STRUCTURAL AND FUNCTIONAL EVALUATION OF URBAN ROAD NETWORK OF PATIALA CITY FOR DEVELOPING COST EFFECTIVE MAINTENANCE STRATEGIES

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Submitted by

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DECLARATION

The author hereby declares that this thesis entitled **"Structural and Functional evaluation of existing urban road network of Patiala city for developing cost effective maintenance strategies"**, in whole or part, has not been used to obtain any degree in this, or any other, institute. Except where references have been given in text, it is entirely the authors own work. The author confirms that the library may lend or copy this thesis upon request for academic purposes.

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CERTIFICATE

This is to certify that the thesis entitled **"Structural and functional evaluation of urban road network of Patiala city for developing cost effective maintenance strategies"** being submitted by **Mr. Mohit Mantrao, Roll No 801123004** in partial fulfillment for the award of degree of **Masters of Engineering in Civil Infrastructure Engineering** at **Thapar University, Patiala** is a bonafide work carried out by him under our guidance and supervision and that no part of this thesis has been submitted for the award of any other degree

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ABSTRACT

Satisfactory maintenance of highway network is essential for any country for its economic growth. The maintenance of pavements and particularly the flexible pavements is an essential requirement for the efficiency of highway network. The magnitude of work involved in maintenance is very large but the funds available are not enough to meet the requirements. The only option left is to manage the roads within the available limited resources, in an optional manner, by making use of the scientific pavement management tools.

There are various factors responsible for early deterioration of the pavements in urban areas like large traffic volume and the inadequate drainage system. The development of higher stresses leads to premature failure of urban pavements. Structural failure occurs if the pavement fails to carry design loads satisfactorily and functional failure occurs if it does not provide a smooth riding surface which in turn increases the discomfort and vehicle operating costs influencing the pavement performance and consequently overall transportation costs. The most versatile approach to predict pavement deterioration is to model the major modes of distress individually because different distress types need different maintenance treatment. Pavement deterioration models, for prediction of pavement condition at a future date, form an important input in the pavement management system for (i) assessing the state of health of the pavements. (ii) Deciding upon the optional maintenance and rehabilitation treatments for a given operating situation. (iii) Planning and programming of short term and long term maintenance budgets. These tools are needed and are used for economic analysis of various alternate maintenance and rehabilitation strategies.

The objective of this study is to evaluate the structural and functional parameters of the selected urban road network of Patiala City after every three months time interval to get the behavior of the distresses in the urban roads. Both the inventory data and the pavement condition data has been stored in databases, created in Highway Development and Management Software (HDM-4). Present Serviceability Index (PSI) has been calculated as an indicator of the pavement health for the selected road network of the Patiala city. The various maintenance alternatives have been analyzed by using Highway Development &

Management System (HDM-4) and an optimum maintenance and rehabilitation (M&R) strategy for a pavement section has been determined on the basis of highest Benefit to Cost ratio for the total analysis period of 15 years. The remaining service life of all the road sections has been calculated, if no maintenance practice is provided to the surface.

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CHAPTER 1
INTRODUCTION

1.1 INDIAN ROAD NETWORK

India has a road network of over 4,236,000 kilometers, the third largest road network in the world. Out of this, the District & Urban Road network accounts for almost 14.1% of the total road network. About 65% of freight and 80% passenger traffic is carried by the roads. Road network is vital to the economic development, trade and social integration. It facilitates smooth conveyance of both people and goods. Size of the road network, its quality and access has a bearing on transport costs. Besides, road network promote specialization, extend markets and thereby enable exploitation of the economies of scale. Easy accessibility, flexibility of operations, door-to-door service and reliability have earned road transport an increasingly higher share of both passenger and freight traffic vis-à-vis other transport modes. Transport demand in India has been growing rapidly. In recent years this demand has shifted mainly to the advantage of road transport, which carries about 87 percent and 61 per cent of passenger and freight transport demand arising for land based modes of transport respectively.

While the vehicle population has grown from just 3 lakh in 1951 to about 450 lakh now, the quantum of goods being carried by road transport has undergone an incredible increase from 600 lakh tonnes to 40,000 lakh tonnes at present. Table 1 gives the growth in number of vehicles over the last 50 years. Also, the share of road transport in passenger movement and freight movement has increased by 20% to 85% and 20% to 70% respectively, during the last 50 years represented in Table 1.1.

Traffic on the Indian roads, in terms of volume and axle loads, is increasing at an alarming rate, with the annual growth rate estimated to be of the order of about 10% [MORT&H 2001c]. This phenomenal growth in vehicle population and road usage has put a tremendous strain on the existing road network. There has been considerable increase in the axle loads carried by freight vehicles, but the regulations governing the axle weight limitations have not been changed significantly for last many years, with consequent negative effect on pavements in terms of fatigue and accelerated deterioration. The present spectrum of axle loads plying on the Indian roads shows that as against a prescribed legal limit of 10.2 tonnes axle load, commercial vehicles with much higher axle loads, even to the extent of 18-22 tonnes are plying on these roads.

Table 1.1 Growth of vehicles during Last 50 Years

Year	**Total No. of Vehicles (in thousands)**	**Commercial Vehicles (in thousands)**
1951	306	116
1961	665	225
1971	1865	437
1981	5391	716
1991	21374	1687
1995	30295	2217
1997	37231	2748
2000	48393	3240
2005	70000*	4500*

* Estimated figures

Source: MORT&H [2001c], and NHAI@2003

Table 1.2 Modal Shifts in Traffic Categories

Traffic Category	**Year 1951**		**Year 2003**	
	Road	Rail	Road	Rail
Passenger	20%	80%	85%	15%
Freight	20%	80%	70%	30%

Source: MORT&H [2001c] and NHAI@2003

According to ‘Road Damage Formula’, pavement that can last for 10 years without overloading will last only for 6.5 years, if there is 10 percent overloading on an average. With 30 percent overloading, the same pavement will last only for 3.5 years [CRRI 1994]. This situation has lead to a much faster rate of pavement deterioration, which calls for timely additional maintenance inputs, not planned otherwise, for preserving and keeping up the roads to the minimum acceptable level of service.

1.2 CLASSIFICATION OF ROADS IN INDIA

The Roads are classified in following categories:

i) Primary system, consists of Expressways and National Highways;

ii) Secondary system, consists of State Highways and Major District Roads;

iii) Tertiary system, consists of Other District Roads and Village Roads;

iv) Urban Roads

1.2.1 Expressways: An expressway is a controlled-access highway; it is a highway that controls entrances to it and exits from it by incorporating the design of the slip roads for entry and exit into the design of the highway itself. Access-control should not be confused with collection of toll. An expressway may be free to use and may not collect toll at all. Expressways are the highest class of roads in the Indian Road Network. These are six- or eight-lane highways with controlled-access. India has approximately 942 km expressways. Currently, a massive project is underway to expand the highway network and the Government of India plans to add an additional 18,637 km of expressways to the network by the year 2022. These roads will be access-controlled roads and will feature between four and six lanes with 3,530 km to come up by 2015. [MORTH & NHAI website]

1.2.2 National Highways: The National Highways network of India is a network of highways that is managed and maintained by agencies of the Government of India. These highways measured over 70,934 km as of 2010, including over 1,000 km of limited-access Expressways. Out of 71,000 km of National Highways 15,000 plus km are 4 or 6 laned and remaining 50,000 km are 2 laned. The National Highways Authority of India (NHAI) is the nodal agency responsible for building, upgrading and maintaining most of the national highways network. It operates under the Ministry of Road Transport and Highways. The National Highways Development Project (NHDP) is a major effort to expand and upgrade the network of highways. NHAI often uses a public-private partnership model for highway development, maintenance and toll-collection. National highways constituted about 2% of all the roads in India, but carried about 40% of the total road traffic as of 2010. The majority of existing national highways are two-lane roads (one lane in each direction), though much of this is being expanded to four-lanes, and some to six or eight lanes. Some sections of the network are toll roads. Over 30,000 km of new highways are planned or under construction as part of the NHDP, as of 2011. This includes over 2,600 km of Expressways currently under construction. [MORT&H Website]

1.2.3 State Highways. The main roads of a state connecting up with the National highways or highways of adjacent states and linking the district head quarters and important cities within the state are called State highways. These provide the main arteries of traffic within a state. State highway refers to the numbered highways which are laid and maintained by the state government. These are not related to national highways and are not involved with the National Highways Authority of India or the central government in any way. The state highways usually are roads which link important cities, towns, district headquarters within the state and connecting them with national highways or highways of the neighboring states. These highways provide connections to industries/places from key areas in the state making them more accessible. These are maintained by the Public Works Department.

1.2.4 Major District Roads: The roads traversing each district serving areas and markets and connecting these with each other or with National and State highways or railways or important navigation routes are called Major district roads**.**

1.2.5 Village Roads: The roads which connect villages or groups of villages with each other and to the nearest district road, National or State highways or railways or navigation routes, are called village roads. The rural roads in India form a substantial portion of the Indian road network. The existing rural road network has a total length of about 2.7 million km. Despite the importance of rural roads, about 40 percent of the 661,000 villages in India are not connected with all-weather roads these roads are in poor shape, affecting the rural population's quality of life and Indian farmer's ability to transfer produce to market. Many rural roads are of poor quality, potholed, and unable to withstand the loads of heavy farm equipment. Government of India launched a national rural road program called "*Pradhan Mantri Gram Sadak Yojna*" (Prime Minister's Rural Road Program) aiming at all-weather road access to all habitations with a population of 1,000 and above by the year 2003, and those with a population above 500 by the year 2007. Besides providing connectivity to about 100,000 habitations, the program also aims to upgrade about 500,000 km of existing rural roads. The major source of funding of the program is the Central Road Funds (CRF), which allocated about Rs. 25 billion in 2001 to rural roads. The current estimated value of the existing rural road network, based on the value of construction work, is about Rs 2,400 billion. The maintenance of the existing rural road network requires about Rs 50 billion per annum, out of which only 20-30 percent is available.

1.2.6 Urban Roads: Urban roads are about 2.5 lac Kilometer which is around 10.18 % as on 31st March, 2002. The urban roads carry large traffic volume and the economic loss due to poor condition of road amounts to a huge sum in spite of their small mileage [MORT&H Website]. Urban roads fall within the jurisdiction of Municipal Corporation, Municipal Boards, Cantonment Boards and Port Trusts which are statutory bodies in urban areas. The urban roads are further classified as:-

- **Arterial roads-** An arterial road is a high-capacity urban road. The primary function of an arterial road is to deliver traffic from collector roads to freeways, and between urban centres at the highest level of service possible. As such, many arteries are limited-access roads, or feature restrictions on private access. Though the design of arterial roads varies from country to country, city to city, and even within cities, they share a number of common design characteristics. For example, in many cities, arteries are arranged in concentric circles (commonly referred to as ring roads) or in a grid. Many jurisdictions also classify arterial roads as either principal (major) or minor.
- **Sub-arterial roads-** The city roads which provide lower level of travel mobility than arterial streets are called Sub-arterial streets. Their spacing may vary from 0.5 km in central business districts to 3 to 5 km in Sub-urban areas. Loading and unloading are usually restricted. Pedestrians are allowed to cross these highways at intersections.
- **Collector Streets-** The city roads which are constructed for collecting and distributing the traffic to and from local streets, and also to provide an access to arterial and sub-arterial streets, are also called Collector streets. These are located

in residential, business and industrial areas. These roads are accessible from the buildings along them. Parking restrictions are few and that too during peak hours.

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

  The Design speeds and space standards for various category of urban road recommended by IRC are given in Table 1.3 [IRC: 86 1983].

Table 1.3 Design Speed and Space Standards for Roads in Urban Areas [IRC: 86 1983]

Road Classification	Design Speed (kmph)	Recommended ROW (meters)
Arterial	80	56-60
Semi-Arterial	60	30-40
Collector Streets	50	20-30
Local Streets	30	10-20

1.3 NEED FOR EXCLUSIVE PAVEMENT MANAGEMENT SYSTEM FOR URBAN ROADS

The use of urban roads and the problems of maintenance and construction are much different than National Highways, State Highways and Multilane Highways. In urban roads the trip length is small, number of tips and diversion is large, intensity of traffic is heavy and non-uniform. The availability of good and serviceable roads is an important issue in an urban area as is the availability of other services like water, electricity, drainage etc [IRC Annual Session 1987]. Any short fall in the serviceability of an urban road immediately results into great dissatisfaction amongst the commuters and the urban population, especially due to inadequate drainage system water stay over the pavement for long time after storm results in great disappointment among urban people. It is therefore, necessary that the roads in the urban area are maintained properly with a view to preserve the assets created at a huge cost and also to afford safety and convenience to road users [Atre 1987].

Problems of the urban roads are much more different than the problems of the other category roads. Therefore, Municipal Road Authorities should keep the continuous watch on the following issues and these parameters should be considered in different manner for developing the maintenance strategies & pavement condition indices for the city roads as compared to other category of the roads.

1.3.1 Drainage Problem in Urban Roads: It is essential that adequate provision is made for road drainage to ensure that a road pavement performs satisfactorily. The main functions of the road drainage system are [Guidelines for Road Drainage, 2004]:-

- To prevent flooding of the road and ponding on the road surface.
- To prevent the bearing capacity of the pavement and the subgrade material.
- To avoid the erosion of the side slopes.

Therefore every road needs a specific drainage system which is required to be maintained throughout the year [PIARC 1994]. In urban area, road levels are governed by the levels of buildings and adjoining constructions such as the roads cannot be raised independently to keep them safe against the water action. Inadequate drainage is largely responsible for failure of city roads. This problem is regarding the storm water drainage because in most of the cities, as a matter of fact, even the existing drainage system is not kept clean with the results that all the storm water and even in certain cases the sewer water finds way only on the carriageway of these roads and leads to formation of cavities underneath the road structure. The object of drainage maintenance is to ensure that drainage system elements remain free of obstructions, and retain their intended cross section and grades. They must function properly so that surface water and ground water can drain freely and quickly away from the road or under the road [PIARC 1994]. Municipal Road Authorities should periodically review the adequacy of the road drainage systems by continuously maintenance of existing road drainage systems and by improvement works which are required to bring the road drainage systems up to acceptable standards.

1.3.2 Traffic Congestion: Cities and Traffic have developed hand-in-hand since the earliest large human settlements. The same forces that draw inhabitants to congregate in large urban areas also lead to sometimes intolerable levels of traffic congestion on urban roads. Traffic congestion is caused by as (a) many people work in the central business areas which generally have narrow streets (b) Shortage of the parking facilities which make the road users to park their vehicles on the roads and thus reducing the city road capacity (c) Lack of proper public transport facilities which lead the people to use their own vehicles. The urban roads are also subjected to severe braking and sharp turning movements. By frequent stopping and starting of vehicles, at the intersection and rotaries which results in corrugation on the surface and poor riding quality of the pavement surface. Moreover the continuous abrasion due to heavy movement of traffic over the city road surface results in gradual reduction in the pavement thickness.

1.3.3 Through Traffic in Patiala City: The major traffic problem of Patiala is passing of the regional traffic through the city which adds to the volume of the city traffic and creates congestion, as it has a radial pattern of roads and the major regional roads namely Patiala – Nabha , Patiala – Sirhind , Patiala – Sangrur , Patiala – Rajpura converges in the central part of the city. A Southern elevated bye- pass i.e. 19.6 km long is under construction that will connect Patiala- Rajpura & Patiala – Sangrur road which will give great relief to the city from through traffic.

1.3.4 Underground Services in Roads: Due to scarcity of land in urban areas, the right of way is also being utilized for carrying trunk services like peripheral sewers, peripheral storm water drains, main water supply lines, telephone ducts etc. as the city develops in stages, quite often these services are either run in parallel or additional lines are laid subsequently. At many places, these services have to be laid under the main road itself, as there is no space available in ROW of the road. It is a difficult task to coordinate with different departments for all the services mentioned above. As utilities service grow, the frequency of occurrence for two or more lines occupying the same space or to interest one another increases, thereby causing problems of operations and maintenance for these services well as the road facility. Cutting of cables for provision of electric poles, telephone lines, sewer lines, storm water drains and repair thereof, is a perennial problem. The water line crossing the roads give rise to leakages and subsequent subsidence. Frequent repairs are not possible and the line joint give problems as they cannot be made 100% water tight. Again, leakage from water supply and sewer pipelines and cross cutting for new service lines is an important cause of early failure of pavement in urban roads. Another common cause of early deterioration is due to improper filling of cuts for taking the new service lines like water supply etc.

1.3.5 Parking Problems: The parking problem in Patiala city can be divided into the following categories:-

- In the walled city: Due to the presence of old structure, mixed land use, presence of wholesale and specialized markets namely Book market, Gur Mandi, Maniari Bazar (Sirhindi Bazar), wholesale cosmetics & shoes (Gher Sodhian), cloth market (Shere-e-Punjab market), Aachar Bazar, Churian wala Bazar, Bartan Bazar (near Kasera Chowk), Timber market near Safabadi Gate, wholesale fruit and vegetable market, dairies, godowns, etc. creates severe traffic problems because of negligible parking space. It gets worsened by the presence of hand carts, horse carts, three wheeler carrier, tempo, rickshaw, rehri etc. which causes traffic bottlenecks in the city.
- In planned commercial centres: In case of Leela Bhawan commercial scheme, provision of parking has fallen short because of sharp rise in the number of vehicles which results in parking overspills on Bhupindra Road and thus reducing the effective width of road. Big branded showrooms have also sprung up with clearance from Municipal Corporation along Bhupindra road with little parking area in front of them, thus creating traffic chaos.
- Along Commercial Streets: Mushrooming of informal commercial on road front without the provision of adequate parking is another major traffic problem in certain pockets of Patiala city like Lower Mall Road, Fountain Chowk, Bhupindra Road (near 22 no pahtak) Gurdwara Dukhniwaran Chowk, Bus Stand Chowk, part of Model Town, Bhadson Road, major roads in Tripuri Township, Jhill road, Seona road, entire Gurbax Colony, etc.
- In Residential Colonies: Roadside parking has reduced the road width which hampers the free flow of traffic and cause traffic problems. Private nursing homes and private tuition schools opened in residential houses without any provision of parking lots hampers free flow of traffic especially in areas like Professor Colony, Hembagh, and Officer’s Colony etc.

- In Institutional Areas: Most of the private schools have inadequate parking facilities that leads to traffic congestion especially during peak hours mainly in front of D.A.V. school (Bhupindra Road), British Co-Ed (Lower Mall Road), Y.P.S. (Stadium Road), Guru Nanak Foundation School (Sular Road) Budha Dal Public School (Lower Mall Road), Lady Fatima School & Saint Peter's School (Ajit Nagar).
- Near Transport Terminals: No organized parking and space for taxi/auto rickshaws near bus stand and railway station because of which autos, taxis, rickshaws etc. are parked along the mall road there by reducing the effective road width to a considerable extent and causes congestion in front of closed 18 No. and 19 No. phataks along Mall Road and in front of Bus Stand.

1.3.6 Problems at Intersections: The distress in the road pavement takes place because of extra forces of braking during acceleration and deceleration at intersections. The multiplicity of traffic / vehicles results in higher density and congestion of vehicles at intersections.

1.3.7 Problems Related to Strengthening and Widening of Roads: The Arterial roads, having ROW of more than 30m, are constructed in two three phases, i.e., 2 lane stage, 4 lane stage, 6 lane stage, cycle path, service lane etc. Widening of roads is however, done in stages depending upon the financial resources available. The construction of roads whether widening or strengthening has inherent difficulties, as the work has to be done at the minimum inconvenience to the road users.

1.3.8 Reduction of Road Width: Encroachment along both sides of the roads by the shopkeepers reduces the effective road width and restricts the free flow of traffic in central business district (Adalat bazaar, Dharampura bazaar). Roadside parking of autos and rickshaws especially near bus stand and railway station reduces the road width.

