PAVEMENT MANAGEMENT SYSTEM FOR URBAN ROAD NETWORK USING HDM-4 & ARC GIS SOFTWARE

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Abstract:

Pavements are major assets of urban infrastructure. But their maintenance and rehabilitation to the desired level of serviceability is one of the most challenging problems faced by pavement engineers.

In this study, the optimum maintenance strategy and a maintenance management plan were developed using the Highway Design and Management tool (HDM-4) software. To provide a powerful system in the urban road network, a study was carried out for the Solapur Road network.

The Highway Development and Management-4 (HDM-4) software has been used for strategy and program analysis of the seven sections of Solapur city. The Pavement Management System plays a priority in the preventive maintenance of roads in good condition rather than constructing roads in poor condition. A good spatial database is essential to ensure maintenance is done in an effective manner. Spatial data must include information such as the road name and length, geometric properties of the road such as whether it is a local or arterial, number of lanes, pavement width, and rating; it should also contain maintenance status and history. This information will be useful for ease of analysis and ease of visual displays of results. Integration with pavement and other roadway maintenance leads to enhanced decision-making processes and cost savings in the future, so the use of a GIS in every transportation agency. Hence an attempt is made to use ARC GIS software for creating a database of the seven sections of Solapur City.

By using the life cycle cost analysis technique through a program analysis tool, a rolling work program for the ten-year period is evaluated. The optimum maintenance treatment for urban roads was identified using HDM--4, a modern and sophisticated tool developed by the World Bank. The project analysis and network analysis of various aspects of PMS have been demonstrated through case studies by making use of HDM--4. This has been used for the planning and programming of various maintenance activities.

Key Words: Highway Development and Management (HDM), Geographic Information System (GIS), Pavement Management System (PMS), Road Investment Design Model (R.I.D.M.).

1 Introduction

1.1 Project Background:

Road transportation has played a significant role in the overall economic growth of India. The growth of road traffic in the past independence era was quite unpredictable both in terms of goods and passenger traffic. The vehicular population increased from 3 lakh kilometers to 430 Lakhs kilometers during the period 1951-2001. Unfortunately, however, there was not a proportional increase in the road network with such huge population growth. Traffic loadings have been much heavier than the specified limit of 10.2 tons. Roads deteriorate excessively without adequate and timely maintenance, leading to higher vehicle operating costs, increased accidents, and reduced consistency of transport services. Thus, there is a need for developing a scientific approach to determining maintenance requirements for pavements. Efforts are also needed to develop road management tools that can improve existing highway networks by assessing financial needs, evaluating alternative maintenance strategies, and prioritizing work programs. In such a situation, an efficient pavement management system would provide objective information and useful analysis needed to ensure consistent decisions related to the preservation of highway networks [1].

1.2 Importance

Roads are the means of transportation that carry goods and people from one place to another. This road network improves socio-economic growth and also the economy of a country. By giving more importance to the improvement of road networks, we can achieve better economic growth and social benefits for a country. Road maintenance is important for mobility, vehicle operating costs, and accident rates. Therefore, it is necessary for governments to invest in regular road maintenance to achieve sustainable road maintenance with scarce public resources. Many developing countries like India, Bangladesh, Malaysia, China, etc. spend just 20-50 percent for the maintenance of their road network. Maintenance of roads is an ongoing or continuous process that requires effective management for keeping the roads in good condition.

In order to improve the condition of the pavement there is a need to spend more funds on road maintenance treatments. But the investment made for the maintenance of the road is very less. So to avoid the gap between available and required funds, there is a need to develop a Pavement Management System to achieve optimum utilization of available funds by deciding the proper treatment over available funds. Now a day various organizations adopted their own method of pavement management systems. But this paper intends to formulate guidelines for the maintenance of pavement management systems on urban roads.

1.3 Present Scenario in Maintenance Activities

The Indian roads are classified into primary, secondary, and tertiary roads. Based on the importance of roads various maintenance activities are practiced. Because of availability of funds is very less for maintenance activities. There is very less importance given to the maintenance of these roads, especially secondary and tertiary roads. Hence, in order to avoid the fewer funds available and to properly utilize the available funds, there is a need to properly plan for maintenance activities.

The major deficiency in selecting the maintenance practice is that there is no proper analytical tool to support particular pavement sections for maintenance activity. Also, in earlier days maintenance activities were selected based on subjective judgment, engineering experience, and periodicity. In order to avoid this method of selection of stretches for maintenance activities use of modern tools like HDM-4, Micro-PAVER, RIDM, etc. is suggested.

The present project work uses World Bank-developed software HDM-4 to analyze pavement deterioration conditions and economic conditions to suggest the optimum maintenance strategy for identified study stretches.

1.4 Application of ArcGIS Software

A geographic information system (GIS), also known as a computerized mapping system, is a powerful tool used to capture, store, query, analyze and display geographic information[7].

1.5 Objectives of the Study

The purpose of this study is to develop a pavement management system for an identified urban road network and propose pavement maintenance treatments and improvement strategies based on the degree of deterioration. Prioritization of pavement sections based on Net Present Value /Cost Ratio. Also, creating various network maps and adding attributes using ArcGIS software.

2 Literature Review

2.1 General

To implement a pavement management system, various literature survey is carried out. Some of the references considered for the present study includes below.

2.2 Review of HDM-4

Sanjiv Agarwal, Prof. S. S. Jain, and Dr. M. Parida (2004)[1] in their paper entitled "***Development of pavement management system for Indian national highway network"*** The purpose of this study is to develop a pavement management system for an identified urban road network. And also, they were interested to develop a systematic procedure to predict the economic maintenance strategy and also prioritization of maintenance activity. To conduct their analysis, they used the software i.e., HDM-4 developed by World Bank in 1998. This study involves various aspects of project-level and network-level PMS. And it is demonstrated through four different case studies.

R. Sudhakar (2009) [2] in their paper entitled ***"Pavement maintenance management system for urban roads using HDM-4"*** This paper presents an analysis of maintenance strategies for urban roads in India, identifying the most promising alternative. Also, The HDM-4 software tool developed by the World Bank can be effectively utilized for identifying optimum maintenance strategies for highway pavements. They did both pavement deterioration and economic analysis using the software HDM-4 and they successfully come up with good results and conclusions.

Geethu Saji, Sreelatha T, and B.G Sreedevi (2013)[3] in their paper entitled ***"A study on pavement performance and overlay design using HDM-4"***The main purpose of this paper is to introduce a cost-effective and feasible Pavement Management System by providing ultrathin white topping as an overlay. And also, did a structural and functional evaluation of the flexible pavement section of about 11.47 km in Kerala city. They also did the analysis work using the scientific software tool HDM-4. From the analysis work, they come to the conclusion that the use of ultra-thin white topping will give good results for a longer design life of the pavement.

S.S.Naidu, Dr.P.K.Nanda, et al., (2003)[4] in their paper entitled ***"Pavement maintenance management system for urban roads using software HDM-4 a case study"*** In this study, have made an attempt to create the pavement management system for inner ring road of Delhi city. And also, their aim is to select optimum maintenance strategies among various other alternatives. Finally, they were able to create maintenance management plans based on the economic analysis of life cycle costs using the Highway Design and Management tool (HDM-4). This paper also studied the existing maintenance practices and their deficiencies and also indicated the serviceability levels for different categories of roads and explained the reason for deficiencies in the current maintenance practices.

The objective of this project is to develop a comprehensive pavement maintenance management system for the inner ring road by using HDM-4 software. For this study, they have selected the major arterial road of Delhi having 48 km length. Also, this study aims to collect the comprehensive database required for developing PMS using HDM-4.

Kunal Jain, Sukhvir Singh Jain, et al., (2013)[5] in their paper entitled ***"Selection of optimum maintenance and rehabilitation strategy for multi-lane highways"*** This paper is intended to select maintenance treatment based on the realistic approach instead of selecting the pavement section based on subjective judgment and engineering experience. They used HDM-4 software in order to implement an effective pavement rehabilitation program that is feasible and globally accepted. HDM-4's program analysis component enables them to collect detailed data and choose the most cost-effective maintenance and rehabilitation strategy.

Maher Abdel Fatah AI-Hallaq (2004)[6] in their project entitled ***"Development of a Pavement Maintenance Management System for Gaza City"*** Here they considered the Ghaza City, which is the main gate between Africa and Asia. And they clearly explained the current threats related to highway projects like an increase in pavement deterioration rates, overloading of vehicles, poor maintenance, rapid increase in traffic growth rate, etc., also some of the future threats. In the report, they also recorded the traditional maintenance practices.

This project report aims to accomplish the following:

1. To develop a suitable database for the Ghaza city pavements.

2. To select the evaluation system for the Ghaza city pavements.

3. For the development of the maintenance management system they used PAVER software to review, interpret and evaluate the data for supporting the decision made.

4. To develop the software which facilitates the management process for Ghaza city pavements.

4. They showed both micro-PAVER and Geo Media Professionals are good tools to enhance the management process and also to facilitate the decision-making processes of Ghaza pavement networks.

3 Identification of Road Network

3.1 Selection of Road Network

The first stage in developing a pavement management system is to determine the roadway network for which the system is needed. In the current study, a network of 5.2 km of road in Solapur city was identified to develop the Pavement Management System. The total length of 5.2 km has been divided into seven segments. The details of the sections are shown in Table- 1. The layout of this road network is shown in Fig.1. This road network carries major traffic throughout the day, and also, educational institutes, colleges, and market yards are situated beside these road sections.

