Development of Pavement Maintenance Management Strategies for Roads of Bilaspur Town in Himachal Pradesh

A Dissertation Submitted in Fulfillment of the Requirement for the Award of the Degree of

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DECLARATION

I hereby declare that this work which is being presented in the report entitled **"DEVELOPMENT OF PAVEMENT MAINTENANCE MANAGEMENT STRATEGIES FOR ROADS OF BILASPUR TOWN IN HIMACHAL PRADESH,"** in partial fulfillment of the requirement for the degree of Master's of Engineering in the field of **Civil Engineering** at **Thapar Institute of Engineering and Technology (Patiala)**, is an authentic record of work carried out by me under the supervision of Dr. Tanuj Chopra (Assistant professor), Prof. Rajesh Pathak (Associate professor) and Mr. Balakrishnan Mahadeva Iyer (Team Leader- LNTIEL), Civil Engineering Department, Thapar Institute of Engineering and Technology, Patiala, Punjab.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma.

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CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct according to the best of our knowledge and belief.

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To Whomever It may concern

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Best Regards

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Abstract

All civil engineering structures deteriorate with time and pavements being no exception undergo deterioration with time. The various factors that influence the deterioration process of pavements include traffic loading, climatic conditions and quality control during construction among others. For this study, the major arterial roads of DHQ Bilaspur of H.P. are selected for evaluation and inspection purposes. Most of the damages and failures were caused by disintegration like loss of aggregate, potholes, stripping etc.

The proposed PMMS methodology includes: identification and selection of the urban road network, collection of field data and database management, and calibration and validation of HDM-4 pavement deterioration models for local conditions. The procedures and equipment used for collection of various kinds of field data on different pavement sections of DHQ Bilaspur have been described.

The data for vehicle fleet plying on the road network, maintenance and rehabilitation activities, cost data for various types of M&R works, and the road user cost data, as obtained from field and relevant government publications has been presented. The time series pavement distress data of cracking, reveling, potholes, rutting and roughness have been collected.

The project level analysis included determination of optimum maintenance & rehabilitation, comparison of scheduled and condition responsive maintenance strategy and estimating remaining service life of urban road sections. The optimum maintenance strategies have been determined based on highest NPV/Cost ratio.

CHAPTER 01

Pavement Management System (PMS):AN INTRODUCTION

1.1 GENERAL

The add-on part gives an introduction and groundwork into Pavement Management System to assess the condition of the pavement periodically so that maintenance work can be taken up accordingly in order to slow down the deterioration rate. With lack of maintenance at right time, pavements deteriorate rapidly, leading to higher Vehicle Operating Costs (VOC), increased number of accidents and reduced level of serviceability.

High-capacity urban road which delivers the traffic from collector roads to freeways, and between city centers at the maximum and possible level of service. As a result, it is critical to maintain these roads since they are subjected to heavy traffic, as well as monsoon or poor drainage conditions, which can cause pavement damage at a faster pace, necessitating more frequent maintenance and costly restoration. This research provides insight into the subject's objective, connotation, and future scenario. Virginia Transportation Research Council report (2002) presented economic analysis components and cost factors for life cycle cost analysis.

The report also showed us the different types of pavement maintenance option for rigid, flexible and composite pavements like asphalt concrete reconstruction, rehabilitation of rigid pavement with overlay, continuously reinforced concrete pavement construction, reconstruction with wide lane and ac shoulder. A picture demonstration is given to show how maintenance strategy and rehabilitation action taken into action for a pavement.

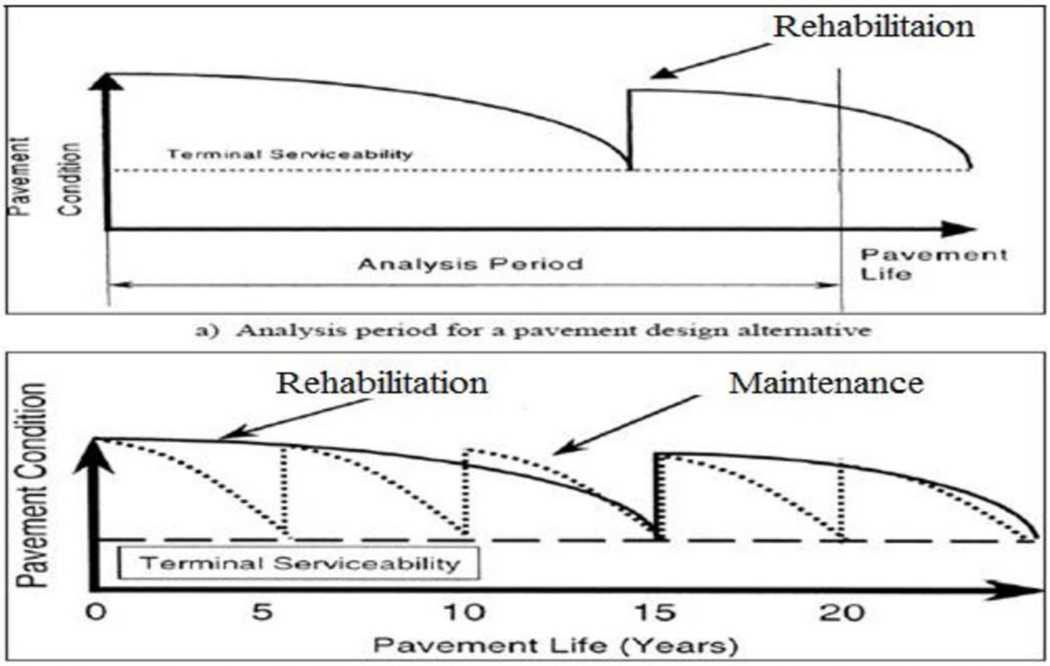

Fig 1.1: Analysis Period for a Pavement Design Alternative.

(Rao Prasada et al.)

The city roads are difficult to maintain because they cater to very heavy but uneven traffic. Furthermore, travel lengths can vary greatly, and a large number of diversions to residential or industrial areas are common. As a result, commuters and riders are often dissatisfied when there is a lack of suitable riding service on a city road. It is consequently critical that these roads be well-maintained in order to provide the best possible service and comfort to road users. The following are the major problems in urban roads:

- Drainage is a significant issue on city streets. The incorporation of a drainage layer, according to **Brain et al. (2005)**, had a favorable influence on the subgrade resilient modulus, effective pavement modulus, and effective structural number of the selected sections under examination. In comparison to pavement portions with good drainage, **Grover and Veeraragavan (2010)** found that the rate of deterioration of functional parameters such as roughness, cracking, and ravelling is faster by 41%, 20%, and 25%, respectively.

- **Prakash (2009)** used HDM-4 to create a Maintenance Management System (MMS) for Patna City designated urban road network. During the monsoon season, storm water tends to sit on the roads for an extended amount of time, causing local cavities and surface distresses such as potholes.

  This is a result of an insufficient and poorly built drainage system, which results in a significant loss of riding quality and user satisfaction; it also generates an unwelcome economic burden, since considerable sums of money are typically necessary for road repair and rehabilitation.

- **Choudhary et al. (2011)** emphasized the significance of drainage in flexible pavement performance by ensuring that system elements are free of impediments and maintain their specified cross section and slopes. In metropolitan highways, high traffic volumes and abrasion of the road surface are a prevalent problem.

  The maneuvers such as sudden braking and starting effect, sharp turns *etc*. often cause localized corrugations and abrasion in the road sections. This results in reduction of pavement thickness and loss of riding quality and comfort, causing significant discomfort to road users**.**

1.2 PAVEMENT MAINTENANCE MANAGEMENT SYSTEM (PMMS)

A Pavement Management System is a set of defined procedures for collecting, analyzing, maintaining, and reporting pavement data, to assist the decision makers in finding optimum strategies for maintaining pavements in serviceable condition over a given period of time for the least cost.

1.2.1 Need of PMMS

There is a need to design a set of methods that will give a systematic evaluation of highway demands, based on proper technical decisions and expert knowledge, in order to improve the state of urban roads. To determine which sections of the road require maintenance and which sections can be postponed.

For the improvement of urban street conditions, it is necessary to develop a set of strategies that will allow for an orderly assessment of pavement surface needs, based on appropriate design choices and master learning, while also determining which street segments require support. For maintenance of the road in comparable minimum time and for identification of road which required maintenance, this study is required. Complacency and inadequacy of road maintenance have caused irreparable damage to economic growth rate, as poorly maintained roads cause congestion, delay, road accidents, and higher vehicle operating costs.

The following are some of the major deficiencies in the Indian road network that highlight the need for PMMS:

1.2.1.1 Inadequacy in Design Standards

The majority of the country's roads are poorly planned, lacking in design standards, geometrics, safety features, and road user comfort. Due of the limited resources available at any one time, this is the case. This means we'll have to build in stages. The pavements are planned for a 15-year initial service life (IRC: 37-2012), with additional reinforcing given as traffic demand grows. However, due to inadequate management and financial constraints, many roads do not even reach their design life.

1.2.1.2 Increase in Pavement Transport Demand

Since independence, India has seen a significant increase in vehicle traffic. The number of vehicles on the road has increased from 3 lakh in 1951 to almost 450 lakh now. ``Furthermore, the volume of commodities transported by road has expanded by more than sevenfold, from 600 million tonnes to 40,000 million tonnes today. During the last 60 years, road transport's share of passenger and freight transit has expanded by 20% to 85% and 20% to 70%, respectively.

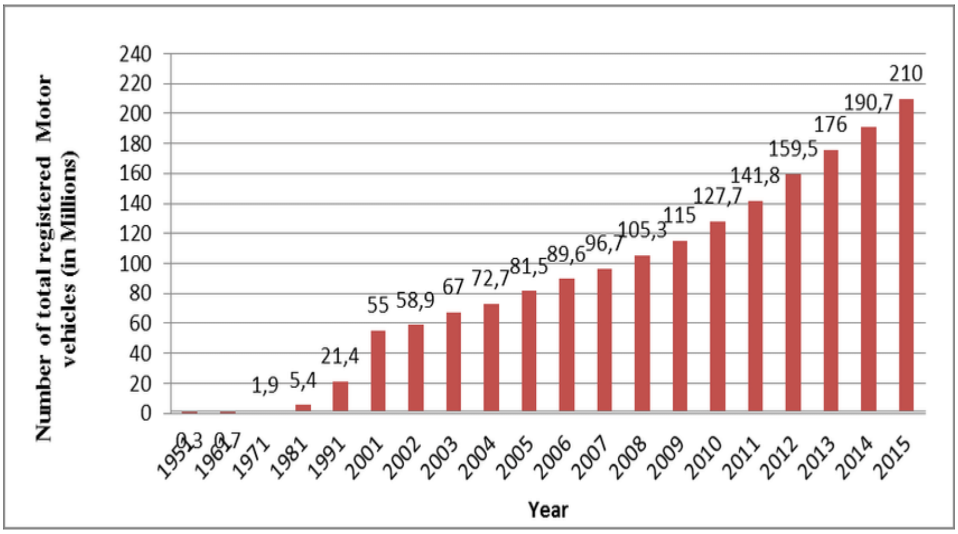

Fig1.2: Growth of Vehicles During last 60 years.(Jain et al.)

1.2.1.3 Decreased Caliber of Pavements

India has a big road network, however the quality of the roads is often poor. More than half of the road network remains unpaved. The existing road network has aged and deteriorated rapidly due to a lack of meaningful management other than frequent overlays, resulting in a variety of distresses such as cracking, ravelling, and potholing on the road surface. These problems have increased the demand for Pavement Management techniques as a result of the combined effects of moving traffic and environmental elements.

1.2.1.4 Increased Traffic and Axle Loads

The volume and axle weights of traffic on Indian highways are expanding at an alarming rate. The annual growth rate is expected to be in the tens of percentiles (MORT&H 2001c). The current road network has been severely strained as a result of the unprecedented expansion in vehicle population and road usage. According to the 'Road Damage Formula,' pavement that can last 10 years without overloading can only last 6.5 years and 3.5 years, respectively, if there is 10% and 30% overloading.

The axle loads carried by freight vehicles have increased significantly. Despite the fact that the axle weight limit is 10.2 tonnes, vehicles with axle loads of 18-22 tonnes can be found on these routes. In order to extend the life of the roads until the restrictions are more firmly enforced, management measures are necessary.

1.2.1.5 Limited Award of Capital

The current allocation of funds is barely 60% of what is required for proper upkeep. Any disregard for maintenance is self-defeating, as every rupee spent on maintenance saves two to three rupees in vehicle operating costs (MORT&H 2001b). As a result, the gap between allocation and requirements has only become wider in recent years, which is bad news given the continually increasing volume and weight of traffic. Furthermore, because maintenance tasks are rarely scheduled in advance, decision-makers have a tendency to make haphazard cuts when faced with resource restrictions.

Following the lack of adequate and timely maintenance measures, the pavement condition may deteriorate very sharply from ‘good’ to ‘poor’ during a very short span of pavement life, leading to 4-5 times higher fund requirements for rehabilitation of the pavement at that stage. Thus, if maintenance and rehabilitation is performed during the early stages of deterioration, before a sharp decline in pavement condition, over 75% of the maintenance costs can be avoided (Shahin 1994).

1.3 DESIGNING A PAVEMENT MANAGEMENT PROCESS

The development of a systematic and repeatable pavement management process is a key component in the effective planning and management of a pavement network. The steps outlined below serve as a Guide for customizing a pavement management process that fits the needs of each local agency.

Prior to starting the implementation process, it is recommended that agencies consider naming a champion and forming a steering committee to work as a group in establishing a process to meet the needs of the agency.

For larger agencies, involving a number of staff from all levels and a variety of divisions within the organization helps shape the management process to meet the needs of all potential users in the organization.

1.3.1 Step 1: Define the Roadway Network and Collect Inventory Data

The first step in designing a pavement management process is to define the roadway network. A roadway network is comprised of an inventory of the physical characteristics of the roadways being managed by the agency. After segments are defined in a manner that best fits the needs of the given agency, the inventory information for each segment is collected by either estimating the data or collecting all needed information. The exact type of inventory information required by an agency depends on what data will be used by the agency to support its decisions.

1.3.2 Step 2: Collecting Condition Data

Pavement condition data are a major factor in any data-driven, decision-making pavement management process. Within the pavement management process, the condition data can be used to help identify current maintenance and rehabilitation needs, to predict future needs, and to assess the overall impact on the network. Therefore, the type of condition data required and the level of detail depends on the agency and the pavement management process used. Condition data will be collected using either manual or automated data collection methods. With either method, distress data will be estimated or measured.

1.3.3 Step 3: Predict Condition

With current pavement condition assessed, agencies are equipped with the information needed to predict the future condition of a segment. In pavement management, conditions are predicted in terms of performance models that estimate the average rate of pavement deterioration each year. Pavement conditions can be predicted for the pavement network using either average deterioration rates or performance prediction models.

1.3.4 Step 4: Select Treatments

The fourth step in designing the pavement management process is to select appropriate treatments for the roadway network. Treatments are selected using cyclical schedules or treatment trigger rules. The recommended treatments are then prioritized using ranking or benefit/cost analysis.

1.3.5 Step 5: Report Results

Project results can be reported using different methods to highlight important factors which will assist decision makers with their final decisions. Data reporting is an effective method of communicating not only the recommendations from the pavement management process but also transferring related information to decision makers. The data can be used to generate reports and charts to extract relevant information pertaining to any segments under consideration. The results can be presented either by using standard charts and reports or customized summaries.

1.3.6 Step 6: Select Pavement Management Tool

The selection of a pavement management tool is influenced by the requirements of the agency and users needs. The tool provides a platform to store the pavement management information and to perform different types of analysis depending on whether a spreadsheet, GIS tool, and/or a pavement management system (public or private) is selected.

Depending on the needs of the agency, a local agency can also opt to use a combination of pavement management software and customized spreadsheets and/or GIS software to suit their requirements.

1.3.7 Step7: Keep the Process Current

Pavement management is a dynamic process that requires regular updates. Pavement management is not a one-time activity, so agencies must make an effort to update the information incorporated in the pavement management process. Data management is a key component to maintaining the database.

Pavement Maintenance Management System (PMMS) is a scientific tool for managing the pavements so as to make the best possible use of resources available or to maximize the benefit for society. Existing pavement deteriorates with age or continuous traffic loadings. Once a PMMS is developed for any road network, an entire and readily available inventory data of that road network can be obtained including up-to-date road conditions. This data is essential for routine use in tracing maintenance work and for reference in preparing reports or studies.

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

1.4 HIGHWAY DEVELOPMENT AND MANAGEMENT SYSTEM (HDM-4)

The World Bank's Highway Development and Management System (HDM-4) is a key instrument for building a pavement maintenance management system that can assess technical and financial aspects of road investments, investigate pavement programs, and analyze preservation methods. The HDM-4's efficiency is determined by the accuracy of its distress prediction models and their flexibility to local conditions. The HDM-4 tool's scope has been expanded significantly beyond standard project assessments, resulting in a robust system for analyzing road management and investment options.

The HDM-4 provides maintenance tools for project-level analysis, road work programming within budget constraints, and long-term network performance and cost planning. It's meant to be used as a decision-making aid in a road-management system. The pavement deterioration models included in the HDM-4 must be calibrated and validated for local conditions.

The calibrated models can be used to forecast pavement deterioration in the future. The HDM-4 application modules 'Project analysis,' 'Program analysis,' and 'Strategy analysis' are used to construct PMMS at the network and project level.

1.4.1 Input Data Requirements

The input data to HDM-4 is held in four data managers, which are described below:

- **Road network -** Defines section ID, description, surface class, and pavement type, section length, carriageway width, traffic & speed flow type, climate zone, and road class. AADT year for both motorised and non-motorized travel.
- **Vehicle fleet -** Defines the vehicle's name and class, as well as fundamental parameters such passenger car space equivalency, operating weight, and economic unit expenses.

- **Road works standards** – Defines various maintenance and improvement standards with designed intervention levels either as scheduled or responsive treatment, along with their unit costs, which will be applied to the different road sections to be analyzed.

- **HDM configuration -** Defines the traffic flow, speed flow, currencies and climate zones along with section aggregate data and tables.

1.4.2 Technical Models

Technical analysis within the HDM-4 is undertaken using the following four sets of models:

- **Road Deterioration (RD) -** For various types of pavements, such as flexible, stiff, and granular roads it predicts pavement surface deterioration in terms of numerous distresses such as cracking, rutting, roughness, potholes, structural number, and ravelling.

- **Works Effects (WE) -** Provides the effects of road maintenance or improvement on pavement condition and determines the corresponding costs.

- **Road User Effects (RUE) -** Calculate vehicle operating expenses and journey time. Under the funding of the Ministry of Surface Transport (MOST), the CRRI completed the RUE study in 1982. (CRRI 1982). A considerable number of commercial and private automobiles were discovered in this survey.

  Then data on the operating costs of these vehicles, as well as the design specifications of the roadways on which they operate, were acquired. By evaluating this data, connections between road design requirements and vehicle operation costs were discovered.

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1.4.3 Application Modules

There are three main application modules in HDM-4, *i.e.*, Project Analysis, Program Analysis, and Strategic Planning **(Kerali 2000, Shah 2012, 2016)**. These are described below:

- **Project Analysis –** In the Project level module of HDM-4, economic analysis of one or more road projects and its investment options can be performed. Road sections with defined maintenance and rehabilitation strategies are analyzed over a specified design life time. Project analysis can be used to estimate the economic viability of the maintenance decision by performing the life cycle cost analysis (LCCA) of road agency cost together with estimates of road user costs to calculate the total transportation cost.

- **Program Analysis –** In the Network level application of HDM-4 maintenance work programme for selected road sections are identified and are assigned various maintenance works applicable for that particular pavement type. Economic Indicators such as NPV/ Cost are calculated for each strategy. Program analysis provides a schedule of optimum pavement maintenance and rehabilitation strategies, which can be performed as per the availability of maintenance funds. Maintenance work programs are generated by HDM-4 under both the constrained & unconstrained budget options

- **Strategy Analysis** – In the Strategic analysis of HDM-4, the analysis of a selected urban road network is carried out as a whole. This network level application is used for strategic planning to prepare a planning estimates of funding needs for the maintenance and improvement works of the road network.

Naidu et al. (2005) made an attempt to select optimum maintenance strategies and developed PMMS based on life cycle costs using HDM 4 for the inner ring road of Delhi. The network of study area consisted of major arterial roads for Delhi having 48 km (96km both directions) road length with six lanes divided carriageway. Project analysis and programme analysis components of HDM 4 were used for developing PMMS.

The major difference between strategy and program analysis is the manner in which the road links and sections are identified. Program analysis deals with individual links and sections that are unique physical units, identifiable from the highway network throughout the analysis.

In strategy analysis, the highway network essentially loses its individual link and section characteristics by grouping all road segments with similar characteristics into the highway network categories.

1.4.4 Interfaces to External Systems

The HDM-4 system design is modular in structure to enable highway agencies to implement the HDM-4 application modules independently within their pavement management systems. The system is designed to interface with external road network information systems through its databases. Data transformation rules may need to be implemented for converting the data held in the external database to the format used by HDM-4.

Data required by HDM-4, such as pavement deterioration calibration factors should be inserted as pre-defined default values according to the type of pavement, road class and other defined factors. These include data on vehicle fleet characteristics, road maintenance and improvement standards, unit costs and economic analysis parameters such as discount rate and analysis period *etc*., (Kerali 2000).

1.4.5 Life-cycle Analysis

HDM-4 simulates the total life cycle conditions and costs for an analysis period under specified circumstances. The model stimulates, for each pavement section, year-by-year, the pavement condition and resources used for maintenance under each strategy, as well as the vehicle speeds and physical resources consumed by vehicle operation.

Interacting sets of costs related to those incurred by the road administration and those incurred by the road user, are added together over time in discounted present values. Economic benefits are then determined by comparing the total cost streams for various maintenance alternatives with a base alternative, usually representing minimum routine maintenance (Odoki and Kerali 2000).

1.5 OBJECTIVES OF THE STUDY

The following are the objectives of this study:

- To make a preliminary condition & detailed condition survey of roads and identify the arterial road length in the selected zone & to identify various types of defects and prepare a list in hierarchy of their occurrence.

- To assess the condition of selected stretches based on distress survey and to develop a systematic approach to ascertain distress and its severity.

- Create a database containing inventory information, pavement condition information, traffic information, and other relevant information for the specified Urban Road Network.

- Development of an evaluation system that aids in the timely and cost-effective decision-making process for pavement maintenance and rehabilitation utilizing HDM-4 pavement performance models.

- Determination of Remaining Serviceable Life (RSL) of Bilaspur Town road sections using Project Analysis in HDM-4 model.

- Determination of Optimum Maintenance and Rehabilitation strategy for road sections of Bilaspur Town using Project Analysis in HDM-4 model.

- Prioritization of Bilaspur Town road sections based on optimum M&R strategy.

- Comparative study of Scheduled Type and Condition Responsive type M&R Strategy for individual road section using Project Analysis in HDM-4 model.

1.6 ORGANIZATION OF THESIS

The research work has been carried out keeping these above said objectives in view. The thesis report presents this work in five chapters. Chapter wise summary of the report is given below:

Chapter – 1:- Presents the statistical data of Indian road network, urban road network, road condition scenario in India, classification of urban roads, various deficiencies and inadequacies of urban road. This chapter also presents the overview of PMMS and the role of HDM-4 for developing PMMS.

Chapter – 2:- Presents the review of the literature. It discusses the various works done on PMMS using HDM-4 model.

Chapter – 3:- Presents a detailed methodology of the development of PMMS for the selected road network. It includes identification and selection of the road network and division of the same into homogeneous pavement sections. It also presents in detail the methodology adopted for collection of various kinds of data required for the development of PMS, such as highway network data, vehicle fleet data, maintenance & rehabilitation activities data, and the cost data.

Chapter – 4:- The PMMS developed at network level and project level using project analysis and programme analysis of HDM-4 tool along with the method of prioritization for the selected urban transport network have been presented in this chapter.

Chapter – 5:- Presents the Road Pavement Condition Index calculation for all the ten road sections of Bilaspur district.

Chapter – 6:- Summarizes the conclusions drawn out on the basis of the present study. Some recommendations for further scope of research in this area are also given in this Chapter.

CHAPTER 02

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter summarizes the studies that are pertinent to the current project. The progress made so far in implementing the PMMS in India, as well as the international PMMS scenarios, have been reviewed. To keep up with the latest techniques used for modeling the different components of PMMS, such as pavement evaluation, pavement performance prediction, resource allocation optimization, pavement drainage, and maintenance prioritization methods, an extensive literature survey was conducted and presented here.

2.2 LITERATURE REVIEW

Tavakoli et al. (1992) presented a PMMS for small communities for supporting the decision of scheduling and budgeting of various levels for the repair of roadways. This was a based on guidelines of "Road Surface Management for Local Government" manual for the U.S. Department of Transportation. They had considered the following data base:

- Section identification (Section number, name, functional class, jurisdiction)
- Pavement characteristics (type, width, drainage system, curb height, number ofinlets)
- Traffic flow (average daily traffic, % trucks etc.)
- Utilities and historical information.

Shah et al. (2013) developed a combined Overall Pavement Condition Index (OPCI) based upon distress data collected for the selected network of Noida roads. The study area consisted of 10 road sections constituting 29.92 km of Noida city. The methodology included identification of urban road sections, pavement distress data collection, development of individual distress index and finally developing a combined OPCI for the network.

The four performance indices viz. Pavement Condition Distress Index ($PCI_{Distress}$), Pavement Condition Roughness Index ($PCI_{Roughness}$), Pavement Condition Structural Capacity Index ($PCI_{Structure}$) and Pavement Condition Skid Resistance Index (PCI_{Skid}) were developed individually.

Thube (2013) developed and calibrated HDM-4 pavement deterioration models for Indian roads. These models were developed for thin-surfaced roads of India and they claimed that these models can be adjusted to any type of terrains by varying the values of calibrated factors of distress type. They had collected data for all the schemes (like plain, rolling and mountains) from the Uttarakhand, India. The data was collected in terms of cracking, ravelling, rut depth, pothole, edge break and roughness progression. They had identified various road sections of selected state and data had been collected during two continuous years (2004-2005). The sample road sections consist of 1 km length and cracking, ravelling, potholes and edge break had been measured by visual condition survey. Their proposed procedure for calibration of pavement performance models was based on the coefficient between the observed years of occurrence as distress to the years of occurrence as predicted by the uncalibrated models and for progression models, it had been done by minimizing the squares of differences between the observed data or sum of differences between the estimated and observed data or sum of squared differences. Their calibration results revealed that:

- The pothole distress was same as with the default values of HDM-4 for all terrains.
- The cracking progression was 77% slower than predicted by default values of HDM-4for all terrains.
- The ravelling progression was 66%, 73% and 46% slower than as predicted by default values of HDM-4 in plain, rolling and mountainous terrains.

- The rate of edge break was about 39%, 56% slower and 1.65 times faster that was predicted by default values of HDM-4 for plain, rolling and mountainous terrains.

- The rut depth progression was 2.7, 2.17 and 1.5 times faster than predicted by default values of HDM-4 for plain, rolling and mountainous terrains.
- The pothole progression was about 94%, 84% and 94% slower than predicted by default values of HDM-4 for plain, rolling and mountainous terrains.

They also claimed that HDM-4 pavement deterioration models in their study can be used for the optimal maintenance of low volume roads and recommended that these can be used in other parts of India also.

2.2.1 Development of PMMS using HDM-4

HDM-4 (Highway Development and Management) model is a pavement maintenance management tool which acts as a decision making tool for estimating the economic or engineering entities of road investment projects. Calibration factors are used for analysis in the HDM-4 model in case of local conditions to get accurate results for the predication of pavement performance by measuring various pavement distresses like cracking, potholes, ravelling, rutting & roughness. Research work of various authors has been discussed below regarding use of HDM modules for predicting the pavement deterioration for various categories of road.

Aggarwal et al. (2004) developed and calibrated the pavement management system for local conditions and they claimed that this system will assist engineers while maintaining the pavements. They used HDM-4 model for this purpose and taken 10 years (2003-2012) of analysis period.

They used 22 sections of national highways. They claimed that to maintain the highway at optimum serviceability level, the sum of 1475.87 million rupees had been required and the available budget was just 60% of the required budget. They also prepared priority ranking list of selected sections. They also concluded in their study that there was not much change in the roughness value if the delay was of any one year, but value will rise 6m/km IRI, if it would be delayed for next two years. This will further give a drastic increase in the VOC for the road users.

Jain et al. (2005) calibrated the HDM-4 pavement deterioration models for a National Highway Network which was located in the Uttar Pradesh and Uttaranchal states of India. The data was collected for potholing, ravelling, cracking, and roughness. They analyzed, and used for the calibration of HDM-4 pavement deterioration model. They monitored and measured the performance sections for a continuous period of 3 to 5 years. This gave way to the pavement performance prediction models for the major modes involved in distress, which includes cracking, potholes, raveling , and roughness which were the most significant from the view point of road maintenance and road user cost considerations. Four types of distress progression models were validated which used a percentage variable and regression coefficient, included:

- Cracking progression model;
- Ravelling progression model;
- Pothole progression model; and
- Roughness progression model.

They claimed that their study gave the HDM-4 deterioration models which were calibrated for the Indian National Highway Network, could be used for other developing countries as well having similar soil types, traffic characteristics, climatic conditions, pavement composition and terrain type.

Jain et al. (2013) developed an optimum maintenance and rehabilitation strategy using HDM-4 on the multilane highways from northern region of India. The implementation criteria had been selected according to the Indian guidelines on pavement maintenance. Input data had been collected and entered in the form of:

- road network data,
- vehicle fleet data and
- work standards

They considered five factors for evaluation also, that were, ravelling, potholes, cracks, rutting and patching. They proposed five M&R alternative strategies. Economic analysis had been done for NH-24 for 8 road sections. They concluded that alternative 3 (i.e., resealing and overlay, 25mm SDBC reseal + overlay of 40mm BC + IRI $\geq$ 2.8 m/km) for Noida-Greater Noida Expressway and alternative 2 (i.e., Thick overlay, overlay of 40mm BC, IRI $\geq$ 2.8 m/km) was considered best for NH- 24 road sections.

Deori et al. (2016) carried out a study to calculate calibration of inbuilt distress models of Highway Development and Management (HDM-4) tool for Indian conditions and then Validation of calibration factors through similar pavement layer composition with different traffic scenario for different environmental and climatic zones of India by considering 23 sections on a National Highway Development Programme Road project and Determination of realistic and logical calibration factors for different inbuilt distress models in HDM-4 where modified bituminous mixes are used in surface course and they concluded that the selected test sections in this study cover almost entire country from east to west and north to south including the variations in climatic and environmental conditions, traffic loading and the prevailing pavement layer compositions and can be adopted for other high-speed corridors, viz. national highways of the country based on climatic conditions.

Adlinge S. Sharad et al. (2013) In terms of reducing serviceability caused mainly by the creation of cracks and ruts, pavement failure was identified. The author described modules on the number of projects in India learned from pavement failures and issues encountered in recent years.

Different pavement maintenance strategies and initiatives that will help enhance the serviceable life of the pavements have been addressed on the basis of previous experience.

It was concluded that a major cause of cracking is the rapid increase in traffic loading, especially on new roads where the design is focused on lower traffic, the provision of weak shoulders leads to edge failure and poor sub-grade corrugation effects on the surface. Bad drainage was also considered as the key issue causing the maximum pavement surface failure.

Katkar R. S et al. (2014) investigated the ultimate aim of the Maintenance Management System (MMS) is to maximize the resources needed to update this utility. 70 pavements were studied and the relationship between the quality of the pavement and the corresponding cost of maintenance was given.

The results of the research include a clear and practical technique for categorizing the condition of the pavement in terms of repair cost. They developed a value for pavement quantification on a scale of 7-1, 7 being the new pavement condition, and 1 being the poor condition.

Zumrawi M.E. Magdi (2015) The analysis of traffic volume and data on riding quality were also considered. It was concluded that the degree and quantity of cracking and patching values play a vital role in the pavement condition index (PCI) does not require any priority-based maintenance operation and pavements with lower pavement condition index requires maintenance on priority. It was concluded that the emphasis should be on developing guidelines that are versatile enough for use in a variety of circumstances that are systematic, straightforward and easy to comprehend.

Andrei Radu et al. (2015) using basic pavement condition metrics, assessed the efficiency of flexible pavements. The pavement serviceability index (PSI), pavement condition index (PCI), skid resistance (SR) and pavement damage were different parameters used in the analysis (consumed life). The PSI was assessed using the AASHTO road test. That ranges from 0-5.0 being the worst pavement condition and the best condition being 5.

The entire pavement is first divided into small sample units for the pavement condition index (PCI) and determined by deduct values and correlated correction curves, SR by the skid resistance tester and pavement damage is a measure of the percentage of life absorbed at any given moment during the pavement's service life. Some ratings for these versatile pavements and suitable treatments were provided after operating on all these parameters.

Shah et al.(2016) aimed to maximising the NPV and minimisation of the cost to achieve target international roughness index and carried out analysis of 21 urban pavement sections. They calculated traffic for motorized and Non-motorized traffic along with characteristics deflection. They reported the variability in roughness 3.21 - 5.65 IRI m/km, deflection 1.287mm - 2.873 mm and considered roughness as primary controlling factor for activating provisions of overlays and strengthening of the pavement.

They revealed that economic analysis for design period of 10 years and they had done work to maximize NPV for 5 sections of urban road with thin overlay of 25mm SDBC, for 2 sections thin overlay of 40mm BC and for remaining sections of the road network with 50 mm DBM and 40 mm BC. They revealed that NPV and minimum cost for targeted IRI was considered as best alternative. They concluded that:

- When the criterion of maximizing NPV had been used, then the best possible treatment applied on the road network depending on the level of maintenance.

- When the criterion of minimizing costs for target IRI was consider, the ' strengthen with 50mm DBM + 40mm BC' came out as the best investment alternative because it can keep the entire road network at an acceptable condition.

2.3 GAPS IN PRESENT STUDY

From the literature review on various components of PMMS following gaps have been identified:

1. It has been determined that a comprehensive PMMS is required, one that incorporates all of the components and can be implemented effectively by urban development authorities.

2. To have an accurate and faster data gathering for an efficient PMMS, advanced mechanisms and automated data collection equipment should be implemented.

3. The HDM-4 Highest Level Calibration of Road Deterioration and Maintenance Effects (RDME) models for urban roads have not been included, which should be considered for an efficient urban PMMS for India that will have a wide range of practical applications in managing India's road infrastructure.

4. There are only few studies being implemented on Hilly Terrains and similarly the calibration factors are also not yet specifically designed for Indian Mountainous Roads.

5. GIS application for PMMS needs to be implemented for the selected road network so that the database related to road conditions can be continuously updated and the developed pavement maintenance management system can be more effectively implemented by the highway authorities.

2.4 SUMMARY

Different organizations and pavement management practitioners have defined the Pavement Maintenance Management System in various ways. Over the last three decades, there have been a number of significant milestones in the growth of pavement management systems.

Many highway development authorities in developed countries are now using systematic and scientific methods to determine pavement condition throughout the design life of the pavements and schedule maintenance activities in response to real-world situations by establishing appropriate intervention criteria in order to maintain highway infrastructure in the desired serviceability conditions while staying within budget constraints.

PMMS is in varying stages of implementation in many developing countries, with different methodologies depending on the needs and difficulties of each country. GIS, ANN, GA, and other cutting-edge technologies are being employed to improve the pavement management process. To schedule repair efforts, many transportation agencies throughout the world have created pavement performance prediction systems, although they are not universally approved. HDM-4, on the other hand, could be an exception.

HDM-4 has been recommended as the best PMMS software for developing pavement maintenance management systems as a decision-making tool for an identified road network by properly calibrating the various pavement deterioration models according to the local conditions, especially for small to medium-sized cities in India where there is a major constraint on the monetary-resources.

CHAPTER 03

METHODOLOGY AND DATA COLLECTION

3.1 GENERAL

This chapter describes the data collection and methodology used to create the Pavement Maintenance Management System (PMMS). All modules and processes involved in the systematic and scientific development and implementation of a PMMS are included in the methodology for developing a PMMS. The methodology and data base collection for developing the maintenance management system have been discussed in this chapter.

3.2 METHODOLOGY FOR DEVELOPING PMMS

An effective PMMS is dependent on database accuracy, integrity, reliability, and, most importantly, completeness. The database should be organized in such a way that data can be easily retrieved for successful analysis.

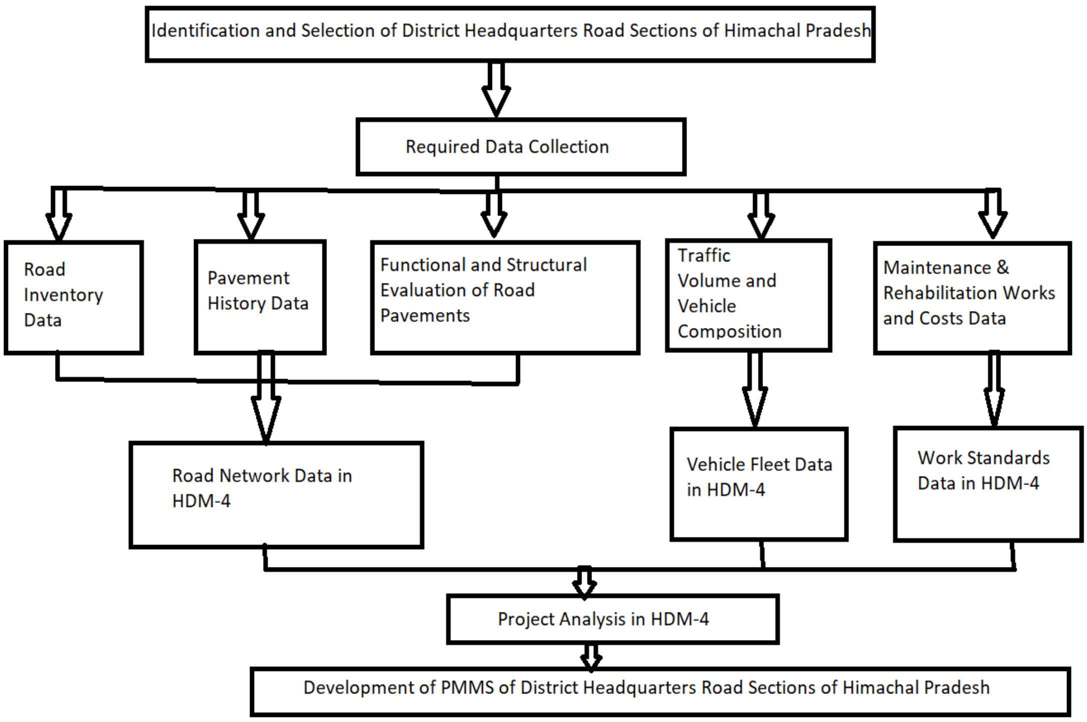


Fig. 3.1: Methodology to develop PMMS for DHQ Roads.

3.3 IDENTIFICATION AND SELECTION OF DHQs ROAD SECTIONS OF HIMACHAL PRADESH

The Government of Himachal Pradesh, in-order to address the issues of unplanned and haphazard development of its major towns has taken up a comprehensive study to develop retrofit designs and development plans to address the issues. With this objective, Himachal Pradesh Road and Infrastructure Development Corporation Limited (HPRIDC) has initiated the preparation of a comprehensive urban road improvement plan for eight major District Head Quarters (DHQs) of the state with a view to improve the Urban Infrastructure of these towns.

The eight district DHQs taken up for the study are:

- Bilaspur
- Chamba
- Hamirpur
- Kullu
- Mandi
- Solan
- Nahan
- Una

3.4 URBAN ROAD NETWORK PLAN – DISTRICT HEAD QUARTER, BILASPUR

Bilaspur is the district headquarters of Bilaspur district in the state of Himachal Pradesh. The town lies at foot of Bandla hill's and near the reservoir of Gobind Sagar on the Sutlej River at an elevation of 673 meters above sea level. The geographical area of the district is 1167 sq.km which covers 2.1% area of the state. The district lies between north latitude 31°12'30" and 33°5'45" and east longitude 76°23'30" and 76°55'40". It is predominately situated in the lower Satluj valley in the outer hills.

It's bounded on the North by Mandi and Hamirpur districts, on the west by Una and Hamirpur districts, on the south by Nalagarh and Arki tehsil of Solan district and towards south-west by the Roopnagar district of Punjab thereby giving it an oblong configuration.

Altitude in the district vary from 1944 meters at the highest point is peak of Dhar Bahadurpur point to about 305 meters at the lowest. The town is regarded as the first planned hill town of the country. The study area is limited to the District Head Quarter (DHQ) limits of Bilaspur district.

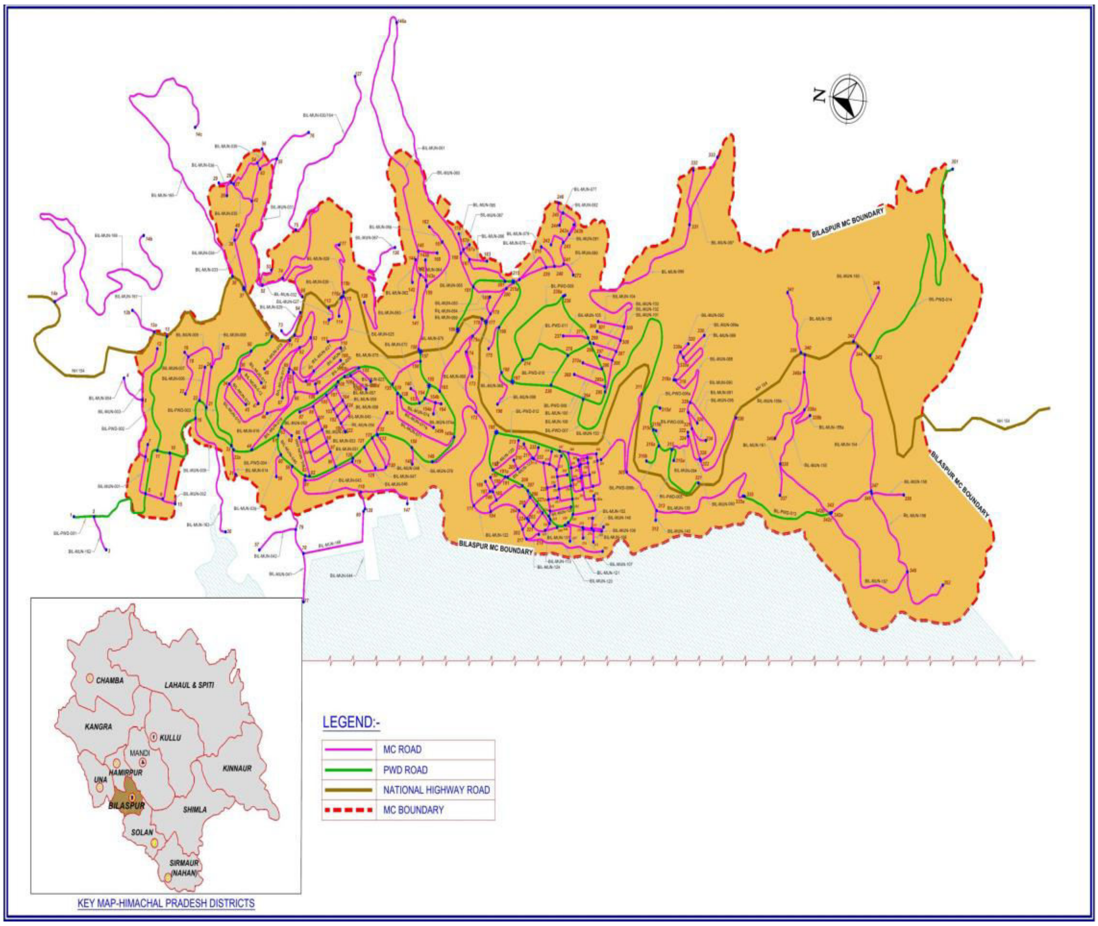


Fig.3.2: Map of Urban Road Network of Bilaspur (H.P. India)

3.5 DETAILS OF DATA REQUIRED

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

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

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

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

3.6 ROAD NETWORK DATA COLLECTION

3.6.1 General

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

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

3.6.1.1 Road Inventory Data

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

(i) Name and Category of road

(ii) Carriageway width

(iii) Shoulder width

(iv) Drainage condition

The above data was collected from visual inspection of the pavement sections, as well as from the H.P.P.W.D, Bilaspur.

3.6.1.2 Traffic Volume Data

Traffic volume counts are conducted manually for 72 hours consecutively by engaging adequate number of enumerators in individual road section. In HDM-4 model, traffic data is entered in the form of Annual Average Daily Traffic (AADT). Instead of expressing AADT in PCU unit, AADT is expressed in PCSE unit in HDM-4. PCSE (Passenger Car Space Equivalent) is termed as the differences in space occupied by each vehicle based on its size (length of vehicle) as compared with that of standard vehicle (car).AADT for each section were calculated by summing up the products of number of individual vehicle and its PCSE factor.

3.6.1.3 Pavement History Data

Pavement History data such as pavement type, year of last construction, surfacing and maintenance were collected from H.P.P.W.D and Municipal Corporation of Bilaspur.

3.6.1.4 Pavement Functional and Structural Evaluation Data

The structural evaluation was undertaken to assess the pavement's structural ability to receive wheel loads plying over it. Measurement of rebound deflection comes under this category. Higher the rebound deflection, poor will be the structural capacity and performance. Use of Falling Weight Deflectometer deflection method for evaluating the structural condition of the flexible pavement was incorporated.

3.6.1.5 Speed flow type

In the study, the speed flow type on selected road sections varied from 'Single Lane Standard' to Two Lane Standard.

3.6.1.6 Climate zone

One climate zone namely 'North India Mountain', has been defined on the basis of temperature (mean annual temperature) and rainfall (mean annual precipitation) characteristics of the study area i.e. Bilaspur town. Mean annual temperature is 18.9 ˚C and Mean annual precipitation is 1078 mm for Bilaspur town (source: Climate-Data.org).

3.6.2 Road Inventory Data

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

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

The above data was collected from visual inspection of the pavement sections, as well as from the Public Works Department, Bilaspur.

Drainage Condition Data: Data regarding side drainage condition on the road sections was collected on the basis of visual inspection and local public opinion. Drainage condition was classified as excellent, good, fair, poor, very poor based on the relationship between drainage time and drainage quality and condition of drains.

Lined drains have been provided in BIL-PWD-002 and BIL-PWD-004. There is no provision of drain in BIL-PWD-006 and also drain is not required in this section. There are choked lined drains in BIL-PWD-008 road section. Table 3.1 shows the drainage condition of selected road sections.

Table 3.1: Relationship between Drainage Time and Drainage Quality

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

Table 3.2: Drainage Condition of Selected Road Sections

Section ID	**Section Name**	**Drainage Condition**
BIL-PWD-001	LOWER NIHAL ROAD GURUDWAR TO INDUSTRIAL AREA	Good
BIL-PWD-002	LOWER NIHAL INDUSTRIAL AREA TO Govt. ITI ROAD	Good
BIL-PWD-003	BILASPUR FIRE STATION TO LOWER NIHAL	Excellent
BIL-PWD-004	COLLEGE CHOWK TO Govt. SENIOR SECONDRY SCHOOL NIHAL	Excellent
BIL-PWD-005	LINK ROAD FROM NH TOWARDS DHOLRA GUEST HOUSE	Fair
BIL-PWD-006	LINK ROAD NEAR DRDA OFFICE TOWARDS POLLUTION CONTROL BOARD	NIL
BIL-PWD-007	HP STATE POLLUTION CONTROL BOARD	Good
BIL-PWD-008	ROAD FROM NH TOWARDS EE OFFICE	Poor
BIL-PWD-009	COURT ROAD NEAR PURNAM MALL CROSSING DC OFFICE TO HOSPITAL	Fair
BIL-PWD-010	LINK ROAD FROM WAR MEMORIAL JUNCTION TOWARDS HOSPITAL	Poor

3.6.3 Traffic Volume Data

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

AADT for each section were calculated by summing up the products of number of individual vehicle and its PCSE factor. Table 3.3 shows the traffic volume of each road section in terms of AADT. As per HDM-4 model, section having traffic volume more than 10,000 AADT is considered as High traffic volume section, section having in between 6,000 to 10,000 AADT as Medium traffic volume section and less than 6,000 AADT as Low traffic volume section.

Table 3.3: Traffic Volume Data of Road Sections

Section ID	Motorized AADT (in PCSE)	Non-Motorized AADT	AADT year	Traffic Volume
BIL-PWD-001	14,232	2,019	2021	High
BIL-PWD-002	16,550	3,320	2021	High
BIL-PWD-003	11,856	2,247	2021	High
BIL-PWD-004	6,120	1,885	2021	Medium
BIL-PWD-005	18,580	1,100	2021	High
BIL-PWD-006	4,325	640	2021	Low
BIL-PWD-007	7,289	1,500	2021	Medium
BIL-PWD-008	10,500	2,450	2021	High
BIL-PWD-009	12,752	2,274	2021	High
BIL-PWD-010	5,745	782	2021	Low

3.6.4 Pavement History Data

Pavement History data as given in Table 3.4 such as pavement type, year of last construction, surfacing and maintenance were collected from PWD and Municipal Corporation of Bilaspur Town.

Table 3.4: Pavement History Data

Section ID	Surfacing Material Type	Current Surface Thickness (mm)	Previous Surface Thickness (mm)	Last Construction Year	Last Rehabilitation Year	Last Surfacing Year	Last Preventive Treatment Year
BIL-PWD-001	Bituminous Concrete (BC)	75	50	2019	2018	2017	2014
BIL-PWD-002	Bituminous Concrete (BC)	75	50	2019	2018	2017	2014
BIL-PWD-003	Bituminous Concrete (BC)	75	50	2019	2019	2017	2014
BIL-PWD-004	Bituminous Concrete (BC)	75	50	2019	2018	2016	2015
BIL-PWD-005	Bituminous Concrete (BC)	75	50	2019	2018	2016	2016
BIL-PWD-006	Bituminous Concrete (BC)	75	50	2019	2018	2018	2014
BIL-PWD-007	Bituminous Concrete (BC)	75	50	2019	2018	2016	2015

BIL-PWD-008	Bituminous Concrete (BC)	75	50	2019	2019	2017	2014
BIL-PWD-009	Bituminous Concrete (BC)	75	50	2019	2019	2018	2016
BIL-PWD-010	Bituminous Concrete (BC)	75	50	2019	2018	2016	2014

3.6.5 Pavement Functional and Structural Evaluation Data

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

3.6.5.1 Cracking Measurement

A number of representative test sections of length 100 m were chosen for cracking measurements for each pavement section. Cracking (Alligator, Longitudinal & Transverse) were visually inspected. In case of alligator cracking, the area covered under the distress was marked in the form of rectangular box with chalk on ground and measured with tape. In case of longitudinal and transverse cracks, effective width was taken as 50 cm and actual length was measured. Cracked area was expressed as percentage of total pavement area.

3.6.5.2 Roughness Measurement

Road Roughness refers to surface irregularities in the longitudinal direction. Roughness is an important pavement evaluation parameter because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs. Roughness was measured with Fifth Wheel Bump Integrator or simply known as Roughometer. The specifications for test are as follow: operational speed of the vehicle should be 32 ± ½ km/hr. The tyre pressure should be 2.1 kg/cm^2.

The equipment was towed by Pick-up and operated with speed 32 kmph. The equipment towed by Pick-up was made to run over wheel path (0.9 m distance from lane edge for two- lane and 1.5 m distance from lane edge for four-lane).

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

Unevenness Index (UI) = Bumps in cm / Length travelled (km)

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

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

Where, UI is Unevenness Index in mm/km. IRI is International Roughness Index in m/km unit. Table 3.5 shows the calculated values of Unevenness Index (UI) and International Roughness Index (IRI) for each road section.

Table 3.5: Determination of UI and IRI values for all Sections

Section ID	Bumps (cm)	Length Travelled (km)	Unevenness Index in (cm/km)	International Roughness Index (IRI)
BIL-PWD-001	136	1.000	136	1.99
BIL-PWD-002	157	1.000	157	2.25
BIL-PWD-003	149	1.000	149	2.16
BIL-PWD-004	285	1.000	285	3.85
BIL-PWD-005	142	1.000	142	2.06
BIL-PWD-006	255	1.000	255	3.15
BIL-PWD-007	175	1.000	175	2.55
BIL-PWD-008	132	1.000	132	1.80

BIL-PWD-009	245	1.000	245	3.05
BIL-PWD-010	139	1.000	139	2.02

Table 3.6: Functional Evaluation Data of Selected Road Sections

Section ID	Condition Year	Roughness IRI (m/km)	Cracking Area (%)	Potholes (no./km)	Rut Depth (mm)
BIL-PWD-001	2021	1.99	2.86	01	3.8
BIL-PWD-002	2021	2.25	3.69	02	5.2
BIL-PWD-003	2021	2.16	3.32	00	4.3
BIL-PWD-004	2021	3.85	4.05	12	3.32
BIL-PWD-005	2021	2.06	2.75	02	5.5
BIL-PWD-006	2021	3.15	3.99	10	3.05
BIL-PWD-007	2021	2.55	2.95	04	4.56
BIL-PWD-008	2021	1.80	2.65	02	2.45
BIL-PWD-009	2021	3.05	3.25	14	4.02
BIL-PWD-010	2021	2.02	3.13	02	2.75

3.7 VEHICLE FLEET DATA

3.7.1 General

A typical traffic flow in Indian urban roads comprises of both Motorized vehicles (MT) and Non-Motorized vehicles (NMT). Both vehicles contribute in traffic flow of Bilaspur town. A typical vehicle fleet in India may be considered to be comprised of the following vehicles for the purpose of economic analysis to be conducted in PMMS.

The same set of vehicles has also been identified as representative vehicle fleet for Indian conditions [Archondo et al., 2003]. These vehicles are:

Motorized (MT) Vehicles

3.7.1.1 *Two Wheeler*

3.7.1.2 *Car/Jeep/Van*

3.7.1.3 *Bus(Medium)*

3.7.1.4 *Mini Truck*

3.7.1.5 *Mini Bus*

3.7.1.6 *Truck*

3.7.1.7 *Auto Rickshaw*

3.7.1.8 *Tractor/Trolley*

Non-Motorized Vehicles

3.7.1.9 *Cycle*

3.7.1.10 *Man Driven Rickshaw*

3.7.1.11 *Cart*

3.7.2 Vehicle Fleet Database

The basic vehicle fleet data items [Archondo et al., 2003], which are required to be specified such as Passenger Car Space Equivalent (PCSE), Number of wheels, Number of axles, Annual number of kilometers driven, Vehicle service life, Operating weight, Equivalent Standard Axle Load Factor (ESALF) etc. for each vehicle type, are given in Table 3.7 and Table 3.8.

All these data items are incorporated in the vehicle fleet database created in HDM-4. This vehicle fleet database has been named as 'Bilaspur Town Vehicle Fleet' for all future references and uses.

Table 3.7: Basic Data of Motorized (MT) Vehicles included in Bilaspur Town Vehicle Fleet.

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

Table 3.8: Basic Data of Non-Motorized (NMT) Vehicles in Bilaspur Town Vehicle Fleet

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

3.7.3 Vehicular Composition and Annual Growth Rate

The vehicular composition for both Motorized (MT) and Non-Motorized (NMT) vehicles was found out from volume count data. The average annual growth rate of vehicles in Bilaspur has been taken as per the Master Plan of Bilaspur District, 2021. Table 3.9 shows vehicular composition and annual average growth rate.

Table 3.9: Vehicular Composition and Annual Growth Rate

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

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

3.8 MAINTENANCE AND REHABILITATION WORKS

3.8.1 Serviceability Levels for Maintenance

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

The maintenance serviceability levels for urban roads as per Guidelines for Maintenance of Primary, Secondary and Urban Roads", [MORT&H, 2004], are given in Table 3.10.

Table 3.10: Maintenance Serviceability Levels for Urban Roads

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

*As per Odoki and Kerali [2000]

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

3.8.2 Maintenance & Rehabilitation (M&R) Treatments and Strategies

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

3.8.2.1 Routine Maintenance

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

3.8.2.1.1 Crack Sealing

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

3.8.2.1.2 Patching

This is also a scheduled type, which is used to repair the following surface distresses: potholing, wide structural cracking, and ravelling. The treatment for pothole patching consists of placing a bituminous mix, either of the same quality as the existing bituminous surface or a superior mix after trimming the potholes to proper shape and depth, and side painting with tack coat.

This is followed by compaction [Specifications clause 3004.1 of MORT&H 2001d]. Patching of ravelled area only prevents the formation of potholes from those areas. It has no effect on future pavement deterioration.

3.8.2.2 Periodic Maintenance

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

3.8.2.3 Preventive Treatment

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

3.8.2.3.1 Resealing

Resealing can be used for low levels of surface distress such as cracking and ravelling, or roughness. For bituminous pavements, it consists of thin surfacing such as Bituminous Surface Dressing (BSD) to seal the entire road surface against the ingress of water and to improve skid resistance. It neither increases the strength of the pavement considerably nor improves the riding quality significantly. A single coat bituminous surface dressing (SBSD) consists of a single application of bituminous binder material followed by aggregate spreading and rolling [Specifications clause 508 of MORT&H 2001d].

