PREDICTION OF PAVEMENT PERFORMANCE USING VARIOUS DETERIORATION MODELS FOR PATIALA URBAN ROAD NETWORK

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Submitted by:
SAHIL KAMOTRA
(ROLL NO. 801523010)

UNDER THE SUPERVISION OF

TANUJ CHOPRA
Assistant Professor
Deptt. of Civil Engineering
Thapar University, Patiala

DEPARTMENT OF CIVIL ENGINEERING
THAPAR UNIVERSITY,
PATIALA-147004
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DECLARATION

I, Sahil Kamotra, hereby declare that this thesis entitled **"Prediction of Pavement Performance Using Various Deterioration Models for Patiala Urban Road Network"** is an authentic record of my study carried out as requirements for the award of degree of **Master of Engineering** in **Civil Infrastructure Engineering** in the Civil Engineering Department, Thapar University, Patiala, under the supervision of **Mr. Tanuj Chopra, Assistant Professor,** Department of Civil Engineering, Thapar University, Patiala during July 2015 to July 2017. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Date: 24/07/2017

(Sahil Kamotra)
Roll No. :801523010

CERTIFICATE

This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge and belief.

Mr. Tanuj Chopra
Assistant Professor
Department of Civil Engineering
Thapar University, Patiala

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(801523010)

ABSTRACT

The study carried out for the urban road network of Patiala city which are Rajendra Hospital Chowk to YPS Chowk (PR-01), Dhukniwaran Sahib to Thapar University (PR-02) and Tripuri to Kohli Sweets (PR-03) to forecast remaining service life of road with the use of HDM-4 software. Prioritizations of the three sections are done on the basis of the Urban Road Maintenance Priority Index (URMPI) which prioritizes the road section which is in the urgent need of maintenance works. The analysis of cost and maintenance planning is done for the network name Dukhniwaran Sahib Gurudawara to Nabha (NUR-01) road as it is one of the Major District Road of State Punjab. The cost of various maintenance works for different intervention levels is done out of which cost of level 3 of serviceability comes out to be economical. Comparative Study of Scheduled and Condition Responsive type Maintenance & Rehabilitation Strategy is also conducted with the help of HDM-4 model to recognize the most effective intervention. The Scheduled maintenance is not able to limit roughness value and leads to low ride quality of the road network whereas responsive alternatives are maintaining road quality to the accepted level of serviceability. The data have been collected for five sections for cracking, roughness, ravelling, deflection which is used for regression analysis. The Indian pavement deterioration model developed by CRRI was validated by comparing the predicted and observed values for the selected pavement sections. The R^2 values obtained for cracking progression (0.7549), ravelling area progression (0.8381) and roughness progression (0.7484) models show good adequacy between observed and predicted values. These pavement deterioration models can be used for prediction of distresses and for development of maintenance management strategies for the selected urban road network.

CONTENTS

ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
BC	Bituminous Concrete
DBM	Dense Bituminous Macadam
DF	Drainage Factor
EIRR	Economic Internal Rate of Return
HDM-4	Highway Development Management Tool-4
IRI	International Roughness Index
M&R	Maintenance and Rehabilitation
MT	Motorized Traffic
MSA	Million Standard Axle
NH	National Highway
NMT	Non-Motorized Traffic
PMS	Pavement Management System
PCNADT	Percentage of Average Daily Traffic
RCI	Road Condition Index
RDWE	Road Deterioration and Work Effects
ROW	Right of Way
RUE	Road User Cost
TVF	Traffic Volume Factor
SDBC	Semi Dense Bituminous Concrete
VOC	Vehicle Operating Cost
UI	Urgency Index
URMPI	Urban Road Maintenance Priority Index

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CHAPTER 1

INTRODUCTION

1.1 General

Transportation by any means characterize the nation's wealth. Road transport in India engrosses a paramount due to its advantages over the other transportation system. It connects venues pliantly with primal reliability. The urban roads have corroborated peculiar increase due to abrupt proliferation in industrial, commercial and residential activities. The cost of road construction is very less as compared to transports. In present era of economic liberalization, utmost accentuation is put on development of infrastructure through building a reliable road network. Thus, constructing of new road networks and maintenance of existing road networks are of great intent. Indian road network holds second position worldwide in its extent. Thus, government considers road network of vital importance for country's rampant internationally by putting down discontinuity between allocation of funds and necessary requirements. The focus of present study is on Indian urban and necessity for their refinement.

Table 1.1: Length of Different Categories of Roads (in year 2016)

Category of Road	Length of Road (km)
National Highways	97,991
State Highways	1,67,109
Other PWD Roads	11,01,178
Rural Roads	33,37,255
Urban Roads	4,67,106
Project Roads	3,01,505
Total	54,72,144

Source: As Per Transport Research Wing, MORT&H (2015-16)

1.2 Condition of Indian Road Infrastructure

The quality of road to be maintained with ever increasing traffic rate is enormous task for transport engineers. This is due to gap between allocation and requirements which are not steadying down with the time. The distresses like cracking, ravelling, potholing etc.

are taking massive leap due to overstraining. The majority of road network in the country are half-way with respect to design, standard, geometry. These are responsible for large number of accidents, congestion, hold ups and towering vehicle operating cost. The freight vehicles whose weights are violating legal weight limits architect to the deterioration of roads. The timely maintenance is of primary concern for maintaining minimum riding quality.

1.3 Classification of Roads

The roads are classified in the following categories:

1.3.1 Primary Roads

This system consists of Expressways and National Highways with different level of service. Expressway is a highway which controls entrances and exits by incorporation of slip roads at certain places. It is high speed divided highway for thorough traffic with aces being partially or fully controlled. These are six or eight lane highways which are maintained and upgraded time to time by National Highway Authority of India (NHAI).

1.3.2 Secondary Roads

It consists of State Highways or Major District Roads (MDR's) whose level of serviceability may vary due to financial constraints. State Highways are those which connect the vicinity of nearby districts within a state or another state. MDR's are serving various districts of state which might be of great importance for economical functioning of the state. These highways are under the jurisdiction of State Government's Public Works Department.

1.3.3 Tertiary Roads

This system consists of Village Roads or Other District Roads (ODR's). These roads connect a village or group of villages to the nearest district, State Highway or National Highway or Railways. The rural roads are the lifeline for the farmers as they help in transporting goods to main districts. Many roads are in adverse condition because of the inability to withstand the load of farming equipment's. Government of India launched national rural scheme named Pradhan Mantri Gram Sadak Yojna aiming to provide access to all habitants with regard to their population in all weather's. These roads are maintained and improved by Central Road Funds (CRF's) released by central government.

1.4 Urban Roads

The roads which are usually planned to connect an interconnected network within a frame by giving access to users of various resources. The urban roads are prone to continuous flow of traffic within limited window of maintenance. Therefore, separate bye-laws for urban roads are practised to keep in check the intactness.

1.4.1 Arterial Road

It is for transport traffic within city. The purpose served is delivering traffic from collector roads to expressways. In it parking, loading, unloading are prohibited and pedestrians are allowed to cross only at intersection. These roads pass through city limits but the by-laws of arterial road may vary worldwide.

1.4.2 Sub- Arterial Street

They carry less traffic than arterial streets. They are feeding of arterial streets in which spacing varies from 0.5km in business areas whereas 3 to 5 km in residential areas. Thus, parking, loading, unloading usually controlled.

1.4.3 Collector Street

These streets are meant for collecting traffic from local streets to arterial streets. They are mostly in residential, commercial and industrial areas. Parking restrictions are few and that too during peak hours.

1.4.4 Local Street

They do not carry large traffic volume. These streets provide access from residence to business building. Parking's may be permitted without any restriction along pedestrian's movement freely.

The design speeds and space standards for various types of urban roads are recommended by IRC: 86 1983 are given below in Table 1.2.

Table 1.2: Design Speed and ROW for Urban Roads

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

1.5 Necessity of Pavement Maintenance Management System (PMMS)

Nowadays, transport system comprises of highways, rail, pipeline and air transportation. The pavements are primary traffic load carrying elements of the network system. It is therefore pivotal to resort to judicious use and constant upkeep and maintenance of road network for smooth flow of traffic. PMMS helps to optimise maintenance strategies to maintain an optimum level of serviceability. It involves a dynamic process to assimilate feedback regarding the various traits, benchmark and abstinence involved in optimization of the proceedings.

1.6 Objective of the study

The following are the major objectives of thesis research study:

i. Identification of urban road sections and preparation of data base for which PMMS is to be developed.
ii. Calculation of Remaining Serviceable Life (RSL) of the selected sections using HDM-4 model.
iii. Calculation of Urban Road Maintenance Priority Index (URMPI) for maintaining the riding quality of network.
iv. Determination of costs for various maintenance strategies along with comparison between Scheduled and Responsive type M&R strategy for the selected network within HDM-4 model using Project Analysis.
v. Validation of pavement distress with help of Indian pavement deterioration models.

1.7 Outline of thesis

The thesis work is arranged systematically in the following manner:

- Chapter 1 provides an introduction of transportation system along with classification of roads and need of development of Pavement Maintenance Management System PMMS.
- Chapter 2 gives an overview of the Pavement Maintenance Management System and the role of the HDM-4 model.
- Chapter 3 covers the review of existing literature on PMMS using HDM-4 showing the work done on it across the globe.
- Chapter 4 consists of field survey conducted for the data collection and determining the Remaining Serviceable Life (RSL) of the selected urban sections. It also discusses the Priority Index for urban roads in order to facilitate maintenance works in time.
- Chapter 5 deals with cost analysis for various works with different intervention levels for urban roads. It also consists of comparison between Scheduled type and Condition Responsive type Maintenance & Rehabilitation strategies for the selected road section.
- Chapter 6 deals with validation of Indian deterioration models using regression analysis.
- Chapter 7 shows the conclusion of the present study and gives recommendations for future research.

CHAPTER 2

OVERVIEW OF PMMS AND HDM-4 MODEL

2.1 Introduction to PMMS

Pavement Maintenance Management System (PMMS) is a methodology for data collection on both structural and functional basis to determine maintenance strategies for optimizing pavement condition with the help of different intervention criteria. It is a single unit to optimize the road parameters with a set of co-ordinated activities for rehabilitation, maintenance and reconstruction within limited financial strings. Its major goal is evolvement of operation for manpower, equipment calibration and periodicity of updating. Therefore, the primary objective of these maintenance strategies is to bring the virtuality of PMMS into real horizon considering every vital constraint for progress.

The Pavement Maintenance Management System performs the following functions:

- To identify projects requiring maintenance on priority basis.
- Identification of the type of maintenance and rehabilitation required.
- Maximize benefits along with reducing life cycle costs.
- Type and timing of future maintenance and rehabilitation.
- Manage resources to provide a standard level of service.

2.2 Importance of Developing PMMS

Roads constitute the primary source of transport for most of the Indian population. Hence, it is important to develop a maintenance system to achieve the following objectives:

- Road System deficient to meet the growing traffic demand. So, it needs to be adequately maintained to provide a standard level of service.
- Information on where maintenance is needed.
- To address the deficiencies in Road Geometrics.
- Data required for forecasting future needs and budget requirements.
- Need for proper Planning and Management of Resources.

2.3 Fundamental Modules of PMMS

PMMS is divided into the following two components:

- **Archive of Data**

  PMMS has a library which consists of information about section, performance, history, policy, geometry, environment and the cost of the road network.

- **Pavement Analysis Program**

  Pavement Analysis Program (PAP) is a decision making tool about pavement health and selection of maintenance strategy based on other criterion. It guides to build up an annual work program while satisfying certain budget constraints.

2.4 Evolvement and detailed use of PMMS

- **Pavement Facts**

  PMMS developed for a network creates a itemize database for accessing and keeping it up to date with respect to various constraints. This data is useful to keep a check on different maintenance works and for preparation of reports.

- **Developing Maintenance Budgets**

  PMMS puts up a set of budgets instead of preparing a typical annual maintenance budget. The period of budget varies in the form of program due to the availability of different alternatives with budget decision makers.

- **Prioritization**

  PMMS permits prioritization of maintenance projects based on capital investment and net present value depending on factors such as traffic, vehicle operating cost, road user cost etc. It helps in ranking of sections along with their budget requirement and financial planning for long term.

2.5 Overview of HDM-4

HDM-4 model (Highway Development and Management model) is a software tool developed by World Bank to investigate road investment choices for highway expenditures. It investigates the characteristics of vehicle, traffic along with the social and environmental effects. The local adaptation and calibration of HDM-4 models can be achieved with the specification of default data sets with respect to a particular location.

2.5.1 Role of HDM-4

The various role of HDM-4 model in the highway management process are as follows:

- **Planning**

  It conducts analysis of the road system as a whole, normally requiring the preparation for an extended term, estimates of expenditure for development and preservation under various budgets. The results of the planning exercise are of great importance to policy makers for political and professional go ahead. The road agencies characterize physical highway system at planning stages:

  1. Characteristics of road network i.e. pavement condition, type, traffic, loading.
  2. Length of road per class.
  3. Characteristics of vehicle fleet for selected road network.

- **Programming**

  It involves making for maintenance a programme under budget constraints or multi-year road work expenditure programmes under various improvements andmaintenance for analysis. Cost-benefit analysis should be conducted to determine economic feasibility for various works. It prioritises works to find out the best value for money in a limited budget scenario.

- **Preparation**

  It is an impermanent planning stage where road gambits are packaged for application. At various stages designs are improved for more details regarding cost, instructions and contracts. The different parameters are analysed and revised to confirm the attainability of the final plot. The adjacent road sections are combined for cost effective package for execution of the work. The detailed design preparations are done for overlay and road refinement works.

- **Operation**

  It covers the on-going activities of an association. The decisions of management on weekly or daily basis are monitored in terms of supervision and labour exercised. The operations are normally taken care of technicians, sub-professional staff, supervisors, and subsequent measurement of their progress at each level minutely.

2.5.2 HDM-4 Input Data

- **Road Networks**

  It is provided to facilitate software different parameters such as length, carriageway, width, shoulder, traffic, geometry, pavement thickness etc. Calibration factors of distresses are assigned with respect to study environment.

- **Vehicle Fleet**

  It contains the details of vehicle fleet running on selected section, whether motorized or non-motorized. It consists of basic characteristics along with the economic unit cost. This guides the user in calculating vehicle speeds, operating costs, travel time costs and other vehicle effects.

- **Work Standards**

  It consists of the specifications for maintenance and improvement standards with various intervention levels that will be applied to road for analysis. The purpose is to obtain road standards at an optimum acceptable or acceptable condition and cost.

- **HDM-4 configuration**

  It is widely used in various environments to reflect the local circumstances. Thus, it can be modified on behalf of various parameters such as traffic flow, currencies, climate zone and section based on aggregate data.

2.5.3 HDM-4 Applications

- **Project Analysis**

  This analysis permits user to evaluate on physical, operational and economic possibility of specified alternatives. The vital issues are as follows:

- Pavement Performance: The amount of traffic running over the pavement section and the load imposed on it depicts the pavement performance. The software provides a useful tool to determine the structural strength of the pavement for the given traffic.

- Life Cycle Prediction: The software calculates the deterioration of the road structure for a given traffic for a particular analysis period. It gives cost of section based on various maintenance and improvement standards along with their after effects.
- Road User Costs / Benefits: It comprises of travel time cost, accident cost and vehicle operating cost. If timely maintenance is not provided, road user cost will be high but if maintenance is provided road quality improves with decrease in road user cost. The cost is calculated by doing comparison between the road condition maintenance provided and no maintenance provided.
- Economic Comparison: The users maintenance strategies for a road network may vary with condition of road. The HDM-4 software helps in calculating the cost by using indicators like net present value, internal rate of return etc. for a defined analysis period. The most economical and beneficial option will be brought into limelight by analysis.

- **Programme Analysis**

  This is a multi-year analysis program for road network which works maximizing the NPV/Cost ratio. Its primary purpose is to prioritize road sections on the basis of the one year or above work programme under defined budget constraints.

- **Strategy Analysis**

  This is an analysis of a whole network for long term planning under the different budget scenarios. The whole network is sub-divided into several networks according to the important attributes that affects the pavement performance. Thus, life cycle analysis can be conducted for finding out the appropriate maintenance option with respect to budget. The road networks can be categorized on the following basis:

  - Allocation of funds by making funding policies.
  - Axle load criteria for the impact limits
  - Pavement design evaluation, maintenance and rehabilitation standards.
  - Road user expenses for boosting up road deposits.

CHAPTER 3

LITERATURE REVIEW

3.1 GENERAL

Over the past years lot of work have been done on Pavement Maintenance Management System using HDM-4 software. The reviews of the work done during different durations are shown below.

Kirori R.R.D. *et al.* (2003) carried study over the length of 228 km of flexible pavements of NH-12 and NH-76 under NH division, PWD Kota, Rajasthan. They used dROAD software mainly containing inventory, condition, traffic and strength. The dTIMS had programmed general features which are adaptable to desired highway conditions. They stated there were variations in International Roughness Index from 5.22 to 11.30 mm/km and Modified Structure Number 3.54 to 4.04. These variations brought change in cost with strategy of software nearly 567.73 lakhs whereas, without strategy it was about 859.76 lakhs. Thus, it brought discrepancy between suggested schedule and real sanctions.

Jain S.S. *et al.* (2005) carried out study of five national highways in the state of Uttar Pradesh and Uttarakhand. They had selected total length of 310 km and road network was further divided into 22 road sections. They collected data for calibration of models with respect to Indian condition. There progression model showed variation of 10.8% to 28.2% for cracking, 15.4% to 39.8% ravelling, 0 to 66% pothole units and roughness 2.1% to 15.1%. Thus, models showed very good agreement between observed and predicted values. They 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.

Khan M.U. *et al.* (2010) conducted study with road database analysis of Road and Highway Development of Bangladesh for reliability analysis, development of treatment intervention criteria and optimum maintenance strategies using HDM-4 software. The whole road network was divided into 48 groups. The road inventory data, condition, history and maintenance strategies with their unit cost were inputted in HDM-4. The strategy analysis was performed which stated optimum standards for overlay with respect to different International Roughness Index and cost. The Net Present Value / Capital Investment showed 90% interval of optimum maintenance standards were derived from 3.5IRI which was within a optimum standard zone of treatment.

Niaraki J.R.M. *et al.* (2011) carried study for the auto updating of GIS road segment for PMMS of Tehran city. GIS comprised of different segments for different road conditions with help of dynamic attributes. They used spatial representation for pavement condition data that was relative. The variability in automatic updating was 0.2 to 0.4 seconds whereas, manually it varied from 15 to 62 seconds. Thus, real time segments need to be updated by new ones in very short time interval for efficient data base.

Mathew B.S. *et al.* (2011) carried study for the rural roads selected all over Kerala and data collected on these sections were during the period from 2004 to 2008. They presumed that the condition of pavement was due to improper drainage and construction quality. They prepared two models based on deterioration of Pavement Condition Index (PCI) and roughness progression. The deterioration model predicted construction quality 0.75 and 0.5 which showed decrease in PCI value from 98% to 38%, 95% to 28% at end of fifth year respectively. Whereas for the IRI value increases from 8.4 mm/km to 10.8 mm/km till the end of fifth year. Thus, these parameters decided the optimal maintenance policy with alternative treatments for rural road.

Jorge D. *et al.* (2012) carried out study to develop PMMS for municipality of Viseu at Portugal. They conducted tests for parameters such as rutting, cracking, IRI for calculating pavement serviceability index (PCI). They prepared alternative Maintenance and Rehabilitation models in accordance of parameters which showed variability of 0 to 18.47% for cracking area, IRI 2000mm/km to 5500mm/km and PSI 1.44 to 4.38. On the behalf of PSI with respect to time the policy with lower cost was incorporated.

Han D. *et al.* (2012) carried study based on approach to solve the calibration of coefficient by using minimum level of pavement condition data. Thus, it helps in setting up a project level application which leads to a unique calibration coefficient set to fit their original deterioration speed. Empirical study was conducted to collect data from 211 sections of Korean National highways with various conditions. For these section the calibrated five coefficients were used and a gap was developed in basic coefficient with respect to calibration. This might increase or reduce the maintenance and rehabilitation programme which is directly dependent on the coefficients. For IRI 3.5 m/km was difference between calibrated and basic with time variation of about 3 to 5 years. Cracked percentage was nearly equal. The model developed by HDM-4 shows higher result for roughness with variation 6.42 to 11.07 IRI. Whereas roughness calibrated model shows variation about 2.63 to 10.86 IRI. Thus, they concluded calibrated model were more economical with respect to basic HDM-4 model.

