.00	0.22	31	+0.04	0.26	0.34						
													<b>D<sub>C</sub></b>	<b>0.48 mm</b>

**Table A.1.3: Calculation of Characteristic Deflection for Passey Road Section i.e., UR-03**

Chainage (km)	Initial Reading (mm)	Inter-mediate Reading (mm)	Final Reading (mm)	RD (mm)	Actual Pavement Temp.	Std Temp	Temp. Correction	Corrected RD (mm)	FMC	SCF	Corrected RD (mm)	Mean	SD	Char. Deflection, D <sub>C</sub> (mm)
0.000	5.24	5.20	5.19	0.10	25	35	+0.10	0.20	4%	1.32	0.26	0.37	0.07	D <sub>C</sub> = (Mean + SD) = (0.37 + 0.07) = 0.44
0.100	4.87	4.77	4.75	0.24	25		+0.10	0.34			0.45			
0.200	4.95	4.89	4.89	0.12	25		+0.10	0.22			0.29			
0.300	3.88	3.80	3.79	0.18	25		+0.10	0.28			0.37			
0.400	5.12	5.07	5.05	0.14	25		+0.10	0.24			0.32			
0.500	4.26	4.26	4.24	0.04	25		+0.10	0.14			0.18			
0.600	4.78	4.67	4.66	0.24	28		+0.07	0.31			0.41			
0.700	5.45	5.36	5.35	0.20	28		+0.07	0.27			0.36			
0.800	3.64	3.35	3.35	0.28	28		+0.07	0.35			0.46			
0.900	6.52	6.45	6.44	0.16	28		+0.07	0.23			0.30			
1.000	5.38	5.30	5.30	0.16	28		+0.07	0.23			0.30			
0.950	6.44	6.35	6.35	0.18	28		+0.07	0.25			0.33			
0.850	5.85	5.79	5.78	0.14	30		+0.05	0.19			0.25			

0.750	4.47	4.42	4.42	0.10	30		+0.05	0.15			0.20				
0.650	4.25	4.13	4.13	0.24	30		+0.05	0.29			0.38				
0.550	3.57	3.41	3.41	0.32	30		+0.05	0.37			0.49				
0.450	4.05	3.98	3.97	0.16	30		+0.05	0.21			0.28				
0.350	4.66	4.52	4.52	0.28	30		+0.05	0.33			0.44				
0.250	5.39	5.36	5.34	0.10	30		+0.05	0.15			0.20				
0.150	4.73	4.57	4.56	0.34	30		+0.05	0.39			0.52				
0.050	5.37	5.30	5.30	0.14	30		+0.05	0.19			0.25				
														<b>D<sub>C</sub></b>	<b>0.44 mm</b>

**Table A.1.4: Calculation of Characteristic Deflection for Ghuman Road Section i.e., UR-04**

Chainage (km)	Initial Reading (mm)	Inter-mediate Reading (mm)	Final Reading (mm)	RD (mm)	Actual Pavement Temperature	Std Temp	Temp. Correction	Corrected RD (mm)	FMC	SCF	Corrected RD (mm)	Mean	SD	Char. Deflection, D <sub>C</sub> (mm)	
0.000	4.30	4.17	4.16	0.28	41	35	-0.06	0.22	4%	1.32	0.29	0.32	0.19	D <sub>C</sub> = (Mean + SD) = (0.32 + 0.19) = 0.51	
0.100	3.28	3.17	3.15	0.26	41		-0.06	0.18			0.24				
0.200	4.56	4.45	4.43	0.26	41		-0.06	0.20			0.27				
0.300	5.32	5.24	5.23	0.18	41		-0.06	0.10			0.13				
0.400	4.63	4.48	4.48	0.30	41		-0.06	0.22			0.29				
0.500	3.89	3.65	3.65	0.48	41		-0.06	0.42			0.55				
0.600	4.46	4.28	4.28	0.36	41		-0.06	0.30			0.40				
0.700	5.35	5.19	5.18	0.34	41		-0.06	0.28			0.37				
0.800	6.31	6.14	6.12	0.38	40		-0.05	0.33			0.44				
0.900	5.28	5.16	5.14	0.28	40		-0.05	0.23			0.31				
1.000	5.36	5.22	5.21	0.30	40		-0.05	0.25			0.33				
0.950	4.64	4.51	4.49	0.30	40		-0.05	0.25			0.33				
0.850	5.11	5.00	4.99	0.24	40		-0.05	0.19			0.25				
0.750	3.66	3.57	3.56	0.20	40		-0.05	0.15			0.20				
0.650	4.77	4.62	4.60	0.34	40		-0.05	0.29			0.38				
0.550	4.92	4.85	4.84	0.17	40		-0.05	0.12			0.17				
0.450	5.21	5.10	5.09	0.24	39		-0.04	0.20			0.26				
0.350	4.23	4.06	4.04	0.38	39	-0.04	0.34	0.45							
0.250	4.56	4.50	4.48	0.16	39	-0.04	0.12	0.17							
0.150	4.21	4.01	3.98	0.46	39	-0.04	0.42	0.55							
0.050	3.59	3.49	3.48	0.22	39	-0.04	0.18	0.24							
														<b>D<sub>C</sub></b>	<b>0.51 mm</b>