When the surface dressing is similarly done in two layers it is termed as Double Bituminous Surface Dressing (DBSD). Resealing works reset surface distresses to zero and thereafter the pavement condition is considered to be new. The default effects of all types of resealing on some distresses [Morosiuk et al., 2001] are specified as follow:

(i) Roughness resets to 2.0 m/km IRI

(ii) Texture depth resets to 2.5 mm

(iii) Skid resistance resets to 0.6 SFC50

3.8.2.3.2 Overlay

For bituminous pavements, it refers to the addition of thick surfacing such as Bituminous Concrete (BC) to restore or improve the structural integrity and to increase the strength of the pavement [Specifications clause 512 of MORT&H 2001d]. Bituminous Concrete is a thoroughly compacted, dense graded bituminous mix.

The Semi-dense Bituminous Concrete (SDBC) has comparatively lower binder content and the aggregate used are less dense-graded [Specifications clause 511 of MORT&H 2001d]. Apart from these, lesser quality mix Premix Carpet (PC) [Specifications clause 509 of MORT&H 2001d] can also be used depending upon the relative importance and traffic volume carried by the road.

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

(i) The rut depth gets reduced to 15 % of the original value

(ii) Roughness resets to 2.0 m/km IRI

(iii) Texture depth resets to 0.7 mm

(iv) Skid resistance resets to 0.5 SFC50

3.8.2.3.3 Mill and Replace

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

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

(i) Roughness resets to 2.0 m/km IRI

(ii) Texture depth resets to 2.5 mm

(iii) Skid resistance resets to 0.5 SFC50

3.8.2.3.4 Reconstruction

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

3.9 COSTS DATA

3.9.1 Costs of Maintenance and Rehabilitation (M&R) Works

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

3.9.1.1 Cost Updating

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

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

Where, F_L, F_M and F_F are the labour component, material component and machinery component of the cost respectively. I_1, W_1 and f_1 are the annual average CPI, WPI and fuel price respectively for the stated year (2015-16 in the present study) and I_0, W_0 and f_0 are the annual average CPI, WPI and fuel price respectively for the base year 1999-2000. The values of these components are given in Table 4.15.

Table 3.11: Price Indices and Fuel Price

Item	Year	
	2009-2010	**2021-2022**
Consumer Price Index (CPI)	425	689
Wholesale Price Index (WPI)	145	322
Fuel Price in Rupees	10	59

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

On the basis of the above model, the percentage increase in costs for the year 2021-22 over the base year costs has been calculated as follow:

Routine maintenance costs = 125.26%,

Periodic maintenance costs = 205.40%

Costs data for stated year 2021 over the base year 2009-2010 has been updated. Table 3.12 shows updated cost data of maintenance and rehabilitation works and drainage works as per the discussions held with field engineer, in-charge of the maintenance of the pavement sections under study.

Table 3.12: Updated Economic Cost Data of M&R Works for year 2021

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

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

3.9.2 Road User Cost (RUC) Data

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

Road User Cost (RUC) = VOC (55 - 70%) + TTC (20 - 40%) + AC (5 - 10%)

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

Table 3.13 shows the current vehicle operating cost inputs i.e., of year 2021.

Table 3.13: Current Vehicle Operating Cost Inputs (All Prices in Rupees)

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

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

Table 3.14: Calculated Values of VOC Components for All Types of Vehicle

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

Congestion Effect: VOC components calculated in Table 4.8 with the help of Annexure B (section B.1) equations are for uncongested free flow conditions. In case of urban traffic, congestion usually occurs. So, it is important to take account for congestion effect [Clause 6.9, IRC SP: 30-2009]. Equations for Congestion Factors are provided in section B.2 of Annexure B referred from table 10 of IRC SP: 30-2009. Table 3.15 shows the calculated values of congestion factors for each type of vehicle.

Table 3.15: Calculated Values of Congestion Factor as per IRC SP: 30-2009

Section ID	**Volume/ Capacity Ratio**	**Two-wheeler**	**Car/Jeep/ Van**	**Bus**	**Light Commercial Vehicle**	**Heavy Commercial vehicle**
BIL-PWD-001	0.9	1.02	1.13	1.79	1.8	1.34
BIL-PWD-002	0.30	1.00	1.08	1.17	1.11	1.07
BIL-PWD-003	0.38	1.00	1.00	1.22	1.28	1.43
BIL-PWD-004	0.38	1.00	1.00	1.22	1.28	1.43
Average Congestion Factor		1.00	1.05	1.35	1.37	1.32

Average Congestion Factors have been multiplied with above VOC components to get the VOC components for congested flow condition. The congested VOC components have been multiplied with current VOC inputs to get the Vehicle Operating Cost (VOC) values of each vehicle. Table 3.16 shows the Vehicle Operating Costs data which are directly going to be entered in HDM-4. All the quantities are in per 1,000 vehicle-km unit.

Economic costs of new cycle, Man-Driven Rickshaw and Cart have been taken as Rs. 2000, 4500 and 6,000. In the present study, Auto Rickshaw is one of the influencing vehicles for each road section. In vehicle fleet part of HDM-4 model, representation of three-wheeler type vehicle i.e. Auto Rickshaw has not been covered.

So, to take account for this vehicle type in HDM-4 model, the Vehicle Operating Cost relationship between Auto Rickshaw and Car (Medium) has been anticipated as given below based on author's interviews with owners/drivers of both categories of vehicles [Prakash, 2009].

VOC of two numbers of Auto Rickshaw = VOC of 1 Medium Car

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

Table 3.16: Vehicle Operating Costs Data Input per 1,000 vehicle-km

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

3.10 ADAPTATION OF HDM-4 MODEL TO INDIAN CONDITION

Since, HDM-4 has been designed to be used in a wide range of environments, it is important that prior to using HDM-4 the system should be configured and calibrated for local use. The use of appropriate calibration factors in HDM-4 pavement deterioration models will facilitate more reliable and rational prediction of pavement deterioration for the highway network under study.

The pavement deterioration models incorporated in HDM-4 were developed from results of large field experiments conducted in several countries. Consequently, the default equations in HDM-4 if used without calibration, would predict pavement performance that may not accurately match that observed on specific road sections [Bennett and Paterson, 2000].

Jain et al. developed the calibration and adaptation of HDM-4 bituminous road deterioration models for Indian Conditions. In that study calibration factors were proposed for National Highway network within the SNP range of 3.0 - 5.5. As in the present study, SNP range is 4.8 – 5.46. So, the same calibration factors have been used in the present study as given in Table 3.17 [Jain et al., 2005].

Table 3.17: Calibration Factors for HDM-4 Deterioration Models

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

3.11 SURVEY METHODOLOGY

The engineering surveys and investigations have been carried out on the study area for pavement evaluation, following the relevant Specifications/Codes to generate adequate database for preparing the most appropriate proposal for the rehabilitation / upgrading of the existing network.

The following engineering surveys & investigations were carried out for developing the study area:

- Road Inventory Survey.
- Pavement Condition Survey.
- Drain Inventory Survey.
- Topographic Survey.
- Pavement Survey.
- Trial Pit and Material Investigation.
- Falling Weight Deflectometer Survey.
- Structure Inventory and condition Survey.
- Land-Use Survey.
- Traffic Surveys.
- Classified Volume count survey.
- Origin – Destination survey.
- Turning Movement Count survey.
- Geotechnical Investigations

3.11.1 Road Inventory Survey

A detailed inventory of roads and structures were carried out and data/details of road inventory were collected, by actual verification & measurements.
The following data were collected in the inventory survey:

- Terrain code - Plain, Rolling, Mountainous, Steep
- Land Use -Built-up/Semi-Built-up

- Width of Right of way – m
- Surfacing type - bitumen, Cement Concrete, Paver
- Carriage way width – m
- Shoulders - Left side: Type, Width (m)
  Right side: Type, Width (m)
- Road Junctions - Type, Details
- Drainage type - Left side: Type
- Right side: Type
- Footpath Width – m
- Median - Type and Width
- Utilities - Nos.

3.11.2 Pavement Condition Survey

Pavement Investigation is an important aspect of any road improvement project, since the performance of urban street network directly depends on the performance of its pavement and the cost of improvement of pavement. The pavement condition survey was carried out on study area to examine the functional efficiency of the existing pavement.

Basic pavement distresses on the corridors were measured by visual observation. Predominant distresses like cracking, ravelling and extent of rutting were noted as percentage area for every 100 m length of road. Number of potholes for each 100 m length will be noted.

Apart from these distresses, sections with excessive bitumen flow bleeding and embankment condition were noted during the survey. The exact nature of various distresses along with their extent on the existing pavement was noted by visual observation. Each of the distress was divided into various kinds based on their severity.

3.11.2.1 Various Distresses

- **Longitudinal Crack** - Longitudinal cracks are parallel to the centerline of the road. Longitudinal cracking in bituminous pavement is usually caused by alternate wetting and drying beneath the shoulder surface or by improper/weak joint between adjoining layers of pavement.
- **Transverse Crack** - Transverse cracks appear in the transverse directions or as interconnected cracks forming series of large blocks perpendicular to the direction of the road. Transverse cracking may occur due to the reflection of crack or joint in an underlying pavement layer. The low temperature brittleness or oxidation of bitumen and structural failure at concrete base course of such cracking. These are usually formed due to shrinkage of bituminous mix on account of low temperature.
- **Alligator Crack** - It is a series of interconnected cracks, having small irregular blocks in pavement surface which resemble the skin of an alligator. The size of irregular cracking shape blocks of cracks varies from less than 30 cm to more. These distresses are occurring due to inadequate pavement thickness, weakening of sub-grade or lower layers of the pavement due to ingress of excessive moisture to pavement and saturation. The above-mentioned cracks may be classified as low severity, medium severity, and high severity and its ranges for measuring the distress is mentioned below.

TABLE.3.18: Distress Level and Severity Type

S.No.	Description	Measurement ranges (mm)
1.	Low Severity	1 to 3
2.	Medium Severity	3 to 6
3.	High Severity	>6

- **Raveling/ Weathering** - Raveling is due to wearing away of the pavement surface caused by the loss of asphalt binder and dislodged aggregate particles. Low level raveling indicates that aggregate or binder has started to wear away. Moderate level raveling indicates that aggregate and/or binder has worn away. High level raveling indicates that aggregate and/or binder has been considerably worn away.

- **Potholes** - Potholes are small bowl-shaped depressions in the pavement surface. The potholes are counted in numbers and the severity defined based on the depth of pothole. The pothole depth of 0-25 mm with 200mm wide, 25-50 mm with 500mm wide, more than 50mm and 500mm wide is classified as low, moderate, and high severity levels respectively.

- **Patching** - A patch is an area where the original pavement is removed and replaced by a filler material. Low level patch is provided at places where little deterioration has occurred. Moderate level patch is provided at places where pavement is moderately deteriorated and/or moderate spalling is seen around the edges. High level patch is provided at places where pavement is badly deteriorated.

3.5.3 Drain Inventory Survey

The detailed inventory of storm water drains structures existing in the study area had been examined and condition of the drain is recorded. Based on the condition and size of the drain, proposal of the storm water drain network formulated. The following details of the storm water drain recorded in the survey:

- Location of the drain
- Size of the drain
- Type of the drain
- Condition of the drain.

3.5.4 Topographic Surveys

3.11.4.1 General

The main objective of the topographic survey is to capture the essential ground features at the study area for working out improvements. Topographic survey was carried out using LIDAR (Light Detection and Ranging - Vehicle mounted) techniques. Where it is found to be impossible to conduct LiDAR survey, electronic Total Station was used to capture the Topographic data.

In terrestrial LiDAR capture, the street view is generated using a Leica Pegasus, Two Mobile LiDAR System, accompanying 360-degree cameras. Wherever required, high resolution still images could also be captured and used to texture building facades to make them look photorealistic. The LiDAR survey equipment and the capturing of details are shown below.

Fig.3.3: Terrestrial LIDAR Survey Equipment.

Fig 3.4: Typical View of the Drawing Produced from LiDAR Survey

The surveyor was maintaining a field book, in which all relevant observations would be noted along with field sketches. Before starting topographic survey all the survey instruments were checked for errors and approved by the site engineer. Qualified, trained surveyors and LiDAR experts were deployed for carrying out the survey work.

3.11.4.2 Methodology

The methodology followed for the topographic surveys is as follows.

a) Fixing of Permanent Control Pillars and Benchmarks

Identification of suitable location for DGNSS Control Pillars is established at permanent structure location and closer interval for Mobile LiDAR data processing.

b) Traverse Survey

Traverse survey was carried out by connecting all the Control Pillars and traverse was closed after fixing of Control Pillars. Ensuring survey networks relate to an accuracy of 1:20,000 for horizontal control.

c) Levelling

After fixing Benchmark pillars, control levelling was carried out by connecting all the DGNSS points. For the purpose of level control, the main DGNSS control pillars were connected to nearest Survey of India GTS Benchmark. Ensuring closing error on level circuit shall not exceed 12√K in mm, where K is distance in km. The closing error is distributed to all the benchmarks in network.

d) Topographic survey

Conducted detailed topographic survey to capture the essential ground features including longitudinal section at every 25m intervals and cross section at 50m intervals for a width of 40m on either side or up to the building lines on either side of the centre line of the existing road and 50m on either side of the centre line of the proposed realignment/Bypass.

3.11.5 Pavement / Subgrade/ Material Investigations

3.11.5.1 Trail Pit

Test pit of 1.0 x 1.0 was excavated in pavement/ at the verge of the shoulder. The general characteristics of materials excavated from pit were recorded and further properties were evaluated.

3.11.5.2 Subgrade

a) Maximum dry density for each pit sample

b) Gradation of the subgrade soil

c) Liquid Limit and Plastic Limit

d) Optimum moisture content

e) 4 days soaked CBR at 3 energy levels tested for each pit sample.

3.11.5.3 Existing Pavement Composition

The existing Pavement Curst thickness is found using Trail pits near/on the existing road. 1 x 1 m pit is dug on the pavement using the excavator and the thickness of the Bituminous and non-bituminous layer is recorded for the overlay analysis.

3.11.5.4 Material Investigation

The materials collected from quarries near the study area were collected for testing. The samples were tested based on MORTH specifications.

The consultant has identified borrow areas near the DHQ. Based on the volume of material available number of samples collected and the properties were studied to conclude its use in the new pavement construction. The following tests will be conducted as per codal procedures.

3.11.5.5 Tests on Coarse Aggregate

- Aggregate Impact value test
- Specific gravity
- Water absorption
- Flakiness & elongation test
- Soundness test
- Stripping value of aggregate

3.11.5.6 Tests on Fine Aggregate

- Silt content
- Specific gravity
- Water absorption
- Sieve analysis and Fineness Modulus
- Organic Impurities
- Soundness test

3.11.5.7 Falling Weight Deflectometer

The strengthening of flexible pavements is based on the pavement rebound deflections obtained from the deflection survey conducted by the Falling Weight Deflectometer (FWD), testing equipment following the guidelines of IRC: 115-2014. KUAB Falling Weight Deflectometer (FWD) a non-destructive pavement testing device was used, which provides an accurate data on pavement response in terms of a typical deflection bowl, simulating actual wheel loads in both response and duration, which allows rapid measurement of pavement deflection under load than traditional methods.

A dynamic load is generated by the dropping of a mass from a pre-set height onto a 300 mm diameter plate. The magnitude of the load and the pavement response are measured by a load cell and geophones.

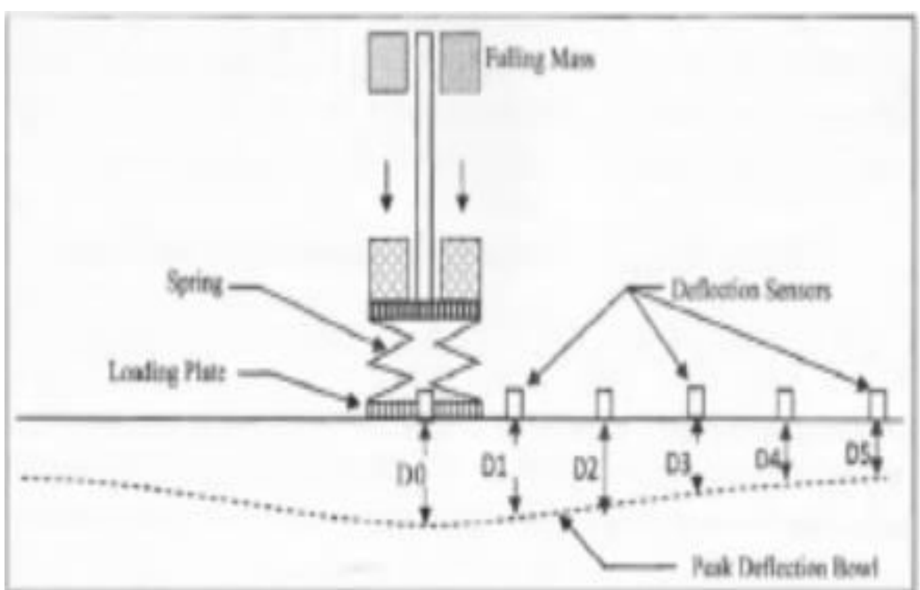
One geophone is located immediately under the load, whilst the others are located at variable offsets at 200, 300, 450, 600, 900, 1200, 1500, and 1800mm as per Clause 4.6 in IRC: 115-2014 The FWD is integrally mounted on a trailer which is towed by a dedicated vehicle. All testing is controlled by a personal computer which is located in the vehicle towing the FWD.

As a result, only one operator is required to conduct a survey on most occasions making it less labour intensive. The test load can be varied between 20 and 250 KN to meet the requirements of the particular task and the pavement response to four different magnitudes of load can be measured during any test sequence. A typical sequence can be completed in approximately one minute. Highly accurate deflection bowl measurements are possible which help in doing large-scale deflection surveys.

3.11.5.8 Working Principle

Falling Weight Deflectometer (FWD) is a fully automatic impulse-loading device in which a transient load is applied to the pavement and the deflected shape of the pavement surface is measured. The working principle of a typical FWD with 5 geo-phones is shown in Figure 3.5.

Fig. 3.5: Working Principle of FWD.



The time taken by the load to achieve from zero-peak-zero is called as "Pulse Duration", the equipment can produce impulse duration from 15 to 50 m.

Geophones or seismometers are used to measure the deflection produced by the load plate. Some of the equipment parameters are presented in the Table 3.19.

Table 3.19 : KUAB FWD Equipment Parameters

S.No.	Decription	Equipment Parameter
1.	Load, Kn	40,50,90,120
2.	Minimum Deflection (mm)	0.001
3.	Plate Diameter (mm)	300
4.	Rubber Pad Thickness (mm)	5
5.	No. of Geophones	9
6.	Spacing of Geophones (mm)	0,200,300,450,600,900,1200,1500,1800

Fig. 3.6: KUAB Equipment

3.11.5.9 Data Collection

In the established urban road network (DHQ), only bituminous road with width of 4 m or more than 4 m is considered for FWD survey. For the identified road section detailed visual pavement condition survey is carried out to identify various distresses and to further categorize the road condition as Good, Fair or Poor. The visual condition survey carried out for the identified road sections and frequency of the points at which the deflection survey is to be carried out was decided. The frequency of the testing was kept in line with the requirements of IRC: 115-2014. The frequency of points that was followed for various pavement conditions is shown in Table 3.19**.**

Table.3.20: Spacing of Test points

Pavement Condition	Spacing of Point, m
Good	500
Fair	250
Poor	130 or less

* Note: The points of testing have been identified in such a way that failed locations which are visible with severe distress are excluded from the testing.

The survey is carried out in accordance with IRC:115-2014. The target peak load applied on bituminous pavements is 40 kN (+/- kN) which corresponds to the load on one dual wheel set of 80 kN which is the standard axle load. Deflections are measured at 0.75 m from the edge of outer lane with points staggered for both the directions. Wherever the load applied is different from 40 kN, the measured deflections are normalized corresponding to standard target load of 40 kN. The FWD machine used for project evaluation work has 9 Geo phones covering half deflection bowl of 1.8 m width. Pavement and air temperatures, as well as field moisture measurements from test pits were also recorded for pertinent temperature and seasonal corrections required for subsequent analysis. The spacing of the deflection sensors from the centre of the load plate is as follows:

Below the load centre, 200, 300, 450, 600, 900, 1200, 1500, 1800.

At a test point, the load is dropped 4 times. Drop 1 corresponds to the seating load which has not been recorded. The load, deflection and other parameters corresponding to drop 2, 3 and 4 have been recorded for a test point.

3.11.6 Landuse Survey

Urban improvement/rejuvenation of the town requires assessing the existing landuse, which will help in understanding the landuse patterns and its impact on the major roads of the town taken up for the improvement under this DPR.

Project team has visited all the 8 project towns and conducted a reconnaissance survey which helped us to understand the city's nature of development and come up with a suitable detailed methodology for conducting the survey along the identified project roads.

3.11.6.1 Survey Methodology

There are established methods for conducting land use surveys. After having the understanding of the towns such as challenging terrain, narrow roads, encroachments, etc. suitable approach is formulated for landuse survey which is mix of both LiDAR survey and physical landuse verification. Topo-data generated with the LiDAR survey was used for marking of ground features and preparation of the basemap. Post preparation of the basemap, physical landuse survey was undertaken. A detailed methodology is prepared for the landuse survey is presented in Figure 3.7.

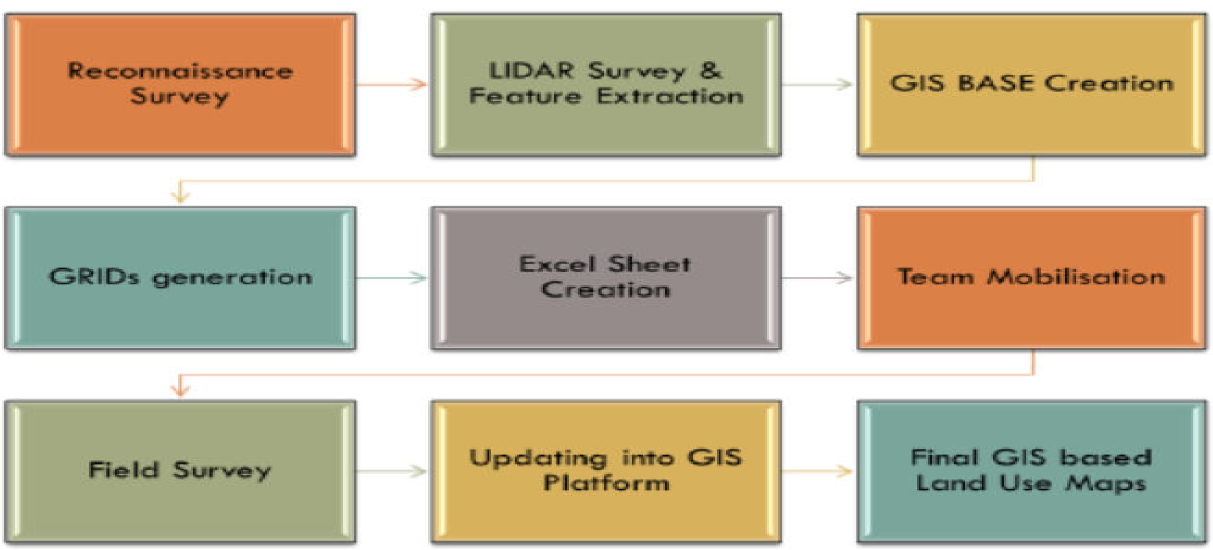


Fig.3.7: Methodology for Land Use Survey

3.11.6.2 Base Map Preparation

Base map was generated from the LiDAR survey data, for the towns with the building footprints along the roads. The data was in line/point format which was brought in GIS platform by assigning the coordinates.

In GIS format the polylines of building footprints were converted into polygons by closing the open features. A draft base map was prepared marking buildings and roads. Each building was assigned unique ID for identification. LiDAR survey output is shown in Figure 3.8.

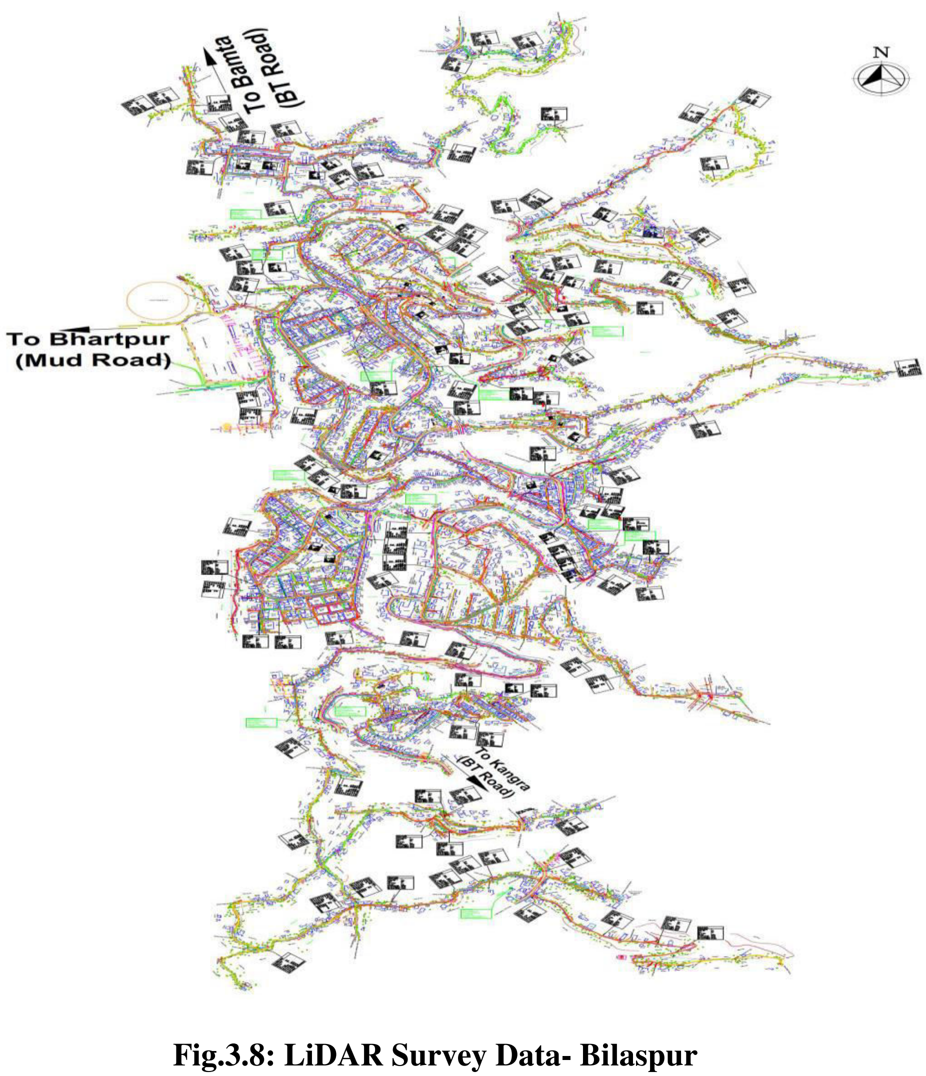


Fig.3.8: LiDAR Survey Data- Bilaspur

Google Imagery was also taken up to create a base map where the features were marked on it. Entire project roads were further divided into grids.

After marking all the features in these grids, unique IDs were generated for each individual entity i.e. for buildings, roads and grids. After digitizing the map, a grid layer was created with the dimensions of 300 meters X 300 meters, which was in 1:1100 scale in A3 paper size. This layer was overlaid on the base map. Each grid was exported in PDF format along with the respective excel sheets. Index map prepared for the town is shown in Figure 3.8 and a grid for Bilaspur town is shown in Figure 3.9.

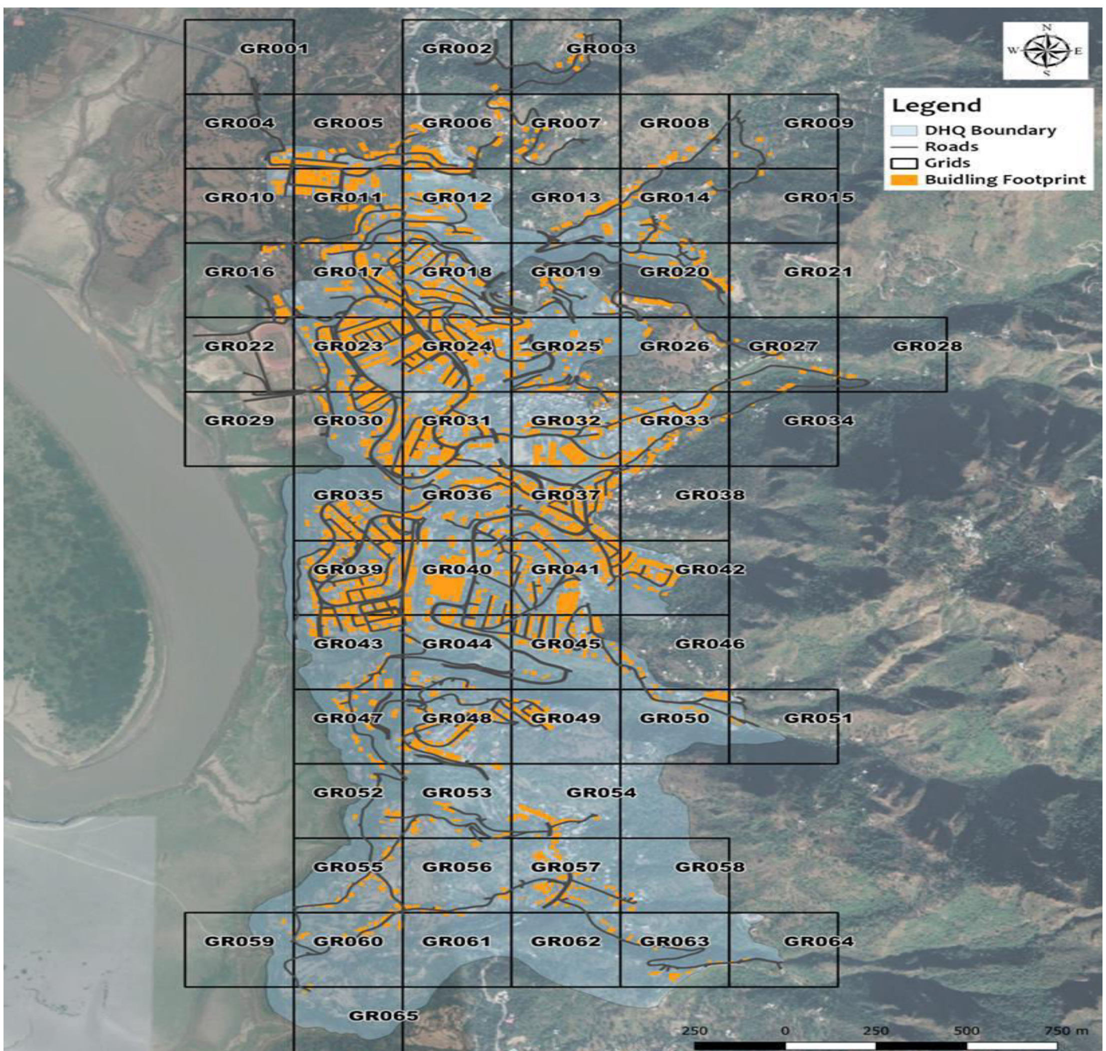


Fig.3.9: Index Grid Map- Bilaspur

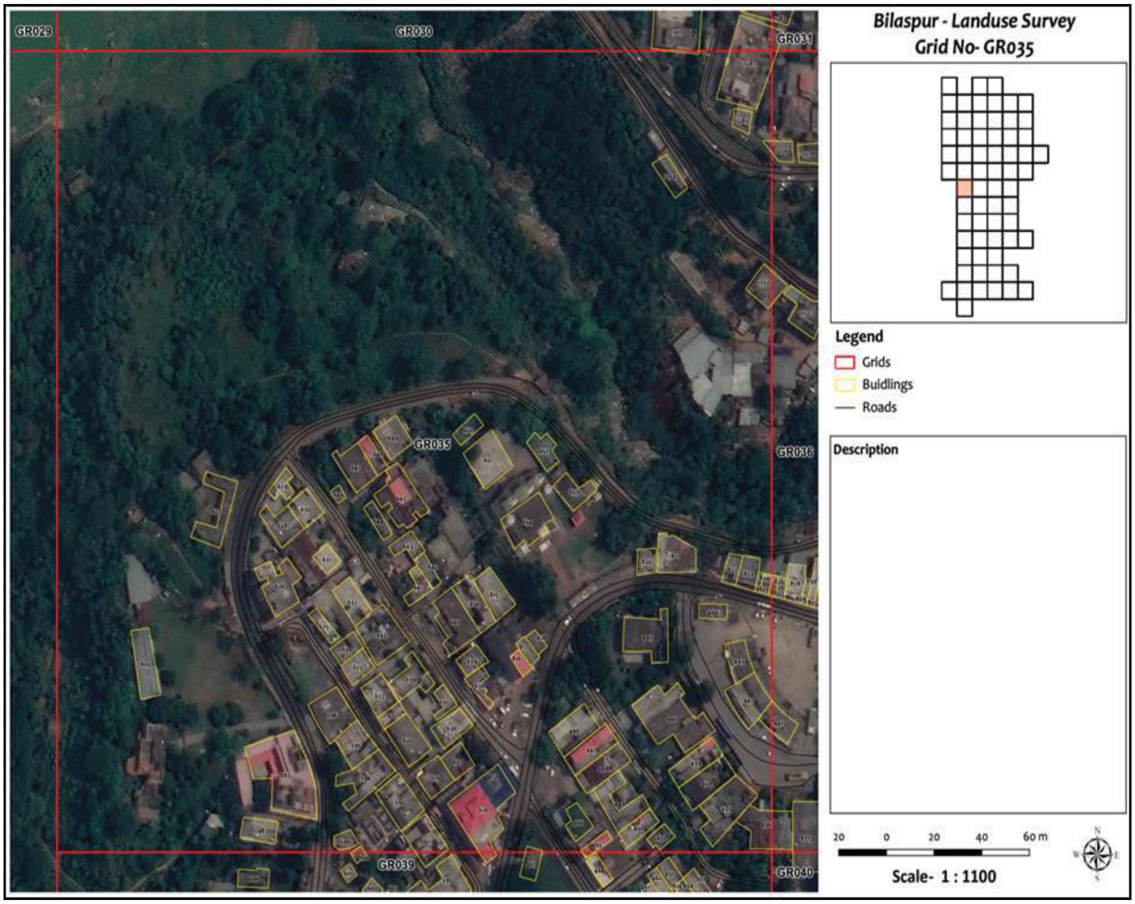


Fig.3.10: Field Grid- Bilaspur

Information to be collected from physical survey in the excel format is shown in Table 3.21:

Table.3.21: Details of data collection in excel format during Landuse survey

S.No.	Category	Remarks
1.	Grid ID	Attribute value in GIS
2.	Building ID	Attribute value in GIS
3.	Road ID	Attribute value in GIS
4.	Landuse	Landuse Class
5.	Floor wise use (G, G+1…)	Landuse Sub-Class
6.	Construction Type	--
7.	Ownership Details	From the Field
8.	Descriptions	Specific to the Building

3.11.7 Physical Landuse survey

The grid maps along with the index grid map were distributed to the survey team which was mobilized to the Bilaspur town. Before starting the survey, one day training on how to conduct survey was given to the enumerator team.

Training was basically focusing on the methodology and use of applications that were used for survey. Post the survey, updated grids are then brought to the GIS platform and required changes have been made. An updated grid is shown in Figure 3.11.

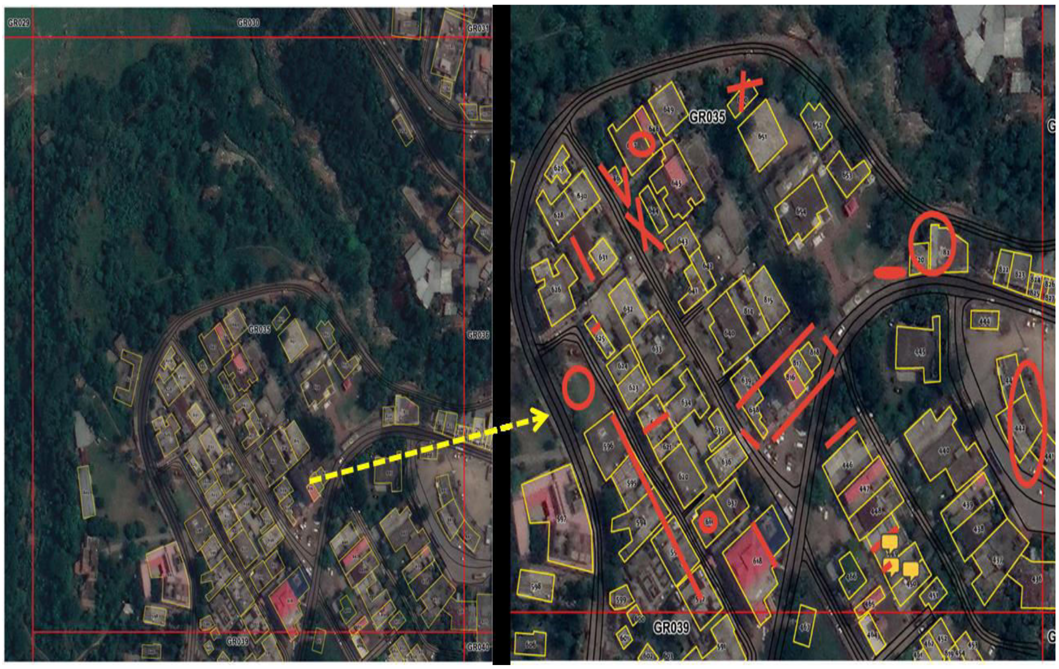


Fig.3.11: Updated Landuse Grids After Physical Survey

3.11.8 Traffic Surveys

The following primary surveys are proposed to capture the traffic pattern on the project road. The traffic surveys will be conducted based on "IRC 9 -1972, Traffic Surveys on Non-Urban Roads". The various traffic surveys include:

- Classified Volume count survey
- Origin – Destination survey
- Turning Movement Count survey
- Pedestrian volume count

3.11.8.1 Classified Volume Count Surveys

The Consultant carried out classified volume counts at identified locations on study area. Educational /Institution Buses, State Transport Buses and Private Buses will be counted separately. The Commercial Goods Vehicles will be classified as LCV type 1

(4 tyre), LCV type 2 (6 tyre), 2 Axle Trucks, 3 Axle Trucks and Multi Axle Trucks. Taxis and private cars (car / jeep / van) will be classified separately.

Sufficient enumerators will be deployed on either side of the road to cater to each direction of traffic so that data collection errors are minimized.

3.11.8.2 Origin - Destination Surveys

Origin-Destination (O-D) Survey and Commodity Movement Survey was carried out in both the directions at the finalized survey locations. The locations for the O-D survey and Commodity Movement survey are same as that of Classified Traffic Volume Count Survey locations.

The survey was carried out on random sample based road side interview method and has covered Car, Bus, LCV and Truck type of vehicles. Commodity movement survey was carried out only for trucks whereas purpose of travel is collected for cars.

The zoning pattern and the zone map will be prepared and submitted as part of the deliverables. The zoning will be done in such a manner that the O-D survey would clearly assess the traffic pattern on the project influence area, keeping in view of the major generation and attraction points.

3.11.8.3 Turning Movement Count Surveys

The Consultant carried out turning movement count survey at major junctions on project corridors. Educational/Institution Buses, State Transport Buses and Private Buses will be counted separately. The Commercial Goods Vehicles will be classified as LCV type 1(4 tyre), LCV type 2 (6 tyre), 2 Axle Trucks, 3 Axle Trucks and Multi Axle Trucks. Taxis and private cars (car/jeep/van) will be classified separately. The surveys will classify exempted vehicles separately. Turning Movement Survey (TMC) will be carried out using video recording survey method continuously for 16 hours at major junctions. Enough trained technicians will be deployed where the cameras are mounted for monitoring the video recording of traffic.

3.11.8.4 Pedestrian Volume Count Surveys

The consultant has carried out Pedestrian volume count survey on busy intersections where large movement of people is observed. Based on the survey results appropriate treatment at the crossing and junction locations shall be explored.

3.12 ANALYSIS OF SURVEY DATA

3.12.1 Road Inventory Survey

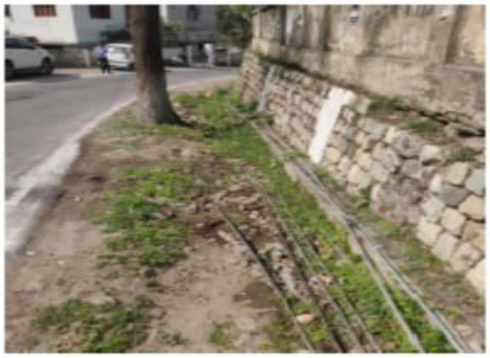
Detailed road inventory survey was conducted for the entire road network identified for development to evaluate the existing pavement condition of the roads, terrain, land-use, existing road width, available width, storm water drain conditions, available utilities, junctions, existing street lighting and project facilities such as bus stops, public toilets, truck parking and other road furniture. The survey was conducted via manual data collection method and on-site data entry with GPS assisted google sheets so that the data gets stored in the central server on real time. A summary of Road inventory data is presented in Table 3.22.

Table.3.22: Road width classification

Width of Road	Length, Km	% of Total Road Length
Below 4.0m	40.50	86%
Between 4m-7m	6.00	14%
Total Length, Km	46.50	100%

	
Bituminous Road >4m Wide	Paver block road -2.5m wide
	
Cement Concrete Road -3m wide	Earthen Road – 2.5 m wide

	
Bituminous Road with storm Water Drain arrangement	Bituminous Road with gutter drain



Available Utilities – Water connection

Available Utilities – Water connection

Steel Grating acts for Drain maintanence

Available utilites – Electrical / Telephone

Fig.3.12: Road Inventory Photographs

3.6.2 Pavement Condition Survey

Pavement condition survey for the paved road network was carried out to assess the existing pavement condition of the different road types. The pavement distress evaluation shall be assessed based on the IRC-82-2015 for Bituminous pavement and IRC-SP-83-2018 for cement concrete pavement. However, based on the existing pavement crust details, it's been observed that the pavement layers and cement concrete pavements are not executed as suggested in the IRC specifications.

The pavement distress assessment for the asphalt road is done as per the IRC standards and its severity measures for the different types of pavements are stated below. The same is adopted for assessing the pavement quality by visual observation and measurements. The Visual pavement condition survey of existing roads with width more than 4m is carried out to identify the distressed pavement location, its severity and the extent. Summary of type of pavement data is presented in Table 3.23:

Table.3.23: Pavement Survey Summary

S.No.	Existing Type of Pavement	Length of Road (Km)	%
1.	Bituminous Road	36.80	78.30
2.	Cement Concrete	3.10	6.60
3.	Paver Block	4.00	8.50
4.	Earthen Road	3.10	6.60

A few Photographs of pavement condition observed is shown in Figure 3.12.


Flexible Pavement in Good condition along BIL-MUN-155


Paver Block in Good Condition BIL-MUN-045


Distressed Cement Concrete pavement BIL-MUN-155


Shoulder Drop off in Flexible Pavement BIL-MUN-122


Potholes in Flexible Pavement BIL-PWD-001


CC pavement with variable Panel Sizes BIL-MUN-122

Fig.3.13: Pavement Inventory Photographs

The type of pavement varied from Bituminous, Cement Concrete, Earthen and Paver block. All the PWD roads is observed with bituminous pavement except BIL-PWD-013 (Lakhanpur Road). Pavement type for Municipal roads varied from paver block, Cement concrete, bituminous and earthen.

The major distresses observed in the Flexible Pavement are:

- Alligator Cracking
- Potholes
- Raveling
- Patching
- Shoulder Drop off at few location

The road section with Paver Block is observed to be in good condition with no major distresses. The road section with Cement Concrete pavement is observed with Edge cracking, variation in panel sizes, no provision of expansion and contraction joints etc.

3.12.3 Drain Inventory Survey

To rebuild the entire storm water, drain network, the details of existing drain details are to be mapped. In view of mapping of the storm water drain network a detailed drain inventory survey was carried out for the selected road network by visual inspection and measurements. The existing drain type, dimensions of the drain details such as width, depth and length of the drain, condition of the drain and flow path of the drain sections are recorded during the inventory survey. A total of 16.00 km of drain is observed in Bilaspur DHQ.

Majority of the existing are observed to be in fair to poor condition. At many locations integration of sewerage lines inside the storm water drain is observed which causes the choking of drains at many locations and also water pipe lines are observed running inside the drain which may leads to disease outbreak.

The summary of existing storm water drains details and cross drain structures is presented in Table 3.23. It is essential to re-establish the complete drain network and the details recorded during the survey are given in as Few Photographs taken during the drain inventory survey is presented in Figure 3.14.

Table.3.24: Existing Storm Water Drain details

S. No.	Drain Type	Length of drain, Km		Total Length, Km
		LHS	**RHS**	
1.	Box Drain	5.23	5.87	11.10
2.	V Shape Gutter Drain	2.64	3.35	5.995
3.	Pipe	-	-	-
4.	Saucer	.70	.045	.745
	Total Length, Km			**17.80**

Flexible pavement with Gutter Drain

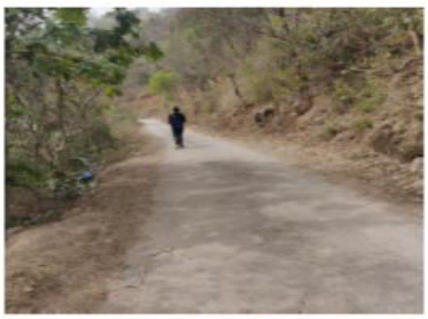
Paver Block with Open Drain

Cross Drainage Structure with Grill arrangement

Existing Open Drain in Poor Condition

Flexible Pavement with open drain in Poor condition

Flexible pavement with Open drain in poor condition



No Drainage location at Hill Side

No Drainage location at Hill Side

Fig.3.14: Drain Inventory Photographs

3.12.4 Topographic Surveys

3.12.4.1 Detailed Topographic Survey

Topographic survey was commenced only after all Control Points, Benchmarks and coordinate

system are established and got approved by the Engineer-in-Charge. Detailed survey was carried out up to 40 m on either side from the centre of the existing road or building lines or as directed by the Engineer In charge. At realignment stretches the width of survey corridor is 50m on both sides from the proposed road centre line.

- Landside features given below, but not limited to, were captured and presented in drawings.
- Existing road pavement edges, shoulders, median, centre line of carriageway, footpaths, side drains, kerb stones, Crash barriers.
- Land use viz., agricultural, residential, commercial, shops and business established areas etc.
- Building lines and type of buildings (kutcha/semi pucca/shops/houses etc.), wherever possible are captured.
- Electrical poles and lines, telephone pole and lines, high tension lines and towers, mast, transformers, water/oil/gas pipelines above and below ground, manholes, repeater stations and all OFC lines are shown in drawing.
- Locations where transmission lines cross the road were identified, recorded, and presented in the drawing. Elevation of transmission lines crossing the road was recorded.
- Tree position and girth of trees were measured.
- Location of traffic islands, median, channelizing islands, rotaries, traffic signals, traffic signs and police chowks with its locations and dimensions.
- Location of bus bays / bus stops, on street/off street parking areas etc.
- Places such as temples, temple mast, mosque, church, graveyard etc.; its location, boundary lines and clear dimensions of compound walls, and entrances.
- Locations and width of drain clearly identifying the type (open/closed/kutcha/pucca, with footpath) including the beginning and end of drain.
- All water features – ponds, tanks, lakes, streams, canals, wells etc.

The detailed survey is carried out by LiDAR and total station is used where the access is inappropriate to do with LiDAR equipment. The summary of the survey assessment by using LiDAR & Total station is provided in the Table 3.25.

Table.3.25: Topodata Survey Details

S.No.	Survey Method	Length of Data covered in (km)
1.	Lidar Survey	40
2.	Total Station	6.5

3.12.4.2 Drawings

While preparing the drawings, it was ensured that all lines are in 3D. All the topographic features, reference pillars indicating complete details such as DGNSS control points, and coordinates etc, were mentioned in the drawing. All key features captured in the survey were described with specified text height and style in the drawing.

Few Photographs taken during Topographic survey along the project road are presented in Figure 3.15.

Fig.3.15: Photographs of LiDAR Survey

3.12.5 Pavement / Subgrade/ Material Investigations

3.12.5.1 Trial Pits

Pavement layer investigations are required to assess the properties of the materials used in various layers of the road pavement and thickness of pavement layers. These data are then further analyzed to evaluate the present pavement condition and to assess the rehabilitation requirement. The objectives of the trial pit investigations are:

- To obtain composition about existing pavement layers.
- To evaluate nature and properties of different layers, this may affect pavement performance.
- To assess the in-situ properties of the various layers through Non-destructive testing
- To collect (subgrade sample) and further assess Sub grade properties in Laboratory

Test pit of 1.0 x 1.0 was excavated in pavement/ at the verge of the shoulder. The general characteristics of materials excavated from pit were recorded and further properties as listed below were evaluated:

3.12.5.2 Subgrade

a) Maximum dry density for each pit sample

b) Gradation of the subgrade soil

c) Liquid Limit and Plastic Limit

d) Optimum moisture content

e) 4 days soaked CBR at 3 energy levels tested for each pit sample.

Few photographs of test pits are shown in Figure 3.13.

Fig. 3.16: Photos of test Pits Depicting Soil Sampling

3.12.5.3 Laboratory Test Results

The subgrade sample collected from site is sent for laboratory testing to further evaluate the subgrade properties.

Fig.3.17: Laboratory Sample Preparation and Testing

3.12.5.4 Existing Pavement Composition

The existing Pavement crust thickness were identified to assess the overlay requirement on the wider roads and to study the existing crust proportion of the municipal roads. Based on the site condition, it has been observed that the overlay has been done without milling and it resulted in the level difference for the access to the property. The consultant has done the existing pavement crust to ensure the pavement layers are provided as per IRC recommendations to propose the improvements. However, the existing scenario is not as per IRC specifications. The crust details are identified over 22 locations in the study area. The trial pit location within the study area is shown in Figure 3.15.

Table.3.26: Details of Average Pavement Crust

S.No.	Road Category	Average thickness of Bituminous Layer (mm)	Average thickness of non-Bituminous Layer (mm)
1.	PWD Roads	60	210
2.	Municipal Roads	65	-

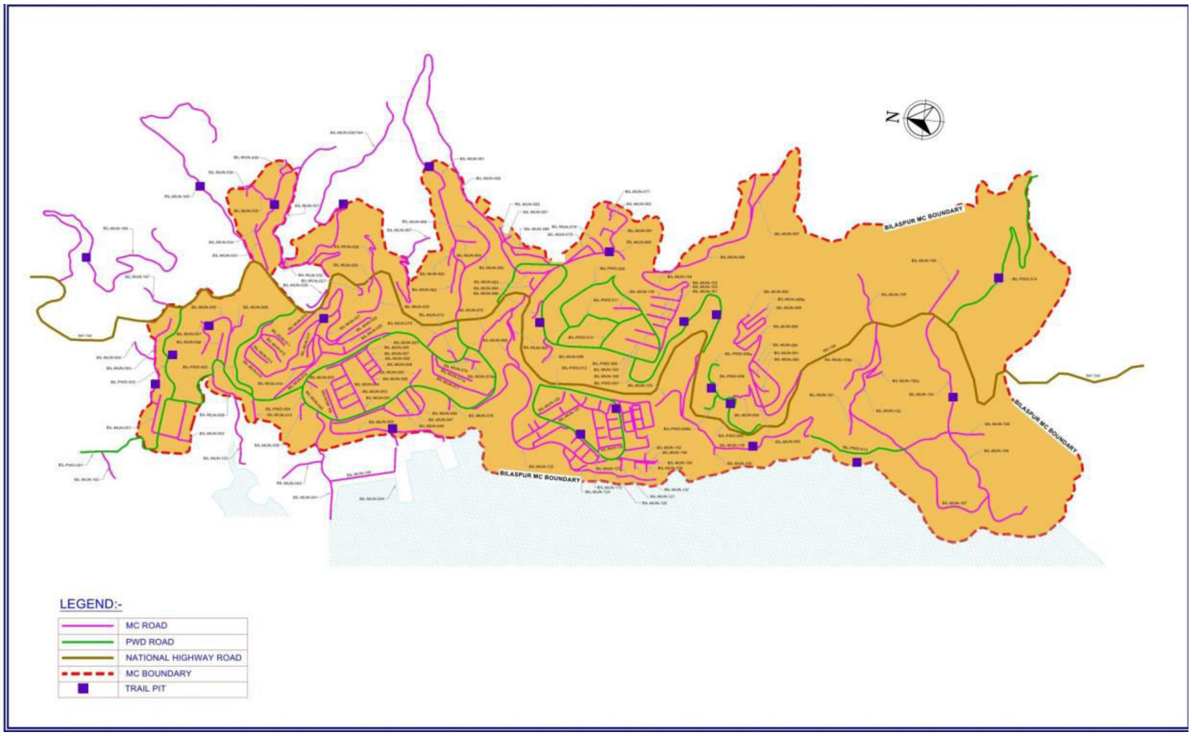


Fig.3.18: Trial Pit Locations

3.12.5.5 Material Investigation

The materials collected from quarries near the project area were collected for testing. The samples are tested based on MORTH specifications, and the test results will be presented in the detailed project report. The details of available quarry material are show in below table:

Table.3.27: Details of available quarry material

S.No.	DHQ	Location	Available Materials
1.	Bilaspur	31.361144:76.781200	Coarse Aggregate & Crusher Sand

3.12.5.6 FWD Analysis for Overlay Assessment

- Existing pavement Layer Details
- Homogenous sections
- Design Traffic

3.12.5.7 Existing pavement layer Details

Soil test pit survey was carried out to know the existing crust details. The crust thickness of the bound and unbound layers is useful for evaluating the back-calculated moduli (MPa). The existing pavement composition is given in Annexures.

3.12.5.8 Homogenous sections

Homogenous sections are identified based on the existing pavement crust details. The details are presented in Table.

Table.3.28: Homogenous Section

Road Name	Chainage, m		Length, m
	Start	End	
BIL-PWD-001	0	1010	1010
BIL-PWD-004	0	1231	1231
BIL-PWD-007	0	840	840
BIL-PWD-008	0	1100	1100
BIL-PWD-010	50	1070	1020
BIL-PWD-002	0	199	199
BIL-MUN-005	0	703	703

3.13 DATA ANALYSIS

The data obtained from the survey was checked for,

a) Unrealistic deflection values

b) Deflection should be decreasing with increase in distance from the loading plate

c) Values obtained should not be beyond capacity of geophones

3.13.1 Moduli and overlay

This program calculates the E modules for the layers in a pavement, given the values for each layer's thickness and Poisson's ratio. By using an iteration procedure, where theoretical deflection values in a mathematical model are compared with the measured data and the program adjusts the layer modules until no further improvement is obtained. The program then calculates the strains in the layers and works out which layer that according to the criteria for strain allowed will fail first and how many years this will take. Finally, the program calculates the overlays required for the pavement to carry a certain load for a certain lifetime. Roads with high traffic often have thick asphalt layers, and then the temperature is an important parameter. The moduli are calculated at the conditions that prevail during the measurement.

Then the modulus of the asphalt layer is converted to modulus at a reference temperature of 350c, and the strains are calculated at this temperature. In accordance with Section 6.5.2 of IRC 115:2014, the calculated modulus values for subgrade and granular layers are adjusted relative to the season (survey is conducted in Monsoon), at the time of the testing for the subgrade and granular layers using the equations 1 and 2 respectively.

$$E_{Subgrade\_Monsoon} = 3.351 * (E_{Subgrade\_Winter})^{0.7688} - 28.9$$

$$E_{Granular\_Monsoon} = 10.5523 * E_{Granular\_Winter}{}^{0.624} - 113.857$$

The modulus is calculated for all the layers at all the points and 15 percentile modulus is taken according to IRC 115:2014 for calculation of existing life and overlay.

3.13.1.1 Modulus

The modulus was calculated for all the layers at all the points and 15th percentile modulus were taken according to IRC: 115-2014 for calculation of existing life and overlay. 15th percentile modulus is given in the Table 3.29.

Table 3.29: 15th Percentile modulus for calculated Homogeneous section

Road Name	Chainage, m		Length, m	Corrected Moduli, MPa		
	From	To		BT	Granular	Sub-grade
BIL-PWD-001	0	1010	1010	1074	68	69
BIL-PWD-004	0	1231	1231	996	66	34

BIL-PWD-007	0	840	840	1940	183	129
BIL-PWD-008	0	1100	1100	1038	209	110
BIL-PWD-010	50	1070	1020	1453	105	67
BIL-PWD-005	0	199	199	4394	143	138
BIL-PWD-003	0	703	703	2331	151	61

3.13.1.2 Overlay

Overlay required is calculated for each homogenous section based on the back calculated moduli and the design traffic and is presented in the Table 3.28.

Table.3.30: Overlay Thickness required for Homogeneous Section.

Road Name	Chainage		Length (m)	Corrected Moduli, MPa			Proposed Overlay, mm	
	Start	End		BT	Granular	Sub-grade	BC	DBM
BIL-PWD-001	0	1010	1010	1074	68	69	40	80
BIL-PWD-004	0	1231	1231	996	66	34	40	70
BIL-PWD-007	0	840	840	1940	183	129	50	-
BIL-PWD-008	0	1100	1100	1038	209	110	40	50
BIL-PWD-010	50	1070	1020	1453	105	67	40	90
BIL-PWD-005	0	199	199	4394	143	138	50	-
BIL-PWD-007	0	703	703	2331	151	61	40	50

3.13.2 Land Use Analysis

The major land use along the project roads is residential and mixed category with commercial activity on ground floor and residential on other floors. It is observed that the first building line along the Gandhi Nagar Market, Chetna Chowk, Gurudwara chowk and Bus Stand- Diara road is commercial use. Public semi-public activities are spread across the Bilaspur town but all the major Govt. offices are on Court road.