Table-1: Selected Road Network

Sr.no.	Section ID	Description
1	Road-1(553.4m)	WIT to Karniknagar stop
2	Road-2(855.21m)	WIT to Civil Chowk
3	Road-3(569.84m)	WIT to Water tank
4	Road-4(803.53m)	Water tank to Old Boramani Naka
5	Road-5(582.24m)	Old Boramani Naka to Market Yard
6	Road-6(798.51m)	Old Boramani Naka to Kannachowk
7	Road-7(954.95m)	Old Boramani Naka to Dyanand College

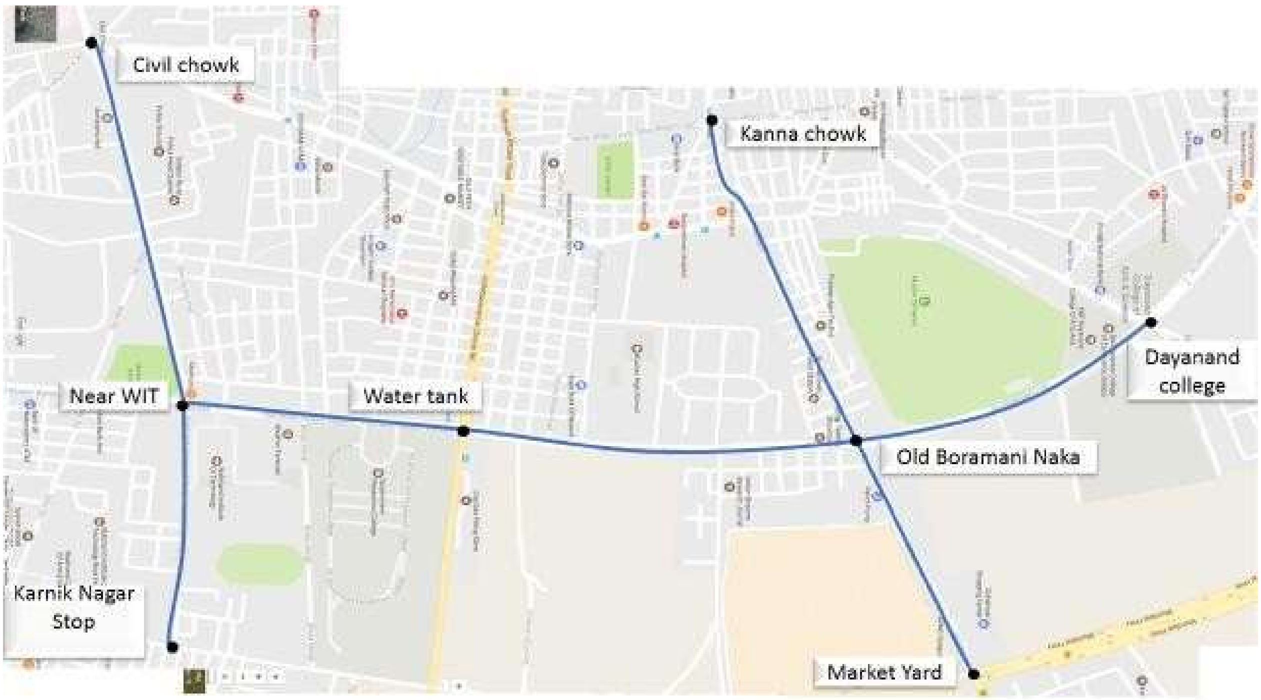

Figure -1 Selected Road Network Map of Solapur City

4 Field Studies and Data Collection

4.1 General

The study has generated a large amount of data, and it is crucial to gather all pavement-related information in order to manage it effectively. While gathering data, it was intended that the data, either directly or in its derived form, should meet the requirements of the HDM-4 system. The four categories below were used to group the data-collecting process:

(i) Road Network Data

(ii) Vehicle Fleet Data

(iii) Maintenance and Rehabilitation Works Data

(iv) Cost Data

i) Road Network Database

Tables 2 to 5 contain all road network data elements that must be provided for each pavement portion. The road network database made in HDM-4 holds all of these data components. For all foreseeable purposes and references, this road network database has been given the name "Arterial Road Network.".

Table 2 Highway Network- Basic Data

Section ID	Road Name	Length (m)	Width of Carriageway (m)	Motorized (AADT)	AADT Year	Comments
R1	WIT to Karniknagar stop	553.4 m	9.7	1429	2017	For all the pavement sections 1)Climatic zone: Semi Arid (Solapur) 2) Traffic Flow Pattern: Inter- Urban
R2	WIT to Civil Chowk	855.21m	14.2	2905	2017	
R3	WIT to Water tank	569.84m	14.8	6424	2017	
R4	Water tank to Old Boramani Naka	803.53m	14	6611	2017	
R5	Old Boramani Naka to Market Yard	582.24m	20	6536	2017	
R6	Old Boramani Naka to Kannachowk	798.51m	20.2	4854	2017	
R7	Old Boramani Naka to Dyanand College	954.95m	15.6	2285	2017	

Table 3 Highway Network - Condition Details

Section ID	Year of Condition	Roughness IRI(m/km)	Crack Area (%)	Raveled Area	No. of Pothole (no./Km)	Rut Depth (mm)	Deflection (mm)	Drainage Condition
R1	2016	4.0	1.0	2.0	0	5.0	0.7	Excellent
R2	2016	3.0	0	0	0.2	5.0	0.47	Excellent
R3	2016	3.0	20.0	4.0	0.3	0	0.7	Excellent
R4	2016	2.0	10.0	12.0	0.55	5.0	0.7	Fair
R5	2016	5.0	20.0	18	0.02	5.0	0.7	Fair
R6	2016	3.0	8.0	21.0	0.06	5.0	0.7	Good
R7	2016	8.0	30.0	40.0	15.0	5.0	0.7	Poor

Table 4 Highway Network - Maintenance history detail

Section Name	Type of Pavement	Current Pavement Thickness (mm)	Previous Pavement Thickness (mm)	Last construction Year	Last Preventive Treatment Year
WIT to Karnik Nagar stop	Bitumen	20	15	2007	2016
WIT to Civil chowk	Bitumen	20	13.2	2007	2016
WIT to Water tank	Bitumen	20	0	2007	2016
Water tank to Old Boramani Naka	Bitumen	20	0	2007	2016
Old Boramani Naka to Market Yard	Bitumen	20	15	2007	2016
Old Boramani Naka to Kanna Chowk	Bitumen	20	15	2007	2016
Old Boramani Naka to Dayanand College	Bitumen	20	13.2	2007	2016

Table 5 Laboratory test results of subgrade soil samples

Section ID	Optimum Moisture Content (OMC)	Atterberg limit (%)			Soaked CBR, %
		Liquid Limit	Plastic Limit	Plasticity Index	
R1	10.3	40	35	5	20
R2	10.9	42	35	7	18
R3	11.5	45	37	8	20
R4	11.2	44	36	8	17
R5	10.5	41	38	3	19
R6	10.1	40	35	5	16
R7	11.12	43	38	5	15

4.2 Vehicle Fleet Data: The following data collected is related to the vehicle fleet such as

a) Categories of vehicles b) Representative vehicles c) Traffic volume counts d) Composition of Traffic and vehicle growth rate:

a) Categories of Vehicles: Both motorized (MT) and non-motorized (NMT) vehicles are typically present in the traffic flow on all types of Indian highways, including National Highways.

b) Representative Vehicles: The makeup of the traffic, the functional distinctions between various vehicle kinds, the study's goals, and the quantity and quality of data all have an impact on the selection of the number of representative cars. For the purposes of the PMS economic study, the following vehicles might be regarded to make up a typical Indian vehicle fleet. In the most recent Road User Cost Study, the same collection of cars was also determined to be a representative vehicle fleet for Indian conditions:

• Two-Wheeler (TW)

• Passenger Car (PC)
• Bus (BUS)
• Light Commercial Vehicle (LCV)
• Medium Commercial Vehicles (MCV)
• Heavy Commercial Vehicles (HCV)

c) Traffic Volume Counts: Three days in a row, traffic counts were manually done continuously, with appropriate staff of enumerators. The traffic volume study includes a count of the different types of traffic. According to the representative cars mentioned in the preceding section, the vehicles were categorized.

d) Composition of Traffic and Vehicle Growth Rate: Despite the fact that traffic volumes varied greatly on all pavement sections, the distribution of representative cars in the traffic was determined to be quite uniform. Table 6 contains the traffic volume composition used for this investigation.