**B.1 Vehicle Operating Costs (VOC) Equations for Individual Components of VOC for Different Types of Vehicle [Clause 6.6, IRC: SP: 30-2009]**

**Table B.1.1: VOC Equations for Two-wheelers**

S. No.	VOC Component	Equation
1.	Free Speed (km/hr)	$V = 45.93 - (0.4465*RF) - 0.00107*(RG-2000)$
2.	Fuel Consumption (litre/1000 km)	$FC = 3.38 + (549.57/V) + 0.00436V^2 + 0.000196*RG + 0.4552*RS - 0.3386*FL$
3.	Lubricating Oil Consumption (litre/1000 km)	$LOC = 0.405 + 0.007899*RF + 0.000125*(RG/W)$
4.	Spare Parts Cost (Rs./km)	$SP = (-55.879 + 0.024*RG)*10^{-5}*NP$
5.	Maintenance Labour (Rs./km)	$LC = 0.5498*SP$
6.	Utility (km/day)	$UPD = 2.119*V$
7.	Annual Overhead (Rs./km)	$AO = 22.47 / UPD$

**Table B.1.2: VOC Equations for Cars**

S. No.	VOC Component	Equation
1.	Free Speed (km/hr)	$V = 73.14 - (0.711*RF) - 0.00171*(RG-2000)$
2.	Fuel Consumption (litre/1000 km)	$FC = 21.85 + (504.15/V) + 0.004957V^2 + 0.000652*RG + 1.0684*RS - 0.3684*FL$
3.	Lubricating Oil Consumption (litre/1000 km)	$LOC = 1.7048 + 0.03319*RF + 0.0005241*(RG/W)$
4.	Spare Parts Cost (Rs./km)	$SP = 0.0018*(RG-2000)*10^{-5}*NP$
5.	Maintenance Labour (Rs./km)	$LC = 0.5498*SP$
6.	Utility (km/day)	$UPD = 6.187*V$
7.	Annual Overhead (Rs./km)	$AO = 365.56 / UPD$

**Table B.1.3: VOC Equations for Buses**

S. No.	VOC Component	Equation
1.	Free Speed (km/hr)	$V = 54.23 - (0.4111*RF) - 0.00098*(RG-2000)$
2.	Fuel Consumption (litre/1000 km)	$FC = 32.97 + (3904.64/V) + 0.0207V^2 + 0.0012*RG + 3.3281*RS - 1.7769*FL$
3.	Lubricating Oil Consumption (litre/1000 km)	$LOC = 1.146 + 0.00398*RF + 0.0021*(RG/W)$
4.	Spare Parts Cost (Rs./km)	$SP = e[-10.44 + 0.007373*RF + 0.0000723*RG + 1.925*W] *NP$
5.	Maintenance Labour (Rs./km)	$LC = 0.5498*SP$
6.	Utility (km/day)	$UPD = 28.07 + 15.1476*V$
7.	Annual Overhead (Rs./km)	$AO = 495.90 / UPD$
8.	Crew Wages	$CW = 938.67 / UPD$

**Table B.1.4: VOC Equations for Light Commercial Vehicle (LCV)**

S. No.	VOC Component	Equation
1.	Free Speed (km/hr)	$V = 57.41 - (0.5119*RF) - 0.00102*(RG-2000)$
2.	Fuel Consumption (litre/1000 km)	$FC = 21.28 + (1615.327/V) + 0.0245V^2 + 0.001524*RG + 5.377*RS - 0.8268*FL$
3.	Lubricating Oil Consumption (litre/1000 km)	$LOC = 1.0635 + 0.0257*RF + 0.000171*(RG/W)$
4.	Spare Parts Cost (Rs./km)	$SP = e[-10.9278 + 0.000141*RG + 3.493*W] *NP$
5.	Maintenance Labour (Rs./km)	$LC = 0.3692*SP$
6.	Utility (km/day)	$UPD = 28.773 + 2.181*V$
7.	Annual Overhead (Rs./km)	$AO = 502.64 / UPD$
8.	Crew Wages	$CW = 359.49 / UPD$