The development pattern of the Bilaspur town is Linear and along the Shimla-Hamirpur road. Landuse pattern along the project roads is represented in Figure 3.19.

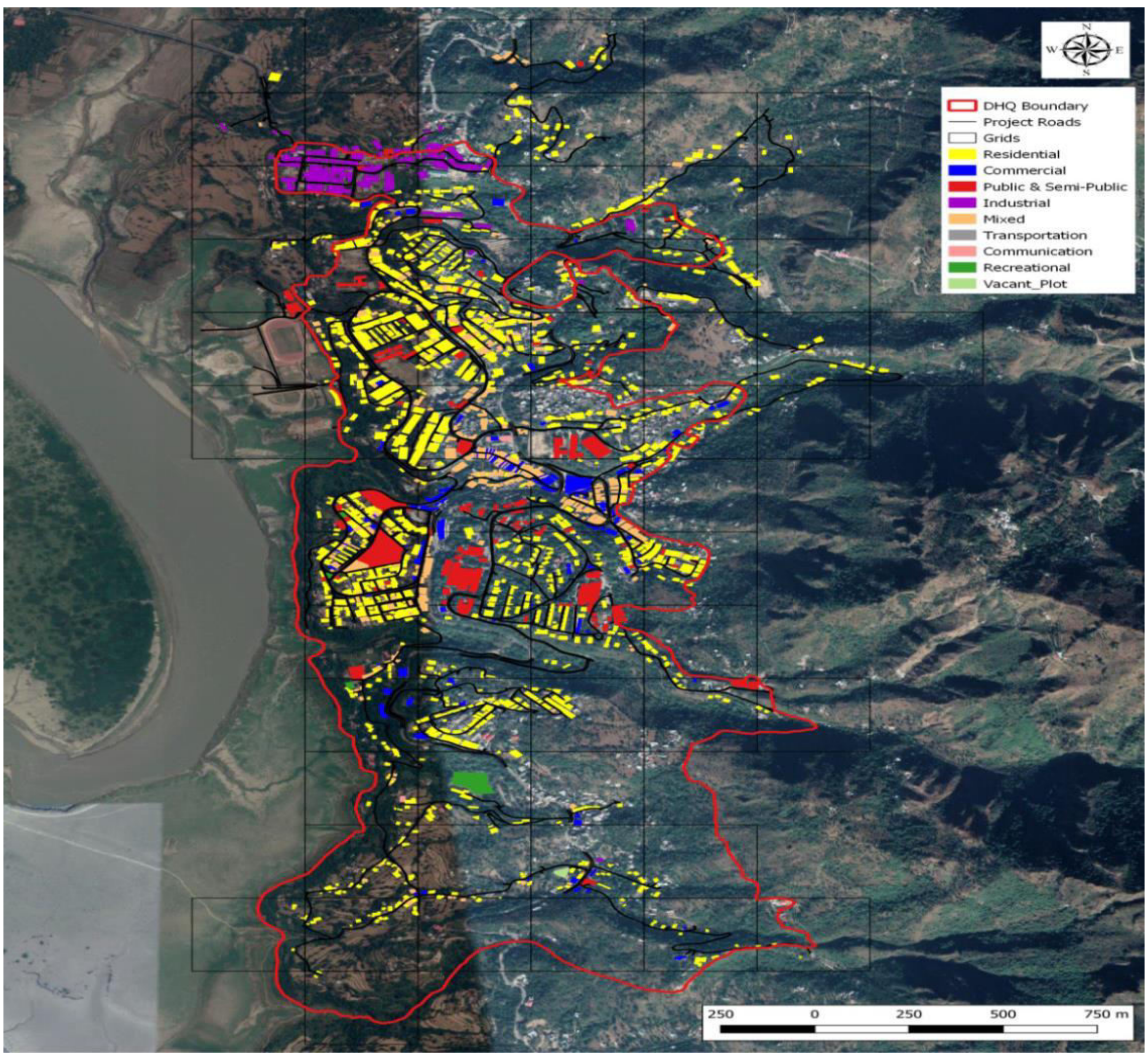


Fig.3.19: Land Use maps along the project roads

Total buildings identified along the project roads are 2196 out of which 1374 are residential contributing 60% of the total buildings, followed by the mixed land use category i.e. 20%. It is observed that there are no designated parking spaces within Bilaspur Town.

Industrial area is contributing 4% of the total land use and situated in Northern part of the town. The percentage of the land use share along the project roads is shown in Figure 3.17.

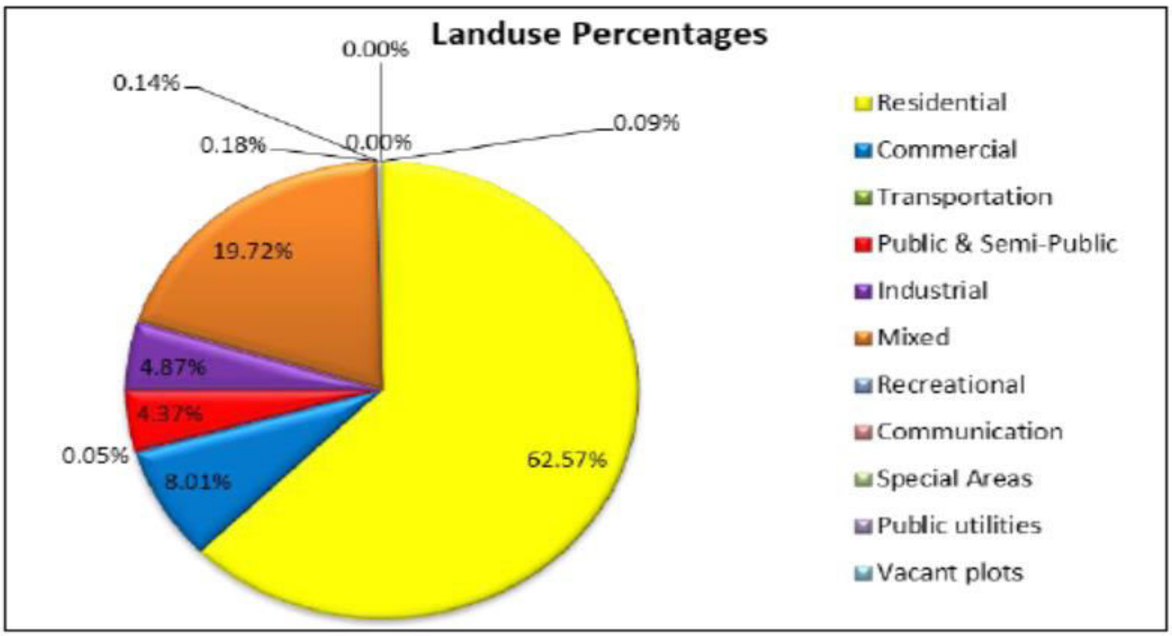


Fig 3.20: Landuse percentages

Building wise land use details of the project roads are shown in Table 3.31

Table.3.31: Landuse Details

S.No.	Landuse Classes	No. of Buildings	Percentages
1.	Residential	1374	62.57
2.	Commercial	176	8.01
3.	Transportation	1	0.05
4.	Public & Semi- Public	96	4.37
5.	Industrial	107	4.87
6.	Mixed	433	19.72
7.	Recreational	4	0.18
8.	Communication	3	0.14
9.	Special Areas	0	0.00
10.	Public Utilities	0	0.00
11.	Vacant Plots	2	0.09
	TOTAL	**2196**	**100.00**

3.13.2.1 Ownership Details

It is observed that almost 88% of the properties along the project roads are private. 11% buildings along the roads belong to various government bodies. Few unauthorized constructions are also observed in Lakhanpur area.

Fig.3.21: Pie chart showing ownership details

3.13.2.2 Major Attractions along the Project Roads.

It is observed that the area near to bus stand is dense and is at the centre of the Bilaspur city. Major roads like Gurudwara chowk, NH 154 road, main market is in mixed category having commercial in ground floor and upper floors are for residential use.

Non-busy roads have majorly residential or which is far away from NH-154 road. Majority of the Government buildings are located along the Court Road. Every house has accessibility to the basic needs in the nearby areas except some parts in Lakhanpur.

Figure indicates the major attractions within project roads and its surrounding landuse.

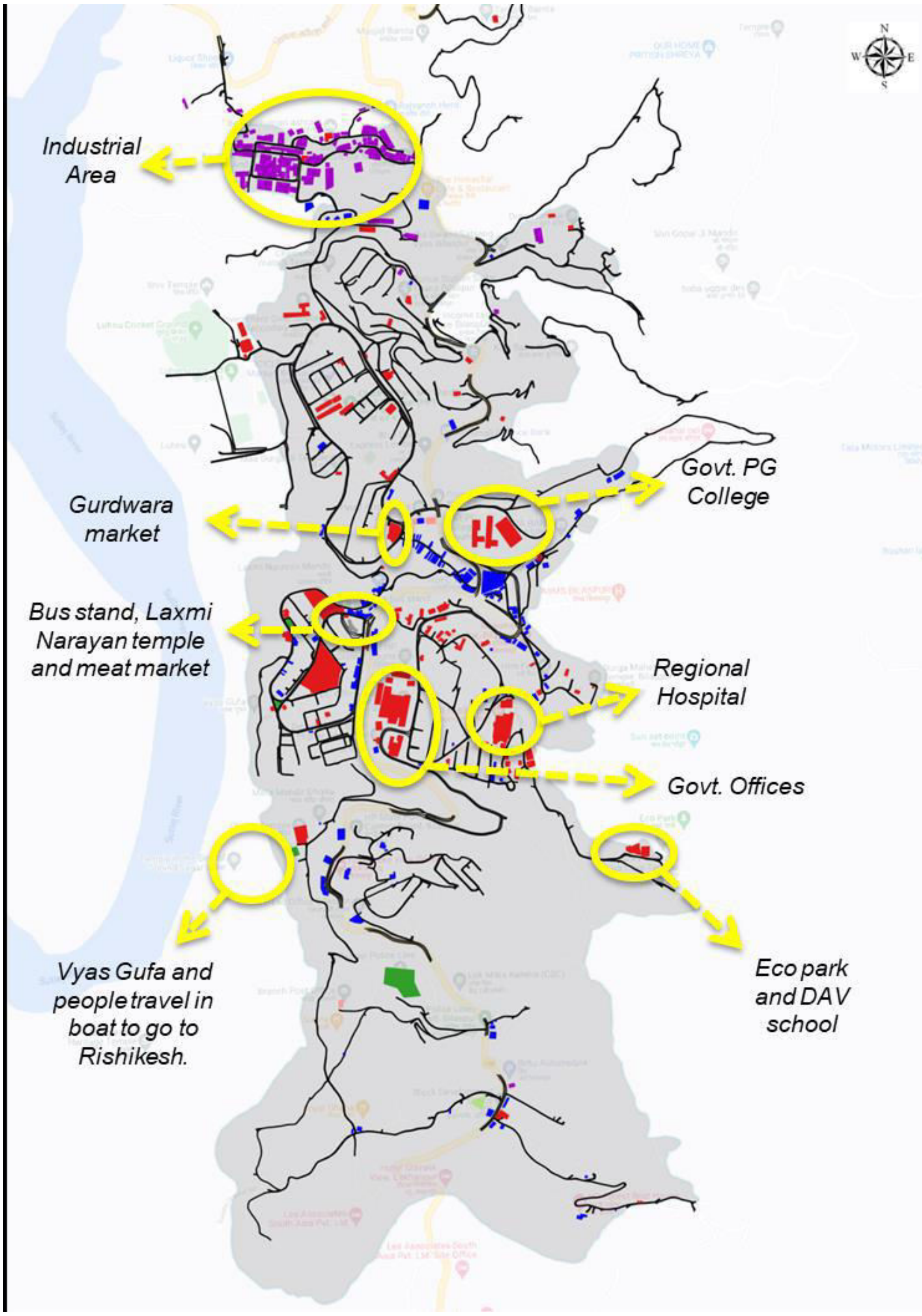


Fig.3.22: Local Attractions

3.13.3 Traffic / Transportation Surveys

Traffic and transportation characteristics help in appreciating the spatial and temporal characteristics of travel within the study area, transport network capacity, utilization and prevailing level of service. To understand the traffic and transportation characteristics in the study area wide range of traffic surveys are carried out.

The details of the primary traffic surveys are given in Table 3.32.

Table.3.32: Details of the Primary Traffic Surveys

S.No.	Type of Survey	Quantity	Duration
1.	Classified Traffic Volume Counts at Cordon Locations	02 Np.	16 Hours
2.	Classified Traffic Volume Counts at Mid-Block Locations	02 No.	16 Hours
3.	Origin & Destination Survey at Cordon Locations	02 No.	16 Hours
4.	Turning Volume Counts at Intersections	04 No.	16 Hours
5.	Pedestrian Count Survey	05 No.	16 Hours
6.	On- Street Parking Survey	04 No.	12 Hours

The survey locations are presented in Figure 3.23.

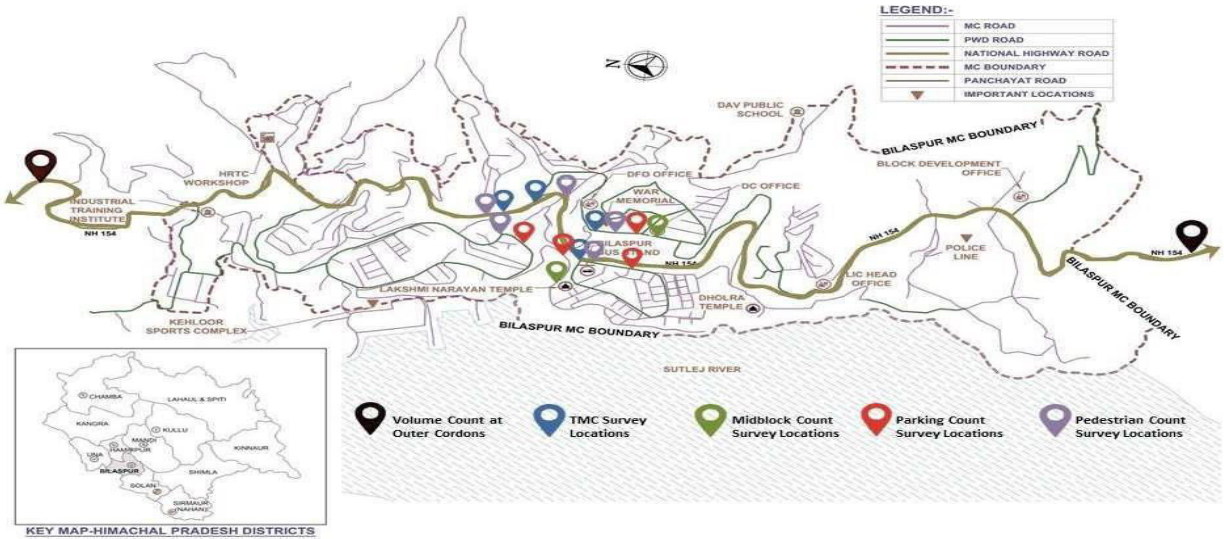


Fig.3.23: Traffic Survey Location Map of Bilaspur DHQ

Various traffic surveys are conducted within the city of Bilaspur and the site photos showing different surveys are presented in Figure 3.24 to Figure 3.25.

Site photographs showing OD questionnaire survey at different OC locations:

Enumerator interviewing vehicles at OC-1

Enumerator interviewing vehicles at OC-1

Enumerator interviewing vehicles at OC-2

Enumerator interviewing vehicles at OC-2

Fig.3.24: Enumerators at Traffic survey location

Site photographs showing on Street parking survey at different locations:

On-street parking survey at Court road Section 1 (LHS)

On-street parking survey at Court road Section 1 (RHS)

On-street parking survey at Court Road Section 2 (LHS)

On-street parking survey at Court Road Section 2 (RHS)

On-street parking survey at Meat Market road

On-street parking survey near Bus Stand

Fig.3.25: On Street Parking Survey at Different Locations

Site photographs showing TMC and Pedestrian count locations:

Volume count at TMC-1

Volume count at TMC-2

Fig.3.26: Pedestrian Survey and Volume Survey count camera locations

3.13.3.1 Traffic Volume Counts

Analysis of Traffic Volume Count at Cordon Locations

Traffic Intensity and Volume Classified traffic volume counts are conducted at 2 cordon locations. Based on the survey results, it is observed that about 22,618 vehicles enter and leave the study area every day.

The daily traffic at the cordon locations is presented in Table 3.33.

Table.3.33: Daily Traffic at Cordon Locations

S.No.	Road Location ID	Total Vehicles	PCUs	Share %
1.	Near Hotel Panchtara(OC1)	11,781	17,006	52.12%
2.	Near Lakhanpur Bus Stop (OC2)	10,837	15,618	47.88%
	Total	22,618	32,624	100%

- Among the two cordon locations, highest traffic volume of about 11,781 vehicles are observed on Hotel Panchtara OC location followed by Lakhanpur Bus Stop OC location with a traffic volume of 10,837 vehicles.

3.13.3.2 Traffic Composition

Composition of traffic considerably varies among the roads depending on location. Passenger traffic share is observed to be high on national highways as well as on other roads whereas Goods traffic share is significant on all roads. The road-wise traffic composition at cordon locations is presented in the Table 3.34.

Table.3.34: Composition of Traffic at Cordon Locations

No.	**Road/Location**	**Private Mode**		**IPT**	**Bus**	**Goods Vehicle**	**Cycle**	**Other Modes**
		Two Wheeler	**Car**					
1.	OC1	20.0%	51.6%	0.6%	4.7%	22.6%	0.0%	0.5%
2.	OC2	21.0%	46.8%	2.9%	3.1%	25.9%	0.0%	0.3%
	AVERAGE SHARE (%)	**20.5%**	**49.2%**	**1.7%**	**3.9%**	**24.25%**	**0.0%**	**0.4%**

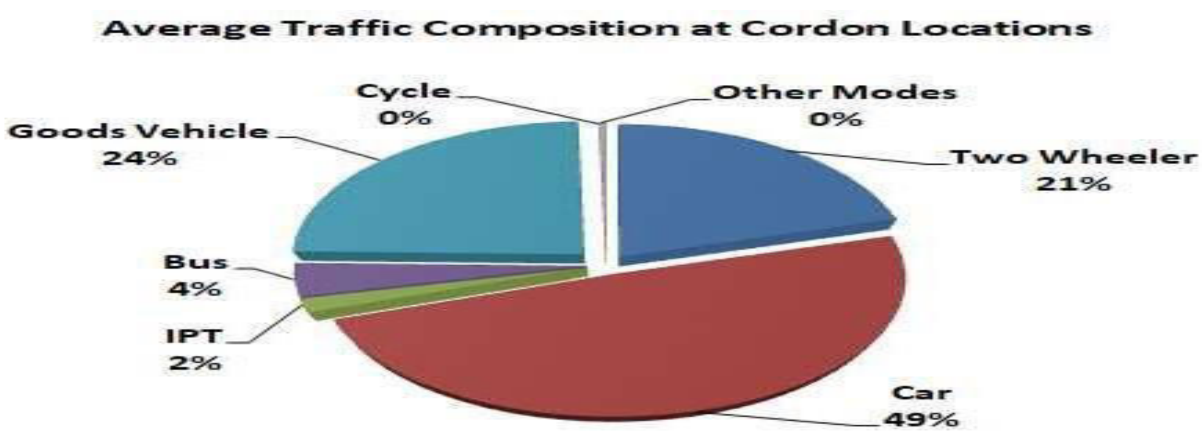


Fig.3.27: Average traffic composition at Cordon locations

3.13.3.3 Peak Hour Traffic

Temporal variation of traffic implies hourly variation of traffic over entire survey period. This variation is important for transport system planning. Table 3.35 presents peak hour traffic and its share in the daily traffic at cordon locations.

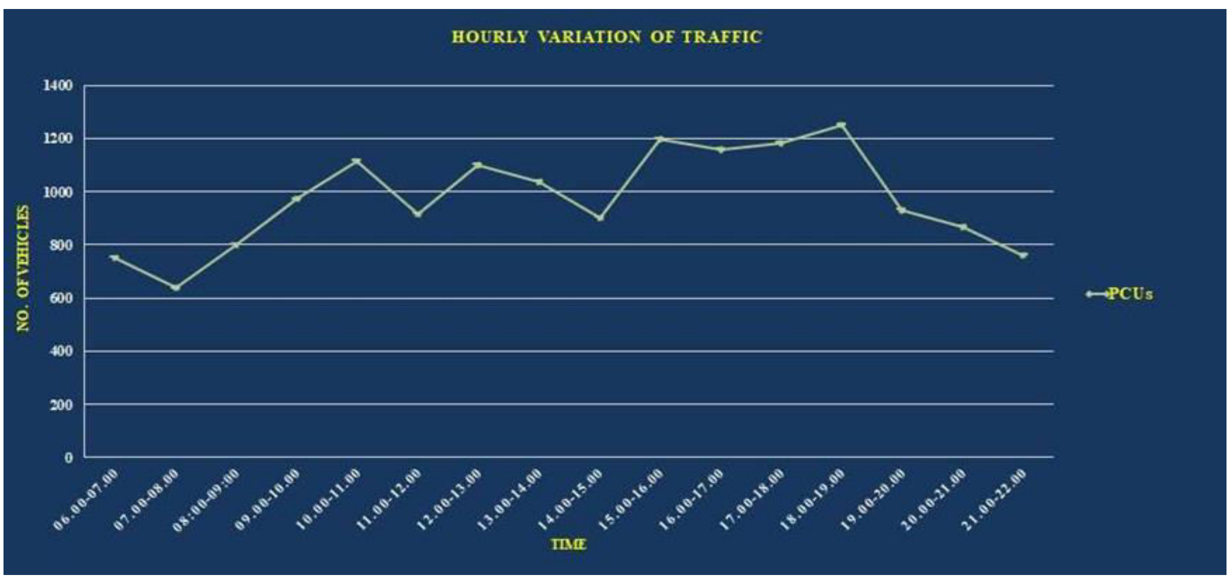
Table 3.35: Peak Hour Traffic at Cordon Locations

S.NO.	Road/Locations	Peak Hour	Peak Hour PCUs	Peak Hour Share
1.	Near Hotel Panchtara (OC1)	18.00-19.00	1,385	8.1%
2.	Near Lakhanpur Bus Stop (OC2)	17.30-18.30	1,256	8.0%

Percentage of traffic in peak hour ranges between 8.1% and 8.0% with an average of 8.05%.

3.6.8.4 Hourly Variation

Hourly variation of the traffic at cordon locations is given in Figure 3.28.



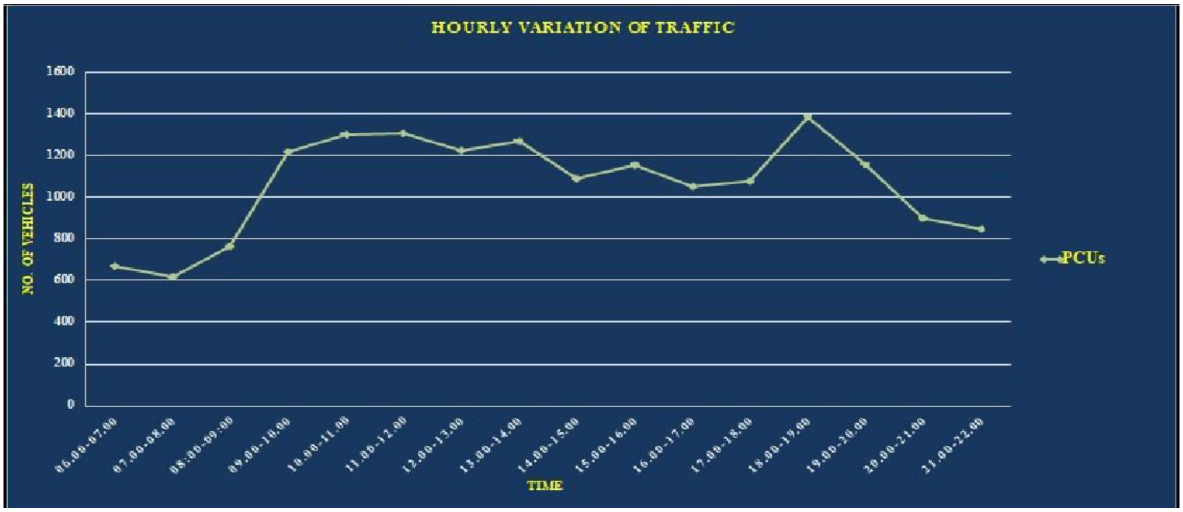


Fig.3.28: Hourly variation of Traffic at Cordon locations

3.13.3.5 Analysis of Traffic Volume Count at Mid-Block Locations

3.13.3.5.1 Volume

Classified traffic volume counts are conducted at 2 mid-block locations for 16 hours. The traffic details observed at these locations are presented in Table 3.36.

Table 3.36: Location wise Traffic on Mid-block Locations

S.No.	Road/ Location ID	Total	
		Vehicles	PCUs
1.	MB-01 (Meat Market Road)	2,050	1,377
2.	MB-02 (Court Road)	8,817	6,421

- Traffic on Court Road near District Court Junction is observed to be 8,817 vehicles.

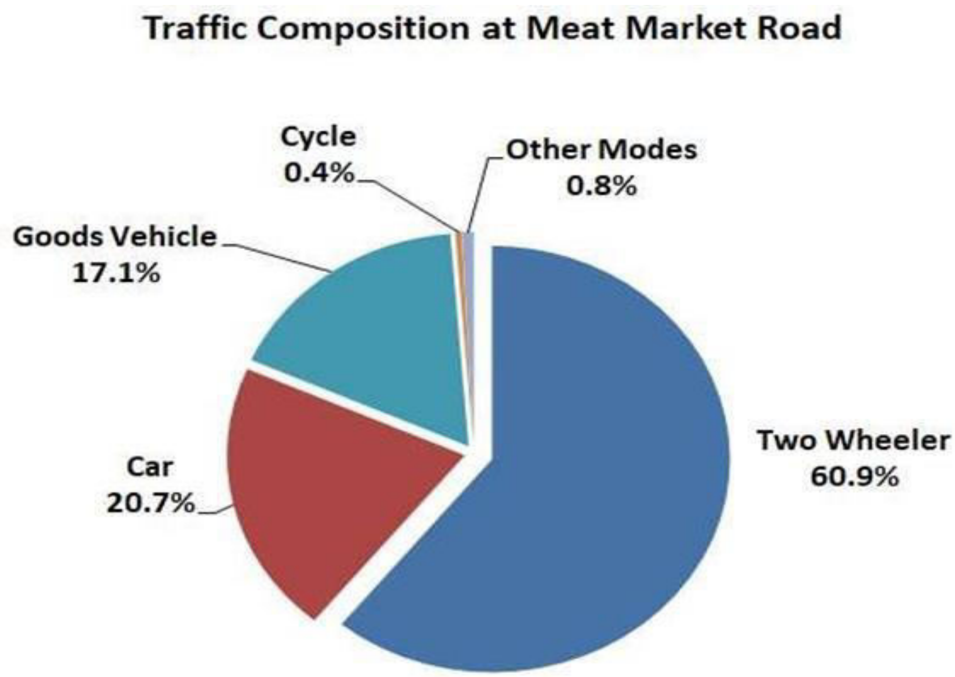
3.13.3.5.2 Composition

Composition of traffic observed at mid-block locations are presented in **Table 3.37.** The share of cars is found to be very high at Court Road while share of two-wheelers found to be high at Meat Market Road.

Table 3.37: Composition of Traffic at Mid-block Locations

S. No.	Road/Locations	Two Wheeler	Car	IPT	Bus	Goods Vehicle	Cycle	Other Modes
1.	Meat Market Road	60.9%	20.7%	0.0%	0.0%	17.1%	0.4%	0.8%
2.	Court Road Near District Court Junction	38.9%	51.8%	4.4%	0.2%	3.5%	0.7%	0.4%

The traffic composition at mid-block locations is presented in Figure 3.29.



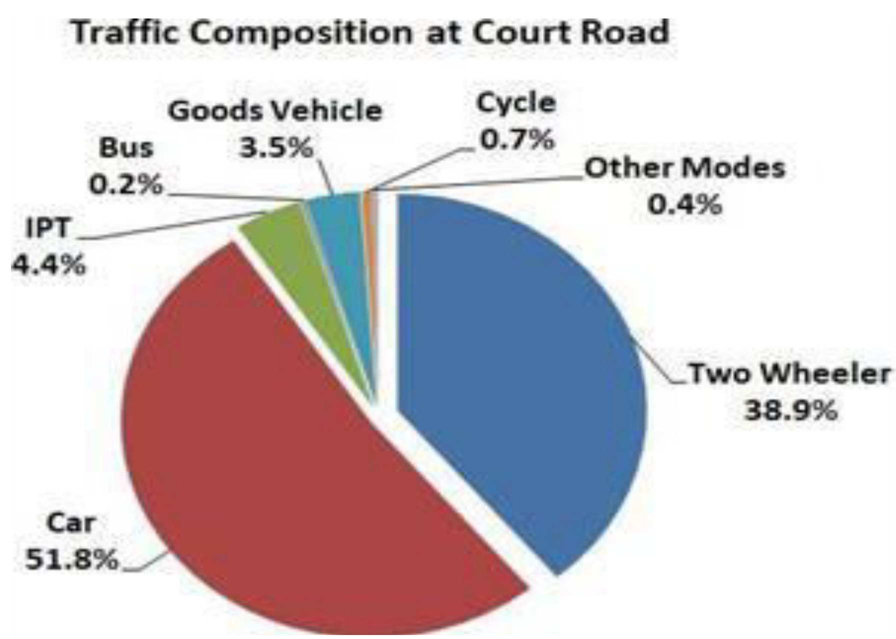


Fig.3.29: Traffic composition at Mid-Block location.

3.13.3.5.3 Peak Hour Characteristics

Peak hour characteristics observed at both the mid-block locations are presented in table below. The share of cars is found to be very high at Court Road while share of two- wheelers found to be high at Meat Market Road. Table 3.38 presents the location wise peak hour traffic at mid-block locations.

Table.3.38: Peak Hour Traffic at Mid-block Locations

S.No.	Road/Location Name	Peak Hour	Peak Hour PCUs	Peak Hour Share
1.	Meat Market Road	14.30-15.30	138	10.0%
2.	Court Road	10.30-11.30	854	13.3%

- The peak hour share on Court Road near District Road Jn is 13.3% while the peak hour share on Meat market road is 10.0%.

3.13.4 Turning Movement Counts

Analysis of Traffic volume count at selected junctions is presented in the following section.

3.13.4.1 Traffic Intensity

Turning movement traffic volume counts are conducted at 4 junctions. The daily traffic at the major junctions is presented in Table 3.39.

Table.3.39: Daily Traffic at Various Junction

S.No.	Junction Name	Total		Share %
		Vehicles	PCUs	
1.	College Road Chowk	22,126	25,258	31.11%
2.	Bus Stand Chowk (TMC2)	16,812	20,602	25.37%
3.	Market Road Chowk (TMC3)	23,557	26,303	32.40%
4.	Court Road Chowk (TMC4)	9,197	9,029	11.12%

3.13.4.2 Traffic Composition

Composition of traffic considerably varies among the junctions depending on location. Goods traffic and passenger car share is observed to be high on junctions located on the national highway. Average traffic composition on major junctions is presented in **Table 3.40**.

Table.3.40: Composition of Traffic at Major Junctions

S.No.	Road/Location	Private Modes		IPT	Bus	Goods Vehicle	Cycle	Other Modes
		Two Wheeler	Car					
1.	TMC1	48.0%	36.9%	9.9%	0.9%	3.7%	0.1%	0.5%
2.	TMC2	37.9%	44.8%	10.8%	1.1%	5.1%	0.1%	0.2%
3.	TMC3	45.5%	39.9%	8.4%	2.8%	2.6%	0.2%	0.6%
4.	TMC4	24.5%	57.6%	2.9%	3.5%	11.2%	0.2%	0.2%
	AVERAGE SHARE	**39.0%**	**44.8%**	**8.0%**	**2.0%**	**5.7%**	**0.2%**	**0.4%**

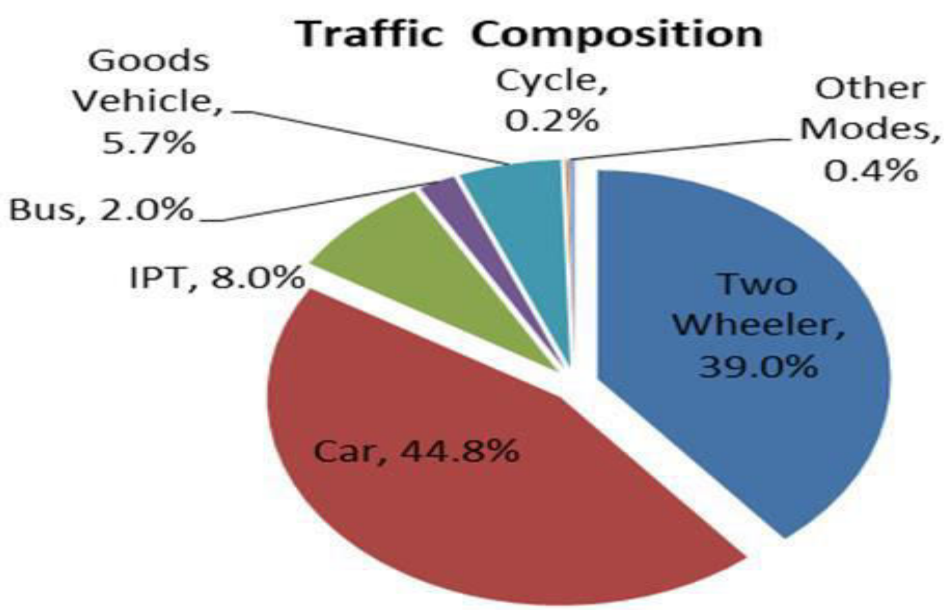


Fig.3.30: Traffic composition at Major Junctions

3.13.4.3 Turning Flow Diagrams

The peak hour turning volumes at some of the major junctions are presented graphically in Figure 3.31 to Figure 3.34.

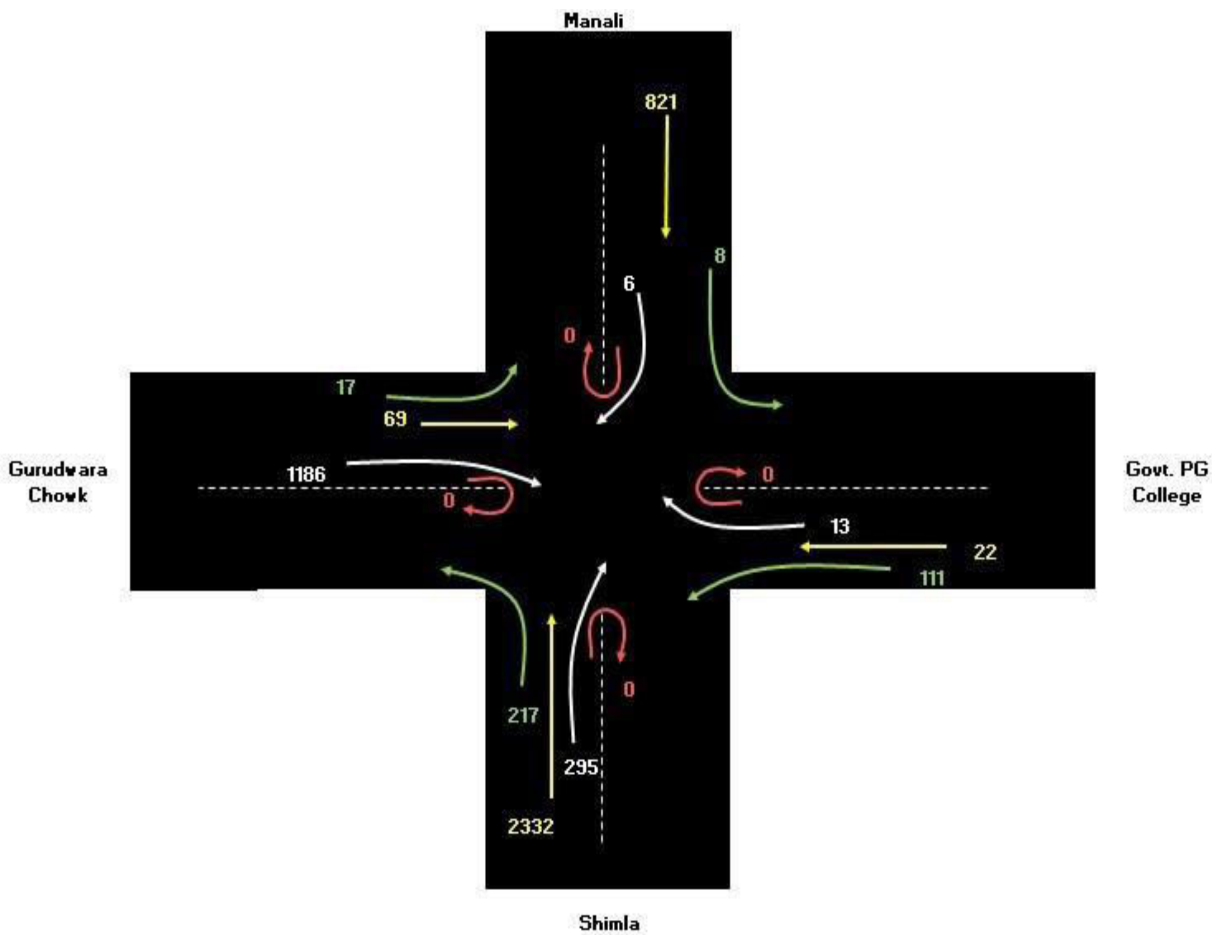


Fig.3.31: College Road Chowk Turning Flow Diagram

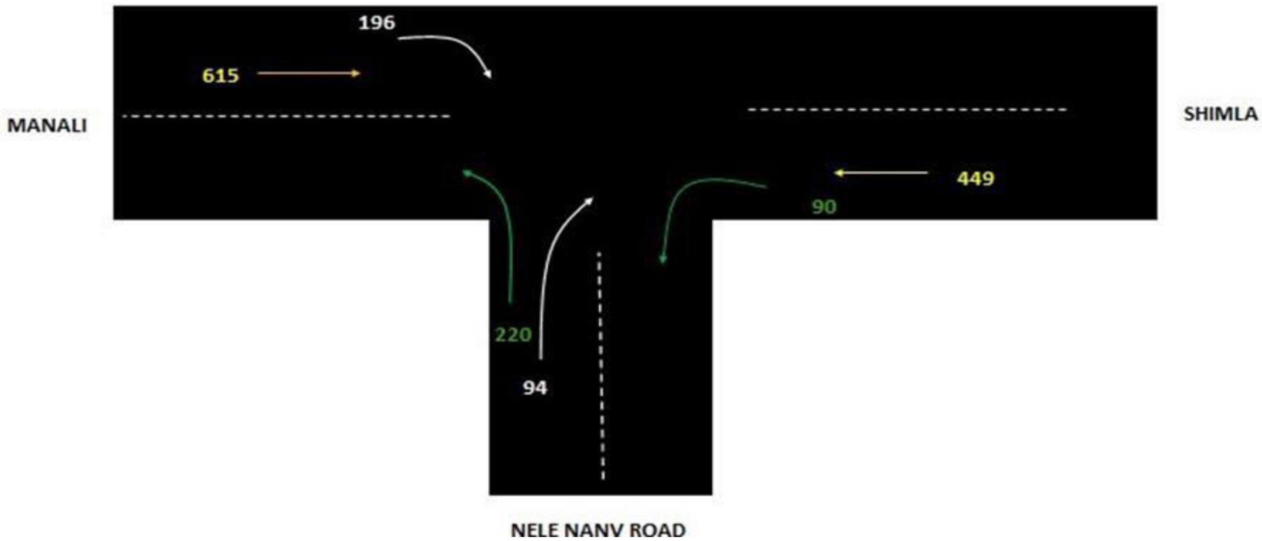


Fig.3.32: Bilaspur Chowk Turning Flow Diagram

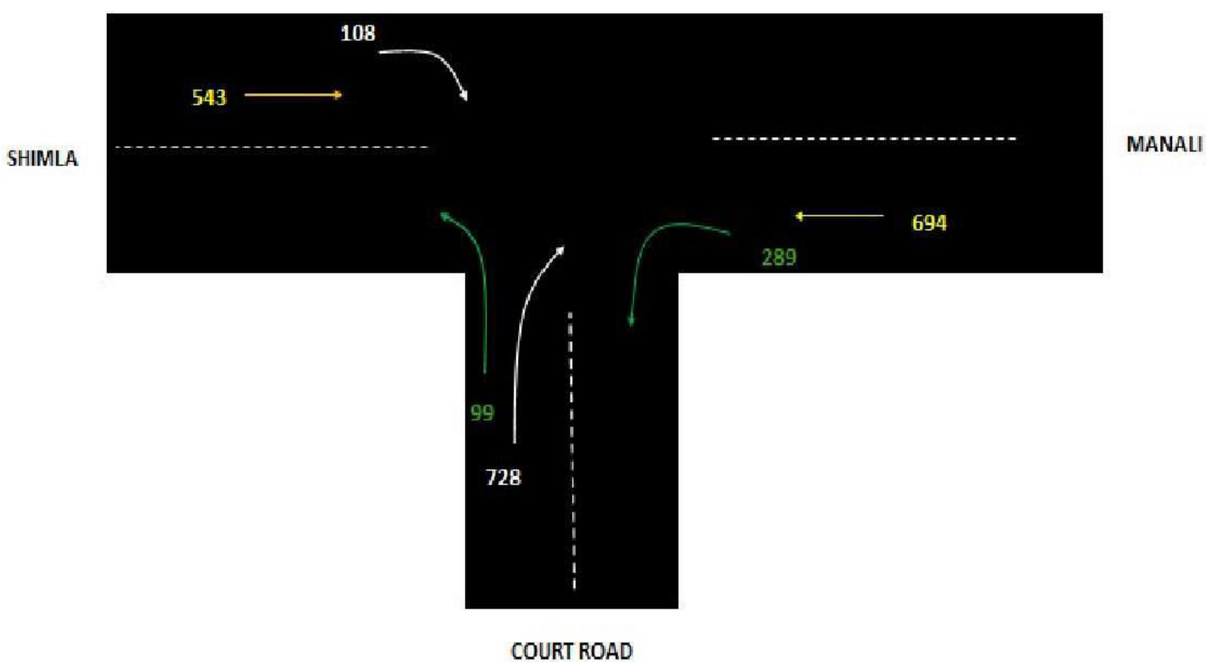


Fig.3.33: Purnam Mall Junction Turning flow diagram

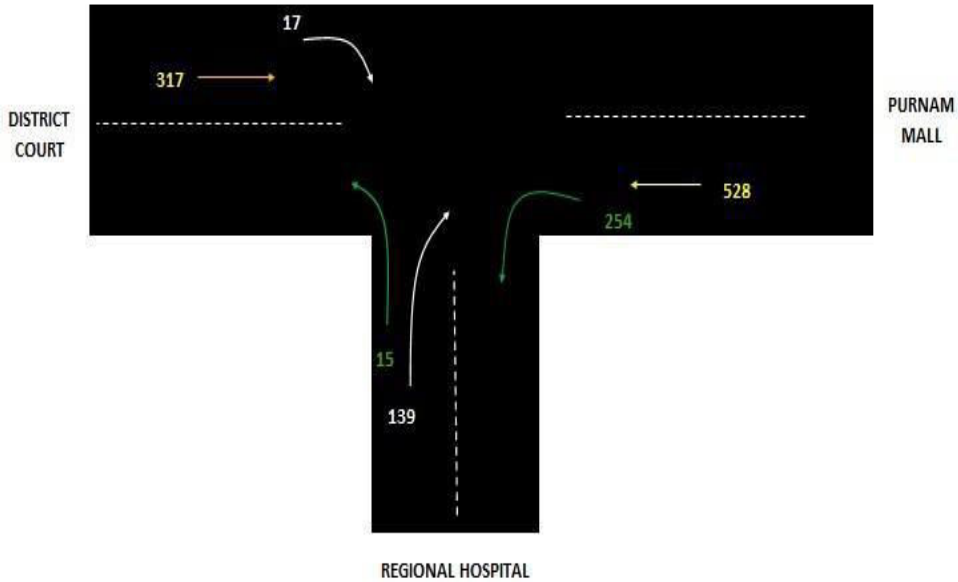


Figure.3.34: War Memorial Junction Turning Flow diagram

3.13.4.4 Peak Hour Volume

Turning Volume Counts are carried out at major junctions for understanding the turning movements at major intersections. Peak hour traffic at major intersections is presented in Table 3.41. Among all 4 intersections, 16 hours PCU and morning/evening peak hour PCUs is observed highest at College Road Chowk followed by Market Road Chowk.

Table.3.41: Peak Hour Traffic at Major Intersections

S.No.	Junction Name	Type	Peak Hr Traffic (PCUs)		Total PCUs
			Morning	Evening	
1.	College Road Chowk	4-Arm	5,095	4,467	25,258
2.	Bus Stand Chowk	3-Arm	1,543	1,664	20,602
3.	Market Road Chowk	3-Arm	2,334	1,933	26,303
4.	Court Road Chowk	3-Arm	1,115	739	9,029

CHAPTER 04
DEVELOPMENT OF PAVEMENT MANAGEMENT SYSTEM (PMMS) USING HDM-4

4.1 GENERAL

The methodology for developing Pavement Maintenance Management System (PMMS) of DHQ, Bilaspur road network using HDM-4 model has been discussed in the previous chapter. The pavement maintenance and management plays a very important role to keep the pavements within the serviceability levels both at the project level considering detailed maintenance management practices. PMMS at project level solve various maintenance management issues related to the selection of the optimal maintenance solutions and to determine the cost effectiveness of various maintenance alternatives. Application of HDM-4 software at project level for developing PMMS of DHQ, Bilaspur road sections has been discussed in this chapter.

4.2 USE OF HDM-4 APPLICATION MODULES FOR PMMS

In this study, PMMS has been developed by analyzing the projects using 'Project Analysis' application module of HDM-4. In the present study, the following types of objectives have been undertaken for the project level analysis of ten road sections of Bilaspur town road network.

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

4.3 ROAD NETWORK AND VEHICLE FLEET DATA INPUT IN HDM-4

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

4.3.1 Road Network

For the present study, Road Network named as 'Bilaspur Town Road Network' has been created. 10 road sections with Section ID BIL-PWD-001 to BIL-PWD-010 have been entered in HDM-4. Each road section with its definition, geometry, pavement and condition data (mentioned in previous chapter) has been inputted. Prior to this, Traffic Flow patterns have been created in Configuration part. Climate Zone 'North India Mountain' has been selected for the study. Snapshots of entering all the data for BIL-PWD-001 have been shown from figure 4.1 to figure 4.9. This road network has been further used for determining the objectives.

Table 4.1: Selected Road Network of Bilaspur Town

Bilaspur Town Road Network				
Road ID	**Name of Road**	**Start Nodes**	**End Nodes**	**Length, Km**
BIL-PWD-001	LOWER NIHAL ROAD GURUDWAR TO INDUSTRIAL AREA	155	1	2.092
BIL-PWD-002	LOWER NIHAL INDUSTRIAL AREA TO Govt. ITI ROAD	11	13	0.401
BIL-PWD-003	BILASPUR FIRE STATION TO LOWER NIHAL	33	51	0.505
BIL-PWD-004	COLLEGE CHOWK TO Govt. SENIOR SECONDRY SCHOOL NIHAL	157	61	1.226
BIL-PWD-005	LINK ROAD FROM NH TOWARDS DHOLRA GUEST HOUSE	321	315a	0.29
BIL-PWD-006	LINK ROAD NEAR DRDA OFFICE TOWARDS POLLUTION CONTROL BOARD	315	315b	0.13
BIL-PWD-007	HP STATE POLLUTION CONTROL BOARD	315c	315d	0.104
BIL-PWD-008	ROAD FROM NH TOWARDS EE OFFICE	316a	316b	0.087
BIL-PWD-009	COURT ROAD NEAR PURNAM MALL CROSSING DC OFFICE TO HOSPITAL	311	294	0.842
BIL-PWD-010	LINK ROAD FROM WAR MEMORIAL JUNCTION TOWARDS HOSPITAL	166	238	1.501
	Total Length			**7.178**

AADT: Traffic on Road (in Vehicles)			
Vehicle Type	**BIL-PWD-001**	**BIL-PWD-002**	**BIL-PWD-003**
Motorised Traffic			
Car	79	127	216
2 Wheeler	31	84	198
3 Wheeler	2	5	4
Mini Bus	12	7	3
Bus	3	2	1
LCV	75	55	47
2 Axle Truck	65	38	57
3 Axle Truck	4	6	3
Multi Axle Truck	17	18	18
Tractor	-	1	-
Tractor + Trailor	2	2	3
Non Motorised Traffic			
Cycle Rickshaw	-	-	-
Bicycle	2	1	5
Others	1	3	2

Table 4.2: Traffic Details for the Bilaspur Road Network

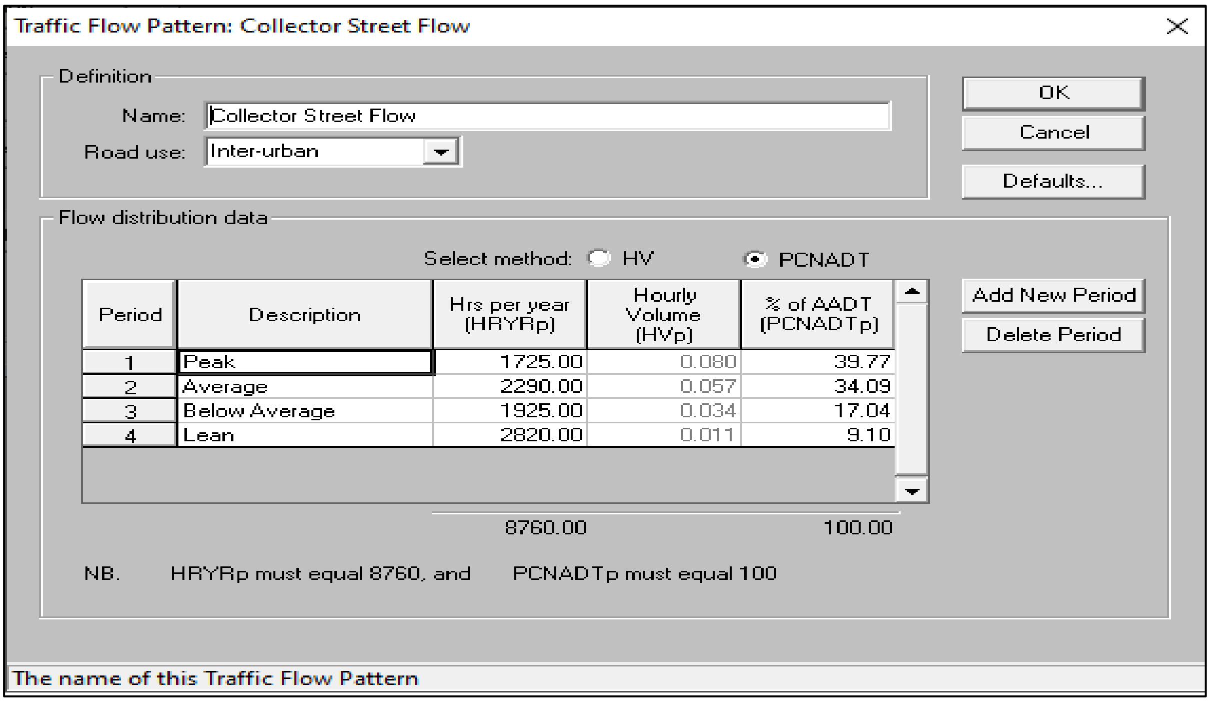


Fig 4.1: Formation of 'Collector Street Flow' Type Traffic Flow Pattern.

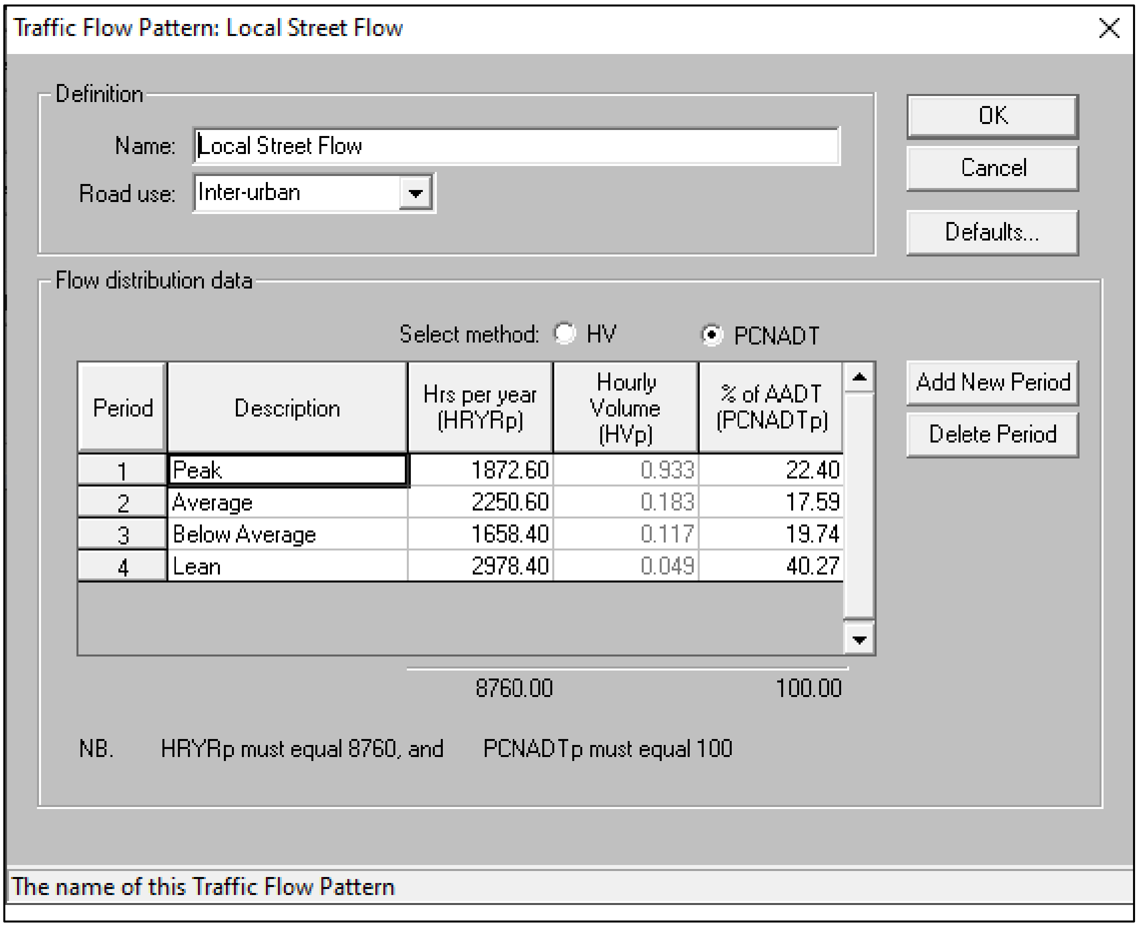


Fig.4.2: Formation of 'Local Street Flow' Type Traffic Flow Pattern.

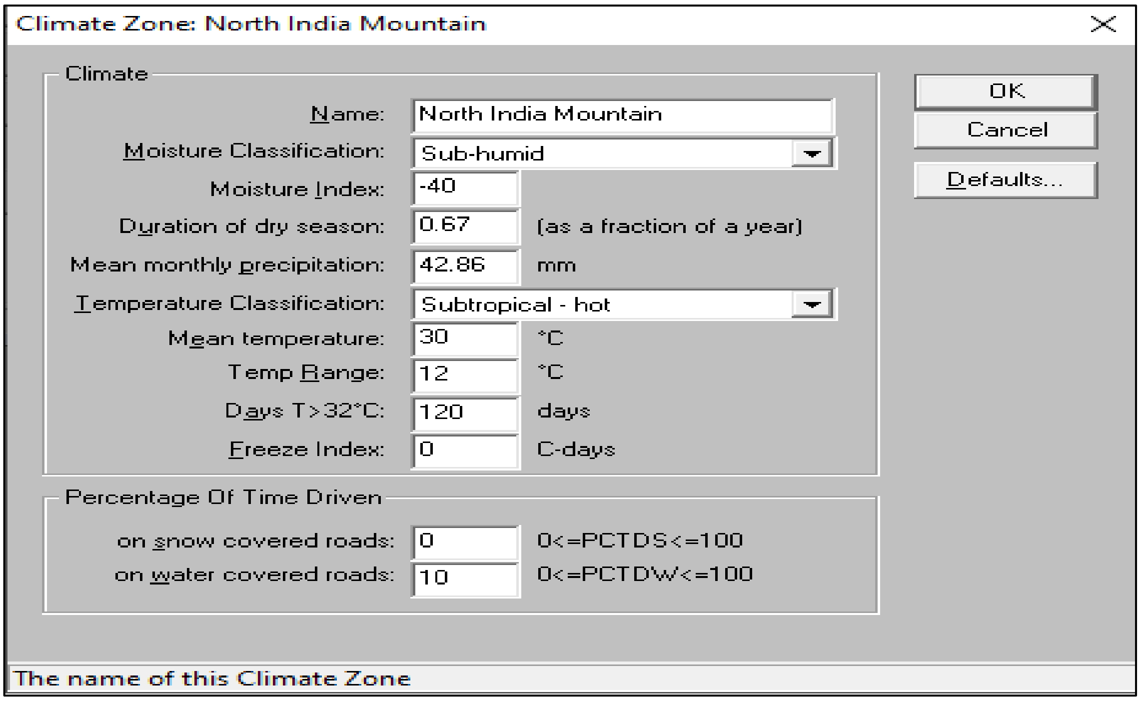


Fig.4.3: Selection of 'North India Mountain' Climate Zone for the study.