Table 6: Classified Vehicle Composition

Road Section Name	Vehicle Type						
	Two Wheelers	Auto Rickshaw	Cars	Mini Bus	Standard Bus	Light Commercial Vehicles	Heavy Commercial Vehicles
	Vehicle Composition, %						
WIT to Karnik Nagar	69	13	14	0	0	4	0
WIT to Civil Chowk	81.33	9.08	6.25	0.04	1.38	1.81	0.11
WIT to Water Tank	61.82	17.53	8.48	0.04	1.3	5.5	5.33
Water Tank to Old Boramani	58.38	11.28	12.41	0.29	0.6	7.38	9.66
Old Boramani Naka to Market Yard	53.32	23.91	9.15	0.07	0.53	5.93	7.09

4.3 Maintenance & Rehabilitation Activities:

The term "maintenance and rehabilitation" (M&R) refers to the measures that an organisation takes on a specific segment to either avoid or react to pavement degradation. A course of action to be followed during the analysis period in order to maintain the road segment in excellent condition is known as the M&R strategy. During the treatment application phase, a method entails applying one or more treatments to the portion at a certain time. Depending on the class and kind of road, the cross-section that has to be maintained, the flaws identified, and the resources available, maintenance tasks might be challenging. Typically, maintenance tasks are grouped into groups based on planning, financing, and organizational structures.

a) Cost Data of M & R Works: Due to the location of all pavement sections on the chosen highway network in the Solapur Circle area of the Maharashtra Public Work Department (MPWD), these prices have been used for this study. The treatment cost details are furnished in Table-7.

Table 7: Treatment Cost details

Sr. No.	Type of Maintenance Work	Treatment Cost (₹/m^2)
1	Asphaltic Concrete On a Granular Base	40-48
2	50mm Overlay Of Asphaltic Concrete	15-18
3	Crack Sealing	05-06
4	Patching of Pothole	12-14.4
5	Edge Repair	14-16.8
6	Surface Dressing	05-06
7	Mill 75mm+Replace 75mm	25.5-30
8	Mill 75mm+ Replace 100mm	30-36
9	Inlay at Rut Depth	20-24

4.4 Road User Cost Data:

Determining the road user cost (RUC) during maintenance and rehabilitation operations is one of the most crucial components of the life-cycle cost analysis of pavements, whether at the network level or project level. RUC models are crucial in contracting techniques that consider how long a project will take to complete before being awarded and paid for. Road user cost studies conducted in India to now have demonstrated the analytical nature of the only methods utilized to calculate RUC. Three key factors make up the road user cost: (i) the cost of operating the vehicle; (ii) the cost of time; and (iii) the cost of accidents. The greatest component is Vehicle Operating Cost (VOC), which is also quite simple to quantify. As a result, this expense is left out of the analysis. The updated road user cost study's guidelines were followed while gathering data on road user costs for all representative vehicles. [MORT&H2001c19].

5 Project Level Analysis and Results

The "Project Analysis" application of the HDM-4 may be used to do the project-level pavement management study. The appraisal of one or more road projects or investment possibilities is the focus of project analysis. For project-level pavement management, the following two types of case studies have been conducted in the current study.

(i) PROJ 1 - Determination of optimum maintenance and rehabilitation strategy.

(ii) PROJ 2 - Determination of the best optimum improvement strategy.

5.1 Determination of Optimum Maintenance and Rehabilitation

This case study gives an economic analysis of alternative maintenance and rehabilitation standards for a pavement section.

5.1.1 Input data

The input data for this case study is found in the previously specified 'Road Network' and 'Urban Road Vehicle Fleet' databases. The analysis period is set by a start year (2017, for example) and a duration of 20 years (2017-2036). All of these project details are defined in the 'Project Analysis' application of HDM-4's initial page.

5.1.2 Proposed M&R alternatives

Table 8 defines the four M&R choices explored for this case study. The first option, the Base option, provides the bare minimum of routine maintenance in the form of crack sealing and potholefixing until the pavement area must be rebuilt. In this case study, several different maintenance and rehabilitation options, including as resealing and overlay, were explored. Because the selected pavement section belongs to the highest serviceability level (Level l) group of pavement sections, the applicable maintenance requirements and acceptable intervention criteria have been determined based on the serviceability indicators. All of the maintenance requirements stated here are effective beginning with the first year of the analysis period, which is 2017.

Table 8 Proposed M&R Alternatives and Intervention Criteria Assigned

Various Alternative	**Details of Work standards**	**Description of work standards**	**Intervention level Assigned**
Base Alternative (Do nothing)	Routine +Maintenance	Edge repair 15% Pothole patching 50% Crack sealing 100%	Transverse cracks> 15 no./km, Severally damaged area> 5% Roughness> 10 IRI
Alternative 1	Routine+ Reconstruction	Reconstruction Patching Crack sealing	Roughness >=10 IRI Total damage area >= 40 % Severely damaged area>= 5 % Wide structural cracking >= 10 %
Alternative 2	Routine + Overlay 50 mm	Crack sealing Patching Overlay 50 mm and 15% cracking	Total Damage Area>=15% Roughness> =5 IRI Severely damaged area >= 5% Wide structural cracking >= 10%

Alternative 3	Routine + Surface dressing+ 50 mm overlay	Overlay 50mm and 15% cracking Crack sealing Patching Resealing with 25 mm SDBC	Roughness>=6.0 IRI Total damaged area >= 15% Severely damaged area >= 5% Wide structural cracking >= 10%
Alternative 4	Mill 75mm + Replace 75mm	Mill 75mm and Replace 75mm Patching Crack sealing	Roughness>=8.0 IRI Total carriageway crack >=20 % Severely damaged area >= 5% Wide structural cracking >= 10%
Alternative 5	Mill 75mm + Replace 100mm	Mill 75mm and Replace 100mm Patching Crack sealing	Roughness>=8.0 IRI Total carriageway crack >=20 % Severely damaged area >= 5% Wide structural cracking >= 10%
Alternative 6	Routine + Inlay	Routine and Inlay Patching Crack sealing	Rut depth mean >= 20mm Severely damaged area >= 5% Wide structural cracking >= 10%

The details of the maintenance standard entered in HDM-4 software are shown in fig-2 to 4.