**Table B.1.5: VOC Equations for Heavy Commercial Vehicle (HCV)**

S. No.	VOC Component	Equation
1.	Free Speed (km/hr)	$V = 53.32 - (0.4755*RF) - 0.00094*(RG-2000)$
2.	Fuel Consumption (litre/1000 km)	$FC = 44.08 + (3904.64/V) + 0.0207V^2 + 0.0012*RG + 3.3281*RS - 1.7769*FL$
3.	Lubricating Oil Consumption (litre/1000 km)	$LOC = 1.73 + 0.042*RF + 0.0003*(RG/W)$
4.	Spare Parts Cost (Rs./km)	$SP = e[-10.3677 + 0.0001413*RG + 3.493*W] *NP$
5.	Maintenance Labour (Rs./km)	$LC = 0.3692*SP$
6.	Utility (km/day)	$UPD = 68.12 + 5.1637*V$
7.	Annual Overhead (Rs./km)	$AO = 641.86 / UPD$
8.	Crew Wages	$CW = 599.15 / UPD$

Where, RF = Rise and Fall, RS = Rise, FL = Fall, RG = Roughness in IRI (mm/km), NP = Net Present Value of Vehicle and W = Carriageway Width

## **B.2 Congestion Effect [Clause 6.9, IRC: SP: 30-2009]**

**Table B.2.1: Recommended Equations for Distance-Related Congestion Effects for Different Types of Vehicle**

S. No.	Type of Vehicle	Road Type	
		Two-Lane Road	Four Lane Road
1.	Two-wheeler	$CF = 0.917 + 0.112*(V/C)$	$CF = 0.934 + 0.104*(V/C)$
2.	Car	$CF = 0.893 + 0.259*(V/C)$	$CF = 1.038 + 0.140*(V/C)$
3.	Bus	$CF = 0.800 + 1.10*(V/C)$	$CF = 1.00 + 0.750*(V/C)$
4.	LCV	$CF = 0.90 + 1.00*(V/C)$	$CF = 0.90 + 0.70*(V/C)$
5.	HCV	$CF = 0.925 + 0.482*(V/C)$	$CF = 0.781 + 0.947*(V/C)$

Where, V = Peak Hour Volume in PCU and C = Capacity per lane per hour

## ANNEXURE C

### C.1 Pavement Deterioration Summary for Bhadson Road Section

**Table C.1.1: Pavement Deterioration Summary of Alternative 1 for Bhadson Road Section i.e., UR-01**

Alternative: Alternative 1		Road Class: Secondary or Main														
Section: Bhadson Road		Surface Class: Bituminous														
Length: 1.00km		Width: 8.40m														
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	15,069	0.93	2.08	2.04	5.30	0.00	0.00	3.98	1.25	5.26						
2018	15,961	0.98	2.19	2.14	5.47	0.00	0.00	2.40	0.79	5.21						
2019	16,912	1.03	2.27	2.23	0.00	0.00	0.00	0.80	0.00	5.42						
2020	17,928	1.09	2.36	2.31	0.50	0.00	0.00	0.98	0.00	5.41						
2021	19,013	1.15	2.45	2.40	1.77	0.00	0.00	1.16	0.00	5.40						
2022	20,172	1.21	2.55	2.50	4.54	0.00	0.00	1.34	0.00	5.38						
2023	21,411	1.28	2.67	2.61	4.81	0.00	0.00	0.88	0.00	5.35						
2024	22,736	1.35	2.47	2.42	0.00	0.00	0.00	0.40	0.00	5.56						
2025	24,154	1.42	2.56	2.51	0.50	0.00	0.00	0.58	0.00	5.56						
2026	25,672	1.50	2.65	2.61	1.77	0.00	0.00	0.76	0.00	5.56						
2027	27,298	1.58	2.77	2.71	4.54	0.00	0.00	0.94	0.00	5.55						
2028	29,040	1.67	2.89	2.83	4.81	0.00	0.00	0.65	0.00	5.53						

**Table C.1.2: Pavement Deterioration Summary of Alternative 2 for Bhadson Road Section i.e., UR-01**

Alternative: Alternative 2		Road Class: Secondary or Main														
Section: Bhadson Road		Surface Class: Bituminous														
Length: 1.00km		Width: 8.40m														
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	15,069	0.93	2.08	2.04	5.30	0.00	0.00	3.98	1.25	5.26						
2018	15,961	0.98	2.19	2.14	10.93	0.00	0.00	4.17	1.57	5.21						
2019	16,912	1.03	2.33	2.26	20.02	0.00	0.00	4.36	2.00	5.13						
2020	17,928	1.09	2.50	2.42	33.64	0.00	0.00	4.56	2.58	4.98						
2021	19,013	1.15	2.92	2.71	52.84	0.00	0.00	4.79	144.12	4.73						
2022	20,172	1.21	4.20	3.56	71.33	0.00	0.00	5.06	438.17	4.44						
2023	21,411	1.28	7.35	5.78	41.89	0.00	0.00	3.08	471.84	4.19						
2024	22,736	1.35	4.29	4.22	0.60	0.00	0.00	1.00	0.00	5.03						
2025	24,154	1.42	4.44	4.37	2.02	0.00	0.00	1.20	0.00	5.03						
2026	25,672	1.50	4.60	4.52	5.03	0.00	0.00	1.40	0.00	5.02						
2027	27,298	1.58	4.79	4.70	10.46	0.00	0.00	1.60	0.00	4.99						
2028	29,040	1.67	5.00	4.90	19.28	0.00	0.00	1.82	0.00	4.95						