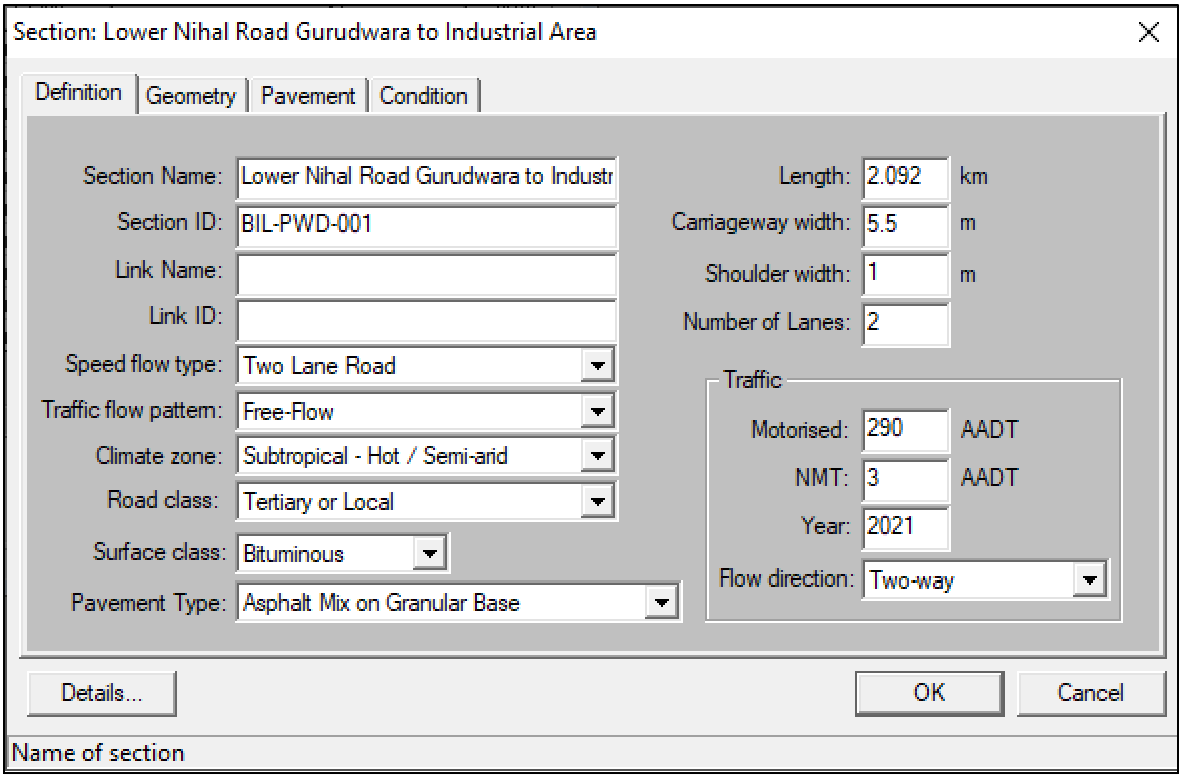


Fig. 4.4: Definition Data Input & a New Section i.e. Lower Nihal Road to Industrial Area, BIL-PWD-001 created in 'Bilaspur Town Road Network'.

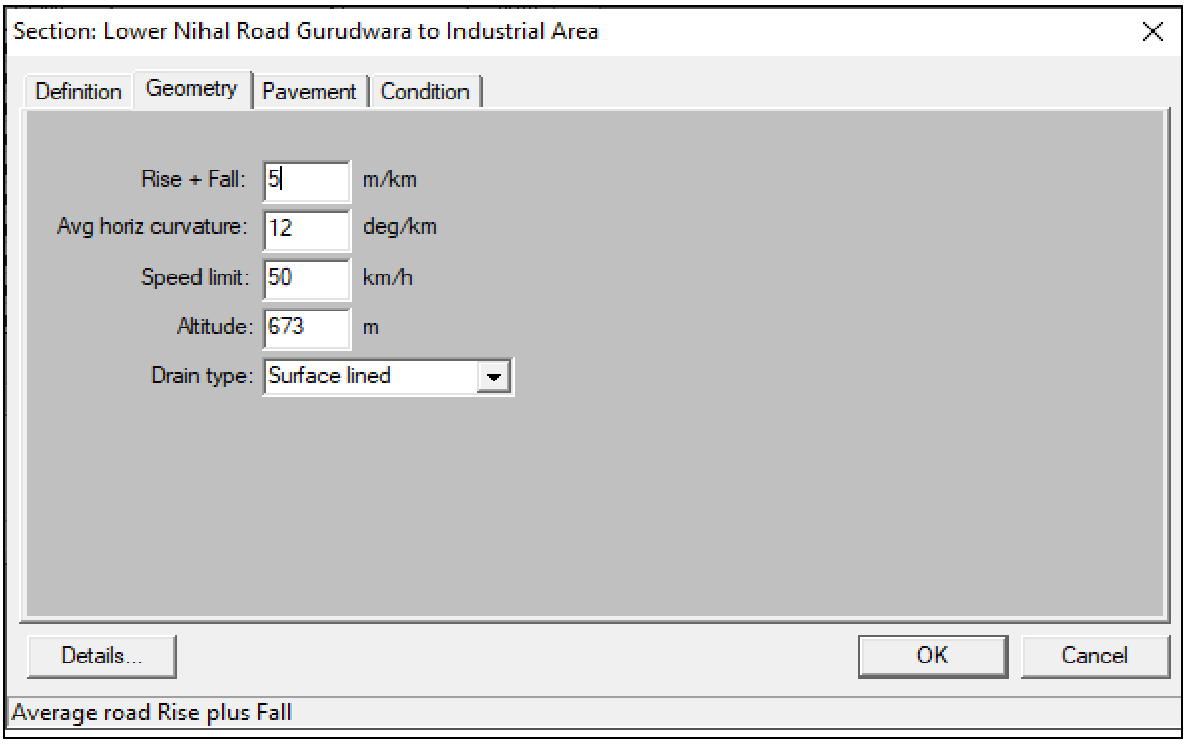


Fig. 4.5: Geometry Data Input for BIL-PWD-001.

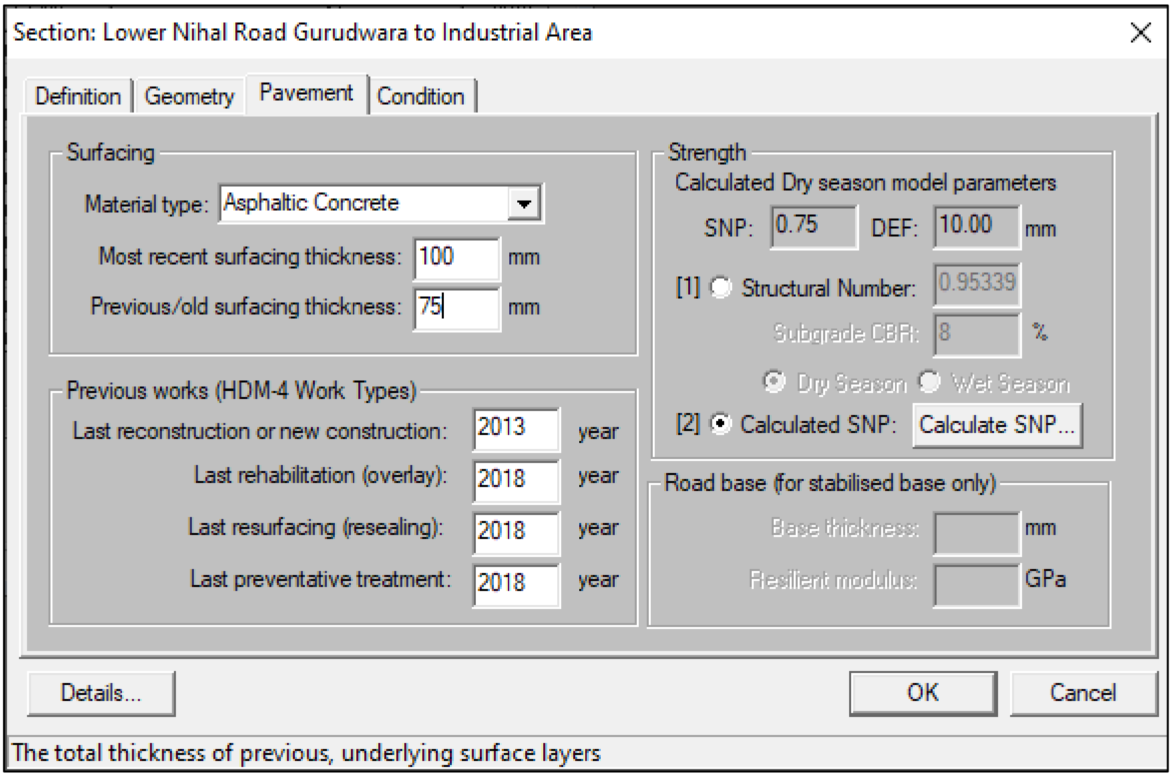


Fig. 4.6: Pavement Data Input for BIL-PWD-001.

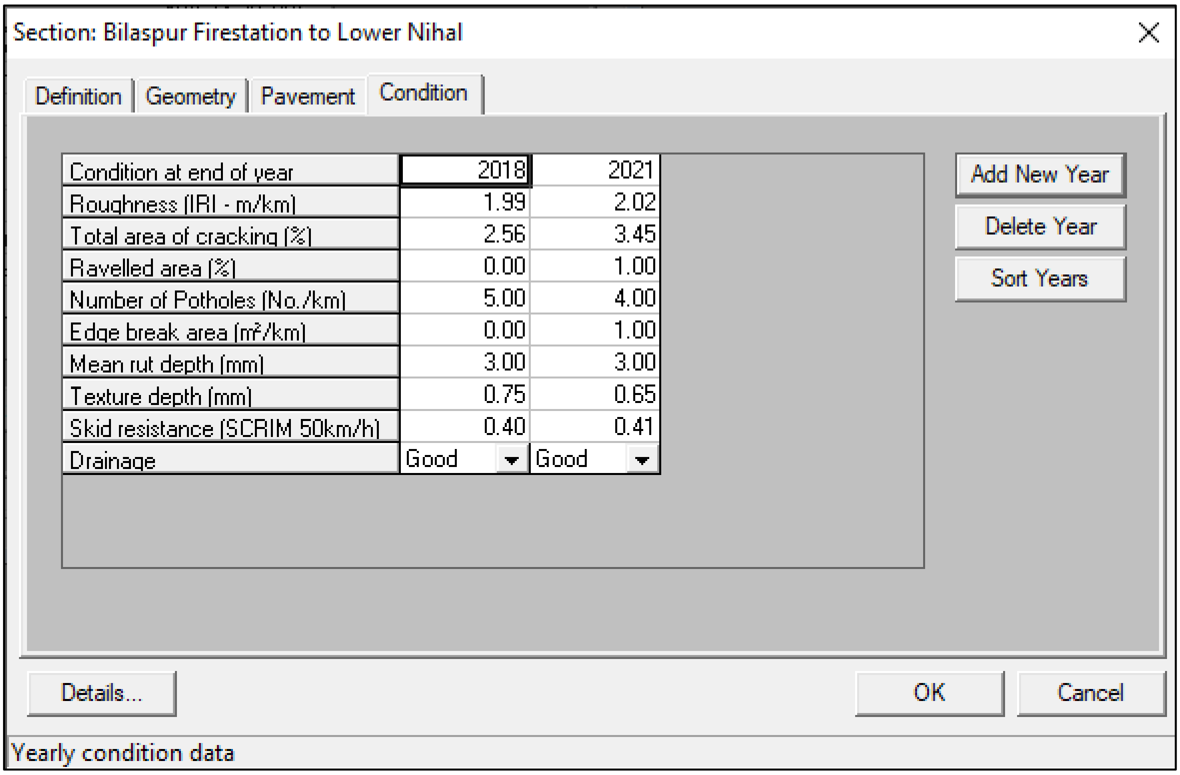


Fig. 4.7: Condition Data Input for BIL-PWD-001.

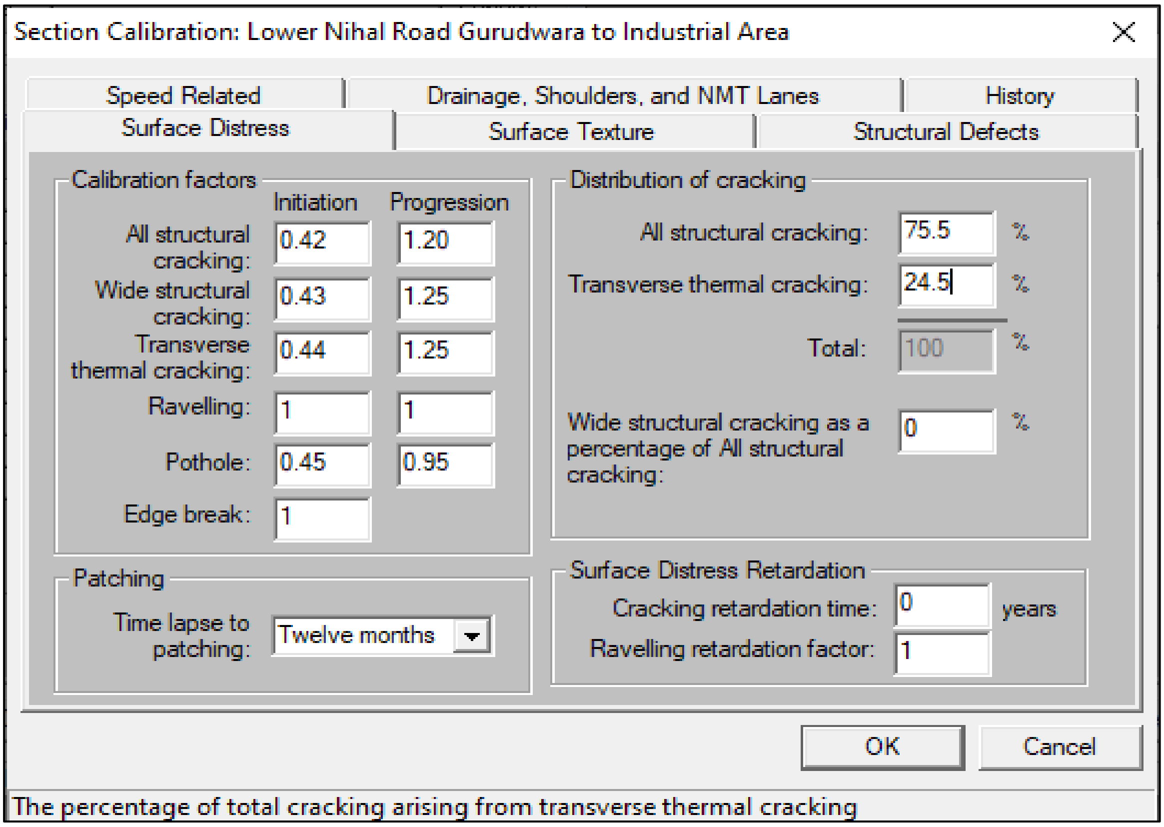


Fig. 4.8: Calibration Factors for BIL-PWD-001.

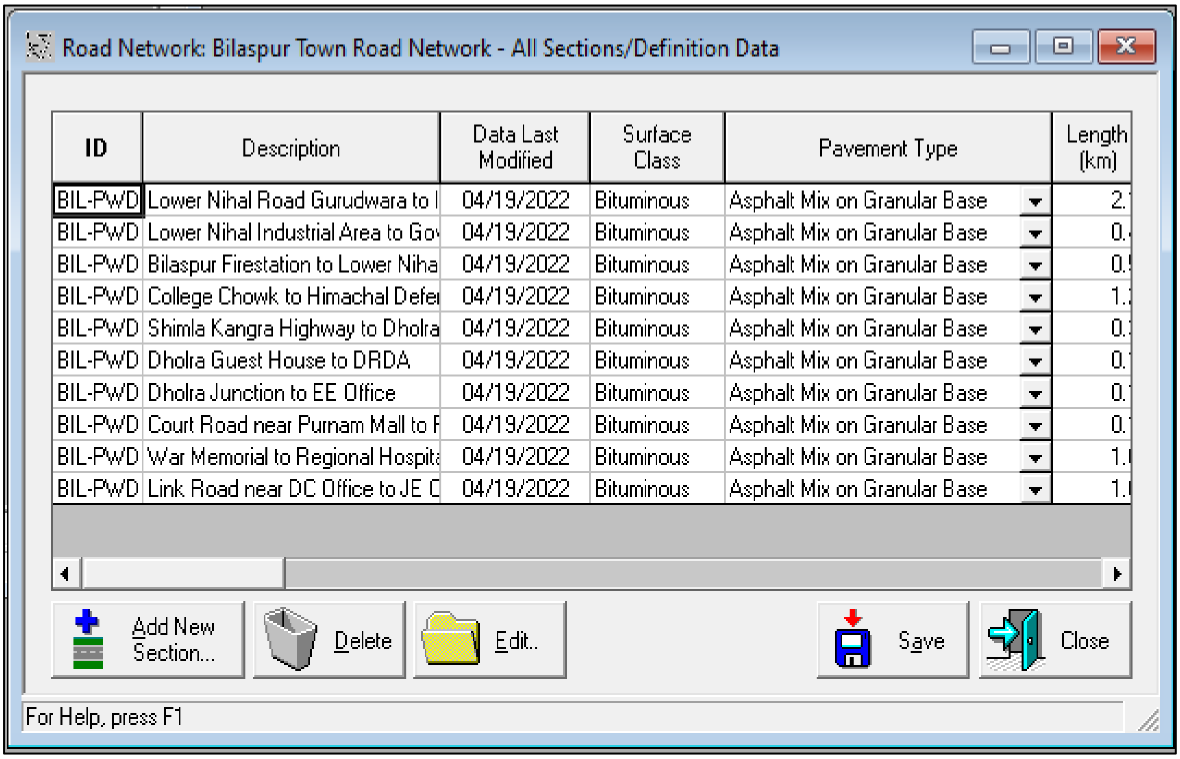


Fig. 4.9: Bilaspur Town Road Network with All the Ten Sections Defined.

4.3.2 Vehicle Fleet

For the study, Vehicle Fleet named as 'Bilaspur Town Vehicle Fleet' has been created. Eight types of Motorized Vehicle (MT) *i.e.*, Two-wheeler, Car/Jeep/Van, Auto-Rickshaw, Bus (Medium), Mini-Bus, Truck, Mini-Truck and Tractor/Trolley and three types of Non-Motorized Vehicle (NMT) *i.e.*, Cycle, Man-Driven Rickshaw and Cart have been included in this vehicle fleet. All the vehicles with their basic characteristic data and economic unit costs (mentioned in previous chapter) are entered as inputs into vehicle attributes under vehicle fleet section in HDM-4 software.

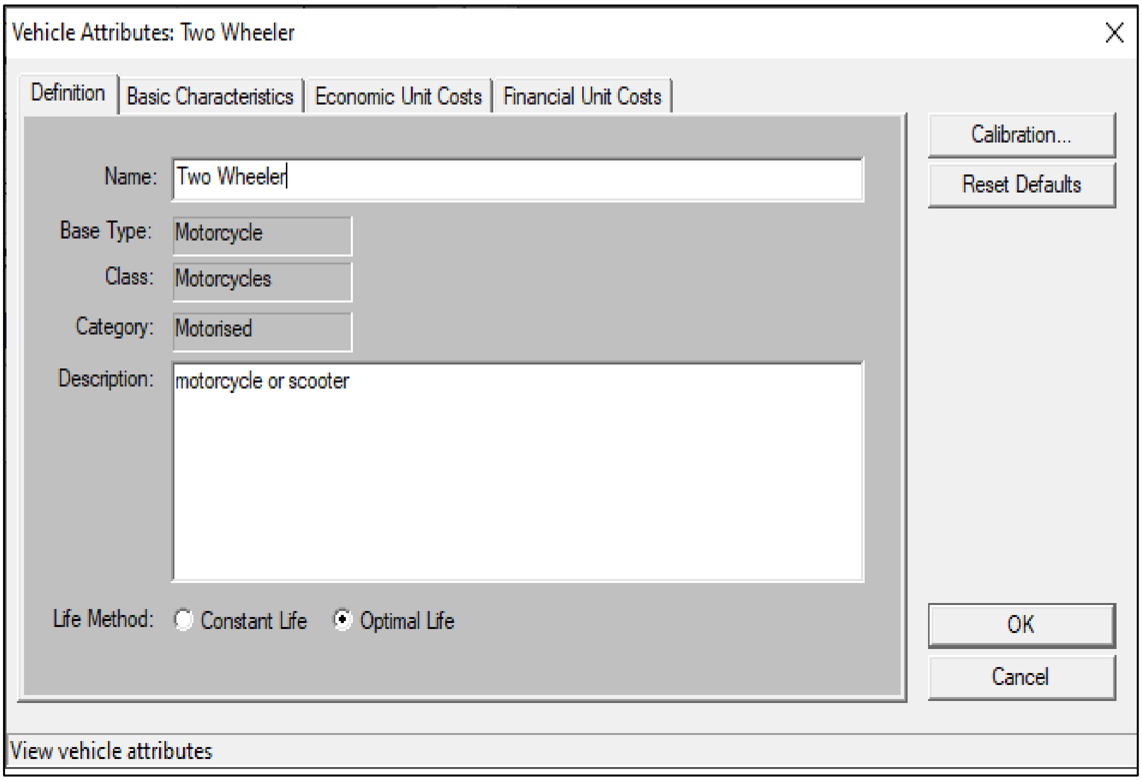


Fig. 4.10: Definition Data Input Entry for Two-Wheeler into Bilaspur town Vehicle Fleet.

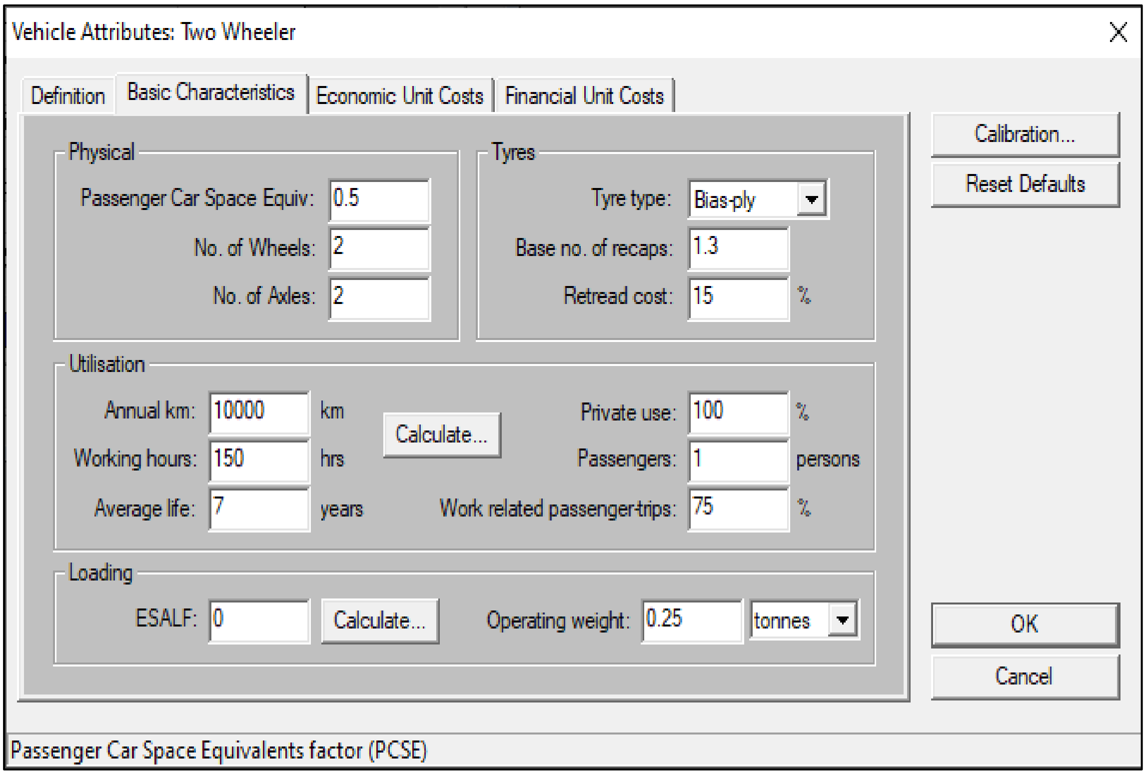


Fig. 4.11: Basic Characteristics Data Input Entry for Two-Wheeler.

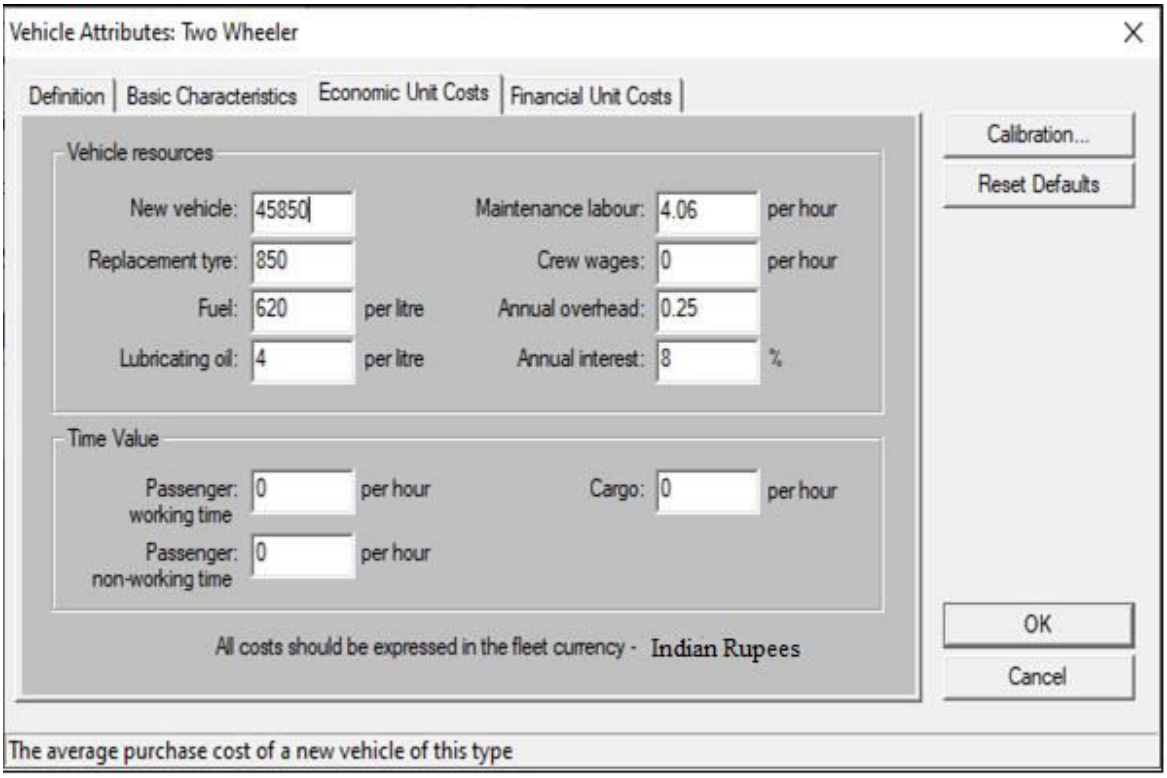


Fig. 4.12: Economic Unit Costs Data Input for Two-Wheeler.

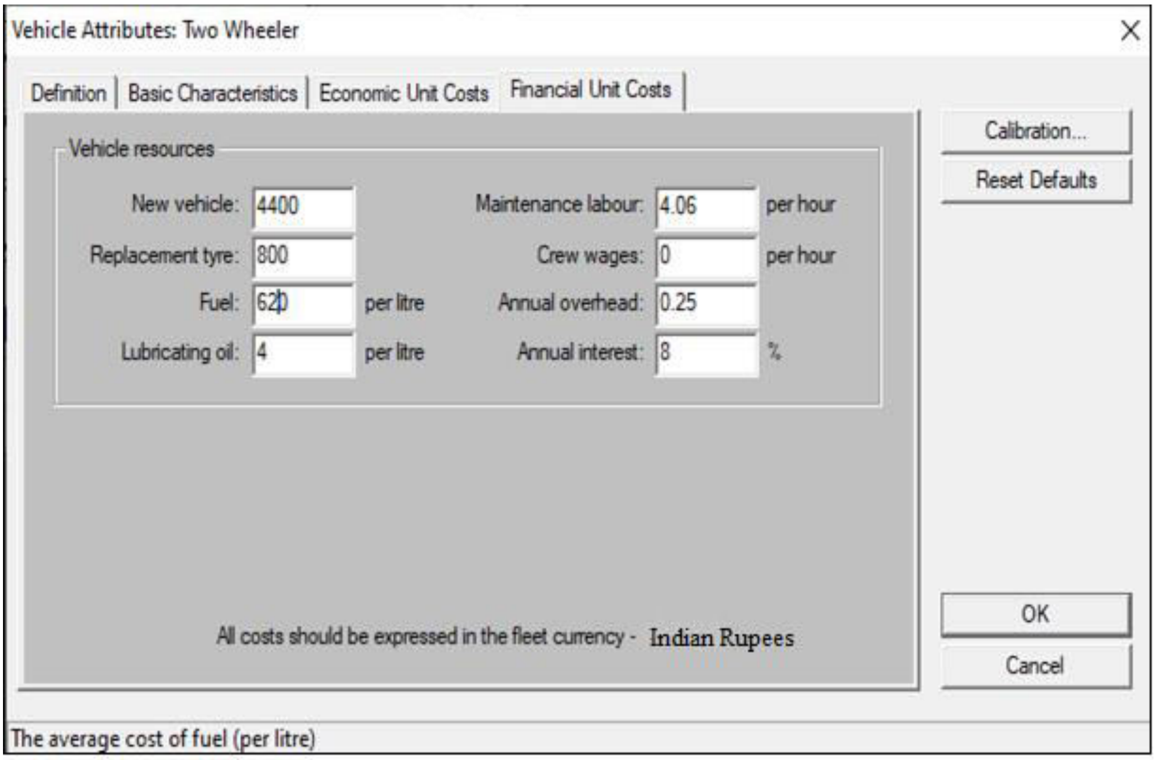


Fig. 4.13: Financial Unit Costs Data Input for Two-Wheeler.

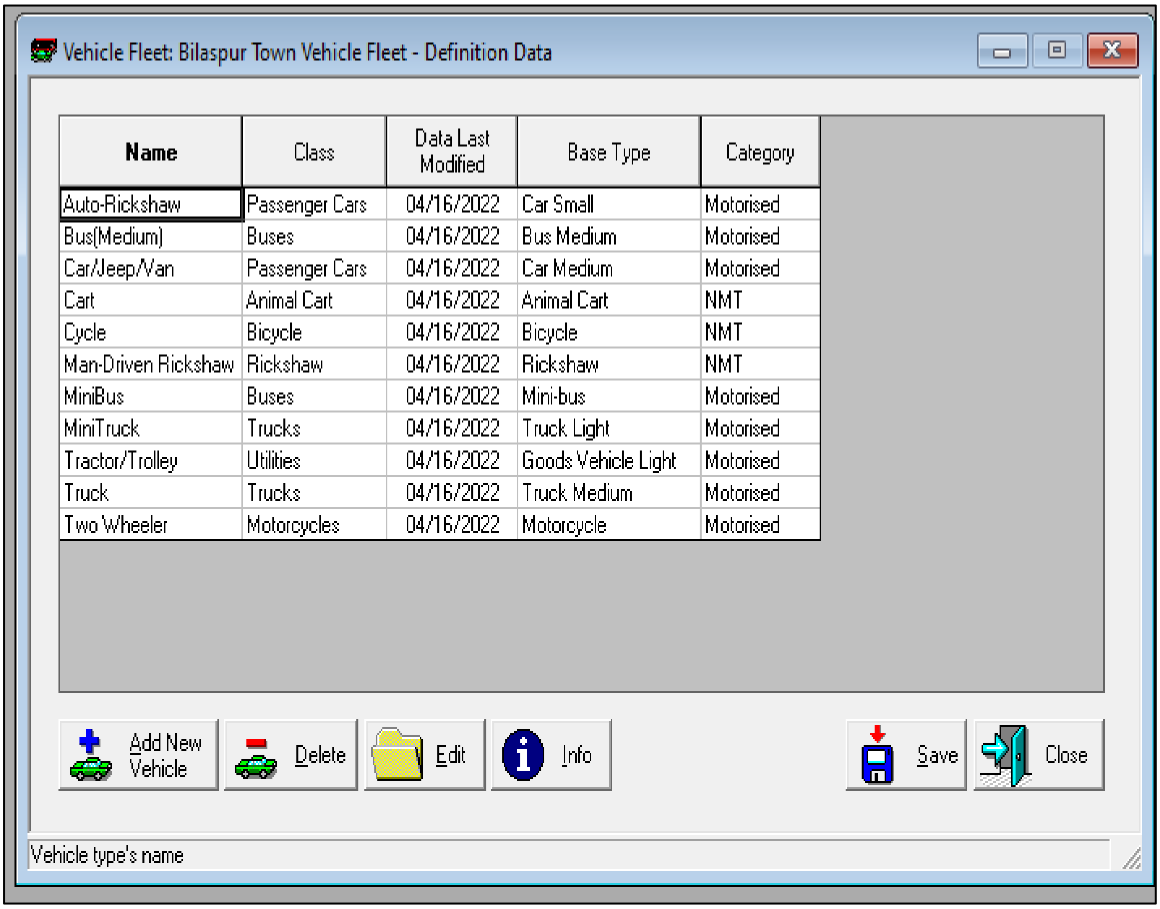


Figure 4.14: Bilaspur Town Vehicle Fleet with All the Vehicles Defined.

4.4 DETERMINATION OF RSL OF ROAD SECTIONS

The aim of the very first objective was to compute RSL of each road section. RSL of a road section means the time period in years after which the reconstruction of the pavement is to be carried out by the agencies, providing no Maintenance and Rehabilitation (M&R) works throughout the intervening period (Gupta and Kumar, 2015). 'Project Analysis' in HDM-4 has been selected for determining this parameter.

4.4.1 Input Data

A new project named as 'Determination of RSL' was created which consisted of 'Bilaspur Town Road Network' and 'Bilaspur Town Vehicle Fleet' as inputs. The intervening period (analysis period) for the analysis of the project was taken as 10 years keeping in mind that all the selected road sections will require reconstruction work within next ten years when no maintenance work is provided during the intervening period.

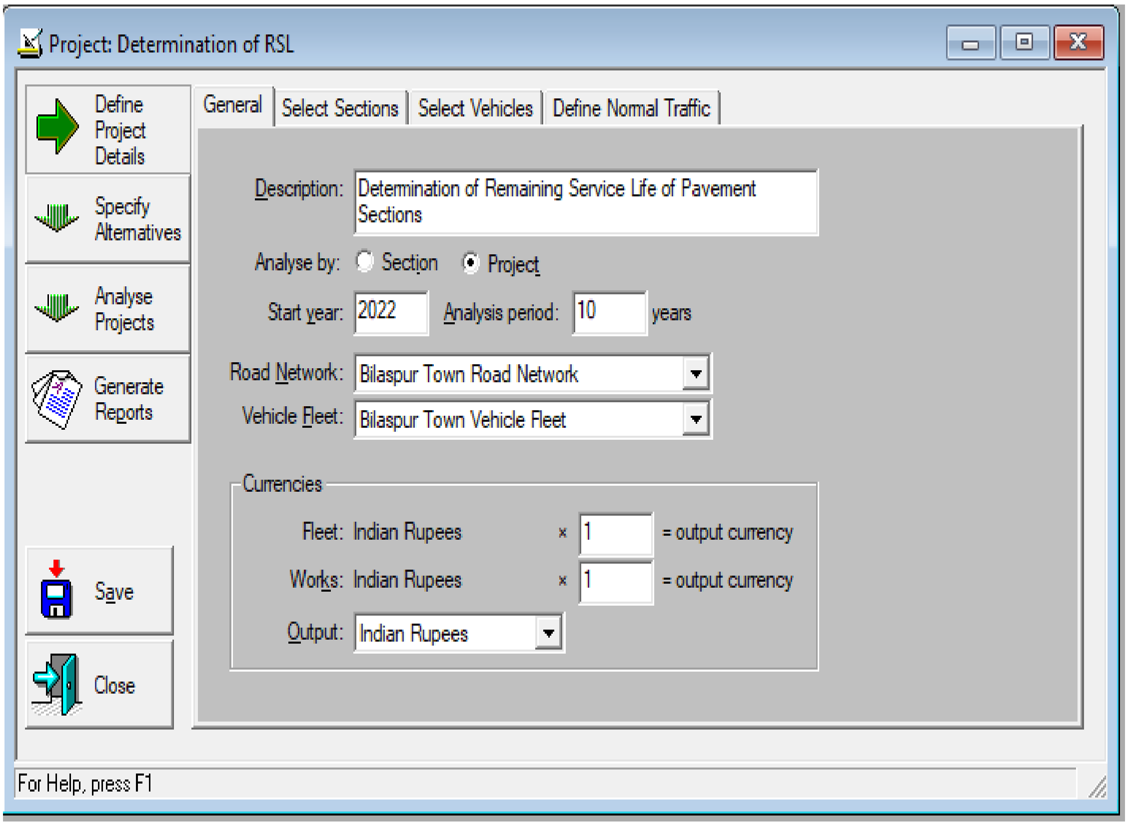


Fig. 4.15: General Input Data for Project: Determination of RSL

4.4.2 Selection of Sections and Vehicles

All the ten sections from Bilaspur Town Road Network and all the types of vehicles from Bilaspur Town Vehicle Fleet were selected for the analysis purpose. Figure 4.16 and Figure 4.17 show the snapshots of selection of sections and selection of vehicles respectively.

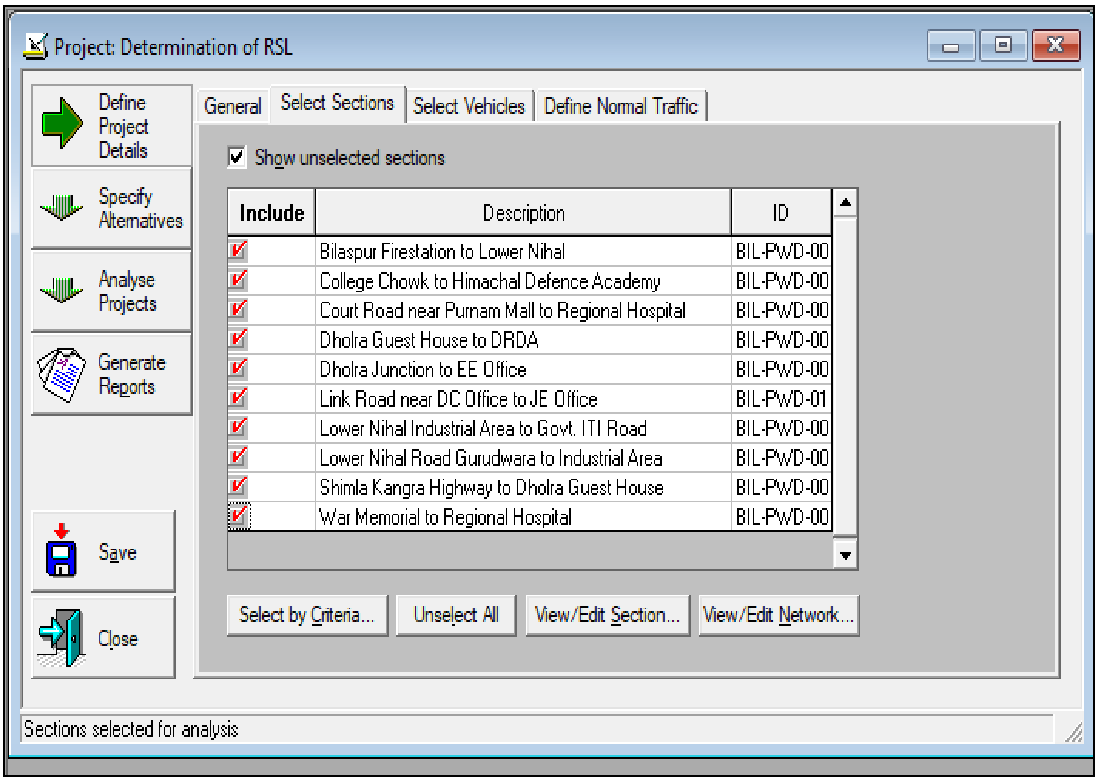


Figure 4.16: Selection of Sections for Project: Determination of RSL.

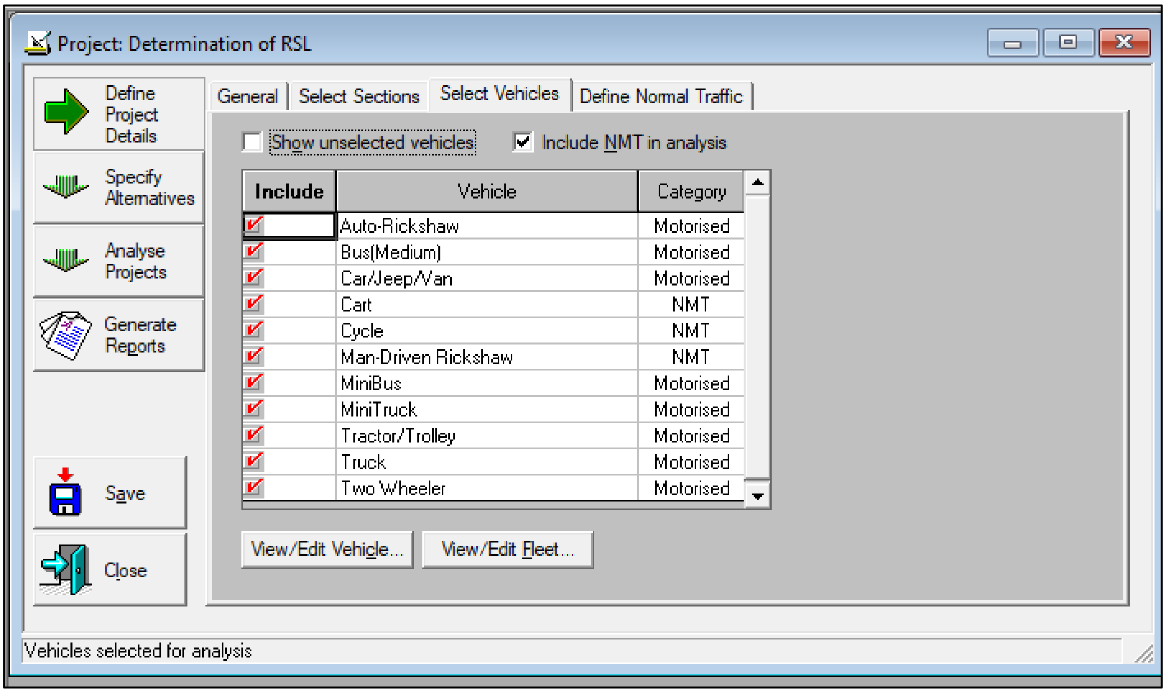


Figure 4.17: Selection of Vehicles for Project: Determination of RSL.

4.4.3 Define Normal Traffic

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

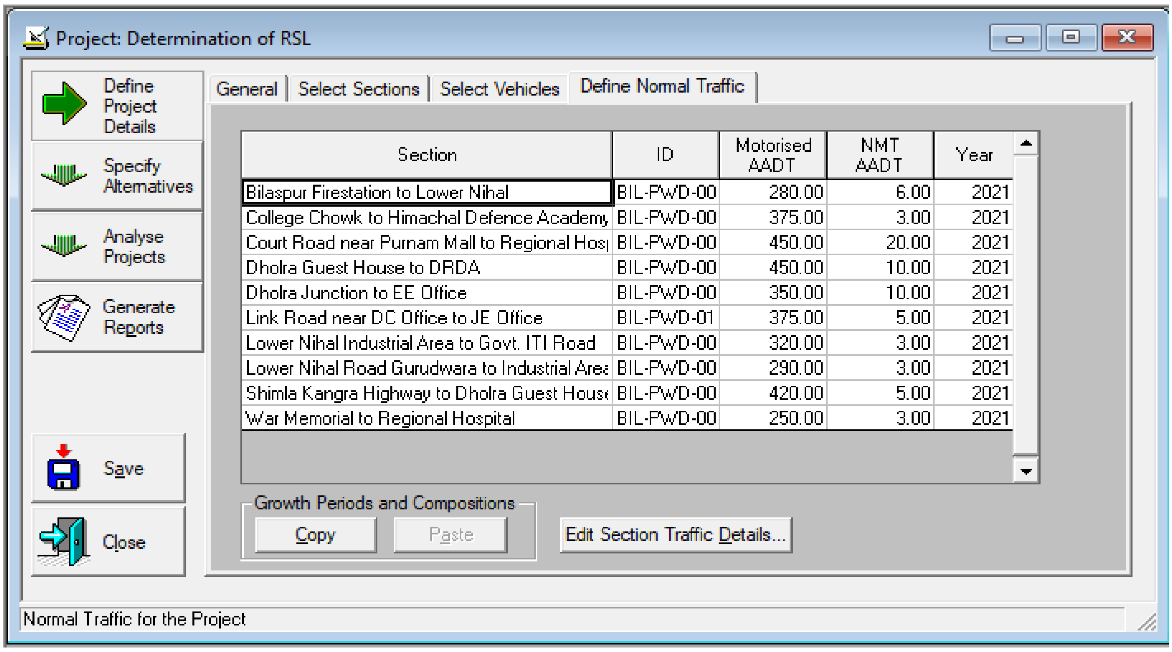


Figure 4.18: Normal Traffic for the Project: Determination of RSL

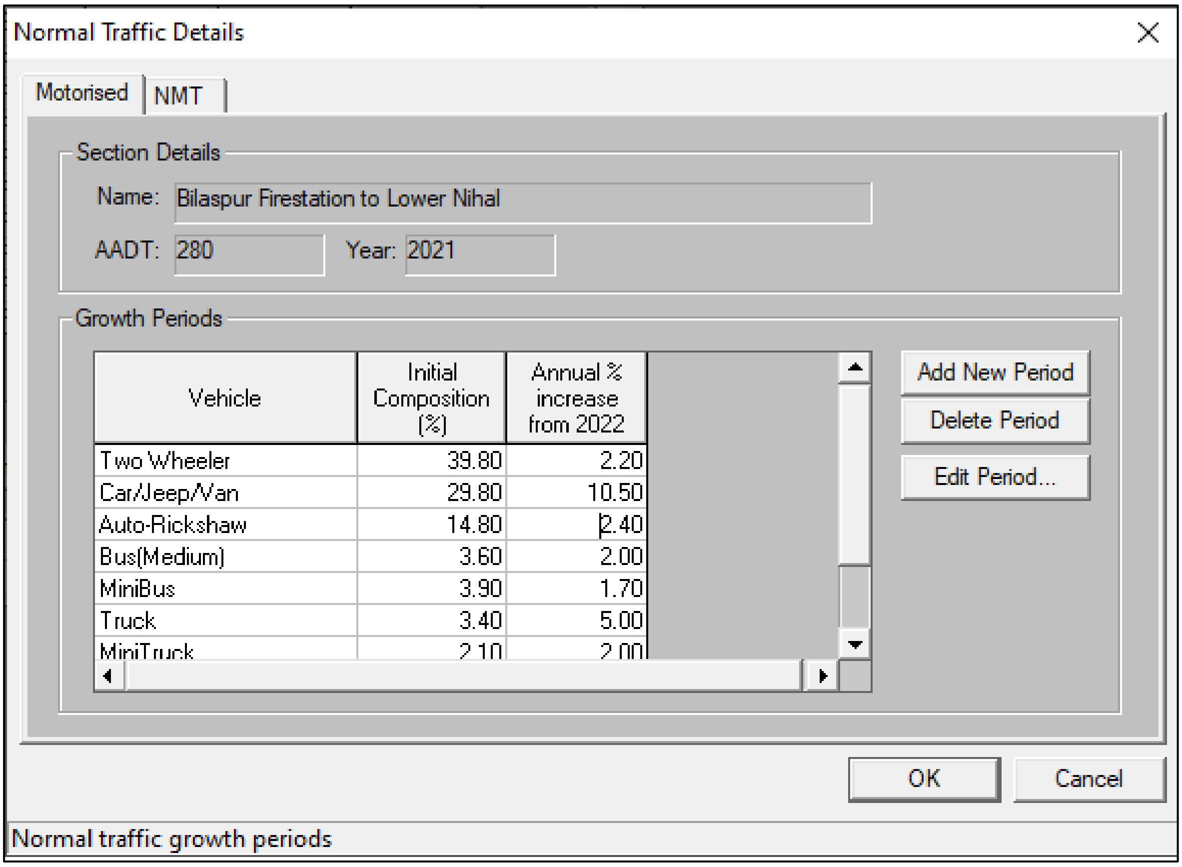


Figure 4.19: Normal Traffic Details of MT vehicle for BIL-PWD-001.

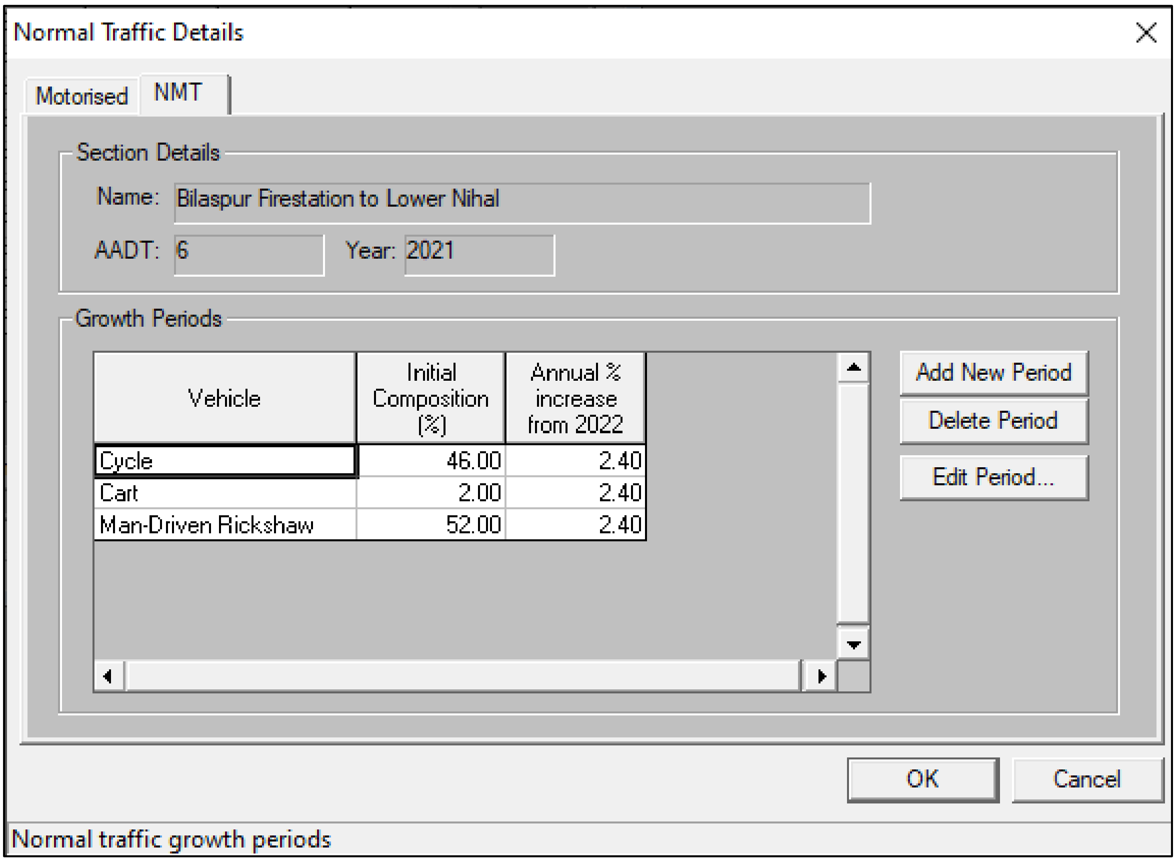


Figure 4.20: Normal Traffic Details of NMT vehicle for BIL-PWD-001.

4.4.4 Specify M&R Alternative

The condition responsive alternative named as 'Do Nothing up till Reconstruction' has been defined for the project in which 'Reconstruction' maintenance work standard was assigned along with intervention criteria to each road section. As road roughness plays a vital role in PMMS, Roughness >= 4 m/km IRI has been taken as intervention criteria for reconstruction work. Figure 4.21 and Figure 4.22 show the specification of M&R alternative.

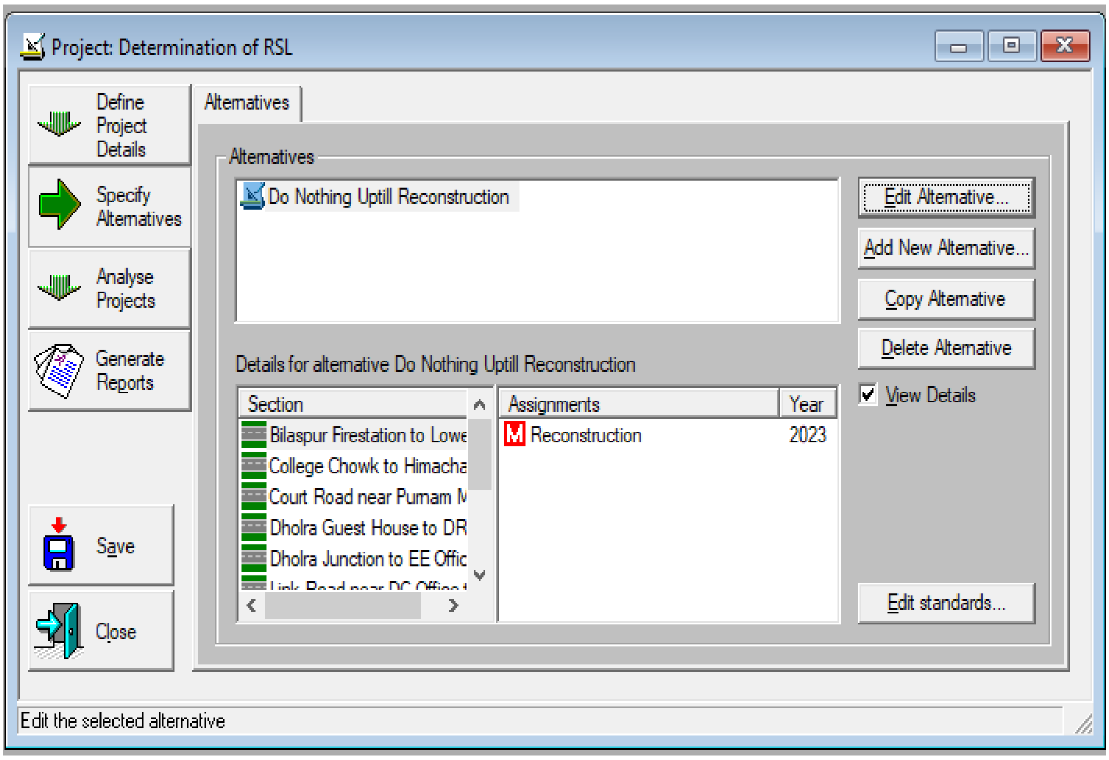


Fig. 4.21: Defined M&R Alternative for all Selected Pavement Sections.

