Development of Pavement Maintenance and Management System (PMMS) for Local Streets of Patiala City Using HDM-4

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Submitted by

SAHIL KUKREJA

Roll No. 801723019

Under the Supervision of

Dr. Tanuj Chopra

Assistant Professor

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY

(A DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB

(July - 2019)

DECLARATION

I, Sahil Kukreja, hereby declare that the work prepared in thesis entitled "Development of Pavement Maintenance and Management System (PMMS) for Local Streets of Patiala City Using HDM-4" in fulfilment of the requirement for the award of degree of Master of Engineering in Infrastructure Engineering in the Civil Engineering Department, Thapar Institute of Engineering and Technology, Patiala is an authentic work carried out under supervision of **Dr. Tanuj Chopra,** Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala during January 2019 to July, 2019. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any degree.

Sahil

Date : 15/07/2019 **Sahil Kukreja**

Place : Patiala **Roll No. 801723019**

CERTIFICATE

It is certified that the above statement made by the student is correct to the best of my own knowledge and belief.

15/7/19

TANUJ CHOPRA
Assistant Professor
CED, TIET, Patiala

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SAHIL KUKREJA

(801723019)

ABSTRACT

The primary objective of this study is to develop Pavement Management and Maintenance System (PMMS) for local streets of Patiala city by using HDM-4 software. 10 road sections were selected for the study after performing traffic survey it was observed that 7 of those roads were having traffic volume less than 6000 AADT and rest of the sections were categorized as medium volume roads with AADT less than 10000. Calibration of HDM-4 deterioration models was also performed in this study and model validation results were found satisfactory with roughness model having R^2 of 0.82 and RMSE of 0.29. Road inventory data was collected and pavement condition was assessed using non-destructive testing, visual inspection and Bump Integrator and data inventory was created in HDM-4. Remaining Service Life (RSL) of all road sections was determined showing that road sections are in good conditions. Optimum maintenance and rehabilitation (M&R) activity was assigned to each road section after performing economic analysis of all proposed M&R alternatives, Net Present Value (NPV) to Cost ratio was used for this purpose as well as for prioritizing road section M&R activities. It was seen that road section 'OC' had maximum NPV to cost ratio and section 'TR' had the least. PMMS created in this study can be applied in practical to utilise the available funds efficiently and effectively benefiting the people and the authorities. The methodology used can be applied to other roads to create their own PMMS and to create a HDM-4 data base to store road and vehicle data

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ABBREVIATION

AADT - Annual Average Daily Traffic

BBD - Benkelman Beam Deflectometer

BI - Bump Integrator

BM - Bituminous Macadam

GDP - Gross Domestic Production

HDM-4 - Highway Development and Management Tool

IRI - International Rougness Index

LOS - Level of Service

LWD - Light Weight Deflectometer

NDT - Non-Destuctive Testing

NPV - Net Present Value

PC - Premix Carpet

PMMS - Pavement Management and Maintenance System

RSL - Remaining Service Life

SBSD - Single Bituminous Surface Dressing

VOC - Vehicle Operating Cost

WBM - Water Bound Macadam

CHAPTER 1

INTRODUCTION

1.1 General

Transportation is lifeline of a country and for its economy, and out of different types of transport, road transport is of utmost importance as all other modes of transport are linked by roads only. Indian road network is second largest network in world with 5,903,293 Km of road, moreover road transport is very important for Indian economy, in 2009-2010 road transport shared 4.7 percent of India's GDP.

Project Maintenance and Management System (PMMS) is a scientific tool developed to manage road network and use all resources effectively, which will benefit the country and its people. This study focus on low volume urban roads which lies under the authority of 'Municipal Commission' and are given low priority than other roads, therefore the funds required for their maintenance are low and a proper management system should be developed to use those resources effectively.

1.2 Classification of urban roads

Classification of roads can be done on basis of construction, location and their purpose, traffic volume, width, etc. For this study we will concentrate on low volume urban roads, government department responsible for construction and maintenance of these roads is Municipal Corporation and other local bodies which are active in those areas. Urban roads can be classified as follows:

1.2.1 Arterial Roads

These roads carry high volume of traffic as compared to other urban roads as these roads are directly connected to national highways and state highways. These roads are situated at city limits and connect collector roads to freeways. As these roads are high volume roads they are kept straight without any sharp curves and high level of service is to be maintained. These roads have a design speed of 80 Km/hour.

1.2.2 Sub-Arterial Roads

These are roads act as a link between arterial roads and city roads, these roads run with-in the city and connect places inside city limits. These roads are 2 to 3km long and are designed for slow moving traffic. Design speed of 60 Km/hour is adopted for these roads.

1.2.3 Collector roads

These roads are situated in residential and factory areas of the city. These roads collect traffic from local streets and other small roads. They are also constructed to access arterial and sub-arterial roads. These roads are further divided into 2 parts major and minor, where major roads are wider and can handle more traffic than minor. Design speed is taken as 50 Km/hour.

1.2.4 Local Streets

These are the city roads used to approach residential and commercial places. Parking is unrestricted and pedestrians use these roads feely. No through traffic is permitted on these roads so they are not linked with arterial roads. As these roads are small with sharp turns design speed is low and is taken as 30 Km/hour.

The roads in this study fall under the category of Local Streets with traffic volume of low to medium values.

1.3 Condition of Urban Roads in City

Urban roads in Patiala city falls under the jurisdiction of Municipal Commission (MC) and Public Works Department (PWD), the local streets the present topic of our study is under the control of MC and during the study observations made about local street are discussed below

- There are no records maintained for the work done on these roads, only the details of latest rehabilitation work done on these roads was readily available. If the records are maintained, the files are buried in store rooms which are nearly impossible to get hands on.
- While gathering information about pavement design and thickness, the MC officials responded by saying as these roads are low volume roads and commercial vehicles on these sections are near to none, that’s why no design is performed and prescribed practice is followed and 150mm WBM is provided in 2 layers of 75mm along with 40 to 50mm of bituminous layer along with a wearing coat.
- The deterioration of road occurred not only due to traffic or climatic condition but due to external reasons like manhole uplift, construction practices by local residents, interference of other government departs like sewage works, water supply etc.
- Maintenance and Rehabilitation of these roads strictly dependent on funds availability, no proper management system was developed and greatly dependent on politics for funds.

1.4 Pavement Evaluation

To create a proper pavement management system we need to perform structural evaluation of pavement. Non-destructive testing (NDT) of pavement is being popularly used to evaluate structural performance of roads. To find out the remaining service life of pavement back calculation is done using results of NDT, using layer thickness and deflection bowl obtained from NDT we can find elastic moduli and predict remaining life of pavement by forecasting future traffic.

FWD and Benkelman Beam are examples of non-destructive tests which provide us with deflection values of pavement. In this study Dynatest LWD 3031 was used to find deflection values of roads which are being used in this literature. Methodology for all the evaluation techniques is discussed in further chapters.

1.5 Objective of the Study

The aim of this study is to create a PMMS for low volume urban roads for Patiala city using HDM-4. To accomplish that following objectives are plotted:

1. To study about PMMS and HDM-4 and developing procedure for data collection as well as creating a database to store all pavement information.
2. Perform functional and structural evaluation of roads to find the level of service provided by them.
3. Study and calibration of HDM-4 models and use them to determine the Remaining Service Life (RSL) of roads under study.
4. To establish optimum M&R strategies for low volume roads by performing economic analysis in HDM-4 and ranking road sections on the basis of M&R strategy.

1.6 Thesis Composition

The objectives given in previous section are discussed in detailed in upcoming chapters in this thesis.

First chapter provides the overview and aim of the study and defines the sections under the study, present scenario of those roads are also discussed

Second chapter give the detailed overview of PMMS and HDM-4 software and there importance in today’s world.

Third chapter is the review of literature and studies done in earlier years related of present objectives directly or indirectly.

Fourth chapter contains the methodology of collecting data, which is required by HDM-4 for creating a data base and analysis.

Fifth chapter is the calibration of HDM-4 models and there results along with analysis of road sections under study using those models.

CHAPTER 2

DETAILED OVERVIEW OF PMMS & HDM-4

2.1 Introduction to PMMS

A tool which can be used by authorities or pavement designers to maintain and protect road assets in a strategical way so that resources available can be used effectively, which can prolong the life of that road network.

With the help of PMMS we can see the results of different activities even before they are applied in a project, and accordingly choose the most suitable approach. We can use PMMS to keep a road network in a particular condition to provide a certain level of service by performing life cycle analysis and find a right time to execute different rehabilitation works on that pavement.

PMMS is not a last step in a project, but a tool to assist engineers, rehabilitation managers, and fund regulators to perform their duties in a more effective way. No program can overrule experience but it can help to make better decisions.

2.2 Benefits of PMMS

A good PMMS have many benefits that experience alone cannot provide. The present pavement will deteriorate with passage of time, due to traffic loading and environmental factors, therefore we require a system or tool which can help us plan activities to keep the road network in a optimum condition.

Figure 2.1 below illustrates how a PMMS can help an organisation to use its resources efficiently, the curve in figure below, represents deterioration of a road and two nodes on the curve show trigger points ‘treatment 1’ and ‘treatment 2’. The treatment 1 is for maintenance activity and treatment 2 is for reconstruction of pavement. If the user have a good management system, the node ‘N1’ will be triggered and maintenance activity will be performed in years A & B at cost X, and if PMMS is not used node ‘N2’ that is reconstruction of road will be opted which will cost Y which is nearly 10 times more as compared to X, that is Y = 10X.

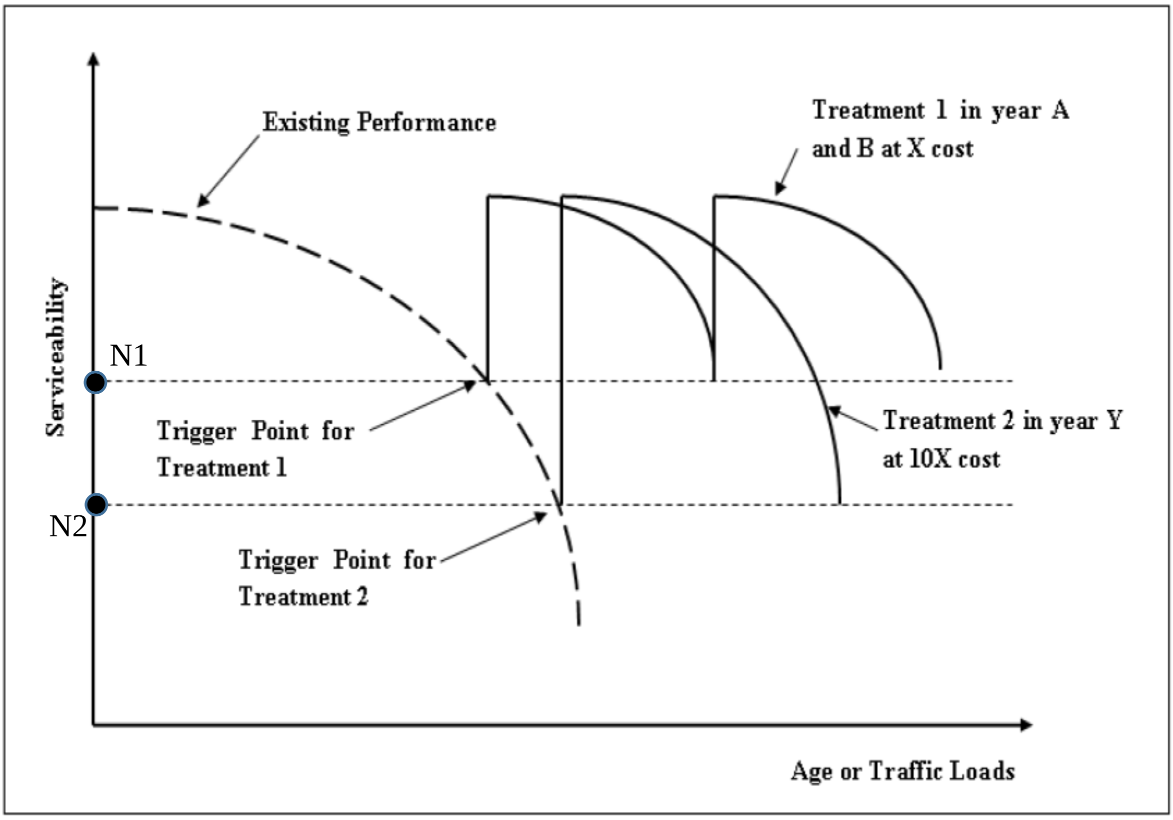


Figure 2.1: Importance of PMMS (T.Chopra et al. 2017)

A PMMS can :

- Maintain records and give us access to information like pavement type, traffic volume, location, paved area, history of maintenance work, road condition data, construction information etc.
- Provide us with present condition of road network according to engineering point of view, which can be used to obtain relative information about pavement.
- Provide us with maintenance strategy and there cost by speculating condition of project over time, and desired level of service of pavement can be maintained.
- Estimate budget for keeping a road at a desired LOS for a defined period of time.
- Help us priorities different activities over others to keep a project in best shape possible when the budget is limited.
- Act as a bridge between department of design, construction, management and planning & maintenance within an organisation.
- Also link different agencies or government bodies involved in a project.
- Provide us with number of options and activities which can be inspected by user or an organisation for final project.

A PMMS will not:

- Give us all the answers.
- Take place of a maintenance activity.
- Define work culture in an organisation.
- “All or nothing” and do not provide us with all the options.
- Substitute engineering experience and evaluation in a project
- Make final decisions.

2.3 Components of PMMS

There are two components of PMMS:

- An archive to save, manage and gather information and data about project like pavement condition, traffic data, rehabilitation, construction, etc.
- Data processing and analysing unit which help in decision making by processing input data like road condition, budget, pavement performance, etc.

2.4 Introduction to HDM-4

Highway Development and Management tool (HDM-4) was created by World Bank by improving Highway Design and Maintenance Standards Model (HDM-III) by performing International Study of Highway Development and Management (ISOHDM). This resulted in creation of a powerful tool for analysis of highway project and investment alternatives.

The objective of HDM-4 is to effectively use all the resources and funds in a highway project by performing scientific and engineering analysis and give the user different ideas and alternatives to properly utilise the budget.

2.5 Role of HDM-4 in Highway Projects

2.5.1 Highway Management

HDM-4 performs all the following functions that are the part of highway management process:

- Planning
- Programming
- Preparation
- Operation

2.5.2 Analytic Framework

It is based on life cycle analysis concept of pavement and is used to predict following parameter over the life cycle of road:

- Road distresses
- Road work effect
- Road user effect
- Socio-economic and environmental effect

After construction of pavement road deterioration takes place due to traffic, climatic condition and poor drainage. The treatment given to pavement distresses have a direct effect on pavement deterioration, moreover life of pavement can be prolonged by giving proper treatment.

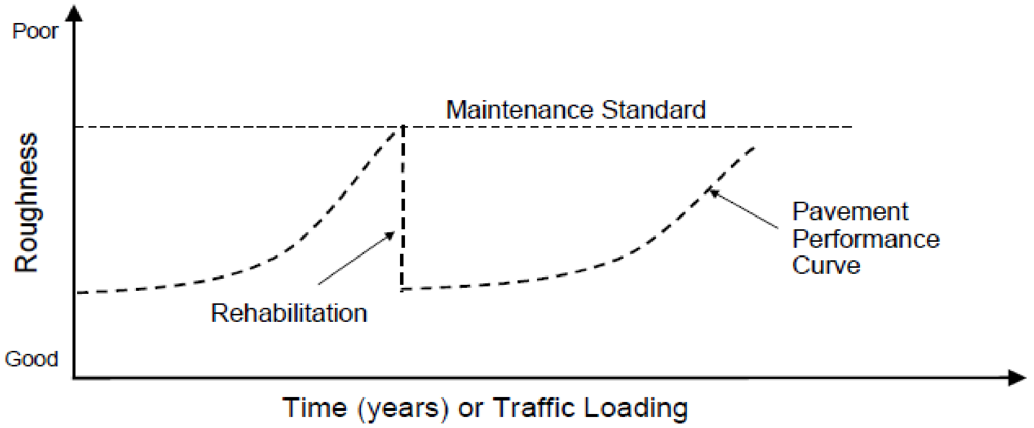


Figure 2.2 : Concept of Life Cycle Analysis in HDM-4 (Kerali et al., 2000)

Road user cost is calculated using various factors that are vehicle operation cost, travel time cost and damage done by accident. All these factors greatly depend on the condition of road, a well maintained road network can decrease road user cost (figure 2.3) and provide safe environment for users.

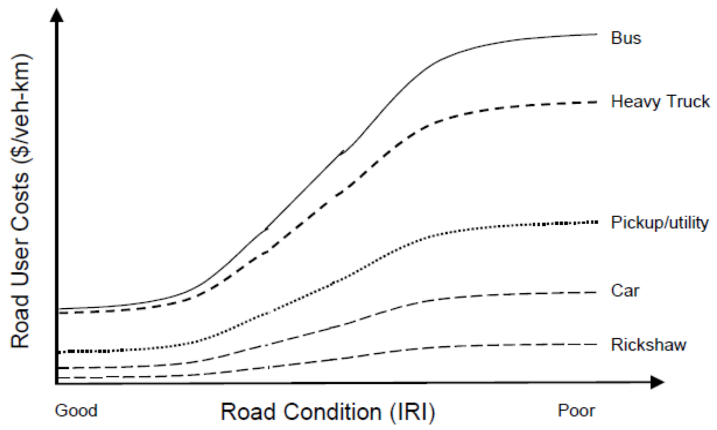


Figure 2.3 : VOC affected by Road Condition (Kerali et al., 2000)

2.6 HDM-4 Applications

2.6.1 Strategy Analysis

This tool help to manage an entire road network or sub-network, for this HDM-4 uses rules of road network matrix comprising types of road network represented according to the key attribute which affect road user cost and performance of that network. Analysis of a full length road is preferred over analysing the same in sections due to the hectic work involved in performing the later procedure. The engineer can define the major factor affecting transport cost in a road network matrix. The forecasted data can be used by planner to prepare budget for road development and conservation.

2.6.2 Programme Analysis

After fixing budget this tool comes in play to rank road sections or projects from a list of road projects or one year or multi-year work programme, all these road projects are parts of a road network. Ranking of these road sections is done on the basis of work standards fixed by the user.

After grading the road sections the application analysis of HDM-4 can be used to compare life cycle cost of present management system to that of different pavement improvement alternative and periodic maintenance which is used to find economic benefit by adding project to budget timeframe.

2.6.3 Project Analysis

Project analysis a road project is used to check feasibility of road project through financially and engineering point of view. The problems that were taken into consideration while analysing the project were structural performance of road, financial comparison of alternatives, road user cost and life-cycle prediction of road deterioration and road work effect. (Henery G.R. Kerali, 2000)

2.7 Data Input Requirements

In this part we have a overview of information required by HDM-4 and it models which are discussed above to work effectively and perform to the fullest. In-depth discussion of this topic will be done in further chapter.

2.7.1 Configuration of HDM-4

Hdm-4 is a tool designed to use all over the world and each place has its unique topography and climatic conditions, therefore all the models and tool in HDM-4 can be adjusted as per requirement. HDM-4 should be used as an extra helping hand for existing management plans, data can be exported and imported from HDM-4 and can be used in various other tools by an organisation.

2.7.2 Road Network

In this user can store data related to roads section under work or project. User can define different road networks and sub-network, in HDM-4 while adding a road network we need to provide 'section name', 'Section ID', 'Link Name', 'Link ID', type of traffic flow, number of lanes, road width, shoulder width, length of section, type of road (urban, rural, etc.), pavement type (flexible or rigid), Geometry of Road, traffic on that section, history of work on that road and deterioration (cracking, ravelling, rutting etc.) data of that network.

2.7.3 Vehicle Fleet

This module in HDM-4 is used to store data regarding vehicles which help in estimating economic factors related to vehicles affected by road conditions, like operating cost, travel cost, etc. there is no limit on the number of vehicles that can be added, both motorised and non motorised vehicles are included in HDM-4 and user can also have an option to create the vehicle type and its specifications, also the cost can be specified for every vehicle.

2.7.4 Road Works

The user working on road project wants that the pavement should provide some certain level of service, which can be achieved by defining road works standards and type of maintenance activities to be performed on that road network. The road work module is used to define those maintenance works and there standards which can be used by any analysis tool (Project analysis, programme analysis and strategy analysis) in HDM-4.

CHAPTER 3

LITERATURE REVIEW

3.1 General

Over the years many researchers has performed studies and research on different pavement management models and expressed their view on it, various methodologies and softwares were developed for this purpose and were tested on field. HDM is also the result of such studies and have become a topic of research itself. Overview of different studies done on objectives related to present literature are discussed in this chapter.

3.2 Studies on HDM-4

Kerali et al. [1998] presented software application of HDM-4 and its role as a Highway Management Tool, the functions of highway management : Planning, Programming, Preparation and Operations all of them are placed in HDM-4 expect the Operation part which is not addressed by the software. Application tools of HDM-4 are also discussed in detailed by the author that are Project Analysis, Programme & Strategy Analysis, Life Cycle Analysis, Economic Benefit and cost optimisation. Calibration of HDM-4 models and its importance along with the data requirement of the tool that give the user ability to use the tool in a large range of environment, which enable the use of HDM-4 on International level.

Jain et al. [2005] performed calibration of HDM-4 models for National Highways passing through Uttar Pradesh and Uttaranchal states of India by collecting the data of cracking, ravelling, pothole and roughness from 145 road sections situated along National and State Highways of Gujarat, Haryana, Rajasthan and Uttar Pradesh over a period of 3 to 5 years. The calibration was done by using the models derived by Central Road Research Institution (CRRI) using the same road networks, and by comparing HDM and CRRI models calibration factor for each model were determined.

The validation of calibrated model was done by selecting 22 homogenous road sections with varying traffic volume, climate, terrain and soil type. The values obtained by prediction model were compared with observed values and coefficient of determination was checked. The author stated that these calibration factors can be used by different developing countries having same climatic, pavement composition, terrain and traffic condition and concluded that there was a difference of 10.8 to 28.2% for cracking area, 15.4 to 39.8% for ravelled area, and 0 to 66%

for pothole numbers was observed, on the other hand roughness variation was as low as 2.1 to 15.1%.

T.Chopra et al. [2017] developed a PMMS for 4 road section each having 1 Km length and also performed economic analysis of whole project. These roads were classified as collector streets and had bituminous topping with speed limit of 30 to 50 Km/hour. Structural and functional evaluation of these roads was performed using BBD and Bump Integrator, moreover traffic survey to determine AADT was also done on these roads.

To perform economic analysis and create M&R strategies the writer followed guidelines of MORT&H and IRC codes. Optimum M&R alternative was determined for each road on the basis of economic analysis, and roughness or overall deterioration was used as the trigger point for different alternatives. Author also performed comparison between schedule type and condition based type alternatives, where schedule type alternatives were found to be 3 times more economic.

Dr Pardeep Kumar Gupta, Rajeev Kumar [2015] used HDM-4 to develop Optimum maintenance strategies for 3 flexible urban roads of Panchkula, India. All the data required for HDM-4 analysis was collected for this study. Detailed analysis was done in HDM-4 project analysis after proper calibration and validation of cracking and roughness progression models, optimum M&R activities were discovered by economic analysis of different alternatives and comparing Net Present Value to cost ratio. The author stated that similar kind of optimum M&R strategies can be developed for different urban roads.

T.Chopra et al. [2017] performed economic analysis using HDM-4 on urban roads of Patiala city already calibrated for Indian conditions. International Roughness Index (IRI) was used as trigger for maintenance work, in depth functional and structural evaluation of selected road sections were performed. Condition responsive and scheduled M&R strategies were compared on the basis of economic analysis and optimum strategies were defined.

Dattatraya Tukaram Thube [2012] used Artificial Neural Network (ANN) in this study to predict future deteriorations for Low Volume Roads (LVR). ANN models were trained using road inventory data, pavement evaluation data, sub grade data and traffic data of 61 road networks, the data was collected for the period of 3 years. ANN distress prediction models of total cracking, ravelling, rut depth and roughness were developed and were compared to HDM-

4 models. Validation of ANN model was done by maximum R^2 and minimum RMSE method, after that results of both ANN and HDM-4 models were compared. On the basis of test results it was concluded that ANN models are better than HDM-4 models as HDM-4 models need to be calibrated for different conditions which is not the case for ANN.

3.3 Study on Pavement Prediction Models & PMMS

T.Chopra et al. [2017] A relation have been developed using Genetic Programming (GP) to predict future deterioration (cracking, ravelling, potholes, rutting and roughness) data of 16 road section have been collected for years 2012 to 2015, where data of year 2012-2013 was used for GP and data of year 2014-2015 was used for validation of the model. The author wanted to test the suitability of GP models for urban roads and was able to validate it with proper reason for little deviation seen in the prediction data. Writer also stated that these models can also be used for other roads of the city with traffic range of 0.1 to 0.85 equivalent standard axel repetition and Modified Structural Number (MSN) having range of 2 to 4.5.

Meshramt et al. [2013] developed Artificial Neural Network (ANN) along with a Multi variate regression model in this study to predict Pavement Condition Index (PCI) of the low volume roads in Madhya Pradesh. Data of 10 low volume roads has been collected for time period of more than 2 years, the data include MERLIN roughness, shoulder condition and its DCP value, drainage condition, surface distresses, CBR of subgrade and shoulder and commercial vehicles per day (CVPD). The data collection was done before and after monsoon season. Following equation was developed to determine PCI of pavement using regression analysis:

$$PCI = 20.92278 - 1.03998X_1 + 0.00764X_2 - 0.00166X_3 - 0.80757X_4$$

Where,

PCI= pavement Condition Index, X_1 = Time in year, X_2 =Traffic in CVPD,

X_3 = Annual rainfall in mm, X_4 = Sub-grade moisture content in %

Both the models were validated by comparing actual and predicted values of PCI, the results represented good relationship between both models but ANN was found to have better results with R^2 value of 0.9230 and RMSE of 0.062, whereas regression model had R^2 value of 0.87 and RMSE of 0.0758.