**Table C.1.3: Pavement Deterioration Summary of Alternative 3 for Bhadson Road  
Section i.e., UR-01**

Alternative:		Alternative 3														
Section:		Bhadson Road					Road Class: Secondary or Main									
Surface Class:		Bituminous														
Length:		1.00km					Width: 8.40m									
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	15,069	0.93	2.08	2.04	5.30	0.00	0.00	3.98	1.25	5.26						
2018	15,961	0.98	2.19	2.14	10.93	0.00	0.00	4.17	1.57	5.21						
2019	16,912	1.03	2.33	2.26	20.02	0.00	0.00	4.36	2.00	5.13						
2020	17,928	1.09	2.50	2.42	33.64	0.00	0.00	4.56	2.58	4.98						
2021	19,013	1.15	2.92	2.71	52.84	0.00	0.00	4.79	144.12	4.73						
2022	20,172	1.21	4.20	3.56	71.33	0.00	0.00	5.06	438.17	4.44						
2023	21,411	1.28	7.35	5.78	83.77	0.00	0.00	5.36	943.67	4.19						
2024	22,736	1.35	14.11	10.73	45.78	0.00	0.00	2.84	865.80	4.05						
2025	24,154	1.42	2.31	2.16	0.60	0.00	0.00	3.66	0.00	3.97						
2026	25,672	1.50	2.46	2.39	3.51	0.00	0.00	3.92	0.00	3.97						
2027	27,298	1.58	2.64	2.55	9.45	0.00	0.00	4.18	0.00	3.95						
2028	29,040	1.67	2.85	2.75	18.85	0.00	0.00	4.46	0.00	3.91						

**Table C.1.4: Pavement Deterioration Summary of Base Alternative for Bhadson Road  
Section i.e., UR-01**

Alternative:		Base Alternative														
Section:		Bhadson Road					Road Class: Secondary or Main									
Surface Class:		Bituminous														
Length:		1.00km					Width: 8.40m									
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	15,069	0.93	2.08	2.04	5.30	0.00	0.00	3.98	0.63	5.26						
2018	15,961	0.98	2.19	2.13	8.67	0.00	0.00	4.17	0.00	5.22						
2019	16,912	1.03	2.28	2.22	10.50	0.00	0.00	4.35	0.00	5.19						
2020	17,928	1.09	2.38	2.31	13.47	0.00	0.00	4.54	0.00	5.16						
2021	19,013	1.15	2.49	2.42	18.17	0.00	0.00	4.74	0.00	5.12						
2022	20,172	1.21	2.63	2.55	25.30	0.00	0.00	4.93	0.00	5.05						
2023	21,411	1.28	2.79	2.69	35.75	0.00	0.00	5.14	0.00	4.95						
2024	22,736	1.35	2.99	2.87	50.50	0.00	0.00	5.36	0.00	4.81						
2025	24,154	1.42	3.20	3.08	66.08	0.00	0.00	5.60	0.00	4.61						
2026	25,672	1.50	3.41	3.29	76.90	0.00	0.00	5.85	0.00	4.40						
2027	27,298	1.58	3.62	3.50	84.08	0.00	0.00	6.12	0.00	4.26						
2028	29,040	1.67	3.84	3.72	88.62	0.00	0.00	6.40	0.00	4.17						