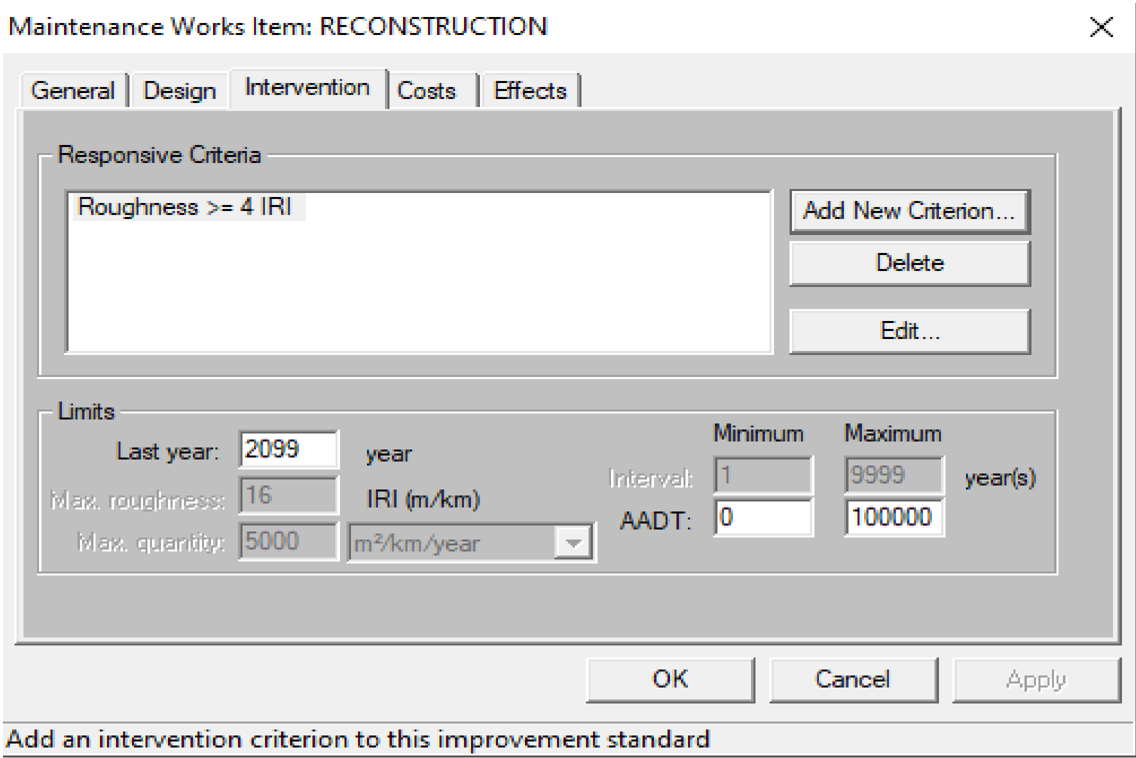


Fig. 4.22: Intervention Criteria for Selected M&R Work Item

4.4.5 Project Analysis

No economic analysis was required to be conducted for this objective because no other alternative was assigned for comparison purpose. The project analysis application was run for analyzing the pavement future condition (pavement deterioration) of all the selected road sections under assigned M&R alternative. Figure 4.23 shows the run analysis of the project.

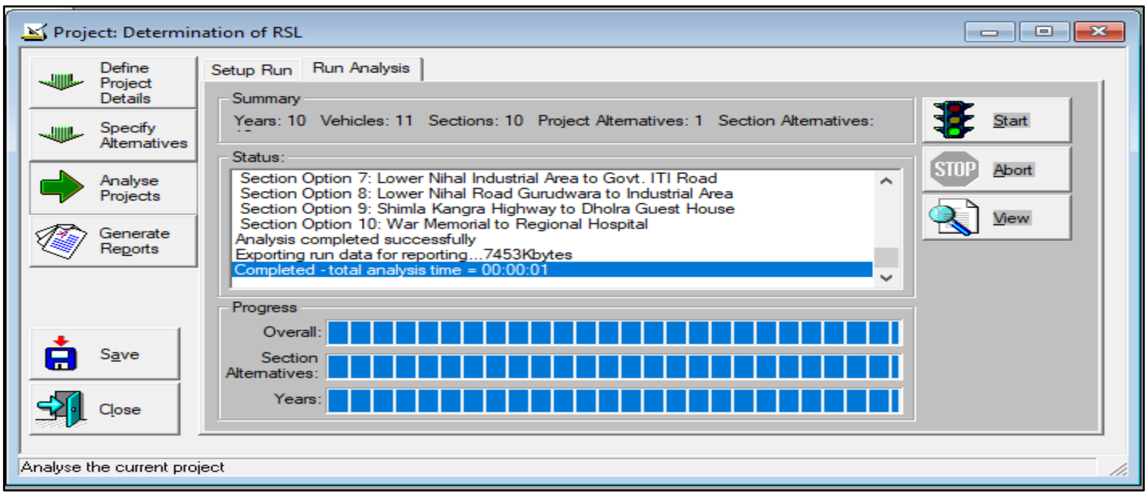


Fig. 4.23: Run Analysis of Project: RSL of Pavement

4.4.6 Roughness Progression

The Roughness progresses with each year. If it exceeds intervention value *i.e.,* > = 4 IRI in a certain year, Reconstruction alternative shall be triggered for that year. The sharp fall in average roughness values indicates the reconstruction work of the road section in that certain year.

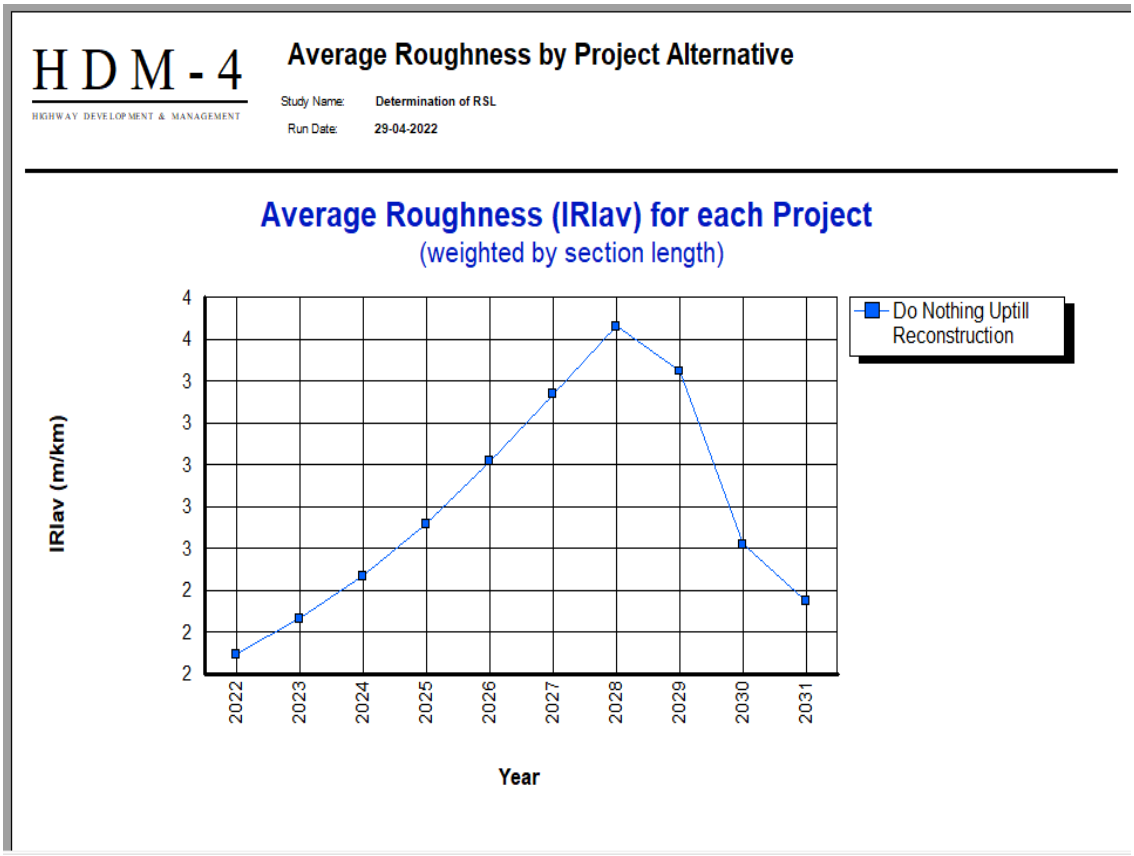


Fig.4.24: Average Roughness Progression by Project Alternative.

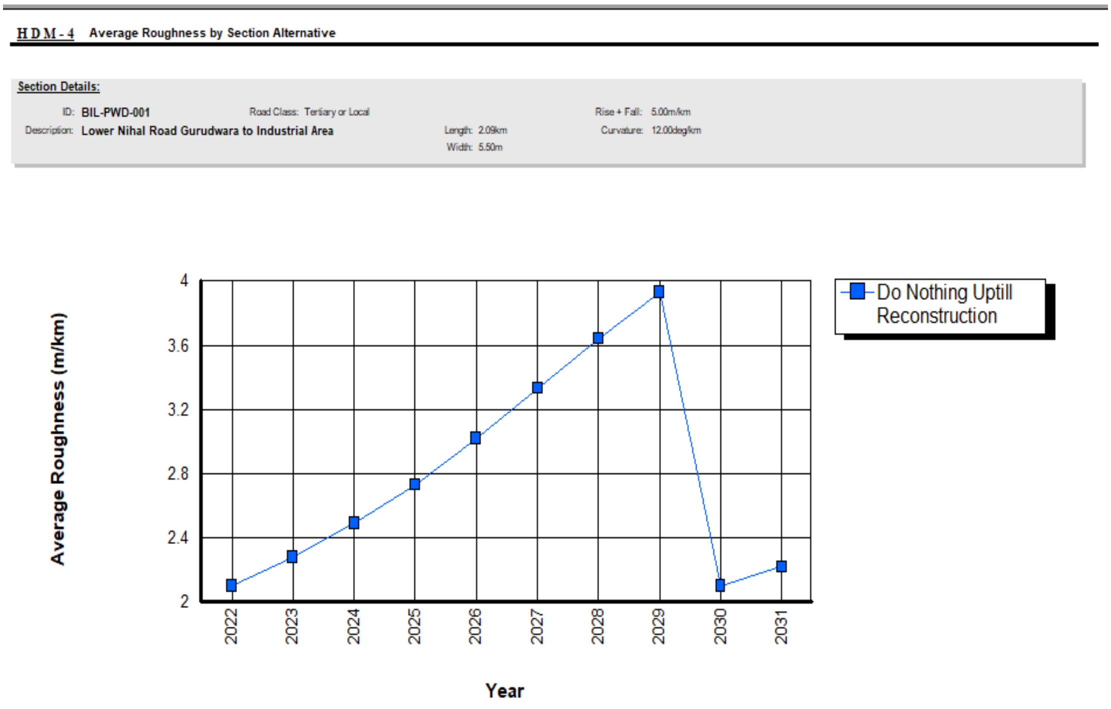


Fig. 4.25: Roughness Progression for BIL-PWD-001.

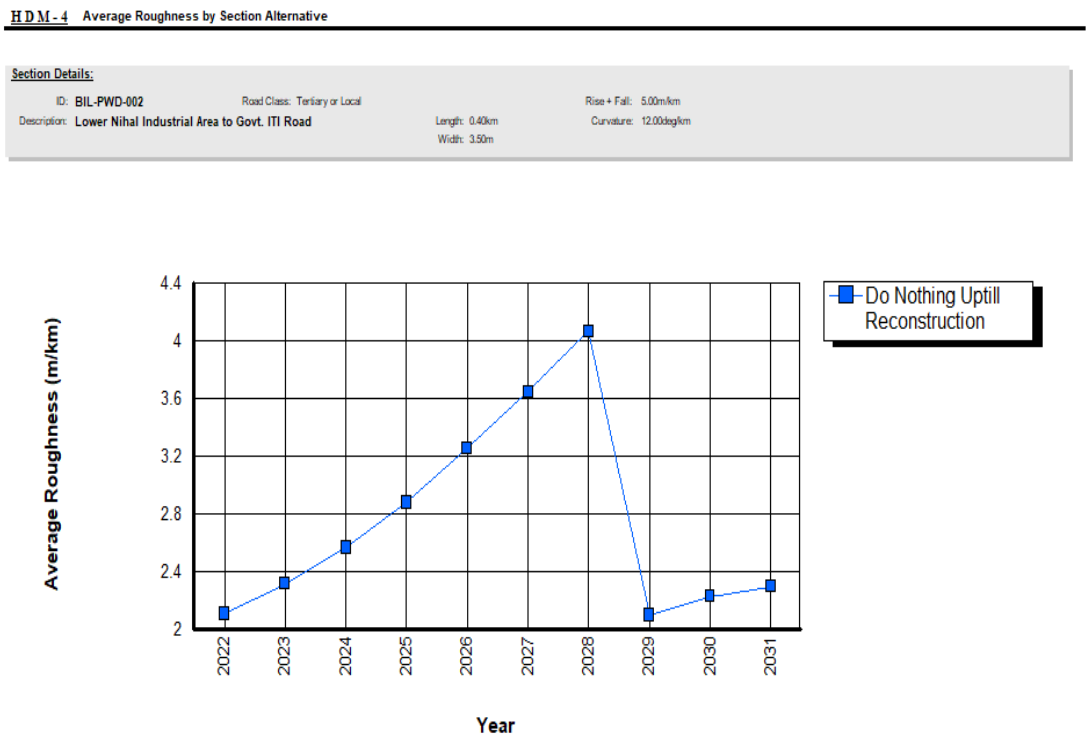


Fig.4.26: Roughness Progression for BIL-PWD-002.

H D M - 4 Average Roughness by Section Alternative

HIGHWAY DEVELOPMENT & MANAGEMENT

Study Name: Determination of RSL

Run Date: 29-04-2022

Section Details:

ID: BIL-PWD-003 Road Class: Tertiary or Local Rise + Fall: 10.00m/km

Description: Bilaspur Firestation to Lower Nihal Length: 0.50km Curvature: 12.00deg/km

Width: 3.00m

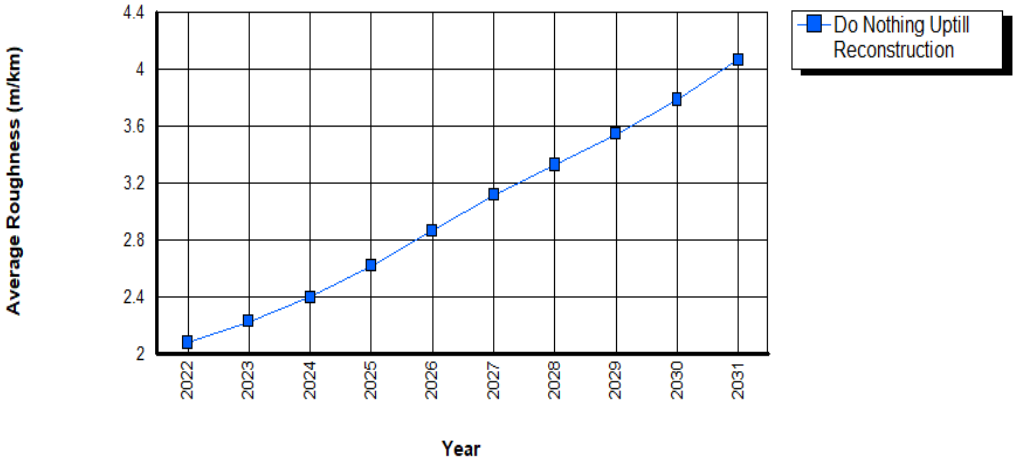


Fig. 4.27: Roughness Progression for BIL-PWD-003.

H D M - 4 Average Roughness by Section Alternative

Section Details:

ID: BIL-PWD-004 Road Class: Tertiary or Local Rise + Fall: 3.00m/km

Description: College Chowk to Himachal Defence Academy Length: 1.23km Curvature: 12.00deg/km

Width: 7.00m

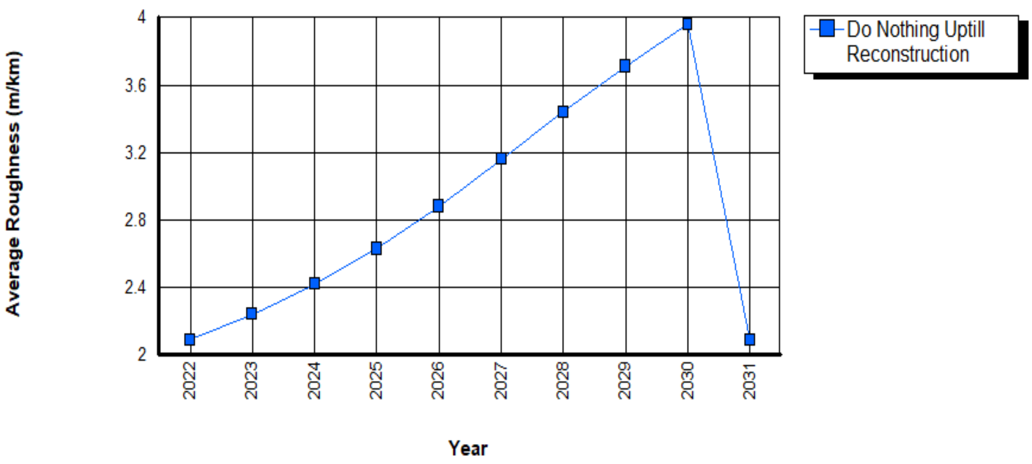


Fig. 4.28: Roughness Progression for BIL-PWD-004.

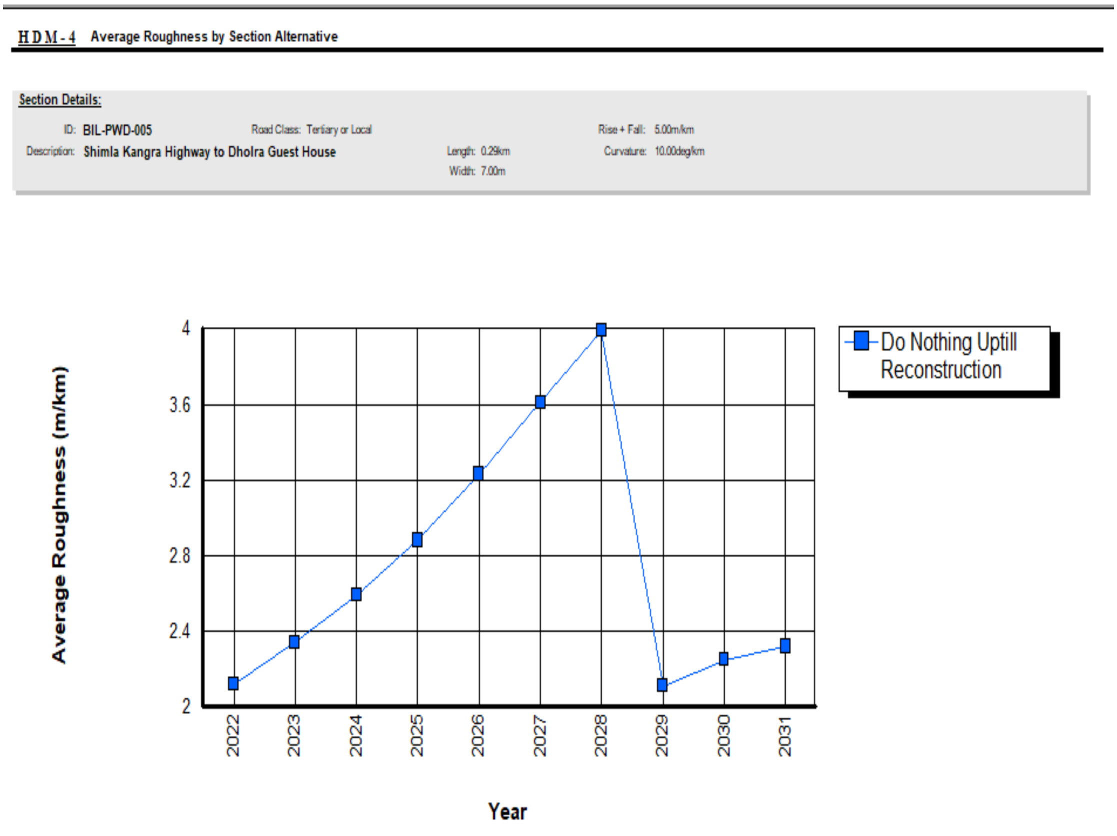


Fig. 4.29: Roughness Progression for BIL-PWD-005.

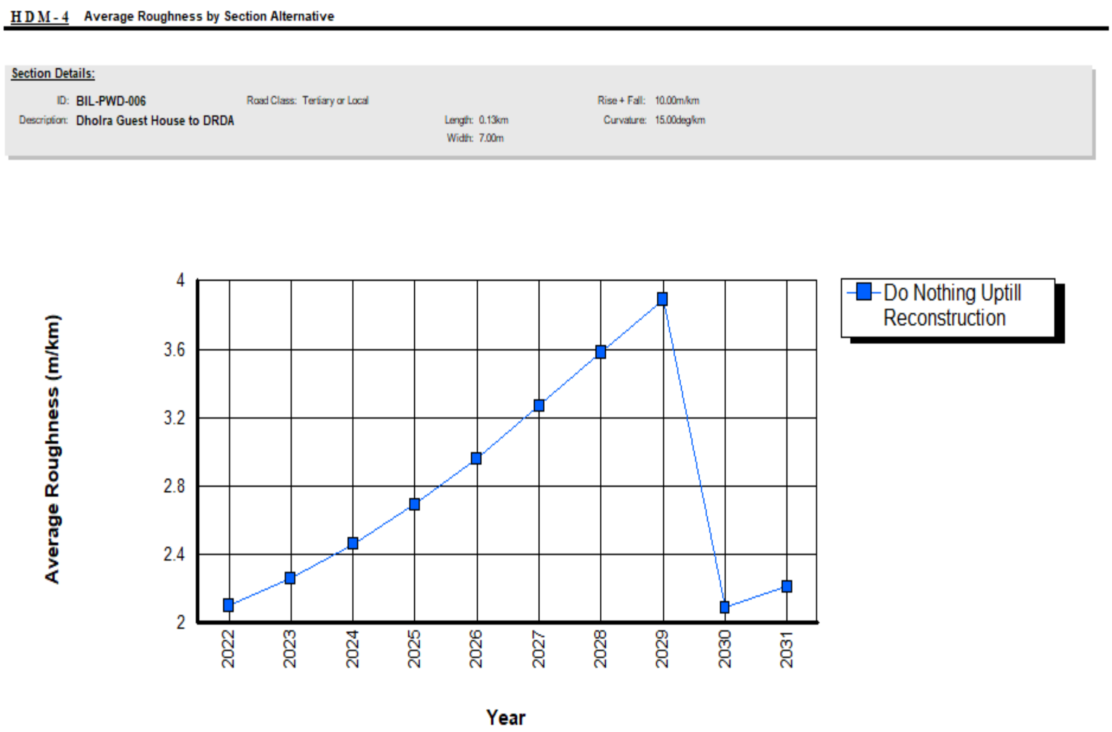


Fig.4.30: Roughness Progression for BIL-PWD-006.

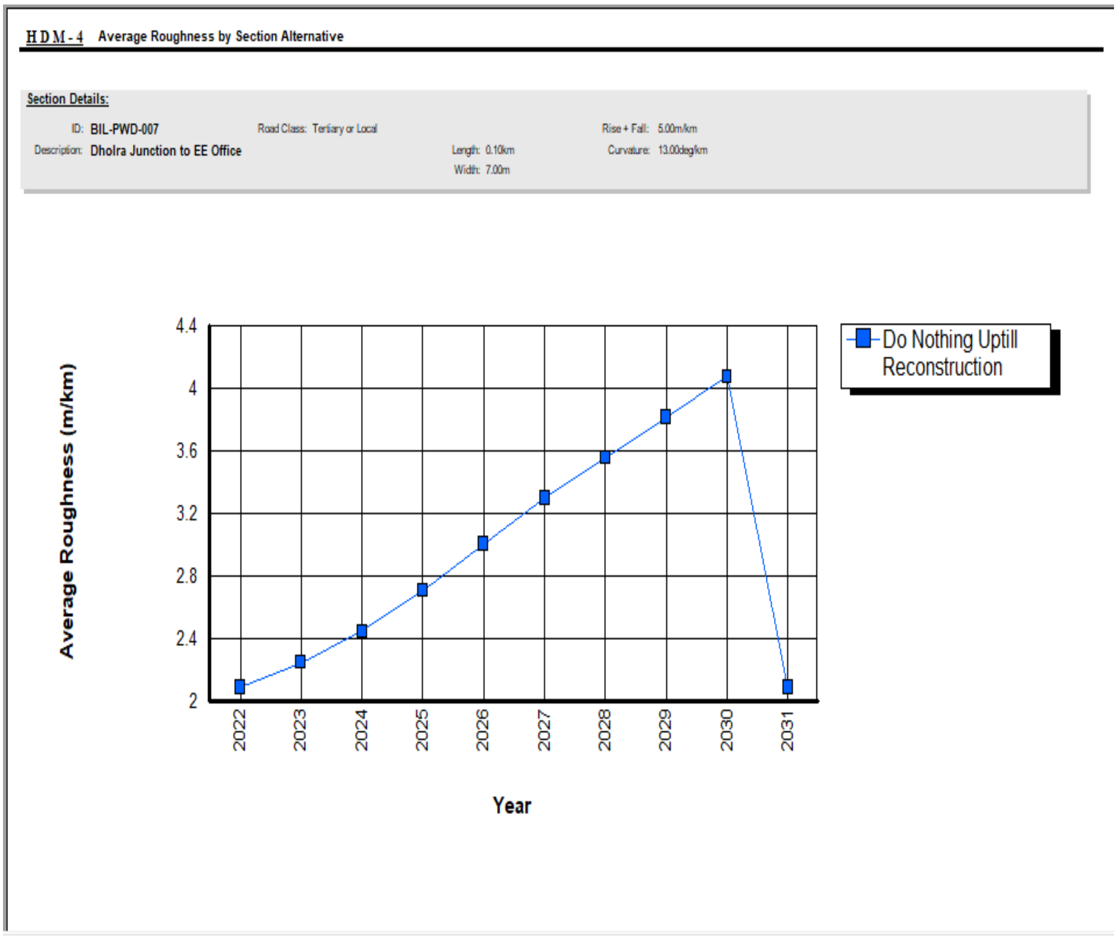


Figure 4.31: Roughness Progression for BIL-PWD-007.

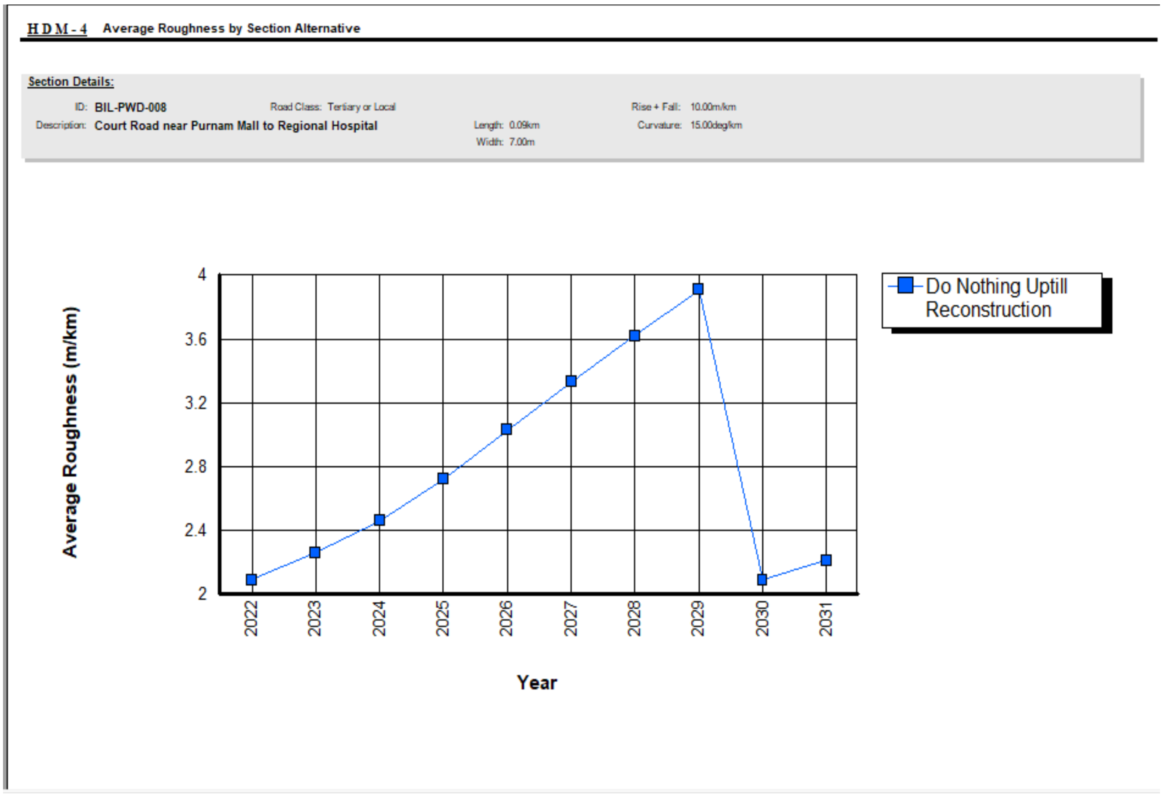


Figure 4.32: Roughness Progression for BIL-PWD-008.

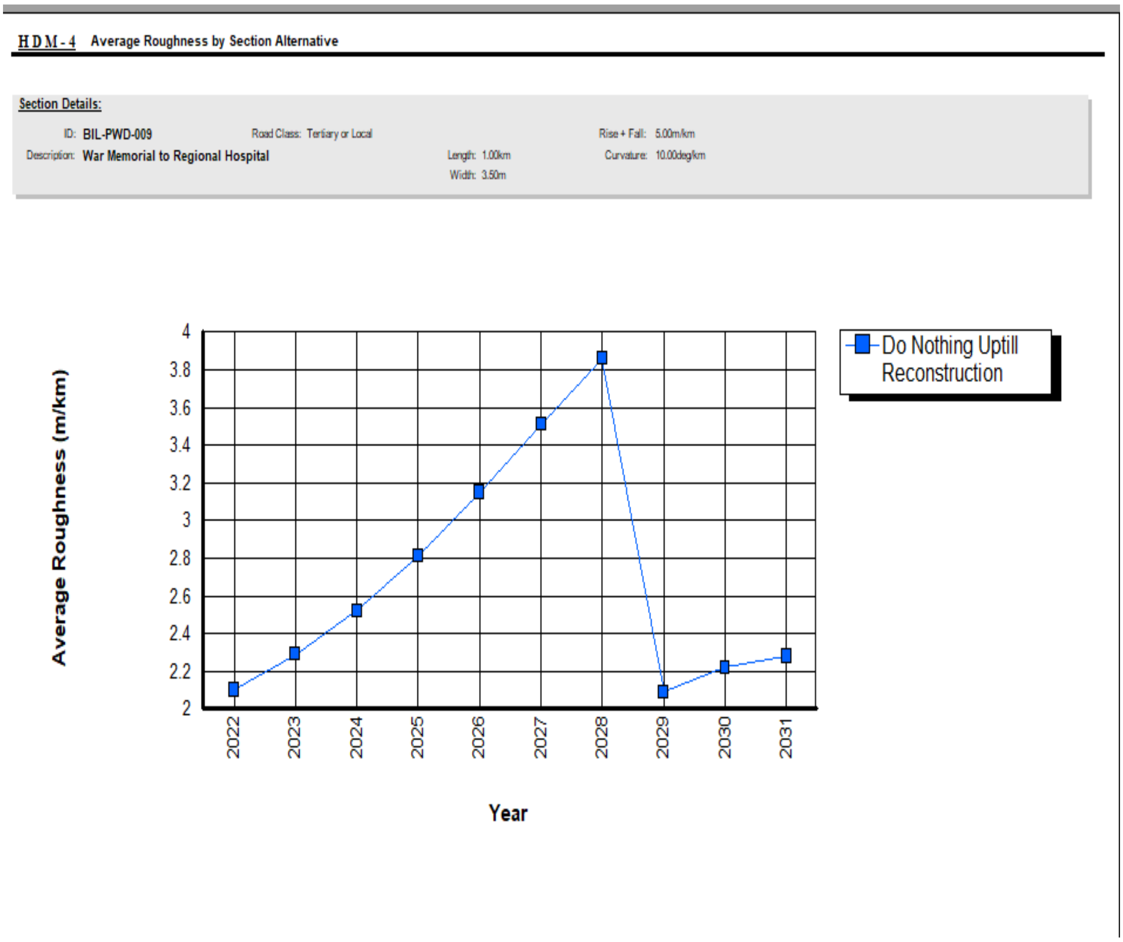


Figure 4.33: Roughness Progression for BIL-PWD-009.

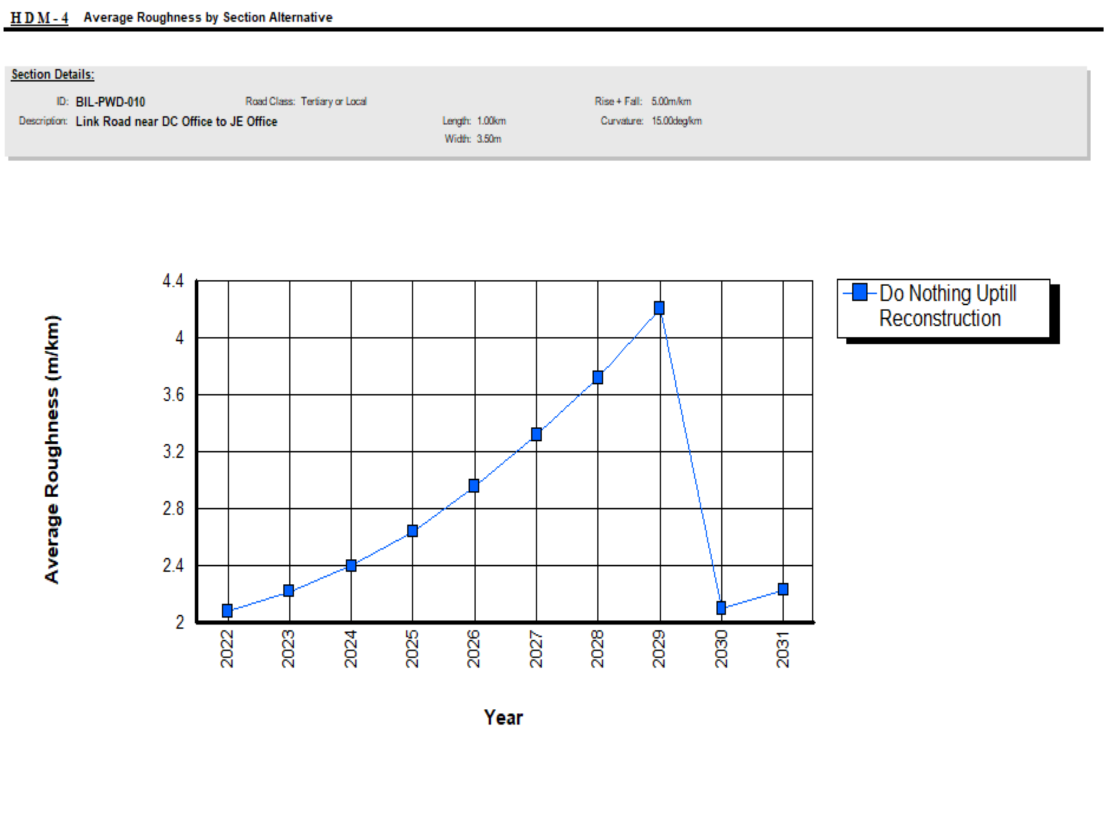


Figure 4.34: Roughness Progression for BIL-PWD-010.

4.4.7 Determination of Remaining Service Life (RSL)

RSL of all the pavements in the network is determined in terms of the number of years left before the reconstruction of the road surface is required based upon the condition responsive intervention criteria of roughness in terms of IRI. Reconstruction will be initiated till the roughness value of the surface progress till the intervention criteria of roughness. RSL of all the road sections were computed from roughness progression graphs and road work summary report of the road sections.

Table 4.3: RSL of Each Road Section

Section ID	Section Name	Reconstruction Year	Remaining Service Life (RSL), in years
BIL-PWD-001	Lower Nihal Road Gurudwara to Industrial Area	2029	7
BIL-PWD-002	Lower Nihal Industrial Area to Govt. ITI Road	2028	6
BIL-PWD-003	Bilaspur Fire station to Lower Nihal	2031	9
BIL-PWD-004	College Chowk to Himachal Defence Academy	2030	8
BIL-PWD-005	Shimla Kangra Highway to Dholra Guest House	2028	6
BIL-PWD-006	Dholra Guest House to DRDA	2029	7
BIL-PWD-007	Dholra Junction to EE Office.	2030	8
BIL-PWD-008	Court Road near Purnam Mall to Regional Hospital	2029	7
BIL-PWD-009	War Memorial to Regional Hospital	2028	6
BIL-PWD-010	Link Road near DC Office to JE Office	2029	7

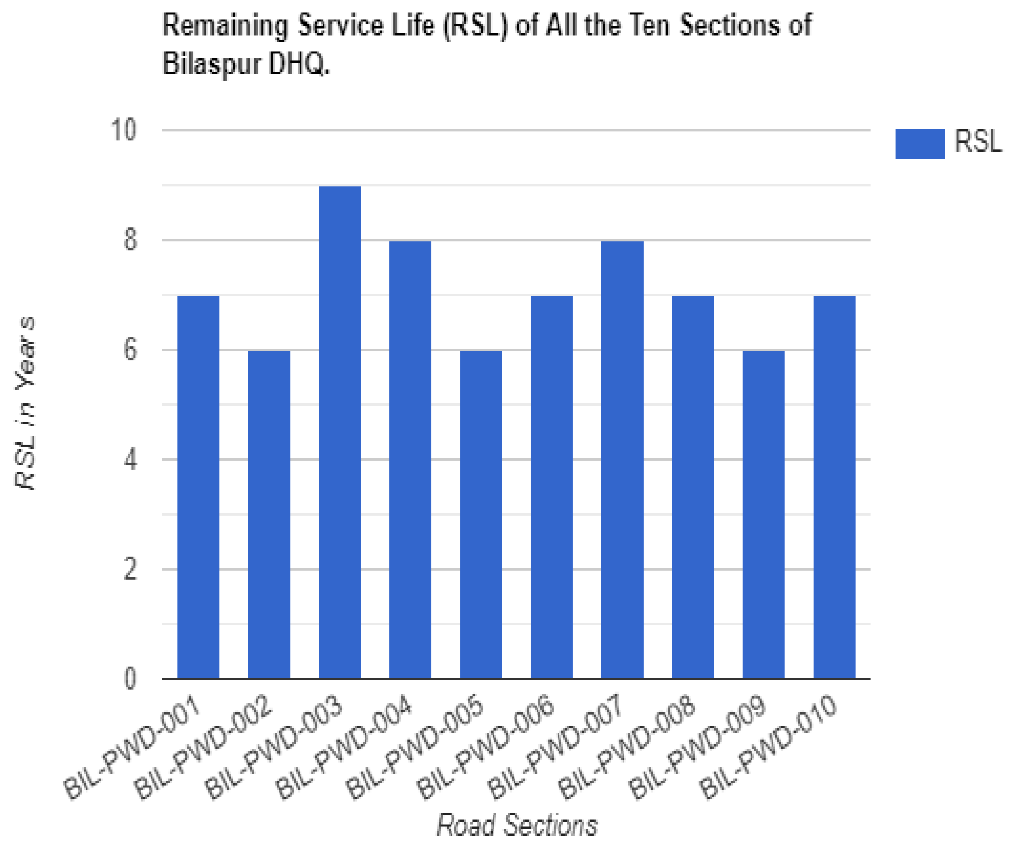


Fig. 4.35: RSL (in years) for various Road Sections

RSL value of the road section will help the road agency to know the imperative time for reconstruction work prior to the failure of entire road. Budgeting and funding for reconstruction work can also be done accordingly.

4.5 Determination of Optimum M&R Strategy For All The Road Sections.

The aim of this objective is to determine the optimum M&R strategy for all the ten road sections. The result shows the economic analysis of M&R strategies for road sections. The importance of this objective is to evaluate the cost-effective benefits resulting from investing in M&R works of a road section at the appropriate time, as compared against carrying out minimum routine maintenance annually. The optimum M&R strategy has been selected on the basis of economic indicators, such as NPV/Cost Ratio. Project Analysis in HDM-4 has been adopted for this objective.

4.5.1 Input Data

A new project named as 'Determination of Optimum M&R Strategy' was created which consisted of 'Bilaspur Town Road Network' and 'Bilaspur Town Vehicle Fleet' as inputs. Analysis period (intervening period for analysis of the project) was taken as 12 years.

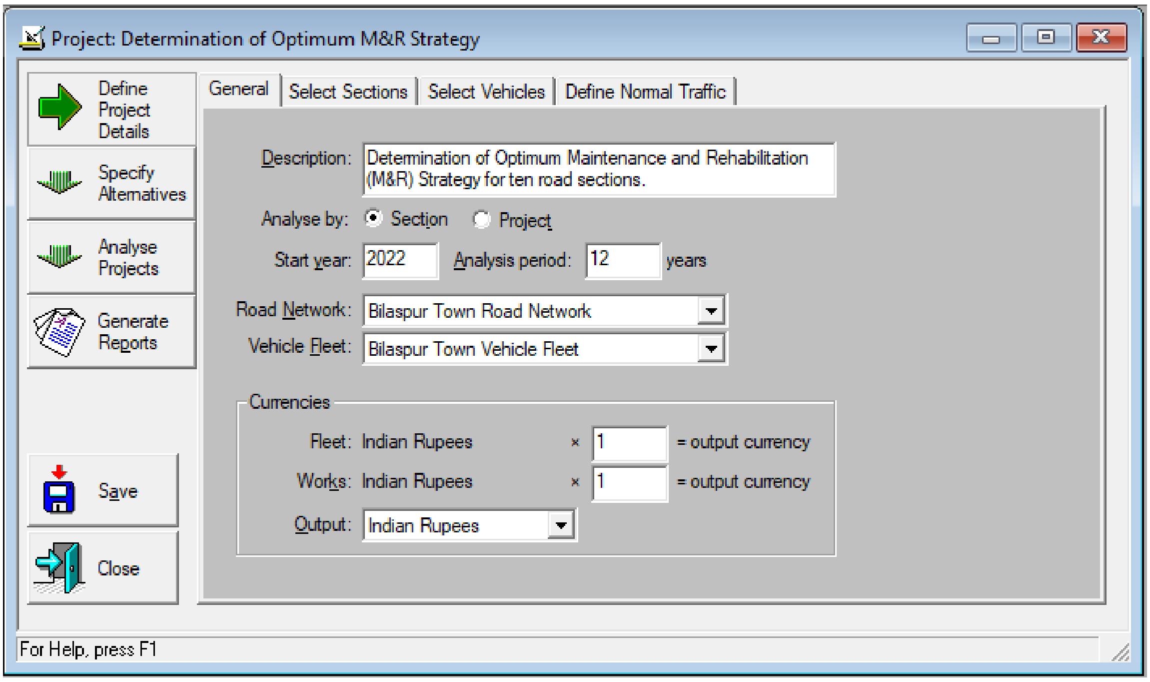


Fig. 4.36: General Data Input for Project to Determine Optimum M&R Strategy

Analyze by section has been chosen. Input and output currencies are taken as Indian Rupees. Fig.4.36 shows general data input for Project to determine Optimum M&R Strategy.

4.5.2 Selection of Sections and Vehicles

In the present study, all the ten road sections have been selected from Bilaspur Town Road Network. All the eleven types of vehicles have been marked and selected from 'Bilaspur Town Vehicle Fleet' for the analysis of this project.

4.5.3 Define Normal Traffic

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

4.5.4 Proposed Maintenance and Rehabilitation (M&R) Alternatives

Four Maintenance and Rehabilitation (M&R) alternatives have been proposed for this objective and given in Table 4.4 (keeping in mind the serviceability level of sub-arterial & other roads).

Table 4.4: Proposed M&R Alternatives

M&R Strategy	Works Standard	Description of Work	Intervention Level
Base Alternative	Routine	Crack Sealing	>10%
		Patching	>10%
		Pothole repair	>3 No.
		Ravel repair	>10%
		Drain cleaning	Scheduled annually
Alternative1	Resealing + Thin Overlay	Provide 25 mm SBSD	Total damage area > 10% of total area
Alternative 2	Thick Overlay	Provide 25mm SDBC overlay	Roughness >4 m/km IRI
Alternative 3	Reconstruction	Provide 30 mm BC overlay	Roughness >4 m/km IRI

Note: IRI-International Roughness Index, SBSD – Single Bituminous Surface Dressing, SDBC – Semi Dense Bituminous Concrete, BC – Bituminous Concrete

4.5.5 Specify M&R Alternatives

Proposed M&R alternatives have been specified in the project. Corresponding to these alternatives, M&R work items with their economic costs have been assigned with the required intervention levels.

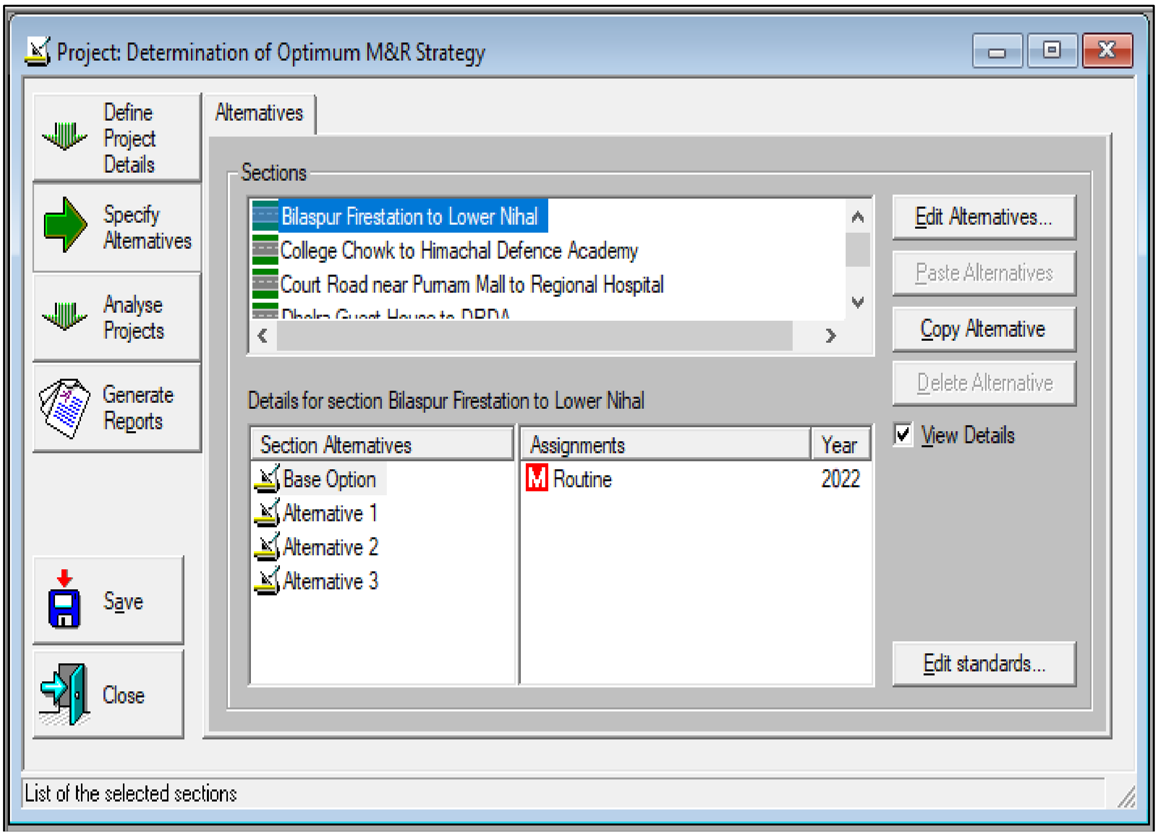


Fig. 4.37: Proposed M&R Alternatives for Project Analysis of Various Road Sections

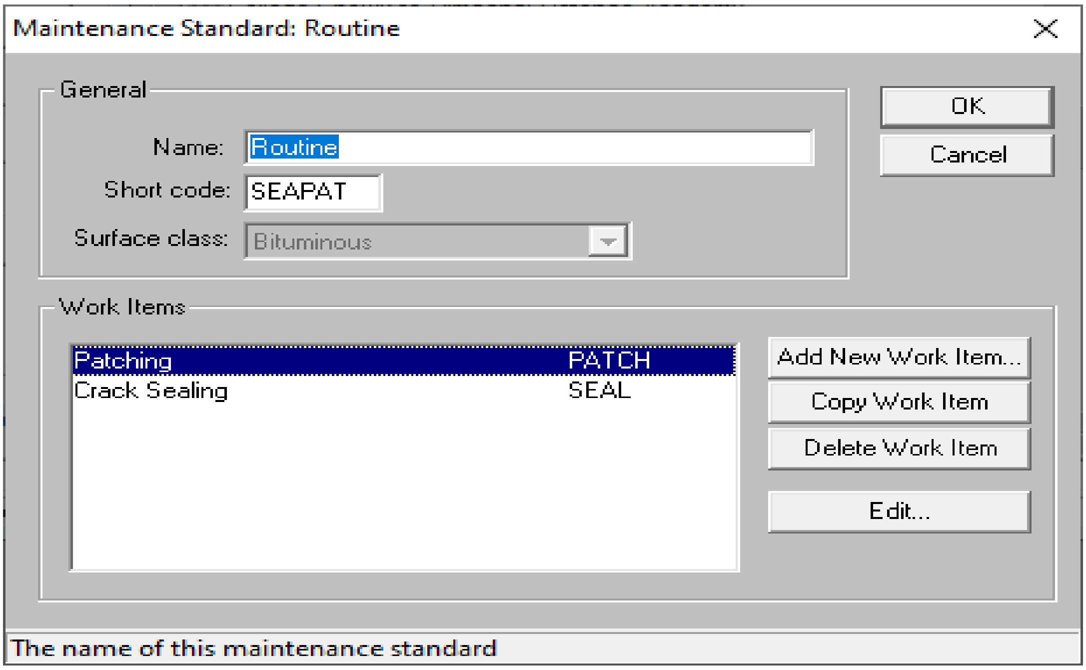


Fig. 4.38: Work Items Assigned for ‘Routine’ Work Standards

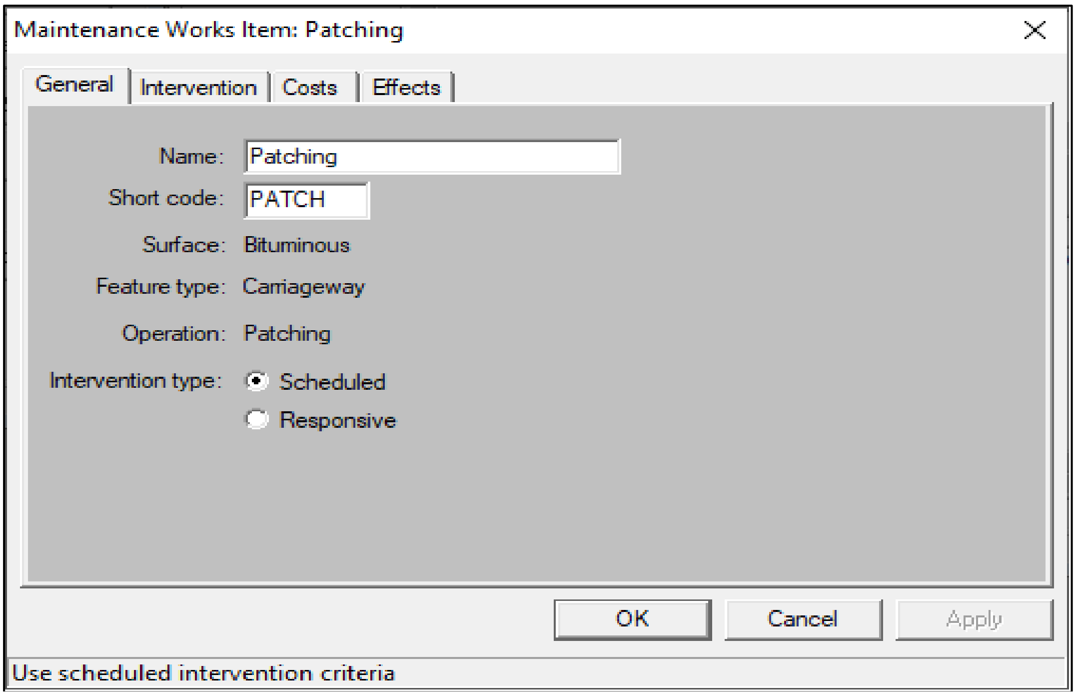


Fig. 4.39: General Input Data for ‘Patching Damaged Area’ Work Item.