1.3.9 Spillage of POL: The spillage of POL (petrol, oil and lubricant) is much more on urban roads especially on intersections which harm the road surface.

1.3.10 Heavy Traffic Level Crossing: Traffic is increasing day by day on bye-pass road which has to cross the level crossing. The present railway line is being upgraded to double track and frequency of trains is going to increase in light of two upcoming Thermal Plants around Bathinda which will make the traffic stranded frequently. At the same time two roads running immediately along the railway track on both sides are creating junctions immediately close to level crossing, thus creating havoc with the traffic. All this hampers the free flow of traffic necessitating the early construction of railway over bridge on this level crossing.

CHAPTER 2

PAVEMENT MAINTENANCE MANAGEMENT SYSTEM (PMMS) & HDM-4

2.1. PAVEMENT MANAGEMENT SYSTEM (PMS)

A Pavement Management System helps in making informed decisions enabling the maintenance of the network in a serviceable and safe condition at a minimum cost to both the agency and the road users. To adequately meet this requirement, well-documented information is essential to make defensible decisions on the basis of sound principles of engineering and management. The objective of establishing a PMS is to improve the efficiency of this decision making, expand its scope, provide feedback about the consequences of decisions, and ensure consistency of decisions made at different levels within an organization.

The elements and products of a Pavement Management System include:

- An inventory of pavements in the network.
- A database of information pertinent to past and current pavement condition.
- An analysis program which, among other things, makes use of prediction models for forecasting pavement condition in the future or in the design horizon.
- Long range budgeting provisions.
- Prioritizing the annual work program.
- A basis for communication of the agency’s plans.
- A feedback system.

The basic modules of PMS include the following:

- A database that contains inventory, condition, traffic, and historical data
- A Pavement Analysis Program (PAP), which determines the condition of a pavement and selects a maintenance action based on its condition and other criteria. Also, it establishes an annual work program and estimates the budget required. A number of reports are generated from the analysis.

Many other modules are established which supply the necessary inputs for the PMS analysis. Deterioration models, maintenance and rehabilitation policies, their unit costs, and vehicle operating costs are such inputs. Deterioration models, which form an important element of PMS analysis, comprise this study. Thus, a Pavement Management System can be applied in the areas of planning, budgeting, scheduling, performance evaluation, and research. It can be used for prioritization, funding, setting strategies, selecting alternatives, identifying problem areas, simplifying communications with the legislature, and providing general and specific information which is useful to decision makers and management.

In order to discuss the benefits and uses of a PMS, it is first necessary to understand the major components of PMS. The primary purposes of any PMS are: 1) to improve the efficiency of making decisions; 2) to provide feedback as to the consequences of these decisions; 3) to ensure consistency of decisions made at different levels within the same organization; and 4) to improve the effectiveness of all decisions in terms of efficiency of results. These all relate to maintaining good control over street maintenance.

2.2 USE OF PAVEMENT MANAGEMENT SYSTEMS (PMS)

With an understanding of the database, an examination of the typical uses of a PMS can be undertaken. The following material briefly describes the main areas where a PMS is applied and the benefits achieved from each:

a) Pavement Inventory Data

The most immediate use of the PMS is in having a complete and readily accessible inventory of city road system including up-to-date conditions. This information is frequently very valuable for day-to-day use in tracking maintenance work and for reference in preparing reports or studies.

b) Developing Maintenance Budgets

Rather than preparing the typical 1-year maintenance budget, a PMS allows to prepare a series of budgets. These budgets can be in the form of a multi-year program, identifying not only short-term (1 year) needs, but outlining needs over the course of many years. Further, alternatives can be prepared and presented to the budget decision makers.

c) Prioritization

A PMS allows for the prioritization of maintenance projects based on cost and condition ratings and other factors such as traffic. It further can be used for selecting and ranking of projects for the upcoming budget year, as well as for long term financial planning.

2.3 CONCEPT OF PAVEMENT MAINTENANCE MANAGEMENT SYSTEM (PMMS)

Pavement Maintenance Management System (PMMS) is a scientific tool for managing the pavements so as to make the best possible use of resources available or to maximize the benefit for society. Thus, PMMS can be used in directing and controlling maintenance resources for optimum benefit. A Maintenance Management System of a city is composed of a group of interrelated management tools designed that provide a basis for planning, scheduling, operating and controlling the highway maintenance effort with economy and effectiveness. The use of this system places continuity emphasis on the economic utilization of personnel , equipment and materials, with the available resources. The maintenance activities need to be considered in a more flexible and integrated decision- making framework. The system should be capable of handling the various aspects in a systematic manner, in view of the changing conditions. There is a strong need to gradually introduce new technologies like Geographic Information System (GIS), Global Positioning System (GPS), work scheduling, reports and inventory management. These will enable the highway agencies to perform tasks better, more economically, effectively and of higher quality. A Maintenance Management is the process of coordinating and controlling a comprehensive set of activities in order to maintain pavements, so as to make the best possible use of resources available. Thus the aspects related to maintenance are the activities undertaken to preserve the surface condition and structural quality of pavement.

A Pavement Maintenance Management System provides a systematic, objective and consistent procedure to evaluate existing and future pavement condition. A PMMS also provides a means to help manage pavement maintenance expenditure more economically and efficiently. They provide an objective approach to pavement management and allow for multiple budget options and assist in project formulation for maintenance and rehabilitation works. This study aims to initiate a Pavement Maintenance Management System (PMMS) in which it provides a systematic process of maintaining, upgrading and operating the city pavements and tools to facilitate a more flexible approach that can enable to perform tasks better, more economically, effectively and of higher quality. A PMMS typically uses a pavement rating system called Pavement Condition Index (PCI), as the basis from which current and future pavement condition can be evaluated. From the estimated future pavement condition, multiple budget and maintenance can be run to determine the most cost effective maintenance solutions for the pavements. Pavement maintenance management systems are designed to manage maintenance and rehabilitation activities to optimize pavement condition with available funds. The use of (PMMS) is becoming increasingly more prevalent due to benefits achieved. It considers current and future pavement condition, priorities, funding, and can reduce pavement deterioration, this helps maintain pavement structural capacity, and may extend pavement life by slowing or limiting future pavement degradation. Pavement condition can be quantified by the pavement condition rating (PCR) which rates the pavement according to the extent and severity of distress types present (cracking, raveling. bleeding, shoving). Pavement Condition Rating ranges from 100 to zero. A major goal of (PMMS) is to keep pavement condition in the upper (PCR) range of (60-90) by limiting surface structural degradation to keep down rehabilitation cost. These procedures is to provide a consistent reasonably objective and systematic procedure for establishing priorities, scheduling and budgeting highway maintenance and rehabilitation requirements.

These pavement Maintenance Management Systems (PMMS) were developed to provide management tools to the local municipal agencies in:

a) Prioritizing those road sections that are in need of maintenance.
b) Predicting the long term performance of maintenance alternative.
c) Estimating costs of pavement maintenance strategies with a view to selecting an optimum strategy.

The maintenance management requires careful planning and implementation, efficient reporting methods, easy information retrieval, and accurate assessment of maintenance practices and problems. A maintenance management system as a whole involves managing highway maintenance, which includes the pavement. The pavement management system involves managing the pavement system, including its maintenance. The two concepts are complementary. In some organizations, pavement maintenance and rehabilitation will be handled through a pavement management concept. In others, the maintenance section will carry the prime responsibility, with input from the pavement management group. The pavement management system is a necessary tool for analyzing and predicting the effect of various maintenance and rehabilitation policies.

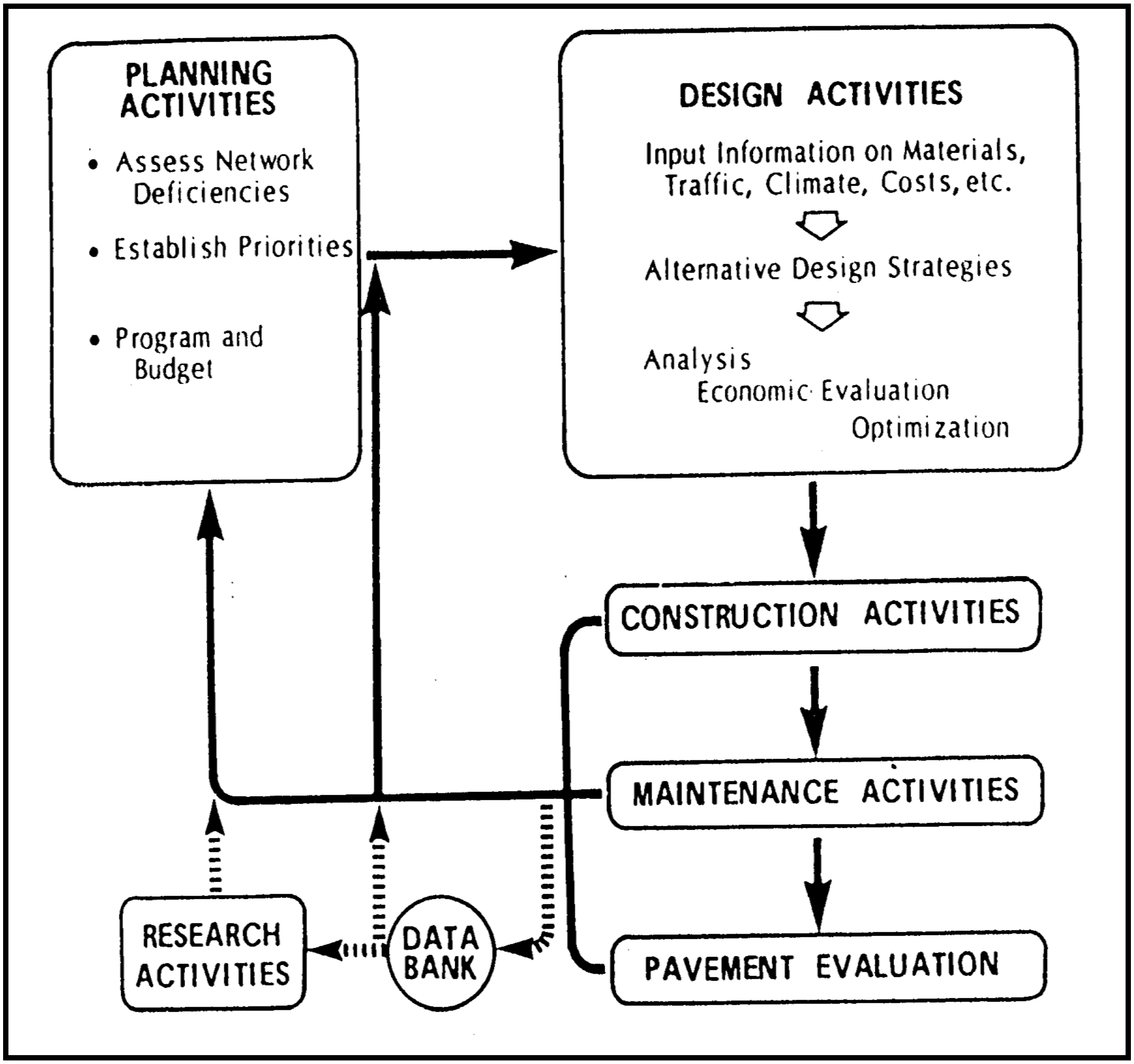

Figure 2.1: Major Classes of Activities of PMS [Haas and Hudson 1978]

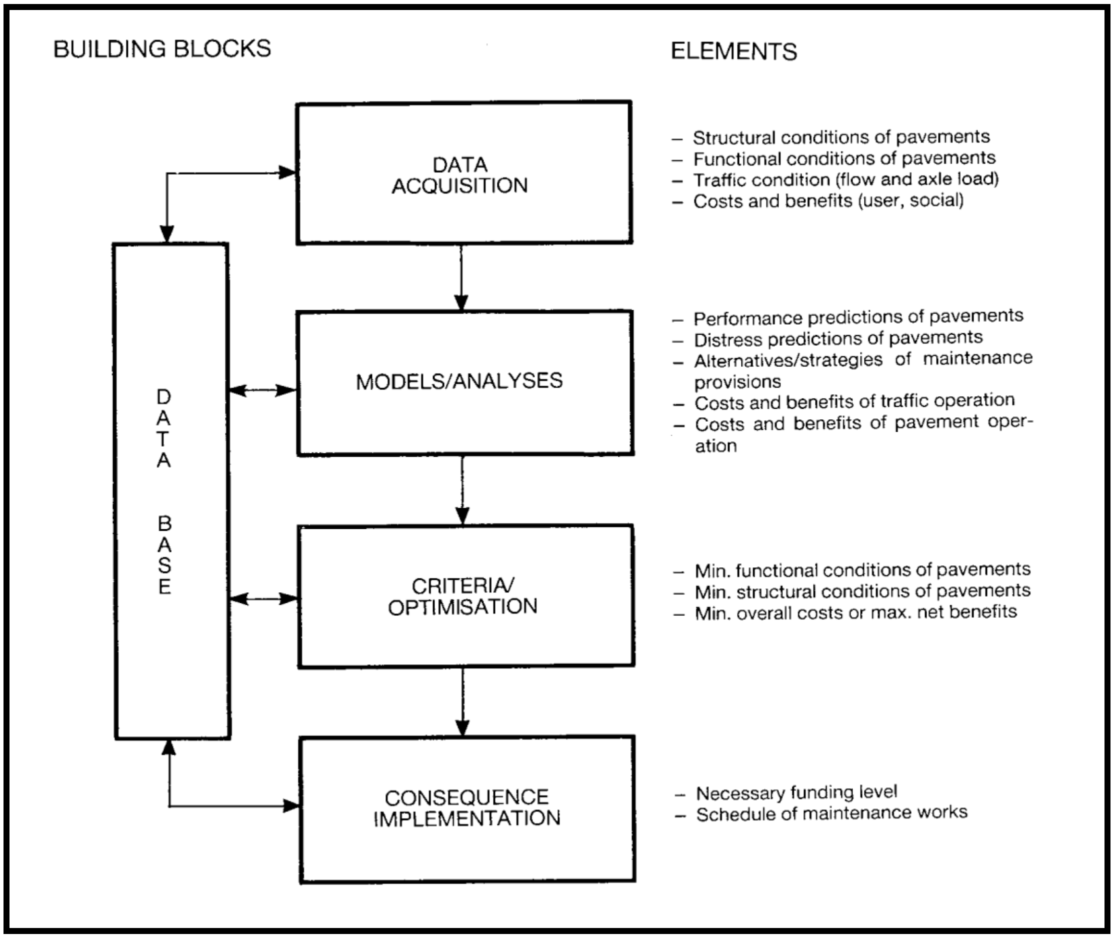

Figure 2.2: Basic Building Blocks of a PMS [OECD 1987]

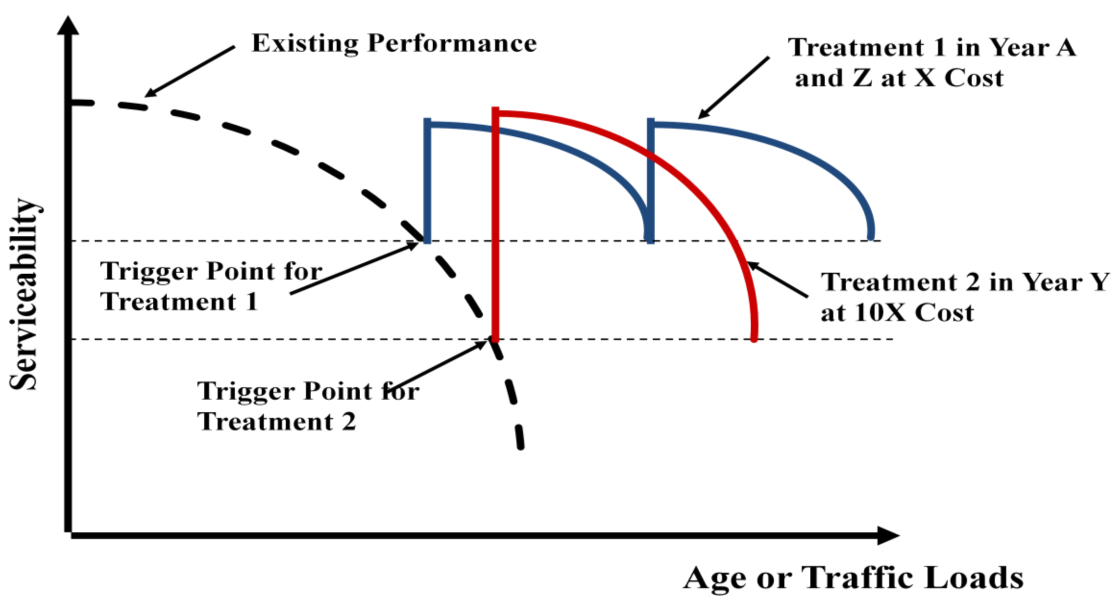

Figure2.3: Importance of the Timely Management on the serviceability of the Pavement

2.4 HIGHWAY DEVELOPMENT AND MANAGEMENT-4 (HDM-4)

The Highway Development and Management System (HDM-4) developed by the World Bank is a powerful pavement management software tool capable of performing technical and economic appraisals of road projects, investigating road investment programs, and analyzing road network preservation strategies. Its effectiveness is dependent on the proper calibration of its predictive models to local conditions. The scope of the new HDM-4 tool have been broadened considerably beyond traditional project appraisals, to provide a powerful system for the analysis of road management and investment alternatives. In addition to updating the HDM-III technical relationships for vehicle operating costs, and pavement deterioration for flexible and unsealed pavements, new technical relationships have been introduced to model rigid concrete pavement deterioration, accident costs, traffic congestion, energy consumption and environmental effects. The HDM-4 incorporates three dedicated applications tools for project level analysis, road work programming under constrained budgets, and for strategic planning of long term network performance and expenditure needs. It is designed to be used as a decision support tool within a road management system. Standard data import and export facilities are provided for linking HDM-4 to various database management systems.

Local adaptation and calibration of HDM-4 models can be achieved by specifying default data sets that represent pavement performance and vehicle resource consumption in the country where the model is being used.

The HDM-4 software applications developed to cater for the following components within the highway management process: Strategic Planning, Work Programming, and Project Preparation. Strategic planning involves the analysis of the road system as a whole, typically requiring the preparation of long term, or strategic, planning estimates of expenditure for road development and preservation under various budgetary and economic scenarios. Work Programming involves the preparation, under budget constraints, of multi-year road work and expenditure programmes in which sections of the network likely to require improvement, are identified and prioritized. Project preparation is the final stage where the economic benefits of road schemes are analyzed prior to implementation.

2.5 ROLE OF HDM-4 IN HIGHWAY MANAGEMENT

When considering the HDM-4 applications, it is convenient to view the highway management process in terms of the following functions (Robinson et al, 1997):

- Planning
- Programming
- Preparation
- Operations

2.5.1 Planning: This involves an analysis of the road system as a whole, typically requiring the preparation of long term, or strategic, planning estimates of expenditure for road development and preservation under various budgetary and economic scenarios. Predictions may be made of expenditure under selected budget heads, and forecasts of highway conditions in terms of key indicators, under a variety of funding levels. The physical highway system is usually characterized at the planning stage by lengths of road, or percentages of the network, in various categories defined by parameters such as road class or hierarchy, traffic flow/capacity, pavement and physical condition. The results of the planning exercise are of most interest to senior policy makers in the road sector, both political and professional. Work will often be undertaken by a planning or economics unit within a road agency.

2.5.2 Programming: This involves the preparation, under budget constraints, of multi-year road works and expenditure programmes in which those sections of the network likely to require maintenance, improvement, or new construction, are identified in a tactical planning exercise. Ideally, cost-benefit analysis should be undertaken to determine the economic feasibility of each set of works. The physical road network is normally considered at the programming stage on a link- by-link basis, with each link characterised by pavement sections and geometric segments, defined by their physical attributes. The programming activity produces estimates of expenditure, under different budget heads, for different treatment types and for different years for each road section. Budgets are typically constrained, and a key aspect of programming is to prioritise works to find the best value for money in the case of a constrained budget.