Shah U.Y. *et al.* (2012) studied for 21 sections of urban road networks which covered all categories of vehicles for Noida City, Uttar Pradesh. There work constituted of structural evaluation by Benkelman Beam Deflection laid down as per IRC : 81 (1997). The each section of road network was divided into section unit of 50 m length for collecting distress data. Pavement Index was prepared with factors including Road Condition Index, Total volume factor, Special factor, Drainage factor in which Maintenance Priority Index with higher value should be served first and RCI will give topmost priority in considering section for maintenance. Now, analysis was carried using HDM-4 software by calibrating it to Indian conditions that is deterioration factor changed from 1 to 1.50 for different progression models. Therefore, priority ranking were given by method based on economic indicator and subjective rating. The comparison between the methods for priority ranking was close to each other in few pavement sections. Thus NPV/ CAP valued for selected pavements were varying from 1.399 to 27.726. There comparison showed inconsistencies in ranking for 7 sections out of 21 and rest were comparable.

Sunitha V. *et al.* (2012) carried studied for 128 sections of Tiruchirappalli district of Tamil Naidu which constituted nearly 14 blocks of rural area. They collected data for every 200m length of pavement stretch. The Visual data survey was conducted for the Visual Condition Index. (VCI) is the function of distress factor, side drainage factor, shoulder vegetation and cross drainage factor. They did clustered analysis in which cases were classified into groups that are relatively homogeneous within themselves and heterogeneous between each other on basis of defined set of variables. They used Non-Hierarchical clustering analysis in which data was collected for 12 indices for nearly 3 year time. The sections were divided into five clusters with variation of variance varies from 12.312 to 28.872 and minimum and maximum distance varied from 1.835 to 9.468.

Pavement deterioration models were prepared on the basis of multiple linear regression analysis with one dependent and other two independent variables. They illustrated analysis with VCI 80,100 for the year of construction 2005, 2011 showing values of VCI with or without cluster model. Therefore, the above model graphs established grouping all pavement sections in one basket and developing a single model for all road sections.

Zaghloul S. *et al.* (2013) carried study for Makkah Municipality of 52 sections to integrate construction quality into PMMS analysis. They had Non-Destructive tests like ground penetrating radar for layer thickness. IRI for ride quality and distress survey for surface defects. The work stated that Overall Pavement Index was equal to average of Structural Adequacy Index (SAI), Roughness Index(RI), Distress Index (DI) which were 16, 14.5 and 12 years. On the other hand OPI equal to min of SAI, RI,DI were 15.5,12.5,10.5 years. This highlighted the significance of the impact of the construction quality on their service life.

Jain K. *et al.* (2013) carried study over Noida to Greater Noida expressway of length 23.5 km and NH-24 Ghaziabad- Hapur of length 40 km. The expressway was divided into five sub-section and NH-24 into eight sub-sections. The factors considered for evaluation were ravelling, potholes, cracks, rutting and patching. On the behalf of factors they provided optimal options for maintenance with intervention criteria. The work varied criteria from IRI≤ or ≥ 2.8 m/ km with overlay of 40 mm , 25mm SDBC reseal with overlay of 40 mm and DBM 50mm wit overlay of 40 mm BC. Thus, keeping in check the NPV/ CAP ratio with optimum Maintenance and Rehabilitation strategy was of prime concerns.

Msallan M. *et al.* (2014) carried design, construction, evaluation and maintenance around the Amman at Jordan. They covered road network length of 8200km within 10 years. Their budget was mainly implicated for road construction nearly 76% of total budget. They used functional and structural evaluation. They brought in limelight that roughness forms 95% of PSI and remaining 5% represent other road stress. They selected values for rut depth from 0 to 25mm, cracking 0 to 150 m^2 / km , pothole size 0 to 7 unit/ km and IRI from 1 to 10 m/km. Thus, PMMS helped the Ministry of Public Works and Health to allocate the network with different vulnerability and to provide financial budget for them. They ranged severity of different parameters for immediate prioritization.

Girimath B.S. *et al*. (2014) carried out study for Bangalore city outer ring road which constituted 12 sections, The methodology in this study involves five stages. First stage is the selection of urban road network. Second stage is collection of secondary data. Third stage is to carry out pavement evaluation. Fourth stage analyse roadway network and fifth prioritization of road network based on economic analysis. The road surveyed showed variation in roughness from 2.71 to 4.50IRI and deflection from .47mm to .89mm. Thus, analysis was carried using HDM-4 software for maintenance alternatives including economic indicator. Therefore, maintenance treatment with 40 mm BC is found to be optimum foe the urban roads and renewing the road surface varies from 2-10 years for the individual roads.

Singh A. *et al.* (2015) conducted study of Patiala city road networks for a stretch of 15.60 km which comprised of five road segments.. They adopted progression methodology which showed increase in roughness value from 4 to 7.5 mm/km. Therefore, remaining service life of pavement on behalf of progression suggested reconstruction within 1 to 4 years, which is uneconomical. Thus, they suggested periodic maintenance of pavement with appropriate treatment alternatives

Hokan S.V. *et al.* (2015) carried out study for the Maharashtra Industrial development corporation which comprised of road network of length 2826 km. They tried to establish maintenance priority index for all sections with the help of road condition index and road use factor. The RCI showed variability from 1 to 12 and MPI 4 to 60. Thus, the roads having highest MPI should be provided with immediate treatments accordingly the prioritization.

Rusu L. *et al.* (2015) carried out analysis on behalf of economic prospects based on life cycle cost by offering treatments and rehabilitation. They conducted visual inspection to all non-specialized so that update can be provided by GIS with least cost. They prepared a model based on inspection, material and source database which comprised of analysis evaluation, image and GPS co-ordinates. This all lead to decision making of cost, prediction and risk involved which was incorporated with help of software COTS which linked management and maintenance module in different phase of analysis.

Ajami A.H. (2015) carried out study for the Riyadh City municipality using structural evaluation *e.g.* riding comfort index (RCI) to measure roughness and PCI for distress conditions. He referred experimental techniques from literature of (Shahin 1994) in order to generate missing or shortage of data. He took in consideration the urban distress Index and is composed of fifteen kinds of pavement distress existed by ranging 0-100. In which 100 was symbolized as excellent condition and PCI provided with treatment strategy of pavement life.

Al-Zoubi M.M. *et al.* (2015) developed a model for populating missing performance data using statistical approach. The technique applied was model free replacement and model distribution. They used linear interpolation based on nearby distresses, regression models and cubic spline. They conducted study over Texas using TxDOT database which divided them into 25 districts. Thus, efficiency differ for one missing data to three missing data point *i.e.* one point data showed 34% accuracy, two point data showed 12% accuracy and 20% accuracy for three point missing data. Therefore, techniques helped to populate missing data leads to a significant improvement in predicting distress score.

Bardessi W.M. *et al.* (2015) carried out study for economic and environmental considerations for management systems which may cause a impact for the process. For it they considered economy, society, environment which may affect overall sustainability. They investigated various tools of environment impact of the product. There work was setting up a framework for life cycle assessment of products in abundance or on verge of extinction. They considered literature from (Ramini *et al* 2009) claiming recycling, reusing and reclaiming of existing materials along with a alternative materials. They used environmental impact tools like MOVES2010, NONROAD and PaLATEW for assessing single or multiple types of pollutants. They laid emphasis on reclaimed asphalt pavement with check of the strength and deserting the material which is on the verge of extinction.

Prakasan C.A. *et al.* (2015) conducted study for 21 urban road sections of Noida City constituting the total length of 60 km. The methodology adopted for study was the field data collection details and deciding the weightage of parameters. The test results showed about drain conditions, roughness variation from 2156 to 4018 UI mm/ km and deflection from 0.52 to 3.34 mm. They compared the variation for direct assessment and analytical hierarchy process by using Priority Index (PI) of road class, riding quality, drainage and structural adequacy. The riding quality had highest weightage of 0.158 in priority ranking process followed by Pavement Serviceability Rating (PSR) 0.158 , SA 0.141, safety condition 0.128, traffic volume 0.115, drainage condition 0.105 and road class 0.088 using AHP. On the other hand by using Direct Assessment (DA) riding quality was 0.178, PSR 0.159, SA 0.124, safety condition 0.123, traffic volume 0.118 and road class 0.108. Thus, the two techniques were compared on priority basis and outcome was less précised in AHP due to fixed scale in some cases.

Gupta K.P. ***et al.*** **(2015)** carried study for urban road section in Panchkula which is under is under Haryana Urban Development Authority (HUDA). The total length of all three roads selected were 3.61 km with carriageway width 9.7 m. The methodology adopted was regression models for cracking and roughness. They showed variations of 12.5% to 1.5% for cracking and 9.9% to 14.7% for roughness. They performed 't' test to find out the significance of difference between observed and predicted distress value in response to various deterioration model. They concluded from the test that difference between observed and predicted distress value is not significant at 5% level of significance are 2.776, 2.776 for roughness and cracking. Therefore, both pavement deterioration models can be used for prediction of distresses and for development of maintenance management strategies for the selected urban road network.

Cutura B. ***et al.*** **(2016)** carried study on the road networks of Bosnia and Herzegovina. They had selected 396 km stretch which comprised 13 road sections with AADT varies from 27 to 12375 VPD. They conducted different tests which showed its average roughness index of network was 4.49 m/km and CBR sub-base, subgrade nearly 80%. They compared budget with the help of HDM-4 which showed budget sanctioned was not sufficient. Net Present Value was negative and internal rate of return obtained for maintenance alternates were below routine alternates of treatment for pavement section.

Shah Y.U. ***et al.*** **(2016)** carried out analysis of 21 urban pavement sections which constitute a total length of 60 km of Noida City. They calculate AADT for motorized and Non-motorized traffic along with characteristics deflection. Their work showed variability in parameters for roughness 3.21 to 5.65 IRI m/km, deflection 1.287mm to 2.873 mm. They considered roughness as primary controlling factor for activating provisions of overlays and strengthening of the pavement. There work showed economic analysis for design period of 10 years. They try to maximize NPV for 5 sections of urban road with thin overlay of 25mm SDBC, for 2 sections thin overlay of 40mm BC. For remaining sections of the road network with 50 mm DBM and 40 mm BC. NPV and minimum cost for targeted IRI was considered as best alternative.

Prachallaja D.*et al.* (2016) developed study for urban road section of Hyderabad City constituting 39.9 km length of road. They observed minimum and maximum range of various pavement performance indicators which were cracking 2.3% to 16.6%, potholes 1to 6 numbers, IRI 2.08 m/km to 5.41 m/km and deflection 1mm to 1.82 mm. They stated that quality of material was not up to the mark and this lead to high maintenance cost for some pavement sections. Thus, prioritization leads to check of various sections with help of OPCI which required immediate Maintenance and Rehabilitation.

Mane S.A. *et al.* (2016) carried out study in Jhunjhunu district of Rajasthan. This district is sub-divided into 8 blocks PMGSY. The total length comprises of 18 km length of rural roads which is about 6 blocks and 180 sections. The road is two lane undivided asphalt pavement and distress are manually identified for each 100 m section. The Potholes depth varied from 1 to 5cm, rutting depth 0 to 1.6 cm, cracking width 1 to 2 cm. They considered above parameters for AHP (Analytic Hierarchy Process) in order to prioritize the pavement sections for maintenance during limited budget allocation.

Chopra T. *et al.* (2017) carried out study for the four urban sections of Patiala city of Punjab. They are Bhadson road, Bhupinder road, Passey road and Ghuman road with section length of 1km each and lane width of 8.4, 6.7, 6.5, and 7.2m respectively. California Bearing Ratio test was done for soaked sample of all road sections with the value of 5.2%, 5.6%, 4.5% and 4.3 % respectively. The optimum maintenance strategy was selected on the basis of highest NPV/ Cost ratio and prioritization was given to Ghuman road with the help of HDM-4 models. The condition responsive maintenances strategy is chosen because it is more cost effective than scheduled maintenance strategy.

3.2 Gap in Literature: The work done for Patiala City is lacking prioritization of sections and validation of pavement deterioration models using equations given by CRRI.

CHAPTER 4

DATA COLLECTION AND PAVEMENT CONDITION EVALUATION

4.1 Selected Urban Road Sections

The major network of roads comes under the jurisdiction of Punjab Public Work Department, Bridges and Roads PWD (B&R) and under Municipal Corporation, Patiala. In the present study, three road sections of Patiala city have been selected with length of 1km for each section. Details of selected road sections of city have been shown in Table 4.1. Table 4.2 shows the data inventory of the road network below.

Table 4.1: Details of Road Sections

Section ID	**Section Name**	**Description of Section**	**Length of Section (Km)**	**Speed Flow Type**	**Type of Road**
PR-01	Rajendra Road	Rajendra Hospital Chowk to YPS Chowk	1.00	Two Lane Wide Road	Sub Arterial
PR-02	Sectarian Road	Dhukniwaran Sahib to Thapar University road	1.00	Two Lane Standard Road	Collector Street
PR-03	Tripuri Road	Tripuri to Kohli Sweets	1.00	Two Lane Narrow Road	Collector street

Table 4.2: Inventory of Data

Section ID	Traffic Flow Pattern	Traffic Flow Direction	Design Speed (km/hr)	Type of Climate Zone	Drainage Condition
PR-01	Inter-Urban	Two-way	50	Subtropical/Hot	Fair
PR-02	Inter-Urban	Two-way	50	Subtropical/Hot	Fair
PR-03	Inter-Urban	Two-way	30	Subtropical/Hot	Poor

Figure 4.1 below displays the urban sections of Patiala City and three selected road sections of study are highlighted with different themes.

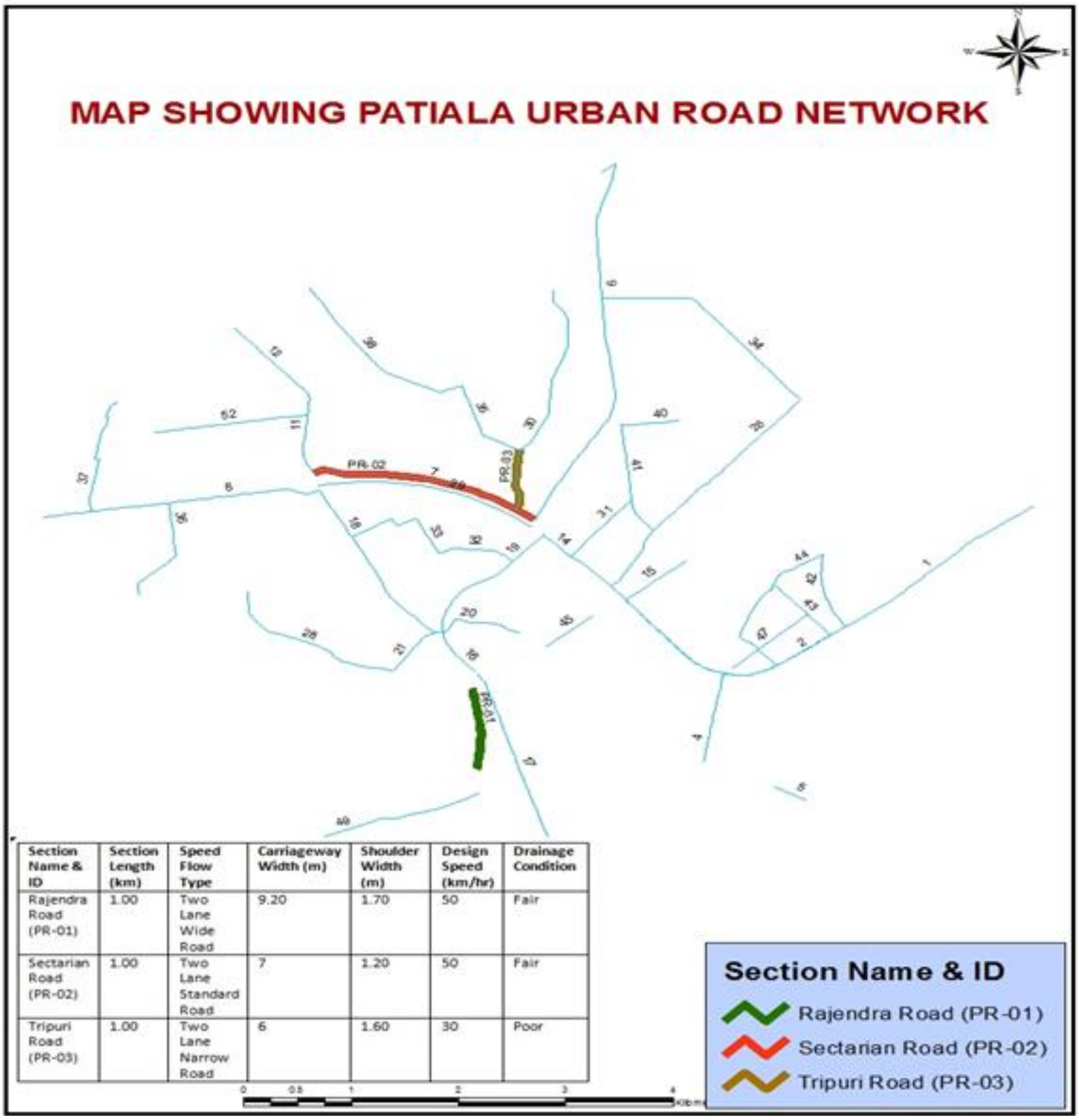

Figure 4.1: Patiala Urban Roads

4.2 Pavement History

Pavement history data (type of pavement, year of the last construction, surfacing and maintenance) has been collected from Public Works Department (PWD) and Municipal Corporation of Patiala. The details of pavement history data are presented in Table 4.3

Table 4.3: History of Pavement

Section ID	Surface Material Type	Current Surface Thickness (mm)	Former Thickness (mm)	Last Reconstruction Year	Last Overlaying Year
PR-01	Bituminous Concrete	50	40	2004	2014
PR-02	Bituminous Concrete	50	40	2005	2013
PR-03	Semi-Dense Bituminous Concrete	40	35	2005	2015

4.3 Evaluation of road pavements

The functional evaluation is measured by the survey to assess the roughness and safety over the pavement section as experienced by road users. The surface irregularity i.e. roughness is measured with the help of fifth wheel integrator known as ‘Roughometer’.The equipment is towed by pick-up vehicle and operated with the speed of 30 kmph and a tyre pressure of 2.1 kg/cm^2 as shown in Figure 4.2. The numbers of bumps (in cms) are noted down corresponding to length travelled (in km).

$$\text{Unevenness Index (UI)} = \text{Bumps in cm} / \text{Length travelled in km} \quad (1)$$

UI value has been converted into International Roughness Index (IRI in m/km) by using the following equation as stated by Odoki and Kerali [2000]:

$$\mathrm{IRI} = \left(\mathrm{UI} \times \frac{1}{630}\right)^{1/1.12} \quad (2)$$

Figure 4.2: Bump Integrator

4.4 Benkelman Beam Test

Benkelman beam is a very simple apparatus and it is commonly used for measuring the surface deflection of a pavement under standard loading conditions.

Procedure for Deflection Measurement (As Per IRC: 81 – 1997)

- For every 1 km stretch, 21 points are selected in such a way that 11 points lie on outer wheel path of one side (at every 100m interval) and 10 lie on other side (at every 100 m interval). The points marked on adjacent lanes should be staggered such that interval between each point should be 50m.
- The point is selected and marked on the pavement. For highways, the point should be located 60 cm from the pavement edge if the lane width is less than 3.5 m and 90 cm from the pavement edge for wider lanes. For divided four lane highway, the points measured should be 1.5 m from the pavement edge.
- The dual wheels of the truck are centred just above the selected point. The probe of the Benkelman beam is inserted between the duals and placed above the selected point. The locking pin is removed from the beam and the legs are adjusted so that 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 1 cm apart. The initial reading is recorded with change in the rate of deformation of the pavement is equal or less than 0.025 mm/min. The truck is slowly driven through a distance of 270 cm and stopped. An intermediate reading is recorded when the change in rate of recovery of the pavement is equal or less than 0.025 mm/min.
- The truck is driven forward 9m. The final reading is recorded when change in the rate of recovery of pavement is equal or less than 0.025 mm/min. The pavement temperature is recorded at least once within an hour with the help of thermometer. The tyre pressure is checked at an interval of two or three hours throughout the day and adjusted to the standard, if required.