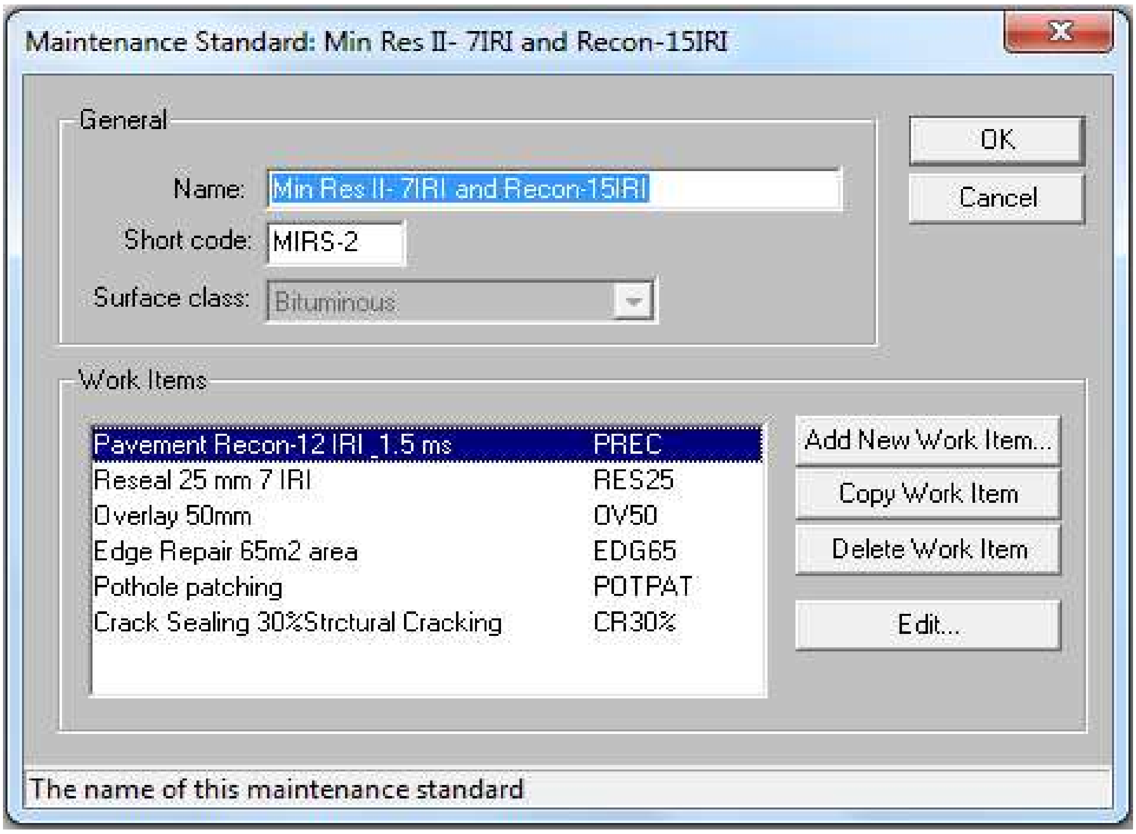

Figure 2 Work Standards for the Solapur City Road Network

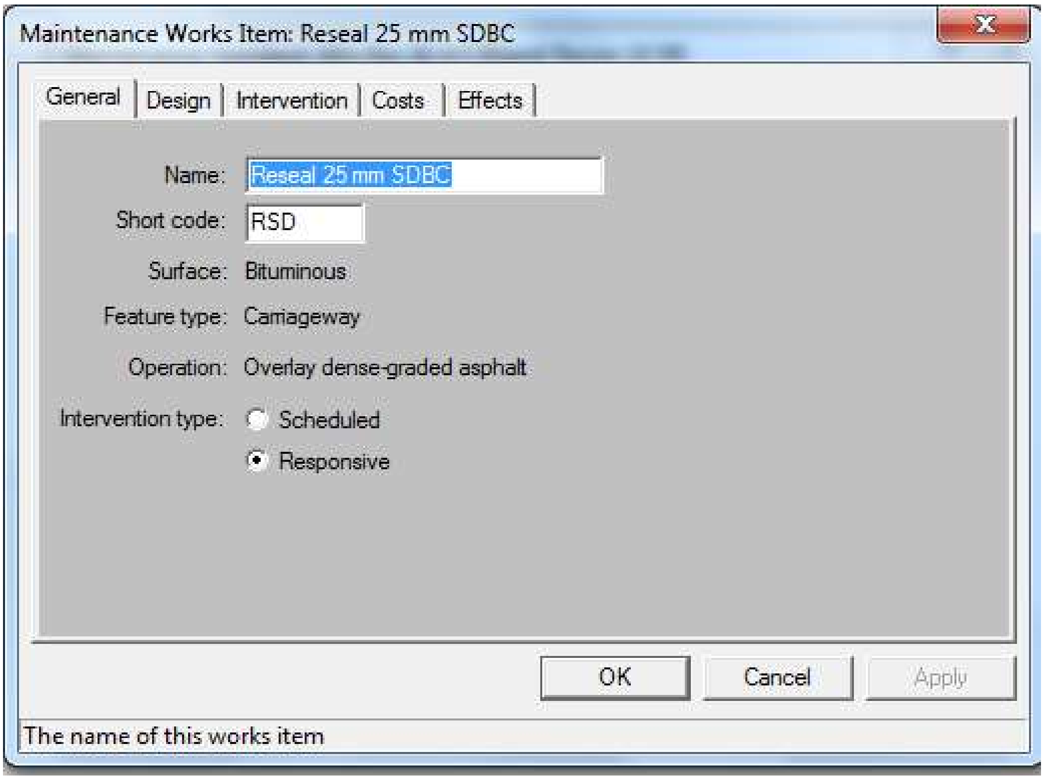

Figure 3 Maintenance Standards Assigned for the Solapur City Network

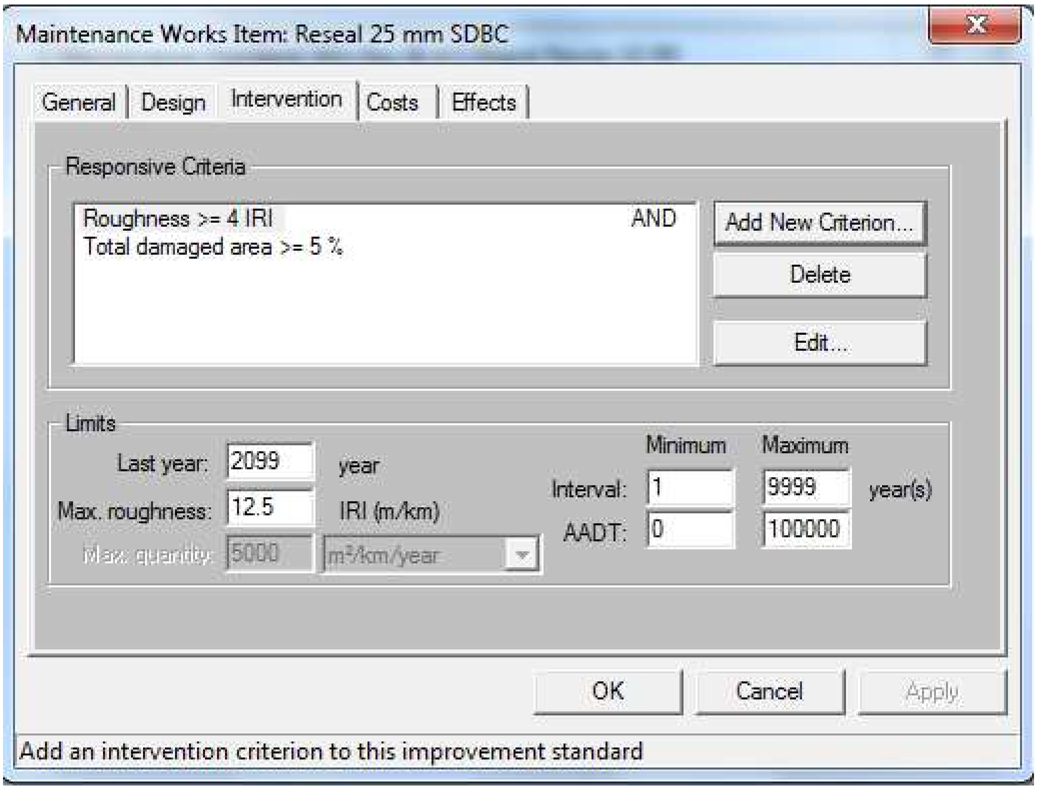

Figure 4 Intervention for Solapur City Network Maintenance Work Items

5.1.3 Project analysis

The Base Alternative is validated during analysis setup, and a discount rate of 12% is selected. Alternatives 1 through 6 are compared to the Base Alternative during the project study, and then the pavement degradation and M&R work reports are prepared.

5.1.4 Economic analysis summary

Table 9 shows the economic analysis summary, which compares the present value of total agency expenses and reductions in road user fees for each M&R alternative to the Base Alternative. For comparison, economic measures such as Net Present Value (NPV) and Internal Rate of Return (IRR) are supplied. The result of the economic analysis is shown in Teble-9 below.

Table 9: Economic Analysis (Rupees millions)

Alternative	Total Agency Cost	Increase In Agency Cost	Decrease in Road User Cost	Net Present Value (NPV)	NPV/Cost Ratio	Internal Rate Of Returns (IRR)
Do Nothing	0.904	0.000	0.000	0.000	0.000	0.000
Alternative1	1.588	0.684	1.539	0.856	1.530	17.500
Alternative2	**1.243**	**0.339**	**6.329**	**5.911**	**13.43**	**47.800**
Alternative3	10.470	9.566	9.621	0.560	0.006	12.100
Alternative4	1.370	0.465	1.394	0.929	2.602	19.000
Alternative5	1.360	0.458	1.322	0.864	2.470	18.700
Alternative6	1.235	0.330	-5.458	-5.788	-393.470	No Solution

5.1.5 Selection of Optimum M&R Strategy

Alternative 2 has been chosen as the best M&R plan for a particular pavement portion based on the summary of the economic study for a selected pavement section that is from Old Boramani Naka to Dayanand College, having the maximum NPV/Cost of 13.43.

5.1.6 Roughness progression

The most reliable indication of pavement degradation or the typical state of the pavement segment at any given moment is roughness. Fig. 5 depicts the impact of the tasks to be completed under each choice on the pavement section's average roughness. To ensure that the activities are properly triggered in accordance with the established intervention criteria, the evolution of roughness can be monitored.

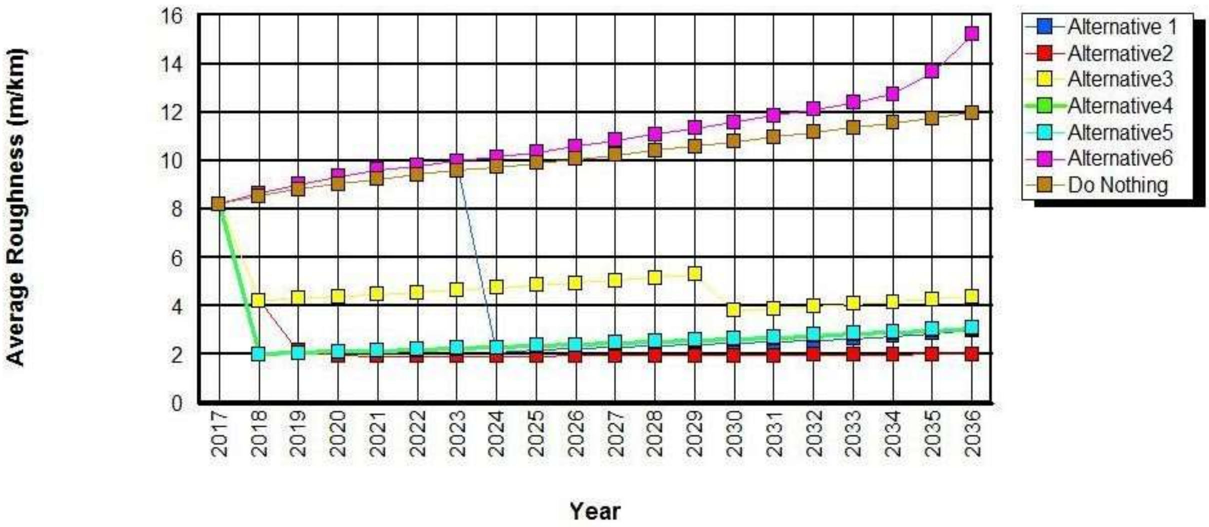

Figure 5: Progression of Roughness under various alternatives

5.2 Determination of Optimum Improvement Strategy

The economic evaluation of several standards for upkeep and upgrading for a single-lane pavement segment is presented in this case study. Based on economic statistics, the best improvement plan is chosen after defining the applicable maintenance and improvement activities and the related application years.

5.3 Determination of Optimum Improvement Strategy

In this case study, the different maintenance and upgrade standards for a single-lane pavement section are analysed economically. The best improvement approach is chosen based on economic data after defining the applicable maintenance and improvement activities and the related application years.