Typical applications are the preparation of a budget for an annual or rolling multi-year work programme for a road network, or sub-network.

2.5.3 Preparation: This is the short-term planning stage where road schemes are packaged for implementation. At this stage, designs are refined and prepared in more detail; bills of quantities and detailed costing are made, together with work instructions and contracts. Detailed specifications and costing are likely to be drawn up, and any cost-benefit analysis may be revised to confirm the feasibility of the final scheme. Works on adjacent road sections may be combined into a package of a size that is cost- effective for work execution. Typical preparation activities are: the detailed design of an overlay scheme; the detailed design of major works, such as a junction or alignment improvement, lane addition, etc. For these activities, budgets will normally already have been approved. Preparation activities are normally undertaken by relatively junior professional staff and technicians in a technical department of a road agency, and by contracts and procurement staff.

2.5.4 Operations: These activities cover the on-going operation of a road agency. Decisions about the management of operations are made typically on a daily or weekly basis, including the scheduling of work to be carried out, monitoring in terms of labour, equipment and materials, the recording of work completed, and the use of this information for monitoring and control. Activities are normally focused on individual road sections with measurements often being made at a relatively detailed level. Operations are normally managed by sub-professional staff, including works supervisors, technicians, clerks of works, and others.

CHAPTER 3
REVIEW OF LITERATURE

3.1 GENERAL

Pavement management as a process based on the integration of system principles, engineering and economic evaluation is supposed to have begun in the late 1960's. The first PMS model were developed in the mid-seventies, and presently many highways authorities in developed countries are using a systematic and objective method to determine pavement condition and programming maintenance in response to observed conditions. Presently most advanced PMS are those applied in North America.

3.2 PMMS STUDIES NATIONAL STATUS

Kerali et.al (1998) has represented the role of Highway Development and Management-4 (HDM-4) in road management. The HDM-4 is the successor to the World Bank Highway Design and Maintenance Standards Model (HDM-III). The scope of the new HDM-4 tools has been broadened considerably beyond traditional project appraisals, to provide a powerful system for the analysis of road management and investment alternatives. The HDM-4 incorporates three dedicated applications tools for project level analysis, road work programming under constrained budgets, and for strategic planning of long term network performance and expenditure needs. It is designed to be used as a decision support tool within a road management system. Standard data import and export facilities are provided for linking HDM-4 to various database management systems. Local adaptation and calibration of HDM-4 models can be achieved by specifying default data sets that represent pavement performance and vehicle resource consumption in the country where the model is being used.

The highway management process as a whole can, therefore, be considered as a cycle of activities that are undertaken within each of the management functions of planning, programming, preparation and operations. The HDM-4 analytical framework is based on the concept of pavement life cycle analysis. This is applied to predict the following over the life cycle of a road pavement, i.e. road deterioration, road work effects, road user effects and socio-economic and environmental effects. Once constructed, road pavements deteriorate as a consequence of several factors, i.e. Traffic loading, Environmental weathering, Effect of inadequate drainage systems.

Medina et al. (1999) cited a portion of the Pavement Policy for Highways that defines pavement management as, "a set of tools or methods that can aid decision-makers in finding cost-effective strategies for providing and maintaining pavements in a serviceable condition" The pavement management system must address methods, schedules, and budgets associated with achieving the goals. The three main components of a pavement management system are data collection, data analysis, and implementation. One approach to pavement management is shown schematically. The data collection component is summarized in a database which includes the inventory, condition evaluation, and maintenance strategies. The analysis portion of the Pavement Management Structure requires the synthesis of the pavement condition assessment, which is determined from the condition evaluation and the maintenance strategies, along with global concerns related to the network. Based on the results of the network need, one can prioritize the work and develop a work plan, which is, of course, constrained by budgets. Once projects have been selected that are high on the priority list and feasible within the budget, they are implemented.

Aggarwal (2004) represents that HDM-4 is a new international standard assisting pavement managers to predict future economic, technical, social and environmental outcome of possible investment decisions concerning maintenance management of pavements. The pavement deterioration models incorporated in HDM-4 have been calibrated to adapt to local conditions and suitable calibration factors have been determined. These calibrated models have also been validated by comparing the values of distresses predicted by the HDM-4 model with those actually observed in the field. In the present study, different aspects of project level PMS have been demonstrated through four different case studies by making use of 'Project Analysis' application of HDM-4. Since the size of the highway network is not very large and the analysis period is of medium duration, the 'Programme Analysis' application of HDM-4 has been used for the network level pavement management analysis.

Tiwari (1997) represents that the concept of "serviceability" of roads and its evolution through time is widely accepted by pavement engineers and professionals as a way to evaluate road quality and conditions. Both the Present Serviceability Index (PSI) and International Roughness Index (IRI) can be used as indicators of road riding quality and serviceability. The objective of the study was to develop realistic models for estimating PSI for asphalt pavement sections located in the urban city of Noida, near Delhi, the capital of India. The PSI model was developed as a function of the pavement age. An attempt was made to calibrate the American Association of State Highway & Transportation Officials (AASHTO) equation for PSI and determine the suitability of this equation in Indian pavement conditions for selected urban roads. The developed models were also validated. Based on the developed PSI model, the maintenance alternatives have been suggested for the urban road sections in the study area.

3.3 PMMS STUDIES INTERNATIONAL STATUS

Douglas et al (2007) an overview of the planning, management and the execution of pavement maintenance and rehabilitation works on the N3 Toll Route between Heidelberg (Gauteng) and Cedara (Kwazulu Natal) which is operated by N3 Toll Concession (Pty) Ltd. (N3TC). They focus on the annual cycle of Pavement Management System (PMS) activities needed to sustain and protect the road asset, with an emphasis on procedures required for meeting contractual obligations of functional condition and hand-back criteria for remaining pavement life. The PMS processes are outlined in the context of a Toll Concession, followed by more in-depth discussions of two key aspects of N3TC's annual PMS cycle, namely (i) compliance and network condition reporting; and (ii) the rule-based deterioration model used for analysing network deterioration under a given maintenance and financial strategy. The paper concludes with a "lessons learnt" section that highlights some of the lessons learnt in the first decade of management of this contract.

Anderson et al. (1994) developed Pavement management system in Australia, like in other countries across the world, is managed at the district and state level, only. It was developed as in-house software to serve as a decision support tool for the road asset maintenance policy and strategy at the state and district levels. All states use pavement data collection systems. Data gathered includes, but is not limited to roughness, rutting, strength, texture, cracking; skid resistance and seal coat age.

Liu (2006) developed Pavement management system in china .Over1, 900,000 km roads had been constructed in China, among them 40,000 km roads were expressways, another 15,000 expressways would have been constructed by 2010(liu 2006) .By 2020, a national highway network would be completed with 85,000 expressways. Clearly, China needed a pavement management plan to address past and future pavements. In 1984, China initialized and developed a PMS and since its introduction significant progress, in terms of pavement management, has been made. The implementation of this PMS has not gone so well, due to less focus and acceptance. Most transportation departments in China are more focused on road construction.

Petuson (1981) developed a PMS that is designed to assist management in making cost effective decisions regarding pavement maintenance and rehabilitation. Caltrans has given rating system for flexible pavements which includes alligator and block cracking, longitudinal cracking, transverse cracking, raveling, rutting and patching.

Burger *et al.* (1994). Design of a new, complete pavement management system is under way in Germany. Major components are already operational. Meanwhile, data on road conditions have been collected with high-speed monitoring systems over the national road network. The data is assembled according to evenness, skid resistance, and surface damage and subsequently classified via a special grading system. By applying special algorithms, a service value, a structural value, and an overall condition value are being developed. The results of the survey are then presented in lists, route section graphs, and network graphs with different colours indicating where specific target, warning, and threshold values are exceeded. By means of continuous feedback, the information collected is used to improve and adjust the system's components and the plausibility of the output. There is an agreement that for an effective PMS application, repeated automated network monitoring is necessary. To minimize necessary monitoring and evaluation efforts, the use of multifunctional automated monitoring systems is used to collect all necessary data during a single pass.

CHAPTER 4

METHODOLOGY AND DATA BASE COLLECTION

4.1 METHODOLOGY OF THE STUDY

The following steps outline the methodology used for the developing the cost effective maintenance strategies for the Patiala city road network by periodic evaluation of the pavements both structurally as well as functionally:-

i. Identification of the urban network for which the PMMS is to be developed.

ii. Preparation of an inventory of all the pavement sections such as section length, carriageway width, and shoulder width, temperature and rainfall characteristics.

iii. Collection of the data related to characteristics of the vehicle fleet using the urban network and also the collection of the traffic volume to ascertain the traffic related characteristics of all the pavement sections.

iv. Collection of the periodic pavement condition data in terms of various pavement distresses such as cracking area, potholing area, rutting, roughness, structural deflection using standard measures and equipments.

v. Calculation of the Pavement Serviceability Index. (PSI)

vi. Development of various maintenance strategies schedule by using HDM-4 and suggesting the optimum cost effective maintenance plan for the Patiala City for the analysis period of the fifteen years.

vii. Calculation of the remaining service life of the pavement sections of the network.

4.2 DATA COLLECTION BASED UPON THE REQUIREMENT OF HDM-4

The effectiveness of any PMMS is dependent upon the data being used (Nashville Department of Transport 2007). Primary types of data needed include pavement condition ratings, costs, roadway construction and maintenance history as well as traffic loading. A major emphasis of any PMS is to identify and evaluate pavement conditions and determine the causes of deterioration. To accomplish this, a pavement evaluation system should be developed that is rapid, economical and easily repeatable. Pavement condition data must be collected periodically to document the changes of pavement condition. Typically, condition inventories are input, stored and retrieved on a roadway segment basis. The maintenance costs used in a PMMS are dictated by the available information on the cost of activities conducted. Costs are typically shown as total unit cost per square meter (m^2) for activities. Cost information must be easily updated to reflect current cost values. The cost data is used to make estimates for maintaining a pavement at a given condition and for projecting long-range budget, based on the condition of the pavement.

The process of data collection was classified under following four categories:

a) Road Network Data
b) Vehicle Fleet Data
c) Maintenance and Rehabilitation Works Data
d) Cost Data

4.3 ROAD NETWORK DATA

The road network data collection is carried out based upon the data requirements of HDM-4, and it consisted of obtaining secondary data from the past records and relevant government publications, and collecting current data from the selected pavement sections by carrying out field studies. The road network data includes the location data that describes the position and geometry of the pavement section, and the attribute data, which describes the road characteristics or inventory associated with it.

The road network data collection in the field is divided under the following heads:

- Inventory data
- Structural evaluation (Structural capacity)
- Functional evaluation (Pavement condition and riding quality)
- Evaluation of pavement material.

4.3.1 Inventory Data of the Selected Road Network: The road network was selected by taking different types of the roads of the Patiala city. Around 19 km of the road length was selected as shown in Table 4.1 along with the section ID.

Table 4.1 Selected Urban Road Network

Section ID	Section Name	Length
UR01	From Thapar University to Nabha Road	2.80
UR02	From Thapar University Chowk to Dukhniwaran Sahib	2.30
UR03	From Dukhniwaran Sahib to Passey Road	2.20
UR04	From Thapar University to Bhadson Road	1.10
UR05	From Leela Bhawan Chowk to Amar Hospital Road.	0.60
UR06	From Samana Chungi to Bhakra.	6.2
UR07	From Samana Chungi to YPS Chowk.	1.00
UR08	From NIS Chowk to Fountain Chowk.	2.20
UR09	From Fountain Chowk to Memorial Chowk.	0.60

The inventory data was collected for the above shown selected city road network in terms of the following parameters:-

- Section ID
- Carriageway and shoulder width
- Drainage conditions
- Pavement Surface type
- Thickness and Pavement layer details etc.
- Last Resurfacing and Maintenance history from Municipal Corporation, Patiala office.

Table 4.2 Inventory Data with Section ID

Sr. No.	**Section ID**	**Length in K.M.**	**Width of Road (in meter)**	**Width of Carriage way (in meter)**	**Divided/ Un-divided**	**Surface Type**
1.	UR01	2.80	16.42	7.00	Divided	Flexible Pavement
2.	UR02	2.30	15.90	7.05	Divided	Flexible Pavement
3.	UR03	2.20	7.70	7.10	Un-divided	Flexible Pavement
4.	UR04	1.10	10.20	9.90	Un-divided	Flexible Pavement
5.	UR05	0.60	30.25	13.4	Divided	Flexible Pavement
6.	UR06	6.20	22.70	10.65	Divided	Flexible Pavement
7.	UR07	1.00	20.71	9.00	Divided	Flexible Pavement
8.	UR08	2.20	21.45	9.1	Divided	Flexible Pavement
9.	UR09	0.60	29.60	13.10	Divided	Flexible Pavement

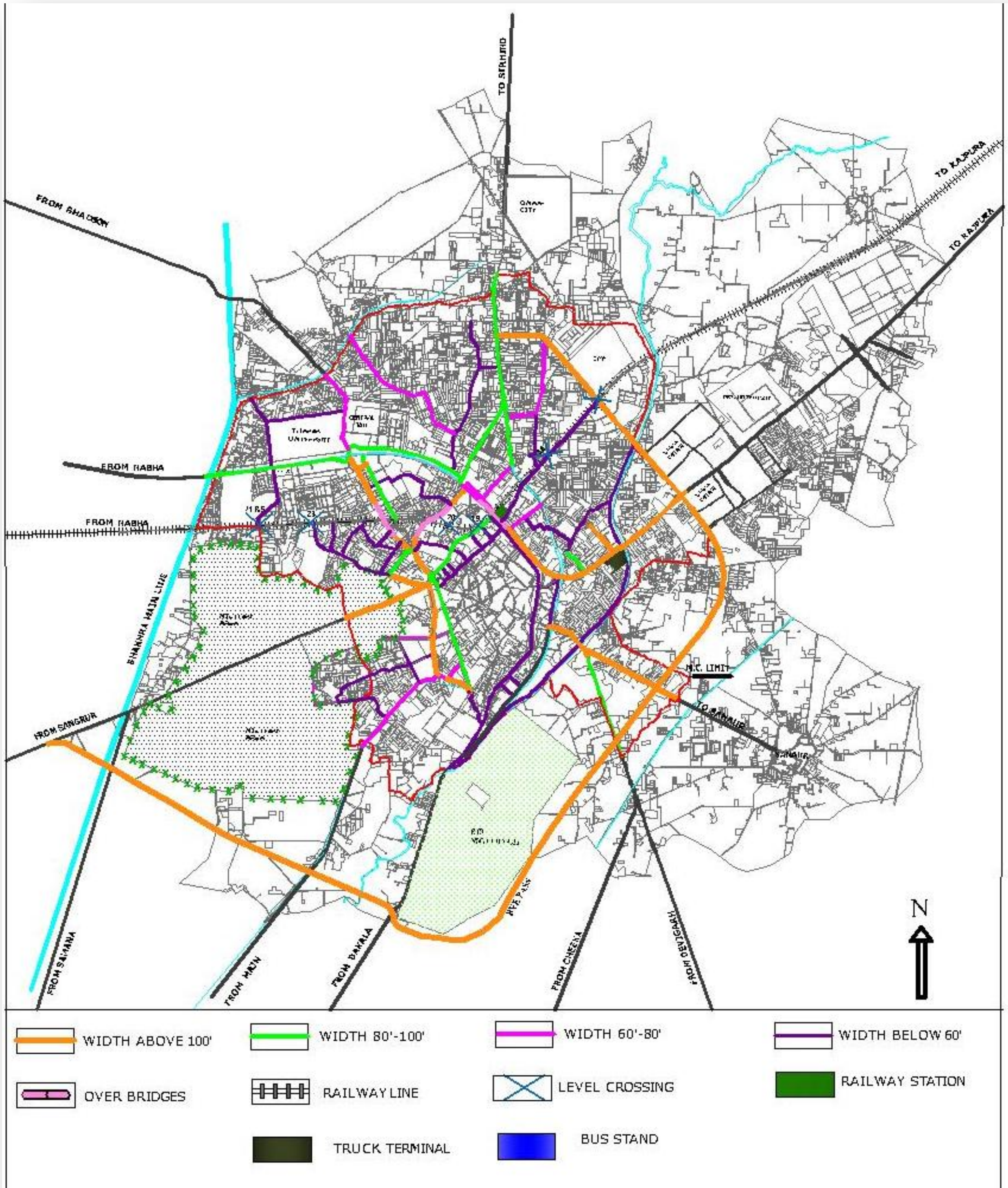

Fig 4.1 Map Showing Patiala Urban Road Network

4.3.2 Drainage condition data: Data regarding side drainage condition was collected as shown in Table 4.2 on the basis of visual inspection and discussion with personnel's of Road Construction Department Patiala along with the local users.

Table 4.3 Drainage Condition of the selected road network

SECTION ID	CONDITION OF DRAIN
UR01	FAIR
UR02	Good
UR03	Poor
UR04	Poor
UR05	Good
UR06	Good
UR07	Good
UR08	Poor
UR09	Good

4.3.3 Traffic Input Data: The traffic input data was collected from the Municipal Corporation and District Town Planner office, Patiala in terms of the PCU for Peak Hour Volume and Peak Hour Capacity to get the volume by capacity ratio of the selected road network. The motorized AADT and non motorized AADT data was also collected as per Table 4.4.

a) Volume Capacity ratio on Selected Road Network of Patiala City

The volume capacity ratio indicates the capacity of roads to hold a given volume of vehicles. The capacity of urban road is normally expressed in terms of a common unit, namely Passenger Car Unit (PCU). The relative PCU of particular vehicle type is affected to a great extent by increase in its proportion in the total traffic.

The value of volume capacity ratio if comes out to 1 is considered as an ideal condition. If the ratio exceeds 1, it indicates

Table 4.4: Traffic Data as per Year 2011 [Municipal Corporation, Patiala 2011]

S.NO	**Section ID**	**Peak Hour Volume, V (PCU)**	**Peak Hour Capacity, C (PCU)**	**Volume /Capacity Ratio**	**Type of Carriageway**
1	UR01	750	2200	0.34	4 Lane divided (two way
2	UR02	2244	2200	1.02	4 lane divided (two way)
3	UR03	1140	1200	.92	2 Lane undivided (two way)
4	UR04	1635	1800	0.90	2 lane undivided (two way)
5	UR05	1433	2200	0.65	Divided 6 lane (two way)
6	UR06	1934	2900	0.67	4 lane divided (two way)
7	UR07	611	2900	0.21	4 lane divided (two way)
8	UR08	1485	1200	1.2	6 lane divided (two way)
9	UR09	1992	4300	.46	6 Lane divided (two way)

Over utilization/ congestion or if it is below 1, the road capacity is under-utilized. The calculated V/C ratio for nine selected road stretches is as shown in Table 4.4.

b) **Vehicle composition on Selected Road Network of Patiala City**

The traffic volume survey of the selected roads of Patiala city was carried out in order to know the vehicular composition and volume on these roads. A mixed composition of vehicles i.e. heavy vehicles like trucks, buses, tractor, medium vehicles, two wheelers, four wheelers and other light weight vehicles are widely observed on the selected roads of Patiala city e.g. the vehicular composition on one of the section id reveals that from Thapar University to Bhadson Road (UR 04) the 31.7% vehicles were Car / Jeep/ Autos while motorized two wheelers (Scooter/Motorcycles) were 30%. The non-motorized traffic (Cycles/ Rickshaws) was 27% of the total traffic volume. The vehicle composition for all the selected sections is given in the Table 4.5 and the history details of the pavement were collected as per Table 4.6.