Figure 4.3: Placement of Benkelman Beam apparatus for measuring deflection

Three types of data are required for knowing the deflection:

1. **Temperature data:** The standard temperature for measuring the deflection readings is 35^{O}C. Since it is not 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 the survey. If the depth of the bituminous surface is more than 40mm, then correction factor has to be applied. If the depth is less i.e. if it is a thin bituminous surfacing like premix carpet and surface dressing, then no

correction is required. The procedure for determining the temperature is given below.

a) A hole has to be drilled into the pavement with the help of a mandrel. The depth of the hole is 45 mm and the diameter of the hole at the top is 1.25 cm and at the bottom is 1 cm.

b) The hole should be filled with glycerol and the temperature must be recorded after 5 minutes with the thermometer (range of temperature between 0 -100^{O}C) with 1^{O} division.

c) The temperature readings should be measured for every hour during the survey.

2. **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 is :

a) Average annual rainfall in that area,

b) Soil classification – sandy / gravelly, clayey with low plasticity or clayey with high plasticity.

c) Field moisture content.

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

i. Make a test pit in the shoulder to a depth up to 15 cm below the subgrade level. There should be one pit for every km in every km. Using an auger, the soil sample should be collected from the subgrade beneath the deflection points (These are the points which are at a distance of 0.6m from the edge of the pavement if the carriageway width < 3.5 m {single lane road} ; 0.9 m if the carriageway width is greater than 3.5 m {Two lane road} and 1.5 m if it is a four lane road) The view of the sample collection is given below in the Figure 4.4.

3. Truck specifications for conducting the test:

Rear axle weight of the truck	= 8170 kg
Tyre pressure	= 5.6 kg / cm^2.

Spacing between the tyre walls = 30-40 mm.

4.4.1 Evaluation of Structural Number of Pavement (SNP)

The adjusted SNP was calculated from deflection values taken with the help of Benkelman Beam Deflection (B.B.D.) as shown in Figure 4.3 and stated in IRC 81: 1997 and calculating Adjusted Structural Number with the help of measured deflection values by using equations given by Odoki and Kerali [2000]:

For granular base layers

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

For bituminous base courses

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

Table 4.4: Structural and Functional Evaluation

Section ID	Condition Year	IRI (m/km)	B.B.D(mm)	SNP
PR -01	2016	2.16	0.49	5.0
PR -02	2016	2.24	0.88	3.50
PR -03	2016	3.87	1.1	3.0

4.4.2 Proctor Compaction Test

The Light compaction test was performed on all section samples for calculating Optimum Moisture Content and Maximum Dry Density , as per procedure specified in IS : 2720 (Part VII) : 1980. Compaction is defined as the compressing of the soil mass by the reduction of air voids. The degree of compaction is determined with help of dry density. The soil attains maximum dry density value at a particular value of water content known as optimum moisture content. Figure 4.4 shows pit digging for the collection of sample. Figure 4.5 shows compaction test on a soil sample. The results of the compaction are given in Table 4.5.

Figure 4.4: Pit Digging

Figure 4.5: Light Compaction Test

The results of the compaction are given in Table 4.5.

Table 4.5: Results of Compaction

Section ID	Max Dry Density (g/cc)	OMC
PR -01	1.846 g/cc	12.12 %
PR -02	1.799 g/cc	12.3 %
PR -03	1.853 g/cc	12.3%

4.5 Pavement Material Evaluation

To get information about the pavement layer thickness with help of IRC 37:2015, C.B.R. (California Bearing Ratio) test along with (OMC) Optimum Moisture Content has been conducted and tabulated in Table 4.6. Figure 4.6 shows CBR test being performed on soaked sample. Table 4.6 shows the soaked CBR results for the samples collected form the three roads.

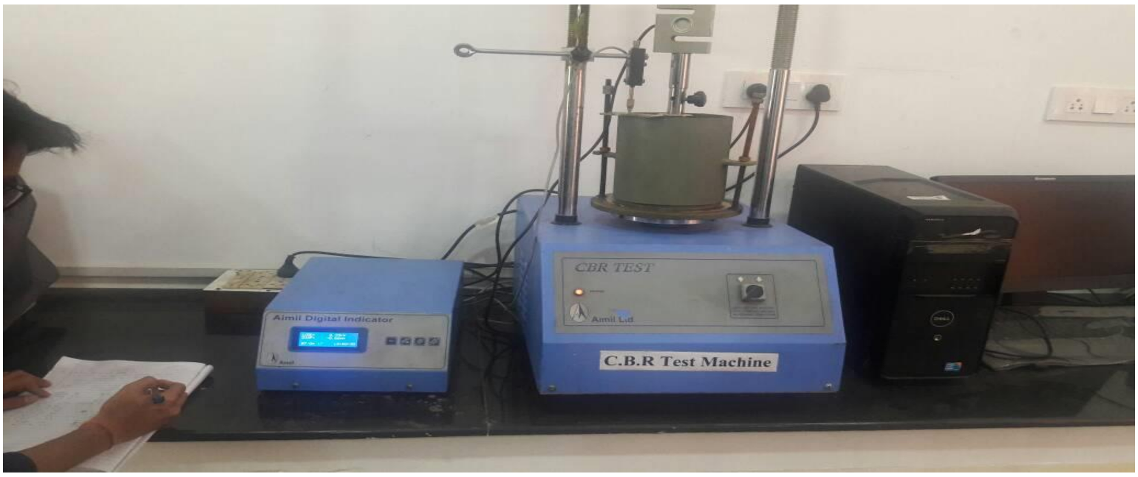

Figure 4.6: CBR testing of soaked sample

Table 4.6: CBR Results

Section ID	Optimum Moisture Content (%)	CBR (%) on soaked sample
PR-01	12.12	7.78
PR-02	12.3	7.30
PR-03	12.3	6.32

4.6 Vehicle Fleet

4.6.1 Vehicles Traffic Volume and Composition Data

Traffic volume data is calculated after conducting counts for 72 hours by involving sufficient number of enumerator's for the corresponding road branches. In this scenario data has been collected by Municipal Corporation Patiala (Department of Town and Country Planning Punjab) mentioning the number of motorised and non-motorised traffic in the Table 4.7 underneath. The Patiala road traffic is comprised of both Motorized (MT) and Non-Motorized (NMT) vehicles and annual growth rate of each section has been provided in Table 4.8. Table 4.9 and 4.10 represent basic data of Motorized (MT) and Non –Motorized vehicles included in vehicle fleet. Passenger Car Space Equivalent (PCSE) factor plays vital role in determination of Annual Average Daily Traffic (AADT) for each section by summing up the products of number of individual vehicle.

Table 4.7: Traffic Classification

Section ID	**Motorized Annual Average Daily Traffic (in PCSE)**	**Non-Motorized Annual Average Daily Traffic (in PCSE)**	**Annual Average Daily Traffic Year**	**Traffic Volume**
PR -01	15255	2219	2016	High
PR -02	12856	2500	2016	High
PR -03	9879	1500	2016	Medium

Table 4.8: Vehicle Composition and Average Annual Growth Rate

Vehicle Type	**Composition of Traffic Flow (%)**						**Average Annual Growth Rate (%)**
	PR-01		PR-02		PR-03		
	MT	NMT	MT	NMT	MT	NMT	
Two Wheeler	76.5	-	27	-	67.6	-	8
Light Good Freight	20.8	-	25	-	19.6	-	4.6
Heavy Truck	2.7	-	48	-	12.8	-	4.3
Animal Cart	-	31	-	51	-	48	3.3
Person	-	69	-	49	-	52	6.6
Total	100	100	100	100	100	100	

Table 4.9: Basic data of Motorized Vehicles

Vehicle Characteristics	**Two-Wheeler**	**Light Goods Freight**	**Heavy Truck**
PCSE	0.5	1	1.6
Number of Wheels	2	4	8
Number of Axles	2	2	3
Annual no. of km driven	10000	30000	90000
Annual no. of working hours	150	1300	2050
VSL (years)	7	8	12
Operating Weight (Tonnes)	0.25	2.5	16
ESALF	0	0.001	7.2

Table 4.10: Basic characteristic data of Non-Motorized Vehicles

Vehicle Characteristics	**Animal Driven Cart**	**Person**
PCSE	-	-
Number of Wheels	2	-
Annual no. of km driven	2500	-
Annual no. of working hours	1300	-
VSL(years)	3	-
Operating Weight (Tonnes)	0.4	1
ESALF	0	0

4.6.2 Maintenance and Rehabilitation Work

The various maintenance levels for urban roads are given by Ministry of Road Transport and Highways. The suggested serviceability levels and limiting levels of surface defects based on measurement of the irregularities like roughness, cracking, rutting *etc.* as per MORT&H [2004] are shown in Table 4.11.

Table 4.11: Serviceability Levels of maintenance for Urban Roads

S. No.	Serviceability Indexes	Serviceability Levels		
		Arterial Roads	Sub-Arterial Roads	Other Roads
1.	Roughness by Bump Integrator (max permissible)	2000 mm/km	3000 mm/km	4000 mm/ 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 (max. permissible)	5 mm	5-10 mm	10-20 mm
5.	Skid number (max. desirable)	50 SN	40 SN	35 SN

4.6.3 Adjustment of HDM-4 Model to Indian Conditions

The HDM-4 model calibration has two primary components to determine the physical quantities, costs and benefits predicted for the analysis, namely:

- Road User Effects (RUE) - It consists of vehicle operating costs (VOC), emissions, travel time, and safety.
- Road deterioration and works effects (RDWE) –It consists of rate of deterioration and the effect of maintenance activities performed on the pavement conditions along with its future outcomes.

The calibration factors for the networks when SNP is in range 3.0-5.5 are given in Jain et al.[2005]. It can be seen in the Table 4.5 that SNP is in the range of 3.0 – 5.0 for present study, therefore the same calibration factor have been considered from the Table 4.12.

Table 4.12: Calibration Factors for HDM-4 Models

Model Description	Average calibration factor
Cracking Initiation Model	0.43
Cracking Progression Model	1.25
Ravelling Initiation Model	0.37
Ravelling Progression Model	0.52
Pothole Initiation Model	0.45
Pothole Progression Model	0.95
Roughness Progression Model	0.85
Rutting Progression Model	1.00

4.7 Computation of Remaining Service Life (RSL)

4.7.1 Introduction

The notion of Remaining Service Life (RSL) has been around for decades and is well rooted within pavement community. The data to be considered are initial construction or reconstruction and first major rehabilitation along with change in age with respect to time. It is the necessity of present era to develop some scientific methodology to compute RSL of road sections with higher reliability.

4.7.2 Maintenance and Rehabilitation Work

For the present study, Maintenance standard in Table 4.13 represents standard for all road sections with intervention criteria, work description and standard practised.

Table 4.13: Maintenance work standard for all road sections

Maintenance Strategy	**Work Details**	**Intervention Standard**
Reconstruction	200 mm WMM +75 mm DBM + 40 m BC	Roughness >= 8 IRI

Based upon the network analysis performed using HDM-4, the remaining service life of all the pavement sections was determined, if the above maintenance of Table 4.13 is provided to the pavements. The remaining serviceable life of all the selected road sections of Patiala city in years is shown in Table 4.14.

Table 4.14: Remaining Serviceable Life (RSL) of all road sections

Section ID	**Reconstruction Year**	**Remaining Serviceable Life (in years)**
PR-01	2023	6
PR-02	2023	6
PR-03	2019	2

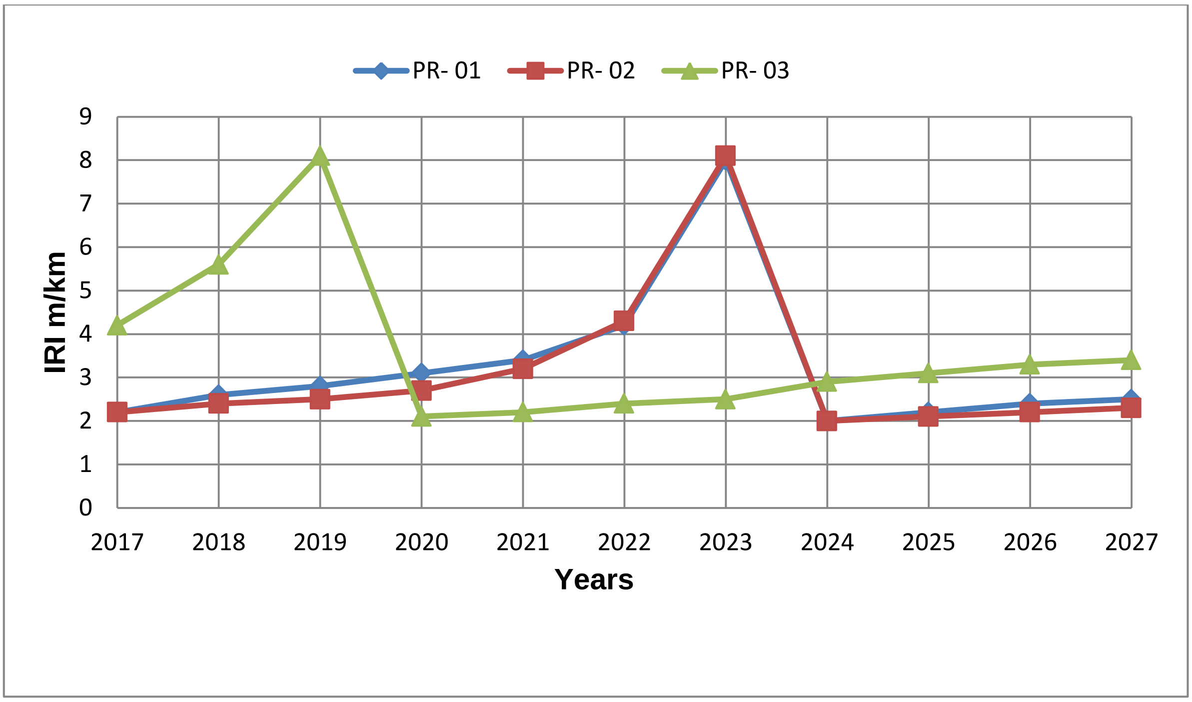

Figure 4.7: Roughness progression graph of all selected road sections

Figure 4.7 shows average roughness progression graph for road sections PR-01, PR-02 and PR-03. The sharp fall in average roughness values shows that reconstruction work has been done for the road section.

4.8 Priority Ranking of Road Sections

4.8.1 Urban Road Maintenance Priority Index (URMPI)

URMPI is an index, which decides the overall priority to a road section of urban roads for maintenance work. URMPI has been defined as per equation: [Shah, Y. et al., 2014]

$$URMPI = RCI*TVF*DF*RCF$$

Where

RCI = Road Condition Index

TVF = Traffic Volume Factor

RCF = Road Classification Factor

DF = Drainage Factor.

The TVF, RCF and DF factors are used to adjust the RCI values in order to assign greater priority to the sections with higher traffic levels, higher functional level of urban roads and poor drainage conditions. Hence these factors have been taken as multiplicative with RCI to estimate the URMPI.

A high value of URMPI depicts the bad state of a road and should be given higher priority while creating the maintenance programme. However, the poor condition of road (RCI) has been given the topmost priority for providing maintenance works.

4.8.2 Urgency Index (UI)

To evaluate the road condition two parameters play an important role i.e. Degree (D) and Extent (E) of distresses. The various distresses are provided with particular value of degree and extent on the behalf of functional evaluation. Degree is the level to which the road has deteriorated and extent is the frequency of the damage occurrence. The values of degree and extent range from 1 to 5. Detailed description of degree and extent for each parameter are given in Tables 4.15, 4.16 respectively. [Shah, Y. et al., 2014]

Table 4.15: Degree of Distress

Degree (D)	**Description**
1	VERY SLIGHT: Of minor importance. No maintenance required.
2	SLIGHT: Easy to recognize but of minor importance. No immediate maintenance required.
3	MODERATE: Evident with respect to consequences but still acceptable. Maintenance is required.
4	SEVERE: Undesirable. Maintenance required at regular intervals.
5	VERY SEVERE: Extreme consequences, not acceptable at all. Immediate maintenance work required.

Table 4.16: Extent of Distress

Extent (E)	**Description**
1	Few isolated occurrences i.e. less than 5% of road affected.
2	Irregular occurrence, i.e. between 5 to 15% of road affected.

3	Frequent occurrence, i.e. between 15 to 30% road affected.
4	Widespread occurrence, i.e. between 30 and 60% road affected.
5	Throughout, Regular occurrence, i.e. more than 60% of road affected.

Urgency Index (UI) = Degree * Extent

4.8.3 Weightage to Distress

The five distress parameters like ravelling, cracks. potholes, rut and patching have been measured. Since, the influence of all distresses are not equal, different weights have been assigned to distress based on expert's opinion to take into account their individual effect. The riding quality of pavement depends upon road roughness and vehicle speed. A team of five experts travel on the selected urban section at the design speed in passenger car and are then asked to access the riding speed of pavement section as per AASHTO 1962 stated in Table 4.17. The relative weight given by experts has been converted to average weight. The weight ranges from 1 to 5 have been thus assigned for different performances as shown in Table 4.18 below.

Table 4.17: Guidelines Adopted for Rating of Riding Quality

Adopted Rating	Quality	Riding Experience
85-100	Excellent	Very Smooth Ride
70-85	Very Good	
55-70	Good	Some minor Bumps Encountered
40-55	Fair	Regular small up and down movement, but reasonably comfortable riding
25-40	Poor	Regular up and down experiencing discomfort
10-25	Very Poor	Uncomfortable ride experiencing severe surface irregularity
0-10	Failed	

Table 4.18: Weightage Assigned to Various Distresses

S.No.	Distress type	Relative Weight	Weight (Wi)
1	Patching	0.080	1

2	Rutting	0.120	2
3	Ravelling	0.183	3
4	Potholes	0.262	4
5	Cracks	0.355	5

4.8.4 Road Condition Index (RCI)

Road Condition index is a number that indicates the overall pavement conditions. It is the weighted average of all UI's and calculated from the equation:

$$RCI = \sum(W_i * UI_i)/\sum W_i$$

Where,

UI_i = Urgency index corresponding to distress i

W_i = Weight of a distress parameter i.

RCI values range from 1 to 25.The usage of Road Condition Index values as per range given in table 4.19 below.

Table 4.19: Road Condition as per RCI

Road Condition Index	Road Condition
1 – 5	Good
5 – 8	Fair with few isolated problems
8 – 10	Acceptable level
10 – 12	Deteriorated condition and requires attention
>12	Badly affected and immediate attention required

4.8.5 Traffic Volume Factor (TVF)

The major factor causing distresses are composition of traffic and volume along with the present condition of the network. The priority for the maintenance of the road will be given on the behalf of factor causing distresses. Traffic volume indicates number of vehicles passing through on the particular network in a day. The traffic volume has been ranged into five categories as per MORTH (2004) and their respective factors are stated in Table 4.20 below. The effect of damage due to vehicle loading has been given for high traffic volume by considering TVF. The factor is of prime importance as the traffic volume is the only thing which will show most variations within the coming period so it is to be studied very cautiously.

Table 4.20: Traffic Volume Factor

Traffic Volume (CVPD)	Condition	TVF
<150	Very Low	1
150 – 450	Low	2
450 – 1500	Medium	3
1500 – 4500	Heavy	4
>4500	Very Heavy	5

4.8.6 Road Classification Factor (RCF)

The urban road networks are categorized on the behalf of the connectivity to the residents. The priority ranking for maintenance also depends on significance of the road. Therefore, road classification factor has been considered as given in table below for different road class.

Table 4.21: Road Classification Factor

Road Class	RCF
Arterial	2.0
Sub-Arterial	1.5
Collector	1.0
Local Street	0.5

4.8.7 Drainage Factor (DF)

One of the major factors for the deterioration of urban networks is drainage. It is very important because choking of drainage will give rise to various surface distresses which are problematic to the normal functioning of the road. If adequate drainage is not provided, the deterioration of the pavement will be much faster compared to the pavement having drainage. Therefore, drainage condition effect is also considered in prioritizing process by taking in account the following factors given in Table 4.22 below.