Hamad Al-Ajami [2015] Importance and working of PMMS have been explained in this literature along with the factors affecting its efficiency. PMMS created by Municipality of

Riyad city is analysed by the author which is dependent on roughness, skid resistance and pavement condition. Index of Urban Distress (UDI) is used to represent pavement condition data which contain 15 kinds of pavement distresses. UDI system defines road network as Excellent, Good, Fair or Poor and data collected is divided into two segments as primary and secondary roads. All the different kind of rehabilitation procedures are selected on the base of UDI and skid Resistance. It was concluded that a PMMS is an extra helping hand which enhance the performance of existing pavement and will guide in using the available resources in best way possible.

Hafez et al. [2017] created four survey form with approximately 26 question each, that were sent to 73 government agencies including Transportation Research Board (TRB), Regional Department of Transportation (DOT), Colorado Local Government, etc. The survey was about Pavement Management System (PMS) for Low Volume Road (LVR), the survey took place between September 2015 and January 2016, the survey aimed to review PMS practices for LVR, how different agencies collect road data, to know policies of different states on LVRs, resource management, different maintenance activity and their effect on budget and different techniques developed by agencies that are proved to be helpful in meeting their goal.
It was concluded that all agencies are facing problems like low budget, different policies of state government and DOTs regarding same roads, while other shared their past experience and stated some of the practices they are following are not effective but they have no choice due to lack of resources.

Ajit Pratap Singh et al. [2017] used two soft computing methods: Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Weighted Average (FWA) method to evaluate condition of five roads and rank them accordingly for M&R treatment, roads are situated in Jhunjhunu district in Rajasthan, India. The performance indicators used in this study to evaluate pavement are : International Roughness Index (IRI), Friction Coefficient (f), Rut Depth (R) and Surface modulus (E_o). Equipments used were bump integrator, LWD, straight edge and skid resistor to determine the above mentioned parameters. The results obtained from both techniques were compared and little variation was observed due to different approach of analysis. It was concluded that these soft computing techniques can be used to prioritise roads for M&R activities as funds available are limited.

Ibrahim Abed Mohammed et al [2017] developed an Electronic Data Base (EDB) to guide the user to select which road network should be prioritised for rehabilitation work, the EDB was named as Road Maintenance Priority Index Program (RMPI). Author stated that a data base is important to store all the information related to pavement and rank different roads in need for M&R. All the factors affecting maintenance priority including external factors were stated in this study, case study of two roads were chosen to implement the programme one of them being express way No. 1 in Iraq and another was the road network of Baghdad University. Microsoft Visual Studio.Net and SQL Server were the languages used to develop RMPI. The software was evaluated by experts having years of experience and were provided with a questionnaire to fill out there opinion about the programme. The responses of experts were highly positive and they confirmed that the programme like this is very important for companies working in Iraq.

3.4 Study on Pavement Testing & Economic Analysis

Prakashkumar Makwana [2016] utilised Light Weight Deflectometer (LWD) and LWDmod software in this literature to determine the elastic modulus of flexible pavements and further establish a relation with density and moisture content using linear regression method. Core cutting method and laboratory were used to find density and moisture content, the site selected was undergoing construction and carried heavy load traffic and had good drainage condition. Data at total 40 points was collected on both sides of the carriageway with LWD generating a force of 7 to 8 kN on a 300 mm diameter plate. The results were obtained and it was noted that with increase in elastic modulus bulk density also increased but moisture content decreased showing good material and construction quality.

Chien-Chiao Chao et al. [2017] conducted **N**on-destructive testing (NDT) of a busy state highway carrying heavy traffic to design proper rehabilitation activity, as the traffic cannot be diverted and due to budget constraint no major maintenance activity or reconstruction of road can be done. NDT carried out on this road section are visual survey, Falling Weight Deflectometer (FWD), Ground Penetration Radar (GPR), coring and dynamic cone penetrometer (DCP). The road under study is 12.8 Km long and carried traffic of 25,000 ADT, with 50% of heavy commercial vehicles. GPR in combination with coring was used to measure the thickness of each pavement layer, whereas MODULUD 6.0 was used to back calculate results obtained from FWD and provided with modulus of pavement layer with represent strength of pavement and DCP was used to determine the strength of base and sub-base. Form the results it was seen that the pavement was lacking structural strength at many points and proper design was proposed.

K. Jain et al. [2013] used Wholesale Price Index (WPI) to find Escalation Factors (EF) to update all the parameters affecting Vehicle Operating Cost (VOC). Author used the WPI_B of base year (2009) and WPI_S of stated year (2013) of all the commodities of all six major groups to find $EF_{B\text{-}S}$ of base year using the following equation:

$$EF_{B-S} = \frac{\Sigma \frac{WPI_S}{WPI_B} \times CommodityWeight}{\Sigma CommodityWeight}$$

Calculated EF that is 1.43 was used to update the VOC equations for the year 2013 by simply multiplying VOC of 2009 with the EF.

$$VOC_{2013} = VOC_{2009} * EF$$

VOC for two wheelers, cars, busses, LCV and HCV were presented in the study for single to four lane roads.

Guzzarlapudi et al. [2016] did comparative study of subgrade moduli of 3 different cohesive soils obtained from Benkelman Beam Deflection (BBD) and Light Weight Deflectometer (LWD) in this literature, the study was conducted on low volume roads. The modulus obtained from both the devices were also compared with the modulus obtained from laboratory test results of soil sample taken from the same location. It was observed that modulus obtained from BBD were at lower side than LWD results and modulus obtained in laboratory were consistent with very low variation, R^2 obtained by comparing LWD and BBD results represented good relation between them. Modulus obtained from CBR values of soil using the relation provided in IRC code was also compared with BBD and LWD results, where LWD showed better correlation when compared with BBD. This study concluded that LWD due to its dynamic property is better suited for determination of subgrade strength as compared to BBD which has more time taking and hectic procedure.

S. Wadalkar et al. [2018] gathered reviews of expert and academicians from field of transport from a survey about the importance of 16 distresses in determining the pavement performance which was used to establish a Relative Importance Index (RII) of all the 16 indicators. RII was computed from the results gathered from the survey by using following equation.

$$RII = \Sigma W / (A*N)$$

Where, W - Weighting given to each factor by the respondents (1 -5)

A - Highest Weight (5)
N - Total number of respondents

The results obtained are presented in the bar graph below where the maximum RII for rigid pavement was obtained for longitudinal cracking whereas, for flexible pavement it was maximum for deflection.

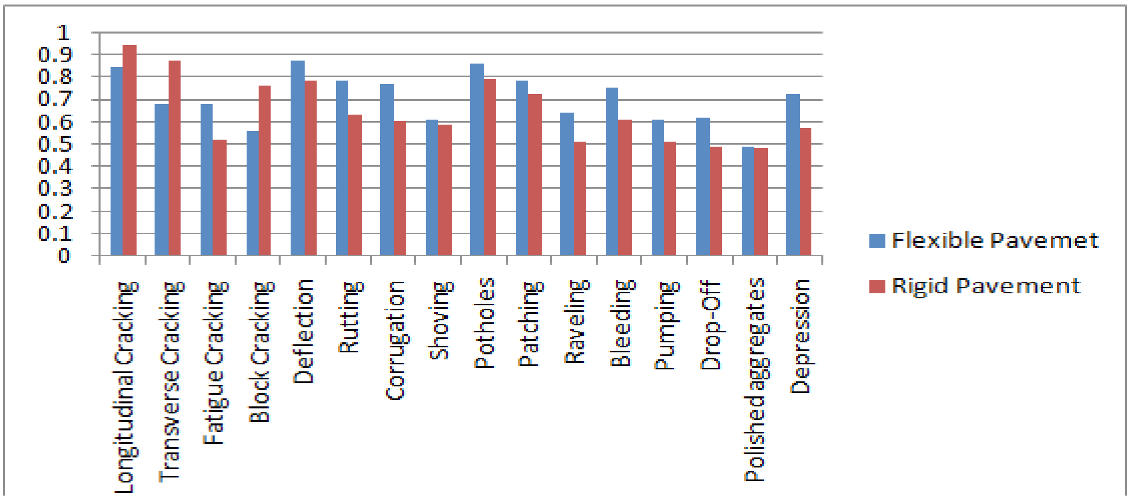


Figure 3.1 : Comparison of RII values for Flexible & Rigid Pavement

CHAPTER 4

DATA COLLECTION AND METHODOLOGY

4.1 General

For preparation of Pavement Management and Maintenance System we need to prepare a proper step by step methodology. In this chapter the process for data collection and suggested approach is shown for low volume urban roads.

4.2 Identification of Road Networks

For this study 10 roads were selected which are spread all over the city. All these roads are surrounded by residential areas, therefore traffic characteristics over these roads are similar but volume vary as population density is different at these locations as well as economic values of the areas are distinct. The roads taken were further divided into 10 homogenous sections having length of 50 meters each, and distresses values were measured for every section and deflection of pavement was measured using LWD under the peak load of 12 KN. Table 4.1 represents the selected sections along with their 'Section Name' and Section ID'.

Table 4.1: Sections Selected for Study

Section ID	Section Name	Description	Road Category
PN	Prem Nagar Road	Thapar diploma road	Local Street
MN	Manjit Nagar Road	Manjit nagar main street	Local Street
DN	Dashmesh Nagar Road	Oxy gym road	Local Street
TR	Tripuri Road	Road parallel to main road of tripuri	Local Street
LC	Lehal Colony Road	Bikram College Link Road	Local Street
SN	Sant Nagar Road	21 to 22 no. Phatak road	Local Street
MT	Model Town Road	Road in front of power colony	Local Street
AN	Ajit Nagar Road	Saint Peters school road	Local Street
LB	New Lal Bagh Road	Colony opposite polo ground back entrance	Local Street
OC	Officers Colony Road	Raja mahal road	Collector Street

4.3 Data Required

Data needed for this study was gathered to meet the requirements of HDM-4 and it was accumulated in following order:

- Pavement Condition Data
- Traffic data
- Maintenance and Rehabilitation Work data (M&R)
- Cost data

Pavement condition data represents distresses, structural evaluation and other data like road width drainage etc. History of pavement refers to history of pavement like, date of construction, maintenance work and there details, reconstruction if any, etc. Traffic data comprises of list of vehicles along with their volume and type using the road network. Cost data is the vehicle operation cost, capital required for maintenance and equipment, etc. Methodology of gathering these information with their details have been discussed in sections below.

4.4 Pavement Condition Data

The data of all roads were collected to fulfil the requirement of HDM-4. Pavement condition data involve following components.

- Road network data
- Pavement Evaluation data
- History of work done on road networks

4.5 Road Network data

For this study we recorded following parameters of a road network:

a) Road length
b) Width of carriageway
c) Drainage condition
d) Shoulder width (if any)

All the above mentioned parameters were obtained visually by visiting every road under study and talking to nearby residence is presented in table 4.2.

Table 4.2: Road Network Data of Selected Sections

Section ID	Section Length	Carriageway Width	Shoulder Width	Traffic Flow Direction	Drainage
PN	500 m	6 m	-	Two-Lane Two-way	Fair
MN	500 m	3.65 m	-	Two-Lane Two-way	Poor

DN	500 m	5 m	-	Two-Lane Two-way	Fair
TR	500 m	7.7 m	2.1 m	Two-Lane Two-way	Good
LC	500 m	3.5 m	-	Two-Lane Two-way	Poor
SN	500 m	6.5 m	2.45 m	Two-Lane Two-way	Good
MT	500 m	6.8 m	1.1 m	Two-Lane Two-way	Poor
AN	500 m	7 m	1.1 m	Two-Lane Two-way	Good
LB	500 m	3.5 m	-	Two-Lane Two-way	Good
OC	500 m	9 m	2.55 m	Two-Lane Two-way	Good

4.6 Pavement Evaluation Data

In this structural & functional condition of the road was an assessed using non-destructive testing technique, that is LWD, visual inspection of distresses and Bump Indicator.

4.6.1 Structural Evaluation using LWD

Light Weight Deflectormeter (LWD) was developed by Federal Highway Research Institution for in-situ testing and to find modulus of sub-grade layer. LWD is a non-destructive testing device which is used for pavement structural evaluation. LWD can provide better results than Benkelman Beam and is easier and faster to operate [Guzzarlapudi et al., 2016].

For this study Dynatest 3031 LWD equipment was used for testing, maximum load of 20 Kgs and maximum drop height was used on a plate of 300 mm diameter so as to generate maximum possible force which was recorded as 12 kN. The test was conducted as per the procedure given in ASTM E2583 (2011), for recording reading all three sensors were used but 2nd sensor was found defective therefore for evaluation only central deflection was used. Total of 20 deflections were recorded on each road at the difference of 50m and in both direction over the wheel path.

The main goal for this study is to use the data collected for creation of PMMS using HDM-4, therefore deflection readings obtained from LWD have to be converted into either BBD or FWD. A relation developed by AHMADUDIN BURHANI (2016) was used where he compared the results obtained by comparing central FWD deflection to LWD deflection after normalising and extrapolating respective deflections to same stress value, the equation used is:

$$D_{FWD} = 1.4607\,(d_{LWD})^{0.8831}$$

The LWD values recorded in this study were 1st extrapolated to 700kPa (as required by HDM-4) then the above relation was used to convert the deflections into FWD deflections.

Figure 4.1: LWD Apparatus with Wheel Assembly

Figure 4.2: LWD with Geophone Sensor

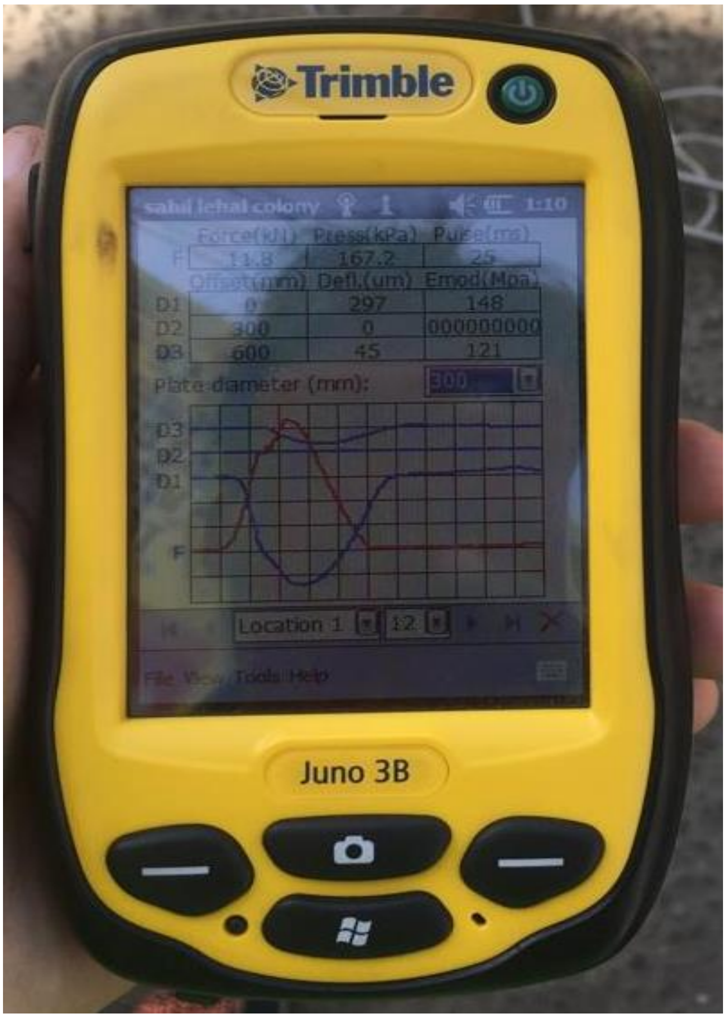


Figure 4.3: Reading of LWD on Handheld Computer

4.6.2 Functional Evaluation of Road

In functional evaluation we gather data related to distresses on a road affecting its serviceability and leading to deterioration of pavement. As discussed earlier all roads were divided into 10 sections of 50 meters each and data regarding cracking, ravelled area, rut depth, edge break, number of potholes and roughness was recorded using appropriate techniques for each road stretch.

4.6.2.1 Cracking Measurement

Cracked area was recorded by visual inspection and for that ,rectangle was drawn around the crack and dimensions were noted using chalk and measuring tape. During this study it was observed that most of the cracks were longitudinal cracks and transverse cracking was not present on these roads. The figures below display measurement of cracking at few sections.

Firgure 4.4 : Cracking on Section PN

Figure 4.5: Cracking on Section AN

Figure 4.6: Cracking Due to Manhole Uplift

4.6.2.2 Ravelling Measurement

Ravelled area was measured in same trend as cracking using a tape and chalk to record width and length of ravelled part. Ravelling is the next stage of cracking in which the material used in HMA layers starts to disintigrate.

Figure 4.7: Ravelling at Section PN

Figure 4.8: Measurement of Ravelling at Section MN

Figure 4.9: Large Ravelled Area at Section DN

4.6.2.3 Potholes

Cavity in pavement having a minimum area of .1 m^2 or diameter of 150 mm and 25 mm depth are defined as potholes. Area and depth of potholes were measured and then those were converted into standard number of potholes per Km.

Figure 4.10: Pothole on Section PN

Figure 4.11: Pothole at section OC

4.6.2.4 Rut depth measurement

Rutting is caused by plastic deformation on road surface and can take place due to any pavement layer. Rutting was measured by using a 1.5m long straight edge which was kept in transverse direction and a scale was used to measure the rut depth. Rutting is very common in flexible pavement which results in bad riding quality and unsafe driving conditions. Structural or material failure can result in rutting, during survey large rut depth (upto 54 mm) were found on test roads indicating bad construction quality.

Figure 4.12: Rutting Measurement at OC Section

Figure 4.13: Large Rut depth on SN Section

Figure 4.14: Rut Depth Measurement at Section TR

4.6.2.5 Roughness of road network

Road roughness is a important parameter which effect the road user directly in terms of overall cost and riding quality. Road roughness can be measured by various devices and is expressed as International Roughness Index (IRI), in this study Fifth Wheel Bump Integrator was used which give us the results in Unevenness Index (UI) which is measured in bumps in cm/ Length travelled in Km. The test was conducted at a speed of 32 ± ½ Km/hour with a tyre pressure of 30 psi. During test main challenge was to maintain the above speed as some of the test sections were narrow and had sharp turns, therefore speed was reduce at those points for safety purposes.

The test was performed on wheel path in both directions and the results were obtained in Unevenness Index (UI) were converted into IRI using following expression.

$$UI = \text{Bumps in cm/ Length travelled in Km}$$

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

In above expression units of IRI is in m/Km, whereas units of UI are in mm/Km. The table 4.3 show the test results of every road under study.

Table 4.3: Roughness Calculation for All Sections

Section ID	Bumps	Length (meters)	Unevenness Index (UI) (mm/Km)	International Roughness Index (IRI)
PN	134	500	2680	3.78
MN	57	500	1140	1.62
DN	112	500	2240	3.17
TR	43	500	860	1.21
LC	143	500	2860	4.05
SN	133	500	2660	3.77
MT	103	500	2060	2.92
AN	112	500	2240	3.17
LB	126	500	2520	3.57
OC	-	-	-	-

For road section 'OC' roughness value could not be recorded as resurfacing of the road was done before the test date, therefore we are adopting maximum permissible roughness.

Figure 4.15: Adjusting Bump Integator on Section LB

Figure 4.16: B.I. Testing on Section MT

Figure 4.17: Bump Integrator Running on Section MN

Figure 4.18: Readings Displayed on Panel Board Placed in Back of Towing Vehicle

All the suruface deterioration data collected in this study is summarized in the table 4.4.

Table 4.4: Values of Distresses and Deflection of All Test Sections

SECTION ID	CRACKING %	RAVELLING %	RUT DEPTH (mm)	POT HOLES	ROUGHNESS (m/Km)	Deflection
PN	1.82	1.37	40	4	3.79	0.84
MN	0	1.064	0	2	1.62	0.58
DN	1.25	2.6	14	5	1.45	0.58
TR	0	0.001	54	3	1.22	0.68
LC	0.004	9.3	16	11	4.05	0.58
SN	2.067	0.86	24	4	3.77	0.68
MT	1.85	1.25	18	5	2.92	0.9
AN	0.54	0.138	24	2	3.17	0.48
LB	0	1.64	35	0	3.57	0.49
OC	0.5	2	23	10	5.2	0.48

4.7 Road Work History

The data of work done on roads was collected from Municipal Corporation of Patiala, the details of each road network is shown in the table 4.5.

Table 4.5 : History and Detail of Work done on Road Sections

Section ID	Last Reconstruction/Construction	Last Overlay	Last Resurfacing	Last Preventive Treatment
PN	150mm WBM+40mm BM (2005)	50mm BM+20mm PC (2014)	-	-
MN	150mm WBM+40mm BM (2005)	50mm BM+20mm PC (2015)	-	-
DN	150mm WBM+40mm BM+ 20mm PC (2005)	50mm BM+20mm PC (2015)	-	-
TR	150 mm WBM+ 50mm BM+25mm SDBC (2018)	-	-	-
LC	150mm WBM+50mm BM (2005)	50mm BM+20mm PC (2016)	-	-
SN	150mm WBM+40mm BM+ 20mm PC (2005)	50mm BM+20mm PC (2015)	-	-
MT	150mm WBM+40mm BM (2005)	-	25mm PC (2012)	BM Patch Work (2015)
AN	150mm WBM+40mm BM (2005)	-	25mm PC (2015)	-
LB	150mm WBM+40mm BM (2005)	-	25mm PC (2015)	-
OC	150mm WBM+40mm BM+ 20mm PC (2005)	-	25mm PC (2016)	BM Patch Work (2017)

4.8 Traffic Data

For these roads information regarding traffic volume and vehicle was not available with Municipal Corporation of Patiala, therefore traffic survey was conducted on each road for 3 days from morning to night and it was assumed that no or very low amount of vehicles were using these roads during night time.

The traffic was recorded hourly and average of 3 days was taken, there were different types of vehicles using these roads and to find the Average Annual Daily Traffic (AADT) all these vehicles were converted into Passenger Car Space Equivalent (PCSE) by multiplying each vehicle with their conversion factor, after which a graph was plotted between AADT and time to check the traffic flow against time and was found satisfactory.

According to HDM-4 manual AADT ranges for low, medium and high volume roads are provided which are also shown in the table 4.6 below.

Table 4.6: Traffic Volume Data of All Roads

Section ID	Motorised AADT	Non-Motrised AADT	AADT Year	Volume
PN	4735	240	2019	Low
MN	4907	393	2019	Low
DN	5373	264	2019	Low
TR	3394	172	2019	Low
LC	5917	541	2019	Low
SN	5680	410	2019	Low
MT	6650	476	2019	Medium
AN	6477	464	2019	Medium
LB	1621	160	2019	Low
OC	11399	1025	2019	High

4.8.1 Vehicle Fleet Data

Before starting survey for traffic volume vehicle fleet data must be defined so that while actual survey there should be no confusion about where to put that particular vehicle. The standard vehicles according to India were taken as there economic analysis data is readily available which is required for completion of PMMS. The vehicle fleet was divided in Motorised vehicles and Non-Motorised vehicles. The vehicles taken are represented in table 4.7.

Table 4.7: Vehicles and there Characteristics

Motorised Vehicles	**Number of Wheels**	**Number of axels**	**Growth Rate %**
Two Wheeler	2	2	4.2
Car/Jeep/Van	4	2	8.5
Auto Rickshaw	3	2	5.4
Goods Delivery Vehicle	4	2	6
Tractor/Trolley	4/6	2/3	6
School Bus	4	2	3.7
Non-Motorised Vehicles			
Bicycle	2	2	3.4
Rickshaw	3	2	3.4
Animal Cart	2	1	3.4

4.8.2 Composition of different Vehicles

To use the data gathered from traffic survey, HDM-4 needs to know the exact contribution of each vehicle on every road so as to calculate its effect on road network and operating cost of every vehicle class. Composition of motorised and non-motorised vehicles was derived from traffic volume survey data and is represented in the table 4.8.

Table 4.8: Composition of Vehicles on Different Sections

Section ID	Motorised AADT						Non-Motorised Vehicles		
	Two wheeler	Car	Auto Rickshaw	Tractor Trolley	School Bus	Delivery Vehicle	Cycle	Rickshaw	Animal Cart
PN	67.1	15.6	7.2	0	0.8	9.3	100	0	0
MN	66.7	23.3	1	0.8	0	8.2	94.5	0	5.5
DN	53.8	19.1	10.6	1.7	0	14.8	88	0	12

TR	71.7	19.3	2.7	0	1.8	4.5	80	20	0
LC	57.9	22.2	11.9	0	0	8	94.8	1	4.2
SN	56.8	20.4	10	3.2	0.6	9	94	0	6
MT	60	20.3	7.2	1.5	0.8	10.2	90	0	10
AN	53	30.2	7.2	0.3	0.3	9	90	10	0
LB	38.4	37.1	8.6	3.8	0	12.1	100	0	0
OC	55	29.7	6.9	0.8	0.6	7	80.7	17	2.3

4.9 Maintenance and Rehabilitation Work Data

As discussed before proper maintenance and rehab of a road network is most important feature of a PMMS and should be planned by keeping in mind the safety and comfort of the user along with environmental concerns. The M&R works are greatly affected by level of service and budget constraints for the project. For this study we will concentrate on level of service and will calculate the budget necessary for maintenance work.

For effective planning of maintenance work, level of service and the factors affecting it must be defined along with their ranges and limits. While proposing these values road user needs and safety is taken into account. For Indian conditions values of these parameters and there level of service is presented in the table 4.9.