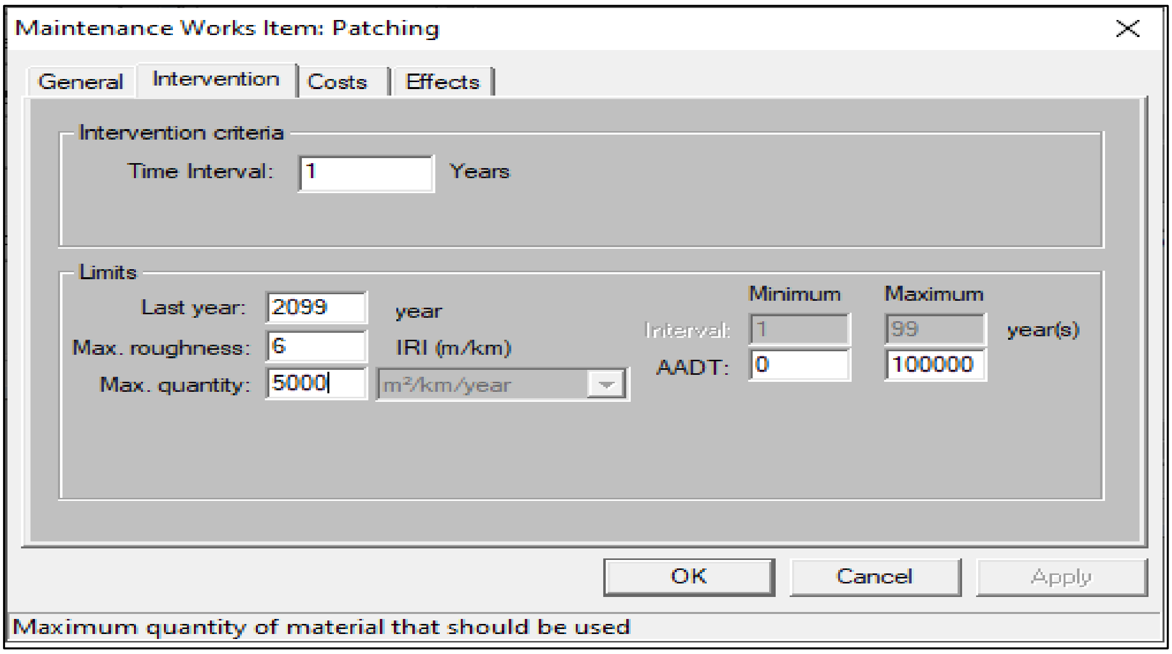


Fig. 4.40: Intervention criteria for 'Patching Damaged Area' Work Item

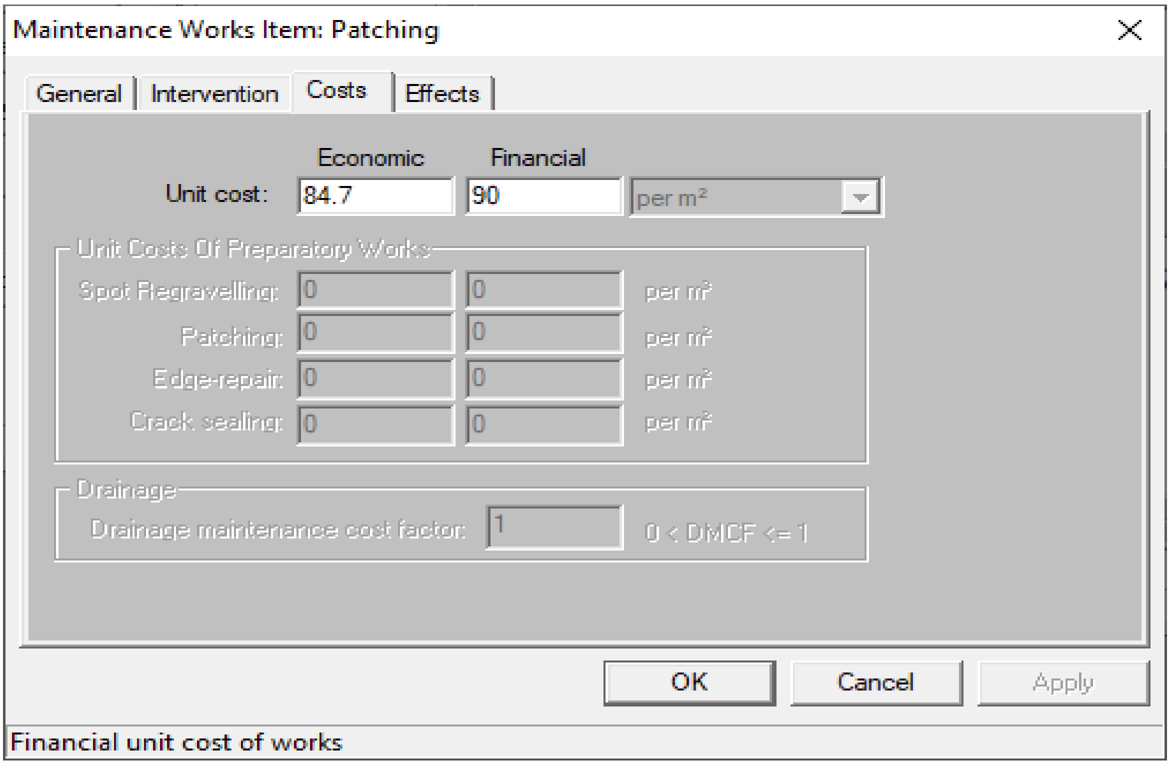


Figure 4.41: Costs Data for 'Patching' Work Item

4.5.6 Project Analysis

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

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

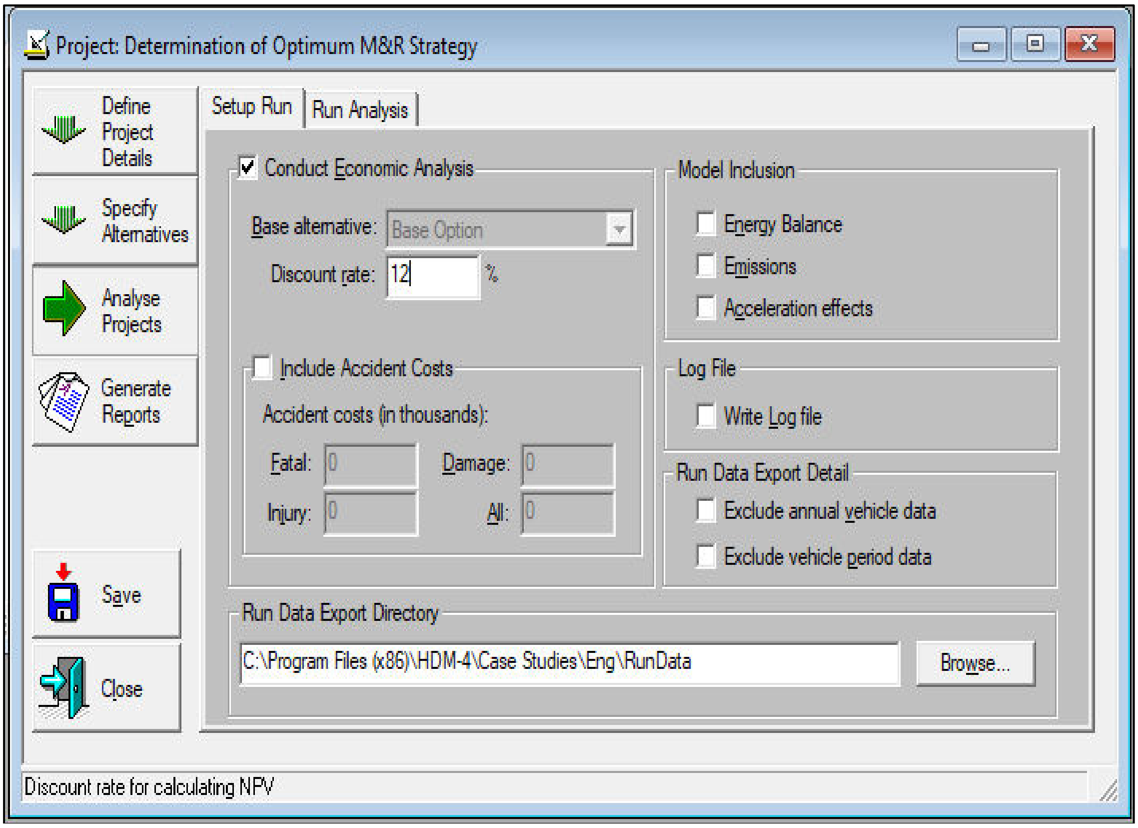


Fig. 4.42: Set-up Run for Project Analysis

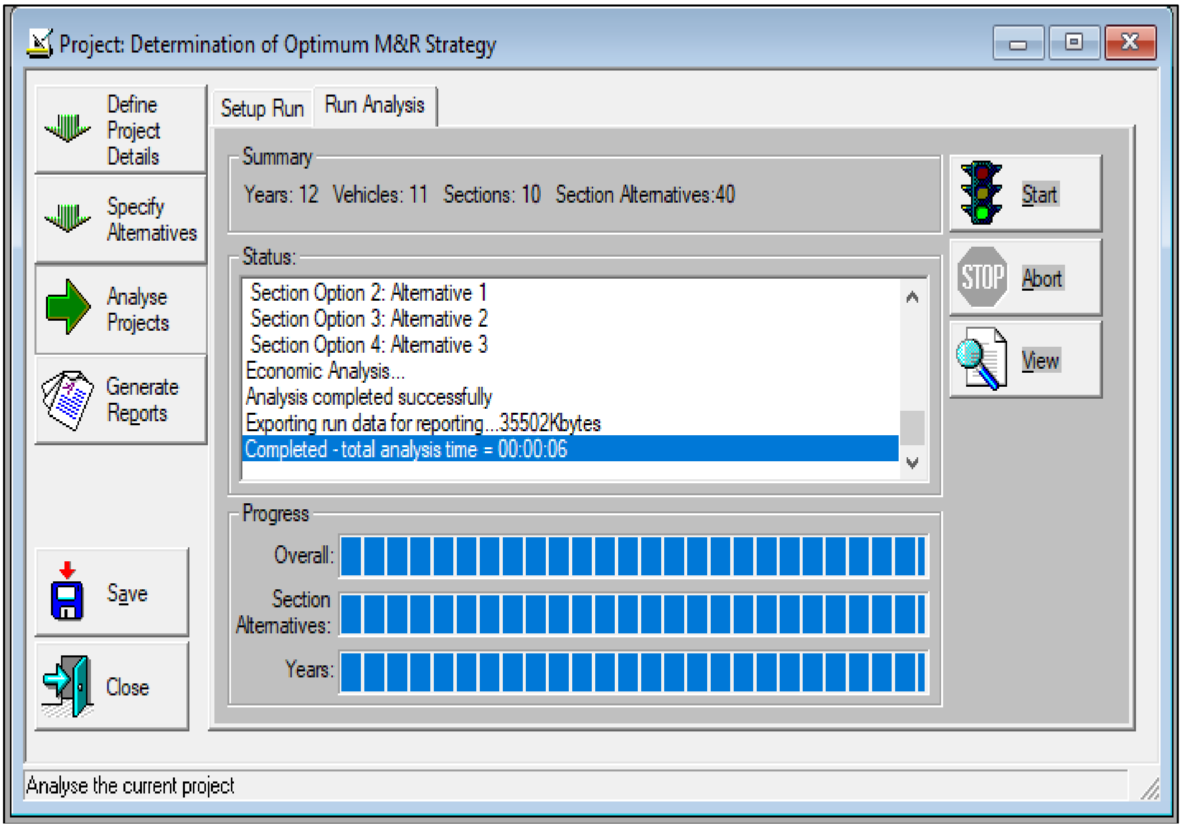


Fig. 4.43: Run analysis for Project to determine Optimum M&R Strategies

4.5.7 Road Pavement Deterioration

The pavement deterioration summary reports for all the road sections have been given in detail in Annexure C. The pavement deterioration summary reports of BIL-PWD-001, as obtained under proposed M&R strategies over the analysis period of 12 years, are given in Table 4.5 to Table 4.8 (Taken from section C4 of Annexure C). From the deterioration reports, it was seen that as the analysis period started , traffic volume on pavement i.e. Motorized AADT increased with each incremental year. Adjusted structural Number (SNP) of the pavement started decreasing until some M&R alternative was assigned. Detailed pavement deterioration i.e. progression of defects such as roughness, cracks, potholes, rut depth etc. with each incremental year corresponding to each alternative have been shown.

Table 4.5: Pavement Deterioration Summary of Section BIL-PWD-001 for Base Alternative.

Year	MT AADT	ESAL Million/ Lane	SNP	Roughness, IRI (m/km)	All Structural Cracks (% area)	No. of Potholes	Mean Rut Depth (mm)
2022	305	0.01	1.50	2.10	6.15	4.05	4.04
2023	321	0.01	1.50	2.28	12.35	4.09	5.11
2024	338	0.01	1.50	2.49	14.85	2.07	6.19
2025	356	0.01	1.50	2.70	14.56	0.00	7.27
2026	376	0.01	1.50	2.93	25.56	0.00	8.37
2027	398	0.01	1.50	3.20	41.64	0.00	9.50
2028	421	0.01	1.50	3.50	34.18	3.12	10.66
2029	447	0.01	1.50	3.50	11.74	0.00	11.77
2030	474	0.01	1.50	3.75	21.55	0.00	12.90
2031	504	0.01	1.50	4.03	35.43	0.00	14.05
2032	537	0.01	1.50	4.36	55.45	7.26	13.97
2033	572	0.01	1.50	4.72	73.41	20.55	16.31

Table 4.6: Pavement Deterioration Summary of Section BIL-PWD-001 for Alternative 1.

Year	MT AADT	ESAL Million/ Lane	SNP	Roughness, IRI (m/km)	All Structural Cracks (% area)	No. of Potholes	Mean Rut Depth (mm)
2022	305	0.01	1.50	2.10	6.15	4.05	4.04
2023	321	0.01	1.50	2.28	12.35	4.09	5.11
2024	338	0.01	1.50	2.49	14.85	4.14	6.20
2025	356	0.01	1.50	2.60	14.56	4.19	7.28
2026	376	0.01	1.50	2.83	18.21	4.25	8.39
2027	398	0.01	1.50	2.97	19.90	4.30	9.50
2028	421	0.01	1.50	3.22	26.11	4.36	10.63
2029	447	0.01	1.50	3.40	31.80	4.42	11.76
2030	474	0.01	1.50	3.69	42.90	4.49	12.93
2031	504	0.01	1.50	3.93	27.81	3.07	8.11
2032	537	0.01	1.50	2.61	0.00	0.00	2.67
2033	572	0.01	1.50	2.74	0.50	0.00	3.23

Table 4.7: Pavement Deterioration Summary of Section BIL-PWD-001 for Alternative 2.

Year	MT AADT	ESAL Million/ Lane	SNP	Roughness, IRI (m/km)	All Structural Cracks (% area)	No. of Potholes	Mean Rut Depth (mm)
2022	305	0.01	1.50	2.10	6.15	4.05	4.04
2023	321	0.01	1.50	2.28	12.35	4.09	5.11
2024	338	0.01	1.50	2.49	22.20	4.14	6.20
2025	356	0.01	1.50	2.73	36.82	4.19	7.31
2026	376	0.01	1.50	3.02	57.22	10.07	8.47
2027	398	0.01	1.50	3.33	74.64	20.92	9.68
2028	421	0.01	1.50	3.64	86.32	35.77	10.95
2029	447	0.01	1.50	3.93	46.79	26.87	7.05
2030	474	0.01	1.50	2.27	0.60	0.00	2.39
2031	504	0.01	1.50	2.40	2.01	0.00	2.94
2032	537	0.01	1.50	2.53	5.02	0.00	3.50
2033	572	0.01	1.50	2.69	10.44	0.00	4.07

Table 4.8: Pavement Deterioration Summary of Section BIL-PWD-001 for Alternative 3.

Year	MT AADT	ESAL Million/ Lane	SNP	Roughness, IRI (m/km)	All Structural Cracks (% area)	No. of Potholes	Mean Rut Depth (mm)
2022	305	0.01	1.50	2.10	6.15	4.05	4.04
2023	321	0.01	1.50	2.28	12.35	4.09	5.11
2024	338	0.01	1.50	2.49	22.20	4.14	6.20
2025	356	0.01	1.50	2.73	36.82	4.19	7.31
2026	376	0.01	1.50	3.02	57.22	10.07	8.47
2027	398	0.01	1.50	3.33	74.64	20.92	9.68
2028	421	0.01	1.50	3.64	86.32	35.77	10.95
2029	447	0.01	1.50	3.93	46.79	26.87	6.13
2030	474	0.01	1.50	2.10	0.00	0.00	1.93
2031	504	0.01	1.50	2.22	0.00	0.00	2.09
2032	537	0.01	1.50	2.29	0.00	0.00	2.25
2033	572	0.01	1.50	2.36	0.00	0.00	2.41

4.5.8 Roughness Progression

HDM-4 **Average Roughness by Section Alternative**

Section Details:

ID: **BIL-PWD-001** Road Class: Tertiary or Local Rise + Fall: 5.00m/km

Description: **Lower Nihal Road Gurudwara to Industrial Area** Length: 2.09km Curvature: 12.00deg/km

Width: 5.50m

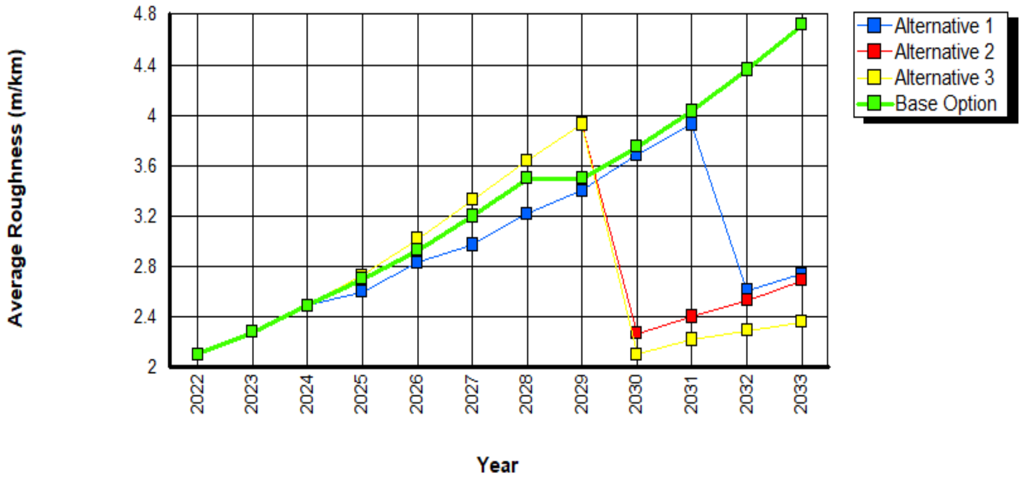


Figure 4.44: Roughness Progressions under All Alternatives for BIL-PWD-001.

HDM-4 **Average Roughness by Section Alternative**

Section Details:

ID: BIL-PWD-002 Road Class: Tertiary or Local Rise + Fall: 5.00m/km

Description: Lower Nihal Industrial Area to Govt. ITI Road Length: 0.40km Curvature: 12.00deg/km

Width: 3.50m

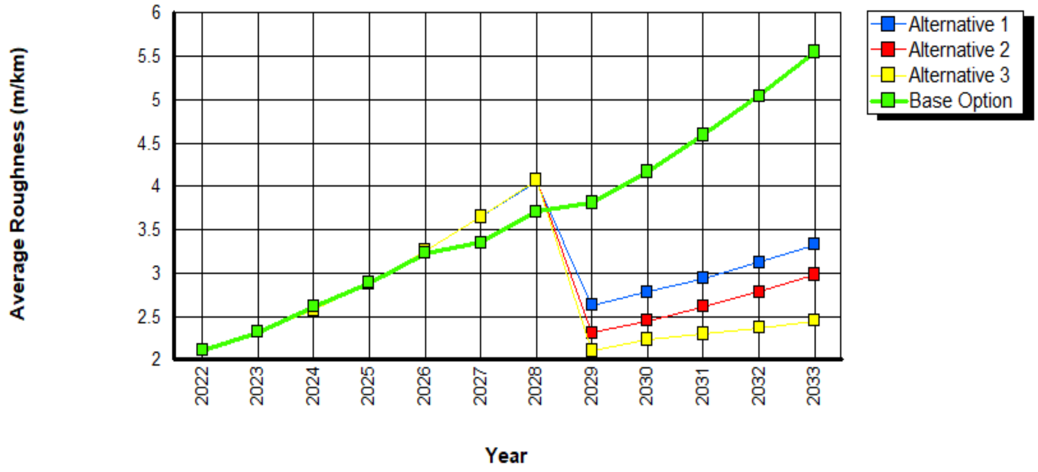


Figure 4.45: Roughness Progressions under All Alternatives forBIL-PWD-002.

HDM-4

HIGHWAY DEVELOPMENT & MANAGEMENT

Average Roughness by Section Alternative

Study Name: **Determination of Optimum M&R Strategy**

Run Date: **29-04-2022**

Section Details:

ID: BIL-PWD-003 Road Class: Tertiary or Local Rise + Fall: 10.00m/km

Description: Bilaspur Firestation to Lower Nihal Length: 0.50km Curvature: 12.00deg/km

Width: 3.00m

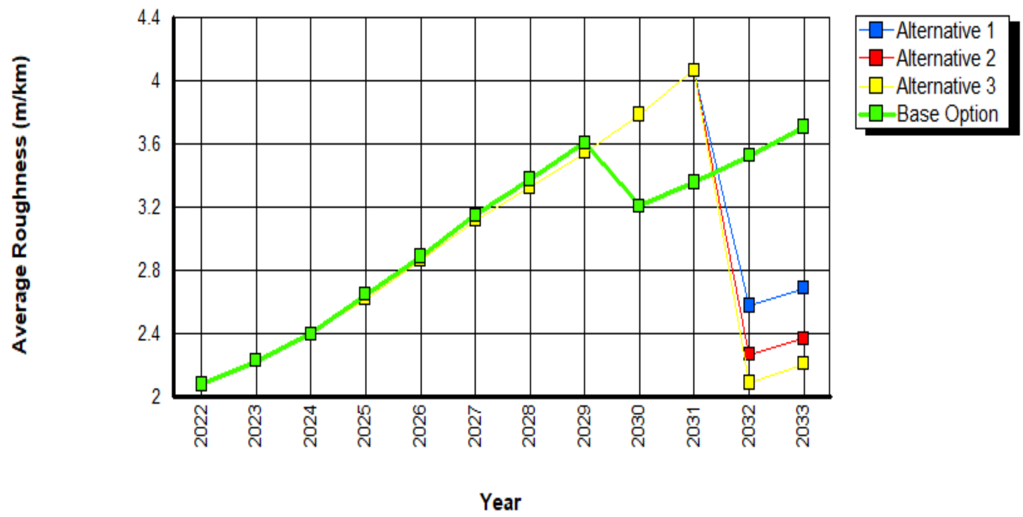


Figure 4.46: Roughness Progressions under All Alternatives forBIL-PWD-003.

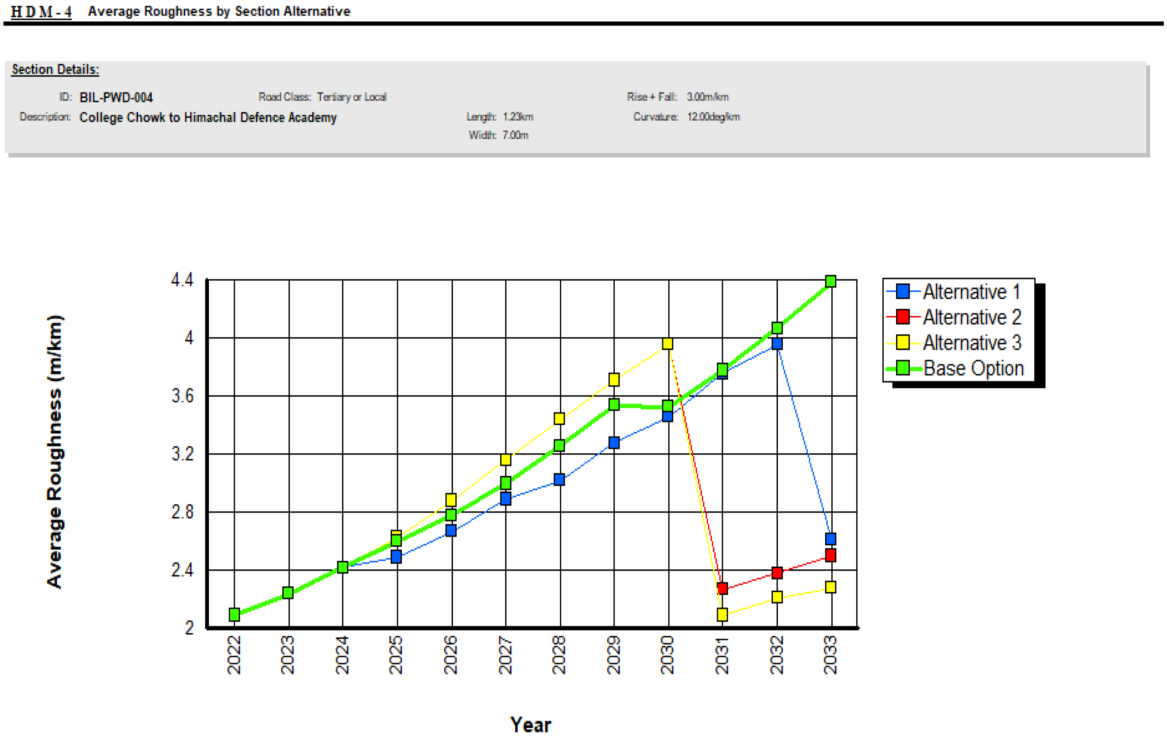


Figure 4.47: Roughness Progressions under All Alternatives forBIL-PWD-004.

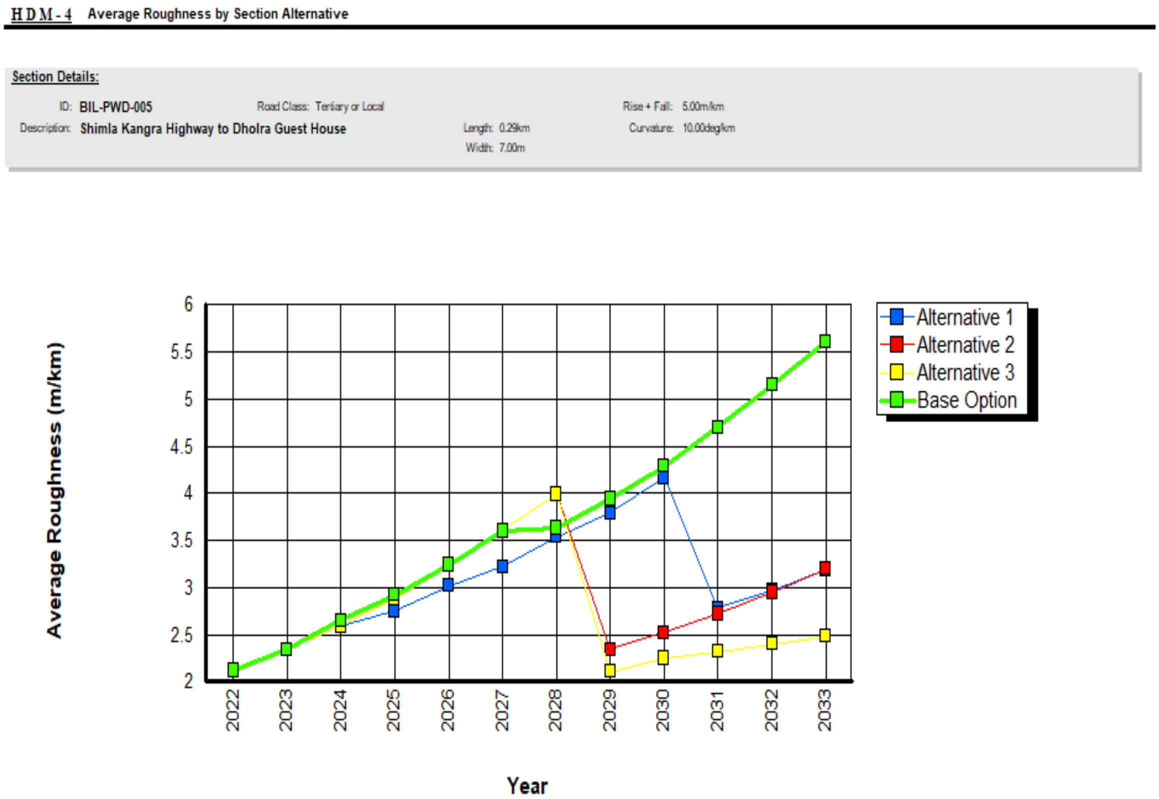


Figure 4.48: Roughness Progressions under All Alternatives forBIL-PWD-005.

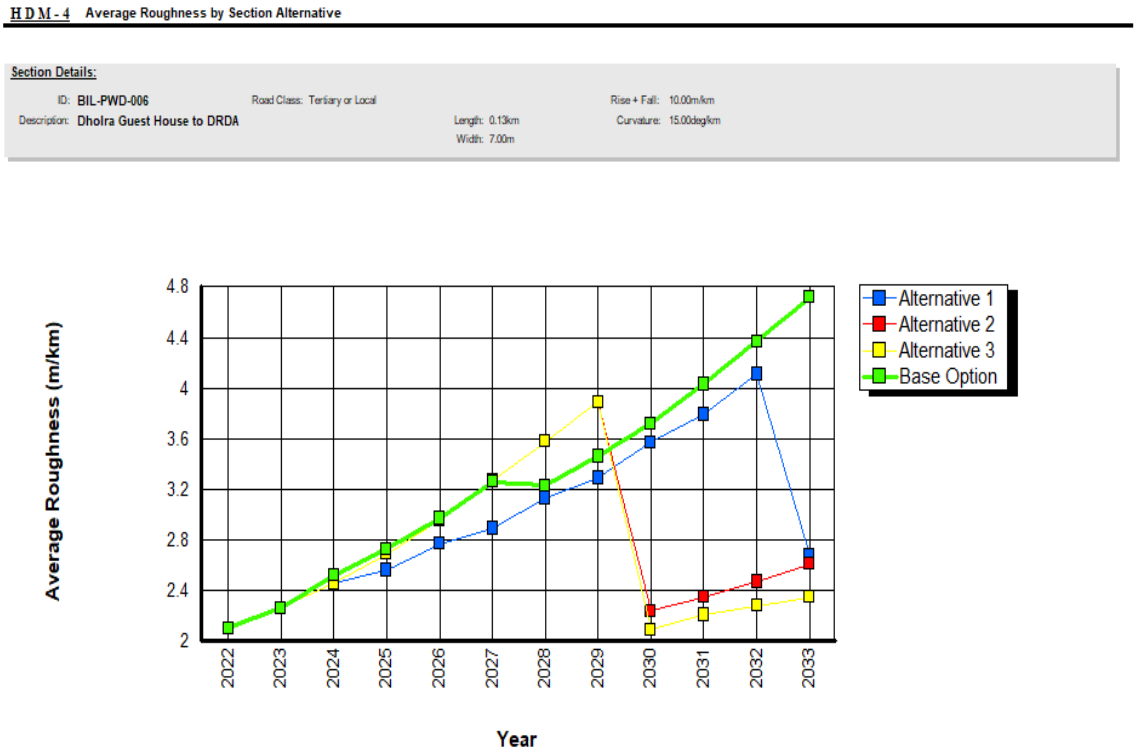


Figure 4.49: Roughness Progressions under All Alternatives forBIL-PWD-006.

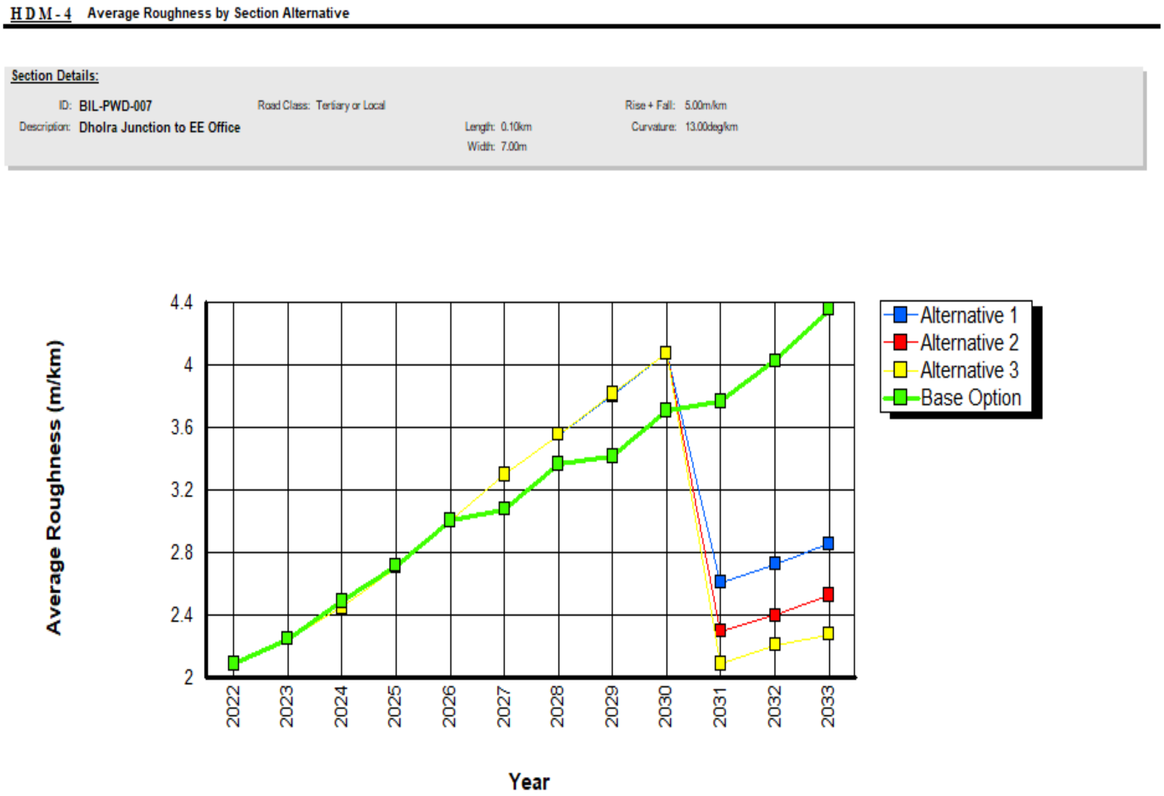


Figure 4.50: Roughness Progressions under All Alternatives for BIL-PWD-007.

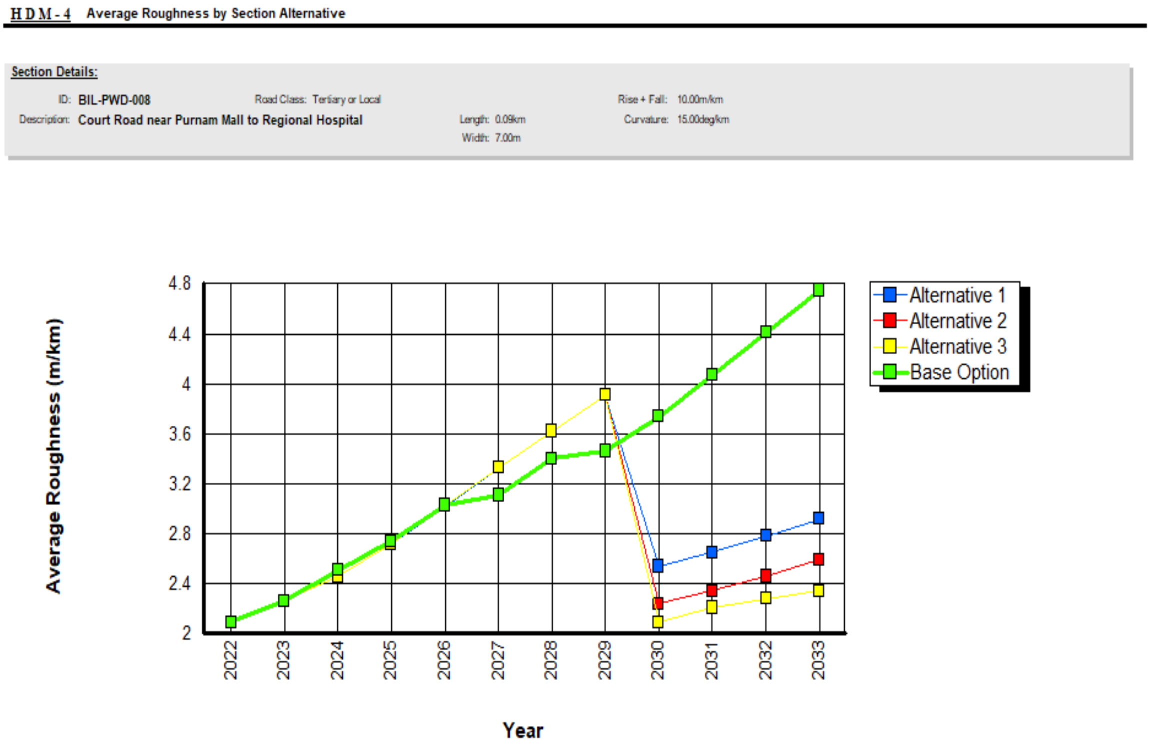


Figure 4.51: Roughness Progressions under All Alternatives forBIL-PWD-008.

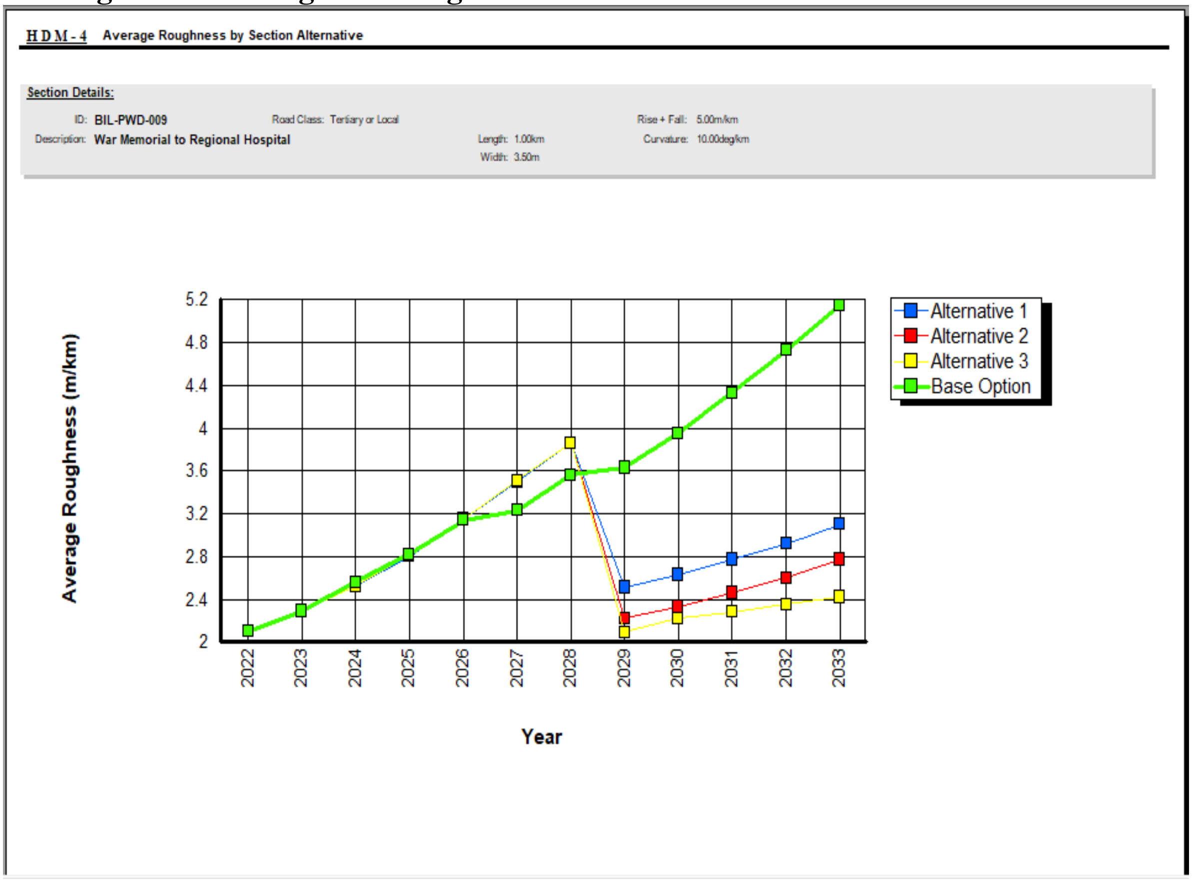


Figure 4.52: Roughness Progressions under All Alternatives forBIL-PWD-009.

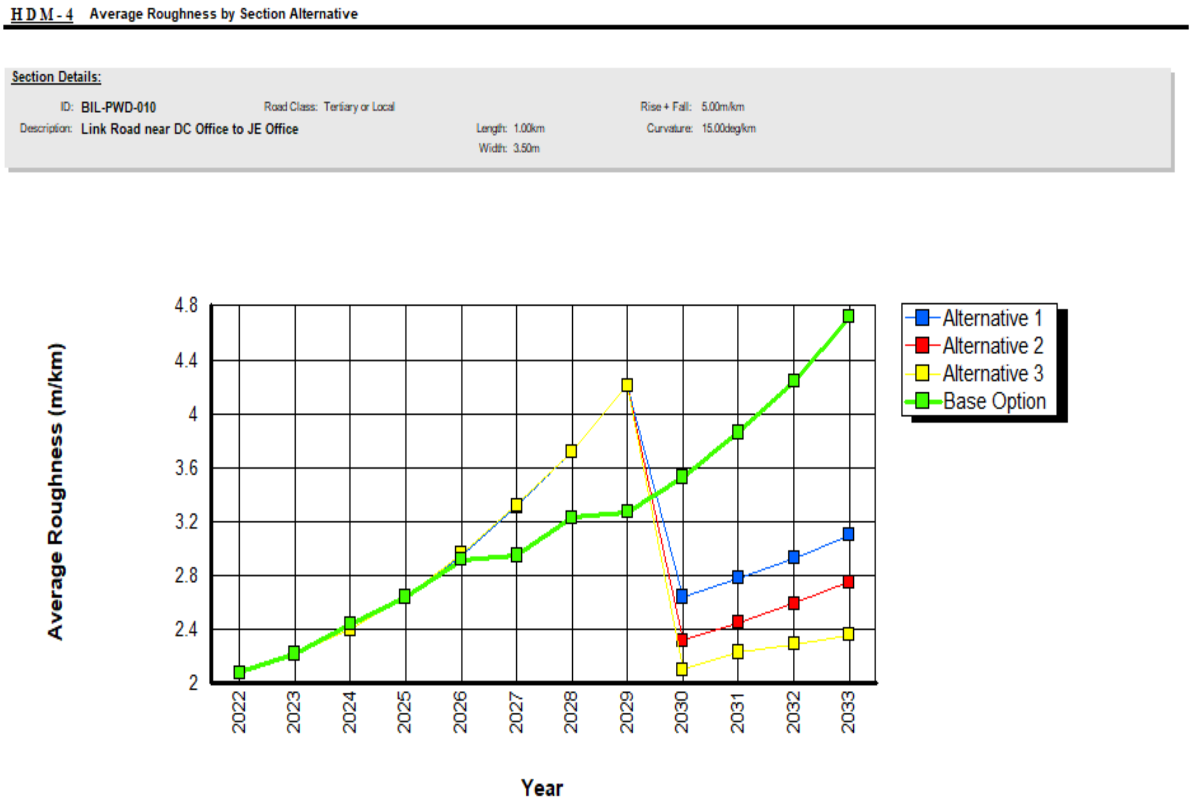


Figure 4.53: Roughness Progressions under All Alternatives forBIL-PWD-010.

4.5.9 M&R Works Report

The various works resulting from application of all the specified M&R strategies (as triggered by the respective intervention parameters), timings of their application and associated cost of each work item are given in the M&R works report of all the ten road sections from Table 4.9 to Table 4.16. The year-wise summary report of each alternative for all the road sections have been mentioned in Table 4.17 to Table 4.19. This works report gives description of the works that would be implemented in each year of the analysis period (2022-2033), under each M&R strategy.

Table 4.9: M&R Works for BIL-PWD-001 During Analysis Period.

Year	M&R Works			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2022	Patching & Crack Sealing	****	****	****
2023	Patching & Crack Sealing	****	****	****
2024	Patching & Crack Sealing	25 mm SBSD	****	****
2025	Patching & Crack Sealing	****	****	****
2026	Patching & Crack Sealing	25 mm SBSD	****	****
2027	Patching & Crack Sealing	****	****	****
2028	Patching & Crack Sealing	****	25 mm SDBC	****
2029	Patching & Crack Sealing	25 mm SBSD	****	30 mm BC Overlay
2030	Patching & Crack Sealing	****	****	****
2031	Patching & Crack Sealing	****	****	****
2032	Patching & Crack Sealing	****	****	****
2033	Patching & Crack Sealing	****	****	****

Table 4.10: Economic Costs of M&R Works for BIL-PWD-001.

Year	M&R Work Economic Costs (in Million Rupees)			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2022	0.003138	0.00	0.00	0.00
2023	0.02751	0.00	0.00	0.00
2024	0.02751	3.269	0.00	0.00
2025	0.02751	0.00	0.00	0.00
2026	0.02751	3.269	0.00	0.00
2027	0.02751	0.00	0.00	0.00
2028	0.02751	0.00	4.456	0.00
2029	0.02751	3.269	0.00	15.421
2030	0.02751	0.00	0.00	0.00

2031	0.02751	0.00	0.00	0.00
2032	0.02751	0.00	0.00	0.00
2033	0.02751	0.00	0.00	0.00
Total Cost in Million Rupees	**0.305748**	**9.807**	**4.456**	**15.421**

Table 4.11: M&R Works for BIL-PWD-002 During Analysis Period.

Year	M&R Works			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2022	Patching & Crack Sealing	****	****	****
2023	Patching & Crack Sealing	****	****	****
2024	Patching & Crack Sealing	25 mm SBSD	****	****
2025	Patching & Crack Sealing	****	****	****
2026	Patching & Crack Sealing	25 mm SBSD	****	****
2027	Patching & Crack Sealing	****	****	****
2028	Patching & Crack Sealing	****	25 mm SDBC	****
2029	Patching & Crack Sealing	****	****	****
2030	Patching & Crack Sealing	25 mm SBSD	****	****
2031	Patching & Crack Sealing	****	****	30 mm BC Overlay
2032	Patching & Crack Sealing	25 mm SBSD	****	****
2033	Patching & Crack Sealing	****	****	****

Table 4.12: Economic Costs of M&R Works for BIL-PWD-002.

Year	M&R Work Economic Costs (in Million Rupees)			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2022	0.00875	0.00	0.00	0.00
2023	0.03027	0.00	0.00	0.00
2024	0.03027	3.778	0.00	0.00
2025	0.03027	0.00	0.00	0.00
2026	0.03027	3.778	0.00	0.00
2027	0.03027	0.00	0.00	0.00
2028	0.03027	0.00	5.557	0.00
2029	0.03027	0.00	0.00	0.00
2030	0.03027	3.778	0.00	0.00
2031	0.03027	0.00	0.00	16.165
2032	0.03027	3.778	0.00	0.00
2033	0.03027	0.00	0.00	0.00
Total Cost in Million Rupees	**0.34172**	**15.112**	**5.557**	**16.165**

Table 4.13: M&R Works for BIL-PWD-003 During Analysis Period.

Year	M&R Works			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2022	Patching & Crack Sealing	****	****	****
2023	Patching & Crack Sealing	25 mm SBSD	****	****
2024	Patching & Crack Sealing	****	****	****
2025	Patching & Crack Sealing	****	****	****
2026	Patching & Crack Sealing	****	****	****
2027	Patching & Crack Sealing	****	****	****
2028	Patching & Crack Sealing	****	****	****

2029	Patching & Crack Sealing	25 mm SBSD	****	****
2030	Patching & Crack Sealing	****	****	****
2031	Patching & Crack Sealing	****	****	30 mm BC Overlay
2032	Patching & Crack Sealing	****	****	****
2033	Patching & Crack Sealing	****	****	****

Table 4.14: Economic Costs of M&R Works for BIL-PWD-003.

Year	M&R Work Economic Costs (in Million Rupees)			
	Base Alternative	**Alternative 1**	**Alternative 2**	**Alternative 3**
2022	0.00377	0.00	0.00	0.00
2023	0.02185	4.256	0.00	0.00
2024	0.02185	0.00	0.00	0.00
2025	0.02185	0.00	0.00	0.00
2026	0.02185	0.00	0.00	0.00
2027	0.02185	0.00	0.00	0.00
2028	0.02185	0.00	0.00	0.00
2029	0.02185	4.256	0.00	0.00
2030	0.02185	0.00	0.00	0.00
2031	0.02185	0.00	0.00	9.952
2032	0.02185	0.00	0.00	0.00
2033	0.02185	0.00	0.00	0.00
Total Cost in Million Rupees	**0.24412**	**8.512**	**0.00**	**9.952**

Table 4.15: M&R Works for BIL-PWD-004 During Analysis Period.

Year	M&R Works			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2022	Patching & Crack Sealing	25 mm SBSD	****	****
2023	Patching & Crack Sealing	****	****	****
2024	Patching & Crack Sealing	****	****	****
2025	Patching & Crack Sealing	****	****	****
2026	Patching & Crack Sealing	****	****	****
2027	Patching & Crack Sealing	****	25 mm SDBC	****
2028	Patching & Crack Sealing	****	****	****
2029	Patching & Crack Sealing	****	****	****
2030	Patching & Crack Sealing	25 mm SBSD	****	****
2031	Patching & Crack Sealing	****	****	30 mm BC Overlay
2032	Patching & Crack Sealing	****	****	****
2033	Patching & Crack Sealing	****	****	****

Table 4.16: Economic Costs of M&R Works for BIL-PWD-004.

Year	M&R Work Economic Costs (in Million Rupees)			
	Base Alternative	Alternative 1	Alternative 2	Alternative 3
2022	0.04384	2.050	0.00	0.00
2023	0.00	0.00	0.00	0.00
2024	0.00032	0.00	0.00	0.00
2025	0.00050	0.00	0.00	0.00
2026	0.00061	0.00	0.00	0.00
2027	0.01729	0.00	2.867	0.00
2028	0.01728	2.050	0.00	10.297
2029	0.01729	0.00	0.00	0.00
2030	0.01791	0.00	0.00	0.00
2031	0.01788	0.00	0.00	0.00

2032	0.01773	0.00	0.00	0.00
2033	0.01887	0.00	0.00	0.00
Total Cost in Million Rupees	**0.16952**	**4.1**	**2.867**	**10.297**

Year-wise summary reports for all the four road sections corresponding to each alternative are mentioned in Table 4.17 to Table 4.19.

Table 4.17: Year Wise Summary Report of Alternative 1 (Resealing + Thin Overlay) for All the Road Sections.

Year	**Alternative 1**									
	BIL-PWD -001	**BIL-PWD -002**	**BIL-PWD -003**	**BIL-PWD -004**	**BIL-PWD -005**	**BIL-PWD -006**	**BIL-PWD -007**	**BIL-PWD -00 8**	**BIL-PWD -009**	**BIL-PWD -010**
2022	****	****	****	25mm SBSD	****	****	25mm SBSD	****	****	****
2023	****	****	25mm SBSD	****	25mm SBSD	****	****	****	****	****
2024	25mm SBSD	25mm SBSD	****	****	****	25mm SBSD	****	25mm SBSD	****	****
2025	****	****	****	****	25mm SBSD	****	****	****	25mm SBSD	****
2026	25mm SBSD	25mm SBSD	****	****	****	****	****	****	****	25mm SBSD
2027	****	****	****	****	****	25mm SBSD	****	****	****	****
2028	****	****	****	****	****		****	****	****	****
2029	25mm SBSD	****	25mm SBSD	****	****	****	****	****	25mm SBSD	****
2030	****	25mm	****	25mm	****	25mm	25mm	****	****	25mm

		SBSD		SBSD		SBSD	SBSD			SBSD
2031	****	****	****	****	****	****	****	****	****	****
2032	****	25mm SBSD	****	****	****	****	****	25mm SBSD	****	****
2033	****	****	****	****	****	****	****	****	****	****

Table 4.18: Year Wise Summary Report of Alternative 2 (Thick Overlay) for All the Road Sections.

Year	Alternative 2									
	BIL-PWD-001	**BIL-PWD-002**	**BIL-PWD-003**	**BIL-PWD-004**	**BIL-PWD-005**	**BIL-PWD-006**	**BIL-PWD-007**	**BIL-PWD-008**	**BIL-PWD-009**	**BIL-PWD-010**
2022	****	****	****	****	****	****	****	****	****	****
2023	****	****	****	****	****	****	****	****	****	****
2024	****	****	****	****	****	****	****	25mm SDBC	****	****
2025	****	****	****	****	****	25mm SDBC	****	****	****	****
2026	****	****	****	****	****	****	****	****	25mm SDBC	****
2027	****	****	****	25mm SDBC	****	****	****	****	****	****
2028	25mm SDBC	25mm SDBC	****	****	****	****	25mm SDBC	****	****	****
2029	****	****	****	****	25mm SDBC	****	****	****	****	****
2030	****	****	****	****	****	****	****	****	****	****
2031	****	****	****	****	****	****	****	****	****	25mm SDBC
2032	****	****	****	****	****	****	****	****	****	****
2033	****	****	****	****	****	****	****	****	****	****

Table 4.19: Year Wise Summary Report of Alternative 3 (Reconstruction) for All the Road Sections.

Year	Alternative 3									
	BIL-PWD-001	BIL-PWD-002	BIL-PWD-003	BIL-PWD-004	BIL-PWD-005	BIL-PWD-006	BIL-PWD-007	BIL-PWD-008	BIL-PWD-009	BIL-PWD-010
2022	****	****	****	****	****	****	****	****	****	****
2023	****	****	****	****	****	****	****	****	****	****
2024	****	****	****	****	****	****	****	****	****	****
2025	****	****	****	****	****	****	****	****	****	****
2026	****	****	****	****	****	****	****	****	****	****
2027	****	****	****	****	****	****	****	****	****	****
2028	****	****	****	****	****	****	****	****	****	****
2029	30 mm BC Overlay	****	****	****	****	****	****	30 mm BC Overlay	****	****
2030	****	****	****	****	****	30 mm BC Overlay	****	****	30 mm BC Overlay	****
2031	****	30 mm BC Overlay	30 mm BC Overlay	30 mm BC Overlay	****	****	30 mm BC Overlay	****	****	****
2032	****	****	****	****	30 mm BC Overlay	****	****	****	****	30 mm BC Overlay
2033	****	****	****	****	****	****	****	****	****	****

4.5.10 Economic Analysis of M&R Strategy

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

Table 4.20: Summary of Economic Analysis for BIL-PWD-001

Alternative (Alt)	Present Value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Cost (B)	Net Present Value, NPV=B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	**(2)**	**(3)**	**(4)**	**(5)=(4)-(3)**	**(6)**	**(7)**
Base Alt	0.060	0.000	0.000	0.000	0.000	0.000
Alt 1	3.845	3.724	25.920	22.196	5.772	49.5
Alt 2	1.580	1.406	2.619	1.213	0.767	20.05
Alt 3	5.363	5.289	7.196	1.907	0.355	14.6

Table 4.21: Summary of Economic Analysis for BIL-PWD-002

Alternative (Alt)	Present Value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Cost (B)	Net Present Value, NPV=B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	**(2)**	**(3)**	**(4)**	**(5)=(4)-(3)**	**(6)**	**(7)**
Base Alt	0.016	0.000	0.000	0.000	0.000	0.000
Alt 1	5.123	3.824	22.253	18.429	3.597	47.6
Alt 2	4.840	4.469	7.986	3.517	0.726	18.8
Alt 3	10.205	9.869	16.983	7.114	0.697	17.3

Table 4.22: Summary of Economic Analysis for BIL-PWD-003

Alternative (Alt)	Present Value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Cost (B)	Net Present Value, NPV=B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	**(2)**	**(3)**	**(4)**	**(5)=(4)-(3)**	**(6)**	**(7)**
Base Alt	0.007	0.000	0.000	0.000	0.000	0.000
Alt 1	5.635	4.010	20.363	16.353	2.902	44.7
Alt 2	3.978	3.258	6.686	3.428	0.861	19.5
Alt 3	8.625	7.924	15.545	7.621	0.883	18.9

Table 4.23: Summary of Economic Analysis for BIL-PWD-004

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

Table 4.24: Summary of Economic Analysis for BIL-PWD-005

Alternative (Alt)	Present Value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Cost (B)	Net Present Value, NPV=B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	**(2)**	**(3)**	**(4)**	**(5)=(4)-(3)**	**(6)**	**(7)**
Base Alt	0.019	0.000	0.000	0.000	0.000	0.000
Alt 1	5.590	5.102	9.586	4.484	0.802	19.1
Alt 2	6.321	4.569	25.698	21.129	3.342	45.8
Alt 3	9.502	8.456	15.753	7.297	0.767	18.56

Table 4.25: Summary of Economic Analysis for BIL-PWD-006

Alternative (Alt)	Present Value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Cost (B)	Net Present Value, NPV=B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	(2)	(3)	(4)	(5)=(4)-(3)	(6)	(7)
Base Alt	0.008	0.000	0.000	0.000	0.000	0.000
Alt 1	8.962	6.429	8.698	2.269	0.253	11.2
Alt 2	6.856	4.751	25.024	20.273	2.956	40.9
Alt 3	5.381	3.589	18.698	15.109	2.807	40.2

Table 4.26: Summary of Economic Analysis for BIL-PWD-007

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

Table 4.27: Summary of Economic Analysis for BIL-PWD-008

Alternative (Alt)	Present Value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Cost (B)	Net Present Value, NPV=B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	(2)	(3)	(4)	(5)=(4)-(3)	(6)	(7)
Base Alt	0.154	0.000	0.000	0.000	0.000	0.000
Alt 1	3.996	3.842	26.092	22.250	5.568	51.5
Alt 2	1.570	1.416	2.918	1.502	0.957	21.3
Alt 3	5.434	5.279	8.186	2.907	0.535	16.8

Table 4.28: Summary of Economic Analysis for BIL-PWD-009

Alternative (Alt)	Present Value of Road Agency Costs (Cost)	Increase in Agency Cost (C)	Decrease in Road User Cost (B)	Net Present Value, NPV=B-C	NPV/Cost Ratio (NPV/Cost)	Internal Rate of Return (IRR)
(1)	**(2)**	**(3)**	**(4)**	**(5)=(4)-(3)**	**(6)**	**(7)**
Base Alt	0.101	0.000	0.000	0.000	0.000	0.000
Alt 1	1.025	1.729	3.102	1.373	1.339	23.5
Alt 2	2.789	2.654	23.852	21.198	7.600	55.8
Alt 3	5.343	5.109	8.256	3.147	0.588	18.6

Table 4.29: Summary of Economic Analysis for BIL-PWD-010

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

4.5.11 Selection of Optimum M&R Strategy for Each Road Section

On the basis of economic analysis of each alternative for all the road sections, optimum M&R strategy or alternative has been selected. The alternative which has higher NPV/Vost Ratio for any road section compared to the other predefined alternatives, is selected as optimum M&R strategy for that section. Table 4.30 shows the optimum M&R alternative selected for each road section.

Table 4.30: Optimum M&R Strategy for Each Road Section.

Section ID	Section Name	Optimum M&R Strategy
BIL-PWD-001	Lower Nihal Road Gurudwara to Industrial Area	Alternative 1
BIL-PWD-002	Lower Nihal Industrial Area to Govt. ITI Road	Alternative 1
BIL-PWD-003	Bilaspur Fire station to Lower Nihal	Alternative 1
BIL-PWD-004	College Chowk to Himachal Defence Academy	Alternative 1
BIL-PWD-005	Shimla Kangra Highway to Dholra Guest House	Alternative 2
BIL-PWD-006	Dholra Guest House to DRDA	Alternative 2
BIL-PWD-007	Dholra Junction to EE Office.	Alternative 2
BIL-PWD-008	Court Road near Purnam Mall to Regional Hospital	Alternative 1
BIL-PWD-009	War Memorial to Regional Hospital	Alternative 2
BIL-PWD-010	Link Road near DC Office to JE Office	Alternative 1

4.5.12. Prioritization of Road Sections based on Optimum M&R Strategy.

Based on optimum M&R strategy of the road sections, prioritization of all the road sections has been done. Higher the NPV/Cost ratio of optimum M&R strategy of the road section, higher will be the prioritization ranking of that road. Table 4.31 shows the prioritization ranking of road sections based on optimum M&R strategy.

Table 4.31: Prioritization Ranking of the Road Section.

Section ID	Section Name	Optimum M&R Strategy	NPV/Cost Ratio	Prioritization Ranking
BIL-PWD-001	Lower Nihal Road Gurudwara to Industrial Area	Alternative 1	5.772	3
BIL-PWD-002	Lower Nihal Industrial Area to Govt. ITI Road	Alternative 1	3.597	5
BIL-PWD-003	Bilaspur Fire station to Lower Nihal	Alternative 1	2.902	9
BIL-PWD-004	College Chowk to Himachal Defence Academy	Alternative 1	8.560	1
BIL-PWD-005	Shimla Kangra Highway to Dholra Guest House	Alternative 2	3.342	7
BIL-PWD-006	Dholra Guest House to DRDA	Alternative 2	2.956	8
BIL-PWD-007	Dholra Junction to EE Office.	Alternative 2	3.448	6
BIL-PWD-008	Court Road near Purnam Mall to Regional Hospital	Alternative 1	5.568	4
BIL-PWD-009	War Memorial to Regional Hospital	Alternative 2	7.600	2
BIL-PWD-010	Link Road near DC Office to JE Office	Alternative 1	2.092	10

Comments: On the basis of economic analysis, Alternative1 i.e. Resealing + Thin Overlay, having the maximum NPV/Cost ratio has been selected as the optimum M&R strategy for all the road sections. IRR value is also higher for Alternative 1 for each road section. Prioritization of the road sections for maintenance work has been done based on optimum M&R strategy. Prioritization ranking has been allotted to each road sections. In case of budget constraints, prioritization ranking will help road agency to choose which road section has to be maintained first.

4.6 Comparative Study of Scheduled type and Condition Responsive type M&R Strategy

The aim of present study is to compare the Scheduled type and Condition Responsive type Maintenance and Rehabilitation strategies. Effect of selecting a scheduled type M&R strategy with respect to a condition responsive type M&R strategy for BIL-PWD-001, BIL-PWD-003 and BIL-PWD-006 road sections has been calculated throughout the analysis period in this objective.