## C.2 Pavement Deterioration Summary for Bhupinder Road Section

**Table C.2.1: Pavement Deterioration Summary of Alternative 1 for Bhupinder Road Section i.e., UR-02**

Alternative: Alternative 1					Road Class: Secondary or Main											
Section: Bhupinder Road					Width: 13.40m											
Surface Class: Bituminous					Length: 1.00km											
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	17,538	0.37	2.35	2.30	6.11	0.00	0.00	5.38	2.57	4.90						
2018	18,591	0.39	2.46	2.40	6.15	0.00	0.00	3.20	1.68	4.85						
2019	19,715	0.41	2.44	2.40	0.00	0.00	0.00	1.01	0.00	5.06						
2020	20,916	0.43	2.52	2.48	0.00	0.00	0.00	1.18	0.00	5.06						
2021	22,198	0.46	2.60	2.56	0.78	0.00	0.00	1.35	0.00	5.05						
2022	23,568	0.49	2.70	2.65	2.45	0.00	0.00	1.53	0.00	5.03						
2023	25,032	0.52	2.80	2.75	5.86	0.00	0.00	1.71	0.00	5.01						
2024	26,599	0.55	2.93	2.87	5.94	0.00	0.00	1.09	0.00	4.98						
2025	28,275	0.58	2.49	2.45	0.00	0.00	0.00	0.46	0.00	5.21						
2026	30,069	0.61	2.57	2.53	0.00	0.00	0.00	0.63	0.00	5.21						
2027	31,990	0.65	2.66	2.61	1.05	0.00	0.00	0.81	0.00	5.21						
2028	34,049	0.69	2.76	2.71	3.04	0.00	0.00	0.98	0.00	5.20						

**Table C.2.2: Pavement Deterioration Summary of Alternative 2 for Bhupinder Road Section i.e., UR-02**

Alternative: Alternative 2					Road Class: Secondary or Main											
Section: Bhupinder Road					Width: 13.40m											
Surface Class: Bituminous					Length: 1.00km											
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	17,538	0.37	2.35	2.30	6.11	0.00	0.00	5.38	2.57	4.90						
2018	18,591	0.39	2.46	2.40	12.29	0.00	0.00	5.56	3.35	4.85						
2019	19,715	0.41	2.60	2.53	22.11	0.00	0.00	5.75	4.42	4.76						
2020	20,916	0.43	2.77	2.68	36.68	0.00	0.00	5.95	5.91	4.61						
2021	22,198	0.46	3.25	3.01	56.94	0.00	0.00	6.18	172.01	4.36						
2022	23,568	0.49	4.94	4.10	74.24	0.00	0.00	6.44	546.66	4.06						
2023	25,032	0.52	9.37	7.16	85.78	0.00	0.00	6.73	1,197.34	3.85						
2024	26,599	0.55	16.00	12.68	92.89	0.00	0.00	7.05	2,238.87	3.73						
2025	28,275	0.58	16.00	16.00	96.01	0.00	0.00	7.38	3,867.47	3.64						
2026	30,069	0.61	16.00	16.00	95.22	0.00	0.00	7.73	6,410.55	3.59						
2027	31,990	0.65	16.00	16.00	92.22	0.00	0.00	8.07	0,421.46	3.56						
2028	34,049	0.69	16.00	16.00	90.00	0.00	0.00	8.42	6,867.15	3.51						

**Table C.2.3: Pavement Deterioration Summary of Alternative 3 for Bhupinder Road  
Section i.e., UR-02**

Alternative:		Alternative 3														
Section:		Bhupinder Road					Road Class: Secondary or Main									
Surface Class:		Bituminous														
Length:		1.00km					Width: 13.40m									
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	17,538	0.37	2.35	2.30	6.11	0.00	0.00	5.38	2.57	4.90						
2018	18,591	0.39	2.46	2.40	12.29	0.00	0.00	5.56	3.35	4.85						
2019	19,715	0.41	2.60	2.53	22.11	0.00	0.00	5.75	4.42	4.76						
2020	20,916	0.43	2.77	2.68	36.68	0.00	0.00	5.95	5.91	4.61						
2021	22,198	0.46	3.25	3.01	56.94	0.00	0.00	6.18	172.01	4.36						
2022	23,568	0.49	4.94	4.10	74.24	0.00	0.00	6.44	546.66	4.06						
2023	25,032	0.52	9.37	7.16	42.89	0.00	0.00	3.37	598.67	3.85						
2024	26,599	0.55	2.25	2.13	0.00	0.00	0.00	3.21	0.00	4.04						
2025	28,275	0.58	2.35	2.30	0.50	0.00	0.00	3.44	0.00	4.04						
2026	30,069	0.61	2.46	2.41	3.23	0.00	0.00	3.67	0.00	4.04						
2027	31,990	0.65	2.60	2.53	8.97	0.00	0.00	3.91	0.00	4.02						
2028	34,049	0.69	2.76	2.68	18.14	0.00	0.00	4.15	0.00	3.99						