5.3.1 Selection of pavement section

For this study, the pavement segment between WIT and Karnik Nagar Stop has been chosen. On the southern edge of Solapur city, there is a three-lane portion. Table 10 provides some general information and pavement characteristics of the chosen portion.

Table 10: Details of the selected pavement section

General Details		**Pavement Characteristics**	
Section name	WIT to Karnik Nagar stop	Material Type	BC
Section ID	R1	Surface Thickness	20mm
Section Length	553.4m	Roughness	8 IRI
Carriageway width	9.7m	Cracked Area	30%
No of Lanes	2	Ravelled Area	40%
Flow Direction	Both	No. of Pothole	15
Motorized AADT	2285	Mean Rut Depth	5mm
Climate Zone	Solapur	Texture Depth	0.7mm
Altitude, m		Skid Resistance	0.4mm

5.3.2 Pavement History

The last renovation of the pavement portion under investigation, which changed the pavement type to AMGB (Asphaltic Mix on a Granular Base), took place in 2000. The pavement type was reset to AMAP (Asphaltic Mix on Asphaltic Pavement) following the installation of the overlay in 2007, and to STAP (Surface Treatment on Asphaltic Pavement) with the application of surface treatment in 2012.

5.3.3 Proposed improvement alternatives

The three-lane addition enhancement options taken into consideration for this case study are outlined in Table 11. Each upgrade option is described in terms of the additional lane width, the kind of new surface, the resurfacing of existing pavement, the associated costs, and the impact of improvement work on the general condition of the pavement. Only the appropriate years will be relevant for all of these improvement requirements. a simple replacement for regularly timed maintenance.

Table 11: Proposed Maintenance and Improvement Alternative

Alternative Considered	Work Standard Assigned	Description of Works
Base Alternative	Routine + Overlay	Crack sealing pothole patching Provide Be 40mm
Alternative 1	Partial Widening	Partial Widen 1m
Alternative 2	Partial widening	Partial Widen 2m
Alternative 3	Lane Addition	Lane Addition (2 lanes)

5.3.4 Project analysis

In order to set up the analysis, a discount rate of 12% that was taken into account in the prior case study is stated. Three Improvement Alternatives are compared to the Base Alternative of doing the yearly regular maintenance only while the project analysis is underway.

5.3.5 Roughness progression

Figure 6 depicts the development of roughness during the 20-year analysis period for the basic option and the three improvement alternatives. It is obvious that if improvement activities are put off by four years, roughness increases to a very high value.

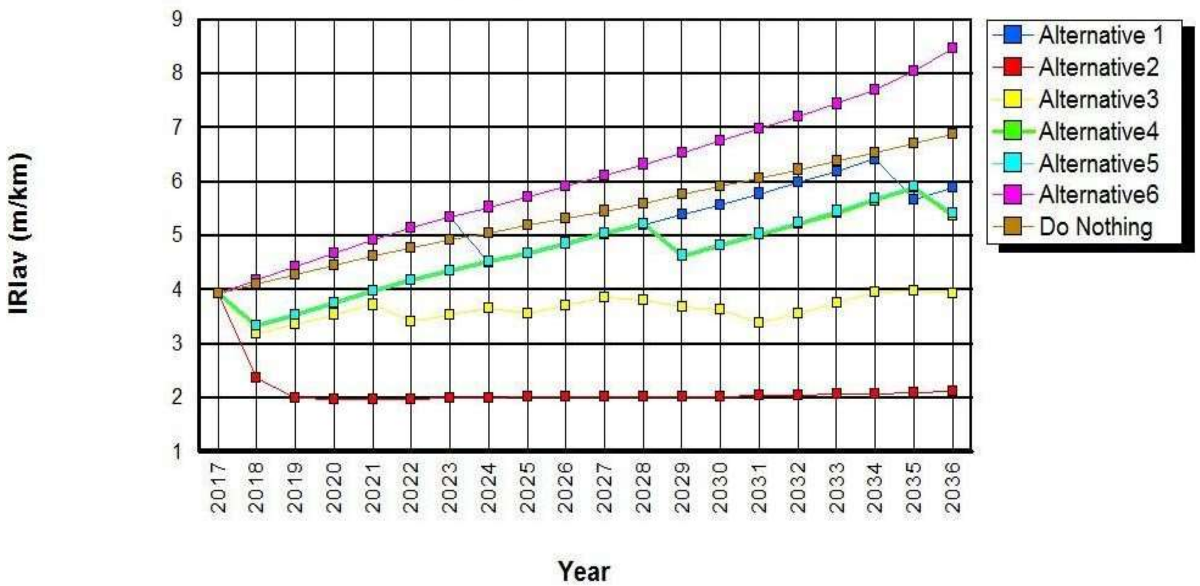

Figure 6: Average roughness value for Road Network form

5.3.6 Summary of Economic Analysis

The economic analysis summary in Table 12 compares the current value of total agency expenses and reductions in road user charges improvement option to the base alternative. For comparative reasons, the economic metric Net Present Value (NPV) is supplied. Table-12 shows the outcome of the economic analysis summary.

Table 12: Economic Analysis Summary

Alternative	Total agency costs	Increase in agency cost	Decrease in Road User Value	Net Present Value (NPV)	NPV/Cost ratio	Internal Rate of Return (IRR)
Do nothing	0.9	0.0	0.0	0.0	0.0	0.0
Alternative 1	1.59	0.68	0.0	0.0	0.86	1.528
Alternative 2	1.24	0.34	0.0	0.0	5.99	13.430
Alternative 3	10.47	9.57	0.0	0.0	0.06	0.006
Alternative 4	1.37	0.47	0.0	0.0	0.93	2.602
Alternative 5	1.36	0.46	0.0	0.0	0.86	2.469
Alternative 6	1.23	0.33	0.0	0.0	-5.79	-393.475

5.3.7 Selection of the Optimum improvement strategy

Based on the summary of the economic study, Alternative 2 may be chosen as the best improvement plan since it has the highest NPV/Cost ratio of 5.99. Therefore, based on the aforementioned economic study, it may be suggested that there is no imminent need to add a second lane to the current pavement segment. To reduce expenses for the road agency, this upgrading work may be preferred for at least two years. But because it would increase prices for road users, this construction shouldn't be put off for another two years.

6 Program Level Analysis & Results

6.1 Road Network Level Pavement Management

The complete road network has been analysed at the programme level using HDM-4 software. This application is primarily concerned with prioritizing a defined lengthy list of prospective pavement sections into a multi-year construction programme within specified budget limits.

6.1 Life Cycle Cost Analysis of Roadway Network

This case study shows how to create a maintenance and rehabilitation plan for the chosen highway system and how to anticipate budgets using HDM-4 over a 20-year time frame.

6.2.1 Input data

The 'Primary Road Network' and 'National Vehicle Fleet' databases that were previously described include the input data for this case study. The 'Primary Road Network's' seven pavement segments have all been chosen for this investigation.