The effect on the roughness progression for different sections due to scheduled or condition responsive maintenance has been studied. The economic indicators have been also summarized for various M&R alternatives. Three types of M&R alternatives have been considered for this objective in which one is a base alternative for comparison i.e., 'Routine Maintenance'. All these alternatives have been defined with two M&R strategies (intervention criteria's) i.e., 'Scheduled' and 'Condition Responsive'. The details of these three alternatives with their intervention criteria's are given in Table 4.32.

4.6.1 Input Data

New Project named as 'Comparison between Scheduled and Condition Responsive M&R Strategy' was created which consisted of 'Bilaspur Town Road Network' and 'Bilaspur Town Vehicle Fleet'. Analysis period was taken as 12 years with start year of 2022. Project analysis has been chosen in the HDM-4 module with input and output currencies in Indian Rupees.

4.6.2 Selection of Sections and Vehicles

For the present study objective, Section ID BIL-PWD-001, BIL-PWD-003 & BIL-PWD-006 have been selected from Bilaspur Town Road Network. All the types of vehicles have been selected from Bilaspur Town Vehicle Fleet for the analysis purpose. Fig. 4.54 shows the selection of sections for the project analysis.

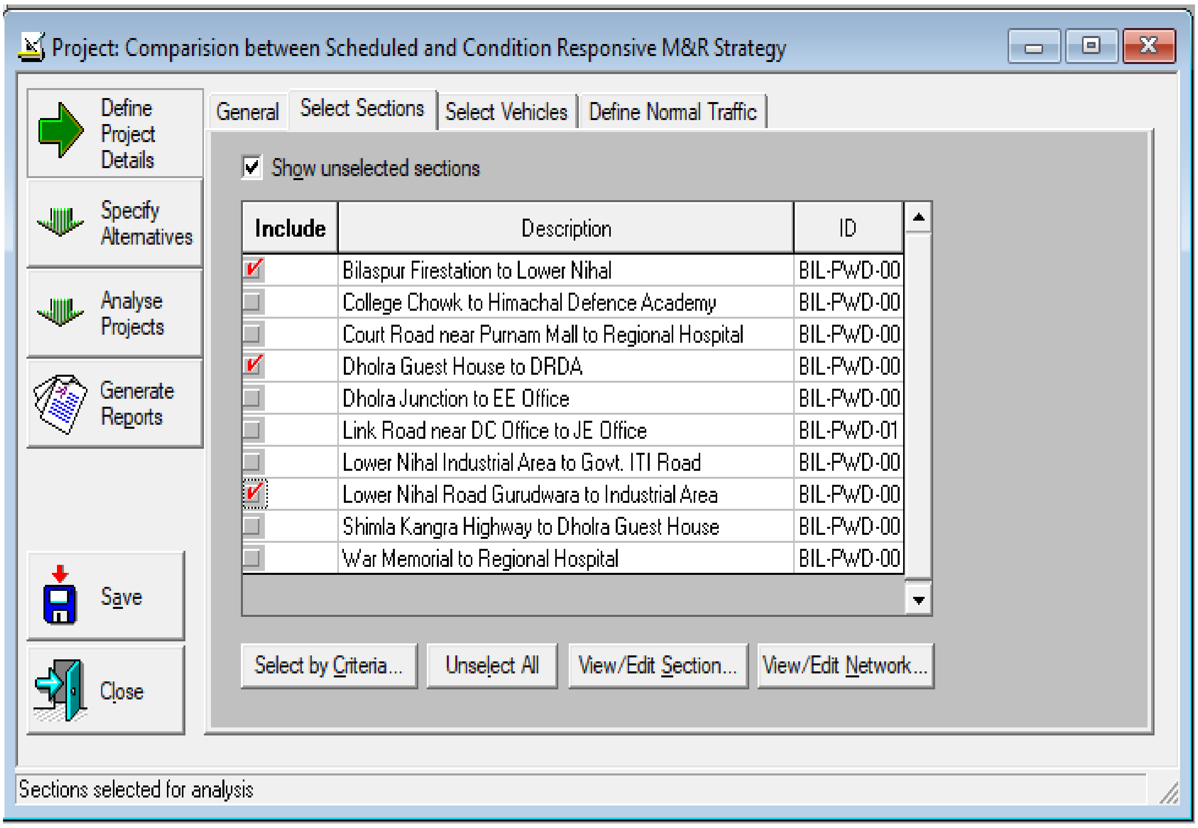


Fig. 4.54: Selection of BIL-PWD-001, BIL-PWD-003 & BIL-PWD-006 for Project Analysis

4.6.3 Define Traffic

Normal traffic details such as Vehicular compositions with their annual average growth rate for both MT and NMT vehicles have been inputted for BIL-PWD-001, BIL-PWD-003 and BIL-PWD-006.

4.6.4 Proposed M&R Alternatives

The Scheduled M&R strategy has been chosen as per the current maintenance norms provided in MORT&H (2001b), whereas the Condition Responsive M&R strategy has been selected as per the serviceability levels up to which the respective pavement section is to be maintained (Guidelines for Maintenance of Primary, Secondary and Urban Roads, MORT&H, 2004). Proposed M&R Alternatives have been presented in Table 4.32.

BIL-PWD-001, BIL-PWD-003 and BIL-PWD-006 comes under sub-arterial category of Indian urban roads. Serviceability levels for 'Other Roads' have been (kept in mind before) proposing the 'Condition Responsive' type M&R strategy for this project.

Table 4.32: Proposed M&R Alternatives for Project Analysis of UR01, UR02 and UR05

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

4.6.5 Specify M&R Alternatives

Proposed M&R alternatives (presented in Table 4.32) have been specified in the project. Corresponding to these alternatives, M&R work items with their economic and financial unit costs have been assigned with the required intervention level. Fig. 4.55 shows the data input entry of M&R alternatives in project.

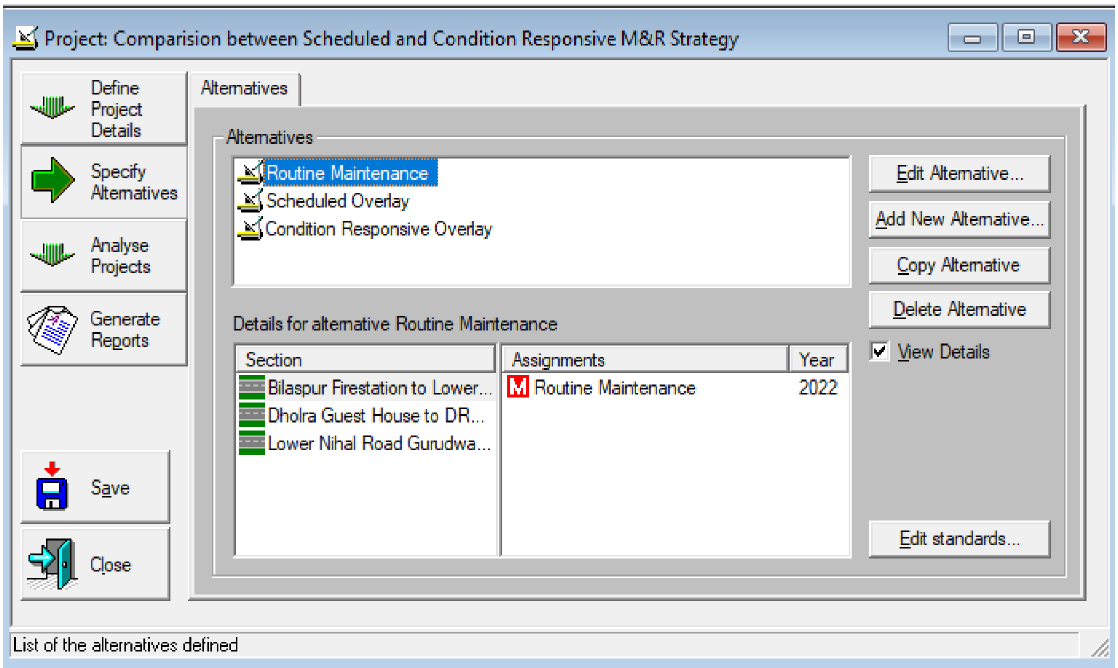


Fig. 4.55: Data Input Entry of M&R Alternatives in Project

4.6.6 Project Analysis

As the economic analysis for the selected section has to be done, so in Set-up Run of Project Analysis and 'Conduct Economic Analysis' has been selected. Base Alternative has been chosen for comparison purpose by default. Discount rate of 12 % was taken. The application was run for simulating the road condition of BIL-PWD-001, BIL-PWD-003 and BIL-PWD-006 under defined M&R alternatives throughout the analysis period of 15 years for this objective.

4.6.7 Roughness Progression

The roughness progression has been traced to know whether the works have been correctly triggered corresponding to the specified intervention criteria. In case of 'Condition Responsive Overlay' alternative, Overlay work has been triggered as soon as the roughness value reaches 4 IRI. But in case of 'Scheduled Overlay' alternative, Overlay work has been triggered in every six years, but at roughness value of IRI of 3.2 m/km which is well below the limiting serviceability value of IRI of 4 m/km as shown in Fig. 4.56.

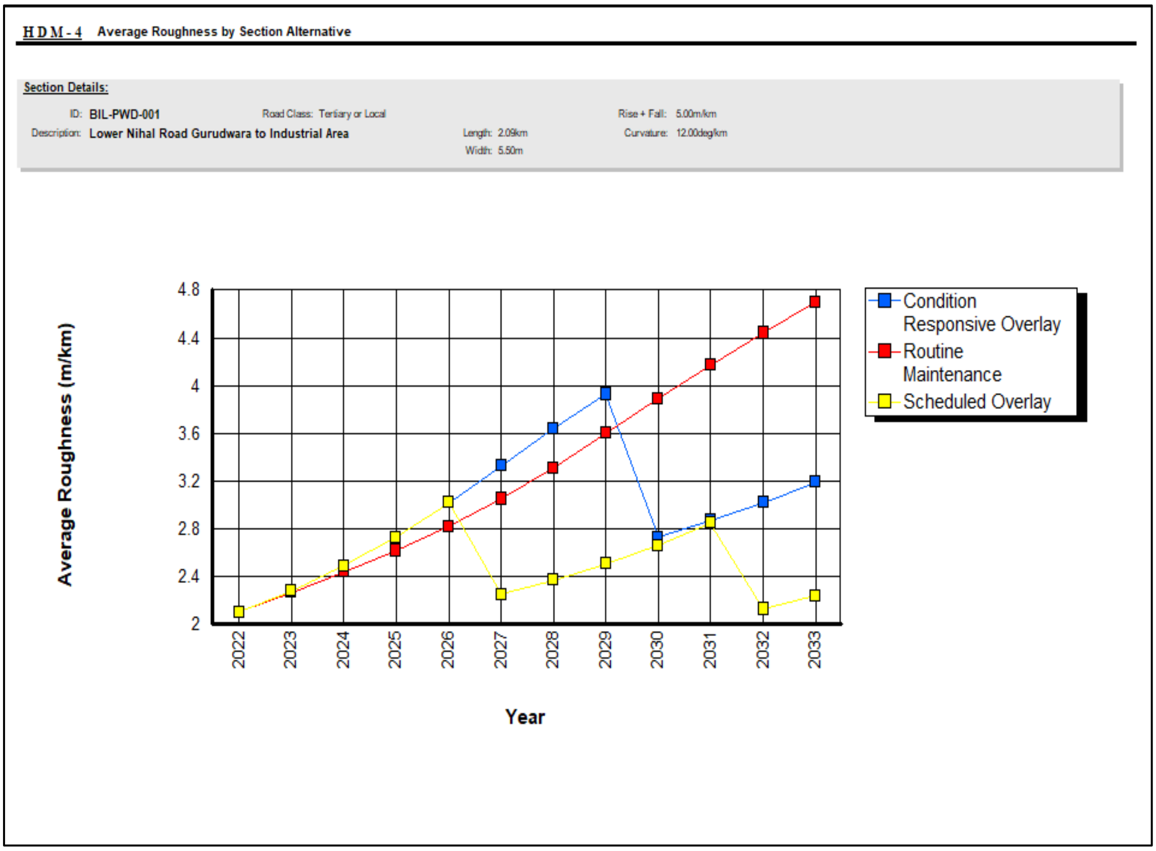


Fig. 4.56: Roughness Progression under the Three Alternative of overlay for BIL-PWD-001.

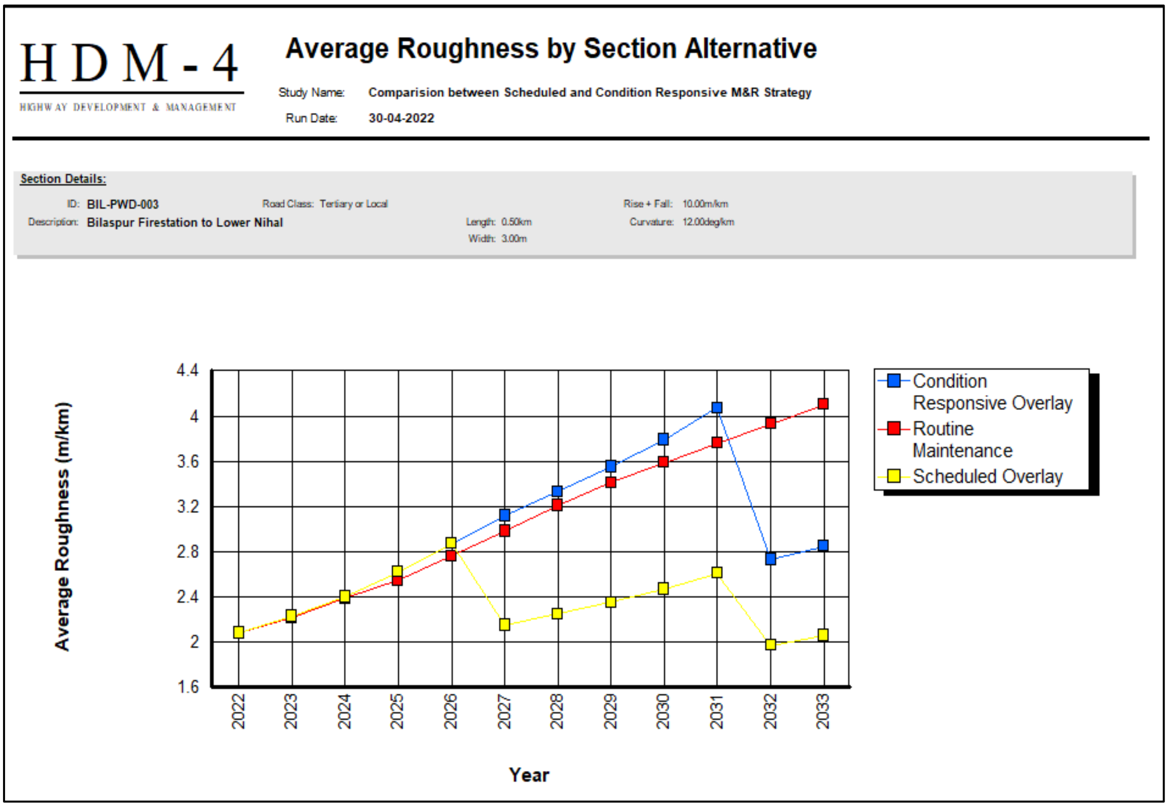


Fig. 4.57: Roughness Progression under the Three Alternative of overlay for BIL-PWD-003.

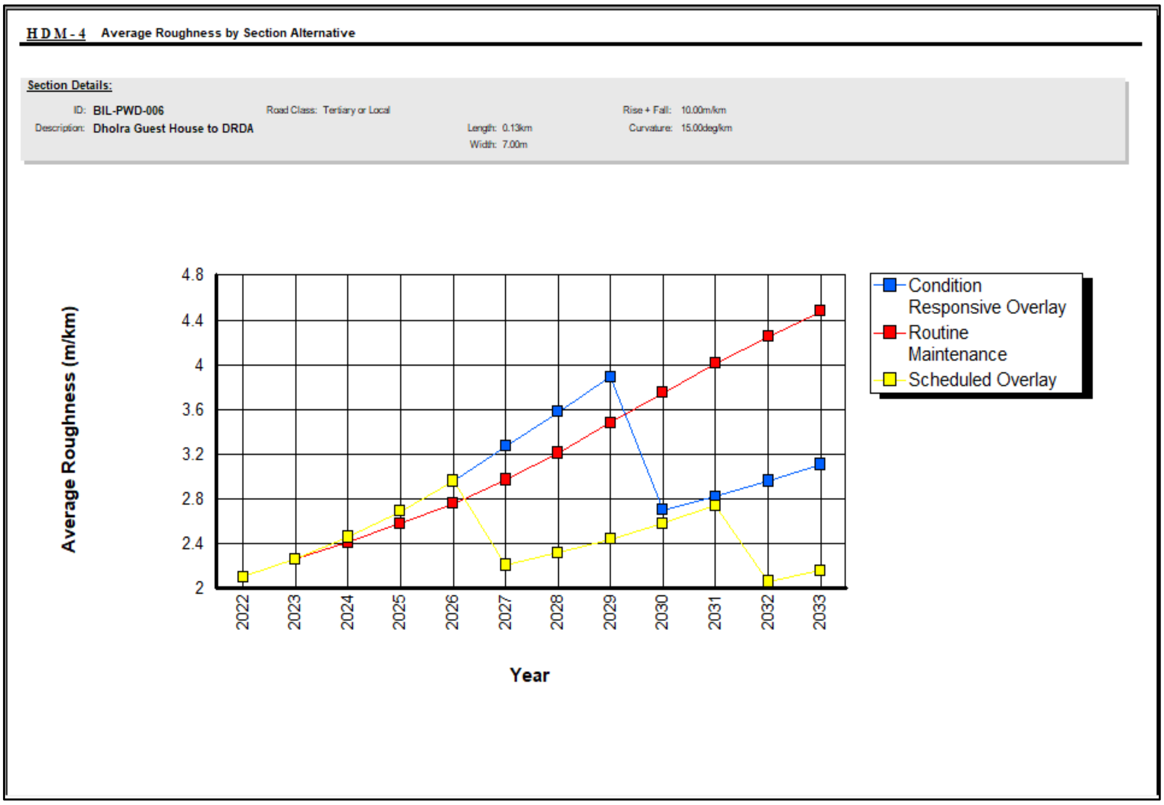


Fig. 4.58: Roughness Progression under the Three Alternative of overlay for BIL-PWD-006.

4.6.8 Economic Analysis of Scheduled and Responsive Maintenance Strategies

The economic analysis summary for section BIL-PWD-001, BIL-PWD-003 & BIL-PWD-006 has been given in Table 4.33 which gives a comparison of the NPV/CAP ratio (Net Present Value / Capital Cost) for the three alternatives with respect to the base alternative. In terms of the economic indicator NPV/CAP, the condition responsive maintenance strategy gives a higher value of NPV/CAP as compared to scheduled maintenance strategy. Hence, maintenance decisions with condition responsive have been selected as an optimum M&R alternative.

Table 4.33: Economic Analysis Results for Scheduled & Condition Responsive M&R Strategy

Section Detail	NPV/CAP Ratio		
	Alternative	**Scheduled Maintenance**	**Condition Responsive Maintenance**
BIL-PWD-001	Resealing	3.605	5.896
	Overlay	3.581	4.234
	Strengthening & Rehabilitation	2.267	4.283
BIL-PWD-003	Resealing	7.538	10.110
	Overlay	5.250	5.459
	Strengthening & Rehabilitation	3.856	6.987
BIL-PWD-006	Resealing	3.453	7.757
	Overlay	5.182	5.691
	Strengthening & Rehabilitation	3.420	5.412

4.7 SUMMARY

- All the road sections taken in this study of Bilaspur Town will be needing reconstruction work within 0 to 9 years if no maintenance and rehabilitation work is assigned to the road sections throughout the intervening period.

- On the basis of the economic analysis summary, the optimum M&R strategy selected for sections BIL-PWD-001, BIL-PWD-002, BIL-PWD-003, BIL-PWD-004, BIL-PWD-008, BIL-PWD-010, is Alternative 1 (Resealing 25 mm SBSD) and for all other sections Alternative 2 (Thin overlay 25 mm SDBC) has been the optimum maintenance strategy with maximum NPV/CAP value.

- An economic indicator proves that the condition responsive maintenance strategy gives a higher value of NPV/CAP ratio as compared to the scheduled maintenance strategy. Hence, maintenance decisions with condition responsive have been selected as an optimum M&R alternative.

- Reducing the annual budget funds for the maintenance of pavement network of urban roads will have significant negative impact on the pavement condition which will increase the road user cost and faster deterioration of pavement surface.

- Delaying the maintenance activities has a negative impact on the overall condition of the pavement surface. The value of IRI touched 9.2 m/km in the year 2025 if the maintenance work is delayed by 4 years but if the maintenance is triggered as per the respective intervention level, the value of IRI is around 3.65 m/km in the year 2025.

Table 4.34: Economic Costs of M&R Works

Alternative option	Year of Implementation	Economic Cost (Rs)
Base Alternative	2021 to 2030	1,090,289.10
Alternative 1	2021, 2026, 2030	3,675,068.40
Alternative 2	2021, 2022, 2026, 2029	7,700,068.40
Alternative 3	2021, 2023, 2024	9,187,568.40

CHAPTER 05
Road Pavement Condition Index (PCI) Evaluation

5.1. INTRODUCTION

Pavement distresses are classified into two different categories. The first is known as functional failure. In this case, the pavement does not carry out its intended function without either causing discomfort to passengers or high stresses to vehicles. The second, known as structure failure, includes a collapse of pavement structure or the breakdown of one or more components of the pavement with such magnitude that the pavement becomes incapable of sustaining the loads imposed upon its surface (Smith et al. 1979).

In some cases, one type of failure may be caused by the other type, but mostly there is only one type of failure. Functional failure depends primarily on the degree of surface roughness. Structure failure in a flexible pavement may be a result of fatigue, consolidation or shear, developing in the subgrade, sub-base, base course or surface (Yoder and Witzak 1975).

The Pavement Condition Index (PCI) is normally determined annually in order to evaluate changes that occur in the road network system. The PCI rating of a roadway is based on the observed surface distresses. The PCI rating is not a direct measure of structural capacity, skid resistance or road roughness; however, it is an objective tool for assessing the M-and-R needs of a roadway section with respect to an entire pavement system (Hajj et al. 2011). Some uses and benefits of PCI include the identification of the need for immediate M-and-R (Galehouse et al. 2003) of roads; development of a road network, preventive maintenance strategies and budgets; and evaluation of pavement materials and designs.

5.2 PCI DETERMINATION PROCEDURE

A visual inspection of the pavement surface can provide valuable information. Visual inspection data can be used to evaluate the current pavement condition, predict future pavement performance, determine and prioritize pavement M-and-R needs, estimate repair quantities and evaluate the performance of different M-and-R techniques and materials.

The PCI procedure is the standard used by the road industry and the military to visually assess the current pavement condition. The procedure is described in the references in PAVER (1982), American Society for Testing and Materials (ASTM) D6433-09 (2009) and Shahin (1997) and it has been used in this study.

During a PCI survey, visible signs of deterioration are recorded and analyzed. The final calculated PCI value is a number from zero to 100, with 100 representing a pavement in excellent condition. The pavement condition rating is determined from a correlation that presents pavement condition rating as a function of the PCI value. Table 5.1 shows the PCI ratings.

Table 5.1: PCI Rating

PCI	RATING
85-100	Excellent
70-85	Very Good
55-70	Good
40-55	Fair
25-40	Poor
10-25	Very Poor
00-10	Failed

When interpreting the collected visual condition data, three different aspects of the collected data are of interest: the composite index, the type of distress present and the rate of deterioration.

The PCI value itself provides a general idea of the pavement condition and the magnitude of work that will be required to rehabilitate the pavement. Pavements at the upper end of the scale are more likely to be candidates for maintenance and minor rehabilitation, while those in the lower ranges are more likely to require structural rehabilitation or reconstruction.

To evaluate a pavement, first of all, the pavement network should be divided into branches (such as streets, parking areas, etc.) and each branch should be divided into sections that have certain consistent characteristics throughout their area or length, such as structural composition, construction history, traffic and pavement condition.

A sample unit is any identifiable area of the pavement section. It is the smallest component of the pavement network. Each pavement section is divided into sample units for the purpose of pavement inspection. Then the steps for performing the condition survey and determining the PCI rating are conducted as per literature (PAVER 1982; ASTM D6433-09 2009; Shahin 1997):

1. Inspect sample unit, determine distress type and severity level and then measure the density

2. The deduct values are determined from the deduct value curves for each distress type and severity.

3. A total deduct value (TDV) is computed by summing all individual deduct values.

4. Once the TDV is computed, the corrected deduct value (CDV) can be determined from the correction curves. When determining the CDV, if any individual deduct value is higher than the CDV, the CDV is set equal to the highest individual deduct value.

5. The PCI is computed using the relation PCI = 100 − CDV. If all surveyed sample units are selected randomly, the PCI of the pavement section is determined by averaging the PCI of its sample units. If any additional sample units are inspected, a weighted average must be used.

The weighted average is computed by using the following equation:

$$PCI_f = \frac{(N - A)}{N} PCI_1 + \frac{A}{N} PCI_2$$

where PCI_f = PCI of pavement section, PCI_1 = average PCI of random samples, PCI_2 = average PCI of additional samples, N = total number of samples in the section, and A = number of additional samples inspected.

Density of the distresses, measured in square metres (m^2) or square feet (ft^2), is calculated as follows:

$$\text{Density} = \frac{\text{Distress amount in m}^2 \ (\text{ft}^2)}{\text{Sample unit area in m}^2 \ (\text{ft}^2)} \times 100$$

Density of distresses measured in linear feet or metres (bumps, edge cracking, joint reflection cracking, lane/ shoulder drop-off as well as longitudinal and transverse cracks) is calculated as follows:

$$\text{Density} = \frac{\text{Distress amount in linear m (ft)}}{\text{Sample unit area in m}^2 \ (\text{ft}^2)} \times 100$$

Density of distresses, as measured by the number of potholes, is calculated as follows:

$$\text{Density} = \frac{\text{Number of potholes}}{\text{Sample unit area in m}^2 \ (\text{ft}^2)} \times 100$$

After the density of distresses for each distress type/ severity combination is calculated, the deduct values are determined from the appropriate distress deduct value curves (PAVER 1982). The CDV is then determined, as explained later.

5.3 PCI VALUES OF BILASPUR TOWN ROAD NETWORK

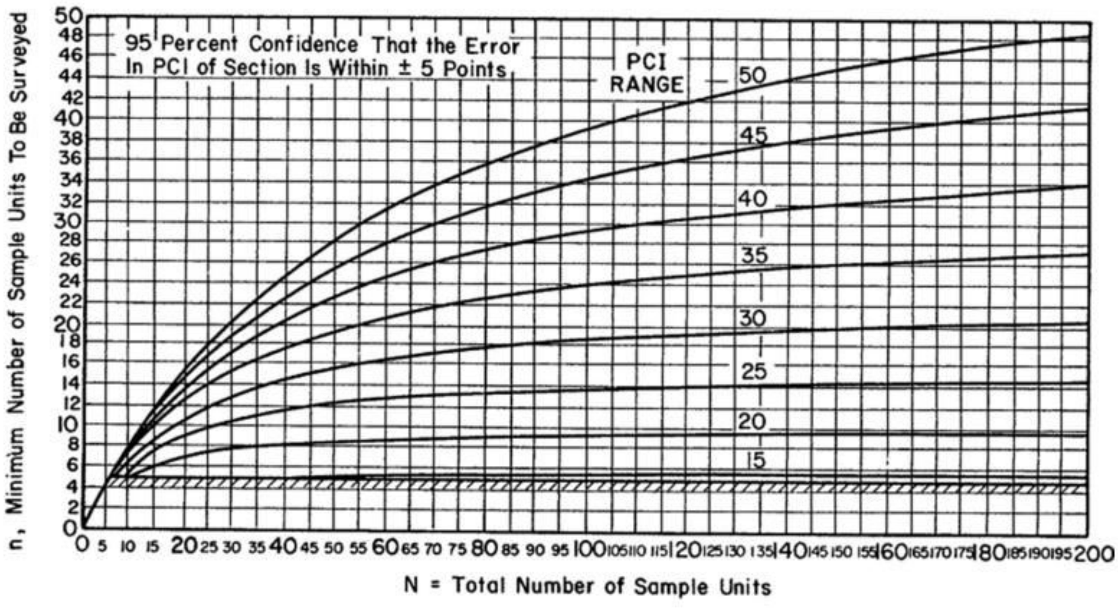
To determine the number of samples to be chosen for inspection. The number of total samples N in a branch is obtained by dividing the length of the branch by the length of the sample, as shown below:

$$N = \frac{\text{length of the section}}{\text{length of the sample}}$$

The curves shown in Figure 5.1 are used to select the minimum number of sample units that must be inspected.

When performing the initial inspection, the PCI range for a pavement section (i.e. PCI of the lowest sample unit subtracted from the PCI of the highest sample unit) is assumed to be 25 for asphalt concrete (AC) surfaces.

However, if the PCI range of the samples considered was found to be >25 for a flexible pavement, it would be necessary to go back to Figure 5.1, start on the N scale again, proceed vertically to the curve for PCI range >25, read the number of samples to be inspected on the n scale and determine the additional samples to be included.



PCI = Pavement Condition Index
PCI RANGE = Highest Sample Unit PCI - Lowest Sample Unit PCI
Assumed PCI Range for asphalt Concrete =25
Assumed PCI Range for Portland Cement Concrete = 35

Fig. 2: Determination of minimum number of sample units to be surveyed.

Fig. 5.1: Determination of minimum number of sample units to be surveyed.

Table 5.2: Data Required for PCI Calculations.

S.No.	Road Name	length (Km)	Carriageway (m)	Gradient (%)	Traffic (MSA)	Visual condition	Soil subgrade (%)	Cracks (mm)
BIL-PWD-001	Lower Nihal Road Gurudwara to Industrial Area	2.092	3.5	2	3.5	POOR	8	>6
BIL-PWD-002	Lower Nihal Industrial Area to Govt. ITI Road	0.401	4	2	3.2	FAIR	8	>4
BIL-PWD-003	Bilaspur Fire Station to lower Nihal	0.505	5	2	2.8	FAIR	8	>4
BIL-PWD-004	College Chowk to Govt . Senior Secondary School Nihal	1.226	5.5	2	3.75	POOR	8	>6
BIL-PWD-005	Shimla Kangra Highway to Dholra Guest House	0.29	7	2	4.2	FAIR	8	>3
BIL-PWD-006	Dholra Guest House to DRDA	0.13	5.5	2	4.5	FAIR	8	>3
BIL-PWD-007	Dholra Junction to EE Office	0.104	5.5	2	3.5	FAIR	8	>3
BIL-PWD-008	Court Road Near Purnam Mall to Hospital	0.087	7	2	4.5	POOR	8	>6
BIL-PWD-009	War memorial to Regional Hospital	0.842	5.5	2	2.5	POOR	8	>6
BIL-PWD-010	Link Road from War Memorial Junction towards Hospital	1.501	3.5	2	2.5	FAIR	8	>3

Table 5.3: Calculation of Deduct Values.

Cracking % (IRC:82-2015, Table 5.3)	Deduct Value for cracking (ASTM-D6433-11, Appendix 3, X3.1)	Ravelling	Ravelling % (IRC:82-2015, Table 5.3)	Deduct Value for Ravelling (ASTM-D6433-11, Appendix 3, Fig X3.25)	Potholes	Potholes % (IRC:82-2015, Table 5.3)	Deduct Value for Potholes (ASTM-D6433-11, Appendix 3, Fig X3.19)
20	70	HIGH	15	50	HIGH	1	28
10	47	MODERATE	7.5	17	MODERATE	0.5	12
20	47	MODERATE	15	17	MODERATE	1	12
20	70	HIGH	15	50	HIGH	1	28
20	47	MODERATE	15	17	MODERATE	1	12
20	47	MODERATE	15	17	MODERATE	1	12
20	47	MODERATE	15	17	MODERATE	1	12
20	70	HIGH	15	50	HIGH	1	28
20	70	HIGH	15	50	HIGH	1	28
10	47	MODERATE	7.5	17	MODERATE	0.5	12

Table 5.4: Calculation of Pavement Condition Index

Rutting	Rut depth (IRC:82-2015, Table 5.3)	Crust Thickness (mm)	Rutting %	Deduct Value for Rutting (ASTM-D6433-11, Appendix 3, Fig X3.21)	Deducted Values in decreasing order	m (Highest no. of deducts) cl 9.5.3	CDV (cl 9.5.5.3, Fig X3.27)	PCI
HIGH	15	300	5	50	70,50,50,28	3.755102	90	**10**
LOW	7.5	300	2.5	28	47,28,17,12	5.867347	55	**45**
LOW	7.5	300	2.5	28	70,50,50,28	5.591837	55	**45**
HIGH	15	300	5	50	70,50,50,28	3.755102	90	**10**
LOW	7.5	300	2.5	28	70,50,50,28	5.591837	55	**45**
LOW	7.5	300	2.5	28	70,50,50,28	5.591837	55	**45**
LOW	7.5	300	2.5	28	70,50,50,28	5.591837	55	**45**
HIGH	15	300	5	50	70,50,50,28	3.755102	90	**10**
HIGH	15	300	5	50	70,50,50,28	3.755102	90	**10**
LOW	7.5	300	2.5	28	47,28,17,12	5.867347	55	**45**

5.4 SUMMARY

- In this study, an attempt was made to evaluate Pavement Condition Index of all the ten road sections of Bilaspur DHQ. An appropriate sample size was selected for visual inspection and rating.

- It has been found that mostly all the samples rated as ‘poor’ with a PCI of 40-55.

- A check was made to determine whether an existing pavement section is strong enough to support moving traffic loads, as it is necessary to find the pavement’s load-carrying capacity.

- Based on the determined rating, the suggested maintenance for the pavement sections is continuation of the previous maintenance and rehabilitation strategies used in HDM-4 .

CHAPTER 06
CONCLUSIONS AND RECOMENDATIONS

6.1 CONCLUSIONS

The present study consists of developing the decision-making pavement maintenance management system for urban road network of Bilaspur Town using HDM-4. The following conclusions have been drawn on the basis of this study:

1. The methodology proposed for developing PMMS for urban roadways in Bilaspur, Himachal Pradesh, India was presented in Chapter 3. Identification and selection of the urban road network, collection of field data and database management, and calibration and validation of HDM-4 pavement deterioration models for local conditions are all part of the proposed PMMS methodology. On 10 pavement sections, the processes and equipment utilized to collect various types of field data have been explained. The data for vehicle fleets plying the road network, maintenance and rehabilitation activities, cost data for various types of maintenance and rehabilitation works, and road user cost data has been presented, as gathered from the field and relevant government publications.

2. Using time series pavement distress data gathered for the years 2019, 2020, and 2021, the HDM-4 road deterioration models were calibrated and verified for ten in-service urban road sections under local conditions. The HDM-4 model's default calibration factors were compared to the specified calibration coefficients for advancement of several pavement deterioration models.

3. Pavement management must be able to be used in whole or in part by various technical and administrative management levels in making decisions about individual projects as well as a complete metropolitan road network. Using several HDM-4 application modules, different features of project and network level PMMS were investigated in this study. This application is for a cost-benefit analysis of one or more maintenance and rehabilitation options. This application is primarily concerned with prioritizing a broad list of candidate pavement sections into a multi-year repair programme while adhering to financial limits.

4. The PMMS, which was created at the project and network levels, has been presented with various case studies demonstrating the impact on pavement condition and maintenance costs for the chosen urban road network. According to the work reported in Chapter 4, all of the road sections used in this study were found to be in good condition. As per the work presented in Chapter 4, it has been concluded that all the road sections taken in this study of Bilaspur town will be needing reconstruction work within 0 to 9 years if no maintenance and rehabilitation work is assigned to the road sections throughout the intervening period.
5. Based on the economic analysis summary presented in Chapter 4, the optimum M&R strategy selected for sections BIL-PWD-003, BIL-PWD-007, BIL-PWD-008, BIL-PWD-009, BIL-PWD-010, and BIL-PWD-005, is Alternative 1 (Resealing 25 mm SBSD), and for all other sections, Alternative 2 (Thin overlay 25 mm SDBC).
6. Based on the case study of the Bilaspur town road network, it has been found that delaying maintenance activities has a significant negative influence on the overall condition of the urban road network. If maintenance is postponed by 4 years, the value of roughness approaches 9.2 m/km in 2024, however if maintenance is activated according to the respective intervention level, the value of IRI is around 3.65 m/km in 2024. The cost of operating a vehicle will be extremely high for road users as a result of this. As a result, M&R activities should not be delayed much after the relevant intervention levels have triggered them.

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ANNEXURE A

A.1 Timing of Works (by Year) for all the Ten Road Sections

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Timing of Works (by Year)

Study Name: **Determination of Optimum M&R Strategy**
Run Date: **27-05-2022**

All costs are expressed in the following currency: Indian Rupees.

Alternative 1

Year	Section	Works Description	Code	Economic Cost	Financia Cost	Work Quantity
2024	Court Road near Purnam	Crack Sealing	CS	117,181.5	135,209.5	90.14 sq. m
	Dholra Guest House to D	Crack Sealing	CS	184,034.8	212,347.9	141.57 sq. m
	Dholra Junction to EE Off	Crack Sealing	CS	7,999.0	9,229.7	6.15 sq. m
	Link Road near DC Office	Crack Sealing	CS	46,786.5	53,984.4	35.99 sq. m
	Lower Nihal Industrial Ar	Crack Sealing	CS	15,350.2	17,711.7	11.81 sq. m
	Lower Nihal Road Gurud	Crack Sealing	CS	2,325,900.5	2,683,731.3	1,789.15 sq. m
	Shimla Kangra Highway	Crack Sealing	CS	430,767.2	497,039.1	331.36 sq. m
	War Memorial to Regiona	Crack Sealing	CS	38,349.8	44,249.8	29.50 sq. m
Total Annual Cost:				3,166,369.6	3,653,503.3	
2025	Dholra Junction to EE Off	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Link Road near DC Office	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Lower Nihal Industrial Ar	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	War Memorial to Regiona	Crack Sealing	CS	0.0	0.0	0.00 sq. m
Total Annual Cost:				0.0	0.0	
2026	Bilaspur Firestation to Lo	Crack Sealing	CS	315,557.3	364,104.5	242.74 sq. m
	College Chowk to Himac	Crack Sealing	CS	1,170,581.0	1,350,670.4	900.45 sq. m
	Court Road near Purnam	Crack Sealing	CS	110,487.8	127,485.9	84.99 sq. m
	Dholra Guest House to D	Crack Sealing	CS	174,402.1	201,233.1	134.16 sq. m
	Dholra Junction to EE Off	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Link Road near DC Office	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Lower Nihal Industrial Ar	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Lower Nihal Road Gurud	Crack Sealing	CS	2,199,170.3	2,537,504.3	1,691.67 sq. m
	Shimla Kangra Highway	Crack Sealing	CS	408,456.1	471,295.4	314.20 sq. m
	War Memorial to Regiona	Crack Sealing	CS	0.0	0.0	0.00 sq. m
Total Annual Cost:				4,378,654.4	5,052,293.6	
2027	Dholra Junction to EE Off	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Link Road near DC Office	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Lower Nihal Industrial Ar	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	War Memorial to Regiona	Crack Sealing	CS	0.0	0.0	0.00 sq. m
Total Annual Cost:				0.0	0.0	
2028	Bilaspur Firestation to Lo	Crack Sealing	CS	314,848.9	363,287.2	242.19 sq. m
	College Chowk to Himac	Crack Sealing	CS	1,232,068.5	1,421,617.4	947.74 sq. m
	Court Road near Purnam	Crack Sealing	CS	110,485.3	127,483.1	84.99 sq. m
	Dholra Guest House to D	Crack Sealing	CS	174,398.0	201,228.5	134.15 sq. m
	Dholra Junction to EE Off	Crack Sealing	CS	0.0	0.0	0.00 sq. m

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2028	Link Road near DC Office	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Lower Nihal Industrial Ar	Thin Overlay	TO	250,524.8	252,630.0	1,403.50 sq. m
		Prep. Patching		24,649.0	26,191.4	291.02 sq. m
		Prep. Edge Repair		2,896.3	2,952.9	24.61 sq. m
	Lower Nihal Road Gurud	Crack Sealing	CS	2,198,792.5	2,537,068.3	1,691.38 sq. m
	Shimla Kangra Highway	Crack Sealing	CS	408,449.6	471,288.0	314.19 sq. m
	War Memorial to Regiona	Thin Overlay	TO	624,750.0	630,000.0	3,500.00 sq. m
		Prep. Patching		24,463.1	25,993.8	288.82 sq. m
		Prep. Edge Repair		1,793.2	1,828.2	15.24 sq. m
Total Annual Cost:				5,368,119.2	6,061,568.8	
2029	Dholra Junction to EE Off	Crack Sealing	CS	0.0	0.0	0.00 sq. m
	Link Road near DC Office	Thin Overlay	TO	624,750.0	630,000.0	3,500.00 sq. m
		Prep. Patching		25,636.8	27,241.0	302.68 sq. m
		Prep. Edge Repair		4,763.0	4,856.0	40.47 sq. m
Total Annual Cost:				655,149.8	662,097.1	
2030	Bilaspur Firestation to Lo	Crack Sealing	CS	314,800.5	363,231.3	242.15 sq. m
	College Chowk to Himac	Crack Sealing	CS	1,232,037.5	1,421,581.8	947.72 sq. m
	Court Road near Purnam	Crack Sealing	CS	110,482.1	127,479.4	84.99 sq. m
	Dholra Guest House to D	Crack Sealing	CS	174,392.9	201,222.6	134.15 sq. m
	Dholra Junction to EE Off	Thin Overlay	TO	129,948.0	131,040.0	728.00 sq. m
		Prep. Patching		49,084.1	52,155.4	579.50 sq. m
		Prep. Edge Repair		201.4	205.3	1.71 sq. m
	Lower Nihal Road Gurud	Crack Sealing	CS	2,198,293.8	2,536,492.8	1,691.00 sq. m
	Shimla Kangra Highway	Thin Overlay	TO	362,355.0	365,400.0	2,030.00 sq. m
		Prep. Patching		252.8	268.6	2.98 sq. m
		Prep. Edge Repair		244.0	248.7	2.07 sq. m
Total Annual Cost:				4,572,091.9	5,199,325.8	
2031	Dholra Guest House to D	Thin Overlay	TO	162,435.0	163,800.0	910.00 sq. m
		Prep. Patching		844.9	897.8	9.98 sq. m
		Prep. Edge Repair		346.5	353.2	2.94 sq. m
	Lower Nihal Road Gurud	Thin Overlay	TO	2,053,821.0	2,071,080.0	11,506.00 sq. m
		Prep. Patching		52.0	55.2	0.61 sq. m
		Prep. Edge Repair		1,402.4	1,429.8	11.92 sq. m
Total Annual Cost:				2,218,901.8	2,237,616.0	
2032	Bilaspur Firestation to Lo	Crack Sealing	CS	314,735.2	363,156.0	242.10 sq. m
	College Chowk to Himac	Crack Sealing	CS	1,231,996.0	1,421,533.9	947.69 sq. m
	Court Road near Purnam	Thin Overlay	TO	108,706.5	109,620.0	609.00 sq. m
		Prep. Patching		312.2	331.8	3.69 sq. m
		Prep. Edge Repair		357.0	364.0	3.03 sq. m
Total Annual Cost:				1,656,106.9	1,895,005.6	
2033	Bilaspur Firestation to Lo	Thin Overlay	TO	270,427.5	272,700.0	1,515.00 sq. m
		Prep. Patching		268.8	285.6	3.17 sq. m
		Prep. Edge Repair		809.9	825.8	6.88 sq. m
	College Chowk to Himac	Thin Overlay	TO	1,531,887.0	1,544,760.0	8,582.00 sq. m
		Prep. Patching		559.4	594.4	6.60 sq. m

2033	College Chowk to Himac	Prep. Edge Repair		315.2	321.4	2.68 sq. m
	Lower Nihal Industrial Ar	Crack Sealing	CS	267,168.9	308,271.8	205.51 sq. m
	War Memorial to Regiona	Crack Sealing	CS	667,539.8	770,238.2	513.49 sq. m
Total Annual Cost:				2,738,976.5	2,897,997.1	
Total Costs for Alternative:				24,754,370.1	27,659,407.4	

Alternative 2

Year	*Section*	*Works Description*	*Code*	*Economic Cost*	*Financia Cost*	*Work Quantity*
2028	Lower Nihal Industrial Ar	Thick Overlay	Tho	396,769.5	421,050.0	1,403.50 sq. m
		Prep. Patching		24,458.9	25,989.3	288.77 sq. m
		Prep. Edge Repair		2,896.3	2,952.9	24.61 sq. m
	Shimla Kangra Highway	Thick Overlay	Tho	573,881.0	609,000.0	2,030.00 sq. m
		Prep. Patching		41,497.6	44,094.3	489.94 sq. m
		Prep. Edge Repair		201.6	205.6	1.71 sq. m
	War Memorial to Regiona	Thick Overlay	Tho	989,450.1	1,050,000.0	3,500.00 sq. m
		Prep. Patching		24,356.9	25,881.0	287.57 sq. m
		Prep. Edge Repair		1,793.2	1,828.2	15.24 sq. m
Total Annual Cost:				2,055,305.0	2,181,001.4	
2029	Dholra Guest House to D	Thick Overlay	Tho	257,257.0	273,000.0	910.00 sq. m
		Prep. Patching		46,199.1	49,090.0	545.44 sq. m
		Prep. Edge Repair		276.2	281.6	2.35 sq. m
	Link Road near DC Office	Thick Overlay	Tho	989,450.1	1,050,000.0	3,500.00 sq. m
		Prep. Patching		25,466.2	27,059.7	300.66 sq. m
		Prep. Edge Repair		4,763.0	4,856.0	40.47 sq. m
	Lower Nihal Road Gurud	Thick Overlay	Tho	3,252,746.3	3,451,800.0	11,506.00 sq. m
		Prep. Patching		34,728.8	36,901.9	410.02 sq. m
		Prep. Edge Repair		1,000.6	1,020.1	8.50 sq. m
Total Annual Cost:				4,611,887.2	4,894,009.3	
2030	Court Road near Purnam	Thick Overlay	Tho	172,164.3	182,700.0	609.00 sq. m
		Prep. Patching		47,136.5	50,086.0	556.51 sq. m
		Prep. Edge Repair		285.8	291.3	2.43 sq. m
	Dholra Junction to EE Off	Thick Overlay	Tho	205,805.6	218,400.0	728.00 sq. m
		Prep. Patching		48,625.7	51,668.4	574.09 sq. m
		Prep. Edge Repair		201.4	205.3	1.71 sq. m
Total Annual Cost:				474,219.2	503,351.0	
2031	Bilaspur Firestation to Lo	Thick Overlay	Tho	428,290.5	454,500.0	1,515.00 sq. m
		Prep. Patching		20,804.3	22,106.2	245.62 sq. m
		Prep. Edge Repair		607.6	619.5	5.16 sq. m
	College Chowk to Himac	Thick Overlay	Tho	2,426,131.5	2,574,600.0	8,582.00 sq. m
		Prep. Patching		37,606.3	39,959.4	443.99 sq. m
		Prep. Edge Repair		258.5	263.5	2.20 sq. m
Total Annual Cost:				2,913,698.6	3,092,048.5	
Total Costs for Alternative:				10,055,110.0	10,670,410.2	

Alternative 3

Year	Section	Works Description	Code	Economic Cost	Financia Cost	Work Quantity
2028	Lower Nihal Industrial Ar	RECONSTRUCTION	RECON	2,006,724.3	2,105,250.0	0.00 sq. m
	Shimla Kangra Highway	RECONSTRUCTION	RECON	2,902,494.0	3,044,999.8	0.00 sq. m
	War Memorial to Regiona	RECONSTRUCTION	RECON	5,004,300.0	5,250,000.0	0.00 sq. m
Total Annual Cost:				9,913,518.3	10,400,249.8	
2029	Dholra Guest House to D	RECONSTRUCTION	RECON	1,301,118.0	1,364,999.9	0.00 sq. m
	Link Road near DC Office	RECONSTRUCTION	RECON	5,004,300.0	5,250,000.0	0.00 sq. m
	Lower Nihal Road Gurud	RECONSTRUCTION	RECON	16,451,279.0	17,259,000.0	0.00 sq. m
Total Annual Cost:				22,756,697.0	23,873,999.9	
2030	Court Road near Purnam	RECONSTRUCTION	RECON	870,748.2	913,499.9	0.00 sq. m
	Dholra Junction to EE Off	RECONSTRUCTION	RECON	1,040,894.4	1,092,000.0	0.00 sq. m
Total Annual Cost:				1,911,642.6	2,005,499.9	
2031	Bilaspur Firestation to Lo	RECONSTRUCTION	RECON	2,166,147.0	2,272,500.0	0.00 sq. m
	College Chowk to Himac	RECONSTRUCTION	RECON	12,270,543.0	12,872,999.0	0.00 sq. m
Total Annual Cost:				14,436,690.0	15,145,499.0	
Total Costs for Alternative:				49,018,547.9	51,425,248.6	

Base Option

Year	Section	Works Description	Code	Economic Cost	Financia Cost	Work Quantity
2022	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				92.3	102.5	
2023	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
		Patching	PATCH	10,100.6	10,732.7	119.25 sq. m
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
		Patching	PATCH	7,948.2	8,445.5	93.84 sq. m
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
		Patching	PATCH	56,371.5	59,898.8	665.54 sq. m
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
		Patching	PATCH	20,196.2	21,459.9	238.44 sq. m

2023	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway t	Drain Cleaning	DC	3.9	4.4	0.29 km
		Patching	PATCH	20,451.9	21,731.7	241.46 sq. m
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
		Patching	PATCH	43,632.5	46,362.7	515.14 sq. m
Total Annual Cost:				158,793.0	168,733.8	
2024	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
		Patching	PATCH	18,391.8	19,542.6	217.14 sq. m
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
		Patching	PATCH	11,116.9	11,812.5	131.25 sq. m
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
		Patching	PATCH	187,747.5	199,495.6	2,216.62 sq. m
	Shimla Kangra Highway t	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				217,348.3	230,953.2	
2025	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
		Patching	PATCH	119,015.2	126,462.5	1,405.14 sq. m
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway t	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				119,107.5	126,565.0	
2026	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
		Patching	PATCH	30,257.3	32,150.6	357.23 sq. m
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
		Patching	PATCH	193,058.8	205,139.3	2,279.32 sq. m
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
		Patching	PATCH	70,846.6	75,279.8	836.44 sq. m
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway t	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
		Patching	PATCH	159,490.3	169,470.2	1,883.00 sq. m
Total Annual Cost:				453,745.3	482,142.4	

2027	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
		Patching	PATCH	55,055.0	58,500.0	650.00 sq. m
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway	Drain Cleaning	DC	3.9	4.4	0.29 km
		Patching	PATCH	122,815.0	130,500.0	1,450.00 sq. m
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				177,962.2	189,102.5	
2028	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
		Patching	PATCH	28,933.0	30,743.5	341.59 sq. m
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
		Patching	PATCH	31,714.6	33,699.1	374.43 sq. m
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
		Patching	PATCH	160,335.1	170,367.9	1,892.98 sq. m
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
		Patching	PATCH	65,188.9	69,268.0	769.64 sq. m
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
		Patching	PATCH	553,661.7	588,306.4	6,536.74 sq. m
	Shimla Kangra Highway	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
		Patching	PATCH	154,422.7	164,085.5	1,823.17 sq. m
Total Annual Cost:				994,348.2	1,056,572.8	
2029	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
		Patching	PATCH	126,182.3	134,078.0	1,489.76 sq. m
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
		Patching	PATCH	319,664.3	339,666.9	3,774.08 sq. m
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				445,938.9	473,847.5	
2030	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
		Patching	PATCH	55,055.0	58,500.0	650.00 sq. m
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km

H D M - 4 **Timing of Works (by Year)**

2030	Dholra Junction to EE Off	Patching	PATCH	29,142.3	30,965.8	344.06 sq. m
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				84,289.5	89,568.4	
2031	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
		Patching	PATCH	28,233.0	29,999.6	333.33 sq. m
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				28,325.2	30,102.1	
2032	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				92.3	102.5	
2033	Bilaspur Firestation to Lo	Drain Cleaning	DC	6.8	7.6	0.50 km
	College Chowk to Himac	Drain Cleaning	DC	16.6	18.4	1.23 km
	Court Road near Purnam	Drain Cleaning	DC	1.2	1.3	0.09 km
	Dholra Guest House to D	Drain Cleaning	DC	1.8	2.0	0.13 km
	Dholra Junction to EE Off	Drain Cleaning	DC	1.4	1.6	0.10 km
	Link Road near DC Office	Drain Cleaning	DC	13.5	15.0	1.00 km
	Lower Nihal Industrial Ar	Drain Cleaning	DC	5.4	6.0	0.40 km
	Lower Nihal Road Gurud	Drain Cleaning	DC	28.2	31.4	2.09 km
	Shimla Kangra Highway	Drain Cleaning	DC	3.9	4.4	0.29 km
	War Memorial to Regiona	Drain Cleaning	DC	13.5	15.0	1.00 km
Total Annual Cost:				92.3	102.5	
Total Costs for Alternative:				2,680,135.0	2,847,895.2	

Summary of Total Annual Costs

	Alternative 1	Alternative 2	Alternative 3	Base Option
2022	0.00	0.00	0.00	92.25
2023	0.00	0.00	0.00	158,793.04
2024	3,166,369.62	0.00	0.00	217,348.34
2025	0.00	0.00	0.00	119,107.49
2026	4,378,654.38	0.00	0.00	453,745.28
2027	0.00	0.00	0.00	177,962.24
2028	5,368,119.23	2,055,305.04	9,913,518.25	994,348.19
2029	655,149.79	4,611,887.16	22,756,697.00	445,938.90
2030	4,572,091.91	474,219.20	1,911,642.63	84,289.54
2031	2,218,901.76	2,913,698.61	14,436,690.00	28,325.23
2032	1,656,106.92	0.00	0.00	92.25
2033	2,738,976.47	0.00	0.00	92.25
Total	24,754,370.08	10,055,110.01	49,018,547.88	2,680,135.00

ANNEXURE B

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

Table B.1.1: VOC Equations for Two-wheelers

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

Table B.1.2: VOC Equations for Cars

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

Table B.1.3: VOC Equations for Buses

S. No.	VOC Component	Equation
1.	Free Speed (km/hr)	V = 54.23 - (0.4111*RF) - 0.00098*(RG-2000)
2.	Fuel Consumption (litre/1000 km)	FC = 32.97 + (3904.64/V) + 0.0207V^2 + 0.0012*RG + 3.3281*RS – 1.7769*FL
3.	Lubricating Oil Consumption (litre/1000 km)	LOC = 1.146 + 0.00398*RF + 0.0021*(RG/W)
4.	Spare Parts Cost (Rs./km)	SP = e[-10.44 + 0.007373*RF + 0.0000723*RG + 1 .925*W] *NP
5.	Maintenance Labour (Rs./km)	LC = 0.5498*SP
6.	Utility (km/day)	UPD = 28.07 + 15.1476*V
7.	Annual Overhead (Rs./km)	AO = 495.90 / UPD
8.	Crew Wages	CW = 938.67 / UPD

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

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

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

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

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

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

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

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

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

ANNEXURE C

C.1 Pavement Deterioration Summary for Bhadson Road Section

Table C.1.2: Pavement Deterioration Summary of Base Option for War Memorial Road Section.

Alternative:	**Base Option**		
Section:	**War Memorial to Regional Hospital**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**1.00km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	262	0.01	2.19	2.10	7.33	3.50	1.61	3.99	4.12	1.50						
2023	275	0.01	2.39	2.29	13.59	4.34	3.33	5.00	2.12	1.50						
2024	289	0.01	2.67	2.56	22.40	1.03	5.24	6.01	0.00	1.50						
2025	304	0.01	2.96	2.82	41.99	2.39	7.35	7.04	0.00	1.50						
2026	321	0.01	3.31	3.14	45.53	2.53	9.70	8.11	5.11	1.50						
2027	339	0.01	3.37	3.23	40.03	0.61	12.31	9.15	0.00	1.50						
2028	358	0.01	3.74	3.56	42.17	0.34	15.24	10.23	6.19	1.50						
2029	379	0.01	3.77	3.63	32.40	1.14	18.51	11.27	0.00	1.50						
2030	401	0.01	4.14	3.95	57.37	2.97	22.19	12.35	11.48	1.50						
2031	426	0.01	4.53	4.33	80.47	8.21	26.34	13.49	39.68	1.50						
2032	453	0.01	4.93	4.73	93.08	4.93	31.03	14.69	90.90	1.50						
2033	482	0.01	5.38	5.15	97.68	0.00	36.36	15.92	155.13	1.50						

Table C.1.3: Pavement Deterioration Summary of Alternative 3 for War Memorial Road Section.