Table 4.22: Drainage Factor

Drainage Condition	**Excellent**	**Good**	**Fair**	**Poor**	**Very Poor**
DF	1.0	1.5	2.0	2.5	3.0

4.8.8 Calculation of Urban Road Maintenance Priority Index (URMPI):

For PR- 01:

Table 4.23: Parameters of the PR-01

Traffic Condition	**Drainage Condition**	**Road Class**	**TVF**	**RCF**	**DF**
Heavy	Fair	Sub-Arterial	4	1.5	2

To calculate RCI:

S.No.	Distress	W_i	D	E	UI	W_i*UI
1	Patching	1	1	1	1	1
2	Rutting	2	2	2	4	8
3	Ravelling	3	3	3	9	27
4	Potholes	4	4	2	8	32
5	Cracks	5	5	3	15	75

$$RCI = \sum(W_i * UI_i)/\sum W_i$$

$$= (1+8+27+32+75)/15$$

$$= 9.54$$

$$URMPI = RCI*TVF*DF*RCF$$

$$= 9.54*4*2*1.5$$

$$= 114.48$$

For PR- 02:

Table 4.24: Parameters of the PR-02

Traffic Condition	Drainage Condition	Road Class	TVF	RCF	DF
Heavy	Fair	Collector Street	4	1	2

To calculate RCI:

S.No.	Distress	W_i	D	E	UI	W_i*UI
1	Patching	1	1	1	1	1
2	Rutting	2	2	2	4	8
3	Ravelling	3	3	3	9	27
4	Potholes	4	4	3	12	48
5	Cracks	5	5	3	15	75

$$RCI = \sum(W_i*UI_i)/\sum W_i$$

$$= (1+8+27+48+75)/15$$

$$= 10.6$$

$$URMPI = RCI*TVF*DF*RCF$$

$$= 10.6*4*2*1$$

$$= 84.8$$

For PR- 03:

Table 4.25: Parameters of the PR-03

Traffic Condition	Drainage Condition	Road Class	TVF	RCF	DF
Medium	Poor	Collector Street	3	1	2.5

To calculate RCI:

S.No.	Distress	W_i	D	E	UI	W_i*UI
1	Patching	1	1	1	1	1
2	Rutting	2	2	4	8	16
3	Ravelling	3	3	3	9	27
4	Potholes	4	4	4	16	64
5	Cracks	5	5	3	15	75

$$RCI = \sum(W_i * UI_i)/\sum W_i$$

$$= (1+16+27+64+75)/15$$

$$= 12.2$$

$$URMPI = RCI*TVF*DF*RCF$$

$$= 12.2*3*2.5*1$$

$$= 91.5$$

4.8.9 Priority Ranking of Urban Roads for Maintenance based on URMPI:

Table 4.26: URMPI based Priority Ranking of given Stretches

Section	**URMPI**	**Priority Ranking**
PR-01	114.48	1
PR-02	84.8	3
PR-03	91.5	2

Thus, Rajendra Hospital Chowk to Y.P.S. Chowk has the highest priority when it comes to maintenance and repair works because of high Urban Road Maintenance Priority Index.

CHAPTER 5

PREDICTION OF PAVEMENT PERFORMANCE USING HDM-4

In this chapter analysis of cost and maintenance planning is shown for the network name Dukhniwaran Sahib Gurudawara to Nabha road as it is one of the Major District Road of State Punjab.

5.1 Data Incorporation to the HDM-4

The input data for the study consists of pavement condition, traffic, distresses, type of vehicle, growth rate, maintenance and rehabilitation for selected road section are shown in succeeding figures below. The Project Analysis is carried out for a period of 15 years. The objective of study is to determine cost of various treatments and comparison of these intervention criteria for maintenance planning. The name of the road is Dukhniwaran Sahib Gurudwara to Nabha (NUR-1). It is Major District road with length of 2.4 km which consists of Asphalt Mix on Asphalt Pavement type. The road has a carriageway width of 10.5 m and a shoulder width of 1 m. The category of road is secondary and climate zone is subtropical. It has inter-urban traffic flow and last treatment year was 2014. The traffic volume stated is high with motorized and non-motorized traffic of 16904 and 3924 Annual Average Daily Traffic (AADT) respectively in year 2010.(PUDA)

Table 5.1: Functional and Structural Evaluation

Section I.D.	Condition Year	IRI (m/km)	B.B.D. (mm)	SNP
NUR-1	2012	3.7	1.30	2.71

The calibration factor for the roughness is equal to 1.52 for the road network when SNP ranges from 2.50- 5.4. It can be observed from Table 5.1 that SNP is 2.71 for this study, thus calibration factor have been taken from Shah *et.al.* [2016] here. They are of great importance for validation of conditions in order to increase the precision of the model. The geometry, history and calibration play a vital role for deciding the maintenance work within a limited budget scenario which is an uphill task for engineers. Therefore, every minor detail needs to be studied with its future outcomes along with recommendations.

The input data snapshots of HDM-4 from initiation till the analysis are shown in figures below. Figure 5.1 is shows currencies used by the various countries which vary from nation to nation.

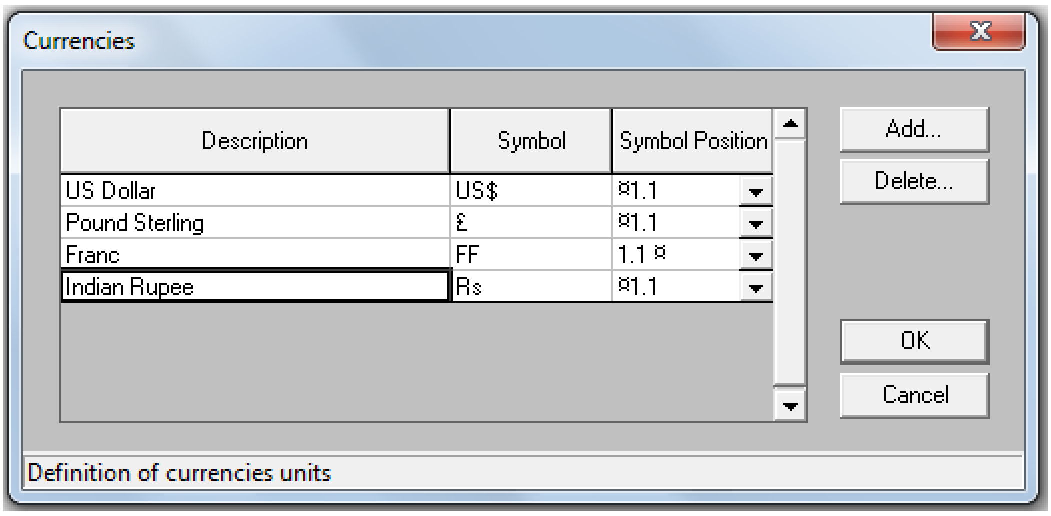

Figure 5.1: Defining the currency used for cost analysis

Figure 5.2 is shows climate which may vary due to the geography of the nation.

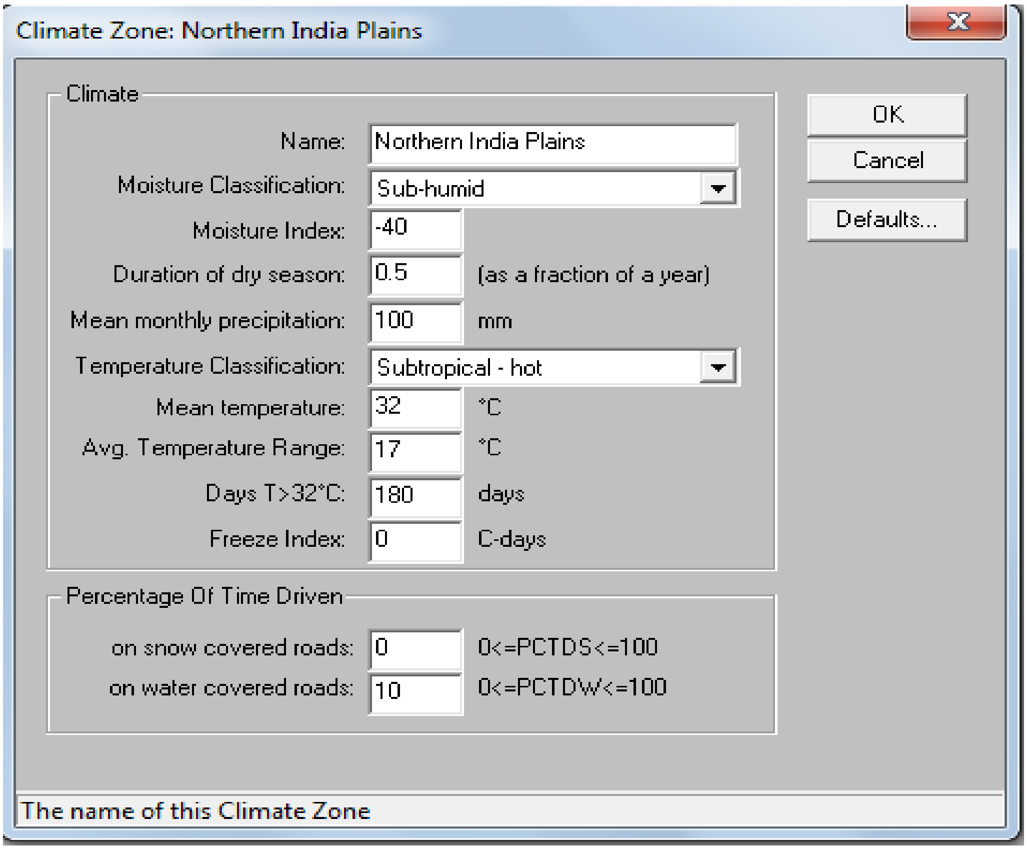

Figure 5.2: Selected climate zone

Figure 5.3 shows change in percentage of average annual daily traffic and hours description on yearly basis.

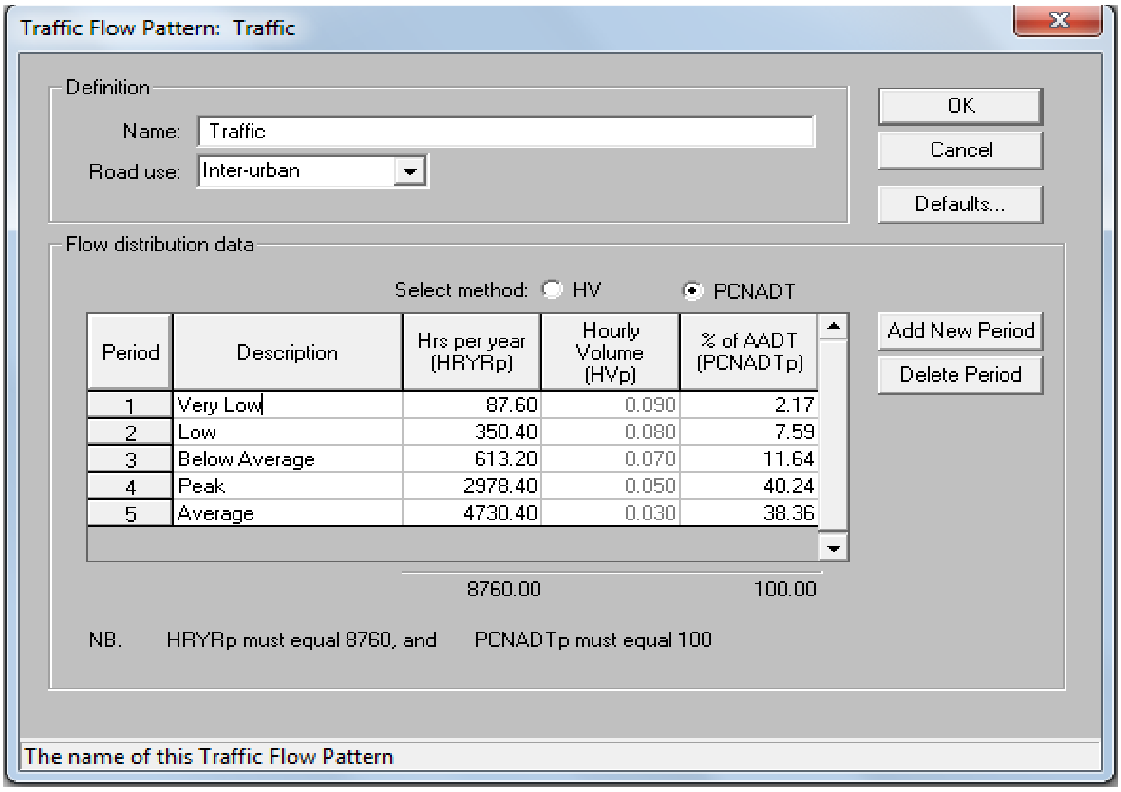

Figure 5.3: Traffic flow pattern

Figure 5.4 shows the basic data to be incorporated i.e. section details to the traffic

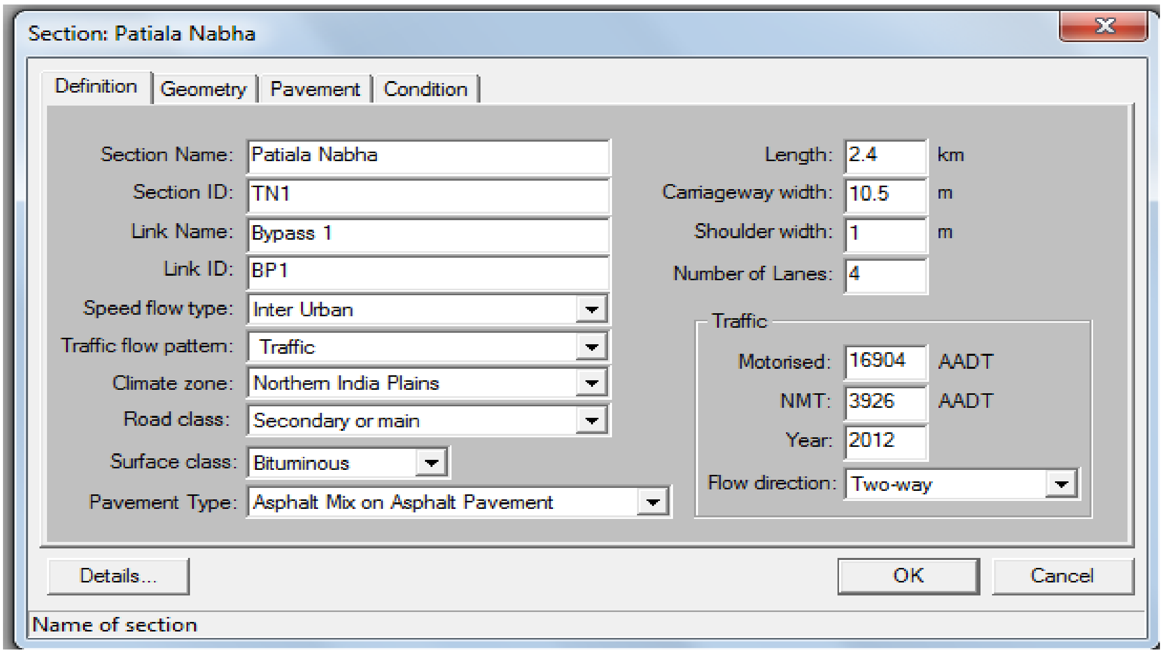

Figure 5.4: Definition data input for Patiala Nabha road section

Figure 5.5 shows the geometry which comprises of rise fall, type of cure, altitude and type of drainage.

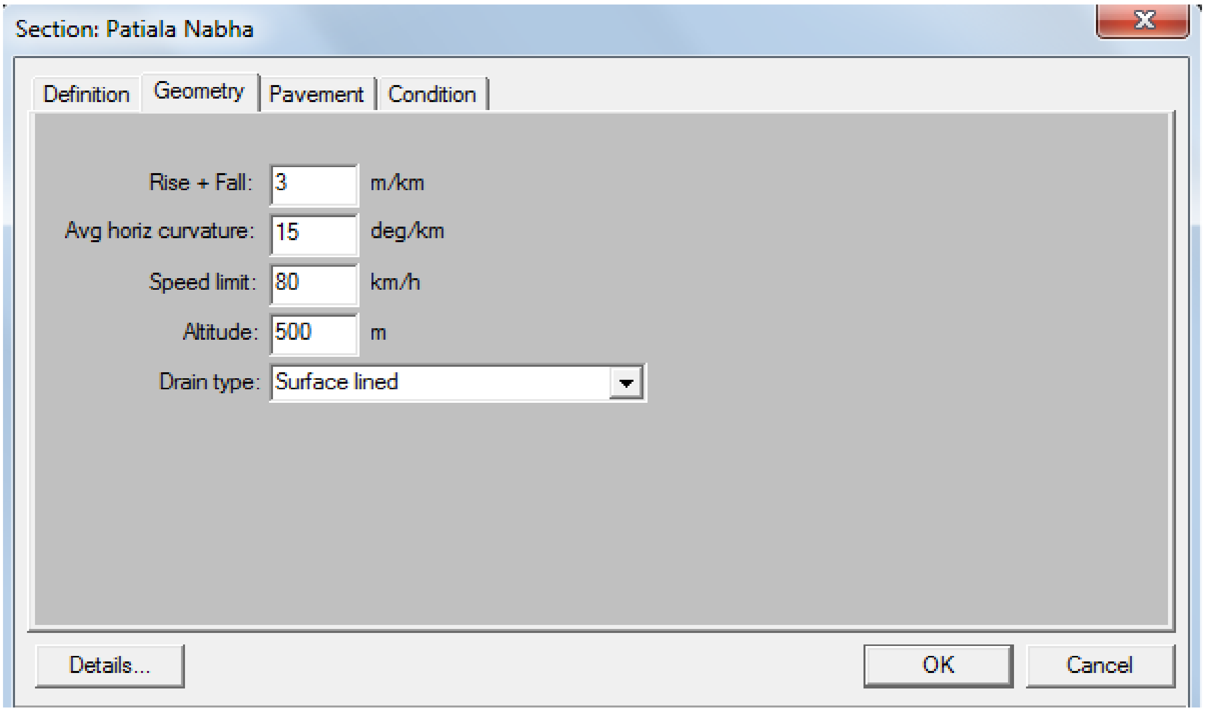

Figure 5.5: Geometry data input for Patiala Nabha road section

Figure 5.6 shows the details of pavement i.e. last maintenance along with thickness of the pavement.

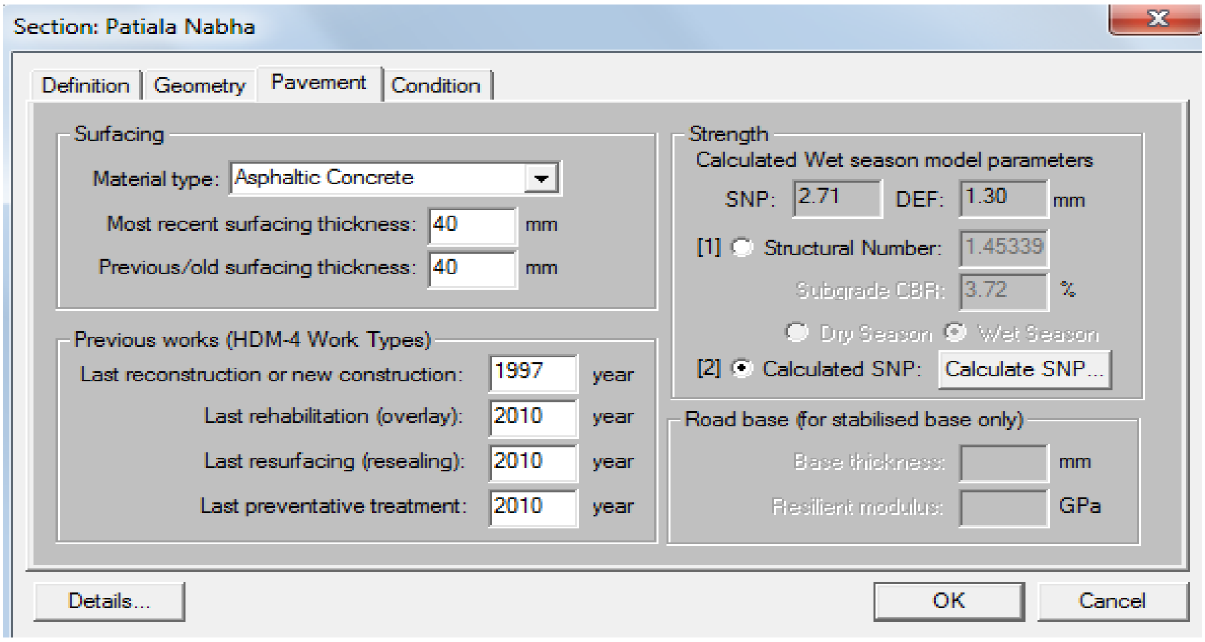

Figure 5.6: Pavement data input for Patiala Nabha road section

Figure 5.7 shows details of condition of pavement along with the distress values.