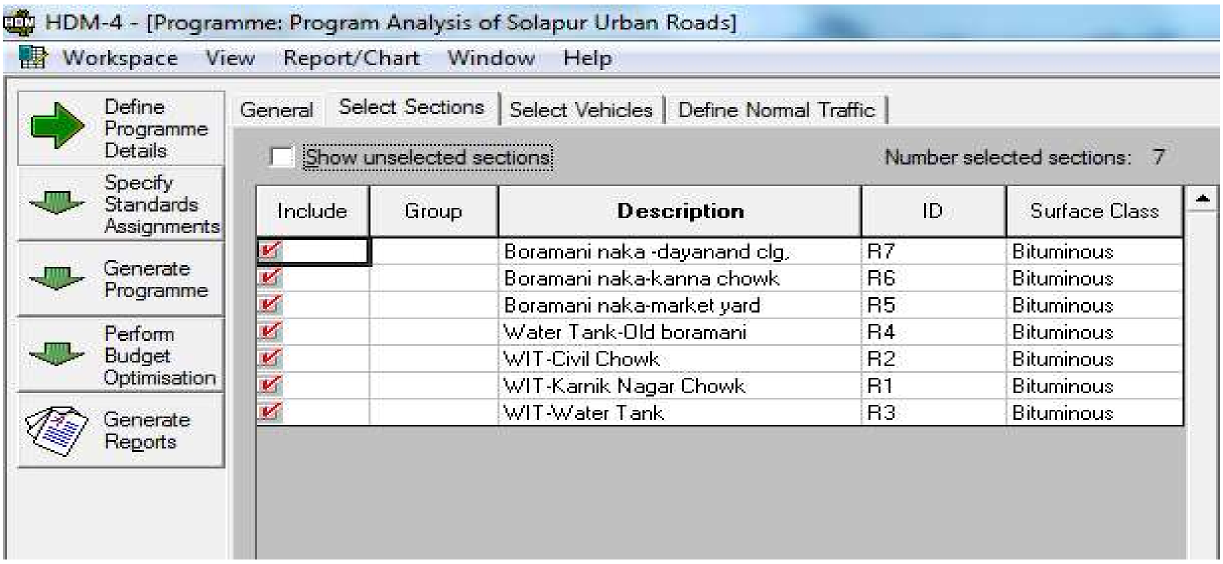

Figure 7: Chosen Road Sections for the Programme Analysis

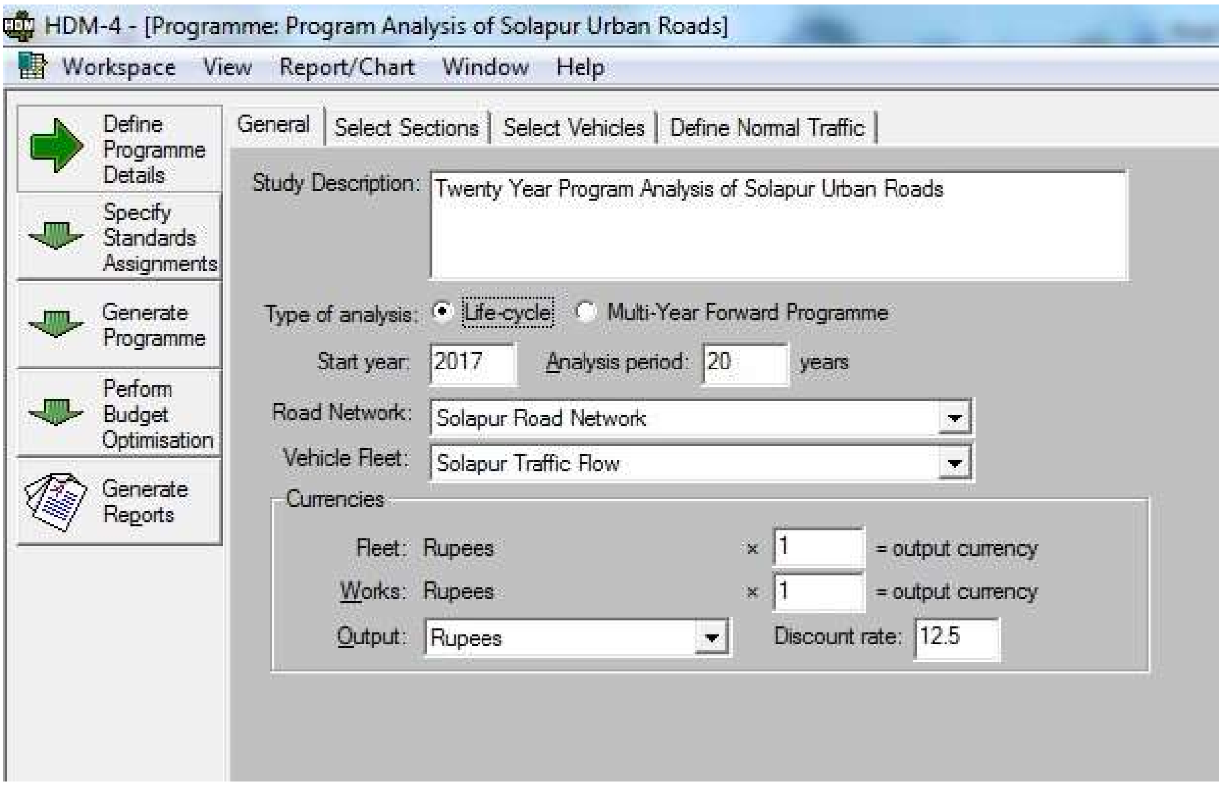

Figure 8 Input Data for Life-Cycle Cost Analysis

6.2.2 Selection of Alternative Maintenance & Rehabilitation Strategies

The life cycle cost analysis necessitates a comparison of a base case (do minimum) option to one or more project case (do something) alternatives. For this case study, two options for each road stretch have been defined: 'Base Alternative' and 'Maintenance & Rehabilitation Alternative' (M&R). The 'Base Alternative' only includes standard pavement repair tasks such as crack sealing and pothole fixing. The 'M&R Alternative' involves labour operations such as resealing, overlays, and reconstruction.

6.2.3 Life-cycle cost analysis

Following the selection of the alternative M&R strategies, the programme analysis application was used to compare the total life-cycle costs, including highway agency and road user costs, predicted by the base alternative of scheduled routine maintenance to those predicted by the condition-responsive M&R alternative. The programme application is launched in order to do a life cycle cost study of the whole pavement network. Following this study, the choices with the highest NPV for each pavement portion are assigned. All of these expenditures have been reduced to the base year 2017 at a discount rate of 12%. Table-13 shows the final outcomes of the Optimised Work Programme by Year.

Table 13: Optimized Work Program by Year

Year	Section	Road Class	Length (Km)	AADT	Type of Surface	Description of work	NPV/CAP	Financial Cost	Cumulative Cost
2017	Water Tank-Old boramani	MDR	0.67	6611	Bituminous	Routine+50 mm Overlay & 15% cracking	10.78	0.17	0.17
	Boramani naka-market yard	MDR	0.56	6536	Bituminous	Routine+50 mm Overlay & 15% cracking	8.79	0.20	0.37
	Boramani naka-kanna chowk	MDR	0.75	4854	Bituminous	Routine+50 mm Overlay & 15% cracking	3.04	0.27	0.65
	WIT-Water Tank	MDR	0.56	6424	Bituminous	Routine+50 mm Overlay & 15% cracking	2.81	0.15	0.79
	Boramani naka - dayanand clg,	MDR	0.58	2285	Bituminous	Milling 75 + Replace 75mm	2.12	0.27	1.07
	WIT-Karnik Nagar Chowk	MDR	0.55	2500	Bituminous	Routine+50 mm Overlay & 15% cracking	0.27	0.10	1.16
	WIT-Civil Chowk	MDR	0.85	2905	Bituminous	Routine+50mm Overlay & 15% cracking	0.01	0.22	1.38

6.2.4 Section-Wise Budget Requirements

For the maintenance management of the highway network throughout the course of the 20-year analysis period, the section-wise budget needs for each alternative are presented in Fig. 9 and Table-14, respectively.

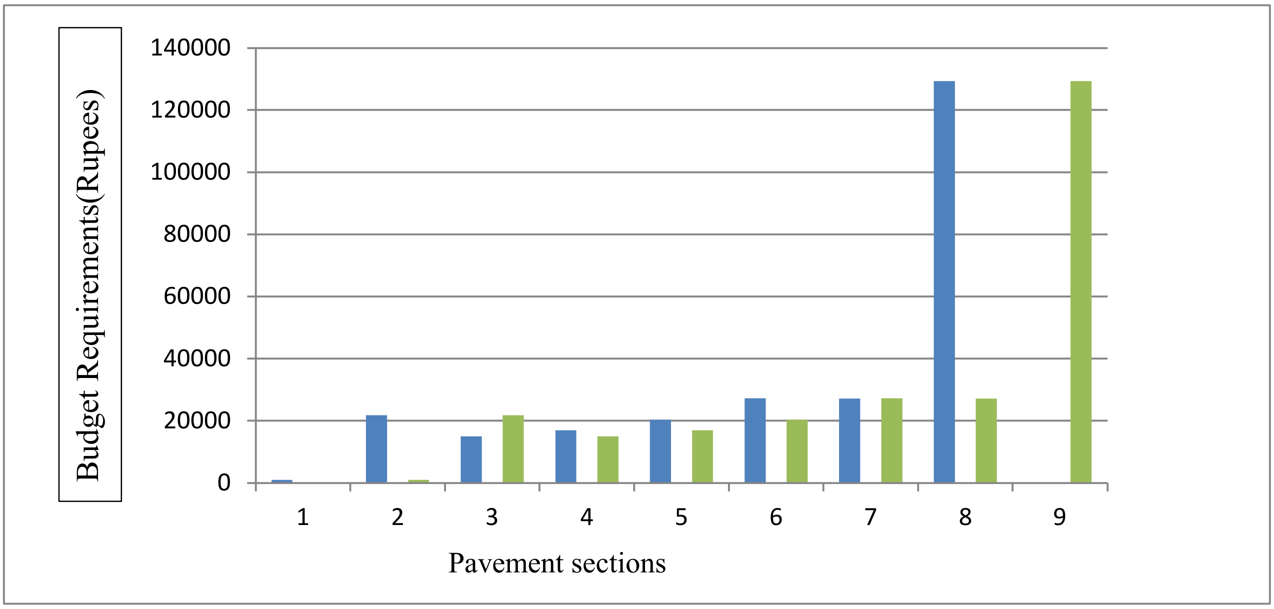

Figure 9: Section-wise Budget Requirement for M&R Alternative

Table 14 Budget requirement for maintenance of roads

Section Name	Budget Requirement (Million Rupees)	
	Base Alternative (Do Minimum)	Maintenance & Rehabilitation Option
WIT to Karnik Nagar	6520	960
WIT to Civil chowk	14750	21730
WIT to Water tank.	10130	14920
Water tank to Old Boramani Naka	11460	16880
Old Boramani Naka to Market Yard	13820	20360
Old Boramani Naka to Kannachowk	18510	27270
Old Boramani Naka to Dyanand College	12010	27140
Total Budget Requirement	87200	129260

6.2.5 Budget Optimization

If the money required for each budget period falls below the specified budget restrictions, the unconstrained works programme can be implemented as is without the need for additional economic analysis.

6.2.6 Optimized Works program

To maximize economic advantages, budget optimization offers the ability to choose pavement portions that may be included within a certain budget.

6.2.7 Prioritization

The annual M&R tasks have also been given more priority as a result of the budget optimization procedure due to the declining NPV/cost ratio. Table 15 displays a prioritized list of M&R projects for the year 2025. The projects will be started and finished in accordance with the given priority order.