**Table C.2.4: Pavement Deterioration Summary of Base Alternative for Bhupinder Road Section i.e., UR-02**

Alternative:		Base Alternative														
Section:		Bhupinder Road					Road Class: Secondary or Main									
Surface Class:		Bituminous														
Length:		1.00km					Width: 13.40m									
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	17,538	0.37	2.35	2.30	6.11	0.00	0.00	5.38	1.29	4.90						
2018	18,591	0.39	2.45	2.39	10.02	0.00	0.00	5.56	0.00	4.86						
2019	19,715	0.41	2.54	2.48	12.71	0.00	0.00	5.74	0.00	4.83						
2020	20,916	0.43	2.65	2.58	16.98	0.00	0.00	5.93	0.00	4.79						
2021	22,198	0.46	2.77	2.69	23.52	0.00	0.00	6.12	0.00	4.73						
2022	23,568	0.49	2.91	2.83	33.17	0.00	0.00	6.32	0.00	4.65						
2023	25,032	0.52	3.09	2.99	46.92	0.00	0.00	6.53	0.00	4.51						
2024	26,599	0.55	3.29	3.17	63.16	0.00	0.00	6.75	0.00	4.33						
2025	28,275	0.58	3.48	3.37	74.92	0.00	0.00	7.00	0.00	4.12						
2026	30,069	0.61	3.65	3.55	82.79	0.00	0.00	7.25	0.00	3.97						
2027	31,990	0.65	3.83	3.73	87.82	0.00	0.00	7.52	0.00	3.88						
2028	34,049	0.69	4.00	3.90	90.89	3.03	0.00	7.80	0.00	3.82						

### C.3 Pavement Deterioration Summary for Passey Road Section

**Table C.3.1: Pavement Deterioration Summary of Alternative 1 for Passey Road  
Section i.e., UR-03**

Alternative:		Alternative 1															
Section:		Passey Road												Road Class:		Secondary or Main	
Surface Class:		Bituminous															
Length:		1.00km												Width:		6.50m	
					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km	
2017	12,222	0.15	2.25	2.20	6.00	0.00	0.00	4.45	0.00	5.19							
2018	12,607	0.16	2.35	2.30	6.05	0.00	0.00	2.65	0.00	5.16							
2019	13,012	0.17	2.42	2.38	0.00	0.00	0.00	0.84	0.00	5.37							
2020	13,439	0.18	2.49	2.46	0.00	0.00	0.00	0.98	0.00	5.37							
2021	13,887	0.19	2.57	2.53	0.50	0.00	0.00	1.13	0.00	5.37							
2022	14,360	0.20	2.65	2.61	1.77	0.00	0.00	1.28	0.00	5.37							
2023	14,858	0.21	2.75	2.70	4.54	0.00	0.00	1.43	0.00	5.37							
2024	15,382	0.23	2.86	2.80	4.81	0.00	0.00	0.91	0.00	5.35							
2025	15,936	0.24	2.47	2.44	0.00	0.00	0.00	0.38	0.00	5.56							
2026	16,519	0.26	2.55	2.51	0.00	0.00	0.00	0.53	0.00	5.56							
2027	17,136	0.27	2.62	2.59	0.00	0.00	0.00	0.68	0.00	5.56							
2028	17,787	0.29	2.71	2.67	1.00	0.00	0.00	0.83	0.00	5.56							

**Table C.3.2: Pavement Deterioration Summary of Alternative 2 for Passey Road  
Section i.e., UR-03**

Alternative:		Alternative 2															
Section:		Passey Road												Road Class:		Secondary or Main	
Surface Class:		Bituminous															
Length:		1.00km												Width:		6.50m	
					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km	
2017	12,222	0.15	2.25	2.20	6.00	0.00	0.00	4.45	0.00	5.19							
2018	12,607	0.16	2.35	2.30	12.10	0.00	0.00	4.60	0.00	5.16							
2019	13,012	0.17	2.48	2.41	21.82	0.00	0.00	4.76	0.00	5.08							
2020	13,439	0.18	2.63	2.55	36.26	0.00	0.00	4.93	0.00	4.95							
2021	13,887	0.19	2.95	2.79	56.38	0.00	0.00	5.12	103.33	4.74							
2022	14,360	0.20	3.78	3.37	73.80	0.00	0.00	5.34	316.09	4.51							
2023	14,858	0.21	5.57	4.68	85.41	0.00	0.00	5.58	647.80	4.38							
2024	15,382	0.23	8.90	7.24	92.60	0.00	0.00	5.83	1,115.67	4.31							
2025	15,936	0.24	14.64	11.77	96.51	0.00	0.00	6.10	1,748.03	4.26							
2026	16,519	0.26	16.00	15.32	96.02	0.00	0.00	6.38	2,588.06	4.23							
2027	17,136	0.27	16.00	16.00	94.32	0.00	0.00	6.66	3,690.91	4.21							
2028	17,787	0.29	16.00	16.00	92.08	0.00	0.00	6.94	5,146.64	4.20							