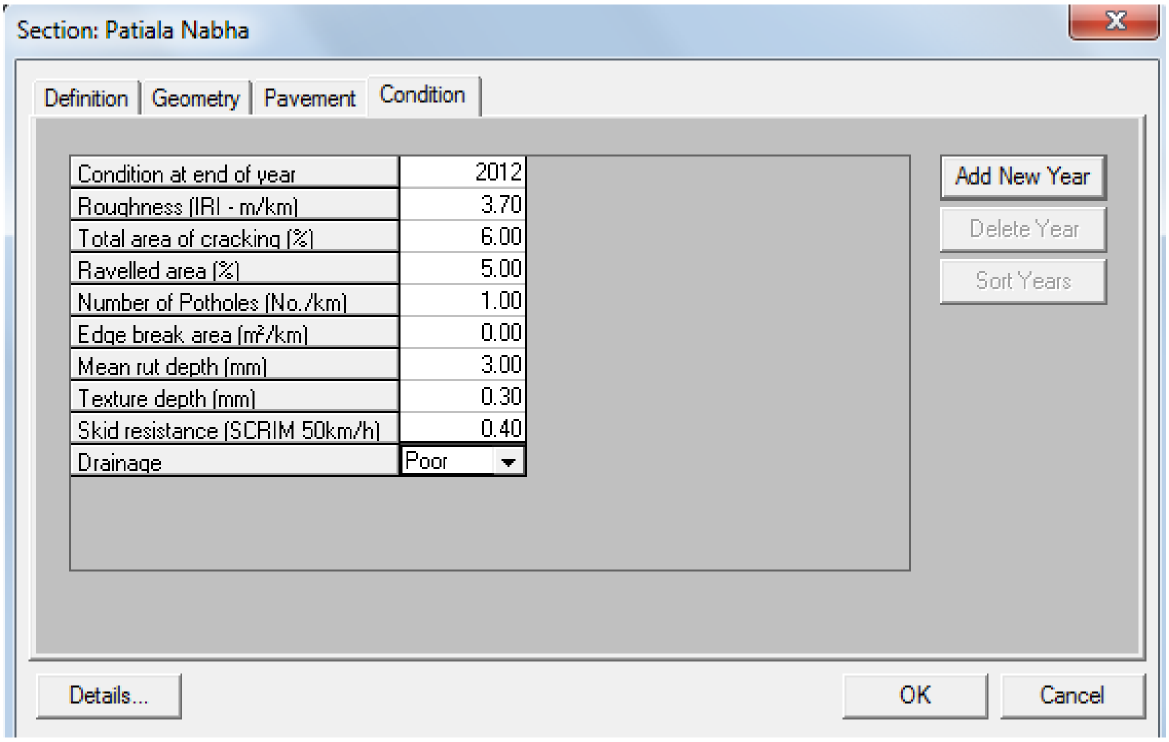

Figure 5.7: Condition data input for Patiala Nabha road section

Figure 5.8 shows the calibration factors used for the section distresses.

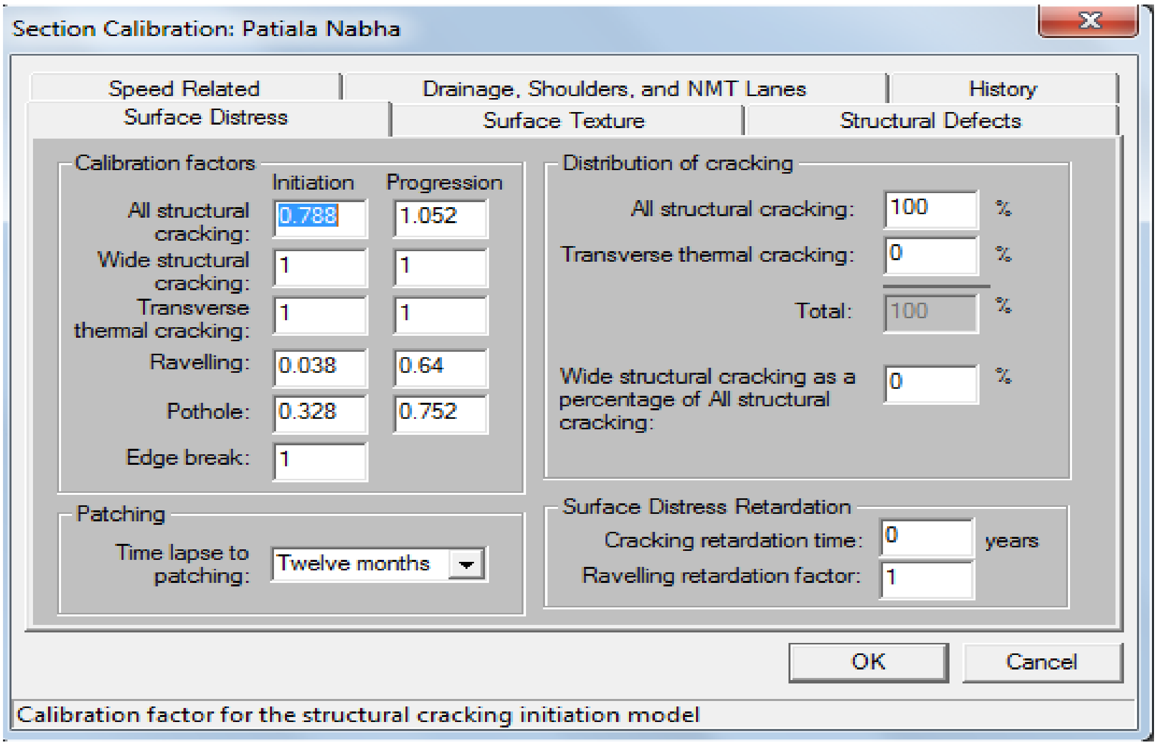

Figure 5.8: Calibration factors input for Patiala Nabha road section

5.2 Vehicle Fleet

For the study, Vehicle Fleet named 'Patiala Fleet' has been created. Six types of Motorized Vehicle (MT) i.e. Auto-Rickshaw, Scooter/Motorcycle, Passenger Car/ Jeep, Bus, Tractor/Trolley and Trucks and two types of Non-Motorized Vehicle (NMT) i.e. Bicycle and Cycle Rickshaw have been included in this vehicle fleet. Figure 5.9 shows class and description of the vehicles.

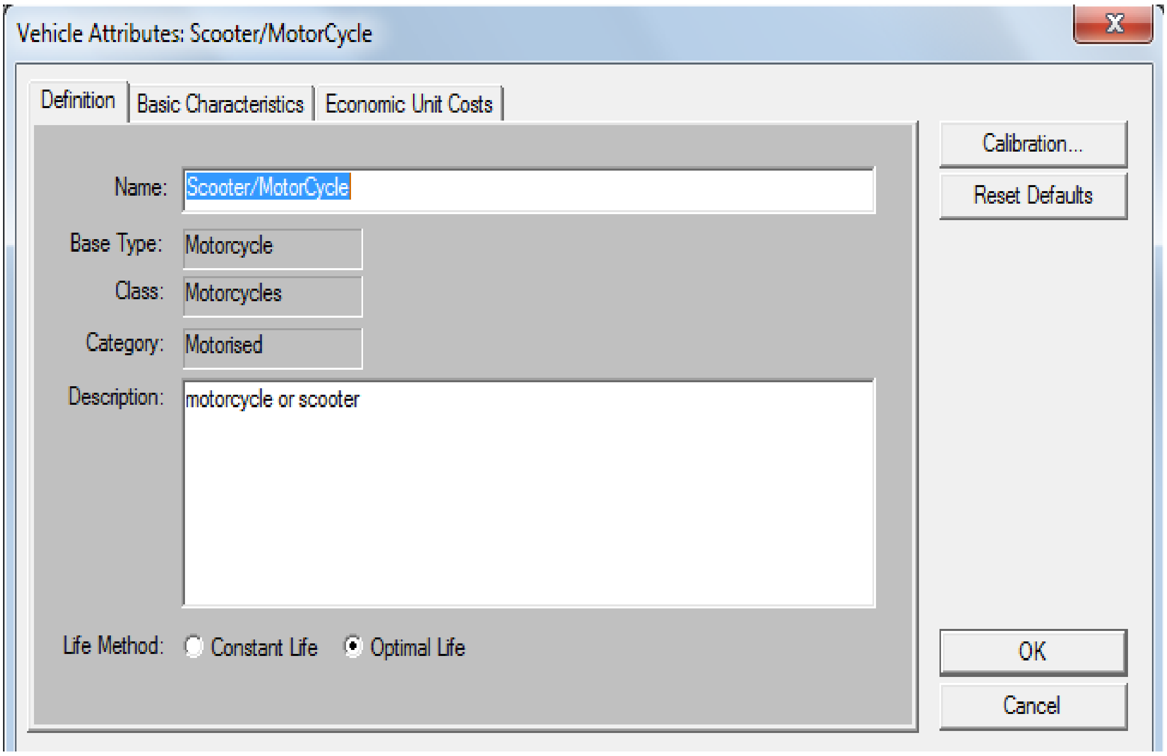

Figure 5.9: Definition data input for Scooter/ Motorcycle

Figure 5.10 shows the vehicle details i.e. service life, usage, weight of the vehicle *etc*.

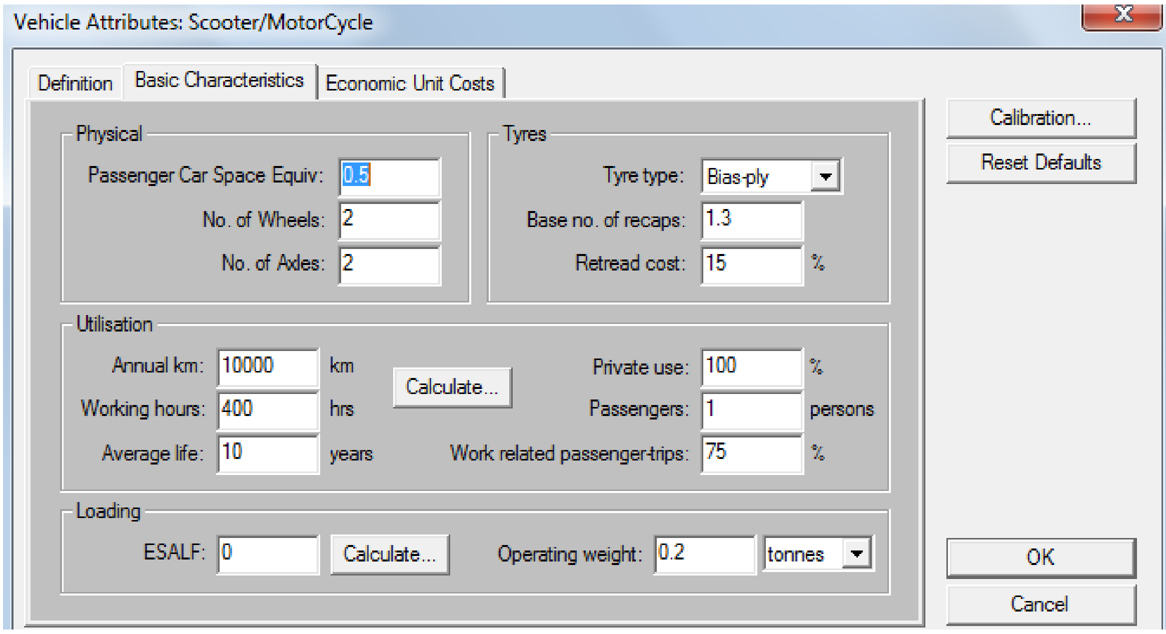

Figure 5.10: Basic characteristics data input for Scooter/ Motorcycle

Figure 5.11 shows the vehicle's cost of spare parts and the cost of maintenance labour.

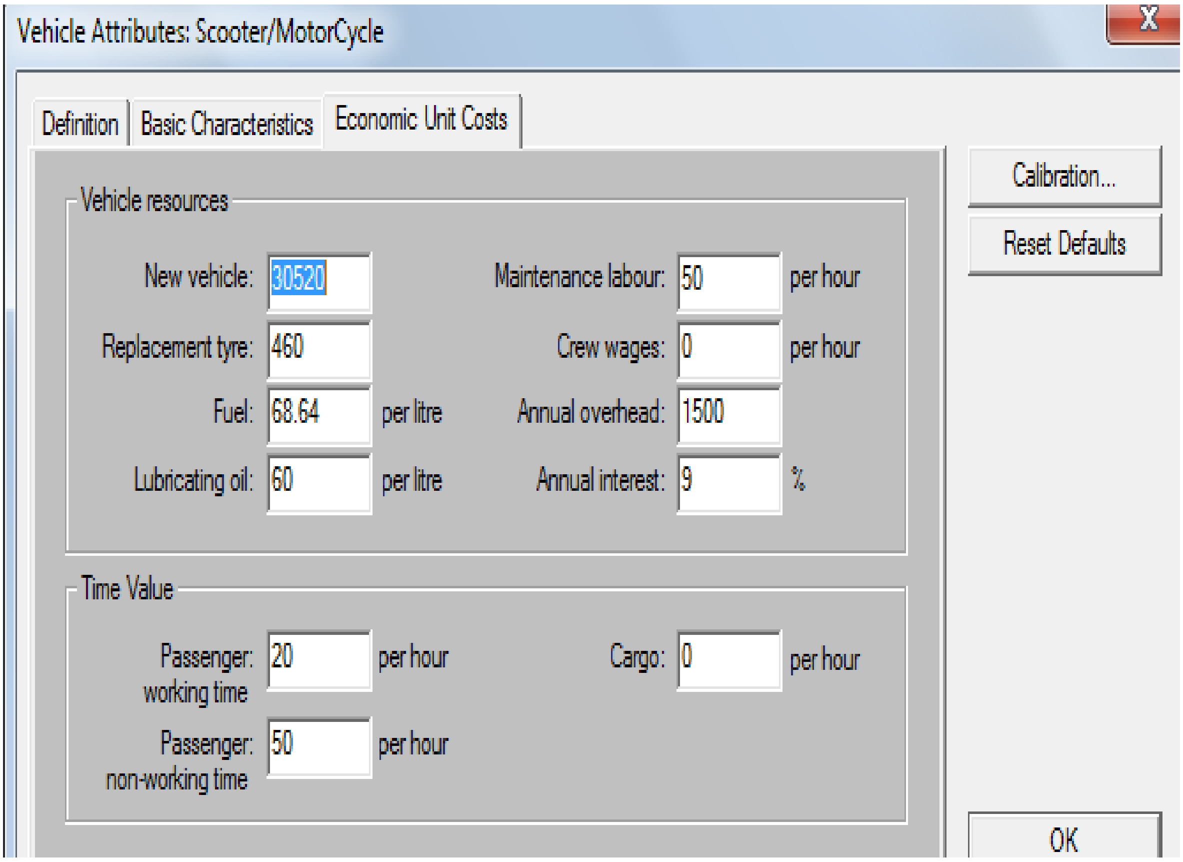

Figure 5.11 Economic unit costs data input for Scooter/ Motorcycle

Figure 5.12 shows the motorized and non-motorized vehicles used for the analysis.

Name	Class	Data Last Modified	Base Type	Category
Auto Rickshaw	Motorcycles	03-06-2017	Motorcycle	Motorised
Bicycle A	Bicycle	03-06-2017	Bicycle	NMT
Bus	Buses	03-06-2017	Bus Medium	Motorised
Cycle Rickshaw	Rickshaw	03-06-2017	Rickshaw	NMT
Passenger Car/Jeep	Passenger Cars	03-06-2017	Car Medium	Motorised
Scooter/MotorCycle	Motorcycles	03-06-2017	Motorcycle	Motorised
Tractor/Trolley	Trucks	03-06-2017	Truck Light	Motorised
Trucks	Trucks	03-06-2017	Truck Medium	Motorised

Figure 5.12: Vehicle fleet with all vehicles defined

Figure 5.13 shows the general details of project analysis such as vehicle fleet to analysis period.

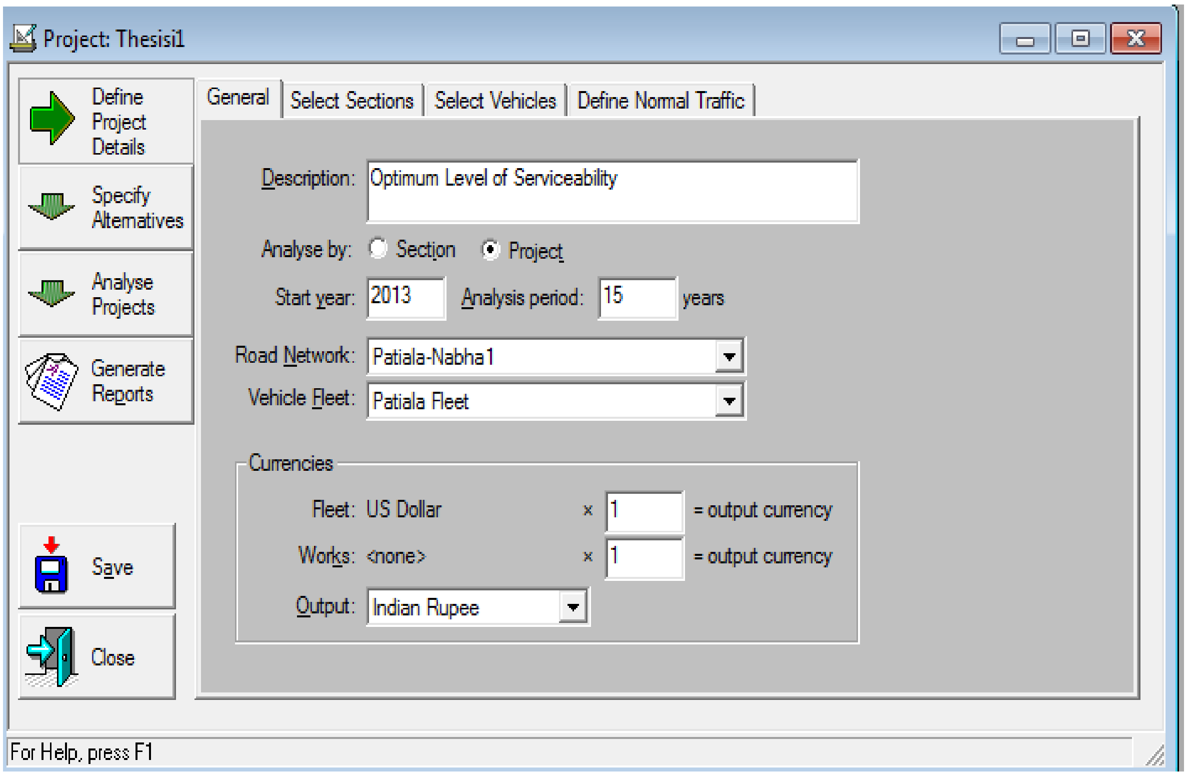

Figure 5.13: Defining general project details

Figure 5.14 provides details of the selected section for the analysis purpose.