Table 15 Prioritized list of M&R works for the year 2017-36

Year	Road Network	Traffic in AADT	Maintenance & Rehabilitation Works	NPV/ CAP Ratio	Ranking
2025	Water Tank to Old Boramani	11358	Routine+50mmOverlay+15% Cracking	10.77	1
	Old Boramani to Market Yard	11230	Routine+50mmOverlay+15% Cracking	8.790	2
	Old Boramani to KannaChowk	8340	Routine+50mmOverlay+15% Cracking	3.038	3
	WIT to Water Tank	11037	Routine+50mmOverlay+15% Cracking	2.808	4
	Old Boramani to DayanandClg.	3926	Routine+50mmOverlay+15% Cracking	2.121	5
	WIT to Karnik Nagar Chowk	4295	Routine+50mmOverlay+15% Cracking	0.267	6
	WIT to Civil Chowk	4991	Routine+50mmOverlay+15% Cracking	0.014	7

7 Application of ArcGIS software in mapping

A computer-based system that saves data with geographic references and links them with non-graphic qualities (data in tables) enables a variety of information processing tasks, such as modification, analysis, and modelling. Map generation and presentation are also features of a GIS. Using a GIS (Geographic Information System) is a powerful method for automating spatial analysis and mapping. A GIS offers the ability to gather, save, retrieve, examine, present, and produce geographic data. The data model of ArcGIS is shown in Figure-10.

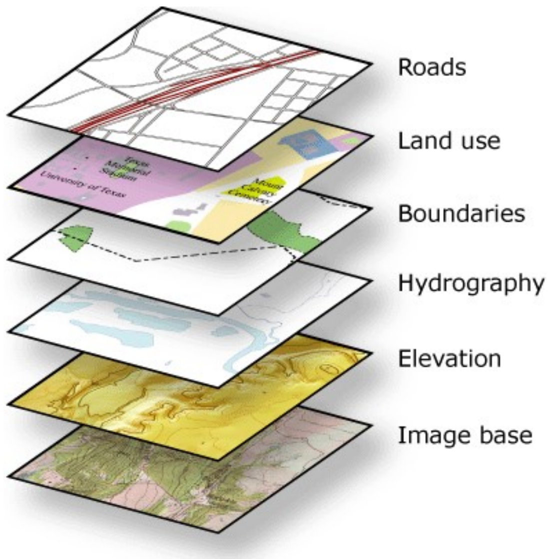

Figure 10- Data Model of ArcGIS

7.1 Objective of Study

Making a map and producing characteristics for each road stretch is the goal of using ArcGIS in the case study.

7.1.1 Study Area

The study area of Solapur city is geographically located southeastern region between 17.6599°N, and 75.9064°E. It shares the Hydrabad-Vijapur bypass with a maximum concentration of traffic. This study area also covers Project Road with Temples, Main Chowk, Drainage Line, National Highway, State Highway, City Roads, Ring Road, Railway Line, Highlighted Project Road, Water Bodies, Educational Institutes, City Boundary, and Rail Station.

7.2 Data Description and Methodology

Global Positioning System (GPS) Data, Field Collected Data (FCD), Web Collected Data, and GIS Datasets (which comprise data produced from distant measurements and surveys) are the four basic categories into which the data utilized in this study may be categorized. This is explained in more depth in the next sections.

- **GPS (Global Positioning System) Data**- The GPS Data has been collected from GPS Receiver (Juno series Trimble). With the help of a GPS Receiver, we get data on the Latitude, Longitude, and Altitude of each road section.
- **Web Collected Data** - Data from online sources have also been used for this study in addition to field surveys. Street names have mostly been removed from online resources in favour of POI designations.
- **GIS Data** - The methodology's cross-disciplinary character allowed for access to a wide range of data sources. Here is a quick explanation of the datasets.
- **Road Network Dataset**- The road network has been digitalized using field-collected data, GPS data, and basic photography.
- **POI (Point of Interest)** – The same sources are also used to gather Point of Interest.
- **Network Dataset**- With the aid of network data and its properties in ArcCatalog, the network dataset has been built.

7.2.1 Software Used

ArcGIS software has been used to carry out the investigation. With the use of ArcGIS software's helpful tools, digitization, calculations, attribution, correction of topological flaws from models of digitized data, the development of network datasets, and network analysis of the data have all been completed. The study's software includes the following:

- Maps and characteristics of road networks are created using ArcGIS 10.2.2.
- AutoMap- Used for converting the Latitude and Longitudes of road section into map and importing it in ArcGIS.

The various maps created using ArcGIS software are shown in fig 11 to 14.