Table 4.9: Serviceability Criteria for Roads (MORT&H)

S.No.	Serviceability factors	Level 1 (Good)	Level 2 (Average)	Level 3 (Acceptable)
1	Roughness by Bump Integrator (Max. Permissible)	2.8 m/Km	4 m/Km	5.2 m/Km
2	Potholes per Km (Max. Number)	Nil	2-3	4-8
3	Cracking and Patch work (Max. Permissible)	5%	10%	10-15%
4	Rutting-20 mm (Max. Permissible)	1%	1.5%	2.5%

For the roads under study ‘Level 3’ of serviceability is adopted as these roads are low volume local streets where only residential traffic is observed.

4.9.1 Norms for Maintenance in India

According to budget availability maintenance has been classified into following heads [MORT&H 2001]:

Ordinary Repairs

These are the routine maintenance work done after a fixed intervals in one year, for flexible pavements these are crack sealing and patch repair. In crack sealing slurry seal is used to close structural cracks on road surface and to retard further deterioration, but it does not affect the riding quality and should not be used if structural cracking is more than 20% of paved area.

Patch repair is used to cover potholes, wide cracks and ravelling area with bituminous mix of same properties or better, it is done after removal of material from a small area and filling it with mix and by compacting it. Patch work may reduce riding quality of the road as undulation increases.

Periodical Renewal

Under this riding quality of flexible pavements are improved by providing a fresh surface layer, these activities are performed after a fixed period of time and are done on large road sections with the help of large machines. Examples of periodic renewal are overlays, preventive treatments, mill and replace and reconstruction.

4.10 Cost Data

For economic analysis of transportation project we need to establish cost of every component involved in project and is affected by it directly or indirectly. Total transport cost comprises of following components [Kunal Jain et al,. 2013]:

- Road Cost
  - Construction Cost
  - Maintenance Cost
- Road User Cost
  - Vehicle Operating Cost
  - Travel Time Cost
  - Accident Cost

As this study is for low volume local streets travel time cost and accident cost will not be included as the length of these roads are very short and speed limit allowed is low as well. The cost for this study have been taken from Delhi Schedule Rates 2019 and previous studies done on urban roads of Patiala [Tanuj Chopra et al., 2017 & 2016] and increasing it by 10% for each gap year.

4.10.1 Construction & Maintenance Cost

This include cost all the activities along with the material required for those activities for construction of road and its maintenance which can be scheduled annually or at a fixed period of time. Cost of each activity used in this study related to M&R are presented in table 4.10.

Table 4.10 : Cost of different M&R Activities

S.No.	Type of M&R Activity	Price /m^2
	Annual Maintenance	
1.	Crack Sealing	88.38
2.	Patch Work	112.74
3.	Rutting Repair	156.7
4	Tack Coat	16.65
5.	Liquid Seal Coat	99.15
	Periodic Maintenance	
1.	Single Bituminous Surface Dressing (SBSD)	196.35
2.	Double Bituminous Surface Dressing (DBSD)	310.2
3.	Premix Carpet (PC) 20mm	200
4.	Premix Carpet (PC) 25mm	241
4.	Bituminous Macadam (BM) 40mm	394.5
5.	Reconstruction (150mm WBM+50mm BM+20mm PC)	1616.31

4.10.2 Road User Cost Data

This consist of cost related directly to user like vehicle operating cost, accident cost and travel time cost in which economic value of time is considered. Road User Cost (RUC) has a total proportion of 80 to 90% of total transport cost [Kunal Jain et al., 2013], as discussed earlier the focus of this study will only be on Vehicle Operating Cost (VOC).

Vehicle Operating Cost

It is the most important factor in RUC data as it comprises of 50-70% of its total cost, as the name suggests VOC is the cost required by vehicle to run it on the road. The VOC increases as defects on the road increases, it can grow by 15% to 50% if no maintenance activities are performed on the pavement. It had been observed that over the life span of road VOC is 4 times the construction cost of road, therefore it is an important factor in economic analysis on any transportation project and it is complicated to calculate as the price affecting VOC keep on fluctuating with time.

The VOC consider all factors like cost of new vehicle, fuel cost, service cost, cost of lubricant, etc. the VOC used in study performed by Tanuj chopra and Jyoti Mandhani in year 2016 has been used for the present year of 2019 after applying an increment of 10% to each component, the VOC calculation in the study (Tanuj Chopra, 2016) was performed using equations and guidelines provided in IRC SP: 30 (2009). The fuel price used in present literature has been taken by surveying local market.

Congestion factor mentioned in IRC SP:30 (2009) is not used for this study as the roads are low volume and the speed limit is very low therefore free flow condition has been assumed. All the data and there calculated values required by HDM-4 has been represented in table 4.11.

Table 4.11 : Vehicle Operating Cost Required by HDM-4

VOC Componeents	Two Wheelers	Car/Jeep/Van	Auto Rickshaw	Goods Delivery Vehicle	Tractor Trolley	School Bus	Bicycle	Rickshaw	Animal Cart
New Vehicle	50,435	7,11,590	2,00,000	4,35,000	6,00,000	8,50,000	4,000	10,000	12,000
Tyres	1,200	5,000	1,500	1,500	3,000	10,000	-	-	-
Fuel / litre	72.96	72.96	65.69	65.69	65.69	65.69	-	-	-
Lubrication Oil / litre	5	18	9	13	13	20	-	-	-
Maintenance Labour/Hour	5.4	8.5	4.25	12.27	12.27	12.27	-	-	-
Crew Wages/Hour	-	-	1.56	2.9	5.4	5.4	-	-	-
Annual Overhead	0.25	0.91	0.12	2.60	4.67	4.67	-	-	-
Annual Interest %	8	8	8	8	8	8	8	8	8

To input fuel cost in HDM-4 we need to define fuel consumption of every vehicle and distance travelled by them annually. These are calculated using IRC SP : 30 (2009) and previous studies done on urban roads of Patiala city (Tanuj Chopra et al., 2017). The table 4.12 represent the details of fuel consumption and annual distance travelled by the selected vehicles.

Table 4.12 : Fuel Comsumption and Cost of Each Vehicle

Vehicles	Fuel Consumption per 1000 km	Fuel Cost per 1000 km	Distance Travelled Annually in km
Two Wheeler	25.47	1,858	6000
Car/Jeep/Van	56.54	4,125	30000
Auto Rickshaw	28.27	1,857	30000
Goods Delivery Vehicle	58.54	3845	60000
Tractor/Trolley	141.33	9,284	60000
School Bus	173.52	11,397	60000

CHAPTER 5

CALIBRATION OF HDM-4 AND ITS APPLICATION

5.1 Importance to calibration

HDM-4 was created by World Bank to be used in every country that wants to take help from world bank for its development, since every country has different topographical and climatic conditions, it is crucial to calibrate HDM-4 before use. The equations used in HDM-4 if not calibrated properly won't give right prediction model and will lead to wrong results therefore we need to use calibration factors achieved by study of past data of that particular location. Results of field investigation performed in various nations were used to structure HDM-4 pavement deterioration models. The reliability of forecasted pavement performance and vehicle resource utilisation can be refined by HDM-4 calibration. There are 3 scales of HDM calibration (Bennett and Paterson 2000) :

- Level 1 : Fundamental application – based on study of old data available through year of experience and pavement performance.
- Level 2 : Validation – Input data based on field survey of roads to calibrate for local conditions.
- Level 3 : Transformation – need long time to gather data from study of local condition and reform and improve the model.

5.2 Data Requirement for HDM-4 Calibration

The data required for calibration are pavement condition data are discussed below :

- Geographical data of the location of interest like mean temperature, rainfall and other parameters which are represented in Figure below.
- General detail of selected road sections like carriageway width, length of section, traffic in AADT, etc. are shown in figure.
- Detail of work done on pavement in past and its present structural condition, presented in figure.
- Data of distresses along with their year of evaluation, given in figure 5.4.

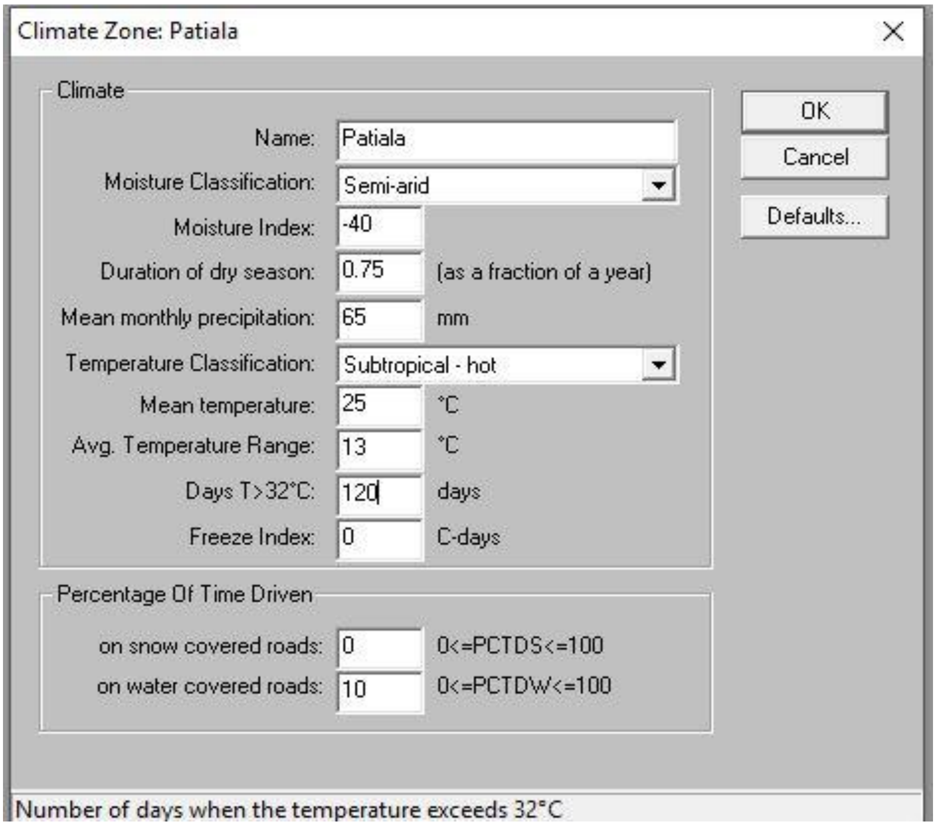


Figure 5.1 : Climate Zone Data in HDM-4

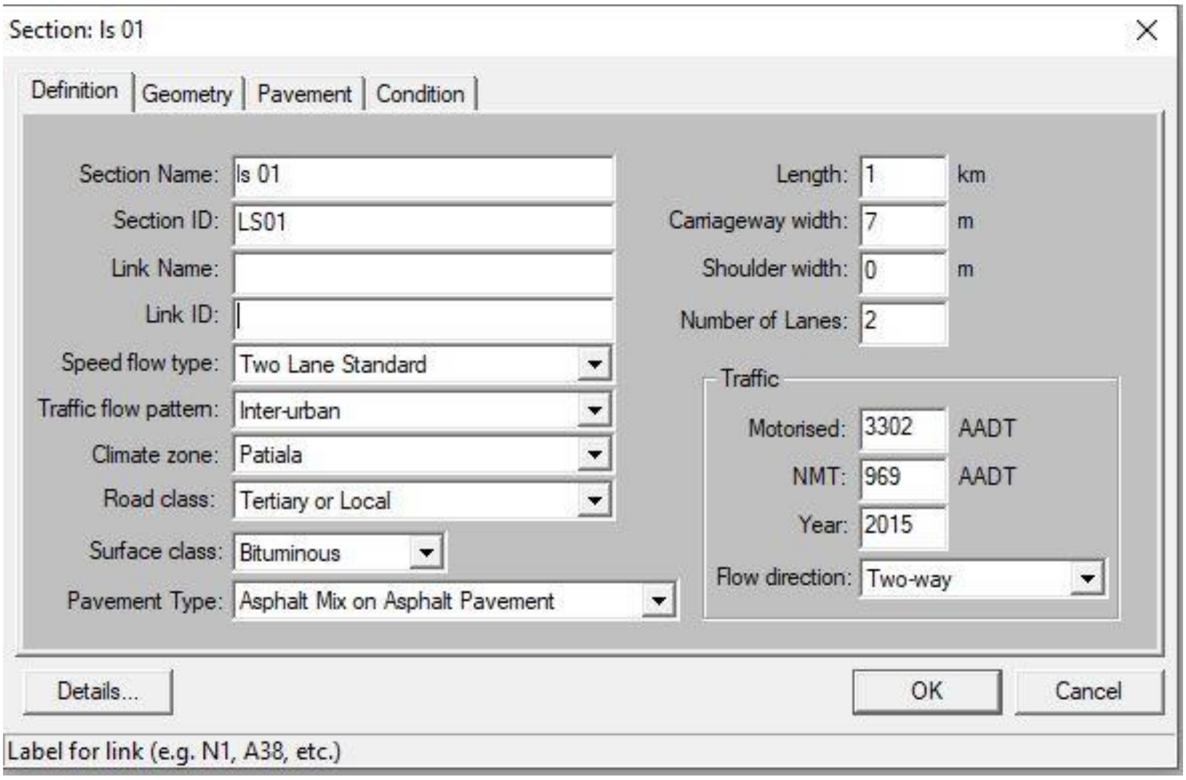


Figure 5.2 : Basic Data of Road Section

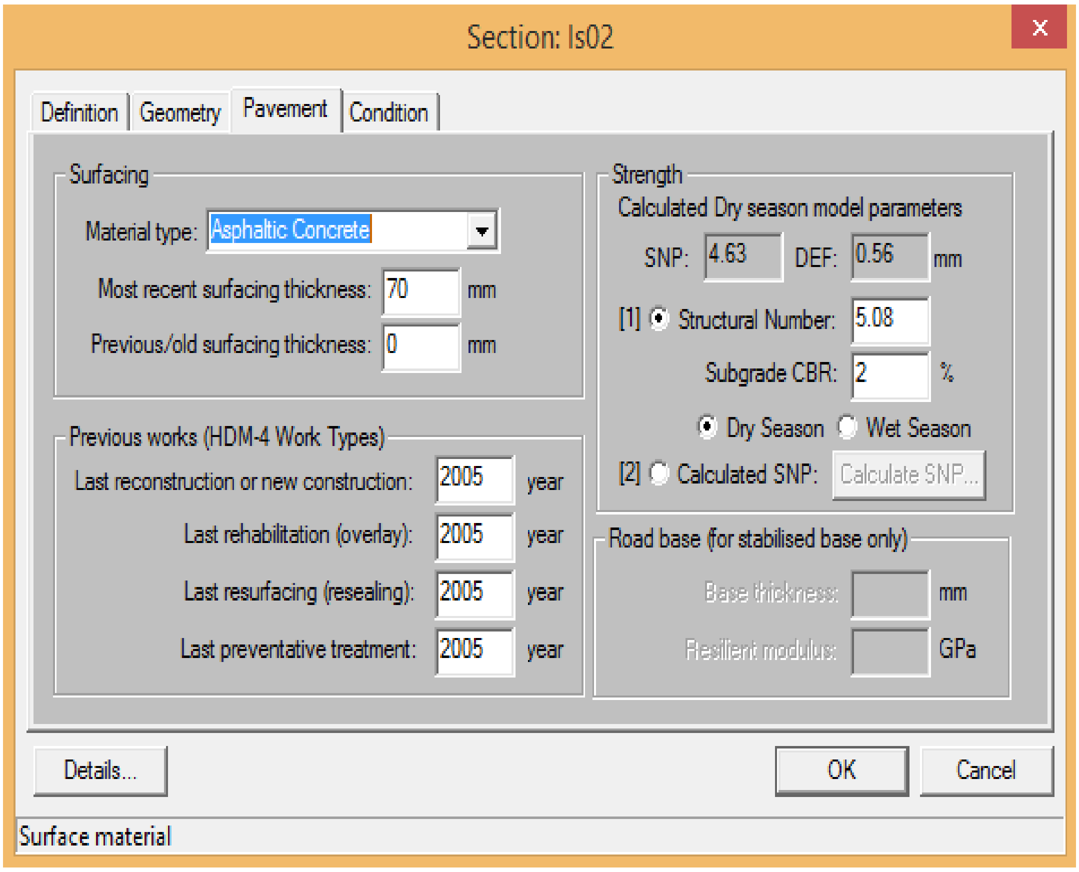


Figure 5.3 : Road Work Data

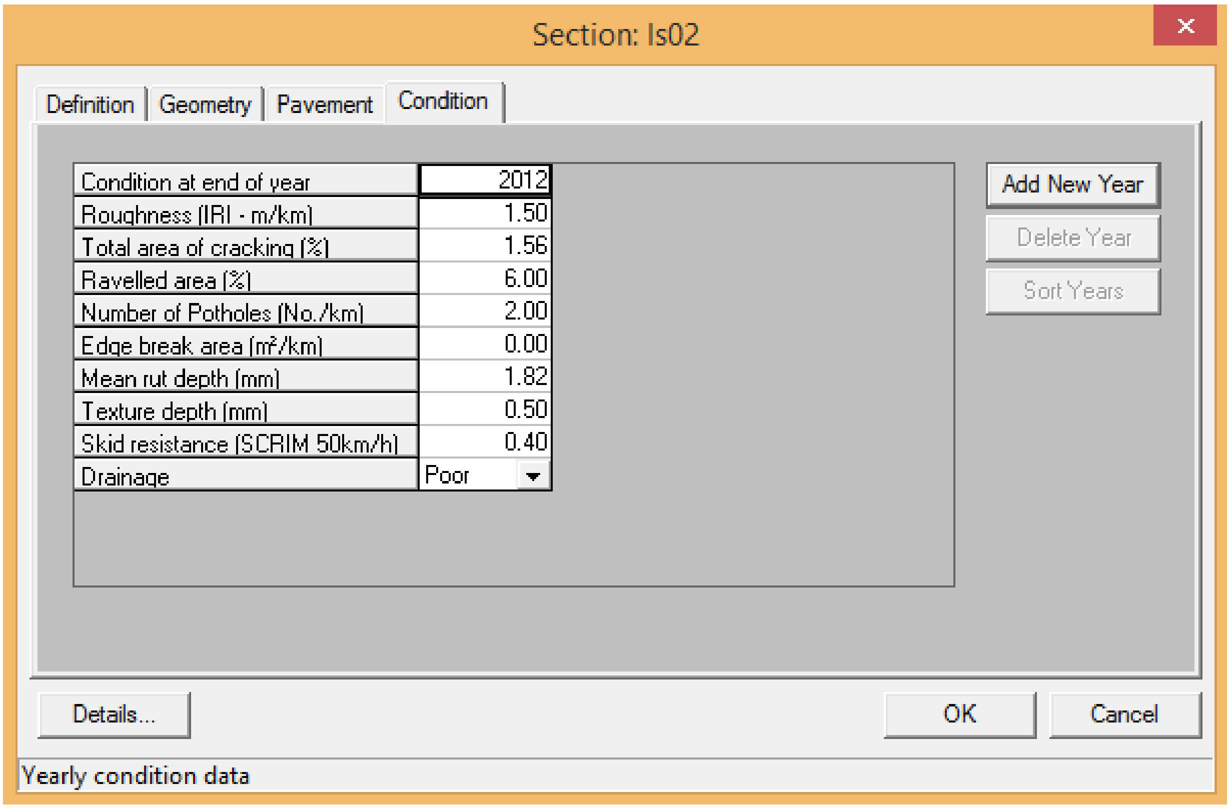


Figure 5.4 : Pavement Condition Data

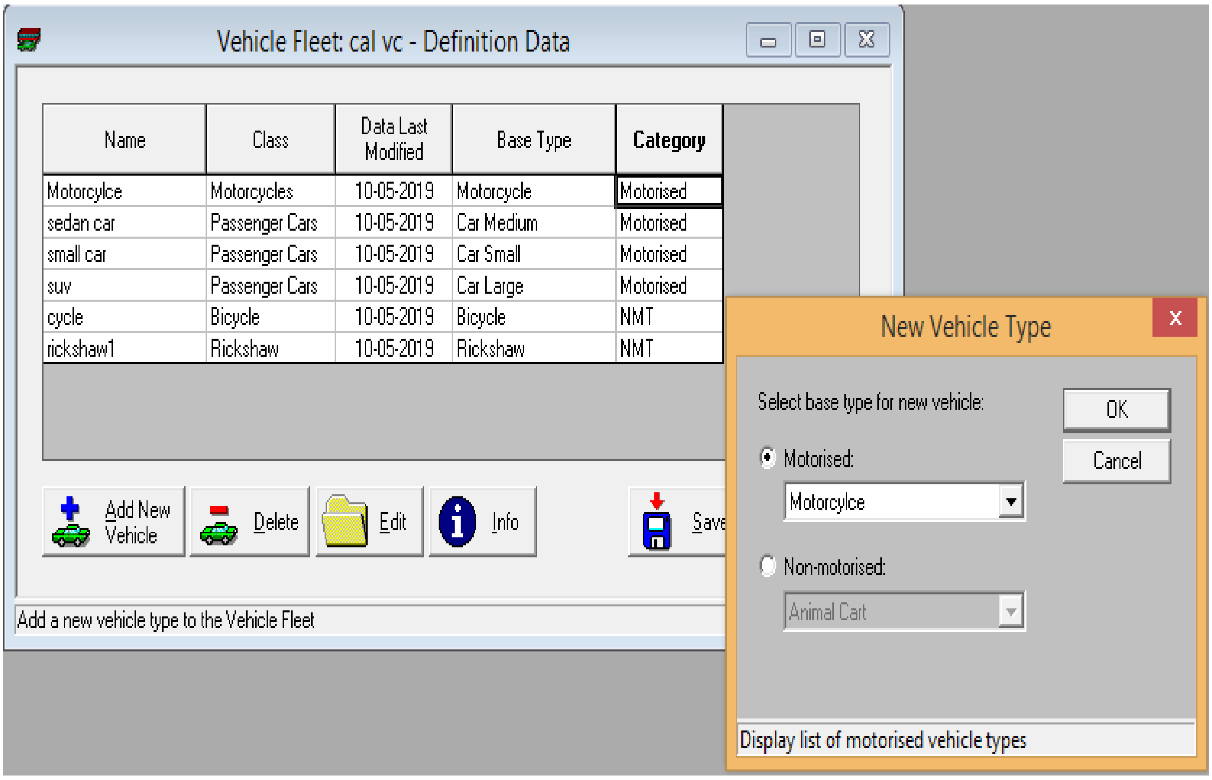


Figure 5.5 : Vehicle Fleet Input

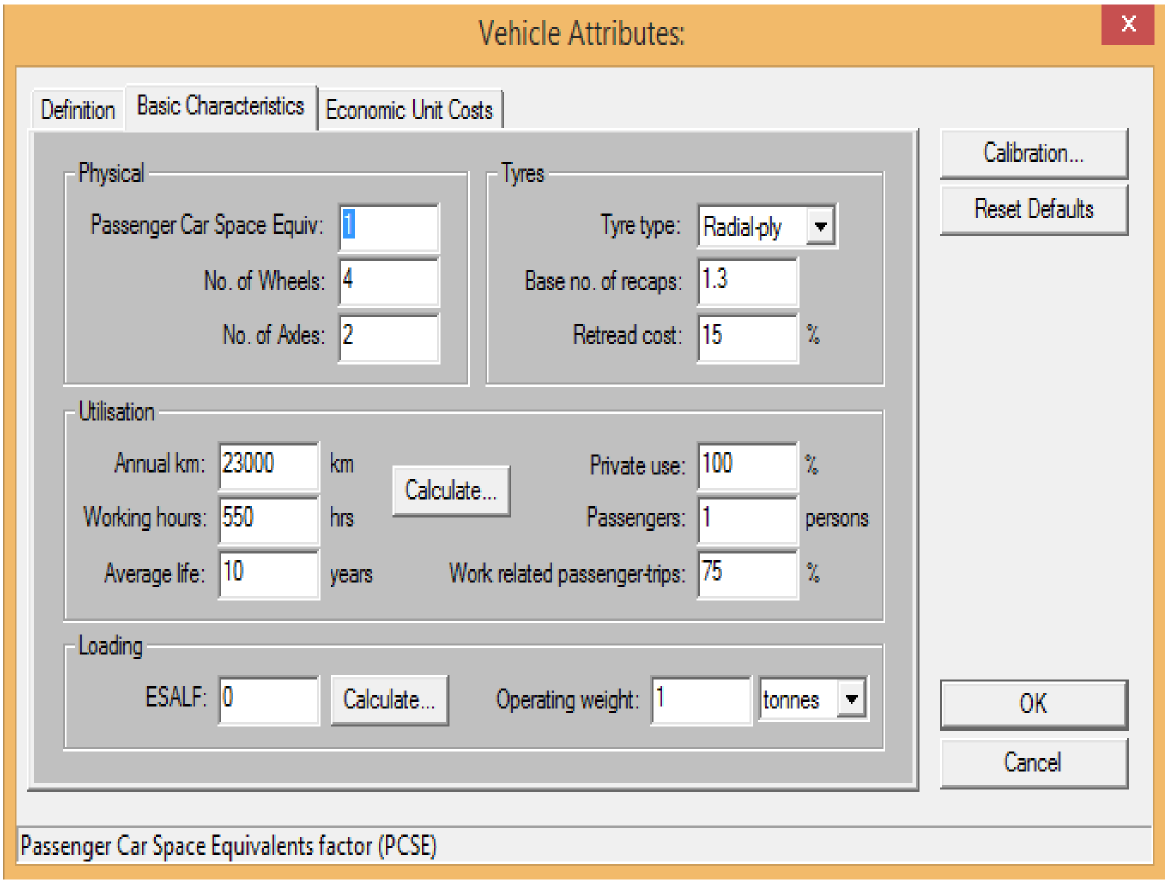


Figure 5.6 : Motorised Vehicle Characteristic Data

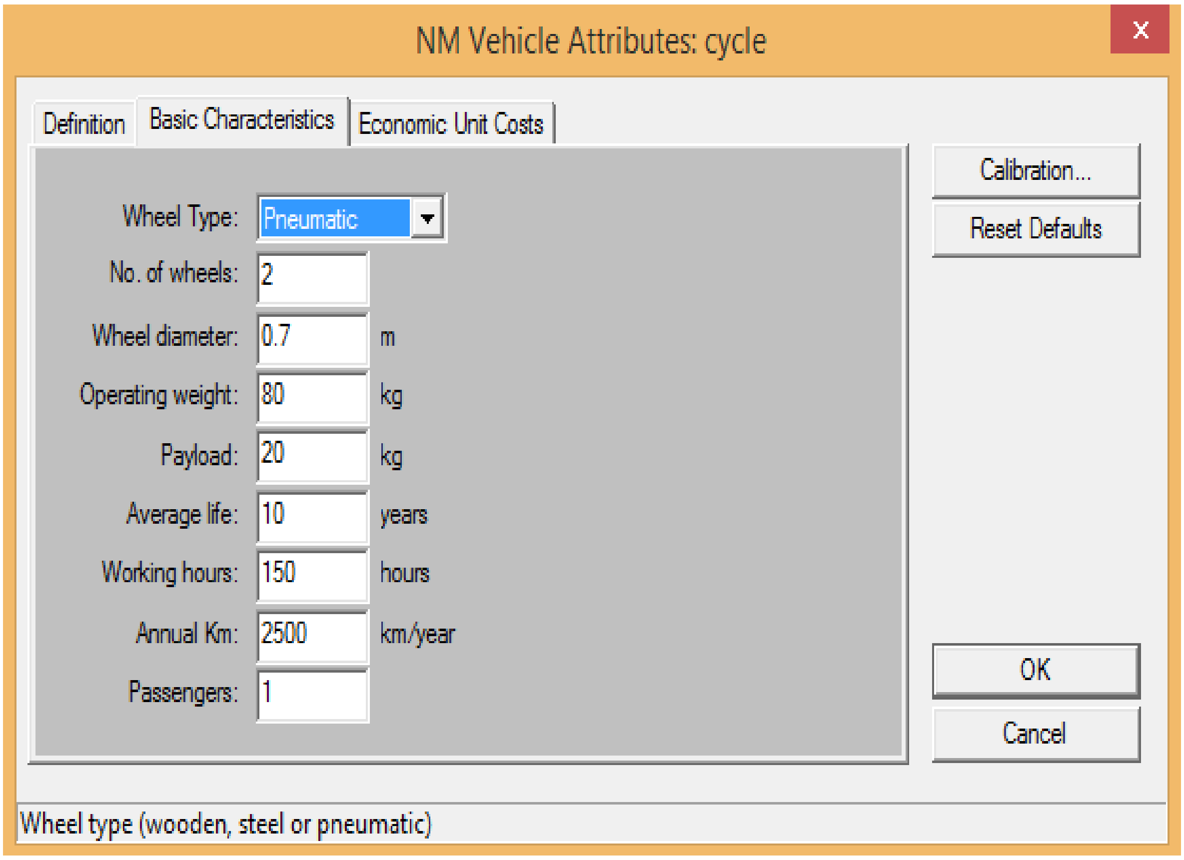


Figure 5.7 : Non-Motorised Vehicle Characteristic Data

5.3 Procedure for Calibrating HDM-4 Models

In calibration our aim is to find calibration factor (k) value for every deterioration model in HDM-4 which provides us the most reliable prediction data with respect to field. To do so we need to have enough data for distresses. To correctly calibrate the models we need to provide right input values for a location and it will provide us with on output.