4.4 STRUCTURAL EVALUATION OF THE PAVEMENT

The magnitude of pavement rebound deflection is an indicator of the ability of the pavement to withstand traffic loading. Higher the rebound deflection, poor is the structural capacity and performance. The practice is to use the Benkelman Beam deflection method for evaluating the structural condition of the flexible pavement. The deflection measurements were taken with Benkelman Beam as per the procedure laid down in IRC: 81 [1997]. The calculations for the overlay deflection and the characteristic deflections were carried out as shown in the Table 4.7. The rebound deflection method of Pavement Evaluation & Overlay design is based on the concept that stretches of flexible pavements that are in service and have been conditioned by traffic, would deform elastically under a wheel load and when the load is removed or is moved forward, the deflected pavement surface would rebound.

Performance of Flexible Pavement is closely related to elastic deflection of pavement under the wheel loads. Pavement deflection is measured by using Benkelman beam which consists of beam of 3.66 m length pivoted at a distance of 2.44 m from the tip and a dial gauge is used for measuring deflection. By suitably placing the beam between the dual wheels of the standard axle, it is possible to measure the rebound deflection of pavement structure.

Table 4.5 Vehicular Composition Percentage & Volume of Traffic at the selected sections.

S. No	Section Id	Cycle	Rickshaw /Rehri	Scooter/ M-Cycle	Car/ Jeep/ Auto	Bus/ Truck/ Tractor/ Trolly	Cart	Total
1	UR01	108	18	251	215	42	3	637
		17	**2.8**	**39.4**	**34**	**6.6**	**0.2**	**100**
2	UR02	404	92	548	347	196	5	2468
		25.4	**5.8**	**34.4**	**21.8**	**12.3**	**0.3**	**100**
3	UR03	171	158	470	338	29	2	1168
		15	**14**	**40**	**28.4**	**2.5**	**0.1**	**100**
4	UR04	198	118	350	371	112	22	1280
		16.9	**10**	**30**	**31.7**	**9.6**	**1.8**	**100**
5	UR05	251	180	547	265	33	4	1280
		20	**14**	**42**	**21**	**2.6**	**0.4**	**100**
6	UR 06	191	207	651	880	425	3	2357
		8.1	**8.8**	**27.61**	**37.34**	**18.03**	**0.12**	**100**
7	UR 07	371	180	580	144	2	3	1280
		29	**14**	**45.3**	**11.3**	**0.15**	**0.25**	**100**
8	UR08	464	358	722	878	34	12	2468
		19	**14.5**	**29**	**35.6**	**1.4**	**0.5**	**100**
9	UR 09	583	247	705	864	438	5	2842
		21	**9**	**25**	**29.8**	**15**	**0.2**	**100**

Table 4.6 Pavement Inventory Data [Municipal Corporation, Patiala]

Section ID	Surfacing Material Type	Current Surface Thickness (mm)	Previous Surface Thickness (mm)	Last Construction Year	Last Rehabilitation Year	Last Surfacing Year
UR01	Bituminous Concrete (BC)	75	50	1997	2005	2010
UR02	Bituminous Concrete (BC)	75	50	1996	2005	2010
UR03	Bituminous Concrete (BC)	75	50	1996	2005	2010
UR04	Bituminous Concrete (BC)	75	50	1997	2004	2010
UR05	Bituminous Concrete (BC)	75	50	1995	2006	2011
UR06	Bituminous Concrete (BC)	75	50	1994	2006	2008
UR07	Bituminous Concrete (BC)	75	50	1999	2003	2010
UR08	Bituminous Concrete (BC)	50	50	2000	2006	2009
UR09	Bituminous Concrete (BC)	75	50	1995	2006	2011

4.4.1 Calculation of the Rebound Deflection:
The rebound deflection value depends on the following parameters**:-**

- Subgrade soil type
- Moisture content of the subgrade soil
- Type and thickness of the pavement component layer
- Temperature of the bituminous layers
- Previous loading history of traffic load on the Pavement
- Magnitude, contact pressure and configuration of the applied load and
- Other environmental factors.

4.4.2 Deflection Measurements at the Road Sections:

- Benkelman Readings were taken at 21 points in each Km.
- Interval between the points was not less than 50 m
- Marking of points was staggered for the roads having more than one lane.
- Transverse distance from the edge of pavement was as per IRC:81-1997

  60 cm if lane width is less than 3.5 m

  90 cm if lane width is more than 3.5 m

  150 for divided four lane highway
- Rear axle load 8170 kg and Tyre pressure in the vehicle was kept as 5.6 kg / cm^2.

4.4.3 Calculations for the Characteristic Deflection:
The Characteristic deflections were calculated for all the sections for measuring the structural adequacy of the pavements by taking the initial, intermediate and final deflections readings of the Benkelman.

- D_0: - Initial reading (obtained when the rate of deformation of pavement is less than 0.025mm per minute)
- D_i: - Intermediate reading (Truck is slowly moved to a distance of 270 cm and stopped and reading obtained when the rate of deformation of pavement is less than 0.025mm per minute)
- $D_{f:}$ - Final reading (Truck is further driven to 9m & final reading is obtained when the rate of deformation of pavement is less than 0 .025mm per minute)

Overlay Deflection (OD) when $D_i - D_f < 0.025$ mm

$$OD = 2\,(D_o - D_f)$$

Overlay Deflection (OD) when $D_i - D_f > 0.025$ mm

$$D = 2\,(D_o - D_f) + 2K\,(D_i - D_f)$$

Where K = 2.91 [IRC: 81-1997]

Temperature Correction: -

- Deflection measurements were generally taken at 35^{0C}.
- If the deflection measurements are taken at any other temperature, the deflection values are corrected by using correction factor of 0.01 mm/degree centigrade.
- The correction is positive (+ve) for pavement temperature is lower than the 35^{0} and negative (-ve) for pavement temperature higher than the 35^{0}.

Seasonal Correction: -

- Depending upon the field moisture content (FMC) and the type of the sub-grade, the Field moisture correction factor was calculated using graphs of IRC: 81-1997.

Initial	Intermed	Final	OD	P. T	S.T	DIFF	CORR	FM%	FMC	COD	Mean	SD	
4.20	3.95	3.94	0.520	37	35	-0.02	0.50	8	1.35	0.68	0.74	0.49	DC = mean +SD = 0.74+0.49 (for Urban Roads)
4.71	4.21	4.19	1.040	37	35	-0.02	1.02	8	1.35	1.38			
3.79	3.10	3.08	1.420	37	35	-0.02	1.40	8	1.35	1.89			
4.43	4.12	4.10	0.660	37	35	-0.02	0.64	8	1.35	0.86			
4.00	3.63	3.62	0.760	37	35	-0.02	0.74	8	1.35	1.00			
11.61	11.32	11.32	0.580	37	35	-0.02	0.56	8	1.35	0.76			
16.27	16.06	16.05	0.440	37	35	-0.02	0.42	8	1.35	0.57			
9.19	9.03	9.03	0.320	37	35	-0.02	0.30	8	1.35	0.41			
5.78	5.46	5.46	0.640	37	35	-0.02	0.62	8	1.35	0.84			
12.81	12.59	12.59	0.440	37	35	-0.02	0.42	8	1.35	0.57			
7.93	7.59	7.59	0.680	37	35	-0.02	0.66	8	1.35	0.89			
10.62	10.41	10.41	0.420	37	35	-0.02	0.40	8	1.35	0.54			
9.23	9.02	9.01	0.440	37	35	-0.02	0.42	8	1.35	0.57			
7.68	7.51	7.51	0.340	37	35	-0.02	0.32	8	1.35	0.43			
3.71	3.59	3.59	0.240	37	35	-0.02	0.22	8	1.35	0.30			
4.54	4.40	4.39	0.300	37	35	-0.02	0.28	8	1.35	0.38			
4.10	3.91	3.90	0.400	37	35	-0.02	0.38	8	1.35	0.51			
3.96	3.44	3.42	1.080	37	35	-0.02	1.06	8	1.35	1.43			
5.02	4.79	4.79	0.460	37	35	-0.02	0.44	8	1.35	0.59			
4.70	4.56	4.54	0.320	37	35	-0.02	0.30	8	1.35	0.41			
4.14	3.91	3.90	0.480	37	35	-0.02	0.46	8	1.35	0.62			
												Dc	**1.23**

Table 4.7: Characteristic Deflection Calculations for the Section ID UR 01

4.4.4 Calculation of Adjusted Structural Number (SNP) – From the BB deflection values determined as above, the adjusted Structural Number (SNP) for all the pavement sections has been deduced as per the relationships given by the following equation [Odoki and Kerali 2000].

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

Table 4.8 First Trial for the Deflection & Structural Number

SECTION ID	DEFLECTION(mm)	STRUCTURAL NUMBER (SNP)
UR01.	1.23	2.8306
UR02.	1.34	2.6830
UR03.	1.41	2.5990
UR04.	1.52	2.4798
UR05.	1.42	2.5875
UR06.	1.28	2.7609
UR07.	1.39	2.6223
UR08.	1.46	2.5430
UR09.	1.58	2.4205

Table 4.9 Second Trial for the Deflection & Structural Number

SECTION ID	DEFLECTION(mm)	ADJUSTED STRUCTURAL NUMBER (SNP)
UR01.	1.24	2.8276
UR02.	1.3440	2.6780
UR03.	1.4169	2.591
UR04.	1.5412	2.4648
UR05.	1.4393	2.5658
UR06.	1.2976	2.7375
UR07.	1.3971	2.6139
UR08.	1.4609	2.542
UR09.	1.5818	2.4188

4.5 FUNCTIONAL EVALUATION OF THE PAVEMENTS

Functional evaluation of the pavements were done to collect the data of functional surface distresses like cracked area, rut depth, number of potholes and surface roughness.

4.5.1 Measurement of Crack Area: A number of representative test sections of length 50 m were chosen for cracking measurements for each pavement section. The affected area was marked in the form of rectangular figures. In case of single longitudinal and transverse cracks, the crack length was measured and the effective width of the crack was taken as 5 mm. Thus crack area [Photo 4.1] was expressed as percentage of total pavement area. Separate measurements were taken for cracks of width up to 3 mm and width more than 3 mm (wide cracks).

Plate 4.1 Cracked Surface

4.5.2 Measurement of ravelled area - Ravelling is the loss of material from wearing surface [photo 4.2]. This distress type is associated with thin surfacing, such as, surface dressing, seal coat and premix carpet. The affected area was measured by taking into account area enclosed in regular geometric shapes such as, rectangle, triangle etc. and then it was expressed as percentage of total pavement area.

Plate 4.2 Ravelled Surfaces

4.5.3 Measurement of Pothole Area: Potholes are bowl shaped holes of varying sizes in a surface layer or extending into base/sub base course. The pothole area is measured in terms of square metres and the depth of each pothole is also measured to convert into volume of potholes. The pothole measurements are finally expressed as number of pothole units per km length of the pavement section, as stipulated in HDM-4 data requirements.

4.5.4 Rut Depth Measurements - The transverse deformation across the wheel path is defined as the rut. The rut depth measurements were taken with a 2 m straight edge, at all deflection points under the wheel path i.e. at a distance of 0.9 m/0.6 m from the pavement edge in case of double lane/single lane carriageway, and maximum value of rut depth was noted down at each observation point.

Plate 4.3: Pothole measurement

Plate 4.4: Rut Depth Measurement

4.5.5 Roughness Measurements: The pavement roughness was measured on each section with 'Fifth Wheel Bump Integrator', towed by the mobile van, as per the standard procedure. The instrument was run at a constant speed of 32 km/h.

The roughness values were obtained in terms of Unevenness Index, using Equation

$$UI = B/W * 460 * 25.4 \text{ mm/km}$$

Where

UI = Unevenness Index in mm/km

B = Bump Integrator reading

W = No. of wheel revolutions

The following relationship has been used to convert the UI into the universally acceptable International Roughness Index (IRI - measured in m/ km) [Odoki and Kerali, 2000].

$$UI = 630 \times IRI^{1.12}$$

Plate 4.5 Bump Integrator for Pavement Roughness

4.6 TEST RESULTS OF THE DIFFERENT TRIALS FOR THE FUNCTIONAL EVALUATION

The trials were performed for getting the values of the pavement distresses. Three trials as per tables 4.10 to 4.12 and figures 4.2 to 4.9 were performed for the functional evaluation of the pavements of the selected nine sections of the Patiala City.

Table 4.10 First Trial of Functional Parameters of the Selected Urban Road Network

Section ID	Roughness IRI (m/km)	Cracking Area (%)	Potholes (no./km)	Rut Depth (mm)
UR01	2.30	0.30	0.00	2.11
UR02	2.10	0.45	0.00	2.66
UR03	1.60	0.26	0.00	2.35
UR04	2.50	2.40	3.00	3.35
UR05	2.35	1.05	0.00	2.55
UR06	2.00	1.25	2.00	2.23
UR07	3.95	0.82	2.00	2.08
UR08	4.30	3.05	7.00	4.10
UR09	2.65	1.24	2.00	2.35

Table 4.11 Second Trial of Functional Parameters of the Selected Urban Road Network

Section ID	Roughness IRI (m/km)	Cracking Area (%)	Potholes (no./km)	Rut Depth (mm)
UR01	2.33	1.03	2.00	2.16
UR02	2.30	1.18	1.00	2.71
UR03	1.85	1	1.00	2.40
UR04	2.53	3.13	3.00	3.40
UR05	2.56	1.77	1.00	2.60
UR06	2.29	1.98	3.00	2.28
UR07	4.17	1.55	2.00	2.13
UR08	4.56	3.78	7.00	4.15
UR09	2.93	1.97	4.00	2.40

Table 4.12 Third Trial of Functional Parameters of the Selected Urban Road Network

Section ID	Roughness IRI (m/km)	Cracking Area (%)	Potholes (no./km)	Rut Depth (mm)
UR01	2.36	1.75	3.00	2.21
UR02	2.50	1.90	2.00	2.76
UR03	2.05	1.72	1.00	2.46
UR04	2.55	3.87	4.00	3.46
UR05	2.78	2.5	2.00	2.66
UR06	2.52	2.71	3.00	2.33
UR07	4.38	2.28	2.00	2.18
UR08	4.79	4.50	8.00	4.21
UR09	3.17	2.7	4.00	2.46