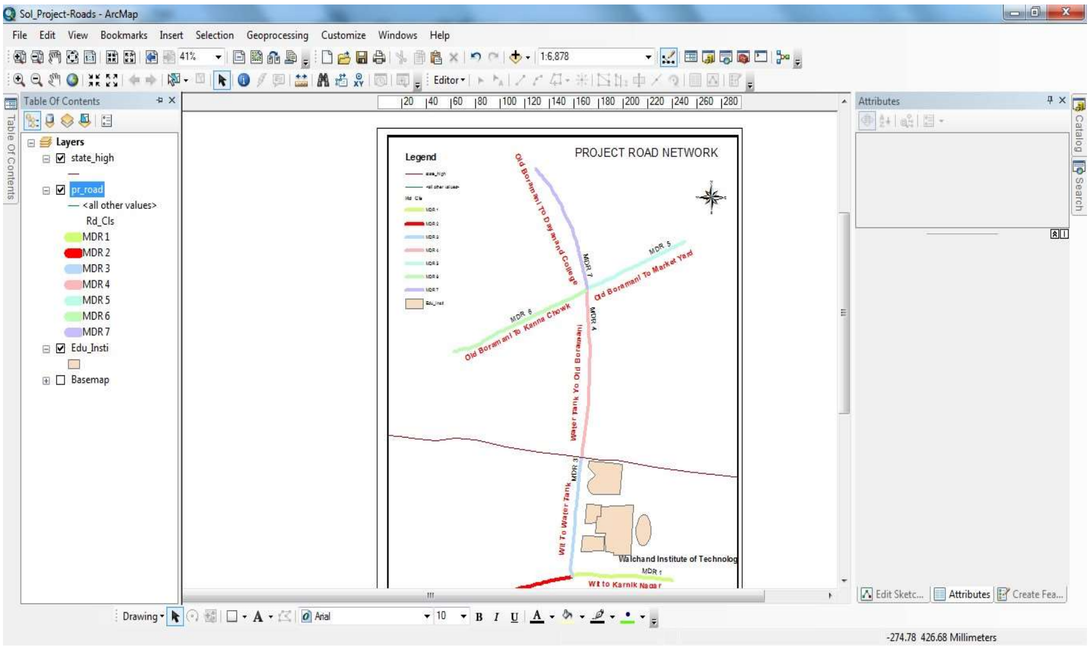

Figure 11 Structure of the Main Window

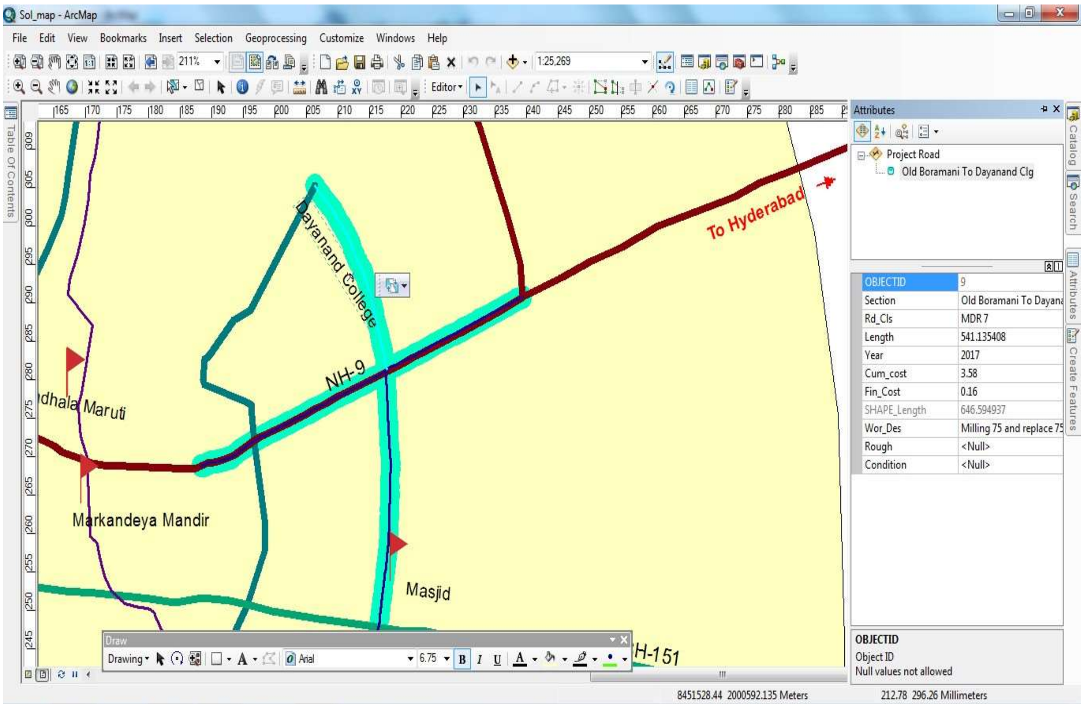

Figure 12 Road Section with Attribute Table

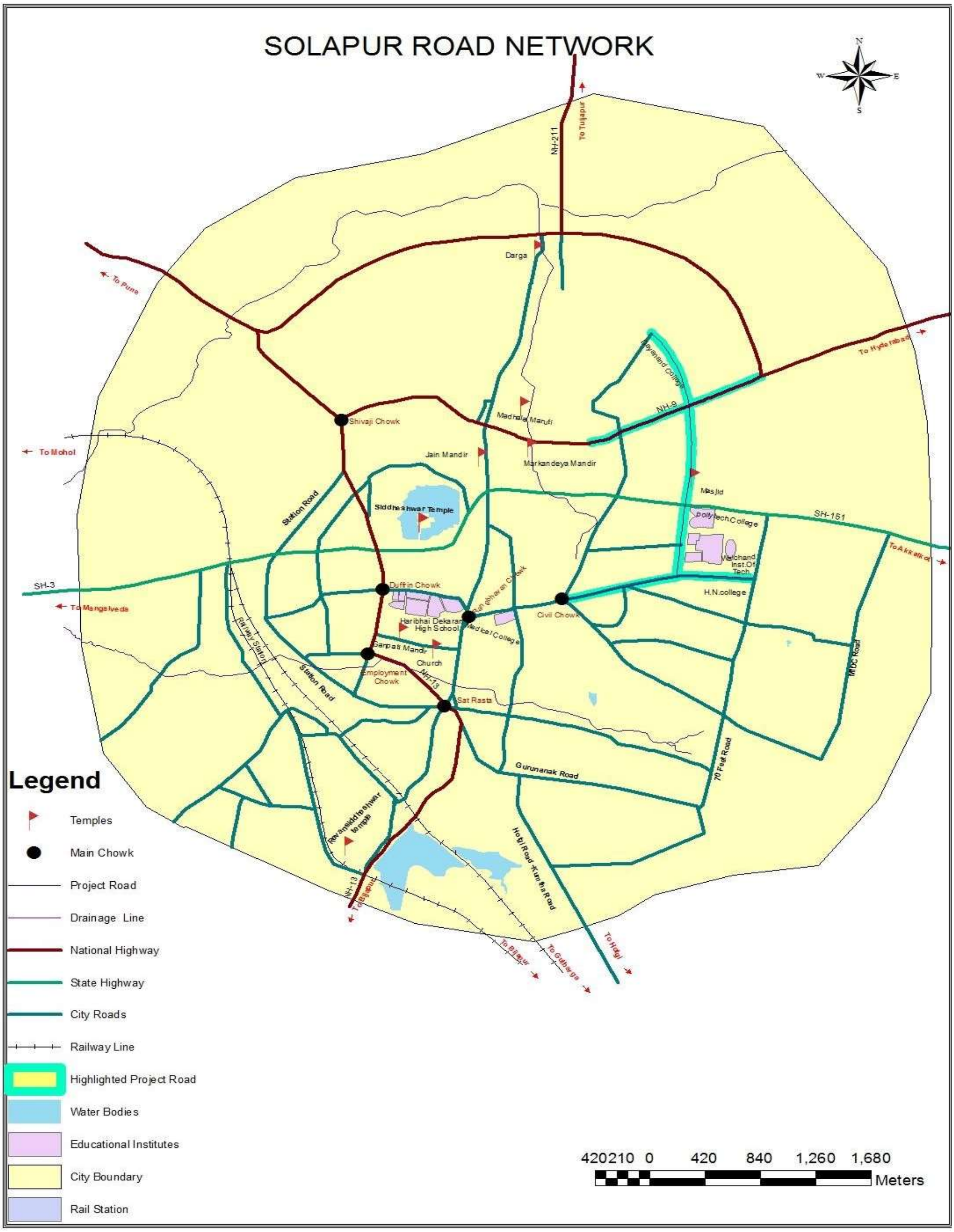

Figure 13 Solapur Road Network Map

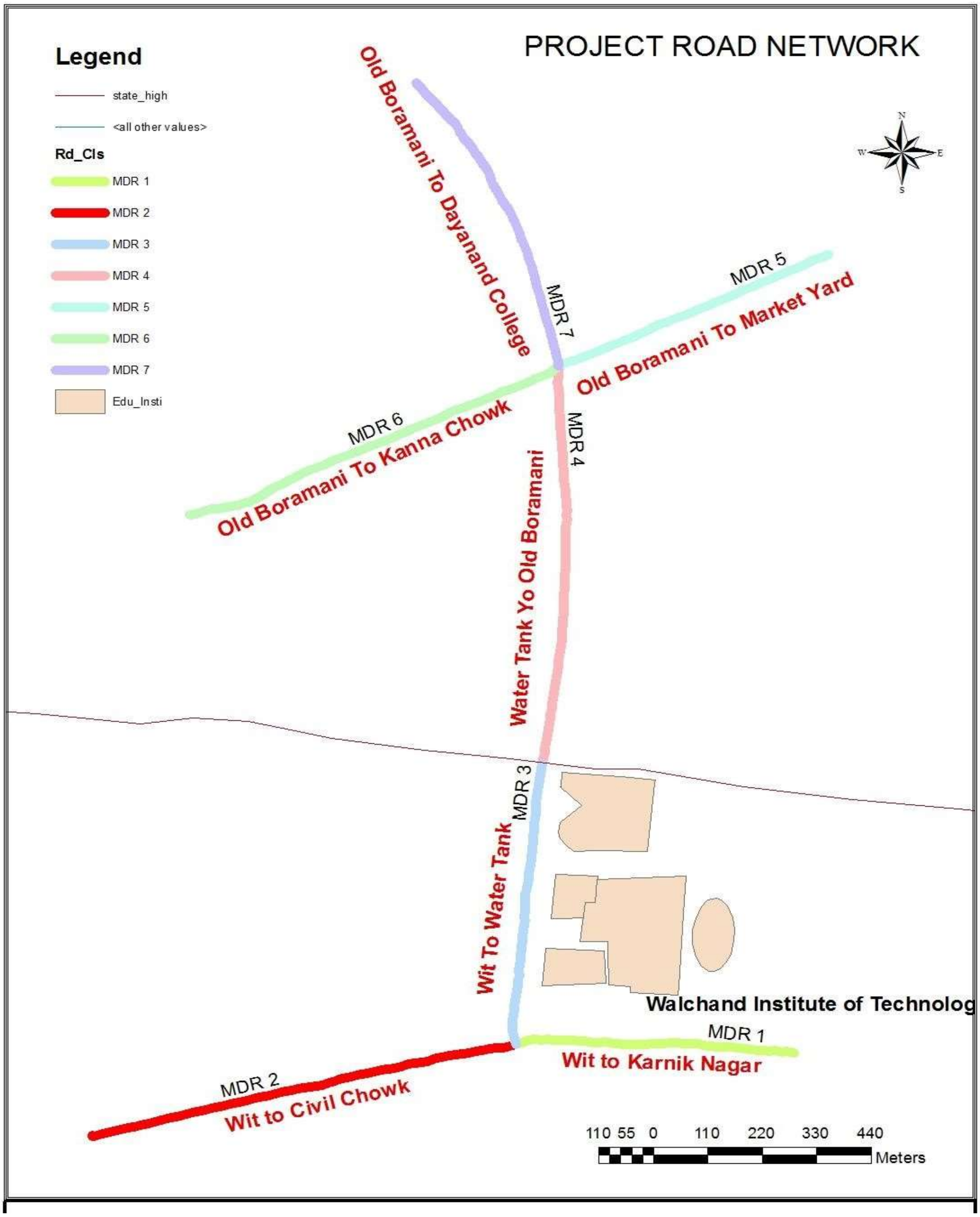

Figure 14 Project Road Network Map

8 Conclusions

The following are the conclusions made for the present study:

1) Due to the lack of funding for maintenance, pavement management is critical for transportation agencies, especially in developing countries like India. However, in order for local engineers to understand and use PMS effectively, the development process must be simplified.
2) The best Maintenance and Rehabilitation approach for a pavement section has been selected during project-level PMS analysis based on the highest Net Present Value/Cost ratio among a set of pre-defined Maintenance &Rehabilitation strategies.
3) Based on the summary of the economic analysis, Alternative 2 (Routine + Overlay) was selected as the optimal M&R strategy for a given road network (from Old Boramani Naka to Dayanand College) which is having the maximum NPV/Cost of 13.43 compared to Routine Maintenance work.
4) An unconstrained program has been developed for twenty years. The total maintenance budget for the entire road network at a given optimal level of maintenance has been determined using road network level PMS analysis and is INR 1,29,260 million.
5) Budget optimization provides an opportunity to select pavement sections that can be included in a given budget to maximize economic benefits. If there are not enough funds to implement all MandR activities according to the available work program list, the work program must be optimized according to the available budget. An optimized and prioritized work program was developed to have 60 percent of the budget.
6) GIS (Geographic Information System) is a powerful tool for computer mapping and spatial analysis. GIS provides functions to capture, store, query, analyze, display and print geographic data. ArcGIS software is used for digitization, calculations, attribution, removal of topological errors, modeling of digitized data, creation of network datasets, and network analysis.

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