Data of 5 years (2012-2016) of 5 local streets was considered for level 1 and level 2 calibration, including traffic volume, pavement age, deflection, values of defects like cracking, ravelling, potholes, etc. Data of year 2012 was used as input data and values of next 3 years were predicted using HDM-4 model which was then validated for year 2016. In this study 'k' value for progression factor have been found as there was no initiation data available but the values for initiation factors was taken from other study done in India by S. S. Jain; Sanjiv Aggarwal; and M. Parida in 2005.

For progression factors we used different k values as input and obtained different outputs from each of them for every model starting from cracking, then ravelling, then potholes and in last roughness and predicted output values were compared with the actual or observed values and there R^2 and root mean square error were compared, 'k' value with highest R^2 and lowest

RMSE were adopted for each model. The calibration factors adopted are shown below with their R^2 and RMSE values.

5.4 Problems faced

Data set for calibration was only of 15 points which is way too low it was because there are no records for low volume local streets with the Municipal Corporation and the data used was collected by students of Thapar Institute for their graduation project. Therefore calibration of roughness gave unexpected results.

Though model of cracking, ravelling and pothole show good results while calibrating the validation model showed reduction in R^2 value as validation was done with 5 sections only. The HDM-4 software gave consistent value of rutting for the created road and vehicle data set the calibration of rutting had to be skipped.

5.5 Calibration Results

Statistical parameters obtained by comparing predicted and observed value for every model with different 'K' factor the observation made are that cracking progression model show good R^2 value of 0.8615 and least RMSE value of 0.331311 at calibration factor 0.25. The ravelling progression model also show good result at 'K' value of 0.13 with higher R^2 value of 0.89 and RMSE figure 0.980. Same trend was seen for pothole progression but the calibration factor (K) was on higher side with a value of 2 showing R^2 of 0.884 and RMSE of 1.06. Roughness progression calibration showed a mean sqaure error as low as 0.6964 which is good enough and the factor was taken as 4.

5.6 Validation of Calibration Factors

Validation of each model is important to know that the results getting from them are reliable and how much further change is required in them in future. The parameters used to validate the models are same that were used in calibration that is coefficient of determination (R^2) and root mean square error (RMSE). Higher the R^2 and lower the RMSE means results obtained prediction models are acceptable.

For validation 5 roads of same type from same city were selected and the deterioration was predicted for the year whose values were already known, and both predicted and observed values were compared. Roughness being the most important factor in condition assessment was choosen for validation and showed good results with R^2 as high as 0.82 shown in figure 5.8 and 0.2937 as RMSE.

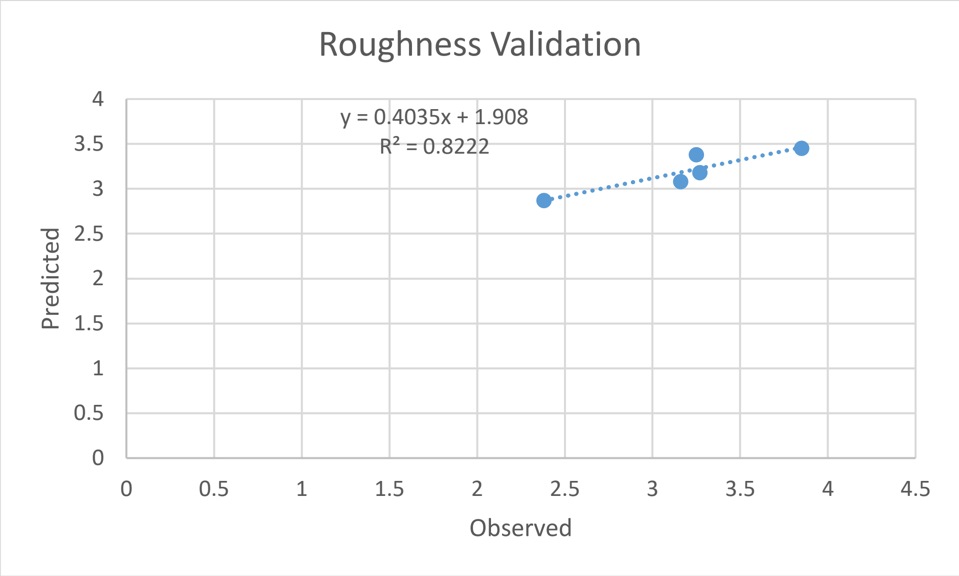


Figure 5.8 : Valdation of Roughness Model

5.7 Using HDM-4 to Develop PMMS

The detailed discussion of role of HDM-4 in development PMMS have already been done in chapter 2, now a database have to be created in HDM-4 to input all the information collected in field for analysis.

5.7.1 Road Network

Data collected which is related to road characteristics and condition is feeded in this module, a road network named 'Patiala local streets' was created and the information of all the 10 roads was input. Screenshots representing all the input data along with 'Section Name' and 'Section ID' are shown below in figure 5.9 to 5.11.

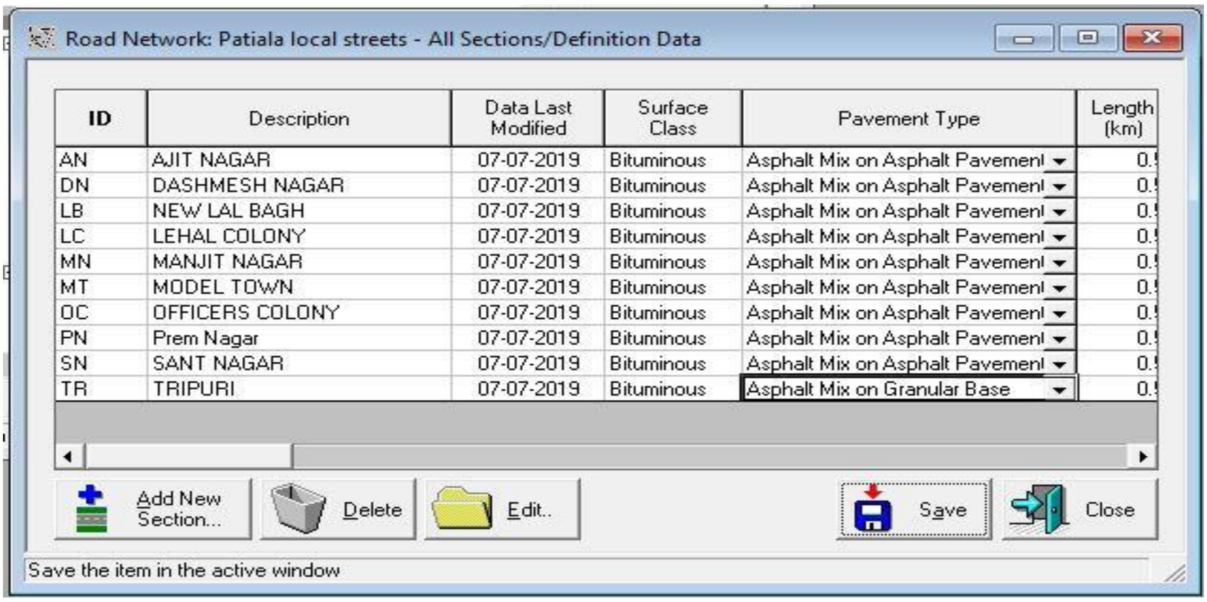


Figure 5.9 : Road Network Under Study in HDM-4

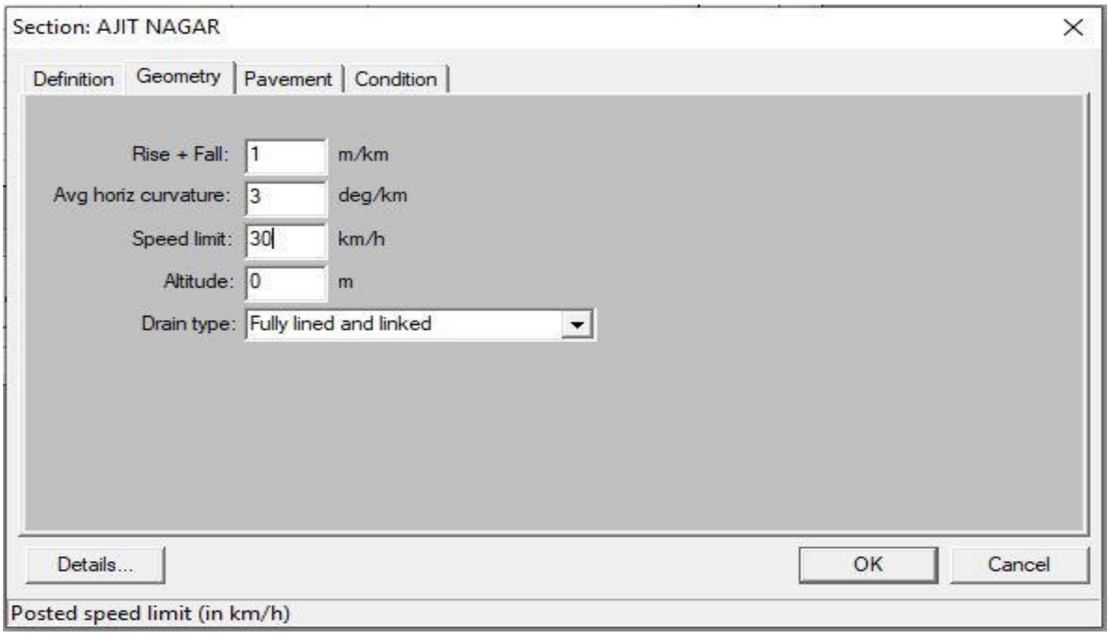


Figure 5.10 : Road Geometry Data for Section AN

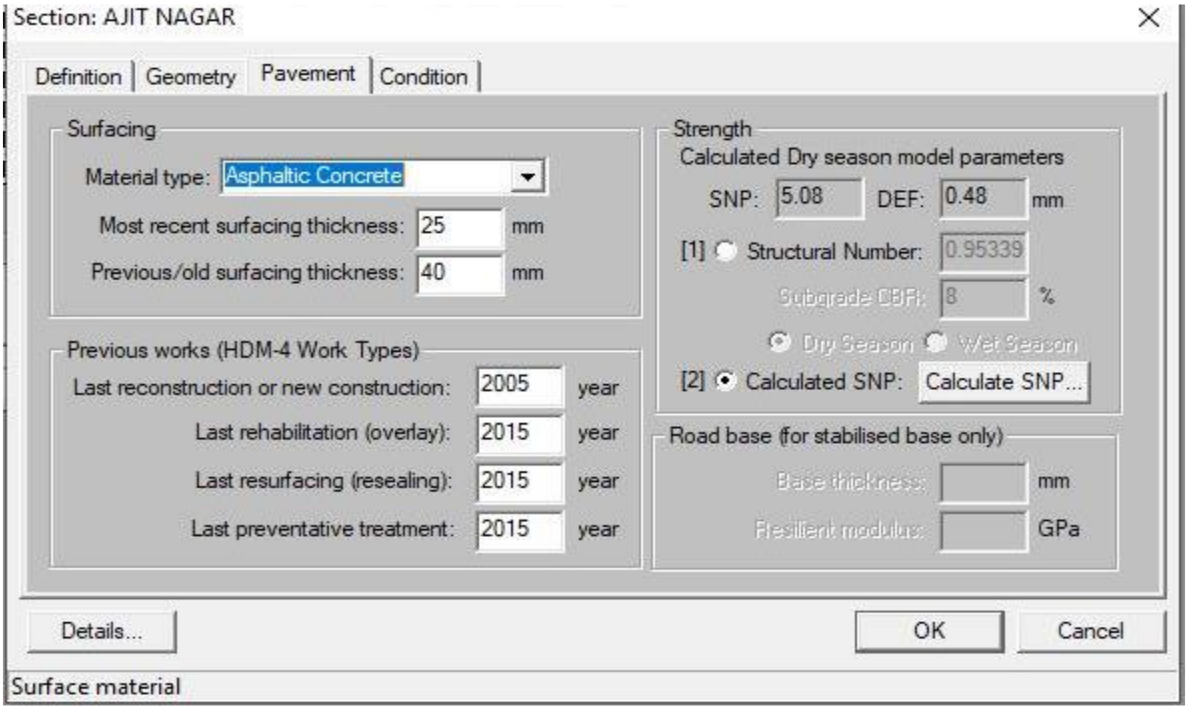
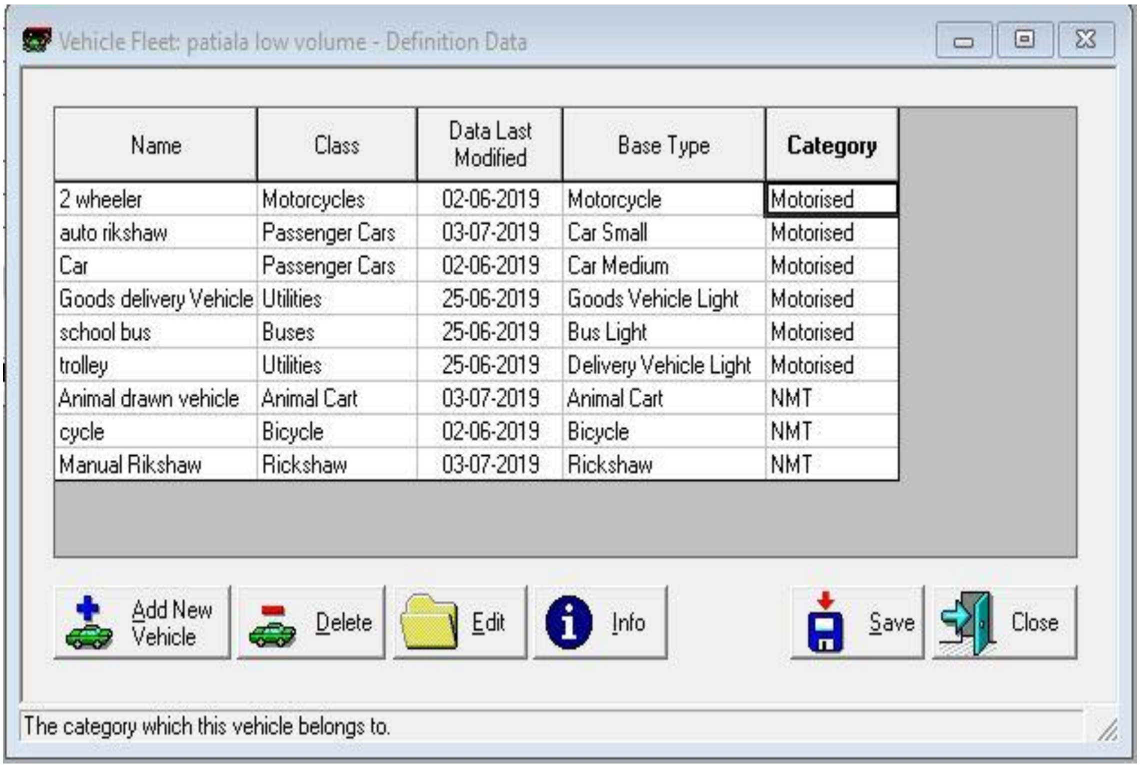


Figure 5.11 : Road Work History of Section AN input in HDM-4

5.7.2 Vehicle Fleet

This module contains all the data associated with traffic using the road network, vehicle fleet created for this study was named as "Patiala low volume' and are shown in figures 5.12.



Name	Class	Data Last Modified	Base Type	Category
2 wheeler	Motorcycles	02-06-2019	Motorcycle	Motorised
auto rikshaw	Passenger Cars	03-07-2019	Car Small	Motorised
Car	Passenger Cars	02-06-2019	Car Medium	Motorised
Goods delivery Vehicle	Utilities	25-06-2019	Goods Vehicle Light	Motorised
school bus	Buses	25-06-2019	Bus Light	Motorised
trolley	Utilities	25-06-2019	Delivery Vehicle Light	Motorised
Animal drawn vehicle	Animal Cart	03-07-2019	Animal Cart	NMT
cycle	Bicycle	02-06-2019	Bicycle	NMT
Manual Rikshaw	Rickshaw	03-07-2019	Rickshaw	NMT

Figure 5.12 : Vehicle Fleet Created for Analysis

5.8 Project Creation and Remaining Service Life of Pavement

For complete analysis of road sections we need to create a project in HDM-4 which will contain both road network and vehicle fleet created earlier as input, to find the remaining service life (RSL) of pavement, that is the period of time in which the road can be used without need of reconstruction when no other M&R activities are performed. The project was named as 'Patiala' and the data was configured for calculation of RSL shown in figure 5.13.

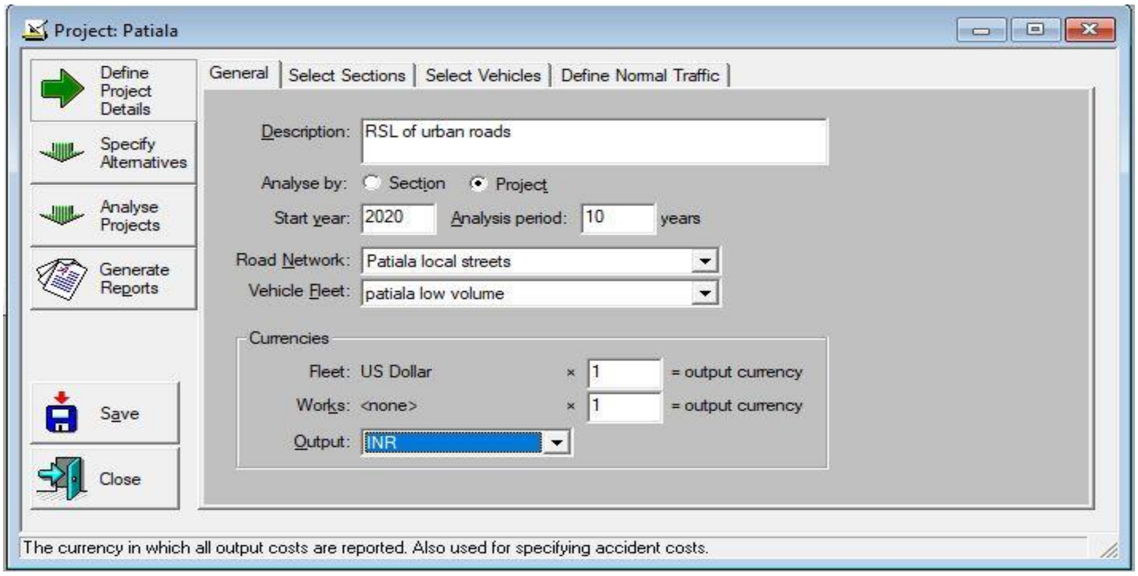


Figure 5.13 : Project Creation for RSL

After providing the basic details selection of road network to be analysed should be performed under ‘Select Section’ tab in figure 5.14.