Alternative:	**Alternative 3**		
Section:	**War Memorial to Regional Hospital**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**1.00km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	262	0.01	2.19	2.10	7.33	3.50	1.61	3.99	4.12	1.50						
2023	275	0.01	2.39	2.29	16.61	8.67	3.33	5.00	4.24	1.50						
2024	289	0.01	2.64	2.52	32.62	17.69	5.24	6.02	4.37	1.50						
2025	304	0.01	2.98	2.81	57.76	31.92	7.35	7.09	14.35	1.50						
2026	321	0.01	3.33	3.15	80.72	18.04	9.70	8.21	41.15	1.50						
2027	339	0.01	3.68	3.51	93.25	5.32	12.31	9.40	82.63	1.50						
2028	358	0.01	4.05	3.86	49.17	0.00	7.62	5.32	66.88	1.50						
2029	379	0.01	2.18	2.09	0.00	0.00	3.28	1.85	0.00	4.44						
2030	401	0.01	2.25	2.22	0.00	0.00	6.96	1.99	0.00	4.44						
2031	426	0.01	2.32	2.28	0.00	0.00	11.10	2.14	0.00	4.44						
2032	453	0.01	2.39	2.35	0.00	0.00	15.79	2.29	0.00	4.44						
2033	482	0.01	2.46	2.42	0.00	0.00	21.11	2.44	0.00	4.44						

Table C.1.4: Pavement Deterioration Summary of Alternative 2 for War Memorial Road Section.

Alternative:	**Alternative 2**		
Section:	**War Memorial to Regional Hospital**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**1.00km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	262	0.01	2.19	2.10	7.33	3.50	1.61	3.99	4.12	1.50						
2023	275	0.01	2.39	2.29	16.61	8.67	3.33	5.00	4.24	1.50						
2024	289	0.01	2.64	2.52	32.62	17.69	5.24	6.02	4.37	1.50						
2025	304	0.01	2.98	2.81	57.76	31.92	7.35	7.09	14.35	1.50						
2026	321	0.01	3.33	3.15	80.72	18.04	9.70	8.21	41.15	1.50						
2027	339	0.01	3.68	3.51	93.25	5.32	12.31	9.40	82.63	1.50						
2028	358	0.01	4.05	3.86	49.17	0.00	7.62	6.11	66.88	1.50						
2029	379	0.01	2.27	2.22	0.60	0.00	1.64	2.10	0.00	1.50						
2030	401	0.01	2.39	2.33	2.01	0.00	3.48	2.61	0.00	1.50						
2031	426	0.01	2.52	2.46	4.99	0.00	5.55	3.12	0.00	1.50						
2032	453	0.01	2.68	2.60	10.39	0.00	7.90	3.64	0.00	1.50						
2033	482	0.01	2.86	2.77	19.15	0.00	10.55	4.16	0.00	1.50						

Table C.1.5: Pavement Deterioration Summary of Alternative 1 for War Memorial Road Section.

Alternative:	**Alternative 1**		
Section:	**War Memorial to Regional Hospital**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**1.00km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	262	0.01	2.19	2.10	7.33	3.50	1.61	3.99	4.12	1.50						
2023	275	0.01	2.39	2.29	16.61	8.67	3.33	5.00	4.24	1.50						
2024	289	0.01	2.64	2.52	32.62	17.69	5.24	6.02	4.37	1.50						
2025	304	0.01	2.97	2.80	57.76	31.92	7.35	7.09	14.35	1.50						
2026	321	0.01	3.33	3.15	80.72	18.89	9.70	8.21	41.15	1.50						
2027	339	0.01	3.67	3.50	93.25	6.16	12.31	9.40	82.63	1.50						
2028	358	0.01	4.04	3.86	49.35	0.24	7.62	6.11	66.88	1.50						
2029	379	0.01	2.57	2.51	0.75	0.00	1.64	2.10	0.00	1.50						
2030	401	0.01	2.69	2.63	2.36	0.00	3.48	2.60	0.00	1.50						
2031	426	0.01	2.84	2.77	5.67	0.00	5.55	3.11	0.00	1.50						
2032	453	0.01	3.00	2.92	11.54	0.00	7.90	3.63	0.00	1.50						
2033	482	0.01	3.19	3.10	13.60	0.00	10.56	4.16	0.00	1.50						

Table C.1.6: Pavement Deterioration Summary of Base Option for Shimla Kangra Highway to Dholra Guest House Road Section.

H D M - 4 Annual Pavement Deterioration Summary (Combined) 5/27/2022

Alternative: Base Option
Section: Shimla Kangra Highway to Dholra Guest House Road Class: Tertiary or Local
Surface Class: Bituminous
Length: 0.29km Width: 7.00m

					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	442	0.03	2.22	2.12	6.29	3.12	1.03	4.03	4.11	1.50						
2023	467	0.03	2.46	2.34	10.48	3.59	1.12	5.11	2.11	1.50						
2024	493	0.04	2.77	2.65	15.88	1.19	1.21	6.19	0.00	1.50						
2025	521	0.04	3.07	2.92	28.00	3.13	1.32	7.30	0.00	1.50						
2026	552	0.04	3.41	3.24	45.79	6.80	1.43	8.44	0.00	1.50						
2027	585	0.04	3.79	3.60	37.09	7.80	1.56	9.62	7.91	1.50						
2028	622	0.04	3.77	3.63	13.98	6.59	1.71	10.74	0.00	1.50						
2029	661	0.04	4.10	3.94	25.11	15.04	1.88	11.87	0.00	1.50						
2030	704	0.04	4.48	4.29	41.64	29.38	2.07	13.04	0.00	1.50						
2031	751	0.04	4.92	4.70	63.41	35.69	2.29	14.25	19.45	1.50						
2032	802	0.05	5.37	5.15	79.47	19.56	2.54	15.53	61.26	1.50						
2033	858	0.05	5.85	5.61	89.76	9.19	2.83	16.85	115.24	1.50						

Table C.1.7: Pavement Deterioration Summary of Alternative 3 for Shimla Kangra Highway to Dholra Guest House Road Section.

Alternative: Alternative 3
Section: Shimla Kangra Highway to Dholra Guest House Road Class: Tertiary or Local
Surface Class: Bituminous
Length: 0.29km Width: 7.00m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	442	0.03	2.22	2.12	6.29	3.12	1.03	4.03	4.11	1.50						
2023	467	0.03	2.46	2.34	12.84	7.17	1.12	5.11	4.22	1.50						
2024	493	0.04	2.72	2.59	23.36	13.91	1.21	6.21	4.34	1.50						
2025	521	0.04	3.04	2.88	39.09	24.20	1.32	7.34	4.47	1.50						
2026	552	0.04	3.42	3.23	60.72	38.38	1.43	8.51	19.69	1.50						
2027	585	0.04	3.80	3.61	77.68	21.37	1.56	9.74	52.11	1.50						
2028	622	0.04	4.19	3.99	44.34	5.16	0.86	5.52	46.04	1.50						
2029	661	0.04	2.21	2.11	0.00	0.00	0.17	2.25	0.00	4.44						
2030	704	0.04	2.28	2.25	0.00	0.00	0.36	2.46	0.00	4.44						
2031	751	0.04	2.36	2.32	0.00	0.00	0.58	2.68	0.00	4.44						
2032	802	0.05	2.44	2.40	0.00	0.00	0.83	2.90	0.00	4.44						
2033	858	0.05	2.52	2.48	0.00	0.00	1.11	3.12	0.00	4.44						

Table C.1.8: Pavement Deterioration Summary of Alternative 2 for Shimla Kangra Highway to Dholra Guest House Road Section.

Alternative:	Alternative 2		
Section:	Shimla Kangra Highway to Dholra Guest House	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	0.29km	Width:	7.00m

					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	442	0.03	2.22	2.12	6.29	3.12	1.03	4.03	4.11	1.50						
2023	467	0.03	2.46	2.34	12.84	7.17	1.12	5.11	4.22	1.50						
2024	493	0.04	2.72	2.59	23.36	13.91	1.21	6.21	4.34	1.50						
2025	521	0.04	3.04	2.88	39.09	24.20	1.32	7.34	4.47	1.50						
2026	552	0.04	3.42	3.23	60.72	38.38	1.43	8.51	19.69	1.50						
2027	585	0.04	3.80	3.61	77.68	21.37	1.56	9.74	52.11	1.50						
2028	622	0.04	4.19	3.99	44.34	5.16	0.86	6.34	46.04	1.50						
2029	661	0.04	2.43	2.34	0.60	0.00	0.08	2.38	0.00	1.50						
2030	704	0.04	2.62	2.52	2.06	0.00	0.18	3.10	0.00	1.50						
2031	751	0.04	2.83	2.72	5.24	0.00	0.29	3.84	0.00	1.50						
2032	802	0.05	3.06	2.95	11.05	0.00	0.41	4.59	0.00	1.50						
2033	858	0.05	3.34	3.20	20.56	0.00	0.56	5.36	0.00	1.50						

Table C.1.9: Pavement Deterioration Summary of Alternative 1 for Shimla Kangra Highway to Dholra Guest House Road Section.

Alternative:	Alternative 1		
Section:	Shimla Kangra Highway to Dholra Guest House	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	0.29km	Width:	7.00m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	442	0.03	2.22	2.12	6.29	3.12	1.03	4.03	4.11	1.50						
2023	467	0.03	2.46	2.34	12.84	7.17	1.12	5.11	4.22	1.50						
2024	493	0.04	2.72	2.59	15.62	13.91	1.21	6.21	4.34	1.50						
2025	521	0.04	2.87	2.75	15.48	25.02	1.32	7.31	4.47	1.50						
2026	552	0.04	3.17	3.02	19.67	41.29	1.43	8.43	4.61	1.50						
2027	585	0.04	3.37	3.22	21.94	62.16	1.56	9.55	8.62	1.50						
2028	622	0.04	3.71	3.54	29.27	62.94	1.71	10.70	15.03	1.50						
2029	661	0.04	3.96	3.79	36.42	63.52	1.88	11.86	22.08	1.50						
2030	704	0.04	4.38	4.17	28.78	21.19	1.04	7.51	14.92	1.50						
2031	751	0.04	2.87	2.78	0.50	0.00	0.11	2.69	0.00	1.50						
2032	802	0.05	3.07	2.97	1.82	0.00	0.23	3.43	0.00	1.50						
2033	858	0.05	3.30	3.19	4.75	0.00	0.38	4.18	0.00	1.50						

Table C.1.10: Pavement Deterioration Summary of Base Option for Lower Nihal Road Gurudwara to Industrial Area Road Section.

Alternative:	Base Option		
Section:	Lower Nihal Road Gurudwara to Industrial Area	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	2.09km	Width:	5.50m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	305	0.01	2.19	2.10	6.15	1.89	1.26	4.04	4.05	1.50						
2023	321	0.01	2.38	2.28	12.35	3.08	1.98	5.11	4.09	1.50						
2024	338	0.01	2.60	2.49	14.85	2.28	2.79	6.19	2.07	1.50						
2025	356	0.01	2.81	2.70	14.56	0.21	3.69	7.27	0.00	1.50						
2026	376	0.01	3.05	2.93	25.56	0.06	4.70	8.37	0.00	1.50						
2027	398	0.01	3.34	3.20	41.64	0.00	5.82	9.50	0.00	1.50						
2028	421	0.01	3.67	3.50	34.18	0.00	7.08	10.66	3.12	1.50						
2029	447	0.01	3.62	3.50	11.74	0.00	8.50	11.77	0.00	1.50						
2030	474	0.01	3.88	3.75	21.25	0.00	10.10	12.90	0.00	1.50						
2031	504	0.01	4.18	4.03	35.43	0.00	11.92	14.05	0.00	1.50						
2032	537	0.01	4.53	4.36	55.45	0.00	13.97	15.23	7.26	1.50						
2033	572	0.01	4.90	4.72	73.41	0.00	16.31	16.48	20.55	1.50						

Table C.1.11: Pavement Deterioration Summary of Alternative 3 for Lower Nihal Road Gurudwara to Industrial Area Road Section.

Alternative:	Alternative 3		
Section:	Lower Nihal Road Gurudwara to Industrial Area	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	2.09km	Width:	5.50m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	305	0.01	2.19	2.10	6.15	1.89	1.26	4.04	4.05	1.50						
2023	321	0.01	2.38	2.28	12.35	3.08	1.98	5.11	4.09	1.50						
2024	338	0.01	2.60	2.49	22.20	4.55	2.79	6.20	4.14	1.50						
2025	356	0.01	2.86	2.73	36.82	6.26	3.69	7.31	4.19	1.50						
2026	376	0.01	3.18	3.02	57.22	8.13	4.70	8.47	10.07	1.50						
2027	398	0.01	3.49	3.33	74.64	11.09	5.82	9.68	20.92	1.50						
2028	421	0.01	3.78	3.64	86.32	12.64	7.08	10.95	35.77	1.50						
2029	447	0.01	4.07	3.93	46.79	2.67	4.25	6.13	26.87	1.50						
2030	474	0.01	2.19	2.10	0.00	0.00	1.60	1.93	0.00	4.44						
2031	504	0.01	2.26	2.22	0.00	0.00	3.41	2.09	0.00	4.44						
2032	537	0.01	2.33	2.29	0.00	0.00	5.47	2.25	0.00	4.44						
2033	572	0.01	2.40	2.36	0.00	0.00	7.81	2.41	0.00	4.44						

Table C.1.12: Pavement Deterioration Summary of Alternative 2 for Lower Nihal Road Gurudwara to Industrial Area Road Section.

Alternative: Alternative 2
Section: Lower Nihal Road Gurudwara to Industrial Area   **Road Class:** Tertiary or Local
Surface Class: Bituminous
Length: 2.09km   **Width:** 5.50m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	305	0.01	2.19	2.10	6.15	1.89	1.26	4.04	4.05	1.50						
2023	321	0.01	2.38	2.28	12.35	3.08	1.98	5.11	4.09	1.50						
2024	338	0.01	2.60	2.49	22.20	4.55	2.79	6.20	4.14	1.50						
2025	356	0.01	2.86	2.73	36.82	6.26	3.69	7.31	4.19	1.50						
2026	376	0.01	3.18	3.02	57.22	8.13	4.70	8.47	10.07	1.50						
2027	398	0.01	3.49	3.33	74.64	11.09	5.82	9.68	20.92	1.50						
2028	421	0.01	3.78	3.64	86.32	12.64	7.08	10.95	35.77	1.50						
2029	447	0.01	4.07	3.93	46.79	2.67	4.25	7.05	26.87	1.50						
2030	474	0.01	2.33	2.27	0.60	0.00	0.80	2.39	0.00	1.50						
2031	504	0.01	2.46	2.40	2.01	0.00	1.71	2.94	0.00	1.50						
2032	537	0.01	2.61	2.53	5.02	0.00	2.74	3.50	0.00	1.50						
2033	572	0.01	2.77	2.69	10.44	0.00	3.91	4.07	0.00	1.50						

Table C.1.13: Pavement Deterioration Summary of Alternative 1 for Lower Nihal Road Gurudwara to Industrial Area Road Section.

Alternative: Alternative 1
Section: Lower Nihal Road Gurudwara to Industrial Area   **Road Class:** Tertiary or Local
Surface Class: Bituminous
Length: 2.09km   **Width:** 5.50m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	305	0.01	2.19	2.10	6.15	1.89	1.26	4.04	4.05	1.50						
2023	321	0.01	2.38	2.28	12.35	3.08	1.98	5.11	4.09	1.50						
2024	338	0.01	2.60	2.49	14.85	4.55	2.79	6.20	4.14	1.50						
2025	356	0.01	2.70	2.60	14.56	7.01	3.69	7.28	4.19	1.50						
2026	376	0.01	2.95	2.83	18.21	10.10	4.70	8.39	4.25	1.50						
2027	398	0.01	3.08	2.97	19.90	14.55	5.82	9.50	4.30	1.50						
2028	421	0.01	3.36	3.22	26.11	20.04	7.08	10.63	4.36	1.50						
2029	447	0.01	3.53	3.40	31.80	27.30	8.50	11.76	4.42	1.50						
2030	474	0.01	3.85	3.69	42.90	36.11	10.10	12.93	4.49	1.50						
2031	504	0.01	4.10	3.93	27.81	22.08	5.96	8.11	3.07	1.50						
2032	537	0.01	2.67	2.61	0.00	0.00	1.03	2.67	0.00	1.50						
2033	572	0.01	2.81	2.74	0.50	0.00	2.20	3.23	0.00	1.50						

Table C.1.14: Pavement Deterioration Summary of Alternative 1 for Lower Nihal Industrial Area to Govt. ITI Road Section.

Alternative:	**Base Option**		
Section:	**Lower Nihal Industrial Area to Govt. ITI Road**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.40km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	336	0.01	2.20	2.11	7.33	4.06	2.00	4.08	4.13	1.50						
2023	353	0.01	2.43	2.32	13.59	5.47	4.84	5.19	2.14	1.50						
2024	372	0.02	2.73	2.61	22.39	1.50	7.99	6.31	0.00	1.50						
2025	392	0.02	3.04	2.89	41.96	4.45	11.49	7.45	0.00	1.50						
2026	413	0.02	3.42	3.23	45.52	5.45	15.38	8.63	5.94	1.50						
2027	436	0.02	3.51	3.35	40.03	1.21	19.73	9.78	0.00	1.50						
2028	462	0.02	3.91	3.71	42.17	1.73	24.61	10.98	7.26	1.50						
2029	489	0.02	3.97	3.81	32.41	1.85	30.08	12.14	0.00	1.50						
2030	519	0.02	4.37	4.17	57.37	6.29	36.25	13.34	13.55	1.50						
2031	551	0.02	4.80	4.59	80.43	17.36	43.21	14.61	47.03	1.50						
2032	587	0.02	5.28	5.04	93.02	4.37	51.10	15.94	108.26	1.50						
2033	625	0.02	5.82	5.55	96.92	0.00	60.06	17.32	185.72	1.50						

Table C.1.15: Pavement Deterioration Summary of Alternative 3 for Lower Nihal Industrial Area to Govt. ITI Road Section.

Alternative:	**Alternative 3**		
Section:	**Lower Nihal Industrial Area to Govt. ITI Road**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.40km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	336	0.01	2.20	2.11	7.33	4.06	2.00	4.08	4.13	1.50						
2023	353	0.01	2.43	2.32	16.60	10.94	4.84	5.19	4.28	1.50						
2024	372	0.02	2.70	2.57	32.60	23.65	7.99	6.32	4.43	1.50						
2025	392	0.02	3.06	2.88	57.72	41.07	11.49	7.50	16.00	1.50						
2026	413	0.02	3.45	3.26	80.67	17.91	15.38	8.74	48.25	1.50						
2027	436	0.02	3.85	3.65	93.20	5.12	19.73	10.06	96.96	1.50						
2028	462	0.02	4.28	4.07	49.01	0.00	12.31	5.71	78.73	1.50						
2029	489	0.02	2.20	2.10	0.00	0.00	5.47	2.04	0.00	4.44						
2030	519	0.02	2.27	2.23	0.00	0.00	11.64	2.21	0.00	4.44						
2031	551	0.02	2.34	2.30	0.00	0.00	18.60	2.39	0.00	4.44						
2032	587	0.02	2.41	2.37	0.00	0.00	26.48	2.57	0.00	4.44						
2033	625	0.02	2.49	2.45	0.00	0.00	35.43	2.75	0.00	4.44						

Table C.1.16: Pavement Deterioration Summary of Alternative 2 for Lower Nihal Industrial Area to Govt. ITI Road Section.

Alternative:	**Alternative 2**		
Section:	**Lower Nihal Industrial Area to Govt. ITI Road**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.40km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	336	0.01	2.20	2.11	7.33	4.06	2.00	4.08	4.13	1.50						
2023	353	0.01	2.43	2.32	16.60	10.94	4.84	5.19	4.28	1.50						
2024	372	0.02	2.70	2.57	32.60	23.65	7.99	6.32	4.43	1.50						
2025	392	0.02	3.06	2.88	57.72	41.07	11.49	7.50	16.00	1.50						
2026	413	0.02	3.45	3.26	80.67	17.91	15.38	8.74	48.25	1.50						
2027	436	0.02	3.85	3.65	93.20	5.12	19.73	10.06	96.96	1.50						
2028	462	0.02	4.28	4.07	49.01	0.00	12.31	6.57	78.73	1.50						
2029	489	0.02	2.38	2.31	0.60	0.00	2.74	2.32	0.00	1.50						
2030	519	0.02	2.52	2.45	2.00	0.00	5.82	2.93	0.00	1.50						
2031	551	0.02	2.69	2.61	4.97	0.00	9.30	3.55	0.00	1.50						
2032	587	0.02	2.87	2.78	10.34	0.00	13.24	4.18	0.00	1.50						
2033	625	0.02	3.09	2.98	19.07	0.00	17.72	4.82	0.00	1.50						

Table C.1.17: Pavement Deterioration Summary of Alternative 1 for Lower Nihal Industrial Area to Govt. ITI Road Section.

Alternative:	**Alternative 1**		
Section:	**Lower Nihal Industrial Area to Govt. ITI Road**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.40km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	336	0.01	2.20	2.11	7.33	4.06	2.00	4.08	4.13	1.50						
2023	353	0.01	2.43	2.32	16.60	10.94	4.84	5.19	4.28	1.50						
2024	372	0.02	2.70	2.57	32.60	23.65	7.99	6.32	4.43	1.50						
2025	392	0.02	3.05	2.88	57.72	41.91	11.49	7.50	16.00	1.50						
2026	413	0.02	3.45	3.25	80.67	18.75	15.38	8.74	48.35	1.50						
2027	436	0.02	3.84	3.65	93.20	5.96	19.73	10.06	97.06	1.50						
2028	462	0.02	4.28	4.06	49.33	0.10	12.31	6.57	78.78	1.50						
2029	489	0.02	2.70	2.63	0.75	0.00	2.74	2.31	0.00	1.50						
2030	519	0.02	2.85	2.78	2.35	0.00	5.82	2.92	0.00	1.50						
2031	551	0.02	3.02	2.94	5.65	0.00	9.30	3.54	0.00	1.50						
2032	587	0.02	3.22	3.12	11.49	0.00	13.24	4.16	0.00	1.50						
2033	625	0.02	3.45	3.33	13.54	0.00	17.72	4.80	0.00	1.50						

Table C.1.18: Pavement Deterioration Summary of Base Option for Link Road near DC Office to JE Office Road Section.

Alternative:	**Base Option**		
Section:	**Link Road near DC Office to JE Office**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**1.00km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	393	0.01	2.14	2.08	6.91	4.54	2.37	3.39	4.17	1.75						
2023	413	0.01	2.29	2.22	12.82	6.49	6.25	3.79	2.18	1.72						
2024	434	0.01	2.53	2.44	21.04	1.95	10.55	4.20	0.00	1.70						
2025	457	0.01	2.76	2.64	39.80	6.45	15.31	4.61	0.00	1.58						
2026	481	0.01	3.07	2.92	43.27	8.23	20.60	5.05	7.69	1.50						
2027	508	0.01	3.07	2.95	36.43	1.82	26.49	5.47	0.00	1.62						
2028	537	0.01	3.39	3.23	39.54	3.11	33.08	5.90	8.78	1.50						
2029	568	0.01	3.38	3.27	30.96	2.47	40.47	6.32	0.00	1.65						
2030	602	0.01	3.68	3.53	54.84	9.31	48.77	6.76	0.00	1.50						
2031	639	0.01	4.03	3.86	78.90	18.30	58.13	7.23	41.64	1.50						
2032	679	0.01	4.45	4.24	92.19	4.48	68.71	7.72	119.51	1.50						
2033	723	0.02	4.98	4.72	96.05	0.00	80.72	8.24	220.36	1.50						

Table C.1.19: Pavement Deterioration Summary of Alternative 3 for Link Road near DC Office to JE Office Road Section.

Alternative:	**Alternative 3**		
Section:	**Link Road near DC Office to JE Office**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**1.00km**	**Width:**	**3.50m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	393	0.01	2.14	2.08	6.91	4.54	2.37	3.39	4.17	1.75						
2023	413	0.01	2.29	2.22	15.83	12.97	6.25	3.79	4.36	1.71						
2024	434	0.01	2.50	2.40	31.32	29.04	10.55	4.21	4.56	1.61						
2025	457	0.01	2.79	2.64	55.47	43.01	15.31	4.64	19.55	1.50						
2026	481	0.01	3.13	2.96	79.32	18.89	20.60	5.09	61.80	1.50						
2027	508	0.01	3.50	3.32	92.47	5.39	26.49	5.58	124.69	1.50						
2028	537	0.01	3.94	3.72	97.45	0.00	33.08	6.09	204.19	1.50						
2029	568	0.01	4.47	4.21	48.73	0.00	20.24	3.31	148.02	1.50						
2030	602	0.01	2.19	2.10	0.00	0.00	8.30	1.95	0.00	4.44						
2031	639	0.01	2.26	2.23	0.00	0.00	17.66	2.11	0.00	4.44						
2032	679	0.01	2.33	2.29	0.00	0.00	28.24	2.27	0.00	4.44						
2033	723	0.02	2.40	2.36	0.00	0.00	40.25	2.43	0.00	4.44						

Table C.1.20: Pavement Deterioration Summary of Alternative 2 for Link Road near DC Office to JE Office Road Section.

Alternative:	Alternative 2		
Section:	Link Road near DC Office to JE Office	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	1.00km	Width:	3.50m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	393	0.01	2.14	2.08	6.91	4.54	2.37	3.39	4.17	1.75						
2023	413	0.01	2.29	2.22	15.83	12.97	6.25	3.79	4.36	1.71						
2024	434	0.01	2.50	2.40	31.32	29.04	10.55	4.21	4.56	1.61						
2025	457	0.01	2.79	2.64	55.47	43.01	15.31	4.64	19.55	1.50						
2026	481	0.01	3.13	2.96	79.32	18.89	20.60	5.09	61.80	1.50						
2027	508	0.01	3.50	3.32	92.47	5.39	26.49	5.58	124.69	1.50						
2028	537	0.01	3.94	3.72	97.45	0.00	33.08	6.09	204.19	1.50						
2029	568	0.01	4.47	4.21	48.73	0.00	20.24	3.80	148.02	1.50						
2030	602	0.01	2.38	2.32	0.60	0.00	4.15	1.54	0.00	1.50						
2031	639	0.01	2.52	2.45	1.99	0.00	8.83	2.10	0.00	1.50						
2032	679	0.01	2.66	2.59	4.94	0.00	14.12	2.66	0.00	1.50						
2033	723	0.02	2.83	2.75	10.28	0.00	20.12	3.22	0.00	1.50						

Table C.1.21: Pavement Deterioration Summary of Alternative 1 for Link Road near DC Office to JE Office Road Section.

Alternative:	Alternative 1		
Section:	Link Road near DC Office to JE Office	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	1.00km	Width:	3.50m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	393	0.01	2.14	2.08	6.91	4.54	2.37	3.39	4.17	1.75						
2023	413	0.01	2.29	2.22	15.83	12.97	6.25	3.79	4.36	1.71						
2024	434	0.01	2.50	2.40	31.32	29.04	10.55	4.21	4.56	1.61						
2025	457	0.01	2.78	2.64	55.47	44.03	15.31	4.64	19.55	1.50						
2026	481	0.01	3.12	2.95	79.32	19.92	20.60	5.09	61.95	1.50						
2027	508	0.01	3.49	3.31	92.47	6.41	26.49	5.58	124.84	1.50						
2028	537	0.01	3.94	3.72	98.33	0.14	33.08	6.09	204.35	1.50						
2029	568	0.01	4.48	4.21	49.00	0.00	20.24	3.80	148.47	1.50						
2030	602	0.01	2.71	2.64	0.75	0.00	4.15	1.54	0.00	1.50						
2031	639	0.01	2.85	2.78	2.34	0.00	8.83	2.09	0.00	1.50						
2032	679	0.01	3.01	2.93	5.62	0.00	14.12	2.65	0.00	1.50						
2033	723	0.02	3.19	3.10	11.43	0.00	20.12	3.21	0.00	1.50						

Table C.1.22: Pavement Deterioration Summary of Alternative 1 for Dholra Junction to EE Office Road Section.

Alternative: Base Option
Section: Dholra Junction to EE Office — **Road Class:** Tertiary or Local
Surface Class: Bituminous
Length: 0.10km — **Width:** 7.00m

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	Average Annual Values: All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	391	0.00	2.16	2.09	7.33	3.02	1.03	3.70	4.11	1.50						
2023	406	0.00	2.34	2.25	13.60	3.42	1.09	4.40	2.11	1.50						
2024	423	0.00	2.60	2.50	22.42	0.62	1.16	5.12	0.00	1.50						
2025	440	0.01	2.86	2.73	42.03	0.73	1.23	5.85	0.00	1.50						
2026	459	0.01	3.18	3.02	45.56	0.13	1.31	6.60	4.58	1.50						
2027	479	0.01	3.21	3.08	40.02	0.06	1.40	7.34	0.00	1.50						
2028	500	0.01	3.55	3.38	42.17	0.00	1.49	8.10	5.42	1.50						
2029	523	0.01	3.56	3.43	32.39	0.00	1.60	8.83	0.00	1.50						
2030	548	0.01	3.88	3.72	33.77	0.00	1.71	9.60	4.90	1.50						
2031	574	0.01	3.90	3.78	21.66	0.00	1.84	10.33	0.00	1.50						
2032	603	0.01	4.19	4.05	40.83	0.00	1.97	11.09	0.00	1.50						
2033	634	0.01	4.56	4.38	68.74	0.00	2.13	11.87	11.32	1.50						

Table C.1.23: Pavement Deterioration Summary of Alternative 3 for Dholra Junction to EE Office Road Section.

Alternative: Alternative 3
Section: Dholra Junction to EE Office — **Road Class:** Tertiary or Local
Surface Class: Bituminous
Length: 0.10km — **Width:** 7.00m

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	Average Annual Values: All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	391	0.00	2.16	2.09	7.33	3.02	1.03	3.70	4.11	1.50						
2023	406	0.00	2.34	2.25	16.62	6.83	1.09	4.41	4.22	1.50						
2024	423	0.00	2.57	2.45	32.66	13.01	1.16	5.13	4.34	1.50						
2025	440	0.01	2.87	2.72	57.85	22.13	1.23	5.88	13.38	1.50						
2026	459	0.01	3.17	3.02	80.82	18.27	1.31	6.67	34.64	1.50						
2027	479	0.01	3.45	3.31	93.38	5.66	1.40	7.52	71.18	1.50						
2028	500	0.01	3.71	3.58	98.84	0.13	1.49	8.39	115.58	1.50						
2029	523	0.01	3.97	3.84	98.90	0.00	1.60	9.28	165.28	1.50						
2030	548	0.01	4.26	4.12	49.45	0.00	0.86	5.09	109.11	1.50						
2031	574	0.01	2.18	2.09	0.00	0.00	0.13	1.79	0.00	4.44						
2032	603	0.01	2.25	2.21	0.00	0.00	0.26	1.92	0.00	4.44						
2033	634	0.01	2.31	2.28	0.00	0.00	0.42	2.06	0.00	4.44						

Table C.1.24: Pavement Deterioration Summary of Alternative 2 for Dholra Junction to EE Office Road Section.

Alternative:	**Alternative 2**		
Section:	**Dholra Junction to EE Office**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.10km**	**Width:**	**7.00m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	391	0.00	2.16	2.09	7.33	3.02	1.03	3.70	4.11	1.50						
2023	406	0.00	2.34	2.25	16.62	6.83	1.09	4.41	4.22	1.50						
2024	423	0.00	2.57	2.45	32.66	13.01	1.16	5.13	4.34	1.50						
2025	440	0.01	2.87	2.72	57.85	22.13	1.23	5.88	13.38	1.50						
2026	459	0.01	3.17	3.02	80.82	18.27	1.31	6.67	34.64	1.50						
2027	479	0.01	3.45	3.31	93.38	5.66	1.40	7.52	71.18	1.50						
2028	500	0.01	3.71	3.58	98.84	0.13	1.49	8.39	115.58	1.50						
2029	523	0.01	3.97	3.84	98.90	0.00	1.60	9.28	165.28	1.50						
2030	548	0.01	4.26	4.12	49.45	0.00	0.86	5.86	109.11	1.50						
2031	574	0.01	2.36	2.31	0.60	0.00	0.06	2.00	0.00	1.50						
2032	603	0.01	2.48	2.42	2.02	0.00	0.13	2.48	0.00	1.50						
2033	634	0.01	2.61	2.54	5.03	0.00	0.21	2.97	0.00	1.50						

Table C.1.25: Pavement Deterioration Summary of Alternative 1 for Dholra Junction to EE Office Road Section.

Alternative:	**Alternative 1**		
Section:	**Dholra Junction to EE Office**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.10km**	**Width:**	**7.00m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	391	0.00	2.16	2.09	7.33	3.02	1.03	3.70	4.11	1.50						
2023	406	0.00	2.34	2.25	16.62	6.83	1.09	4.41	4.22	1.50						
2024	423	0.00	2.57	2.45	32.66	13.01	1.16	5.13	4.34	1.50						
2025	440	0.01	2.86	2.71	57.85	22.13	1.23	5.88	13.38	1.50						
2026	459	0.01	3.17	3.01	80.82	19.12	1.31	6.67	34.64	1.50						
2027	479	0.01	3.44	3.31	93.38	6.50	1.40	7.52	71.18	1.50						
2028	500	0.01	3.70	3.57	98.84	0.98	1.49	8.39	115.58	1.50						
2029	523	0.01	3.97	3.84	99.74	0.00	1.60	9.28	165.28	1.50						
2030	548	0.01	4.26	4.12	49.83	0.00	0.86	5.86	109.31	1.50						
2031	574	0.01	2.69	2.63	0.75	0.00	0.06	2.00	0.00	1.50						
2032	603	0.01	2.81	2.75	2.37	0.00	0.13	2.48	0.00	1.50						
2033	634	0.01	2.95	2.88	5.70	0.00	0.21	2.96	0.00	1.50						

Table C.1.26: Pavement Deterioration Summary of Base Option for Dholra Guest House to DRDA Road Section.

Alternative:	**Base Option**		
Section:	**Dholra Guest House to DRDA**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.13km**	**Width:**	**7.00m**

					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	515	0.01	2.18	2.10	6.15	3.50	1.05	3.98	4.24	1.50						
2023	540	0.01	2.36	2.27	10.09	4.28	1.18	4.97	2.25	1.50						
2024	567	0.01	2.62	2.52	15.09	1.55	1.33	5.97	0.00	1.50						
2025	597	0.01	2.84	2.73	26.35	4.50	1.49	6.98	0.00	1.50						
2026	628	0.01	3.11	2.98	42.76	10.29	1.67	8.02	0.00	1.50						
2027	662	0.01	3.43	3.27	35.26	13.15	1.87	9.09	16.53	1.50						
2028	699	0.01	3.35	3.24	13.53	14.63	2.10	10.10	0.00	1.50						
2029	739	0.01	3.59	3.47	24.00	30.01	2.35	11.13	0.00	1.50						
2030	782	0.01	3.88	3.73	23.44	34.30	2.63	12.18	3.58	1.50						
2031	829	0.01	3.99	3.88	12.27	16.05	2.94	13.21	1.82	1.50						
2032	880	0.01	4.31	4.19	18.55	2.96	3.30	14.25	0.00	1.50						
2033	935	0.01	4.60	4.46	31.50	10.68	3.70	15.31	0.00	1.50						

Table C.1.27: Pavement Deterioration Summary of Alternative 3 for Dholra Guest House to DRDA Road Section.

Alternative:	**Alternative 3**		
Section:	**Dholra Guest House to DRDA**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.13km**	**Width:**	**7.00m**

					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	515	0.01	2.18	2.10	6.15	3.50	1.05	3.98	4.24	1.50						
2023	540	0.01	2.36	2.27	12.36	8.56	1.18	4.97	4.50	1.50						
2024	567	0.01	2.57	2.46	22.21	17.24	1.33	5.99	4.78	1.50						
2025	597	0.01	2.81	2.69	36.83	30.76	1.49	7.02	5.10	1.50						
2026	628	0.01	3.13	2.97	57.20	41.87	1.67	8.09	43.20	1.50						
2027	662	0.01	3.51	3.32	74.57	24.40	1.87	9.21	113.78	1.50						
2028	699	0.01	3.94	3.73	86.19	12.64	2.10	10.38	203.14	1.50						
2029	739	0.01	4.48	4.21	46.70	2.64	1.18	5.79	158.53	1.50						
2030	782	0.01	2.18	2.09	0.00	0.00	0.28	1.81	0.00	4.44						
2031	829	0.01	2.25	2.21	0.00	0.00	0.60	1.95	0.00	4.44						
2032	880	0.01	2.32	2.28	0.00	0.00	0.95	2.09	0.00	4.44						
2033	935	0.01	2.38	2.35	0.00	0.00	1.36	2.23	0.00	4.44						

Table C.1.28 Pavement Deterioration Summary of Alternative 2 for Dholra Guest House to DRDA Road Section.

Alternative:	Alternative 2		
Section:	Dholra Guest House to DRDA	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	0.13km	Width:	7.00m

					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	515	0.01	2.18	2.10	6.15	3.50	1.05	3.98	4.24	1.50						
2023	540	0.01	2.36	2.27	12.36	8.56	1.18	4.97	4.50	1.50						
2024	567	0.01	2.57	2.46	22.21	17.24	1.33	5.99	4.78	1.50						
2025	597	0.01	2.81	2.69	36.83	30.76	1.49	7.02	5.10	1.50						
2026	628	0.01	3.13	2.97	57.20	41.87	1.67	8.09	43.20	1.50						
2027	662	0.01	3.51	3.32	74.57	24.40	1.87	9.21	113.78	1.50						
2028	699	0.01	3.94	3.73	86.19	12.64	2.10	10.38	203.14	1.50						
2029	739	0.01	4.48	4.21	46.70	2.64	1.18	6.66	158.53	1.50						
2030	782	0.01	2.43	2.38	0.57	0.00	0.14	2.23	0.00	1.50						
2031	829	0.01	2.55	2.49	1.95	0.00	0.30	2.72	0.00	1.50						
2032	880	0.01	2.68	2.62	4.90	0.00	0.48	3.21	0.00	1.50						
2033	935	0.01	2.84	2.76	10.24	0.00	0.68	3.71	0.00	1.50						

Table C.1.29: Pavement Deterioration Summary of Alternative 1 for Dholra Guest House to DRDA Road Section.

Alternative:	Alternative 1		
Section:	Dholra Guest House to DRDA	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	0.13km	Width:	7.00m

					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	515	0.01	2.18	2.10	6.15	3.50	1.05	3.98	4.24	1.50						
2023	540	0.01	2.36	2.27	12.36	8.56	1.18	4.97	4.50	1.50						
2024	567	0.01	2.57	2.46	14.86	17.24	1.33	5.99	4.78	1.50						
2025	597	0.01	2.66	2.56	14.57	31.51	1.49	6.99	5.10	1.50						
2026	628	0.01	2.89	2.77	18.22	52.42	1.67	8.02	11.70	1.50						
2027	662	0.01	3.02	2.90	19.90	72.50	1.87	9.04	23.40	1.50						
2028	699	0.01	3.29	3.15	26.12	66.41	2.10	10.08	40.88	1.50						
2029	739	0.01	3.47	3.33	31.81	68.06	2.35	11.13	59.19	1.50						
2030	782	0.01	3.80	3.63	42.91	49.56	2.63	12.20	80.32	1.50						
2031	829	0.01	4.05	3.88	27.81	22.09	1.47	7.63	49.88	1.50						
2032	880	0.01	2.61	2.55	0.00	0.00	0.18	2.48	0.00	1.50						
2033	935	0.01	2.73	2.67	0.50	0.00	0.38	2.98	0.00	1.50						

Table C.1.30: Pavement Deterioration Summary of Base Option for Court Road near Purnam Mall to Regional Hospital Road Section.

Alternative:	Base Option		
Section:	Court Road near Purnam Mall to Regional Hospita	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	0.09km	Width:	7.00m

					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	520	0.00	2.16	2.09	6.01	2.32	1.05	3.81	4.14	1.50						
2023	547	0.00	2.32	2.24	11.87	4.45	1.16	4.64	4.28	1.50						
2024	576	0.00	2.51	2.42	14.11	3.80	1.29	5.47	2.22	1.50						
2025	608	0.00	2.70	2.61	13.70	0.64	1.43	6.30	0.00	1.50						
2026	642	0.01	2.90	2.80	23.83	1.15	1.58	7.15	0.00	1.50						
2027	679	0.01	3.15	3.03	38.55	1.84	1.76	8.01	0.00	1.50						
2028	720	0.01	3.44	3.30	31.78	1.37	1.96	8.90	9.12	1.50						
2029	764	0.01	3.37	3.27	10.40	1.03	2.18	9.75	0.00	1.50						
2030	812	0.01	3.58	3.47	18.83	2.53	2.43	10.60	0.00	1.50						
2031	864	0.01	3.83	3.71	31.38	5.22	2.71	11.48	0.00	1.50						
2032	921	0.01	4.13	3.98	49.09	9.63	3.03	12.38	21.93	1.50						
2033	983	0.01	4.48	4.31	68.13	16.92	3.40	13.31	60.76	1.50						

Table C.1.31: Pavement Deterioration Summary of Alternative 3 for Court Road near Purnam Mall to Regional Hospital Road Section.

Alternative:	Alternative 3		
Section:	Court Road near Purnam Mall to Regional Hospita	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	0.09km	Width:	7.00m

					Average Annual Values												
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	520	0.00	2.16	2.09	6.01	2.32	1.05	3.81	4.14	1.50						
2023	547	0.00	2.32	2.24	11.87	4.45	1.16	4.64	4.28	1.50						
2024	576	0.00	2.52	2.42	21.09	7.59	1.29	5.48	4.44	1.50						
2025	608	0.00	2.74	2.63	34.64	11.94	1.43	6.33	4.60	1.50						
2026	642	0.01	3.02	2.88	53.59	17.75	1.58	7.22	21.60	1.50						
2027	679	0.01	3.32	3.17	71.35	26.08	1.76	8.15	53.50	1.50						
2028	720	0.01	3.63	3.47	83.63	15.35	1.96	9.11	99.04	1.50						
2029	764	0.01	3.95	3.79	91.59	7.31	2.18	10.11	156.39	1.50						
2030	812	0.01	4.32	4.14	48.15	1.25	1.22	5.57	112.17	1.50						
2031	864	0.01	2.18	2.09	0.00	0.00	0.28	1.77	0.00	4.44						
2032	921	0.01	2.24	2.21	0.00	0.00	0.61	1.91	0.00	4.44						
2033	983	0.01	2.31	2.28	0.00	0.00	0.97	2.04	0.00	4.44						

Table C.1.33: Pavement Deterioration Summary of Alternative 2 for Court Road near Purnam Mall to Regional Hospital Road Section.

Alternative:	**Alternative 2**		
Section:	**Court Road near Purnam Mall to Regional Hospita**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.09km**	**Width:**	**7.00m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	520	0.00	2.16	2.09	6.01	2.32	1.05	3.81	4.14	1.50						
2023	547	0.00	2.32	2.24	11.87	4.45	1.16	4.64	4.28	1.50						
2024	576	0.00	2.52	2.42	21.09	7.59	1.29	5.48	4.44	1.50						
2025	608	0.00	2.74	2.63	34.64	11.94	1.43	6.33	4.60	1.50						
2026	642	0.01	3.02	2.88	53.59	17.75	1.58	7.22	21.60	1.50						
2027	679	0.01	3.32	3.17	71.35	26.08	1.76	8.15	53.50	1.50						
2028	720	0.01	3.63	3.47	83.63	15.35	1.96	9.11	99.04	1.50						
2029	764	0.01	3.95	3.79	91.59	7.31	2.18	10.11	156.39	1.50						
2030	812	0.01	4.32	4.14	48.15	1.25	1.22	6.40	112.17	1.50						
2031	864	0.01	2.39	2.33	0.55	0.00	0.14	2.14	0.00	1.50						
2032	921	0.01	2.50	2.44	1.84	0.00	0.30	2.62	0.00	1.50						
2033	983	0.01	2.63	2.56	4.57	0.00	0.49	3.09	0.00	1.50						

Table C.1.35: Pavement Deterioration Summary of Alternative 1 for Court Road near Purnam Mall to Regional Hospital Road Section.

Alternative:	**Alternative 1**		
Section:	**Court Road near Purnam Mall to Regional Hospita**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.09km**	**Width:**	**7.00m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	520	0.00	2.16	2.09	6.01	2.32	1.05	3.81	4.14	1.50						
2023	547	0.00	2.32	2.24	11.87	4.45	1.16	4.64	4.28	1.50						
2024	576	0.00	2.52	2.42	14.11	7.59	1.29	5.48	4.44	1.50						
2025	608	0.00	2.59	2.51	13.70	12.64	1.43	6.31	4.60	1.50						
2026	642	0.01	2.80	2.70	16.86	19.60	1.58	7.16	4.78	1.50						
2027	679	0.01	2.90	2.80	18.02	29.50	1.76	8.01	4.98	1.50						
2028	720	0.01	3.13	3.02	23.24	42.49	1.96	8.87	5.19	1.50						
2029	764	0.01	3.27	3.15	27.63	58.41	2.18	9.74	10.80	1.50						
2030	812	0.01	3.54	3.40	36.92	56.04	2.43	10.62	19.04	1.50						
2031	864	0.01	3.73	3.59	47.12	52.80	2.71	11.51	27.75	1.50						
2032	921	0.01	4.05	3.89	33.34	16.62	1.52	7.15	18.43	1.50						
2033	983	0.01	2.62	2.57	0.00	0.00	0.18	2.34	0.00	1.50						

Table C.1.36: Pavement Deterioration Summary of Base Option for College Chowk to Himachal Defence Academy Road Section.

Alternative:	**Base Option**		
Section:	**College Chowk to Himachal Defence Academy**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**1.23km**	**Width:**	**7.00m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	434	0.01	2.15	2.08	1.05	2.39	1.03	3.83	4.17	1.50						
2023	457	0.01	2.29	2.22	2.64	4.71	1.11	4.67	4.34	1.50						
2024	481	0.01	2.44	2.36	5.51	8.19	1.20	5.52	4.54	1.50						
2025	508	0.01	2.60	2.52	8.49	6.55	1.30	6.37	2.37	1.50						
2026	537	0.01	2.86	2.77	12.18	0.65	1.41	7.23	0.00	1.50						
2027	568	0.01	3.06	2.96	19.99	1.28	1.53	8.10	0.00	1.50						
2028	602	0.01	3.28	3.17	30.88	2.29	1.67	8.98	0.00	1.50						
2029	639	0.01	3.55	3.42	25.41	1.91	1.82	9.89	8.82	1.50						
2030	679	0.01	3.57	3.47	9.86	0.96	2.00	10.76	0.00	1.50						
2031	723	0.01	3.78	3.67	16.64	2.34	2.20	11.65	0.00	1.50						
2032	771	0.01	4.02	3.90	26.26	4.85	2.42	12.55	0.00	1.50						
2033	823	0.01	4.31	4.17	39.33	8.98	2.68	13.47	21.19	1.50						

Table C.1.37: : Pavement Deterioration Summary of Alternative 3 for College Chowk to Himachal Defence Academy Road Section.

Alternative:	**Alternative 3**		
Section:	**College Chowk to Himachal Defence Academy**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**1.23km**	**Width:**	**7.00m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	434	0.01	2.15	2.08	1.05	2.39	1.03	3.83	4.17	1.50						
2023	457	0.01	2.29	2.22	2.64	4.71	1.11	4.68	4.34	1.50						
2024	481	0.01	2.44	2.36	5.51	8.19	1.20	5.53	4.54	1.50						
2025	508	0.01	2.60	2.52	10.13	13.09	1.30	6.38	4.74	1.50						
2026	537	0.01	2.79	2.70	17.03	19.71	1.41	7.25	4.97	1.50						
2027	568	0.01	3.00	2.90	26.81	28.39	1.53	8.13	5.21	1.50						
2028	602	0.01	3.25	3.13	40.09	39.51	1.67	9.04	5.48	1.50						
2029	639	0.01	3.54	3.40	56.77	43.11	1.82	9.98	41.56	1.50						
2030	679	0.01	3.88	3.71	70.77	29.03	2.00	10.95	96.01	1.50						
2031	723	0.01	4.25	4.06	40.57	9.29	1.10	5.98	80.32	1.50						
2032	771	0.01	2.18	2.09	0.00	0.00	0.23	1.83	0.00	4.44						
2033	823	0.01	2.25	2.22	0.00	0.00	0.48	1.97	0.00	4.44						

Table C.1.38: : Pavement Deterioration Summary of Alternative 2 for College Chowk to Himachal Defence Academy Road Section.

Alternative:	Alternative 2			
Section:	College Chowk to Himachal Defence Academy		Road Class:	Tertiary or Local
Surface Class:	Bituminous			
Length:	1.23km		Width:	7.00m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	434	0.01	2.15	2.08	1.05	2.39	1.03	3.83	4.17	1.50						
2023	457	0.01	2.29	2.22	2.64	4.71	1.11	4.68	4.34	1.50						
2024	481	0.01	2.44	2.36	5.51	8.19	1.20	5.53	4.54	1.50						
2025	508	0.01	2.60	2.52	10.13	13.09	1.30	6.38	4.74	1.50						
2026	537	0.01	2.79	2.70	17.03	19.71	1.41	7.25	4.97	1.50						
2027	568	0.01	3.00	2.90	26.81	28.39	1.53	8.13	5.21	1.50						
2028	602	0.01	3.25	3.13	40.09	39.51	1.67	9.04	5.48	1.50						
2029	639	0.01	3.54	3.40	56.77	43.11	1.82	9.98	41.56	1.50						
2030	679	0.01	3.88	3.71	70.77	29.03	2.00	10.95	96.01	1.50						
2031	723	0.01	4.25	4.06	40.57	9.29	1.10	6.88	80.32	1.50						
2032	771	0.01	2.37	2.32	0.00	0.00	0.11	2.28	0.00	1.50						
2033	823	0.01	2.48	2.43	1.01	0.00	0.24	2.77	0.00	1.50						

Table C.1.39: Pavement Deterioration Summary of Alternative 1 for College Chowk to Himachal Defence Academy Road Section.

Alternative:	Alternative 1			
Section:	College Chowk to Himachal Defence Academy		Road Class:	Tertiary or Local
Surface Class:	Bituminous			
Length:	1.23km		Width:	7.00m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	434	0.01	2.15	2.08	1.05	2.39	1.03	3.83	4.17	1.50						
2023	457	0.01	2.29	2.22	2.64	4.71	1.11	4.68	4.34	1.50						
2024	481	0.01	2.44	2.36	5.51	8.19	1.20	5.53	4.54	1.50						
2025	508	0.01	2.60	2.52	10.13	13.09	1.30	6.38	4.74	1.50						
2026	537	0.01	2.79	2.70	11.80	19.71	1.41	7.25	4.97	1.50						
2027	568	0.01	2.90	2.81	11.75	28.85	1.53	8.12	5.21	1.50						
2028	602	0.01	3.10	3.00	13.86	40.65	1.67	9.00	5.48	1.50						
2029	639	0.01	3.23	3.13	14.40	55.54	1.82	9.88	11.98	1.50						
2030	679	0.01	3.45	3.34	17.62	68.63	2.00	10.77	21.51	1.50						
2031	723	0.01	3.61	3.50	19.86	79.15	2.20	11.66	34.21	1.50						
2032	771	0.01	3.87	3.74	25.19	69.18	2.42	12.57	50.13	1.50						
2033	823	0.01	4.07	3.93	15.22	34.72	1.34	7.75	33.02	1.50						

Table C.1.40: Pavement Deterioration Summary of Base Option for Bilaspur Firestation to Lower Nihal Road Section.

Alternative:	**Base Option**		
Section:	**Bilaspur Firestation to Lower Nihal**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.50km**	**Width:**	**3.00m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	324	0.00	2.13	2.07	1.39	3.14	1.09	3.57	4.10	1.50						
2023	341	0.00	2.25	2.19	3.92	7.32	1.37	4.15	4.21	1.50						
2024	359	0.00	2.39	2.32	8.84	7.16	1.67	4.73	2.17	1.50						
2025	379	0.00	2.66	2.57	17.25	0.85	2.01	5.32	0.00	1.50						
2026	401	0.00	2.86	2.76	30.40	1.86	2.39	5.92	0.00	1.50						
2027	424	0.00	3.12	2.99	49.69	3.60	2.82	6.54	0.00	1.50						
2028	450	0.01	3.39	3.26	70.73	7.02	3.30	7.18	0.00	1.50						
2029	477	0.01	3.65	3.52	42.48	7.03	3.84	7.85	14.40	1.50						
2030	507	0.01	3.30	3.23	1.73	1.89	4.46	8.45	0.00	1.50						
2031	540	0.01	3.46	3.38	4.65	5.87	5.16	9.05	0.00	1.50						
2032	576	0.01	3.64	3.55	10.15	13.76	5.96	9.66	0.00	1.50						
2033	614	0.01	3.85	3.74	19.36	27.33	6.88	10.27	0.00	1.50						

Table C.1.1: Pavement Deterioration Summary of Alternative 3 for Bilaspur Firestation to Lower Nihal Road Section

Alternative:	**Alternative 3**		
Section:	**Bilaspur Firestation to Lower Nihal**	**Road Class:**	**Tertiary or Local**
Surface Class:	**Bituminous**		
Length:	**0.50km**	**Width:**	**3.00m**

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	324	0.00	2.13	2.07	1.39	3.14	1.09	3.57	4.10	1.50						
2023	341	0.00	2.25	2.19	3.92	7.32	1.37	4.15	4.21	1.50						
2024	359	0.00	2.39	2.32	8.84	14.32	1.67	4.74	4.33	1.50						
2025	379	0.00	2.56	2.48	17.25	24.96	2.01	5.33	4.45	1.50						
2026	401	0.00	2.77	2.66	30.40	40.16	2.39	5.94	4.58	1.50						
2027	424	0.00	3.02	2.89	49.69	50.15	2.82	6.56	8.15	1.50						
2028	450	0.01	3.30	3.16	70.73	29.09	3.30	7.21	12.86	1.50						
2029	477	0.01	3.57	3.44	84.57	15.13	3.84	7.90	42.07	1.50						
2030	507	0.01	3.87	3.72	92.96	6.58	4.46	8.61	83.84	1.50						
2031	540	0.01	4.20	4.03	48.72	0.96	2.58	4.68	66.60	1.50						
2032	576	0.01	2.18	2.09	0.00	0.00	0.80	1.77	0.00	4.44						
2033	614	0.01	2.24	2.21	0.00	0.00	1.72	1.90	0.00	4.44						

Table C.1.1: Pavement Deterioration Summary of Alternative 2 for Bilaspur Firestation to Lower Nihal Road Section

Alternative:	Alternative 2		
Section:	Bilaspur Firestation to Lower Nihal	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	0.50km	Width:	3.00m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	324	0.00	2.13	2.07	1.39	3.14	1.09	3.57	4.10	1.50						
2023	341	0.00	2.25	2.19	3.92	7.32	1.37	4.15	4.21	1.50						
2024	359	0.00	2.39	2.32	8.84	14.32	1.67	4.74	4.33	1.50						
2025	379	0.00	2.56	2.48	17.25	24.96	2.01	5.33	4.45	1.50						
2026	401	0.00	2.77	2.66	30.40	40.16	2.39	5.94	4.58	1.50						
2027	424	0.00	3.02	2.89	49.69	50.15	2.82	6.56	8.15	1.50						
2028	450	0.01	3.30	3.16	70.73	29.09	3.30	7.21	12.86	1.50						
2029	477	0.01	3.57	3.44	84.57	15.13	3.84	7.90	42.07	1.50						
2030	507	0.01	3.87	3.72	92.96	6.58	4.46	8.61	83.84	1.50						
2031	540	0.01	4.20	4.03	48.72	0.96	2.58	5.38	66.60	1.50						
2032	576	0.01	2.31	2.26	0.00	0.00	0.40	1.88	0.00	1.50						
2033	614	0.01	2.42	2.37	1.01	0.00	0.86	2.36	0.00	1.50						

Table C.1.1: Pavement Deterioration Summary of Alternative 1 for Bilaspur Firestation to Lower Nihal Road Section

Alternative:	Alternative 1		
Section:	Bilaspur Firestation to Lower Nihal	Road Class:	Tertiary or Local
Surface Class:	Bituminous		
Length:	0.50km	Width:	3.00m

					Average Annual Values											
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2022	324	0.00	2.13	2.07	1.39	3.14	1.09	3.57	4.10	1.50						
2023	341	0.00	2.25	2.19	3.92	7.32	1.37	4.15	4.21	1.50						
2024	359	0.00	2.39	2.32	8.84	14.32	1.67	4.74	4.33	1.50						
2025	379	0.00	2.56	2.48	17.25	24.96	2.01	5.33	4.45	1.50						
2026	401	0.00	2.77	2.66	22.41	40.16	2.39	5.94	4.58	1.50						
2027	424	0.00	2.86	2.76	26.07	61.50	2.82	6.54	8.15	1.50						
2028	450	0.01	3.11	2.98	35.45	56.40	3.30	7.16	13.87	1.50						
2029	477	0.01	3.26	3.13	45.45	54.35	3.84	7.78	19.52	1.50						
2030	507	0.01	3.55	3.41	59.50	32.28	4.46	8.42	25.38	1.50						
2031	540	0.01	3.74	3.59	71.96	27.77	5.16	9.07	29.49	1.50						
2032	576	0.01	3.99	3.86	77.46	14.25	5.96	9.75	30.57	1.50						
2033	614	0.01	4.14	4.01	41.93	7.91	3.44	5.99	15.87	1.50						

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