**Table C.3.3: Pavement Deterioration Summary of Alternative 3 for Passey Road**

**Section i.e., UR-03**

Alternative:		Alternative 3														
Section:		Passey Road					Road Class: Secondary or Main									
Surface Class:		Bituminous														
Length:		1.00km					Width: 6.50m									
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	12,222	0.15	2.25	2.20	6.00	0.00	0.00	4.45	0.00	5.19						
2018	12,607	0.16	2.35	2.30	12.10	0.00	0.00	4.60	0.00	5.16						
2019	13,012	0.17	2.48	2.41	21.82	0.00	0.00	4.76	0.00	5.08						
2020	13,439	0.18	2.63	2.55	36.26	0.00	0.00	4.93	0.00	4.95						
2021	13,887	0.19	2.95	2.79	56.38	0.00	0.00	5.12	103.33	4.74						
2022	14,360	0.20	3.78	3.37	73.80	0.00	0.00	5.34	316.09	4.51						
2023	14,858	0.21	5.57	4.68	85.41	0.00	0.00	5.58	647.80	4.38						
2024	15,382	0.23	8.90	7.24	46.30	0.00	0.00	2.92	557.84	4.31						
2025	15,936	0.24	2.24	2.12	0.00	0.00	1,062.70	3.05	0.00	3.89						
2026	16,519	0.26	2.32	2.28	0.00	0.00	1,170.00	3.27	0.00	3.89						
2027	17,136	0.27	2.41	2.37	1.69	0.00	1,170.00	3.50	0.00	3.89						
2028	17,787	0.29	2.53	2.47	6.04	0.00	1,170.00	3.72	0.00	3.88						

**Table C.3.4: Pavement Deterioration Summary of Base Alternative for Passey Road**

**Section i.e., UR-03**

Alternative:		Base Alternative														
Section:		Passey Road					Road Class: Secondary or Main									
Surface Class:		Bituminous														
Length:		1.00km					Width: 6.50m									
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	12,222	0.15	2.25	2.20	6.00	0.00	0.00	4.45	0.00	5.19						
2018	12,607	0.16	2.34	2.29	9.83	0.00	0.00	4.60	0.00	5.16						
2019	13,012	0.17	2.42	2.37	12.41	0.00	0.00	4.76	0.00	5.15						
2020	13,439	0.18	2.52	2.46	16.50	0.00	0.00	4.91	0.00	5.12						
2021	13,887	0.19	2.62	2.55	22.80	0.00	0.00	5.08	0.00	5.08						
2022	14,360	0.20	2.75	2.67	32.13	0.00	0.00	5.24	0.00	5.02						
2023	14,858	0.21	2.91	2.81	45.46	0.00	0.00	5.42	0.00	4.93						
2024	15,382	0.23	3.08	2.98	61.83	0.00	0.00	5.60	0.00	4.79						
2025	15,936	0.24	3.24	3.15	74.01	0.00	0.00	5.80	0.00	4.62						
2026	16,519	0.26	3.39	3.30	82.20	0.00	0.00	6.01	0.00	4.51						
2027	17,136	0.27	3.52	3.44	87.45	0.00	0.00	6.23	0.00	4.44						
2028	17,787	0.29	3.65	3.57	90.67	0.00	0.00	6.45	0.00	4.39						

## C.4 Pavement Deterioration Summary for Ghuman Road Section

**Table C.4.1: Pavement Deterioration Summary of Alternative 1 for Ghuman Road Section i.e., UR-04**

Alternative:		Alternative 1															
Section:		Ghuman Road										Road Class: Tertiary or Local					
Surface Class:		Bituminous															
Length:		1.00km										Width: 7.20m					
					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km	
2017	6,494	0.07	3.98	3.91	3.19	13.03	0.00	2.00	7.17	4.59							
2018	6,892	0.07	2.59	2.55	0.00	0.00	0.00	0.67	0.00	4.77							
2019	7,318	0.08	2.66	2.62	0.00	0.00	0.00	0.83	0.00	4.77							
2020	7,773	0.08	2.74	2.70	0.50	0.00	0.00	0.98	0.00	4.77							
2021	8,259	0.09	2.83	2.79	1.77	0.00	0.00	1.13	0.00	4.77							
2022	8,779	0.10	2.93	2.88	4.54	0.00	0.00	1.29	0.00	4.76							
2023	9,334	0.10	3.05	2.99	4.81	0.00	0.00	0.84	0.00	4.73							
2024	9,929	0.11	2.49	2.46	0.00	0.00	0.00	0.37	0.00	4.95							
2025	10,566	0.12	2.57	2.53	0.00	0.00	0.00	0.52	0.00	4.95							
2026	11,247	0.13	2.64	2.60	0.00	0.00	0.00	0.68	0.00	4.95							
2027	11,977	0.13	2.73	2.69	1.20	0.00	0.00	0.83	0.00	4.95							
2028	12,760	0.14	2.82	2.77	3.37	0.00	0.00	0.99	0.00	4.94							