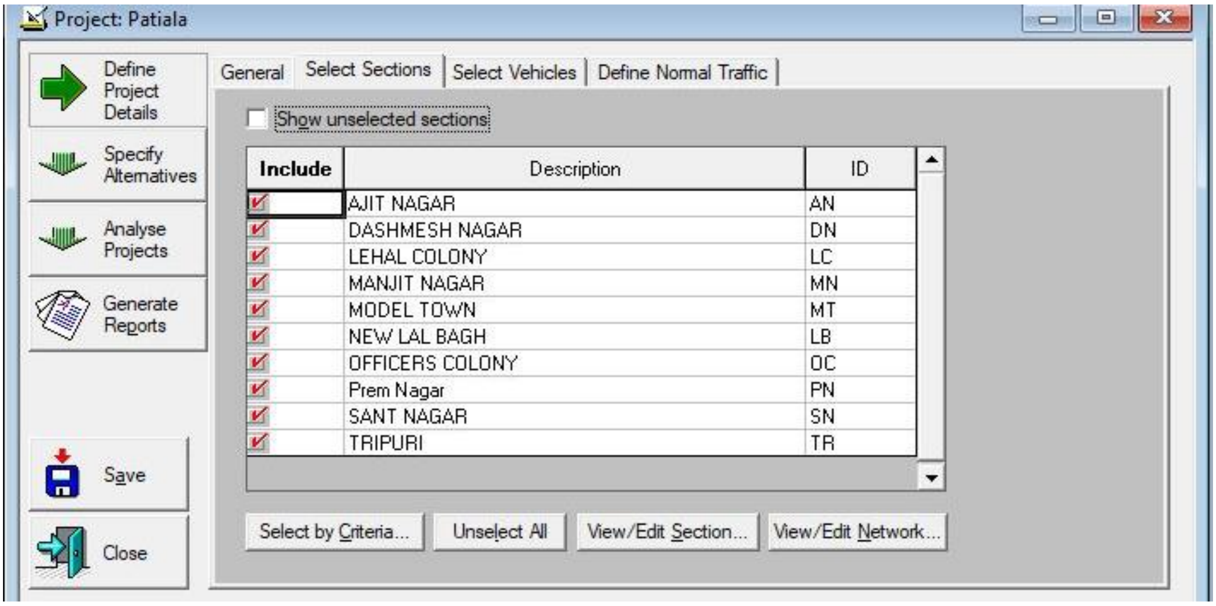


Figure 5.14 : Road Section Data for RSL Project

Next step is to select vehicles using the road network from the selected vehicle fleet (figure 5.15) and defining proportion of each vehicle class and there growth rate along with it (figure 5.16)

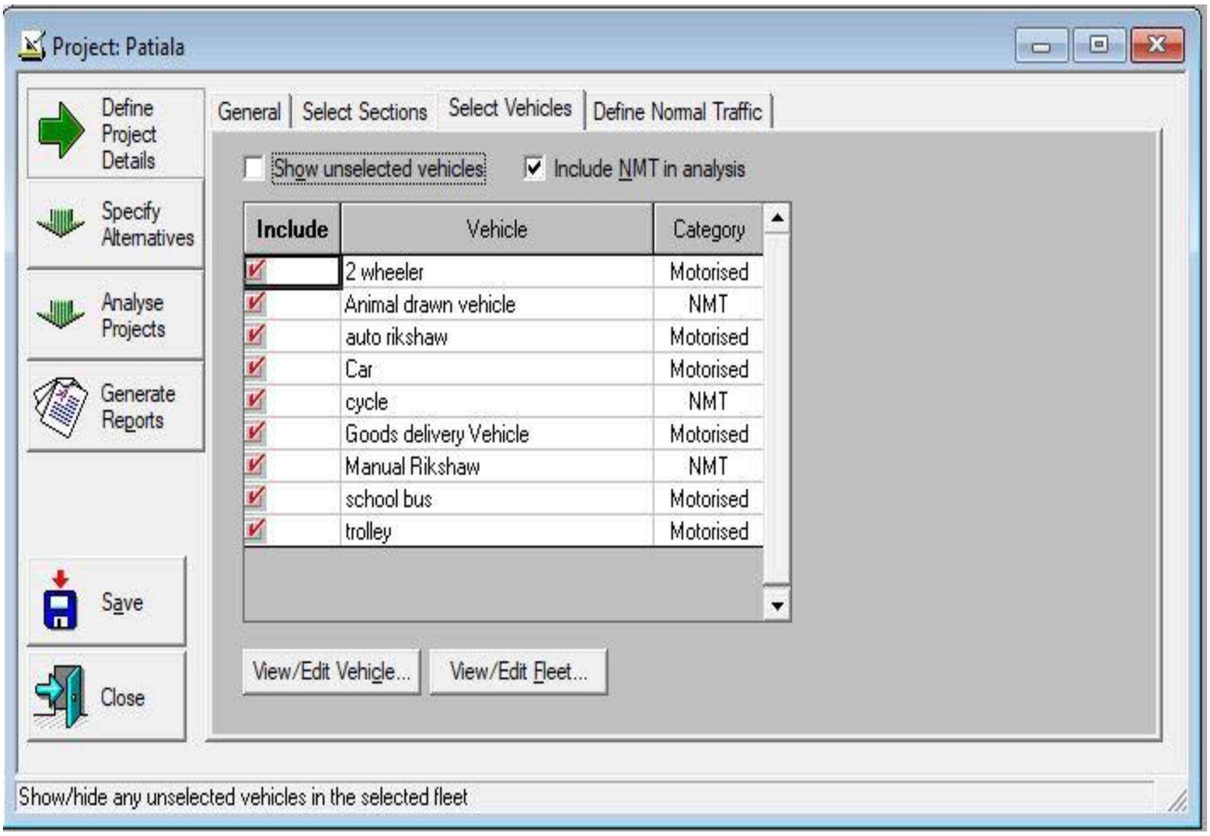


Figure 5.15 : Vehicle Selection for RSL Project

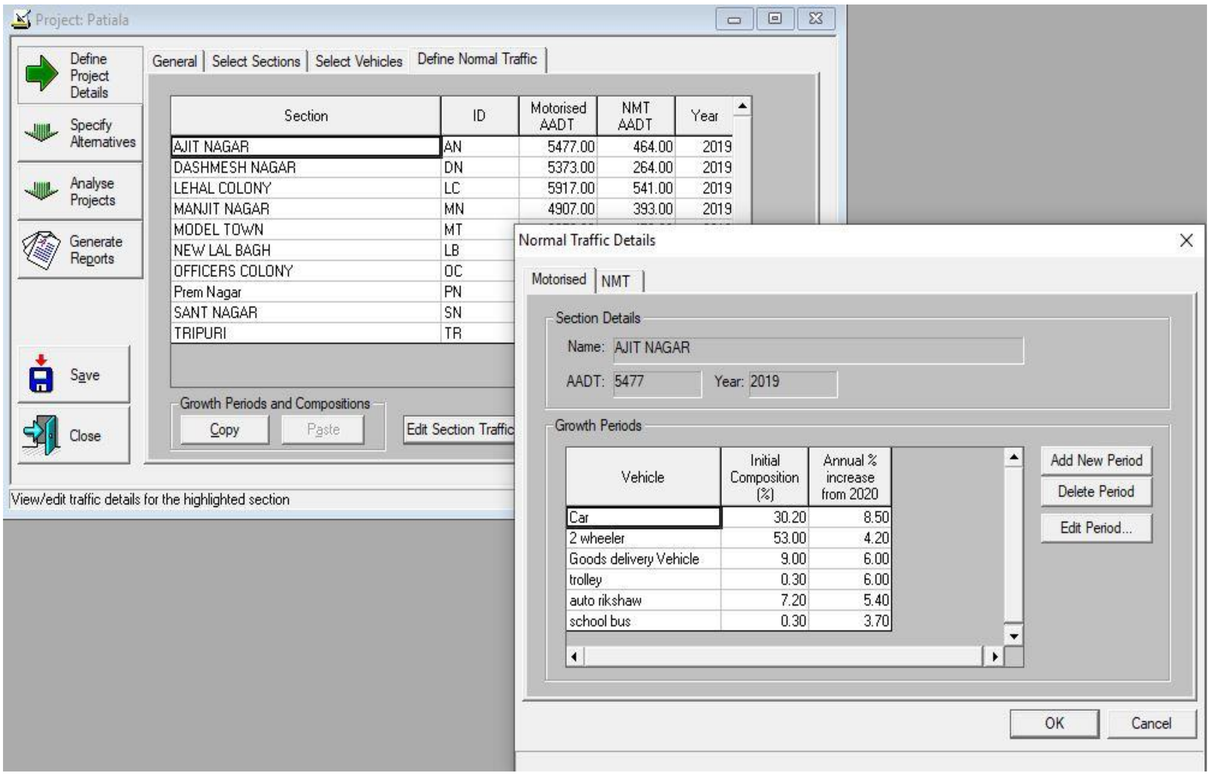


Figure 5.16 : Details of Vehicle Fleet Data

After all the parameters are defined and the data is feeded into created project, M&R activities are assigned under 'Specify Alternatives' tab. For determining RSL only reconstruction of pavement is assigned as a condition responsive activity that will trigger if roughness of road becomes more than equal to 8 IRI, after this project is analysed and report is generated to check the results. Figure show the specified maintenance activity and project analysis respectively.

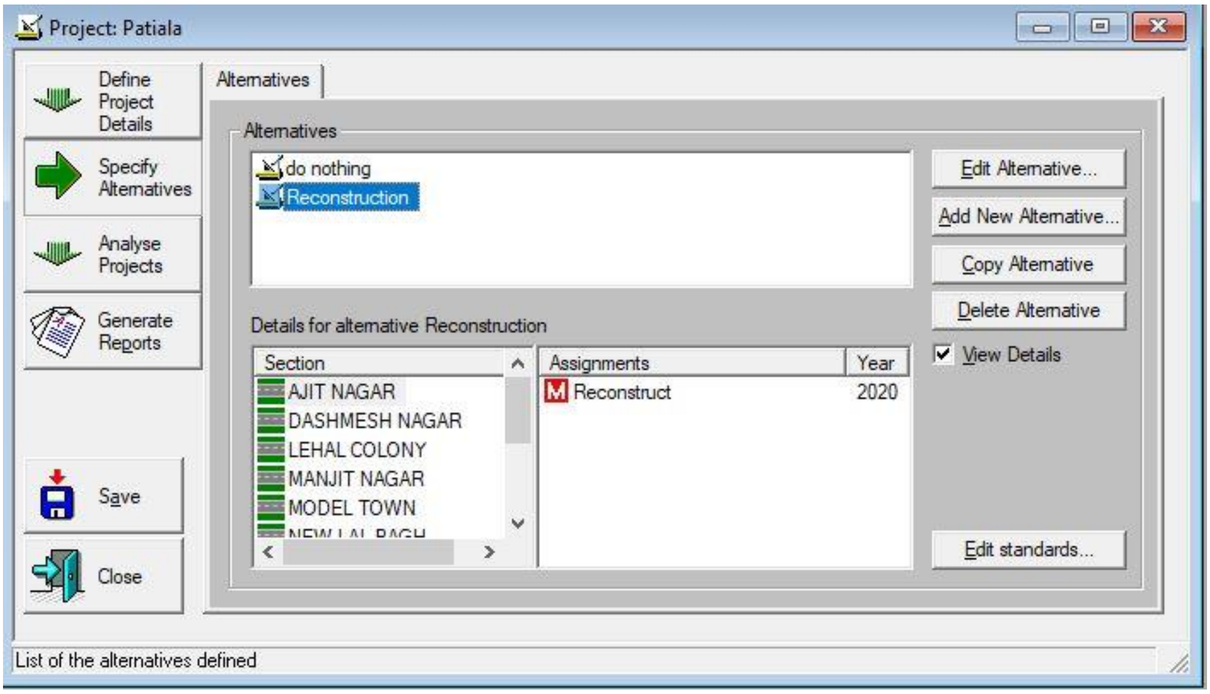


Figure 5.17 : Assigning Alternatives to Road Sections

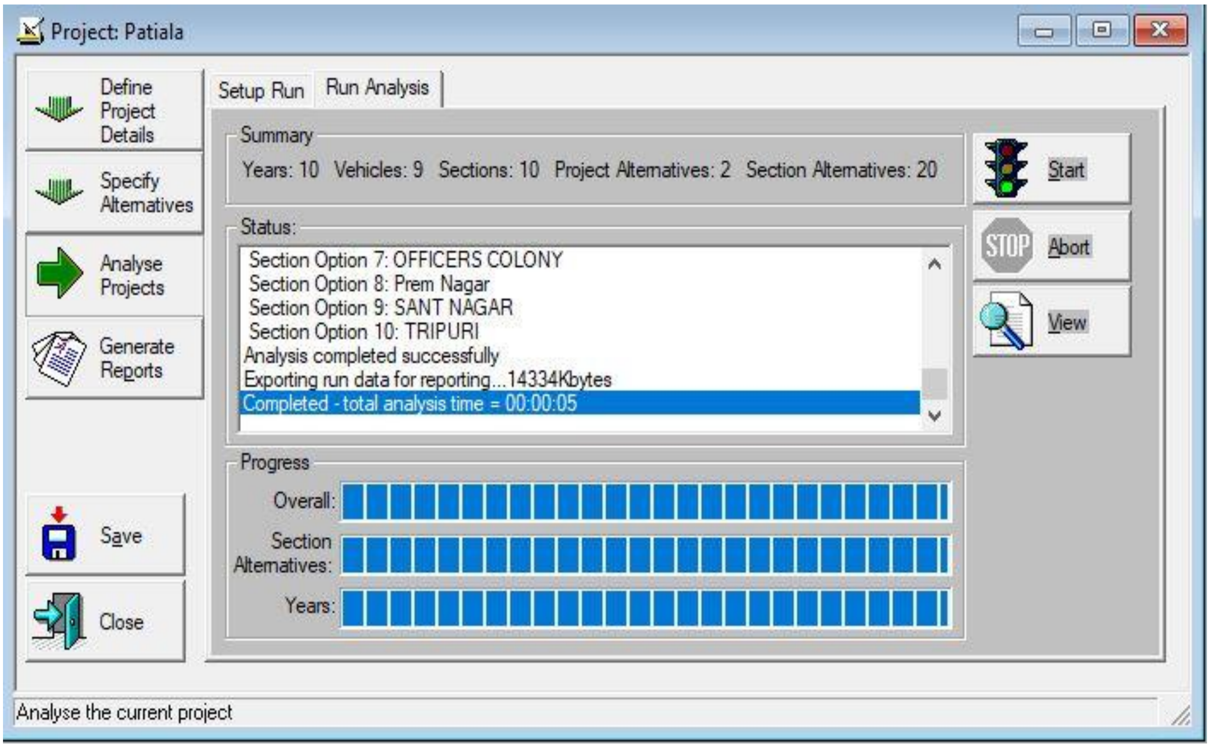


Figure 5.18 : Project Analysis in HDM-4

Graphs between roughness and time in years representing the roughness progression are shown in figures 5.19 to 5.28.