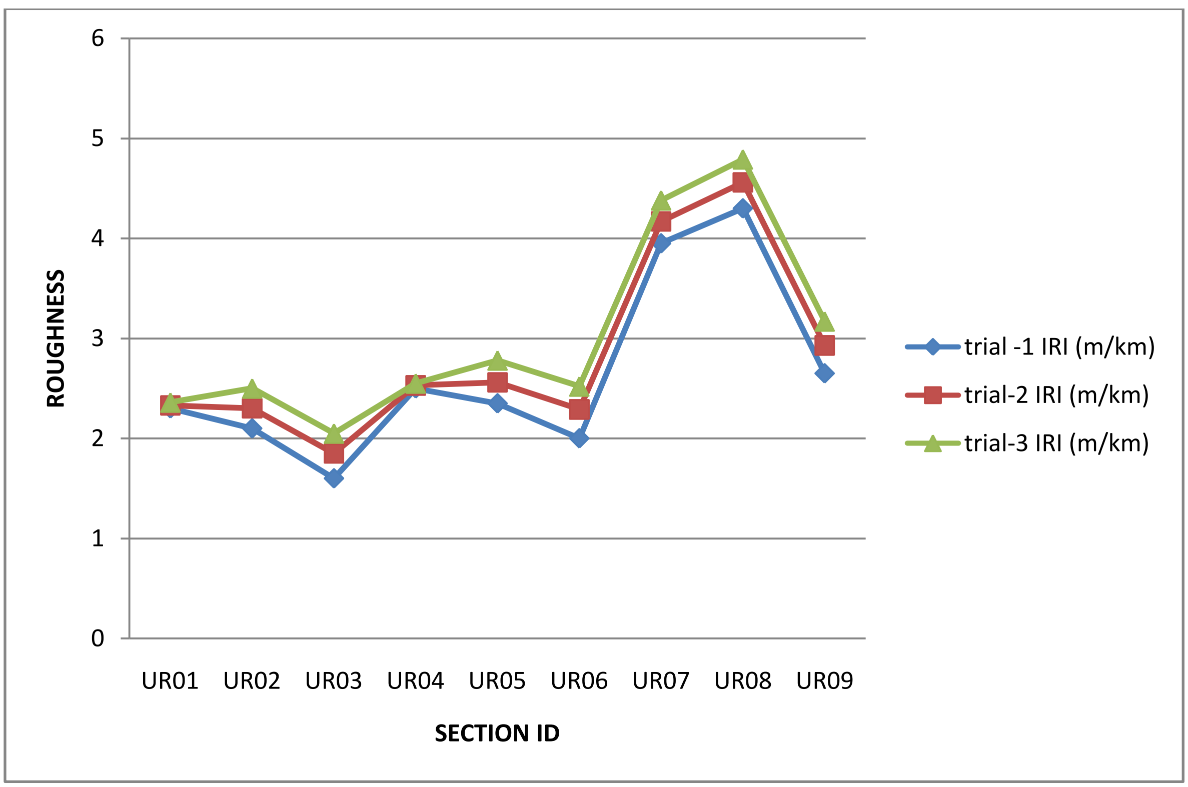

Figure 4.2 Trends Showing between Section ID and Roughness

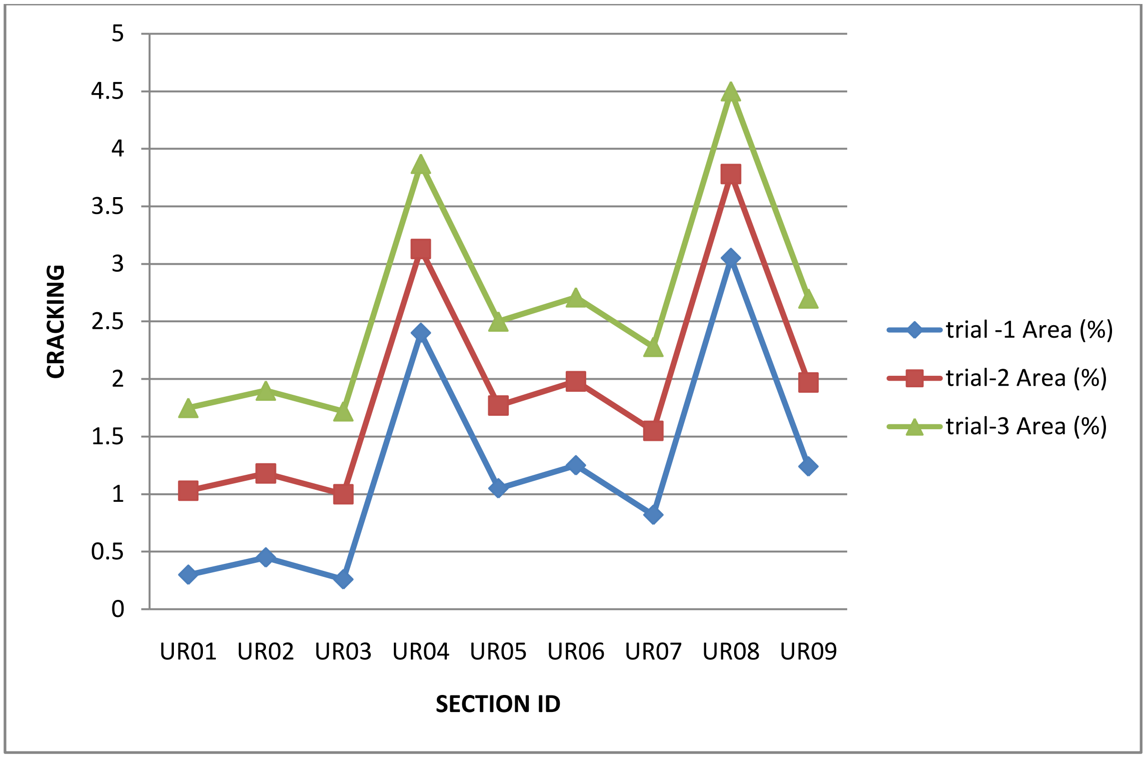

Figure 4.3 Trend Showing between Section ID and Cracking Area

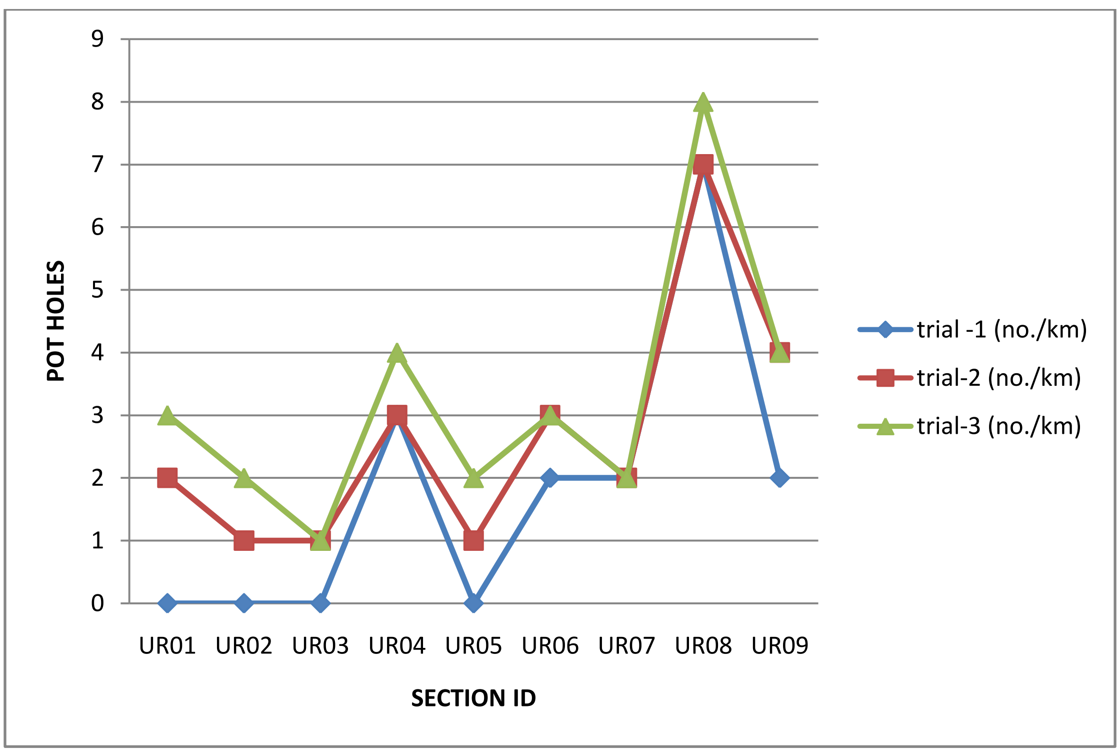

Figure 4.4 Trend between Section ID and Potholes

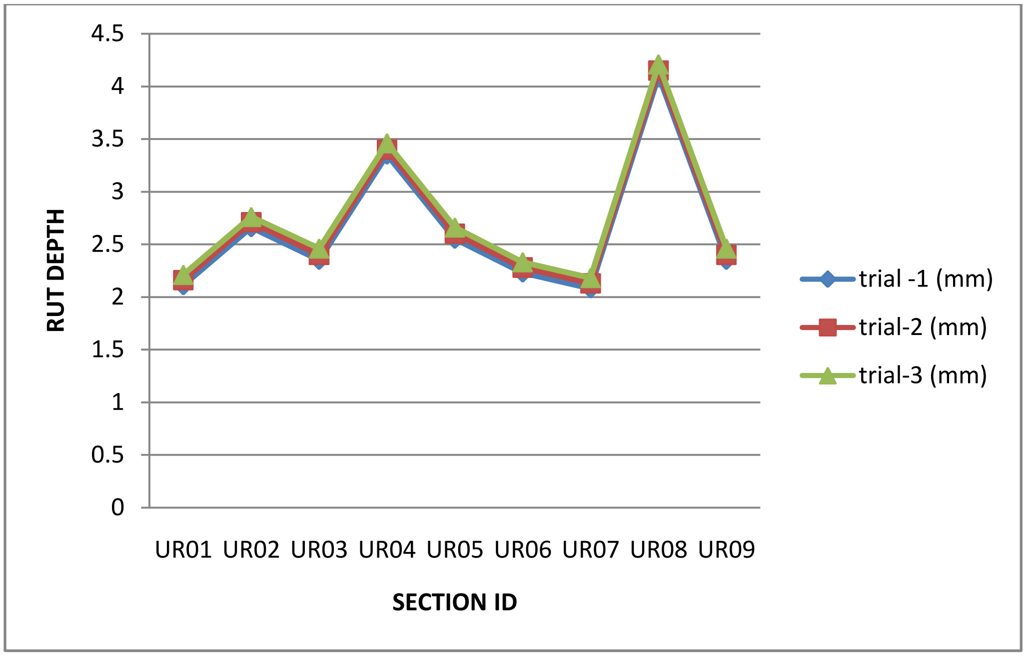

Figure 4.5 Trend between Section ID and Rut Depth

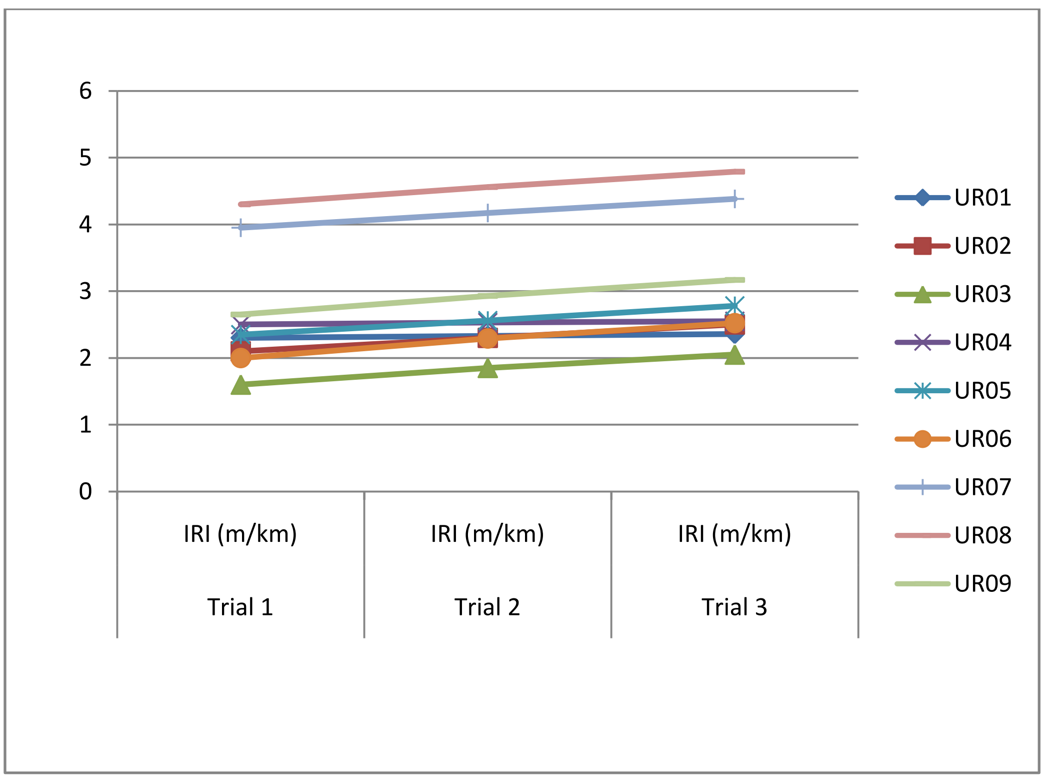

Figure 4.6 Trend between Section ID and Roughness

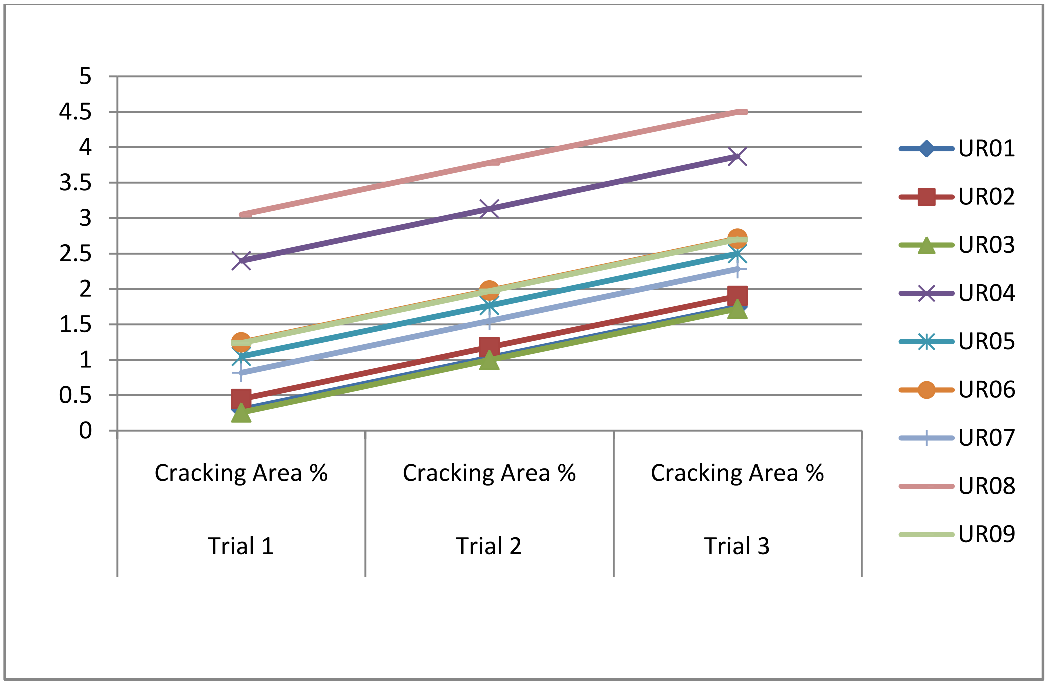

Figure 4.7 Trend Showing between Sections ID and Cracking area

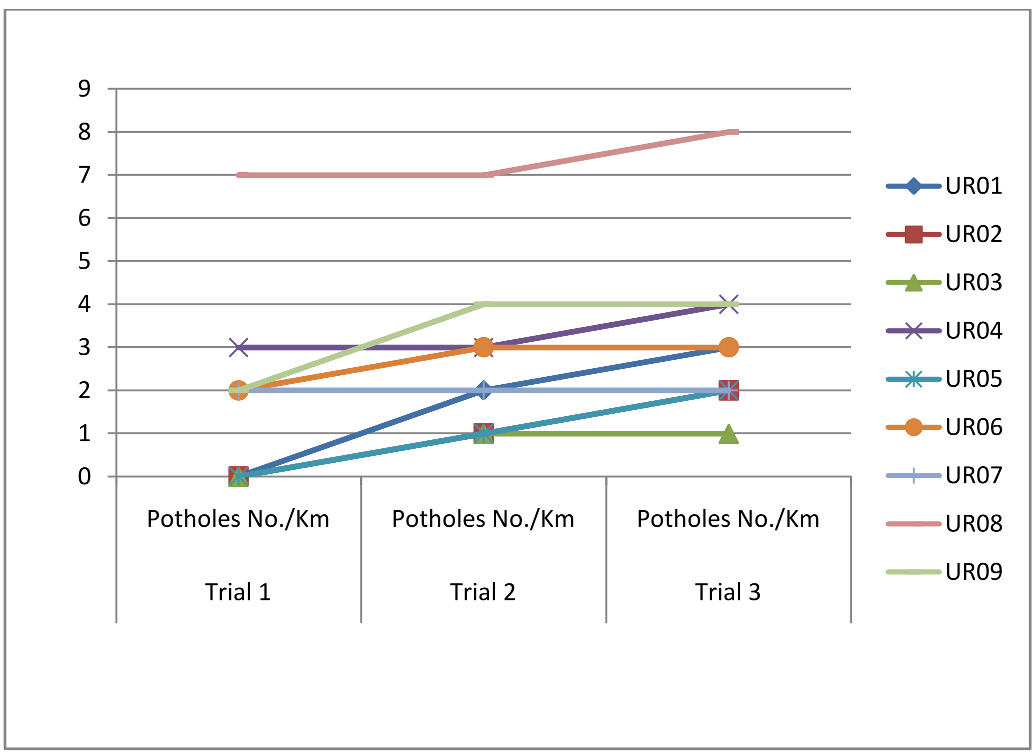

Figure 4.8 Trend Showing between Section ID and Potholes

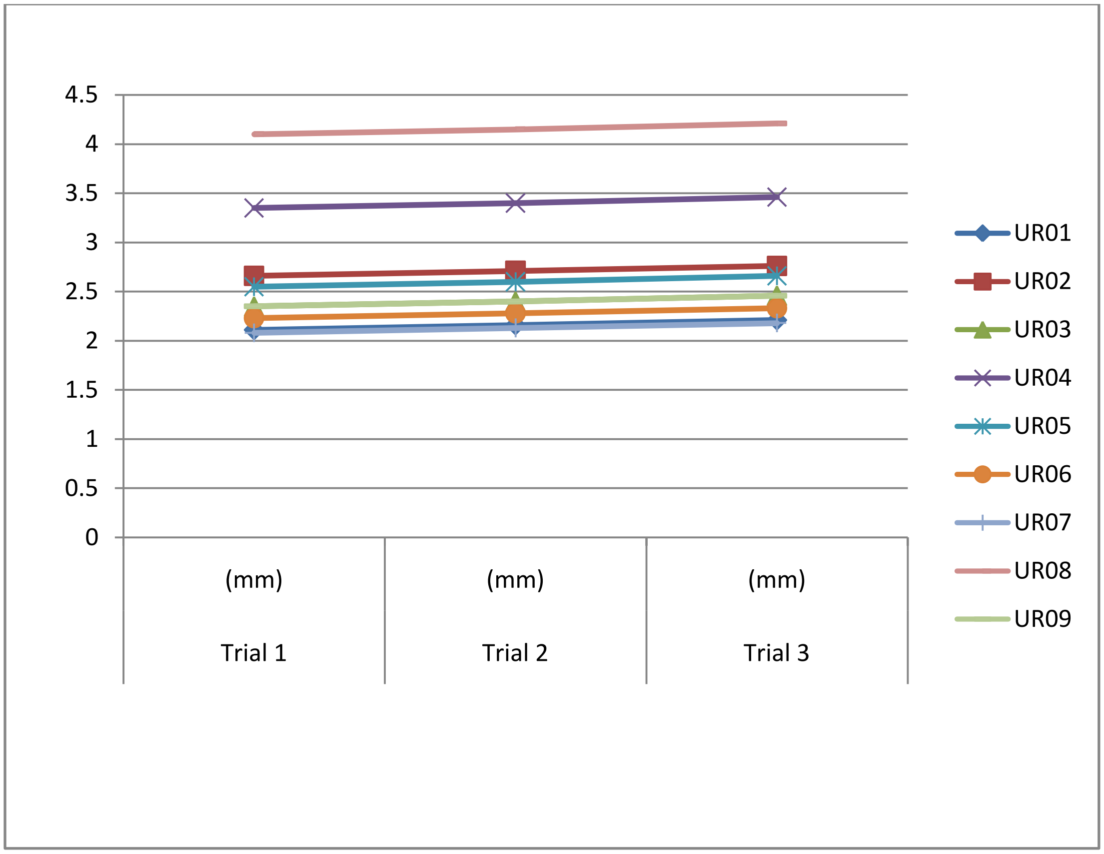

Figure 4.9 Trend Showing between Section ID and Rut Depth

CHAPTER 5

APPLICATION OF HDM-4 FOR OPTIMUM MAINTENANCE STRATEGIES

5.1 GENERAL

This study presents the application of the HDM-4 for the economic analysis of alternative maintenance and rehabilitation (M&R) strategies for individual pavement sections. The main purpose of this case study is to assess the economic benefits arising out of investing in maintenance and rehabilitation of a pavement section at the appropriate time, as compared against carrying out minimum routine maintenance annually. Applicable maintenance and rehabilitation activities, and the corresponding intervention levels are defined, and the timing of selected M&R activities are determined. The optimum M&R strategy is selected on the basis of economic indicators of benefit to cost.

5.2 DATA INCORPORATION TO THE HDM-4

The input data for this study is included in the 'Patiala Urban Road Network', 'Patiala Urban Vehicle Fleet', and 'Maintenance and Rehabilitation works Standards' databases as defined in various sections of the previous chapter with the description as "Cost effective Maintenance strategies for Patiala Urban Network. The pavement section UR-04 of identified urban Road Network has been selected for this study. Some of the snapshots of HDM-4 are as shown in Figures 5.1 to Figure 5.7

Pavement condition characteristics, such as cracking area, roughness, structural number, pothole units, and rut depth values were recorded at the time of data collection. These values are used as input pavement condition data in HDM-4 as shown in Figure 5.3.

The maintenance and rehabilitation history of the pavement section, used as input data in HDM-4 is shown in Figure 5.7.

The total traffic on the identified pavement section is collected in terms of AADT. Initial composition of various representative vehicles in the vehicle fleet, and the annual growth rate of each type of vehicles for the selected pavement section, is shown in Figure 5.5 to Figure 5.6.