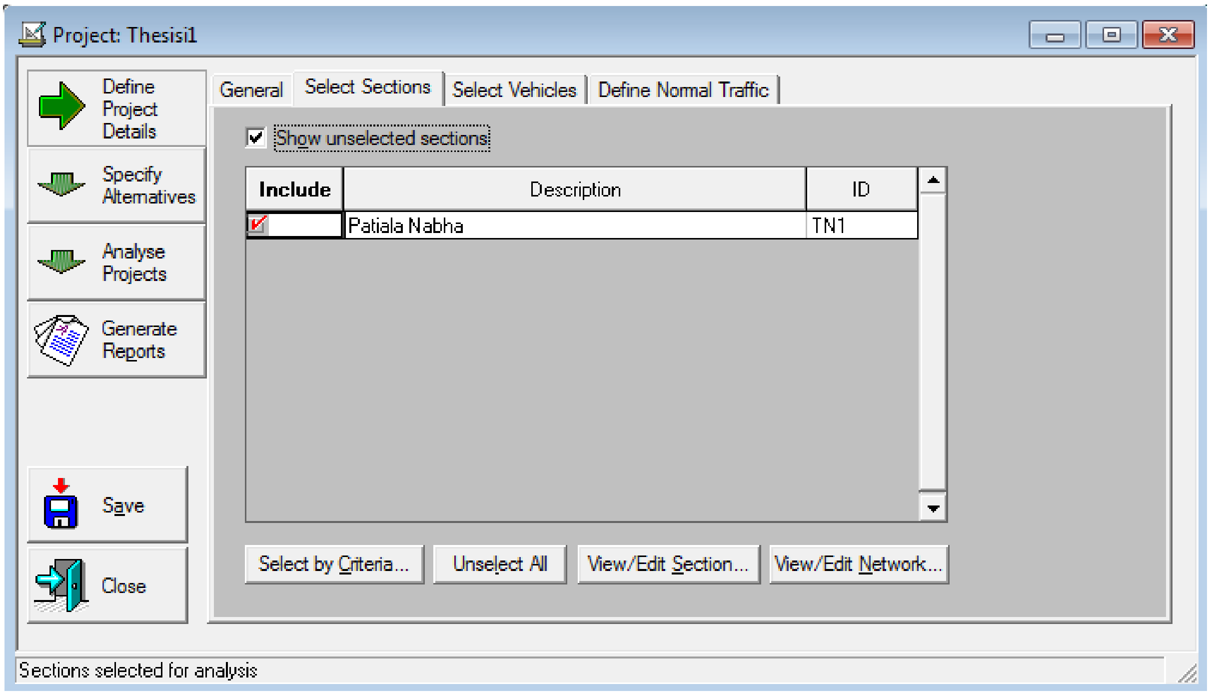

Figure 5.14: Selected section for the analysis

Figure 5.15 shows details of all selected vehicles of the section.

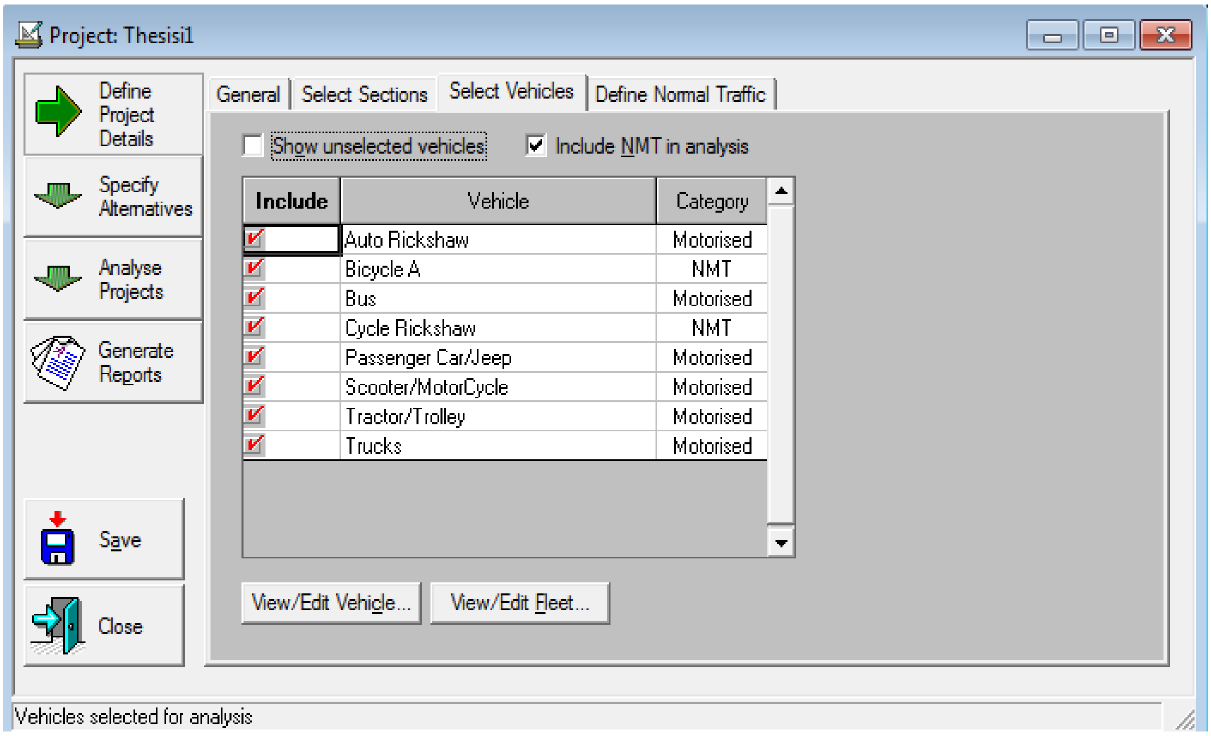

Figure 5.15: Selected vehicles for the analysis

Figure 5.16 provides detail about type of traffic and vehicle along with geometry.

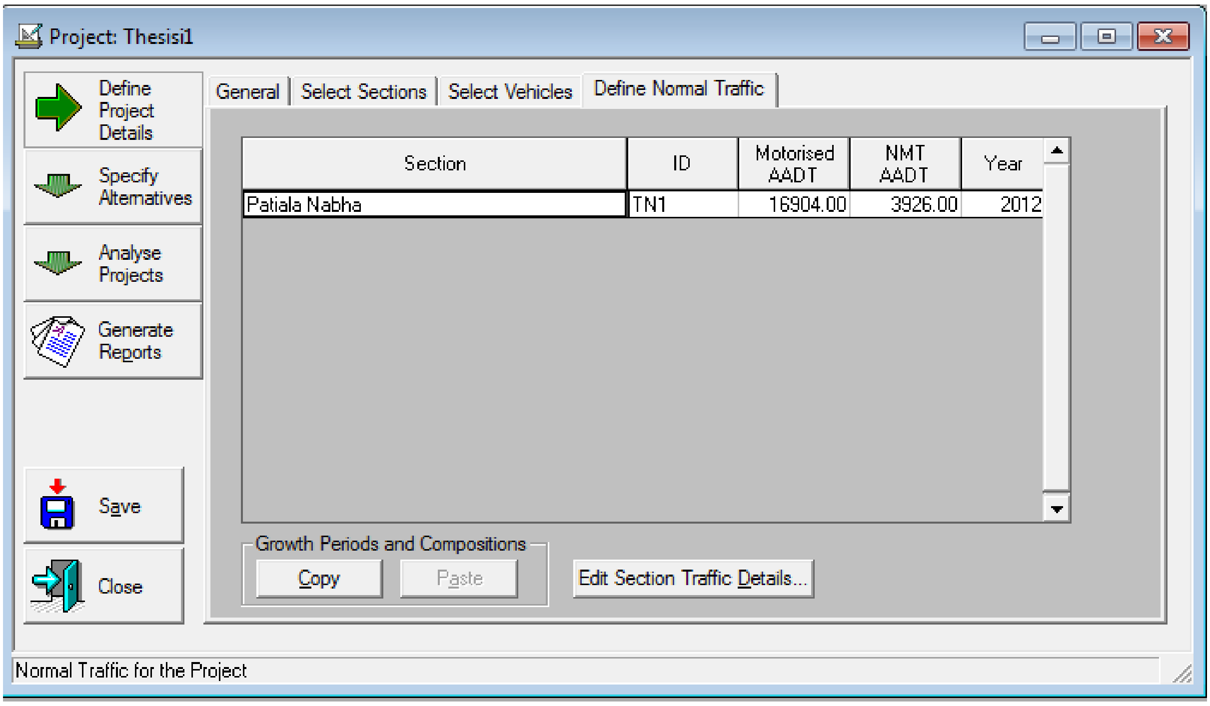

Figure 5.16: Defined normal traffic for the analysis

Figure 5.17 and 5.18 shows the initial composition and annual increase in traffic for motorized and non-motorized vehicle.

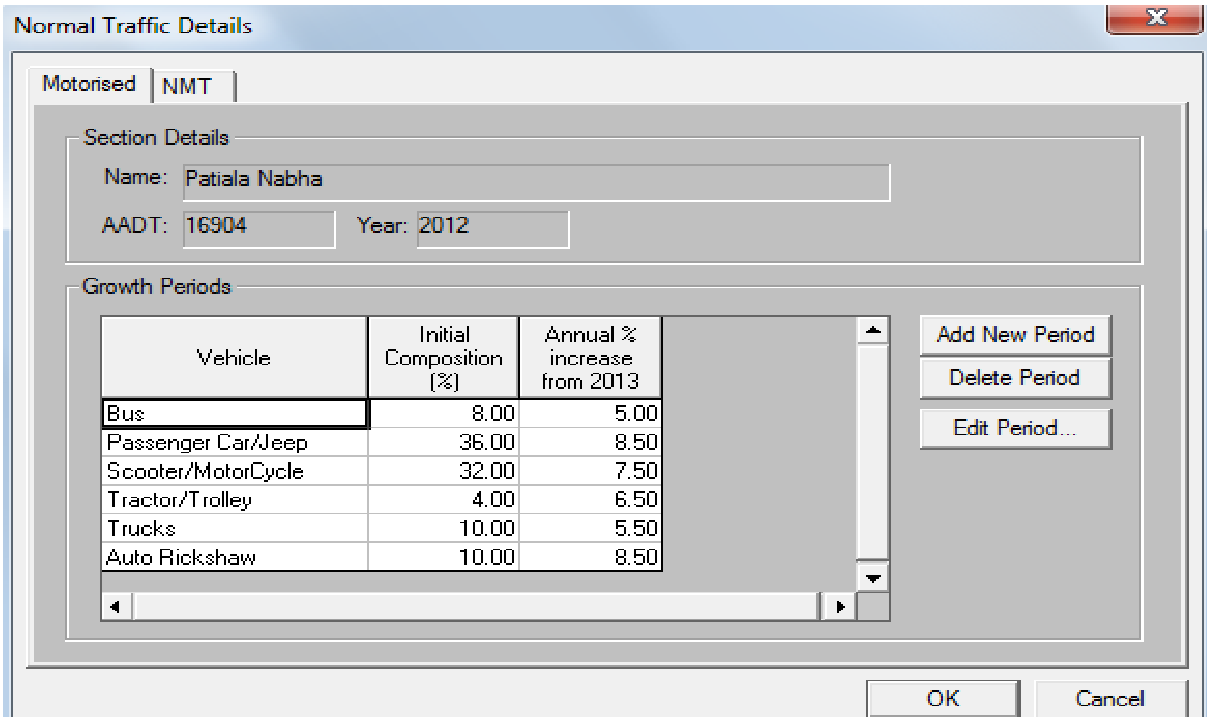

Figure 5.17: Defined normal motorized traffic for the analysis

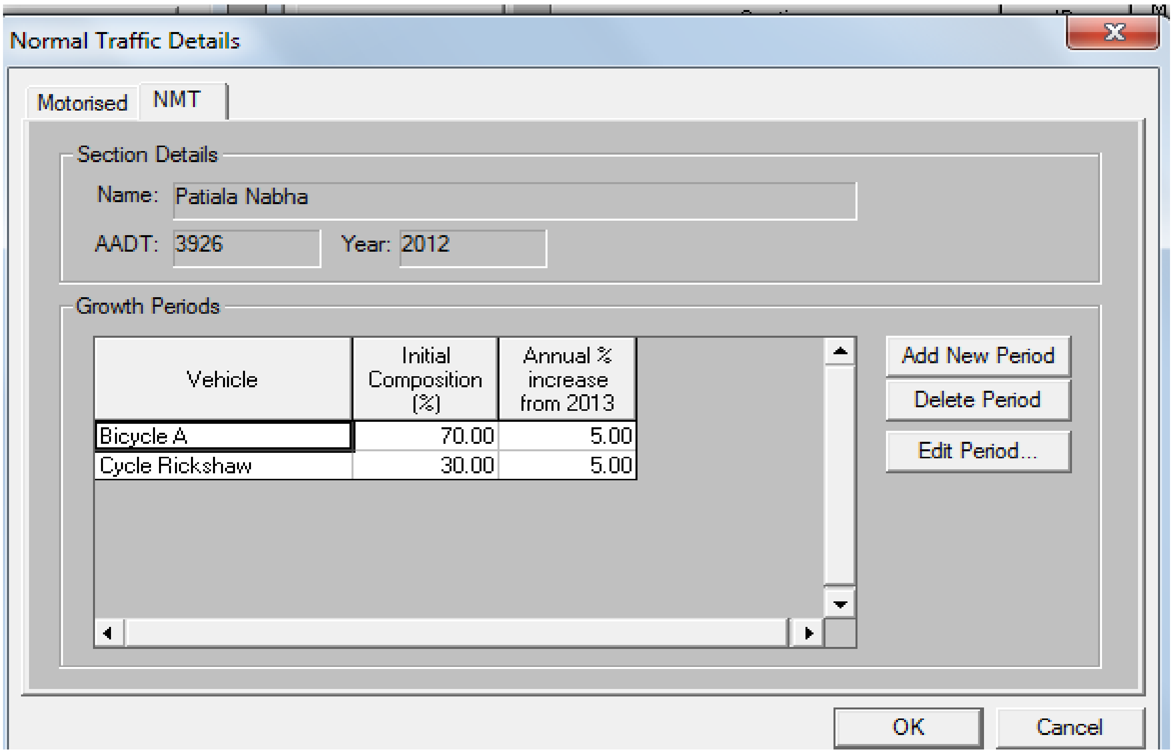

Figure 5.18: Defined normal non-motorized traffic for the analysis

5.3 Specification of Maintenance & Rehabilitation

The M& R alternatives used for the analysis are routine maintenance like patching and major maintenances are surface treatment along with strengthening. The analysis of M&R is conducted for the suggested intervention levels for the urban roads which are stated below in the Table 5.2 as given by Indian Road Congress (MORT&H 2004):

Table 5.2: Intervention Levels for Urban Roads

S.No.	Serviceability Indicator	Level 1	Level 2	Level 3
1	Roughness by Roughometer (maximum permissible)	3 m/km	4 m/km	5 m/km

Table 5.3: Proposed Maintenance with Intervention Levels

S.No.	M & R Alternatives	M&R Work	Intervention Criteria		
			Level 1	Level 2	Level 3
1	Basic Alternative	No work done			

2	Routine Maintenance	Patching	Scheduled After 2 years	Scheduled After 2 years	Scheduled After 2 years
3	Surface Treatment	Overlay 20mm Premix Carpet	Roughness ≥ 3m/km IRI	Roughness ≥ 4m/km IRI	Roughness ≥ 5m/km IRI
4	Surface Treatment	Overlay 25mm Semi-Dense Bituminous Concrete	Roughness ≥ 3m/km IRI	Roughness ≥ 4m/km IRI	Roughness ≥ 5m/km IRI
5	Strengthening	Overlay of 40mm Bituminous Concrete	Roughness ≥ 3m/km IRI	Roughness ≥ 4m/km IRI	Roughness ≥ 5m/km IRI

Figure 5.19 shows the detail of maintenance work item used for the analysis.

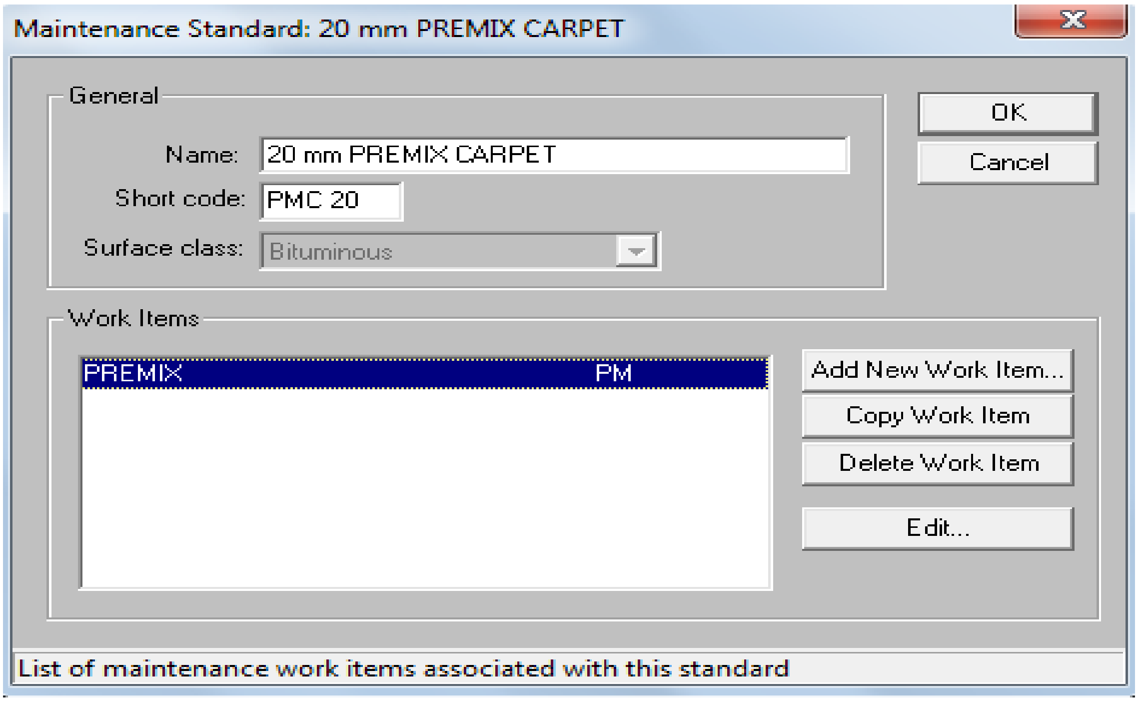

Figure 5.19: Defining maintenance standard

Figure 5.20 shows detail of work item code, type of surface, operation and intervention level.

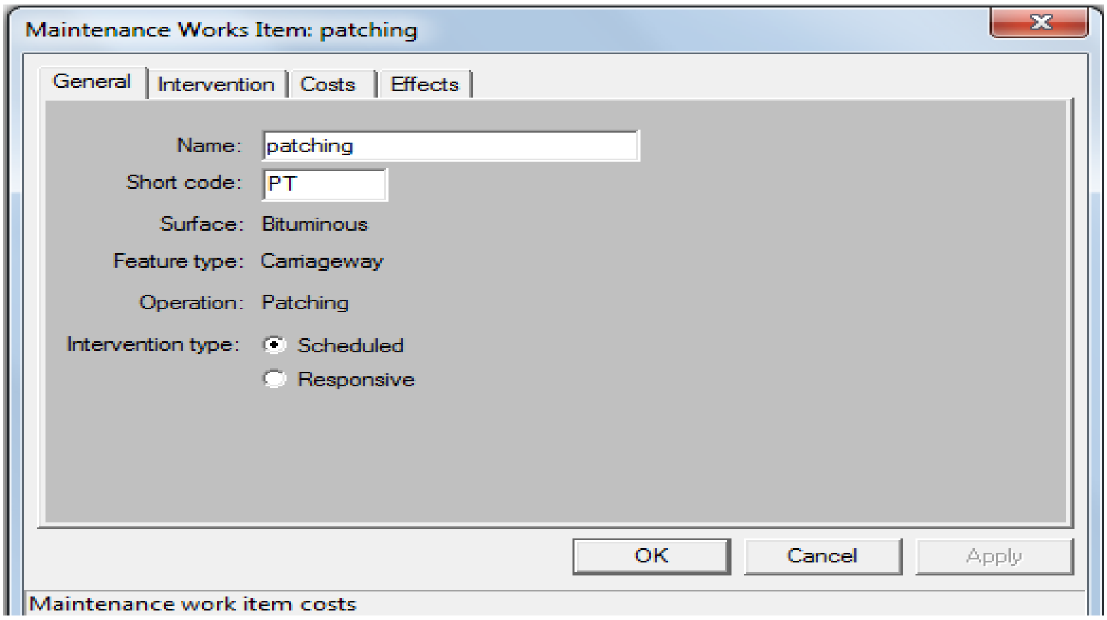

Figure 5.20: Defining the work items in the given maintenance work

Figure 5.21 tells about the intervention criteria selected is responsive and condition applied is of the roughness >= 3 IRI.