1. Section PN

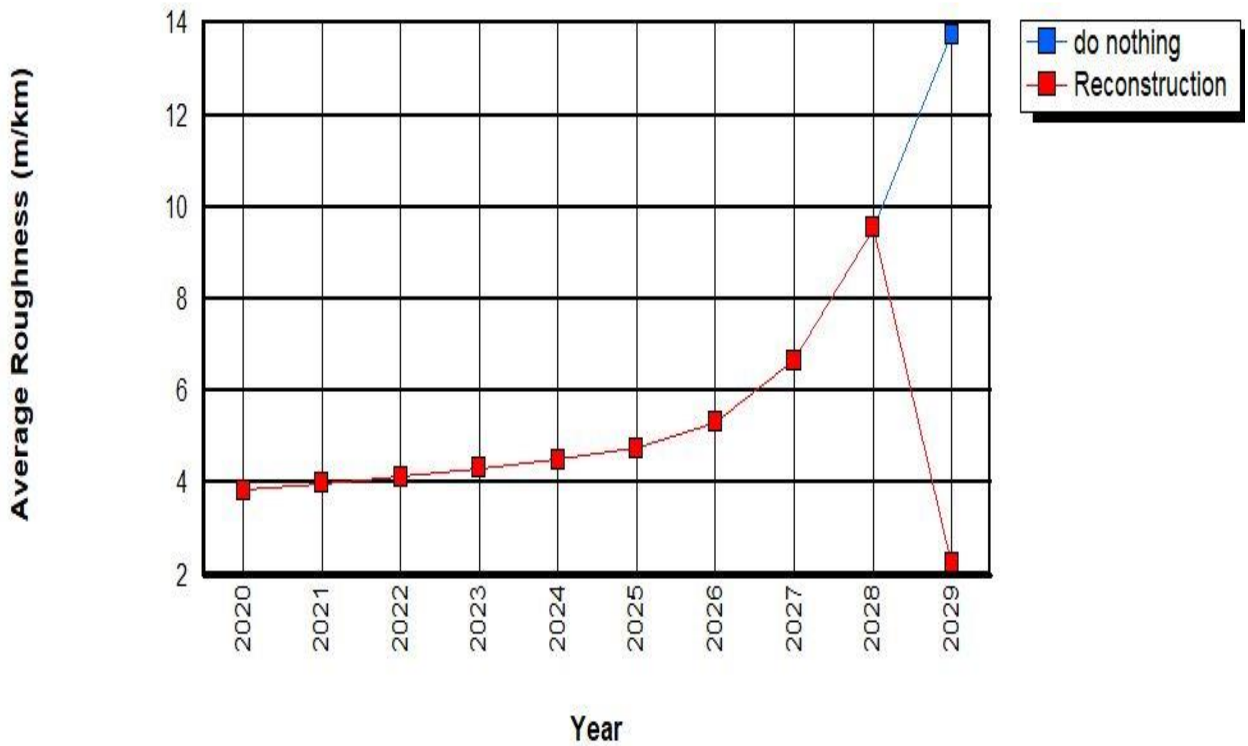


Figure 5.19 : Roughness Progression Graph for Section PN

2. Section MN

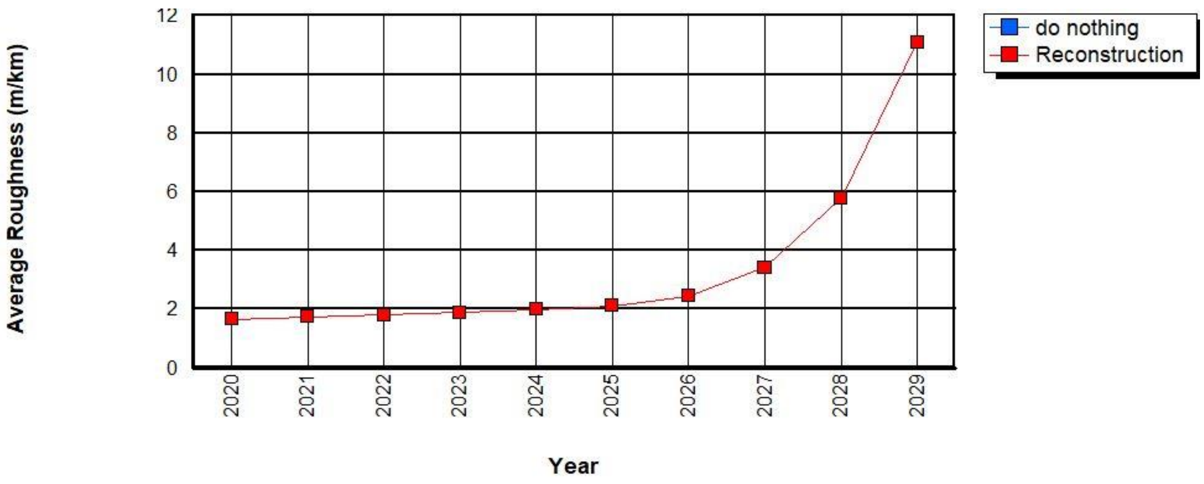


Figure 5.20 : Roughness Progression Graph for Section MN

3. Section DN

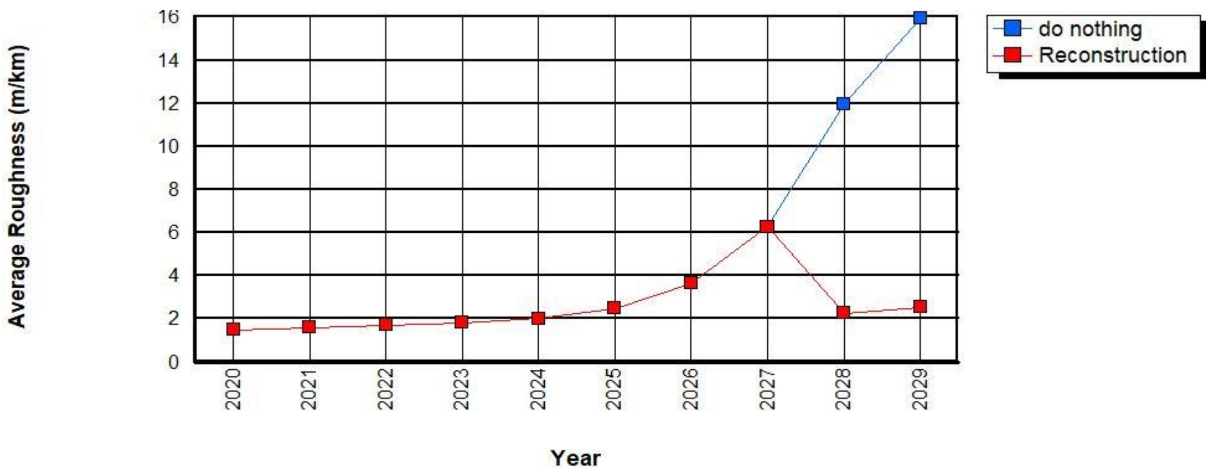


Figure 5.21 : Roughness Progression Graph for Section DN

4. Section TR

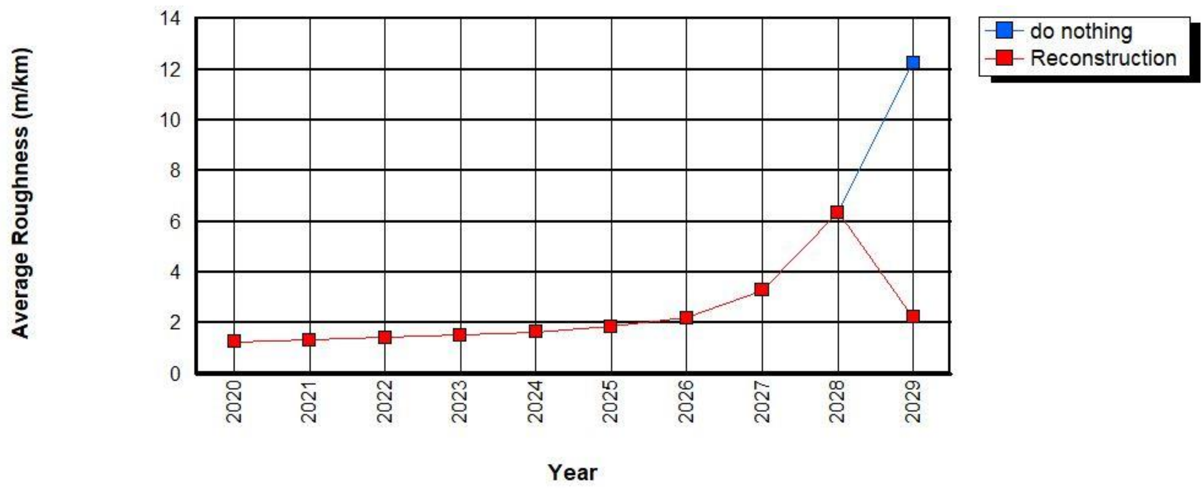


Figure 5.22 : Roughness Progression Graph for Section TR

5. Section LC

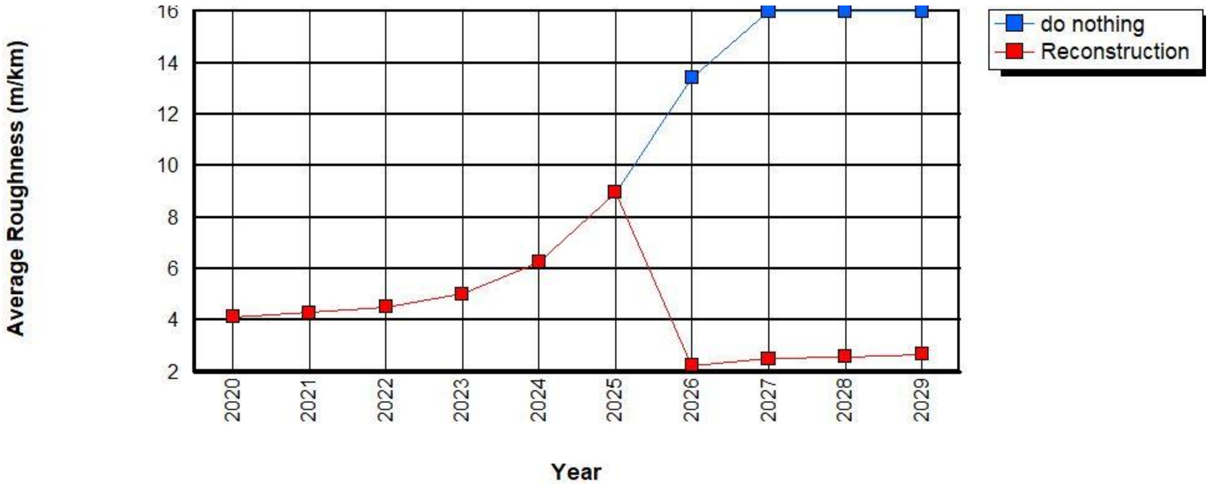


Figure 5.23 : Roughness Progression Graph for Section LC

6. Section SN

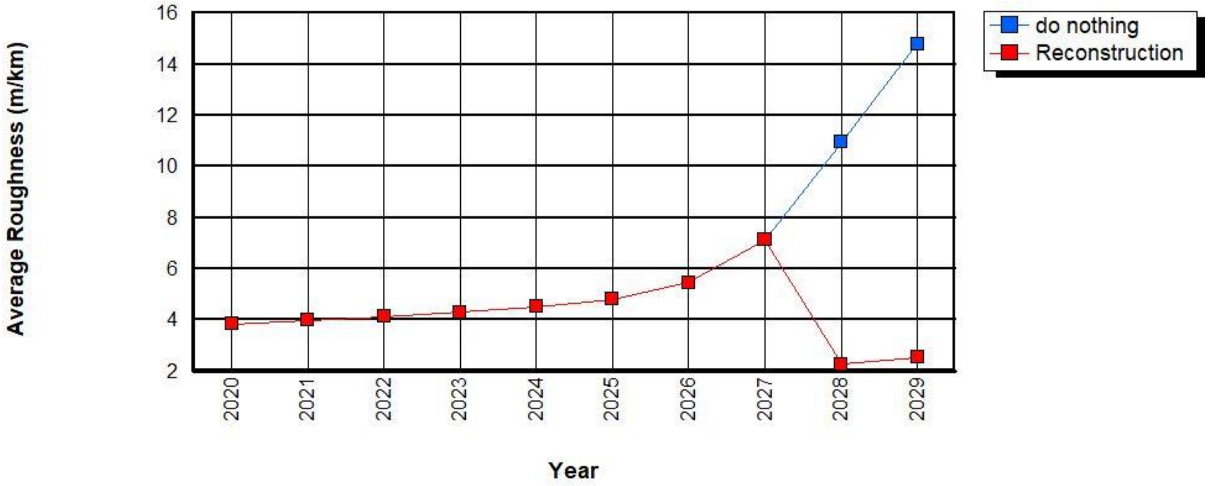


Figure 5.24 : Roughness Progression Graph for Section SN

7. Section OC

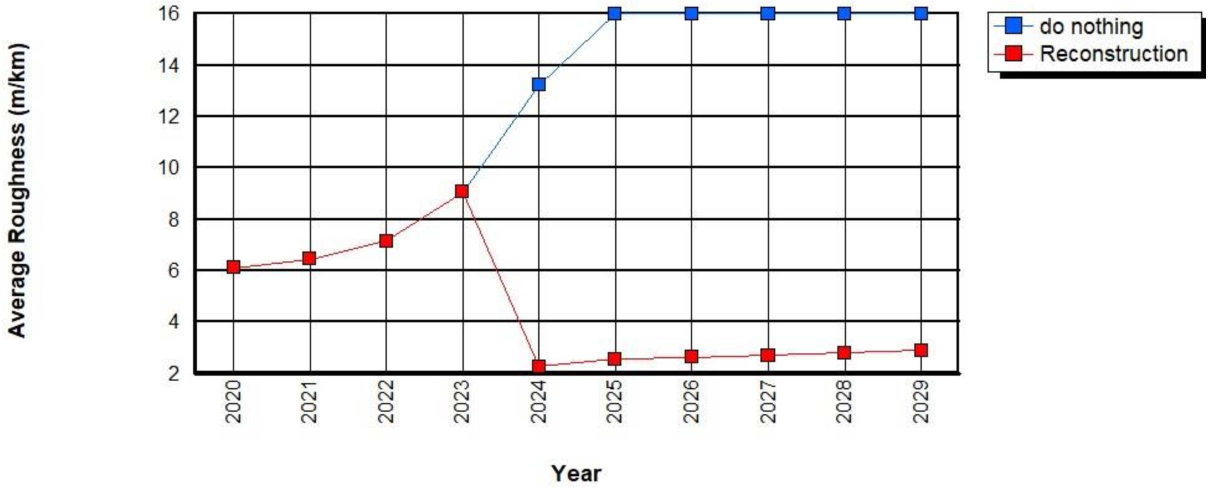


Figure 5.25 : Roughness Progression Graph for Section OC

8. Section LB

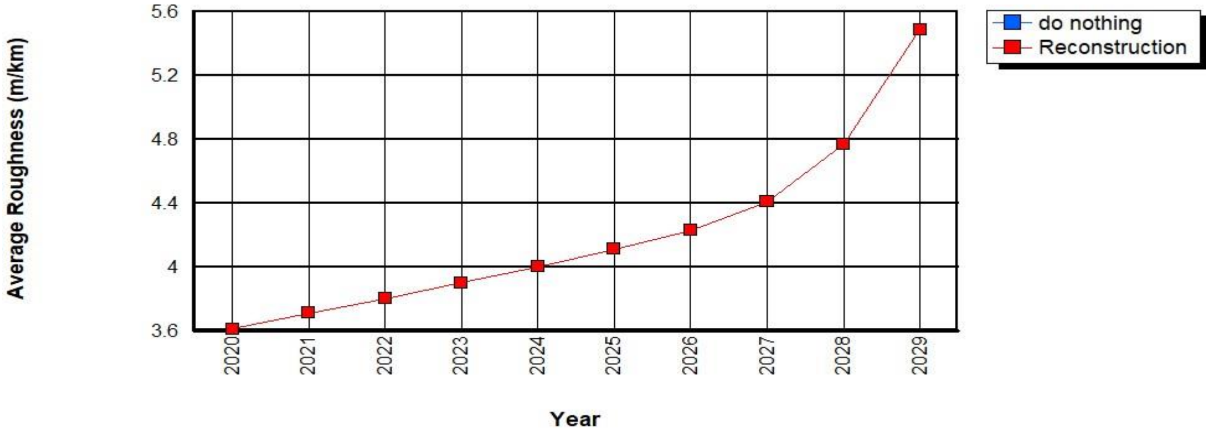


Figure 5.26 : Roughness Progression Graph for Section LB

9. Section AN

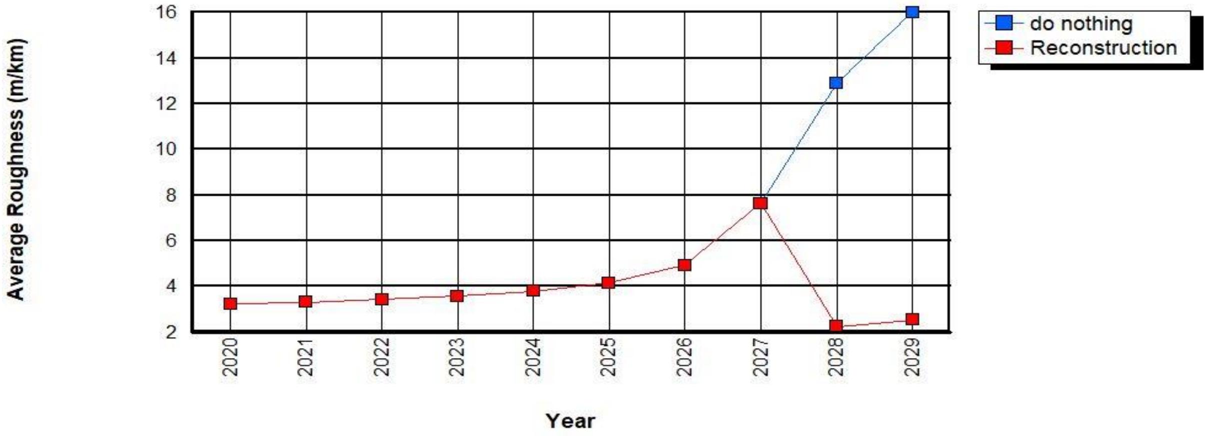


Figure 5.27 : Roughness Progression Graph for Section AN

10. Section MT

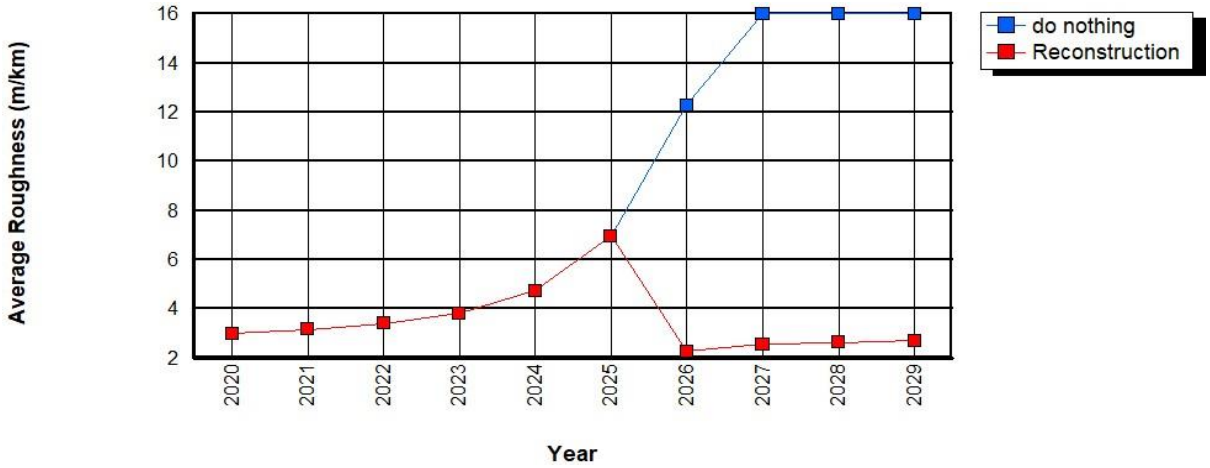


Figure 5.28 : Roughness Progression Graph for Section MT

RSL observed from above roughness progression graph are summarized in table 5.1

Table 5.1 : Remaining Service Life of Pavement Sections

Section ID	Section Name	Remaining Service Life (RSL) in years
PN	Prem Nagar	9
MN	Manjit Nagar	10
DN	Dashmesh Nagar	8
TR	Tripuri Road	9
LC	Lehal Colony	6
SN	Sant Nagar	8
OC	Officers Colony	4
LB	New Lal Bagh	11
AN	Ajit Nagar	8
MT	Model Town	6

5.9 Application of Proposed M&R Activities

While deciding M&R activities serviceability level of road is considered, both routine and preventive treatments are selected for the project analysis and results are compared. Table 5.2 represent the M&R alternatives that are proposed for this study.

Table 5.2 : Proposed M&R Alternatives

M&R Strategy	Works Standard	Description Of Work	Intervention level
Base Alternative	Routine	Crack Sealing	Scheduled Annually
		Patch Work	Scheduled Annually
Alternative 1	Resealing	Provide 25mm SBSD	Total Damaged Area >= 8%
	Thin Overlay	Provide 25mm PC	4 IRI =< Roughness =< 5.8 IRI
Alternative 2	Thick Overlay	Provide 40mm BM	5.8 IRI =< Roughness =< 8 IRI
Alternative 3	Pavement Reconstruction	Reconstruct with 150mm WBM+50mm BM+20mm PC	Roughness >= 8 IRI

The proposed M&R alternatives were assigned to all road sections under study and analysis of project was carried out and roughness was used as a parameter for comparing the effect of all alternatives on pavements. Additions were made to same project as used during RSL determination. Figure 5.30 to 5.35 show the input requirement for this project.

Project analysis period was set to 15 years, rest all other project details were kept same as RSL project as shown in figure 5.29.

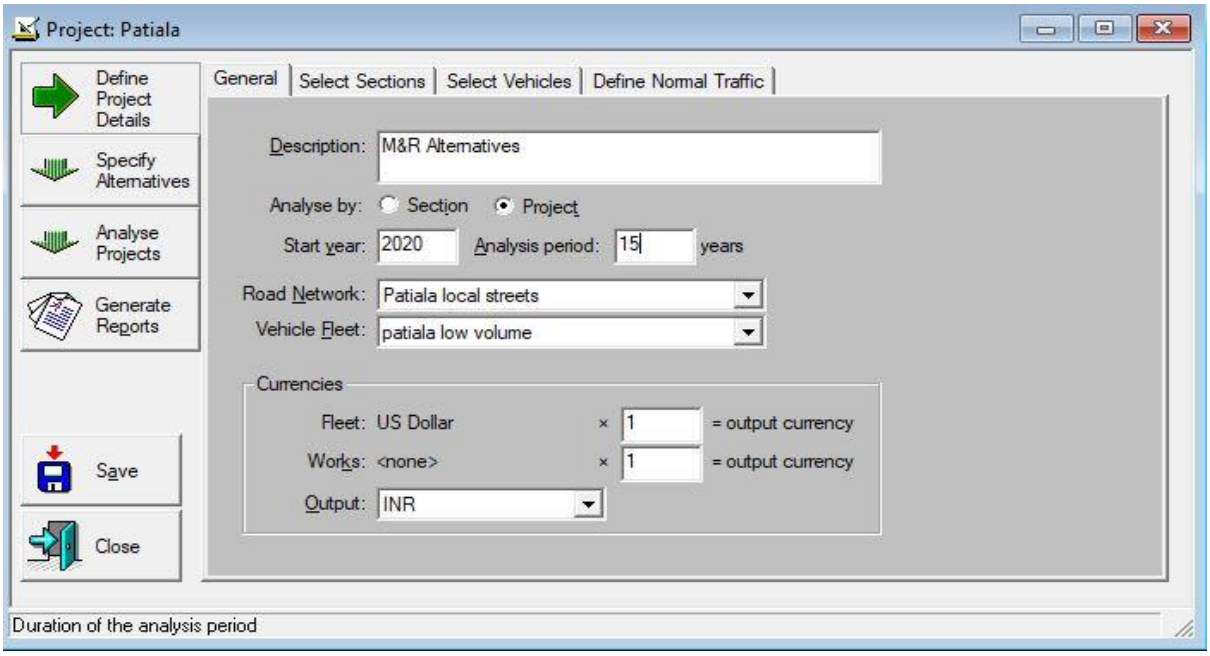


Figure 5.29 : General Data Required by Project

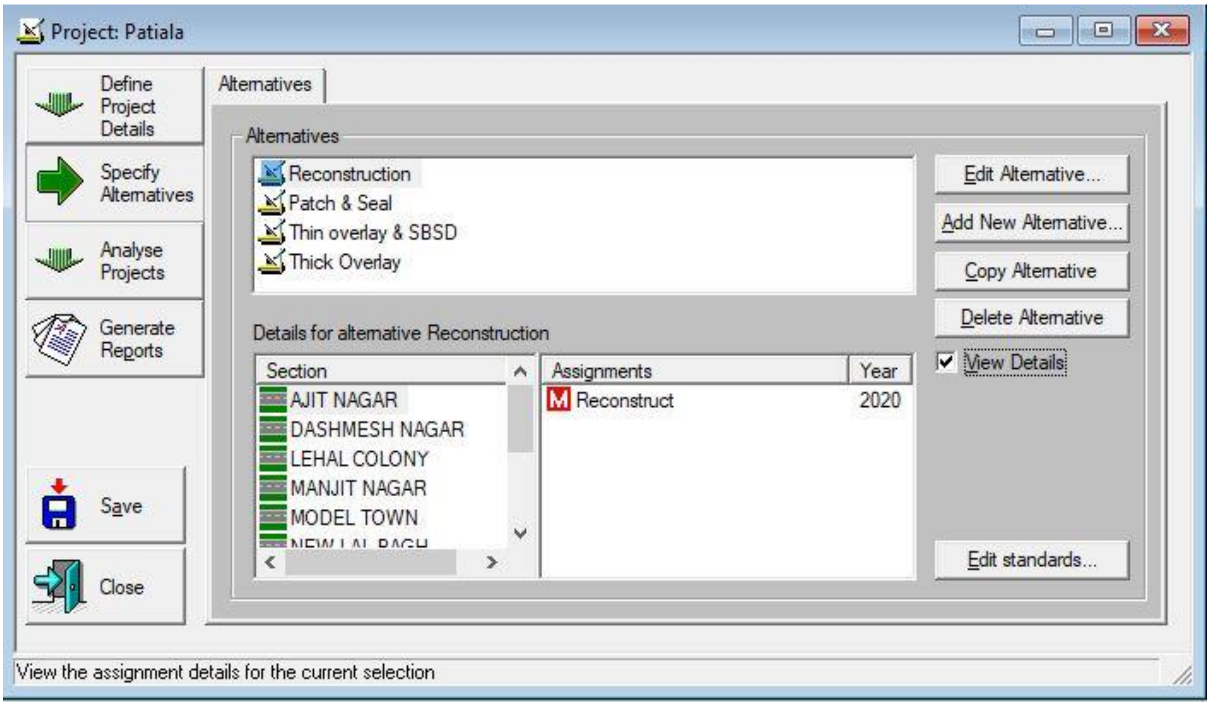


Figure 5.30 : Assigning Proposed Alternatives to Road Sections

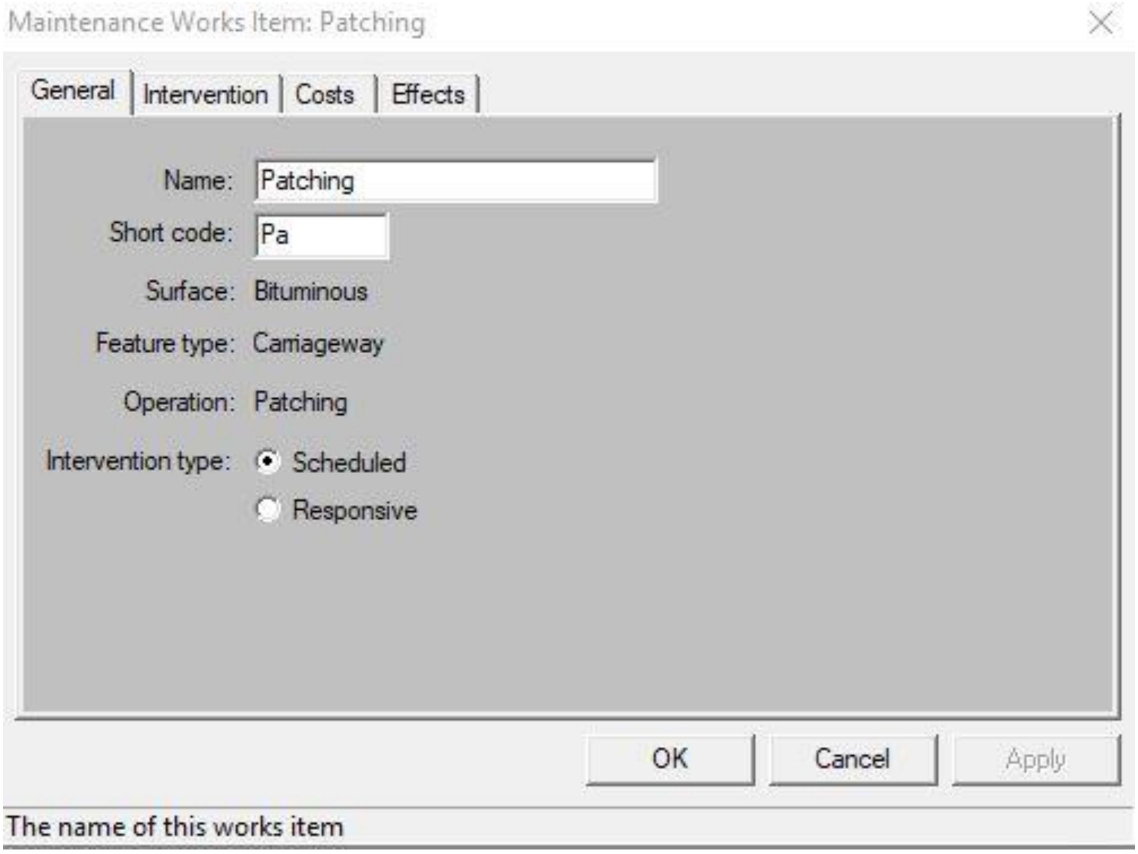


Figure 5.31 : General Information of Maintenance Activity

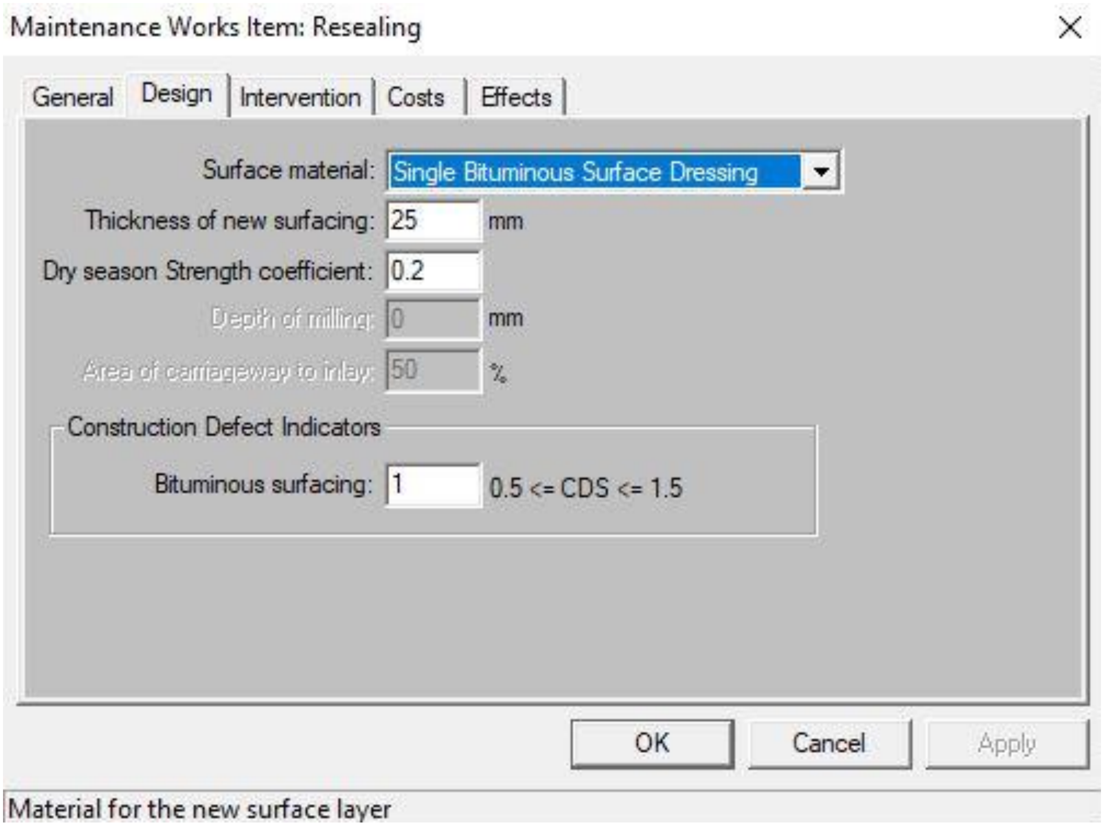


Figure 5.32 : Design of Selected Activity

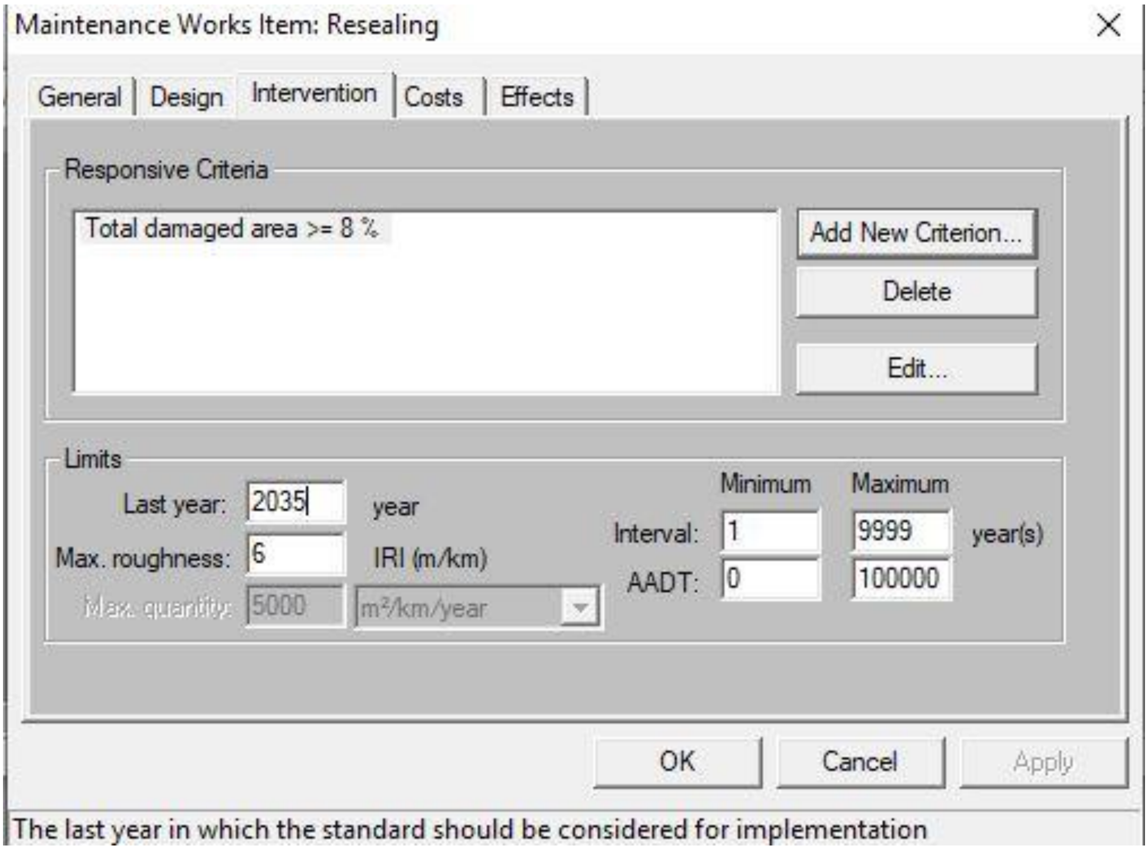


Figure 5.33 : Defining Response Criteria for M&R Activity

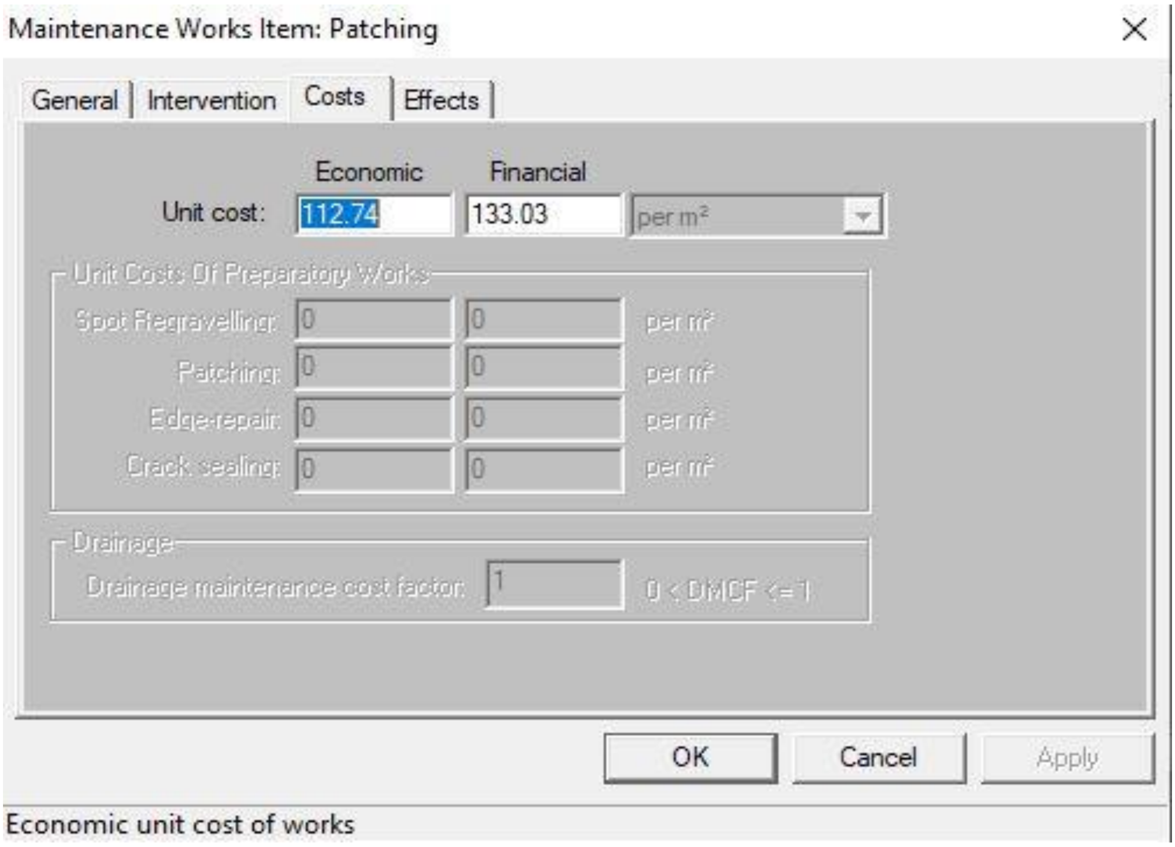


Figure 5.34 : Cost Data Input for the Activity

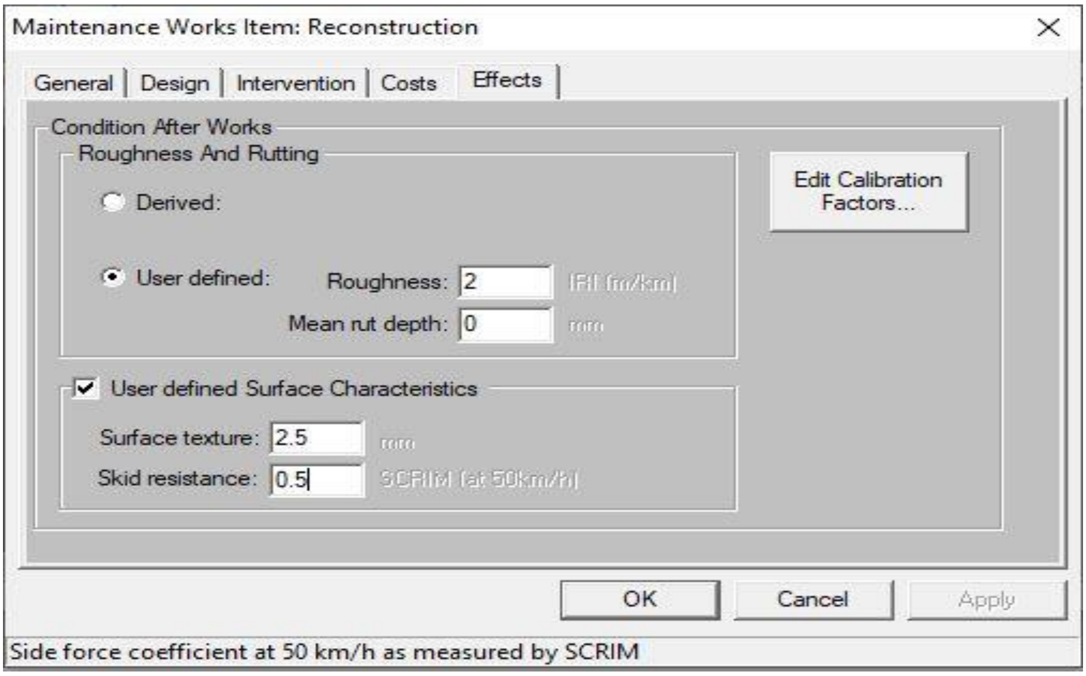


Figure 5.35 : Defining Effect M&R Activity

5.10 Project Analysis

After applying all the M&R alternatives project analysis is carried out as shown in figure 5.36.