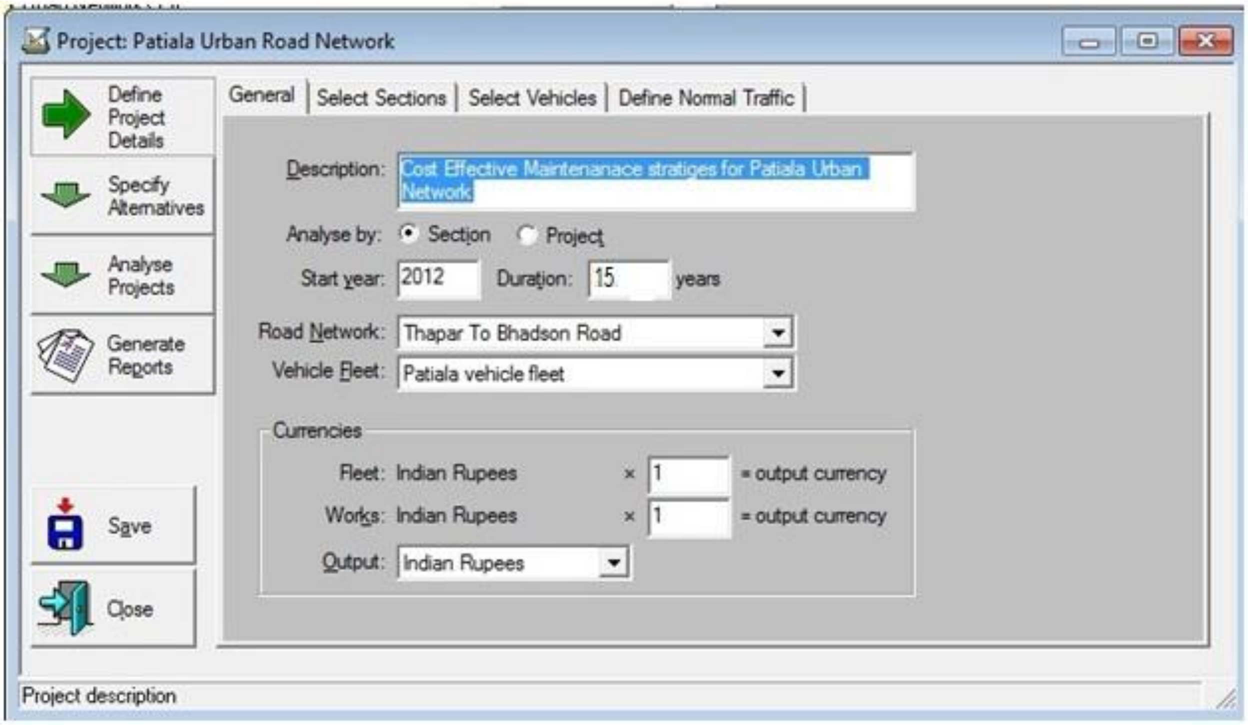

Figure 5.1 Input Details for the Project Analysis

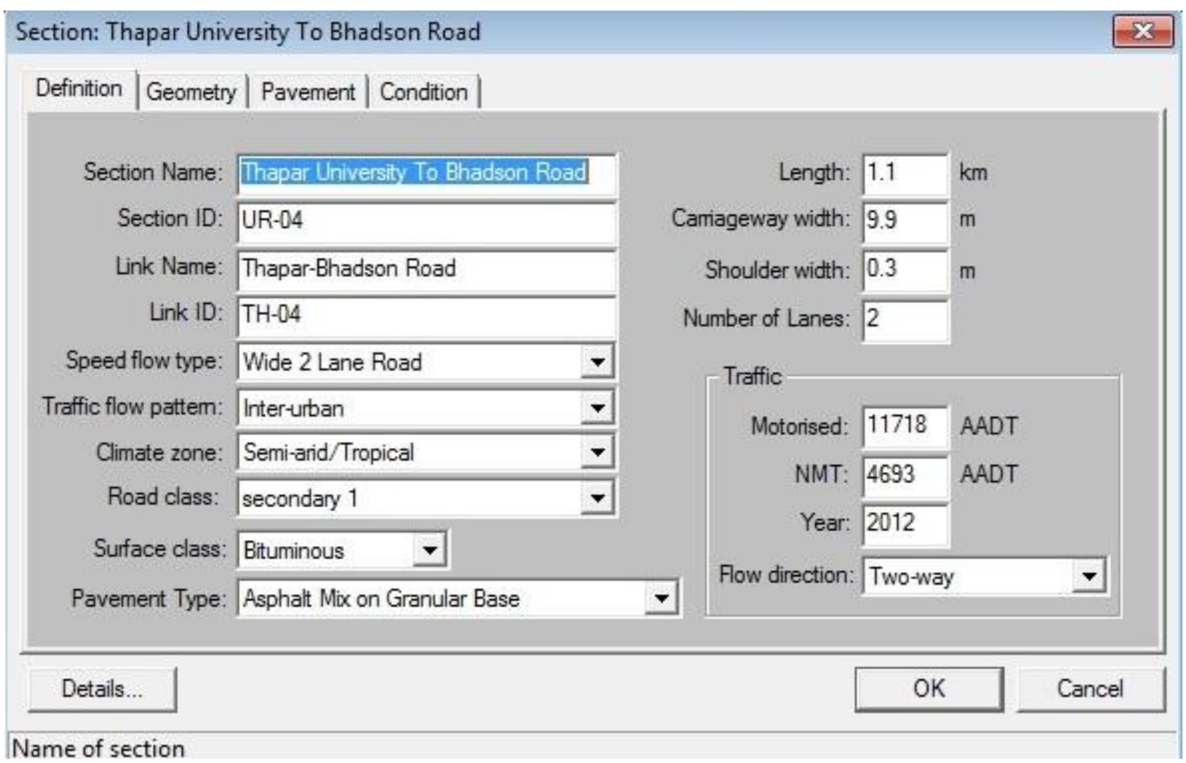

Figure 5.2 General Details of the Selected Pavement Section UR-04

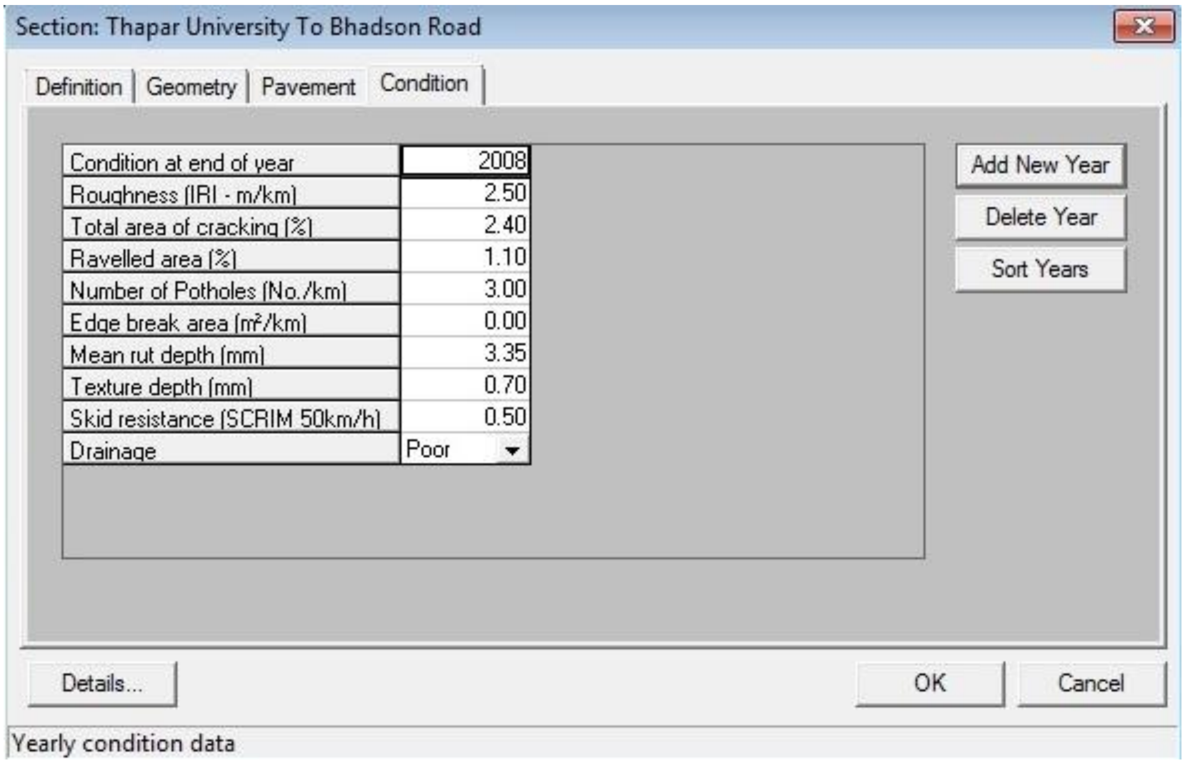

Figure 5.3 Pavement Condition Characteristics of the Pavement Section UR-04

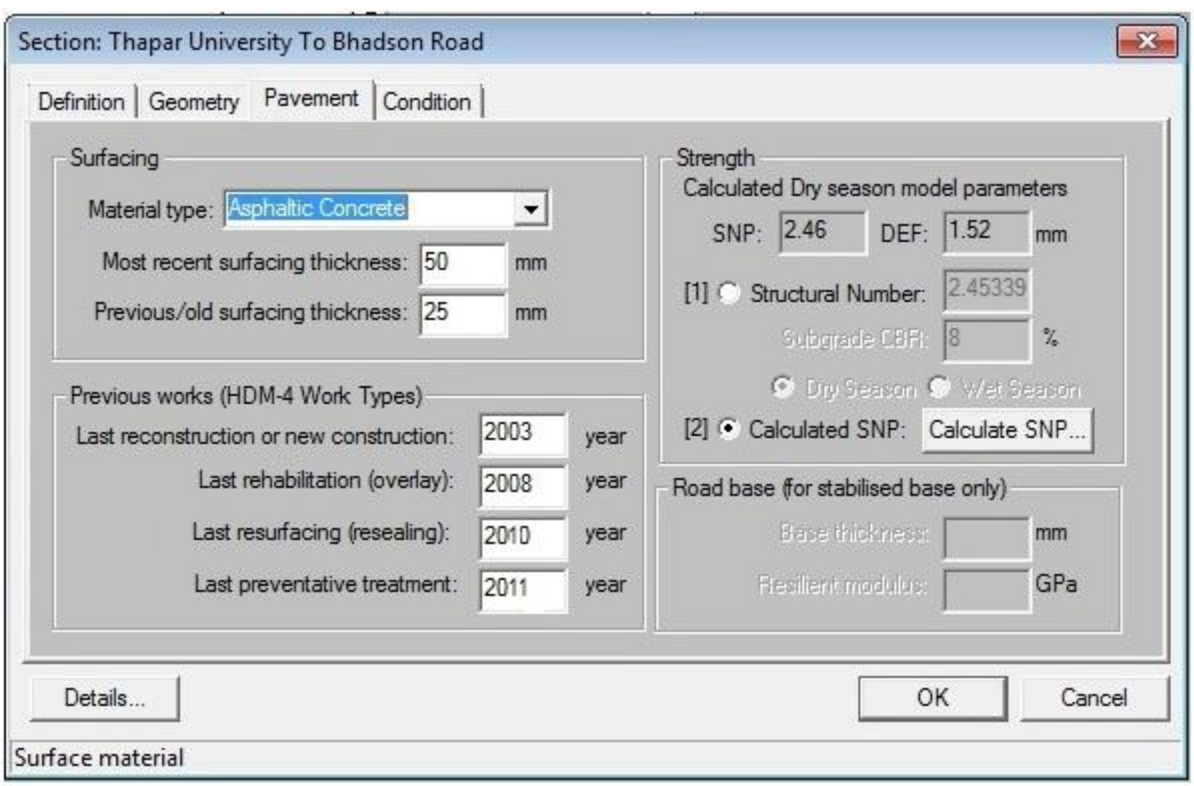

Figure 5.4 Pavement History of the Selected Section UR-04

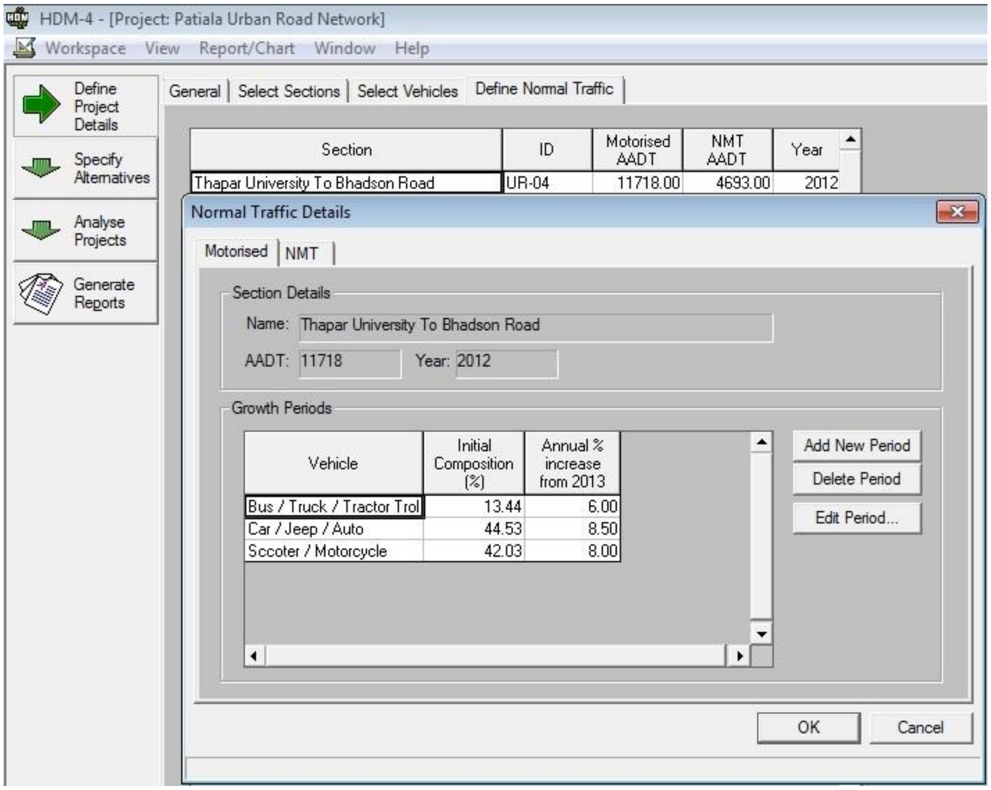

Figure 5.5 Traffic details of selected section UR-04

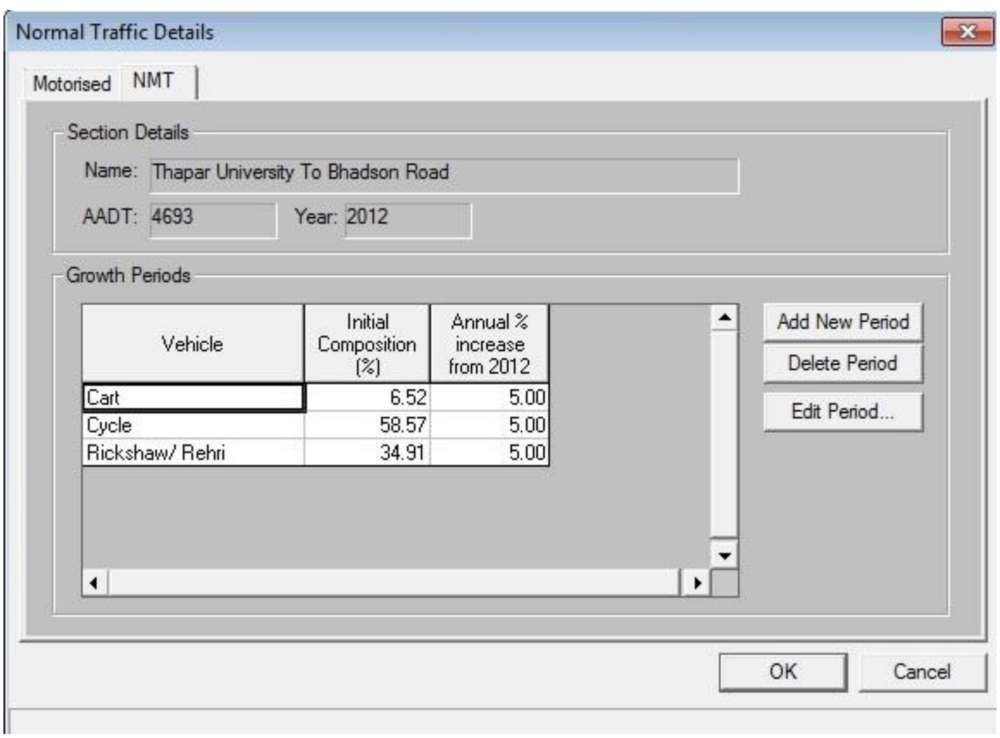

Figure 5.6 Initial composition and Growth rate of Traffic for Pavement Section UR-04

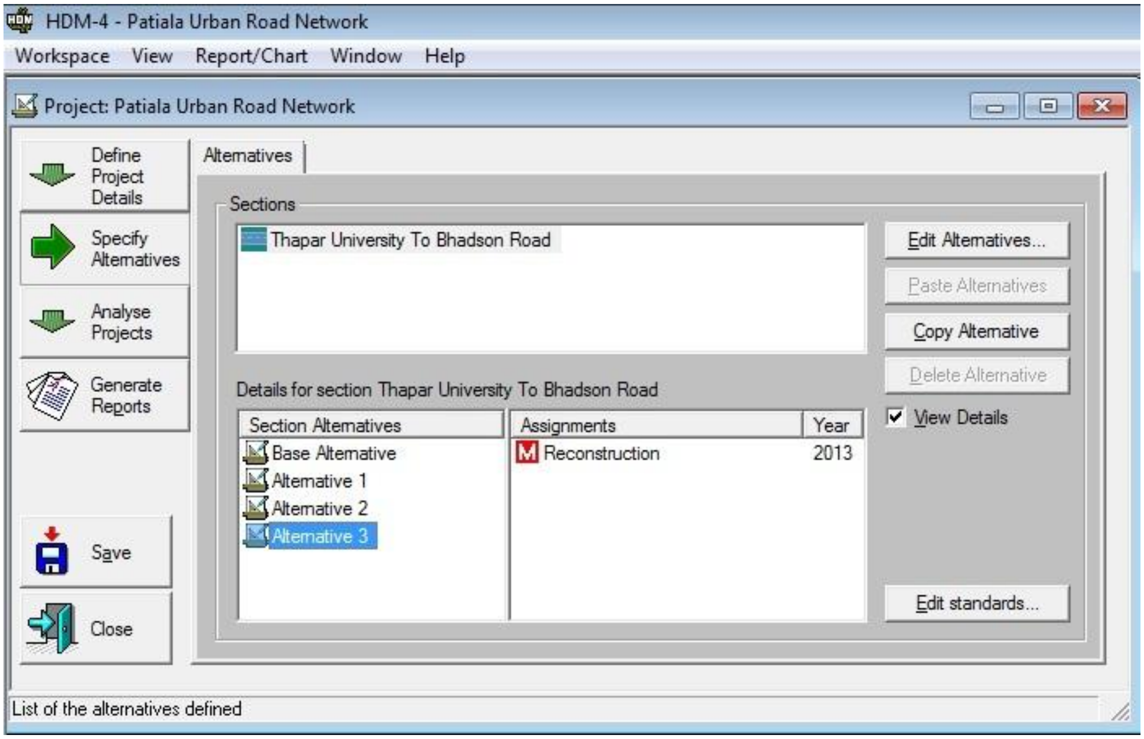

Figure 5.7 Alternative details of pavement section UR-04

5.3 PROPOSED MAINTENANCE & REHABILITATION ALTERNATIVES

The maintenance and rehabilitation strategies, applicable to the pavement section were defined in the HDM-4 as per Table 5.1.

Table 5.1 Proposed M&R Strategies and Intervention Criteria for project Analysis

M&R Strategy	**Alternative 1**	**Alternative 2**	**Alternative 3**
Works Standard	Routine Maintenance	Overlay	Reconstruction
Description of Work	Patch work on Pot Holes	Laying 25 mm DBSD (SDBC)	Provide (250mm WMM Macadam + 125 mm Dense Bituminous Macadam + 50 mm Bituminous Concrete)
Intervention Level	Annually Scheduled	Roughness >=3.0, <=8.0	Roughness >= 8.0 AND Total Damaged Area >= 25 %

5.4 PROJECT ANALYSIS

The HDM-4 Project Analysis is carried out for the selected pavement section. During set up of the project analysis, all the alternatives were compared with respect to routine and base alternatives. The pavement deterioration readings for all M&R strategies as shown in Table 5.1 were generated for the analysis period of 15 years from 2013-2027.

- The pavement deterioration of the section UR-04 (Thapar University to Bhadson Road) as obtained under alternative M&R strategies over the analysis period of 15 years is given in table 5.2. The behavior of all the distresses was plotted as per their respective deterioration models incorporated in HDM-4.
- The various maintenance work items and timing of their application are given in the M&R work report in table 5.3. This work report gives description of the work that would be implemented in each year of the analysis period (2013-2027), under each M&R strategy. The cost associated with each work item is also provided in this report. The total cost to be incurred by the highway agency on maintenance management of the pavement section under each alternative M&R strategy, is calculated over the whole analysis period of 15 years.