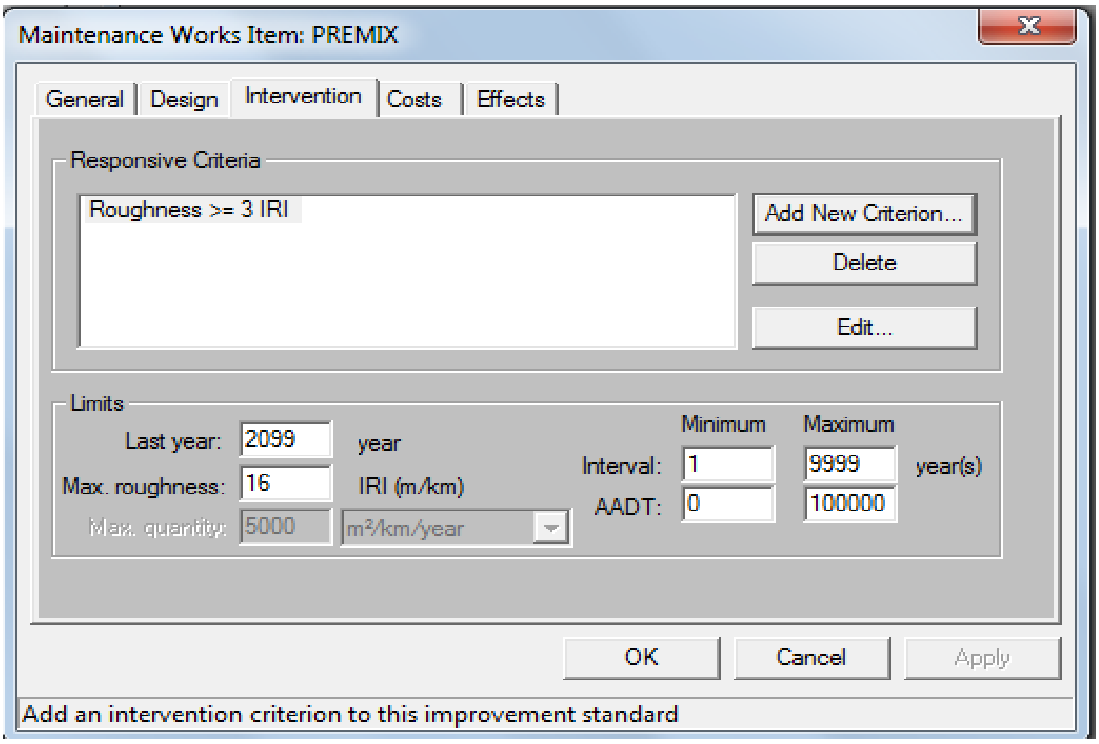

Figure 5.21: Defining the intervention level for the given work item

Figure 5.22 provides a summary of analysis conducted.

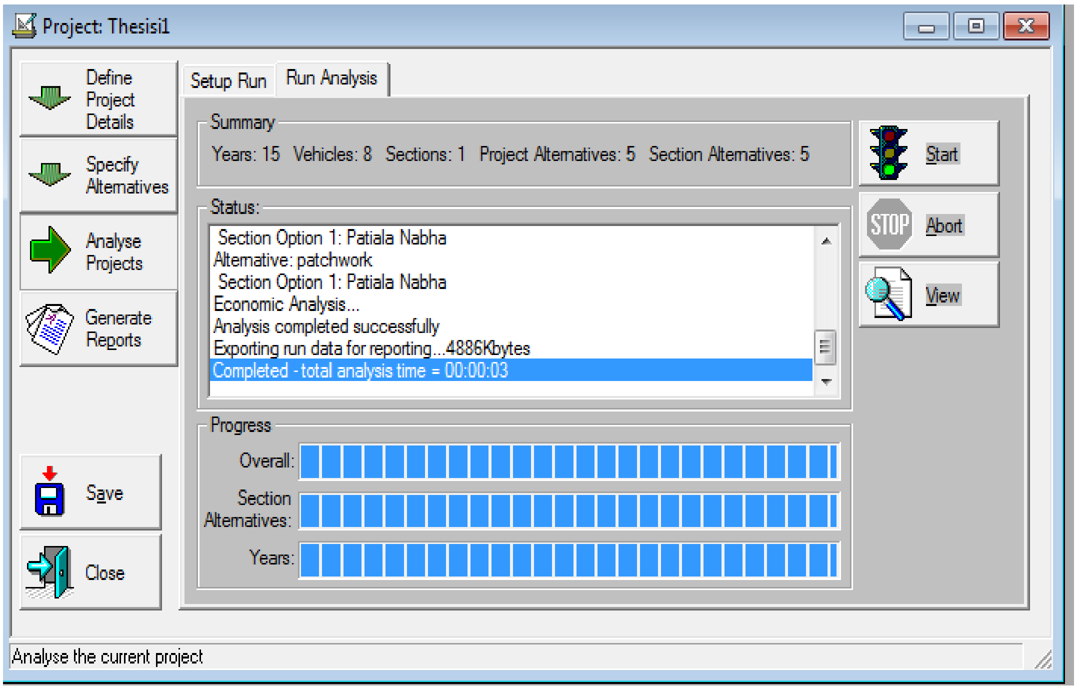

Figure 5.22: Analysis performed by HDM-4

5.3.1 Roughness Progression

The Roughness progresses with each year and change in roughness for various interventions are shown in figures below. The sharp fall in roughness values with all alternatives triggering years are also represented. Figure 5.23 shows the change in roughness value under various maintenance works for level 1 in which patching is implemented seven times. Surface treatment involving 20mm premix carpet and 25mm semi- dense bituminous concrete overlay is done six times. The overlay of 40mm bituminous concrete is implemented four times in the analysis period of 15 years.

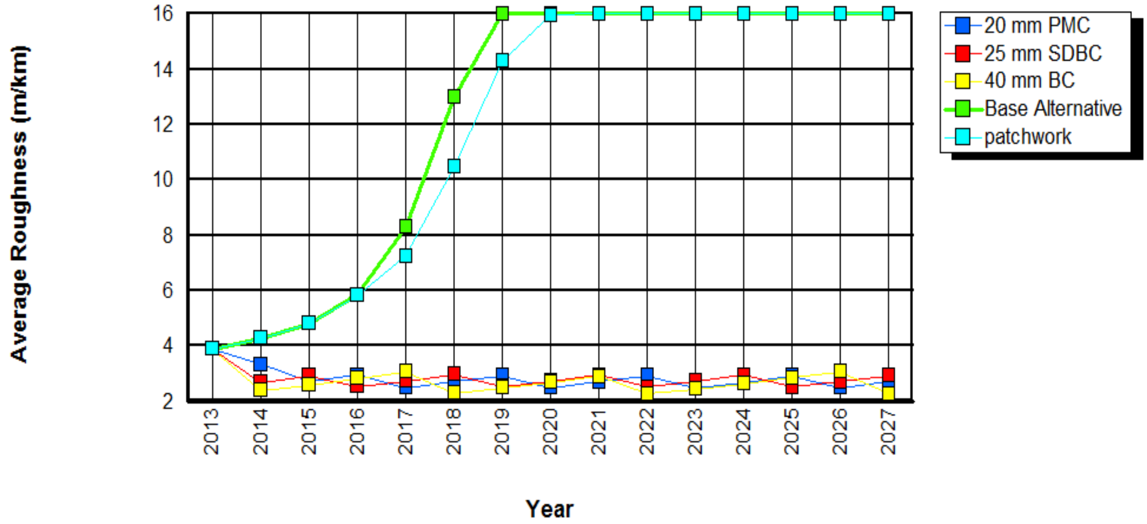

Figure 5.23: Average roughness of carriageway for level 1 of serviceability

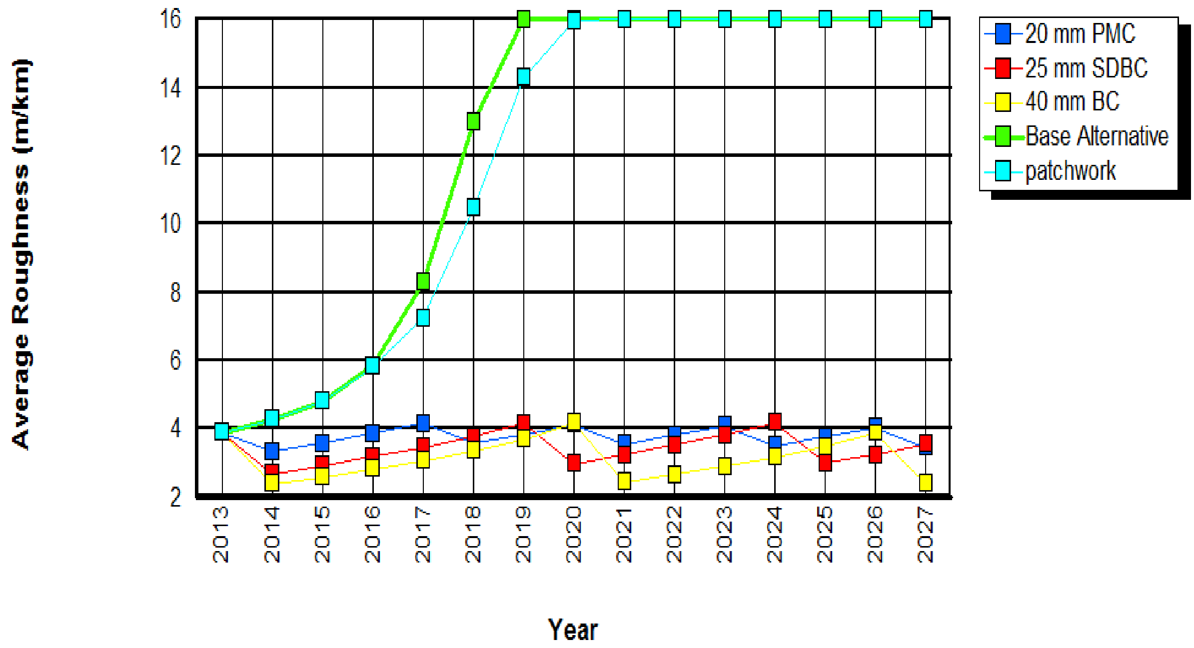

Figure 5.24: Average roughness of carriageway for level 2 of serviceability

Figure 5.24 shows the change in roughness value under various maintenance works for level 2 in which patching is implemented seven times. Surface treatment of 20mm premix carpet overlay is done five times whereas 25mm semi- dense bituminous concrete overlay is done three times. The overlay of 40mm bituminous concrete is implemented thrice number in the analysis period of 15 years.

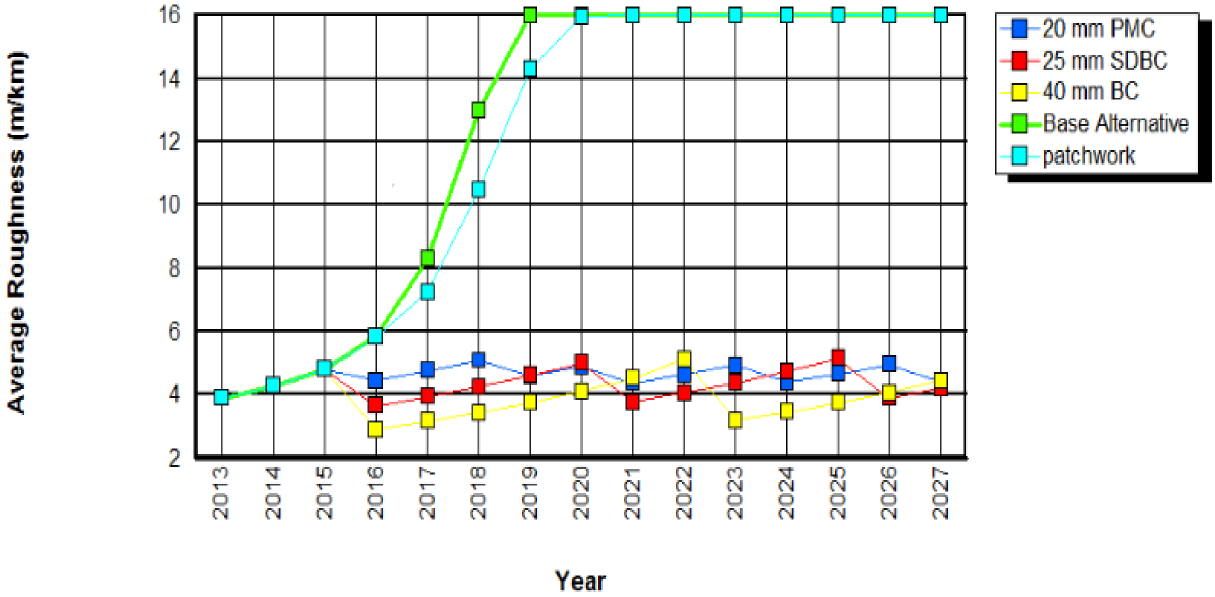

Figure 5.25: Average roughness of carriageway for level 3 serviceability

Figure 5.25 shows the change in roughness value under various maintenance works for level 3 in which patching is implemented seven times. Surface treatment of overlay 20mm premix carpet is done five times whereas 25mm semi- dense bituminous concrete is done three times. The overlay of 40mm bituminous concrete is implemented twice in the analysis period of 15 years.

5.3.2 Cost Analysis

The cost analysis is done for NUR-01 stretch with various levels of serviceability. Cost of the various M&R works has been obtained from the Punjab Urban development Authority (PUDA) as per prevailing market rates. The maintenance alternatives under each strategy and their corresponding costs are given in Table 5.4

Table 5.4: Cost Data for Maintenance and Rehabilitation Works

S.No.	Type of Work	Rate (Rs.)	Unit
1	Patching	109	Sq.m

2	Overlay 20mm Premix Carpet	223	Sq.m
3	Overlay 25mm Semi-Dense Bituminous Concrete	240	Sq.m
4	Overlay of 40mm Bituminous Concrete	370	Sq.m

The cost comparisons of the different maintenance alternatives performed and the number of times they are implemented for the intervention criterion are shown in the Table 5.5 for level 1of serviceability. Table 5.6 shows level 2 of serviceability and Table 5.7 for level 3 of serviceability.

Table 5.5: Cost comparison of maintenance alternatives for Level 1 serviceability

S.NO.	Type of Work	Cost in (Rs)	Number of time Maintenance implemented
1	Patching	1,92,27,600	7
2	Overlay 20mm Premix Carpet	3,37,17,600	6
3	Overlay 25mm Semi-Dense Bituminous Concrete	3,62,88,000	6
4	Overlay of 40mm Bituminous Concrete	3,72,96,000	4

Table 5.6: Cost comparison of maintenance alternatives for Level 2 serviceability

S.NO.	Type of Work	Cost in (Rs)	Number of time Maintenance implemented
1	Patching	1,92,27,600	7
2	Overlay 20mm Premix Carpet	2,80,98,000	5
3	Overlay 25mm Semi-Dense Bituminous Concrete	1,81,44,000	3
4	Overlay of 40mm Bituminous Concrete	2,79,72,000	3

Table 5.7: Cost comparison of maintenance alternatives for Level 3 serviceability

S.NO.	Type of Work	Cost in (Rs.)	Number of time Maintenance implemented
1	Patching	1,92,27,600	7
2	Overlay 20mm Premix Carpet	2,80,98,000	5
3	Overlay 25mm Semi-Dense Bituminous Concrete	1,81,44,000	3
4	Overlay of 40mm Bituminous Concrete	1,86,48,000	2

5.3.3 Summary of Cost Analysis

The routine maintenance patching is provided to the road network for all levels of serviceability and its cost comes out to be same for all serviceability levels as it is scheduled after every two years. Tables 5.5-5.7 suggest that the 20mm Premix Carpet cost is higher for level 1 serviceability as compared to other two levels whose costs are same. It is also observed that the surface treatment of 25mm Semi-Dense Bituminous Concrete cost is expensive for level 1 of serviceability as compared to the other two levels whose cost comes out to be same. The overlay of 40mm Bituminous Concrete is cheaper for level 3 serviceability followed by level 2 and level 1 serviceability respectively. Table 5.8 shows the consolidated comparison of all maintenance alternatives as discussed in Tables 5.5-5.7.

Table 5.8: Summary of Cost Analysis

Serviceability Levels	Maintenance and Rehabilitation Works Cost in (Rs.)			
	Patching	20mm PMC	25mm SDBC	40mm BC
1	1,92,27,600	3,37,17,600	3,62,88,000	3,72,96,000
2	1,92,27,600	2,80,98,000	1,81,44,000	2,79,72,000
3	1,92,27,600	2,80,98,000	1,81,44,000	1,86,48,000

5.4 Comparative Study of Scheduled and Condition Responsive type Maintenance & Rehabilitation Strategy

The objective of the study is to compare Scheduled and Condition Responsive type Maintenance and Rehabilitation strategy for the section Dukhniwaran Sahib Gurudwara to Nabha Road i.e. (NUR-1). Nowadays, HDM-4 is considered as the supreme driver for economical assessment of capital investment in various road projects.

5.4.1 Input Data

The road consists of Asphalt Mix on Asphalt Pavement type and is a Major District Road. The network has carriageway width of 10.5 m, shoulder width of 1 m, category of road is secondary and climate zone is subtropical. It has inter-urban traffic flow and last treatment year being 2014. The traffic volume stated is high with motorized and non-motorized traffic of 16904 and 3924 Annual Average Daily Traffic (AADT) respectively in year 2010.(PUDA)

Table 5.9 represents functional and structural evaluation data for models:

Table 5.9: Functional and Structural Evaluation

Section I.D.	Condition Year	IRI (m/km)	B.B.D. (mm)	SNP
NUR-1	2012	3.7	1.30	2.71

The calibration factor for the roughness is equal to 1.52 for the road network when SNP ranges from 2.50- 5.4. It can be observed from Table 5.9 that SNP is 2.71 for this case study, thus calibration factors provided by Shah et al. (2016) have been considered in the study. They are of great importance for validation of conditions in order to increase the precision of the model.

5.4.2 Proposed Maintenance and Rehabilitation Alternatives

The present two types of input used are as follows:

1. Scheduled Maintenance: In this policy the pavement maintenance is based upon by bounding the maintenance alternatives to a particular period without analysing its economic effects. The shortcoming of this policy is that road carrying high traffic deteriorates beforehand and the renewal lies outside the maintenance cycle. This, adds up to increased vulnerability in the road network.

2. Responsive Maintenance: In this policy the pavement maintenance is based upon the criteria of widely accepted performance indicators such as roughness, cracks, rutting, skid resistance, potholes, etc.
3. The suggested intervention levels for the urban roads are stated below in the Table 5.10 as given by Indian Road Congress(MORT&H 2004):

Table 5.10: Intervention Levels for Urban Roads

S.No.	Serviceability Indicator	Level 1	Level 2	Level 3
1	Roughness (measured by Bump Integrator)	3 m/km	4 m/km	5 m/km

The details of the alternatives with their intervention criteria are given in Table 5.11 below:

Table 5.11: Interventions Criteria's for the alternatives

S.No.	M & R Alternatives	M&R Work	Intervention Criteria	
			Scheduled	Condition
1	No maintenance	No work is done		
2	Routine Maintenance	Patching	Scheduled Annually	After 2 years
		Side Drain Cleaning		Scheduled Annually
3	Thin Overlay	Overlay 25 mm Semi dense Bituminous Concrete	Scheduled Every 3 years	Roughness > 4m/km IRI
4	Thick Overlay	Overlay 40 mm Bituminous Concrete	Scheduled Every 6 years	Roughness > 4m/km IRI
5	Strengthening And Rehabilitation	50 mm DBM + 40 mm BC	Scheduled Every 8 years	Roughness > 4m/km IRI

The pavement condition of the sections has been considered under the four defined M&R alternatives for an analysis period of 15 years. The progressions of roughness for the analysis under the three alternatives for the scheduled and responsive intervention criterion are shown in Figures 5.26, 5.27, 5.28 respectively.