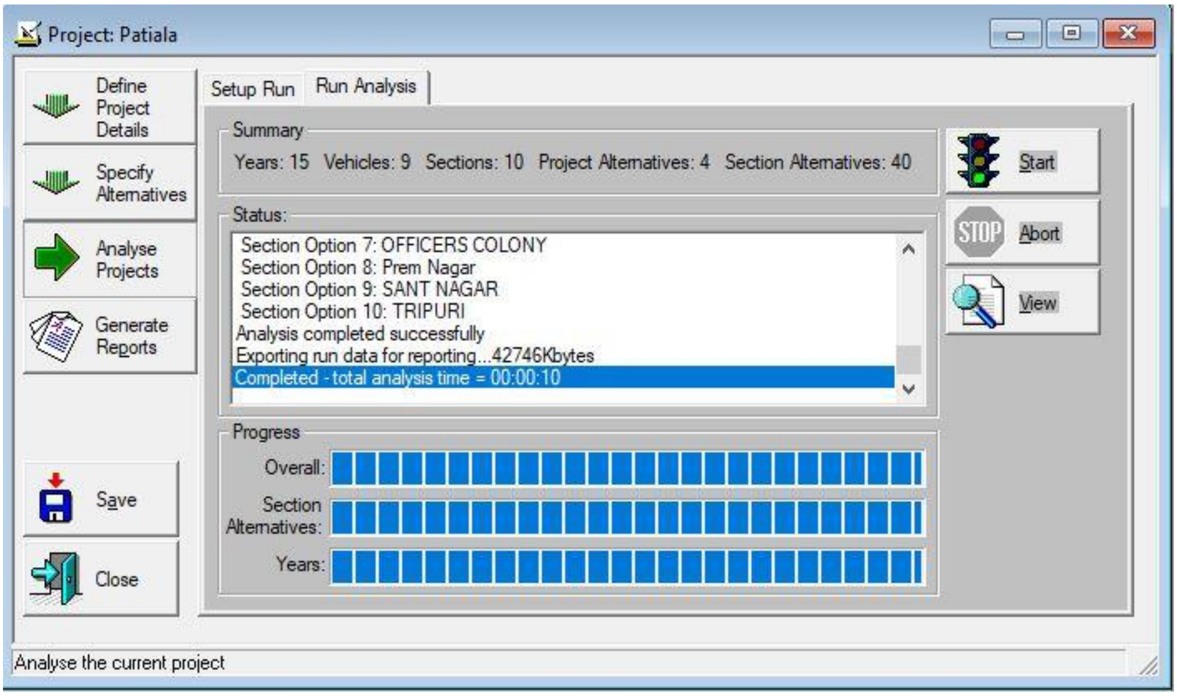


Figure 5.36 : Analysis of Project

Roughness progression graph of all the sections comparing all the alternatives were checked to see whether the proposed M&R activities were successfully applied on specified criteria or not, figure 5.37 to 5.46 represent the roughness progression graph of all the road sections.

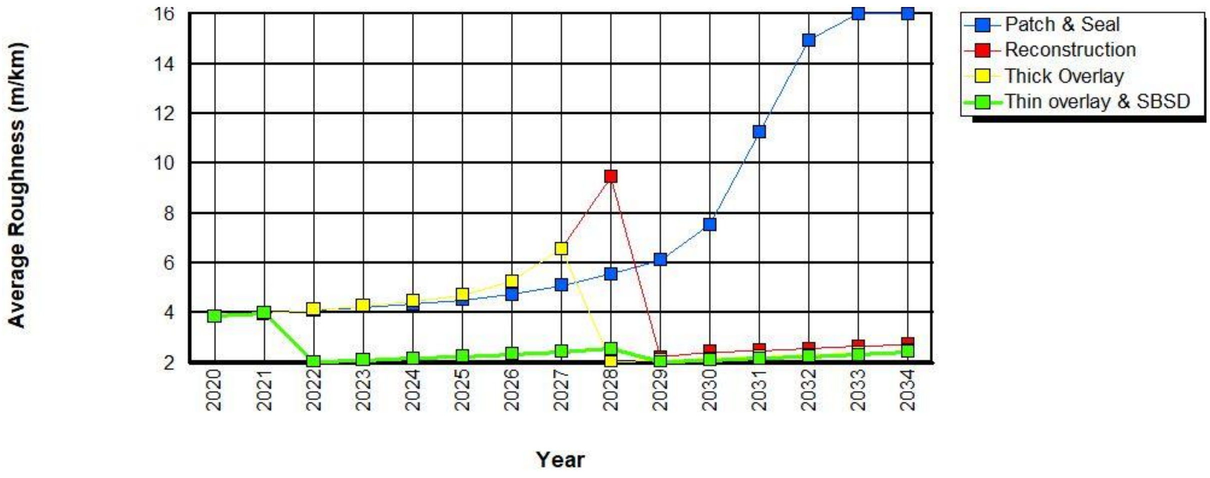


Figure 5.37 : Roughness Progression of All Alternatives for Section PN

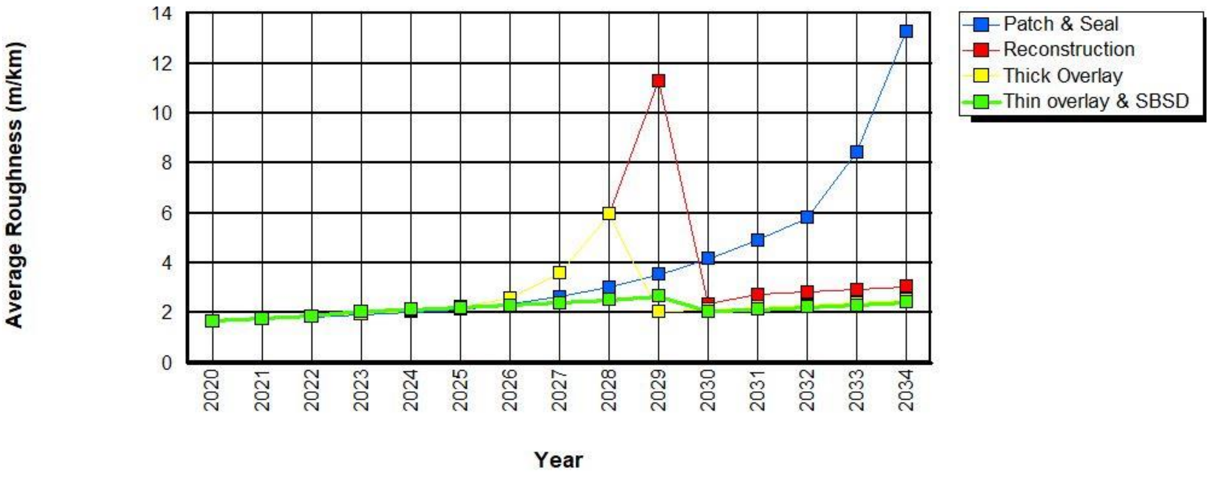


Figure 5.38 : Roughness Progression of All Alternatives for Section MN

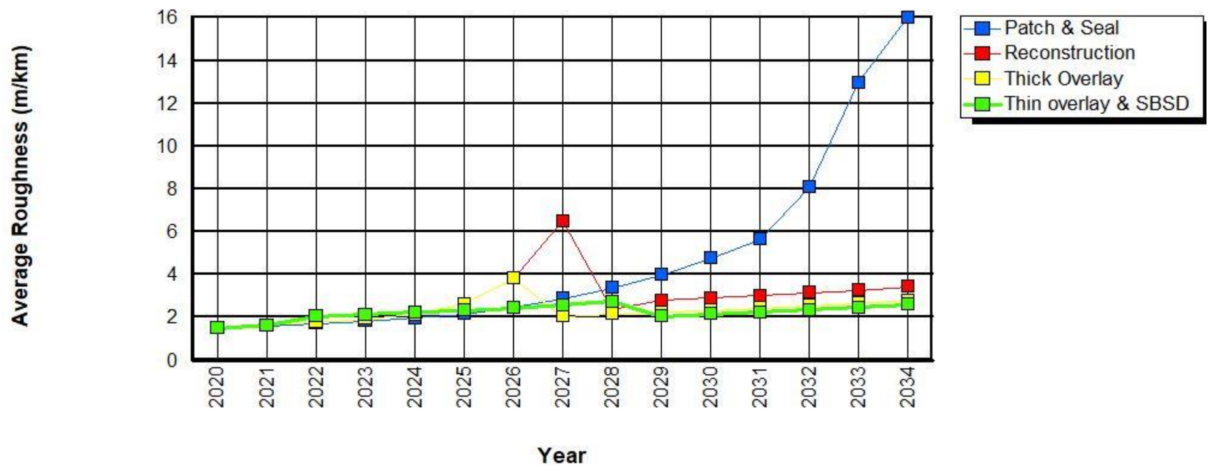


Figure 5.39 : Roughness Progression of All Alternatives for Section DN

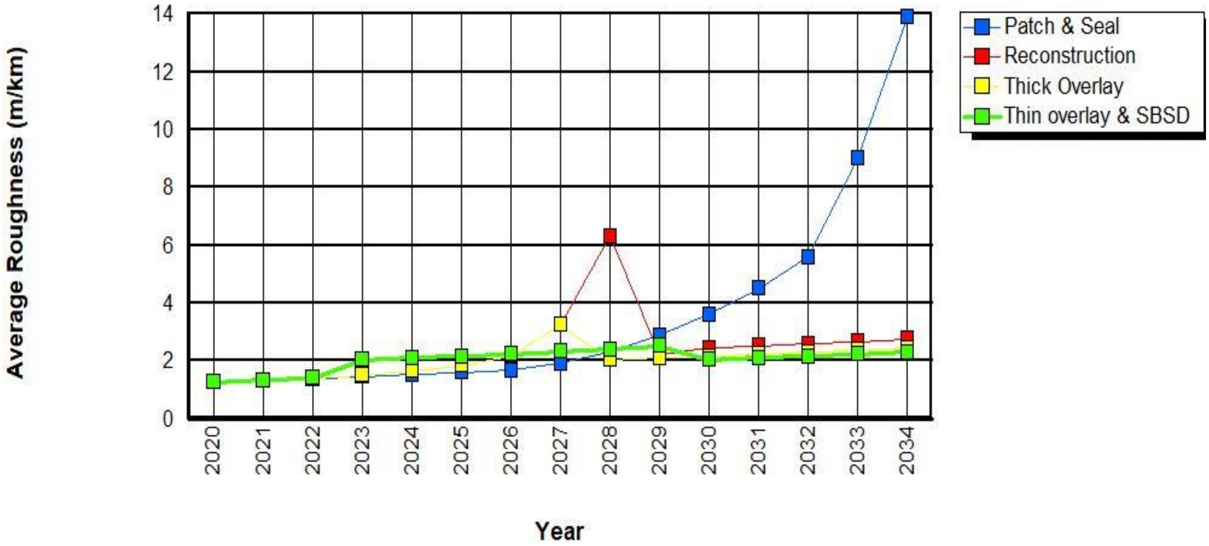


Figure 5.40 : Roughness Progression of All Alternatives for Section TR

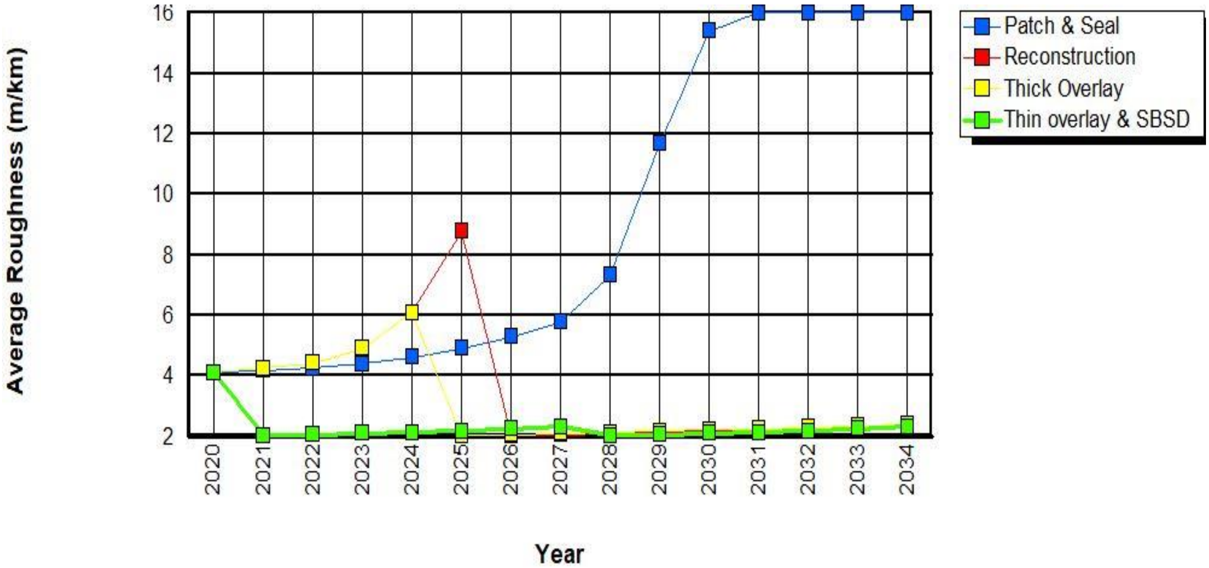


Figure 5.41 : Roughness Progression of All Alternatives for Section LC

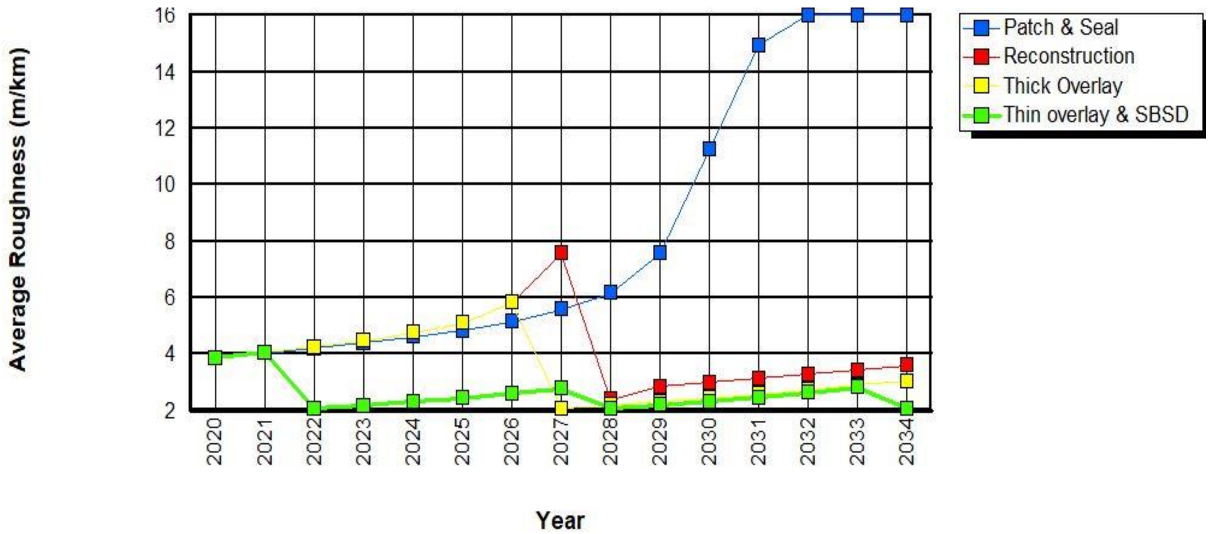


Figure 5.42 : Roughness Progression of All Alternatives for Section SN

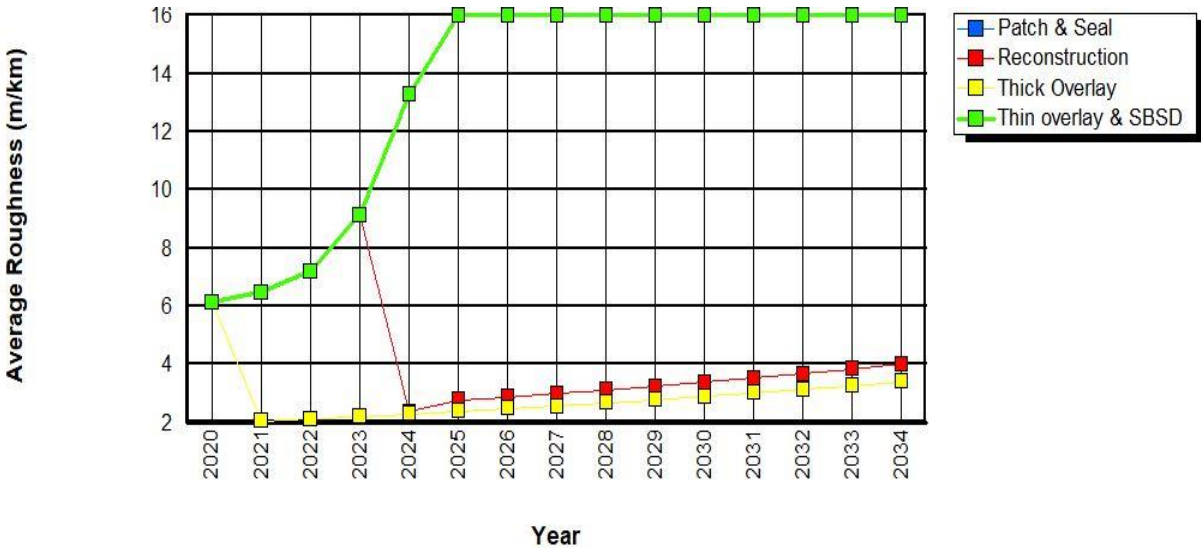


Figure 5.43 : Roughness Progression of All Alternatives for Section OC

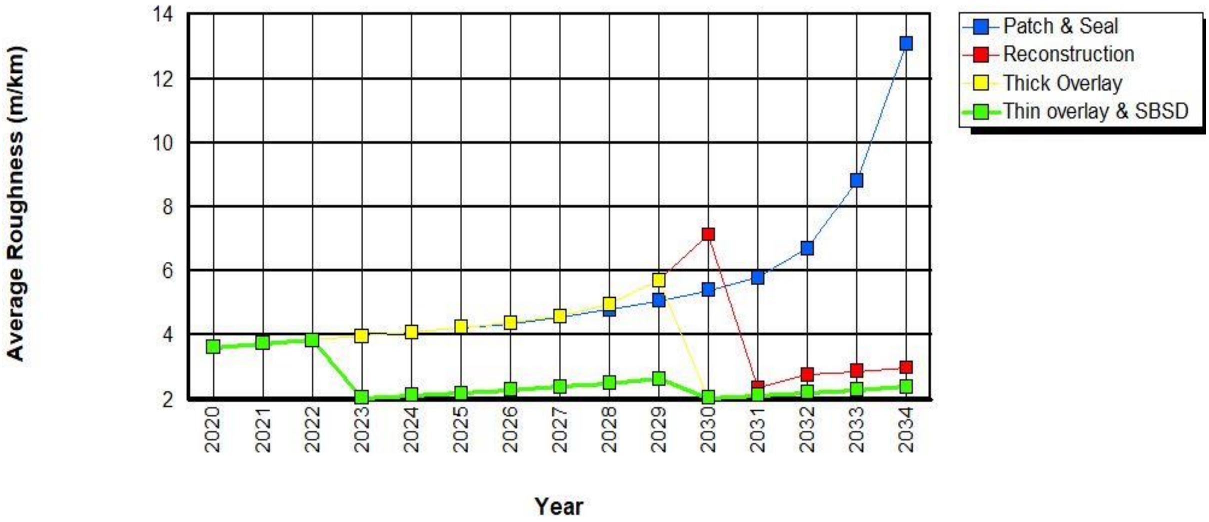


Figure 5.44 : Roughness Progression of All Alternatives for Section LB

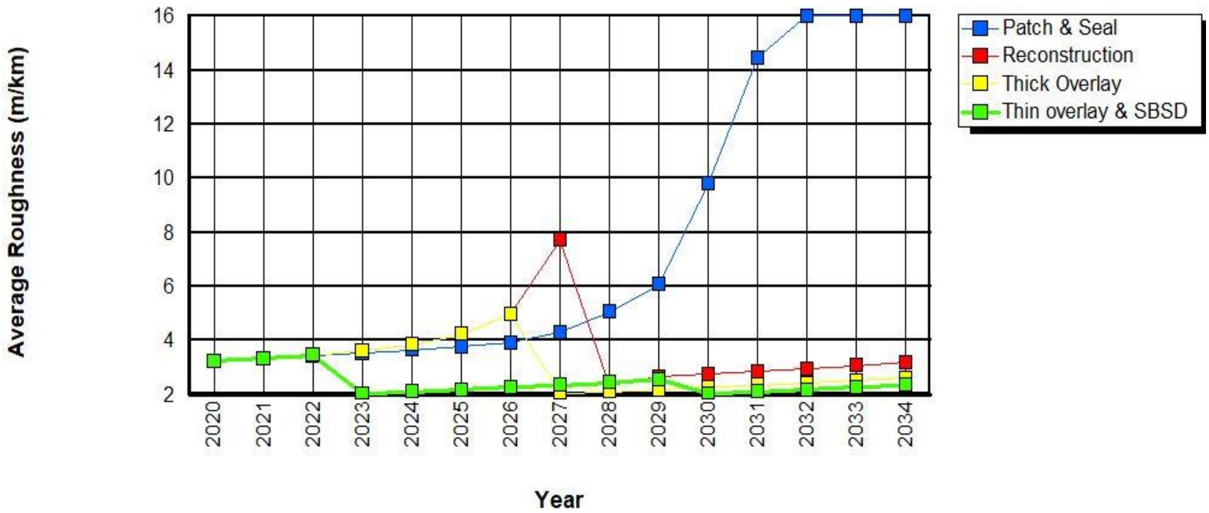


Figure 5.45 : Roughness Progression of All Alternatives for Section AN

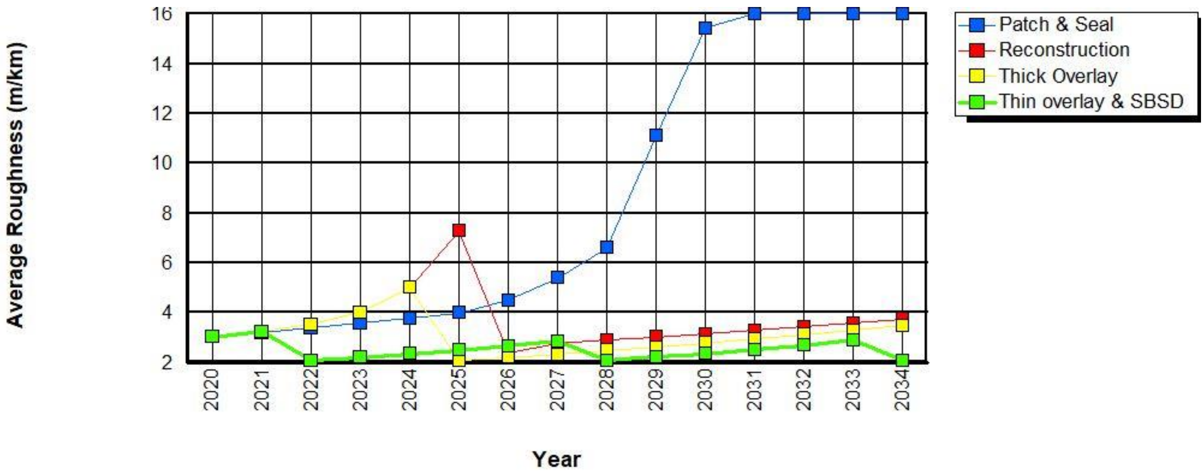


Figure 5.46 : Roughness Progression of All Alternatives for Section MT

5.11 Road Work Summary

It is important to know when to perform a maintenance activity on a road, though we know the trigger point but we need to know the right time or year to perform it and on the basis of deterioration model the PMMS can tell us when to perform a certain alternative. Table 5.3 represent road work summary of proposed alternatives and years in that they are performed.