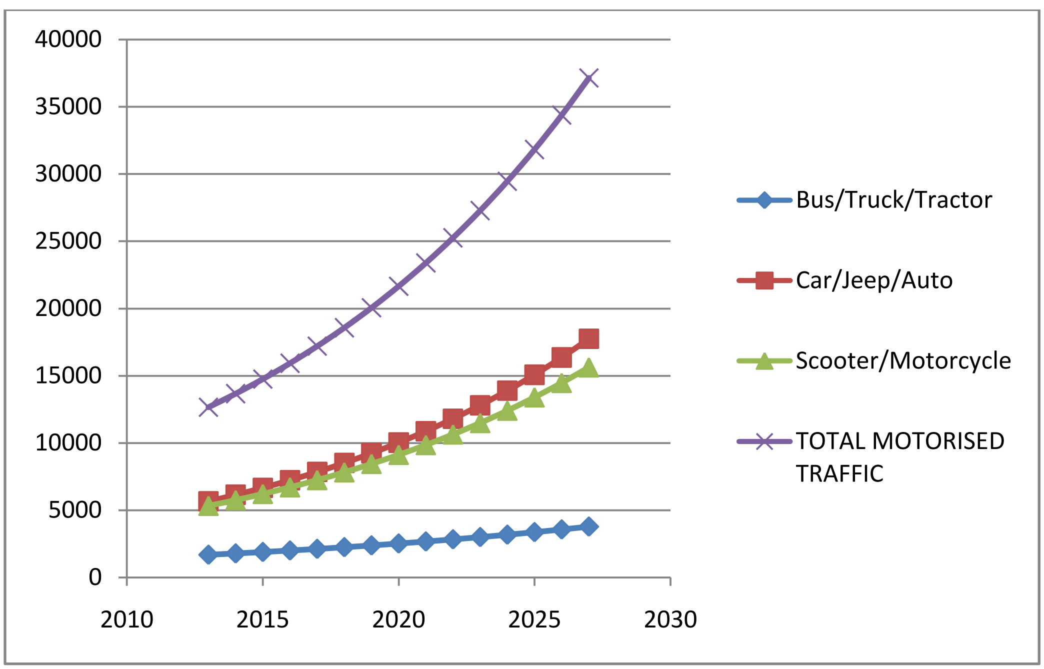

Figure 5.8 Yearly variation of traffic volume with Motorized traffic

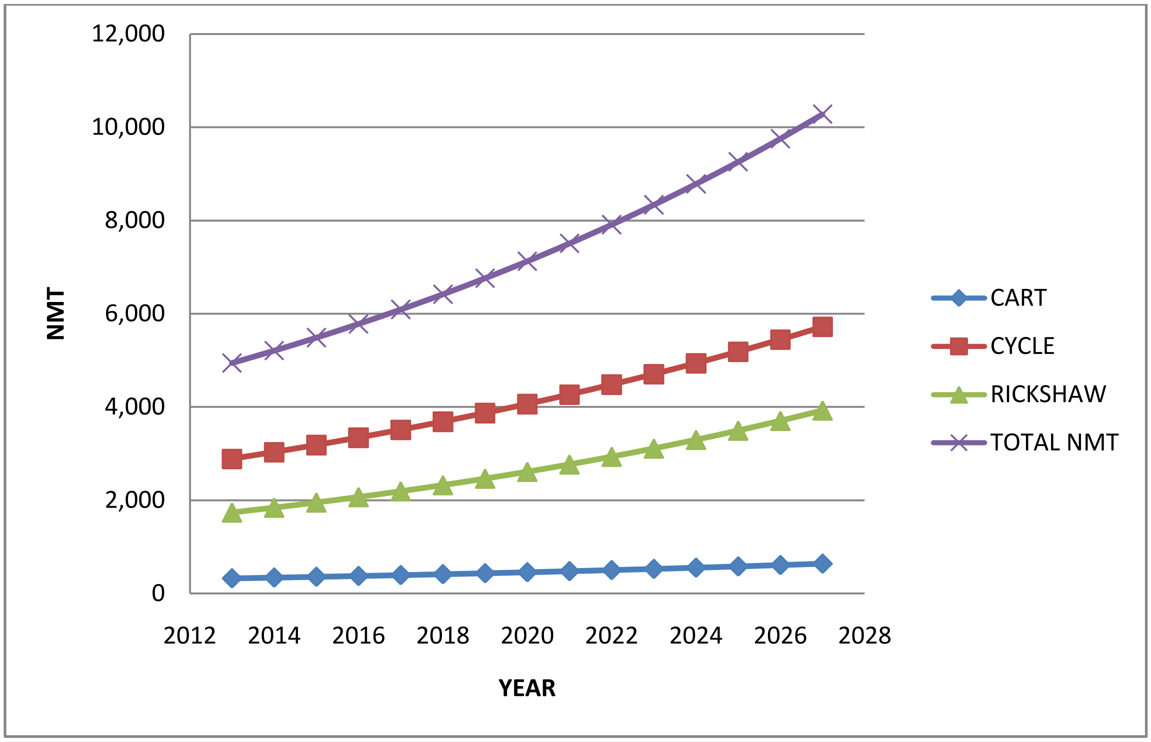

Figure 5.9 Yearly variation of traffic volume with Non-Motorized traffic

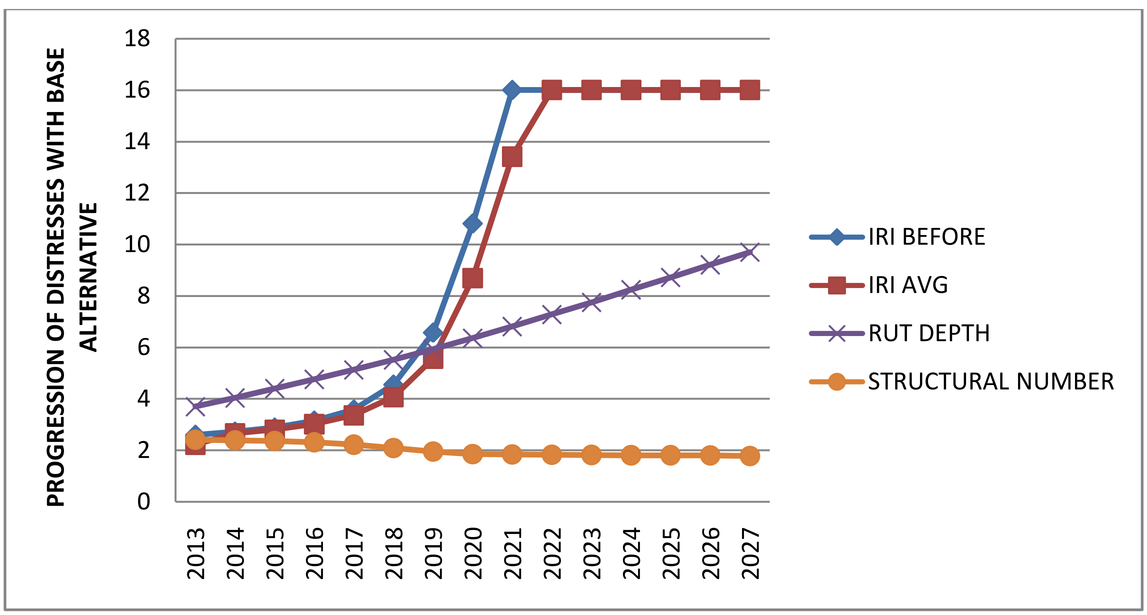

Figure 5.10 Variation of Distresses with base alternative of drainage repair

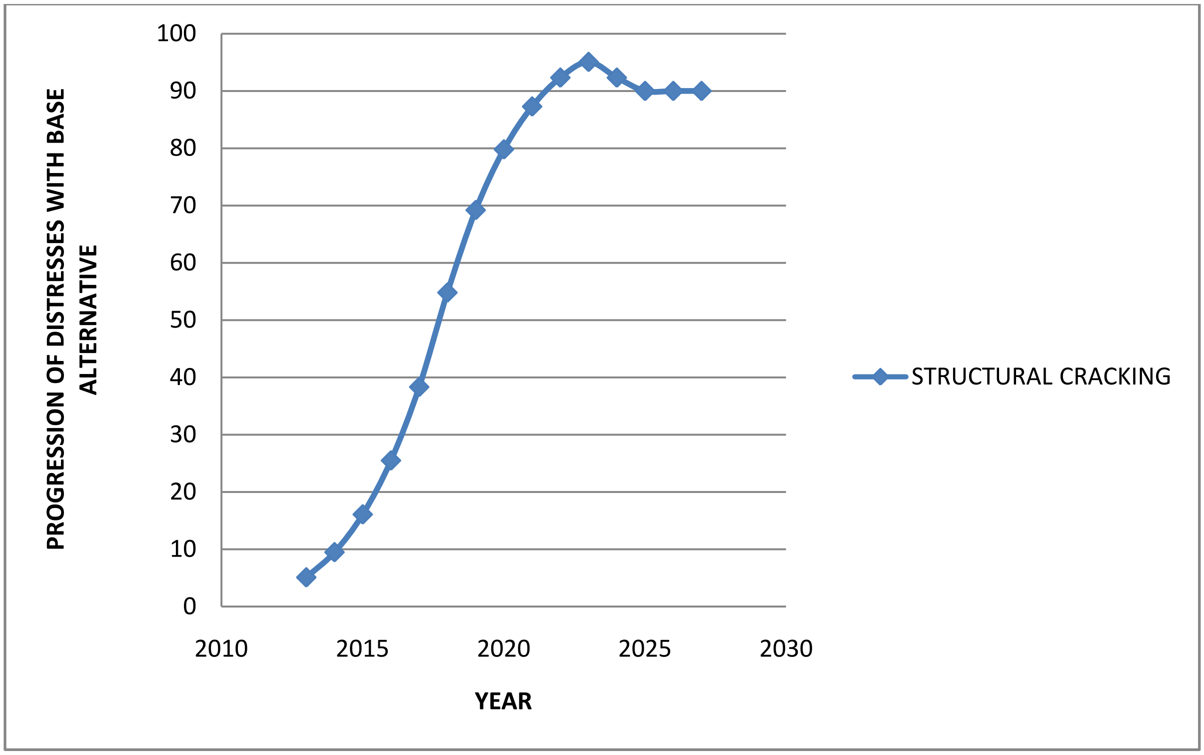

Figure 5.11 Variation of structural cracking with base alternative

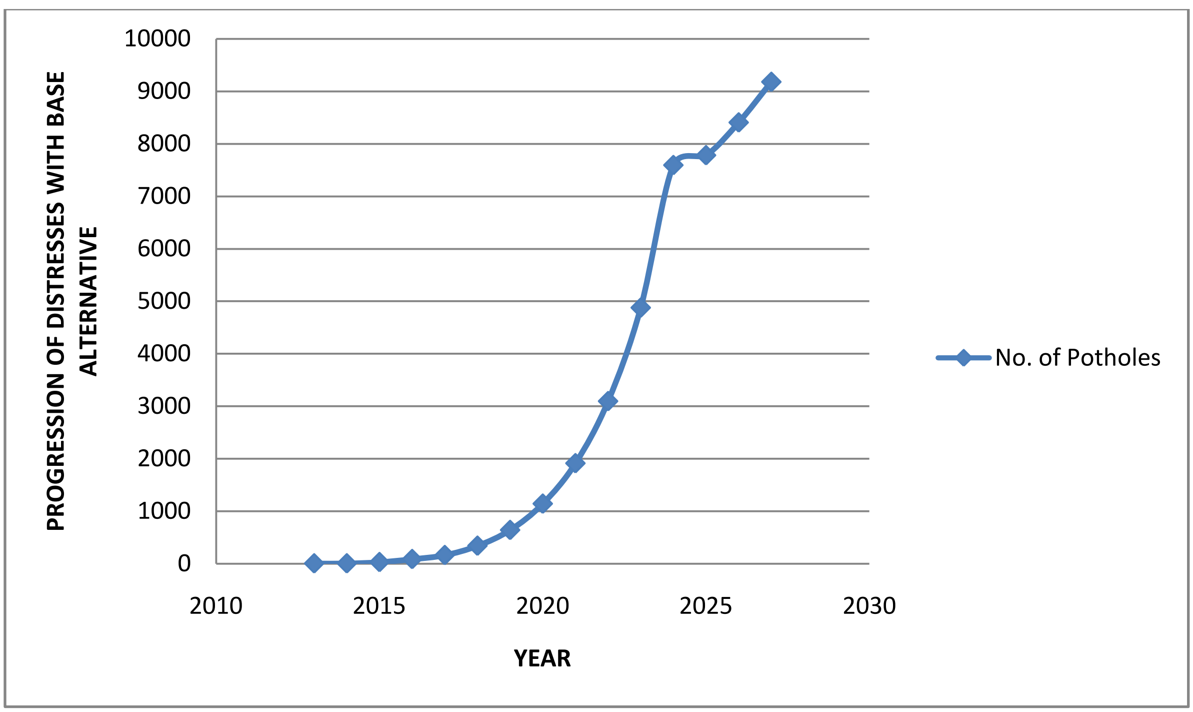

Figure 5.12 Variation of Pot holes with base alternative

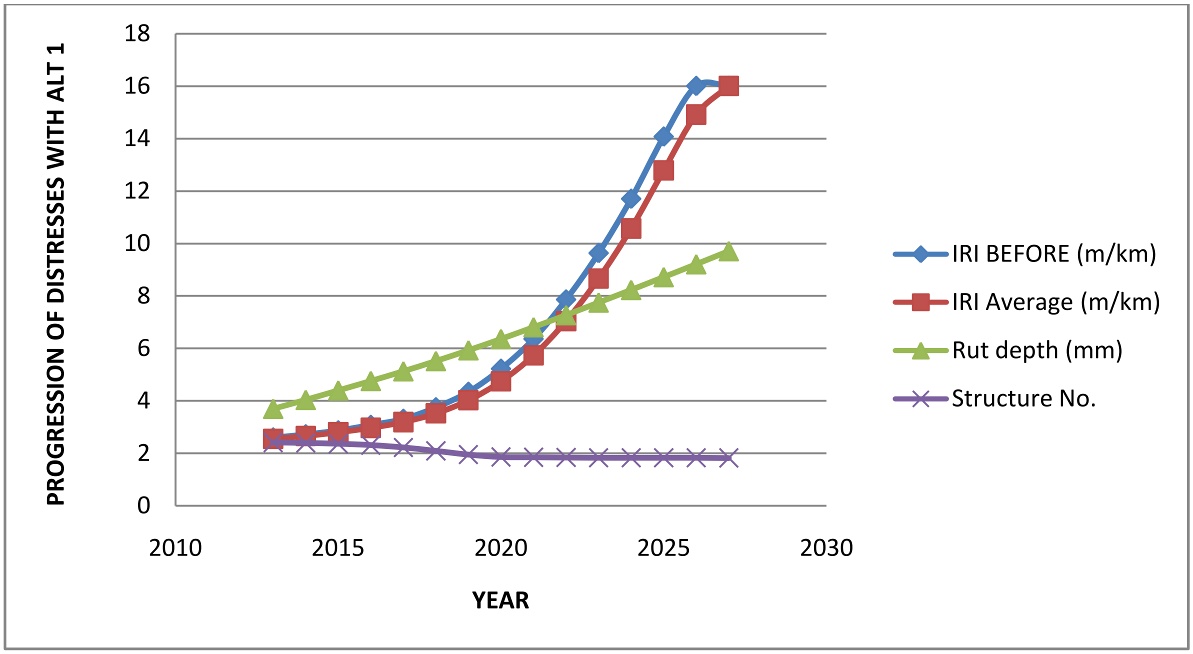

Figure 5.13 Variations of Distresses with Alternate 1

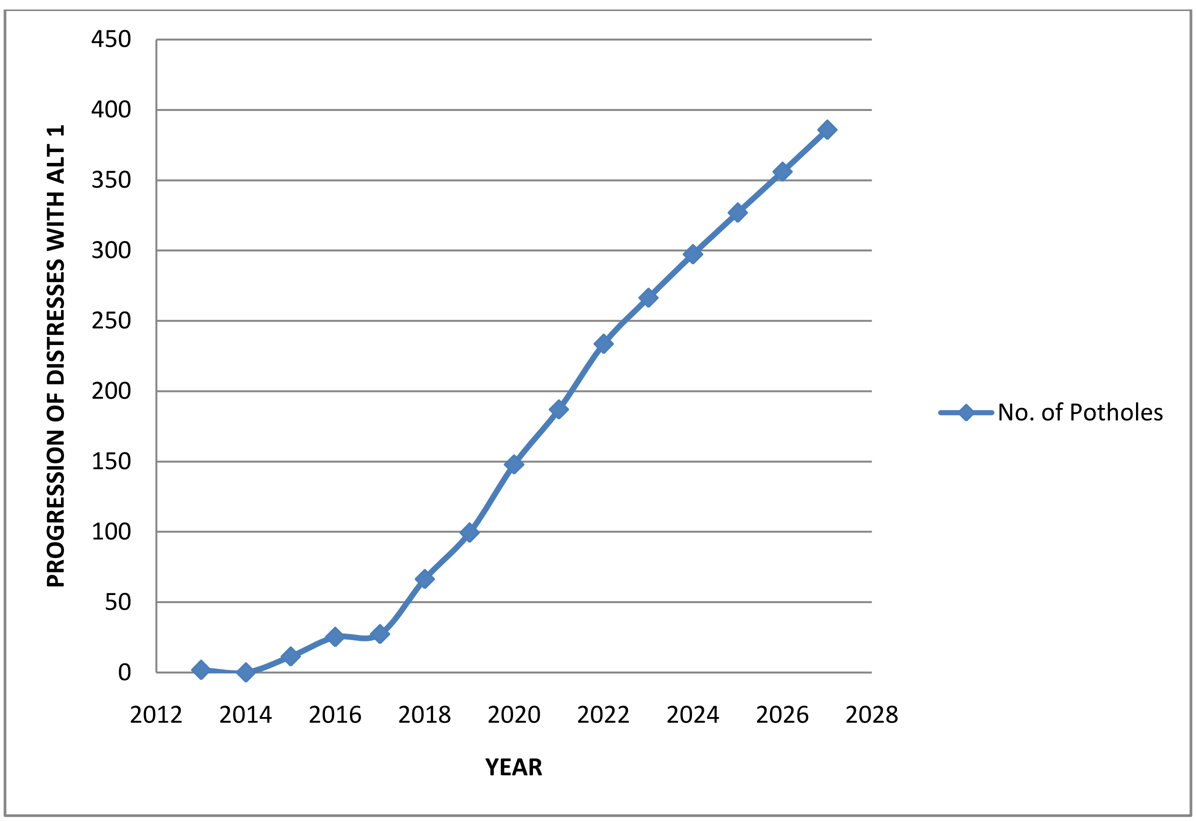

Figure 5.14 Variation of Pot holes with alternative 1

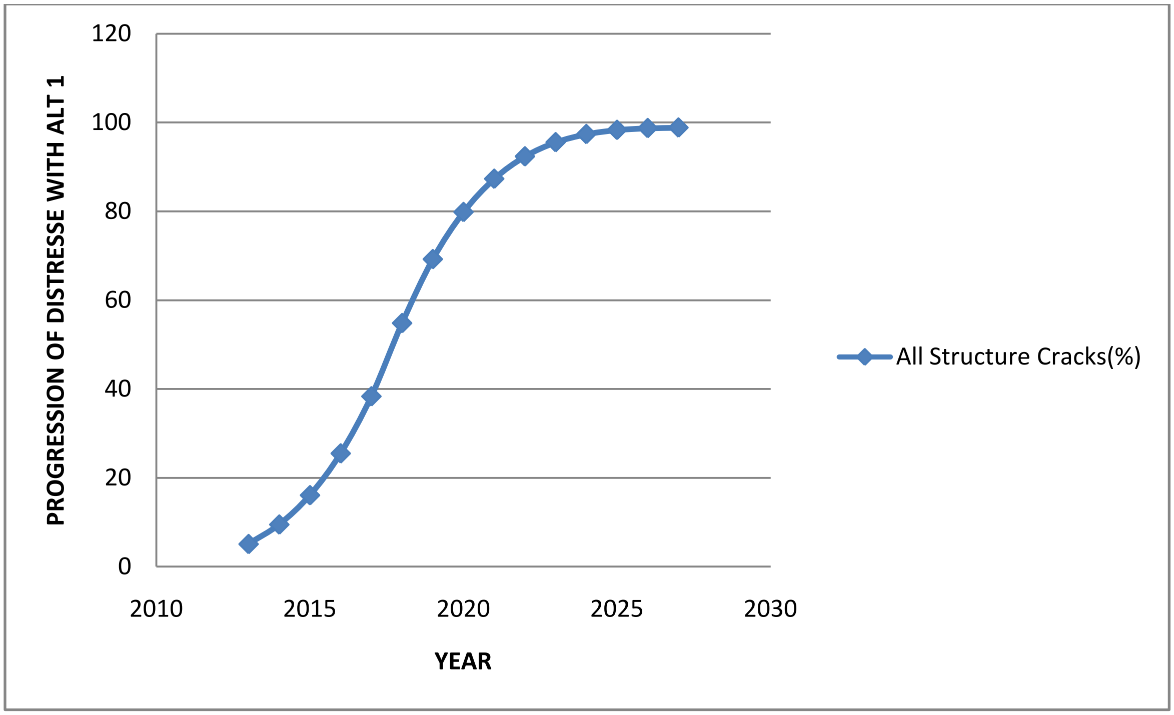

Figure 5.15 Variation of structural cracks with alternative 1

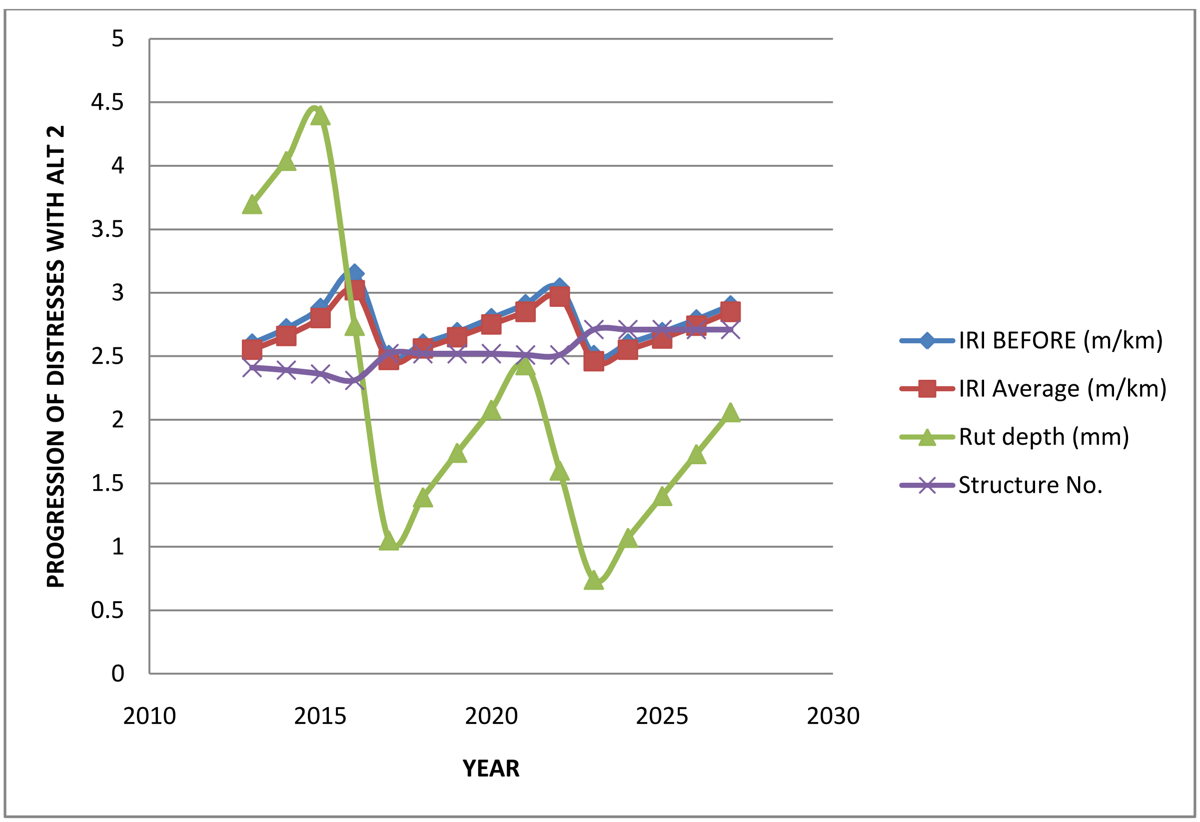

Figure 5.16 Variations of Distresses with Alternate 2

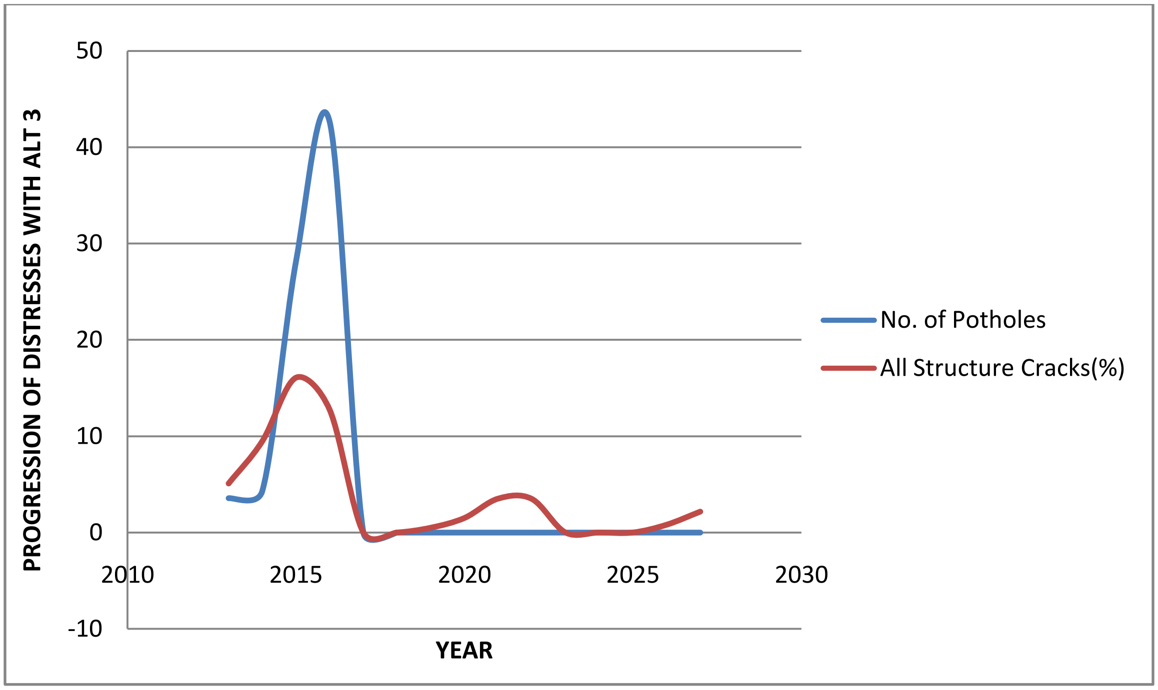

Figure 5.17 Variations of Potholes and Structural Cracks with Alternate 2

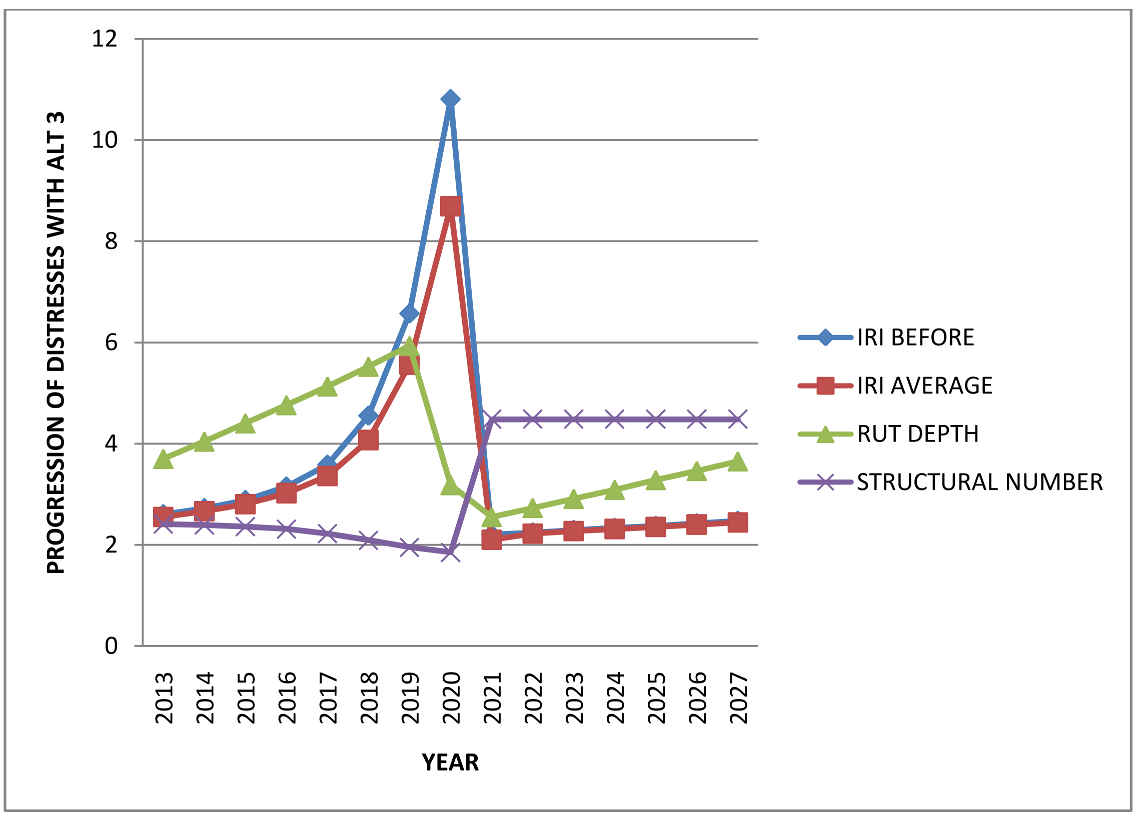

Figure 5.18 Variations of Distresses with Alternate 3

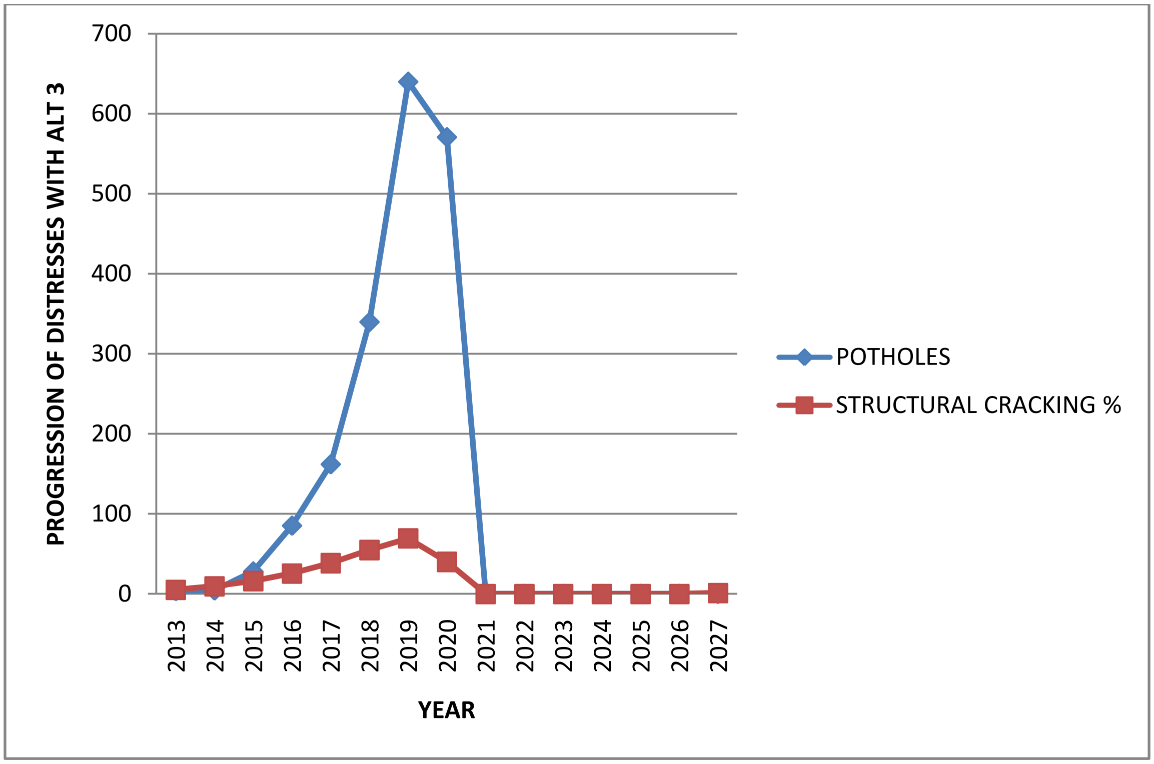

Figure 5.19 Variations of Potholes and Structural Cracks with Alternate 3

5.5 PAVEMENT CONDITION BASED UPON FUNCTIONAL PARAMETERS

In AASHO ROAD test (1958-60), the term Present Serviceability Index of the Pavement (PSI) was used for rating the pavement condition by the road users. Pavement performance, which involves a study of the functional behavior of a length of pavement, can be evaluated with the help of PSI. The AASHO road test results suggest a mathematical equation for computing 'present serviceability index' (PSI) of pavements. PSI equation only in terms of the roughness was used in the study to get the pavement condition.

The results of AASHO road test give following equation for flexible pavement.

$$\textbf{PSI} = 5e^{(-.18IRI)}$$

Where: IRI= International Roughness Index

PSI value is calculated for the Section UR 04 for the entire analysis period with different alternatives as shown in Table 5.2 and Fig 5.20

Table 5.2 Condition of road UR04 with different alternatives based upon PSI VALUE

YEAR	SECTION ID	ALT 1	ALT 2	ALT 3
2013	UR04	GOOD	GOOD	GOOD
2014	UR04	GOOD	GOOD	GOOD
2015	UR04	FAIR	FAIR	FAIR
2016	UR04	FAIR	FAIR	FAIR
2017	UR04	FAIR	GOOD	FAIR
2018	UR04	FAIR	GOOD	FAIR
2019	UR04	FAIR	GOOD	POOR
2020	UR04	POOR	GOOD	VERY POOR
2021	UR04	POOR	FAIR	GOOD
2022	UR04	POOR	FAIR	GOOD
2023	UR04	VERY POOR	GOOD	GOOD
2024	UR04	VERY POOR	GOOD	GOOD
2025	UR04	VERY POOR	GOOD	GOOD
2026	UR04	VERY POOR	GOOD	GOOD