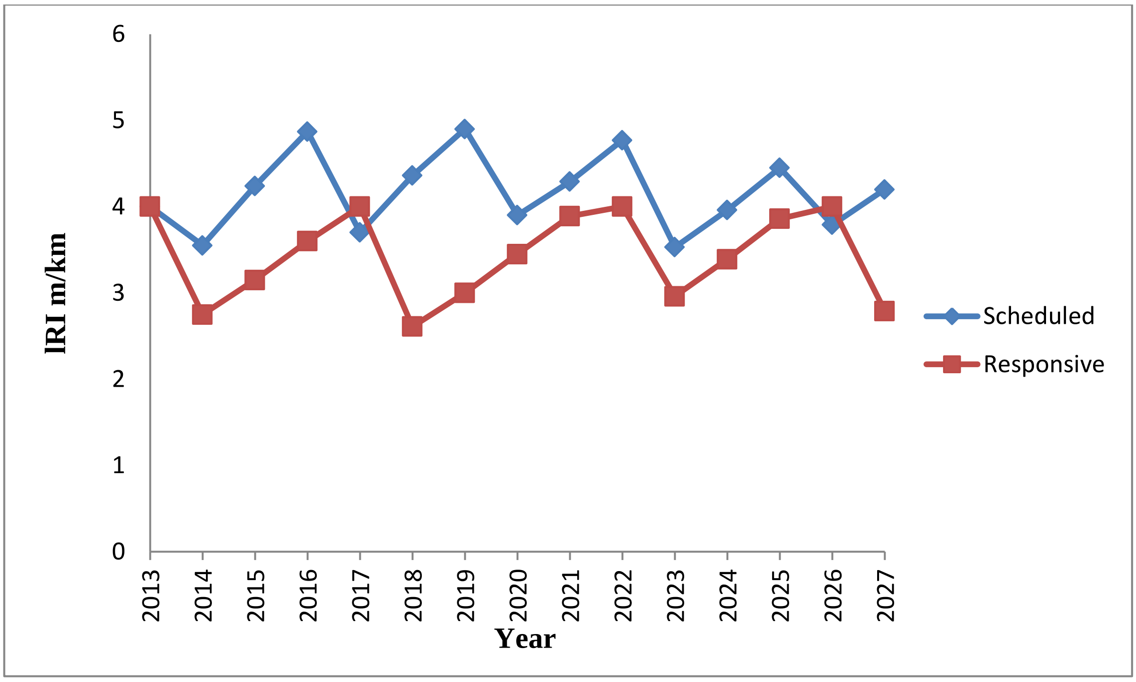

Figure 5.26: Comparison of roughness progression for thin overlay

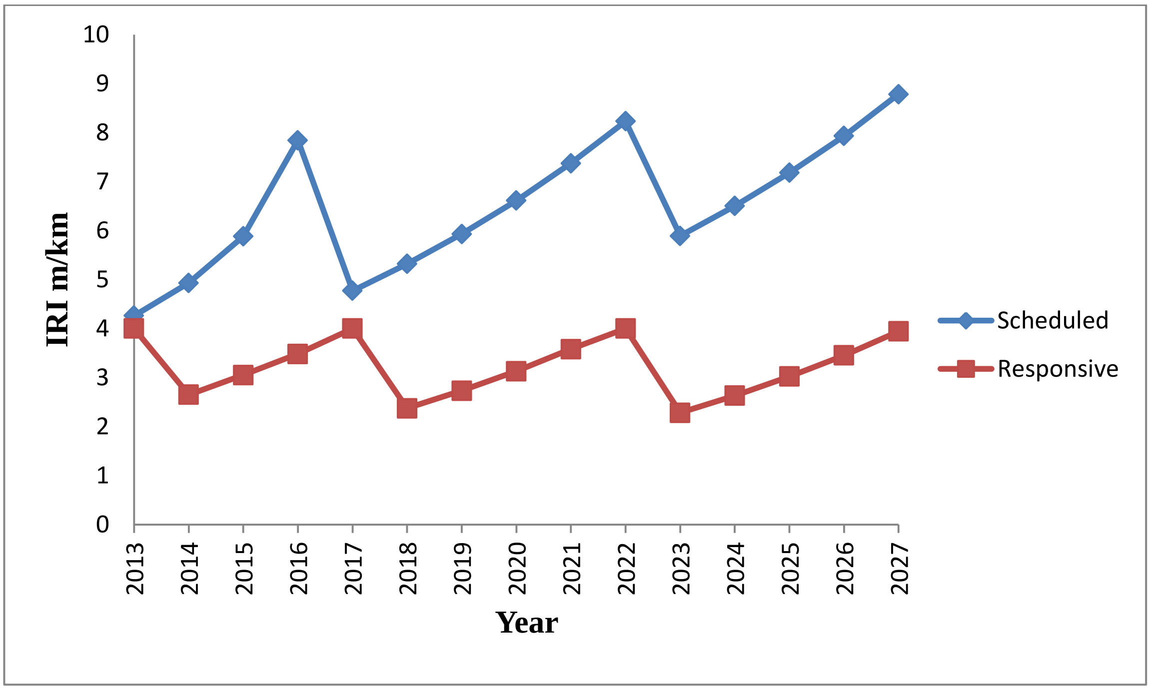

Figure 5.27: Comparison of roughness progression for thick overlay

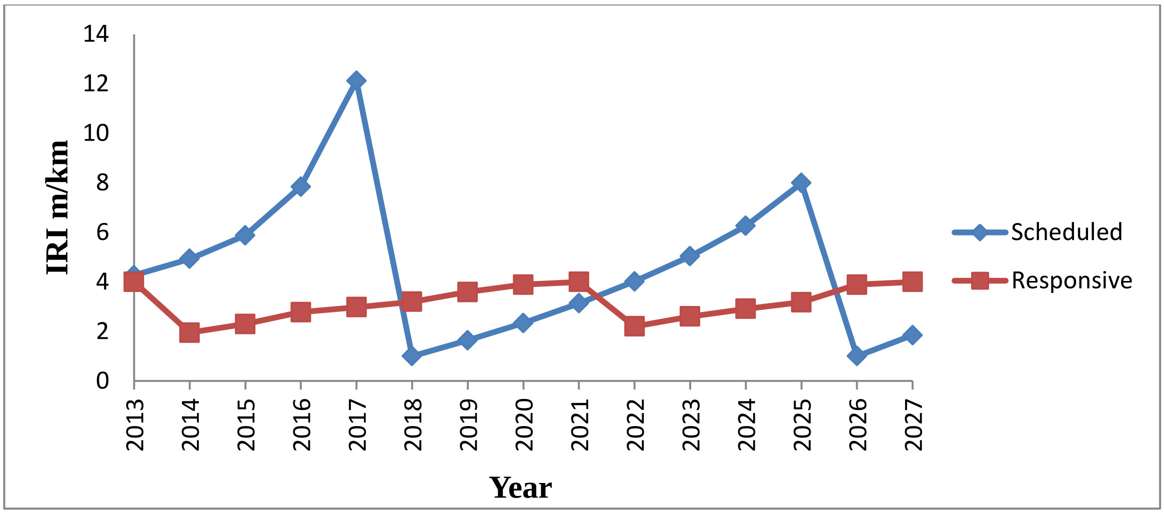

Figure 5.28: Comparison of roughness progression for strengthening & rehabilitation

On comparing the roughness progression for different M&R alternatives following observations have been made:

- From Figure 5.26 it can be observed that for condition responsive alternative, overlay is triggered in years 2013, 2017, 2022 and 2026 as soon as roughness reaches IRI = 4m/km, but for scheduled alternative the overlay is triggered after every three years with variation of IRI = 4 to 4.87 m/km which is above the limiting values. These alternatives are triggered in years 2013, 2016, 2019, 2022 and 2025.
- From the Figure 5.27 it can be observed that condition responsive alternative is triggered thrice in years 2013, 2017 and 2022 as soon as roughness reaches to IRI = 4 m/km, but for scheduled alternative the overlay is triggered twice in 2016 and 2022 as it’s for 6 years period. However, the schedule treatment is not able to maintain the level 2 condition of the road network as the roughness exceeds 4m/km.
- From the Figure 5.28 it can be observed that condition responsive alternative is triggered in years 2013 and 2021 as soon as roughness reaches the IRI = 4 m/km, but in case of scheduled strengthening it is triggered after eight years in year 2018 and 2026 leading to an increase the value of roughness nearly to IRI = 12 m/km which is unacceptable for the urban road network.

It clearly shows that scheduled maintenance is not able to limit roughness value and leads to low ride quality of the road network whereas condition responsive alternatives are maintaining road quality to the accepted level of serviceability as the intervention criteria is 4 m/ km (Level 2).

CHAPTER 6

VALIDATION OF INDIAN PAVEMENT DETRIORATION MODELS

6.1 Introduction

The data was collected for the five roads of Patiala city from the data bank created by Prof. Tanuj Chopra Thapar University, Patiala. The data was used in the prediction models developed by Central Road Research Institute (CRRI) for prediction of distress and the predicted distresses values are compared with the experimental values.

6.2 Data Collection

The incremental distress for Indian deterioration models has been fixed at one year with annual growth rate of traffic is 5.5% assumed uniformly. The Modified Structural Number ranges from 4.28 to 6.2. The time lapse factor (TLF) has been assumed to one, considering the facts that distress are not patched within a year of their occurrence. The carriageway width was in range of 6 to 7m and traffic ranges from 0.6 to 1.2 million standard axles. The ravelled area shows variation within range of 4% to 18% and cracking area range from 1.5% to 6.2% for five roads. The roughness shows variation range from 1.5 m/km to 3.85 m/km and pavement age range 5 to 9 years along with an environmental factor value of 0.04.

6.3 Equations of Indian Models

The equations of Indian Models for various distresses are as follows:

1. Cracking Progression

$$\frac{\Delta CR_t}{t_i} = 4.26 \times \frac{(CSALYR)^{0.65}}{(MSN)^{0.65}} \times SCR_i{}^{0.32}$$

2. Ravelling Progression

$$\frac{\Delta RV_t}{t_i} = 3.94 \times AXLEYR^{0.32} \times SRV_i{}^{0.46}$$

3. Roughness Progression

$$\Delta RG_t = [34856\left(\frac{\Delta CSAL}{SNCK^5}\right) \times EXP(m\ PAGE) + [7.43\ \Delta CR_t] + [190.57\ \Delta PH_t] + [22.34\ \Delta PT_t] + [m\ RG_i \times t_i]$$

Where,

VDF = vehicle damage factor

PAGE = pavement age since last renewal / strengthening (years)

CR_i = initial cracking area (%)

RV_i = initial ravelling area (%)

PH_i = initial pothole area (%)

ΔCR_t = present change in cracked area over time *t* in years

ΔRV_t = present change in ravelled area over time *t* in years

ΔPH_t = present change in pothole area over time *t* in years

ΔPT_t = present change in patched area over time *t* in years

ΔRG_t = change in roughness over time *t* in years (mm/km)

SCR_i = minimum $\{CR_{i,}\ (100- CR_i)\}$

SRV_i = minimum $\{RV_{i,}\ (100- RV_i)\}$

CSALYR = cumulative standard axles per year (msa)

AXLEYR = number of vehicles axle per year (millions)

ΔCSAL = change in cumulative standard axles (msa) over time *t* in years

SNCK = modified pavement strength = (1+MSNR)

MSNR = reduced modified structural number due to cracking

m = environmental factor

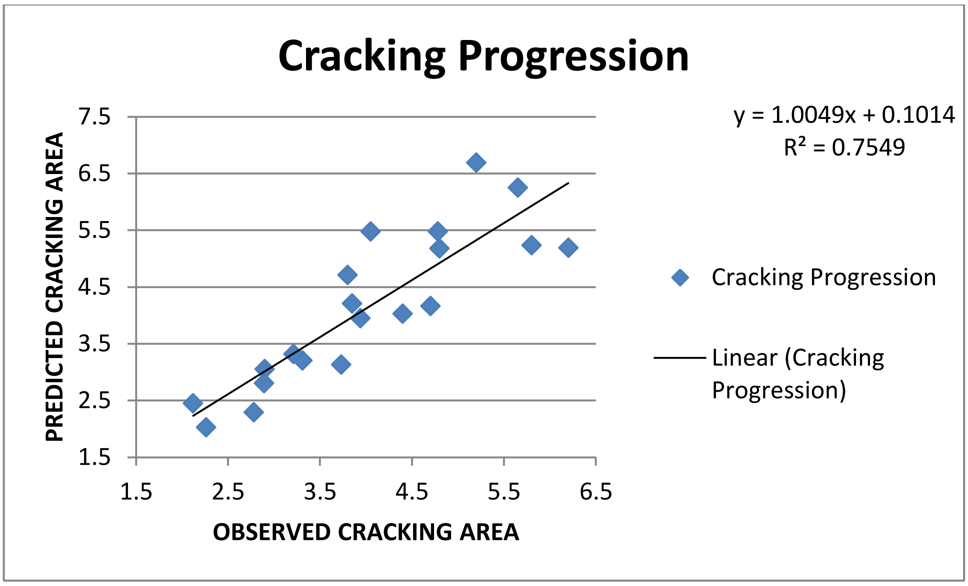

Figure 6.1: Observed versus predicted cracking (percent area)

The linear regression relationship between the observed and predicted value of cracking has been developed by plotting the scatter plots as presented in Figure 6.1 with coefficient of determination R^2 as 0.7549. The percentage variability between observed and predicted cracking values ranges between 1.02 and 28.84 %.The plot being good proves the adequacy of the cracking progression model.

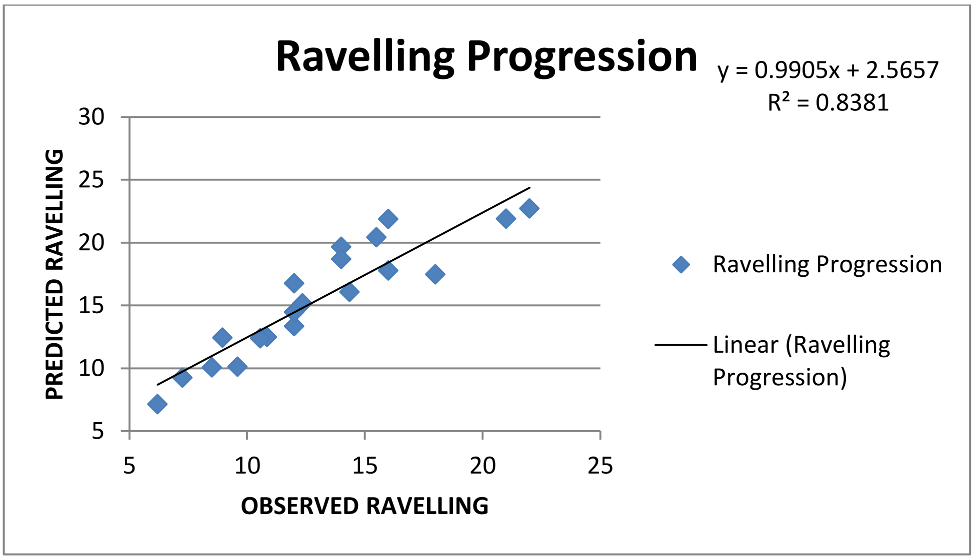

Figure 6.2: Observed versus predicted ravelling (percent area)

The linear regression relationship between the observed and predicted value of ravelling has been developed by plotting the scatter plots as presented in Figure 6.2 with coefficient of determination R^2 as 0.8381. The percentage variability between observed and predicted ravelling values ranges between 15.16 and 40 %. The plot being good proves the adequacy of the ravelling progression model.

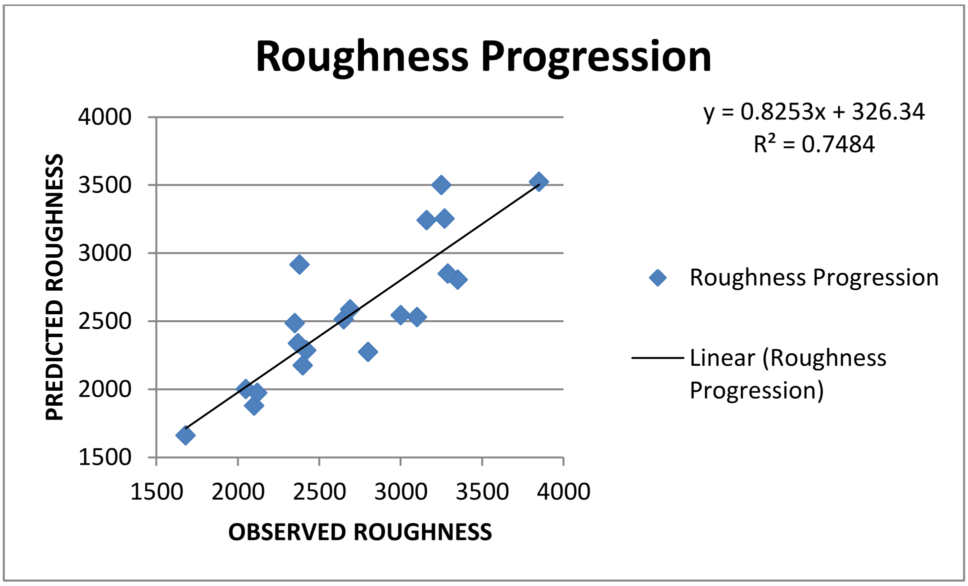

Figure 6.3: Observed versus predicted roughness (m/km IRI)

The linear regression relationship between the observed and predicted value of roughness has been developed by plotting the scatter plots as presented in Figure 6.3 with coefficient of determination R^2 as 0.7484.The percentage variability between observed and predicted roughness values ranges between 1.2 and 9.2 %. This proves the adequacy of the roughness progression model.

Thus, it is observed that data of the five roads are validated with help of equations which come out to be reliable for the deciding the models of deterioration along with the maintenance strategies within a limited budget.

CHAPTER 7

CONCLUSIONS

7.1 Major Findings

The following are the major conclusions of this research study:

1. The functional and structural evaluations of three road sections of Patiala city have been conducted effectively. The internationally recognized HDM-4 model is used for development of Pavement Maintenance Management System (PMMS) for the selected road networks.
2. Remaining Serviceable Life of selected sections of Patiala city has been carried out in HDM-4 software. This depicts reconstruction is required after 6 years for Rajendra road (PR-01), Sectarian road (PR-02) and after 2 years for Tripuri road PR-03. These values give advantage to road agency for budgeting and funding beforehand.
3. Prioritization of the road sections for maintenance works has been successfully done for all the road sections by Urban Road Maintenance Priority index. In case of constrained budget, maintenance of road sections could be done based on prioritization ranking of road sections. First preference will be given to PR-01 with URMP Index of 114.48, second to PR-03 with URMPI 91.5 and last preference will be given to PR-02 with URMPI 63.525 for maintenance work.
4. Cost analysis is conducted for Major District Road Dukhniwaran Sahib Gurudwara to Nabha (NUR-1) with different intervention criteria's along with various level of serviceability. The 20mm Premix Carpet cost is higher for level 1 of serviceability as compared to other two levels of serviceability whose cost comes out to be same. The surface treatment of 25mm Semi-Dense Bituminous Concrete cost is expensive for level 1 of serviceability as compared to the other two levels of serviceability whose cost comes out to be same. The overlay of 40mm Bituminous Concrete is cheaper for level 3 of serviceability followed by level 2 of serviceability and level 1 of serviceability.
5. Comparative study of scheduled type and condition responsive type maintenance strategies has been carried out for Dukhniwaran Sahib Gurudwara to Nabha (NUR-1). The scheduled maintenance is not able to limit roughness value and leads to low ride quality of the road network whereas responsive alternatives are maintaining road quality to the accepted level of serviceability as the intervention criteria is 4 m/ km (Level 2). The road agency will have to spend more than that of condition responsive maintenance

strategy due to higher rate of occurrence in scheduled maintenance strategy. Condition responsive maintenance strategy is hence chosen as effective maintenance strategy.

6. The Indian pavement deterioration models developed by CRRI were validated by comparing the predicted and observed values for the selected pavement sections. The R^2 values obtained for cracking progression (0.7549), ravelling area progression (0.8381) and roughness progression (0.7484) models show good adequacy between observed and predicted values. These pavement deterioration models can be used for prediction of distresses and for development of the maintenance management strategies for the selected urban road networks.

7.2 Scope for Future Work

1. Data set can be increased by taking progressive time series data for at least 5years so that HDM-4 models of pavement deterioration can be calibrated to a maximum of level 3.
2. The deterioration models of pavement distresses can be prepared with the help of Genetic Algorithm and Programming for the local site condition

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