Table 5.3 : Years in which M&R Alternatives are performed

Section ID	Base Alternative (Patch & Seal)	Alternative 1		Alternative 2 (Thick Overlay	Alternative 3 (Reconstruction)
		Resealing	Thin Overlay		
PN	Annually till 2028	2021, 2028	-	2027	2028
MN	Annually till 2031	2022, 2029	-	2028	2029
DN	Annually till 2030	2021, 2028	-	2026	2027
TR	Annually till 2031	2022, 2029	-	2027	2028
LC	Annually till 2026	2020, 2027, 2034	-	2024	2025
SN	Annually till 2027	2021, 2027, 2033	-	2026	2027
OC	Never	Never		2020	2023
LB	Annually till 2030	2022, 2029	-	2029	2030
AN	Annually till 2028	2022, 2029	-	2026	2027
MT	Annually till 2027	2021, 2027, 2033	-	2024	2025

CHAPTER 6

ECONOMIC ANALYSIS & OPTIMUM M&R STRATEGY

6.1 General

After proposing M&R alternatives figuring out which alternative is the most beneficial is determined by performing economic analysis of every alternative and its effect on road agency cost and road user cost and comparing Net Present Value (NPV) to cost ratio. The alternative having maximum NPV to cost ratio is selected as most beneficial alternative.

6.2 Economic Analysis

Economic analysis under analysis section of project analysis is performed with a discount rate of 12% as prescribed by IRC SP : 30, 2009 keeping 'Patch & Seal' as base alternative shown in figure 6.1. Road Agency Cost (RAC), Road User Cost (RUC), increase in RAC, decrease in RUC are obtained from reports of economic analysis and are summarized in table 6.1 to 6.10 below for all the sections and alternatives.

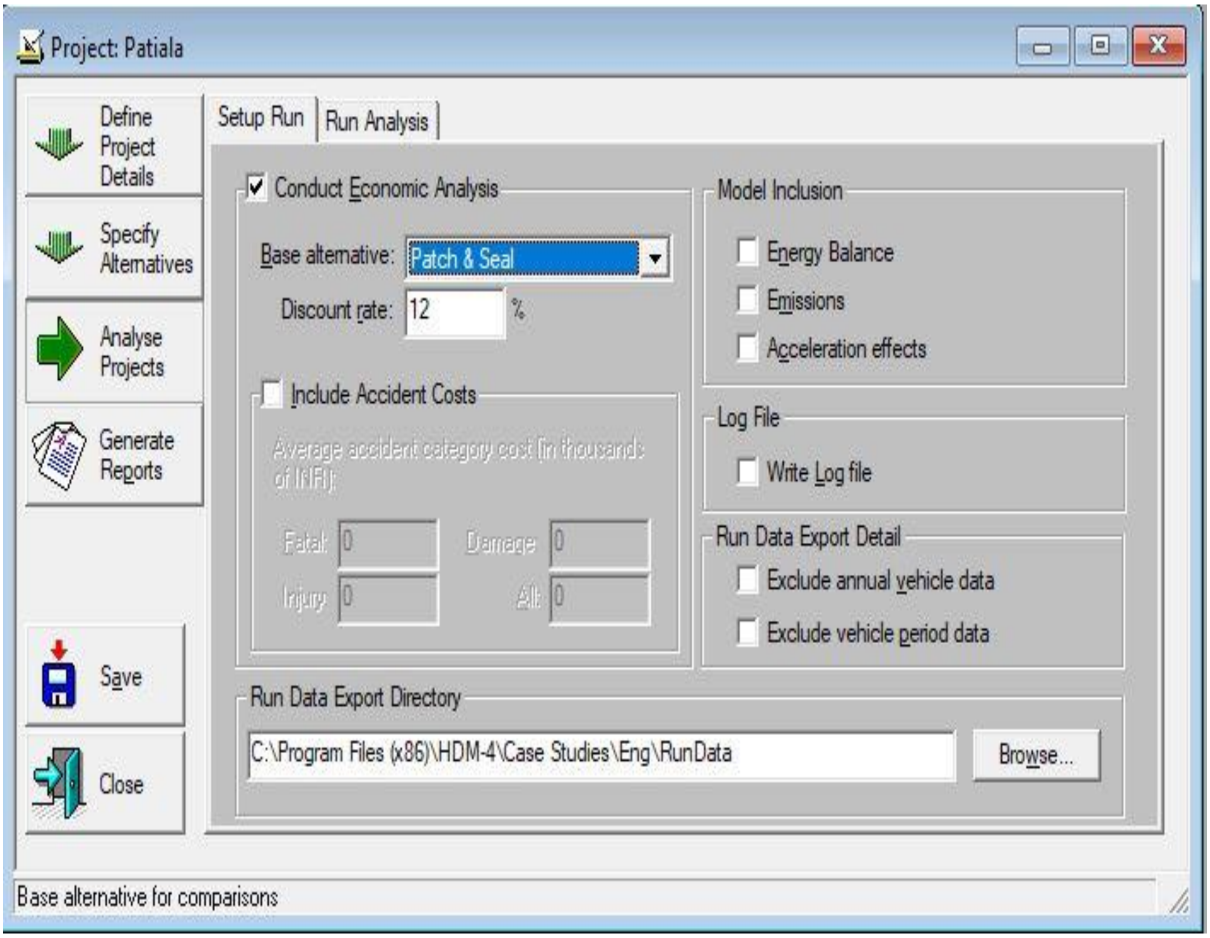


Figure 6.1 : Economic Analysis with Routine Maintenance as Base Alternative

Table 6.1 : Economic Analysis for Section PN

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	1.178	0.764	40.228	39.464	33.501
Alternative 2	1.184	0.536	30.737	30.201	25.507
Alternative 3	4.849	1.958	25.75	23.792	4.906

Table 6.2 : Economic Analysis for Section MN

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	0.717	0.415	13.855	13.44	18.745
Alternative 2	0.720	0.292	11.261	10.969	15.235
Alternative 3	2.95	1.064	3.7	2.636	0.893

Table 6.3 : Economic Analysis for Section DN

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	0.982	0.637	26.562	25.925	26.4
Alternative 2	0.989	0.5	25.879	25.379	25.66
Alternative 3	4.041	1.828	19.168	17.34	4.29

Table 6.4 : Economic Analysis for Section TR

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	1.512	0.875	7.087	6.212	4.108
Alternative 2	1.519	0.687	7.794	7.107	4.678
Alternative 3	6.223	2.513	5.288	2.775	0.446

Table 6.5 : Economic Analysis for Section LC

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	1.031	0.569	81.402	80.833	78.402
Alternative 2	0.693	0.439	70.896	70.457	101.67
Alternative 3	2.829	1.605	64.848	63.243	22.355

Table 6.6 : Economic Analysis for Section SN

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	1.914	1.005	83.371	82.366	43.033
Alternative 2	1.282	0.65	69.382	68.732	53.613
Alternative 3	5.253	2.376	60.576	58.2	11.079

Table 6.7 : Economic Analysis for Section OC

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	0	0	0	0	0
Alternative 2	1.775	1.775	379.72	377.945	212.93
Alternative 3	7.273	5.177	332.59	327.413	45.017

Table 6.8 : Economic Analysis for Section LB

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	0.687	0.398	13.608	13.21	19.228
Alternative 2	0.69	0.249	8.312	8.063	11.685
Alternative 3	2.829	0.911	5.877	4.966	1.755

Table 6.9 : Economic Analysis for Section AN

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	1.374	0.8	67.265	66.465	48.373
Alternative 2	1.381	0.7	59.81	59.11	42.802
Alternative 3	5.657	2.559	52.03	49.471	8.745

Table 6.10 : Economic Analysis for Section MT

Alternatives (1)	Road Agency Cost (2)	Increase in Road Agency Cost (3)	Decrease in Road User Cost (4)	Net Present Value NPV= (4)-(3)	NPV/COST Ratio =NPV/(2)
Alternative 1	2.003	1.051	95.459	94.408	47.133
Alternative 2	1.343	0.853	87.079	86.226	64.204
Alternative 3	5.495	3.118	77.727	74.609	13.577

Bar graph in figure 6.2 represent the coparison of CPV to Cost ratio of all alternatives for all sections with routine maintenance as base alternative.

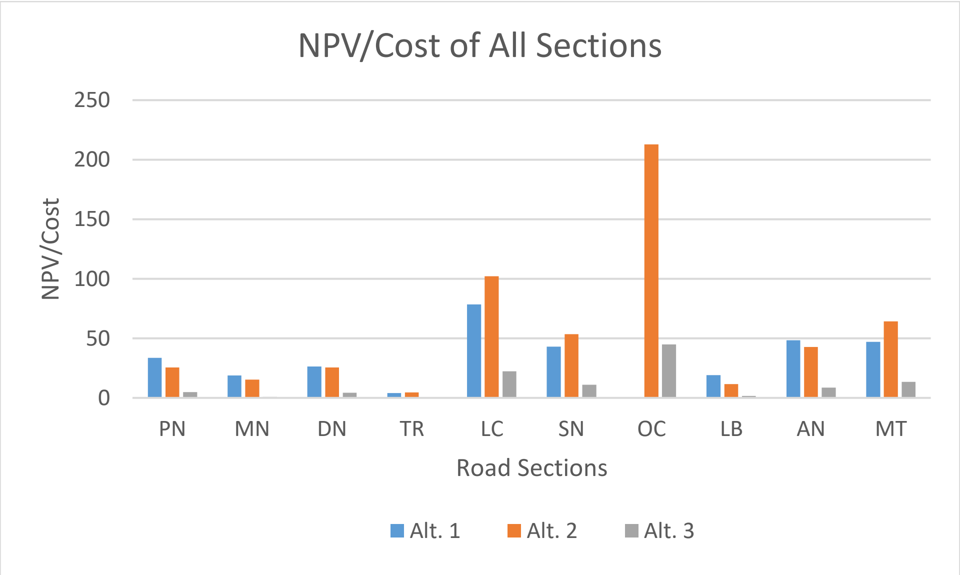


Figure 6.2 : Comparitive Bar Graph of Economic Analysis for All Road Sections

6.3 Assigning Optimum M&R Practices to Sections

From economic analysis done on each road section for every alternative keeping routine maintenance as base of comparison, each pavement section under study is assigned a single most beneficial M&R activity based on their NPV to cost ratio. Table 6.11 present all the sections along with their chosen M&R alternative.

Table 6.11 : Assigned M&R Activity to each Road Section

Section ID	Section Name	Assigned Alternative	Year of Appliction	Description of Alternative
PN	Prem Nagar	Alternative 1	2021. 2028	Resealing with 25mm SBSD
MN	Manjit Nagar	Alternative 1	2022, 2029	Resealing with 25mm SBSD
DN	Dashmesh Nagar	Alternative 1	2021, 2028	Resealing with 25mm SBSD
TR	Tripuri	Alternative 2	2027	Thick Overlay 40mm BM
LC	Lehal Colony	Alternative 2	2024	Thick Overlay 40mm BM
SN	Sant Nagar	Alternative 2	2026	Thick Overlay 40mm BM
OC	Officers Colony	Alternative 2	2020	Thick Overlay 40mm BM
LB	New Lal Bagh	Alternative 1	2022, 2029	Resealing with 25mm SBSD
AN	Ajit Nagar	Alternative 1	2022, 2029	Resealing with 25mm SBSD
MT	Model Town	Alternative 2	2024	Thick Overlay 40mm BM

6.4 Ranking of Road Sections for Work

After assigning maintenance activity to all road networks ranking of sections is done to prioritize the sections, in case of limited budget the user will know on which road section maintenance work should be done to get maximum benefit. This is also decided by NPV/ Cost ratio, maximum the value lower will be its ranking and higher the priority, ranking of each section along with its NPV/Cost ratio are shown in table 6.13 and graphical representation is dont in figure 6.3.

Table 6.12 : Road Section Ranked for M&R Activities

Section ID	Alternative	NPV/Cost Ratio	Ranking
OC	Alternative 2	212.93	1
LC	Alternative 2	101.67	2
MT	Alternative 2	64.204	3
SN	Alternative 2	53.613	4
AN	Alternative 1	48.373	5
PN	Alternative 1	33.501	6
DN	Alternative 1	26.4	7
LB	Alternative 1	19.228	8
MN	Alternative 1	18.754	9
TR	Alternative 2	4.678	10

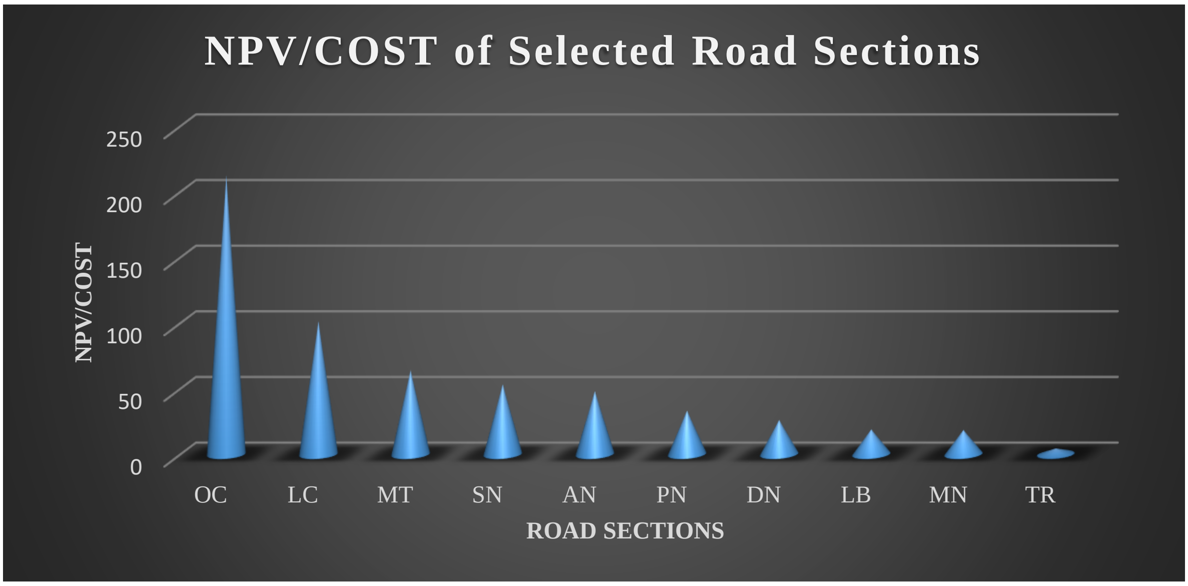


Figure 6.3 : NPV/Cost Ratio of Selected M&R Activities on Respective Sections

Road section OC is ranked 1 that means if funds are limited then the maintenance activity on road OC will be done prior to other road sections and section TR will be attended in end, irrespective of its maintenance year.

6.5 Life Cycle Cost Analysis

After deciding the treatments and maintenance activity for each road section we need to define the budget required to carry out the prescribed work. Detail of cost required by each road section for a period of 15 years in give in table 6.12.

Table 6.13 : Budget Requirement of each Section for 15 Years

Road Section	Activity to be Performed	Budget Required In Millions
PN	Resealing (Times 2)	1.39
MN	Resealing (Times 2)	0.8456
DN	Resealing (Times 2)	1.158
TR	Thick Overlay	1.7922
LC	Thick Overlay	0.816
SN	Thick Overlay	1.5129
OC	Thick Overlay	2.0948

LB	Resealing (Times 2)	0.811
AN	Resealing (Times 2)	1.6218
MT	Thick Overlay	1.5827
Total		**13.6**

Total budget required to keep all road sections in desired level of service is 13.6 million rupees. Further their is need to divide this budget according to time and aaplication of different M&R activities as it is not possible to provide the project with required budget all together as most of the project are long time project we should divide the budget requirement on yearly basis or define how much budget is required in what year. The budget detailing obtained by running Life Cycle Cost (LCC) analysis in HMD-4 is show in table 6.14 and figure 6.4.

Table 6.14 : Year-wise Budget Allocation

Year	Road Section	Description of Work	Cost (million)	Total	Cummulative
2020	OC	Thick Overlay	2.1	2.1	2.1
2021	DN	Resealing	0.5792	1.3	3.4
	PN	Resealing	0.6951		
2022	AN	Resealing	0.8109	1.6	5
	MN	Resealing	0.4228		
	LB	Resealing	0.4055		
2024	LC	Thick Overlay	0.8146	2.4	7.4
	MT	Thick Overlay	1.5827		
2026	SN	Thick Overlay	1.5129	1.5	8.9
2027	TR	Thick Overlay	1.7922	1.8	10.7
2028	DN	Resealing	0.5792	1.3	12
	PN	Resealing	0.6951		
2029	AN	Resealing	0.8109	1.6	**13.6**
	MN	Resealing	0.4228		
	LB	Resealing	0.4055		

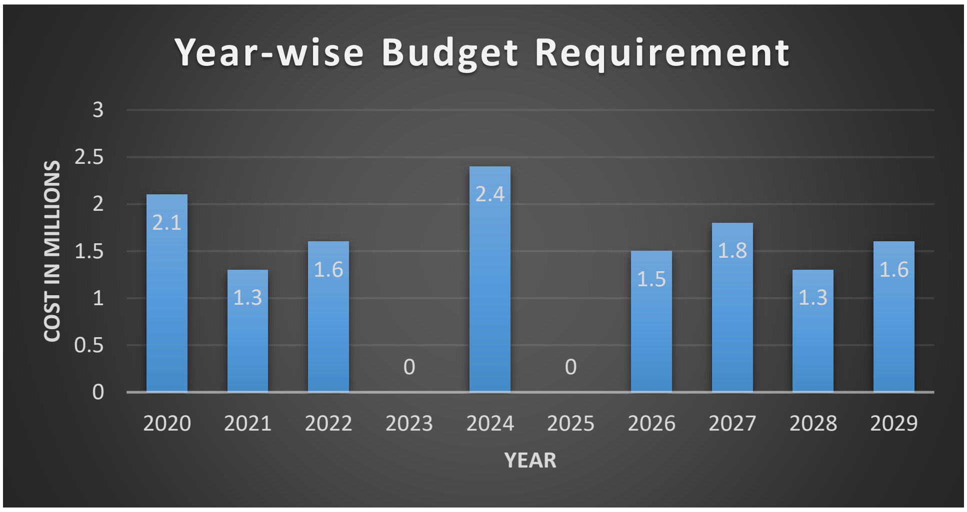


Figure 6.4 : Yearly Budget Requirement

6.6 Effect of Budget Reduction

It is not always possible to fullfil budget requirement of the project, this may lead to budget reduction. In this study the project requires 13.6 million INR and the effect of budget reduction is analysed by optimising the project budget on 5, 7, and 10 million INR using HDM-4 programme analysis and the its effect on road condition is compared with unconstraint condition that is when we have no budget reduction. Optimised M&R activities by reducing budget to 5, 7, and 10 million INR, are shown in table 6.15, 6.16 and 6.17 respectively.

Table 6.15 : Optimised Alternatives for 5 million

Year	Road Section	Description of Work	Cost (million)	Total	Cummulative
2020	OC	Thick Overlay	2.1	2.1	2.1
2024	LC	Thick Overlay	0.8146	2.4	**4.5**
	MT	Thick Overlay	1.5827		

Table 6.16 : Optimised Alternatives for 7 million

Year	Road Section	Description of Work	Cost (million)	Total	Cummulative
2020	OC	Thick Overlay	2.1	2.1	2.1
2022	MN	Resealing	0.4228	0.43	2.5
2024	LC	Thick Overlay	0.8146	2.4	4.9
	MT	Thick Overlay	1.5827		
2026	SN	Thick Overlay	1.5129	1.52	6.4
2029	MN	Resealing	0.4228	0.43	**6.9**

Table 6.17 : Optimised Alternatives for 10 million

Year	Road Section	Description of Work	Cost (million)	Total	Cummulative
2020	OC	Thick Overlay	2.1	2.1	2.1
2021	PN	Resealing	0.6951	0.67	2.8
2022	AN	Resealing	0.8109	1.234	4
	MN	Resealing	0.4228		
2024	LC	Thick Overlay	0.8146	2.4	6.4
	MT	Thick Overlay	1.5827		
2026	SN	Thick Overlay	1.5129	1.52	7.9
2.28	PN	Resealing	0.6951	0.7	8.6
2029	AN	Resealing	0.8109	1.234	**9.9**
	MN	Resealing	0.4228		

Effect of budget reduction on road condition is presented graphically in figure 6.5, where it is observed that road deterioration will occur at fast pace if budget is reduced and proper M&R activities are not performed. From the graph it can be concluded that when budget is reduced to 5 million INR average roughness of project increase dramatically after year 2026 and when budget is reduced to 7 and 10 million the average roughness increases suddenly after year 2028 and 2030 respectively.

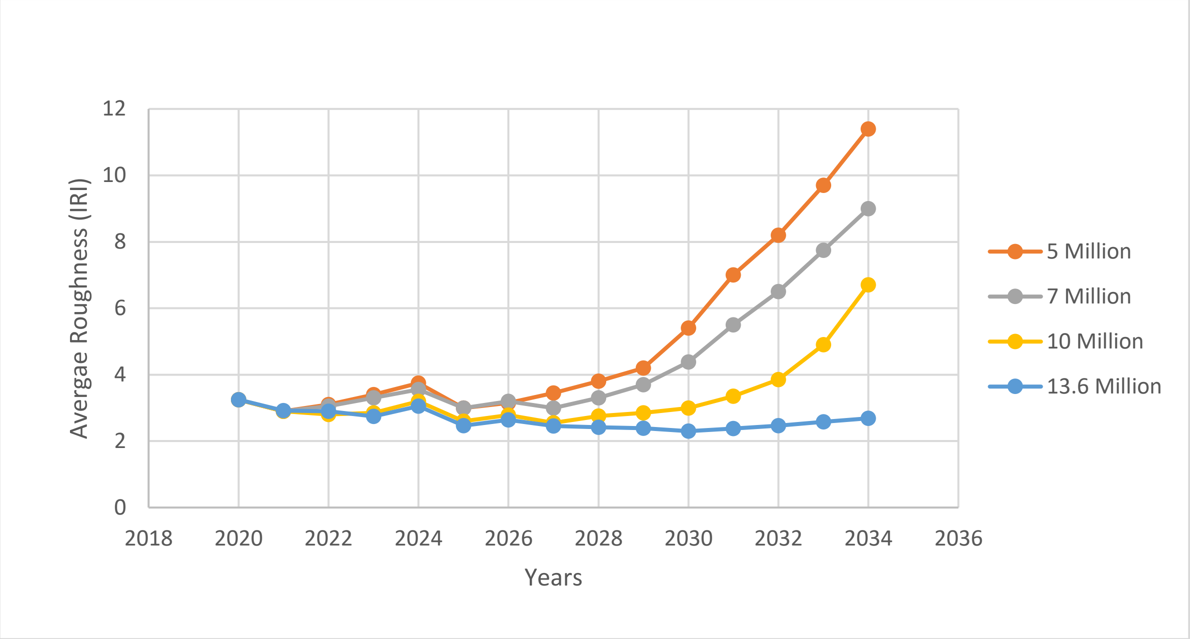


Figure 6.5 : Comparison of Different values of Budget Reduction on Average Roughness of Project

CHAPTER 7

CONCLUSION

Following conclusions are made on the basis of above study:

1. Functional and structural conditions of local streets of Patiala was successfully assessed using LWD, visual inspection and bump indicator. The result of pavement evaluation shows that many roads are in fairly good condition and are providing better level of service.
2. While performing data collection it was noticed that roads were damaged due to other factors like manhole uplift, activities of local residents and repair work by other local departments, this effect is random and can not be predicted properly.
3. Calibration of HDM-4 models was achieved with satisfactory result, cracking model having R^2 of 0.86 whereas ravelling and potholes having R^2 values of 0.89 and 0.88, respectively. While validating the models roughness progression displayed fairy good result with RMSE of 0.29 and R^2 of 0.822. The result obtained can be improved in future by adding more data to it.
4. Database to store road condition and vehicle fleet was created using HDM-4 that can be used in future studies.
5. PMMS for 10 local streets of Patiala city was successfully developed using HDM-4 software.
6. Remaining service life of all road sections was found using HDM-4 models and it was observed that section LB have RSL of 11 years and 5 other sections have a RSL of more than 8 years whereas section OC is in need for reconstruction or other major rehabilitation work.
7. Out of proposed M&R alternatives, alternative 1 (resealing & thin overlay) and alternative 2 (thick overlay) were selected for 5 road sections each with the help of NPV to Cost ratio obtained from economic analysis of all road sections and alternatives.
8. Ranking of road sections were done for prioritizing which section should undergo M&R activity if budget was limited and section OC was ranked 1 whereas lowest priority was given to section TR.
9. Total budget requirement for each road section was determined by performing life cycle cost analysis in HDM-4, and effect of reduction of budget was also observed which led to the conclusion that M&R activities can not be performed effectively if proper finance

is not provided, after year 2028 sudden increase in average roughness was observed. More the reduction in budget faster is the deterioration of pavements

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