**Table C.4.2: Pavement Deterioration Summary of Alternative 2 for Ghuman Road Section i.e., UR-04**

Alternative:		Alternative 2															
Section:		Ghuman Road										Road Class: Tertiary or Local					
Surface Class:		Bituminous															
Length:		1.00km										Width: 7.20m					
					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km	
2017	6,494	0.07	3.98	3.91	6.37	26.06	0.00	3.48	14.34	4.59							
2018	6,892	0.07	4.12	4.05	11.45	50.24	0.00	3.64	17.30	4.50							
2019	7,318	0.08	4.32	4.22	18.95	70.66	0.00	3.81	52.46	4.41							
2020	7,773	0.08	4.62	4.47	29.45	69.50	0.00	3.99	111.40	4.28							
2021	8,259	0.09	5.38	5.00	43.47	55.24	0.00	4.19	290.94	4.08							
2022	8,779	0.10	6.90	6.14	29.98	19.18	0.00	2.53	284.90	3.82							
2023	9,334	0.10	4.02	3.96	0.60	0.00	0.00	0.83	0.00	4.53							
2024	9,929	0.11	4.14	4.08	2.02	0.00	0.00	0.99	0.00	4.53							
2025	10,566	0.12	4.28	4.21	5.03	0.00	0.00	1.17	0.00	4.51							
2026	11,247	0.13	4.43	4.36	10.46	0.00	0.00	1.34	0.00	4.49							
2027	11,977	0.13	4.61	4.52	19.28	0.00	0.00	1.52	0.00	4.43							
2028	12,760	0.14	4.81	4.71	32.56	0.00	0.00	1.71	0.00	4.33							

**Table C.4.3: Pavement Deterioration Summary of Alternative 3 for Ghuman Road  
Section i.e., UR-04**

Alternative:		Alternative 3														
Section:		Ghuman Road					Road Class: Tertiary or Local									
Surface Class:		Bituminous														
Length:		1.00km					Width: 7.20m									
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	6,494	0.07	3.98	3.91	6.37	26.06	0.00	3.48	14.34	4.59						
2018	6,892	0.07	4.12	4.05	11.45	50.24	0.00	3.64	17.30	4.50						
2019	7,318	0.08	4.32	4.22	18.95	70.66	0.00	3.81	52.46	4.41						
2020	7,773	0.08	4.62	4.47	29.45	69.50	0.00	3.99	111.40	4.28						
2021	8,259	0.09	5.38	5.00	43.47	55.24	0.00	4.19	290.94	4.08						
2022	8,779	0.10	6.90	6.14	59.95	38.36	0.00	4.40	569.80	3.82						
2023	9,334	0.10	9.85	8.38	36.45	12.42	0.00	2.32	497.38	3.53						
2024	9,929	0.11	2.22	2.11	0.00	0.00	0.00	2.88	0.00	3.72						
2025	10,566	0.12	2.30	2.26	0.00	0.00	0.00	3.09	0.00	3.72						
2026	11,247	0.13	2.38	2.34	0.74	0.00	0.00	3.31	0.00	3.72						
2027	11,977	0.13	2.48	2.43	3.88	0.00	0.00	3.52	0.00	3.72						
2028	12,760	0.14	2.60	2.54	10.10	0.00	0.00	3.74	0.00	3.69						

**Table C.4.4: Pavement Deterioration Summary of Base Alternative for Ghuman Road  
Section i.e., UR-04**

Alternative:		Base Alternative														
Section:		Ghuman Road					Road Class: Tertiary or Local									
Surface Class:		Bituminous														
Length:		1.00km					Width: 7.20m									
					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2017	6,494	0.07	3.98	3.91	3.19	26.06	0.00	3.48	7.17	4.59						
2018	6,892	0.07	4.04	3.98	0.86	50.66	0.00	3.64	0.00	4.61						
2019	7,318	0.08	4.18	4.11	2.27	71.55	0.00	3.79	15.82	4.60						
2020	7,773	0.08	4.33	4.25	4.87	84.96	0.00	3.96	23.69	4.58						
2021	8,259	0.09	4.51	4.41	9.13	90.78	0.00	4.12	29.83	4.55						
2022	8,779	0.10	4.70	4.59	13.77	84.33	0.00	4.29	33.81	4.49						
2023	9,334	0.10	4.88	4.76	17.85	80.25	0.00	4.46	33.33	4.45						
2024	9,929	0.11	5.07	4.95	23.61	74.49	0.00	4.64	33.68	4.40						
2025	10,566	0.12	5.29	5.15	31.52	66.58	0.00	4.82	33.22	4.31						
2026	11,247	0.13	5.51	5.37	42.14	55.97	0.00	5.01	31.56	4.20						
2027	11,977	0.13	5.76	5.61	55.24	42.87	0.00	5.21	28.21	4.03						
2028	12,760	0.14	5.99	5.85	66.50	31.63	0.00	5.43	22.99	3.82						