2027	UR04	VERY POOR	FAIR	GOOD

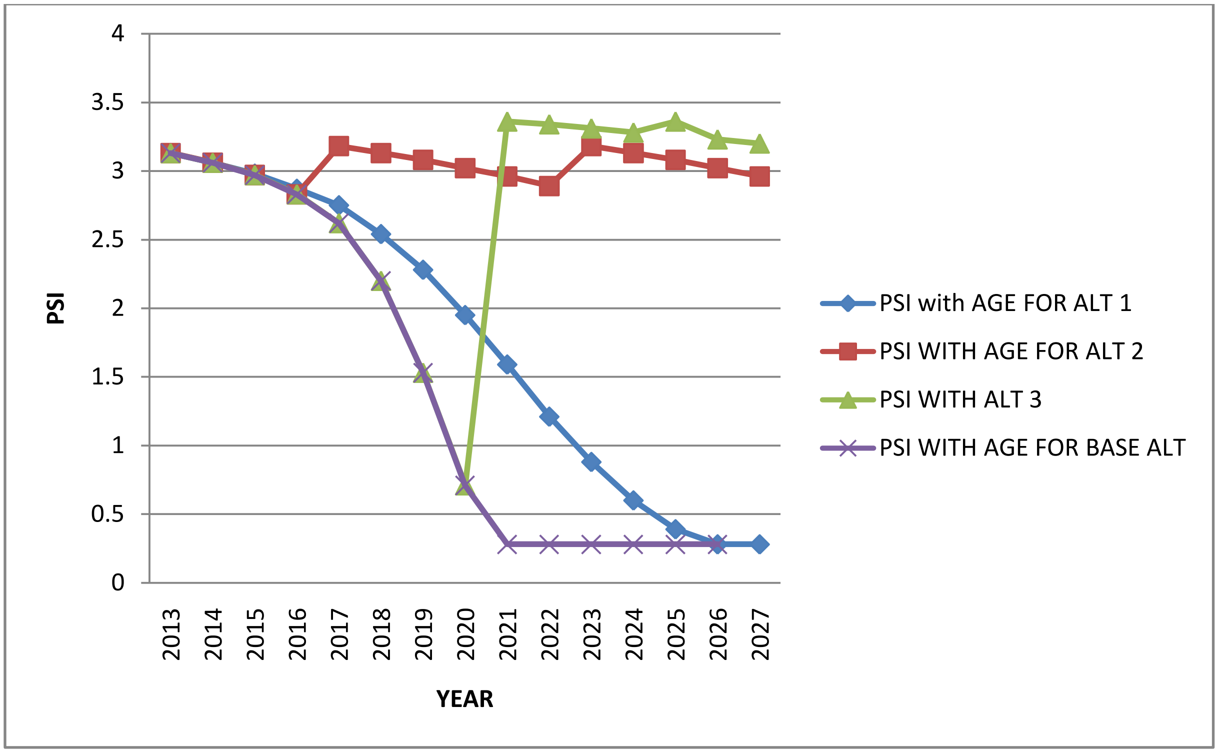

Figure 5.20 Variation of pavement serviceability index with time and different maintenance practices.

It has been observed that the Pavement of section UR04 will be in a good condition in the year 2020 with Alternate 2 as compared to poor and very poor with the Alternate 1 and Alternate 3 as per PSI values.

The maintenance works schedule for the single section of UR04 from Thapar University to Bhadson road was generated for the time period from 2013-2027 using HDM-4 as shown in Table 5.3 and the benefit cost ratio has been calculated for this section by comparing alternate 2 and 3 with the alternate 1 and as shown in Table 5.4. The alternate 2 of 25 mm SDBC overlay is having higher benefit cost ratio as compared to alternate 3 of reconstruction calculated by comparing the increase in the capital cost and decrease in the road user cost with respect to the alternate 1.

Table 5.3 Maintenance works schedule for the single section UR04: Thapar University to Bhadson road

YEAR	BASE ALTERNATE	ROUTINE MAINTENANCE	25mm OVERLAY OF SDBC	RECONSTRUCTION	BASE ALTERNATE	ROUTINE MAINTENANCE COST	25mm OVERLAY OF SDBC	RECONSTRUCTION
2013					8250	59.00		
2014					8250	0.00		
2015					8250	377.5		
2016					8250	832.1	4900500	
2017					8250	903.9		
2018					8250	2253.7		
2019					8250	3367.10		
2020					8250	4979.1		24502500
2021					8250	6249.5		
2022					8250	7705.10	4900500	
2023					8250	8788.9		
2024					8250	9806.3		
2025					8250	10782.3		
2026					8250	11745.6		
2027					8250	12726.2		
TOTAL COST (Rs)					**1,23,750**	**80,576.3**	**98,01,000**	**2,45,02500**

Table 5.4 Benefit-Cost ratio of section UR04 with alternatives 2 & 3 with respect to alternate 1

Thapar University to Bhadson Road (UR-04)	**Alternate 2 of 25 mm SDBC**	**Alternate 3 of Reconstruction**
Total Increase in Capital cost compared to Alternate 1 Patch work	9720424	24421924
Total Decrease in Road user cost compared to Alternate 1Patch work	60000000	53000000
Benefit / Cost Ratio (NPV/Cost Ratio)	6.17	2.17

5.6 PROGRAMME ANALYSIS FOR THE ENTIRE SELECTED URBAN ROAD NETWORK

The HDM-4 Network Analysis was also carried out for all the selected pavement sections from UR01 to UR09. During the network analysis also, all the alternatives were compared with respect to routine and base alternatives.

The Schedule of providing alternate 1, alternate 2 and alternate 3 for the entire selected urban road network of the Patiala city from section ID UR01 to UR09 is as shown in the table 5.5, 5.6, 5.7.

Table 5.5 Schedule of providing alternate 1 of routine maintenance (patch work for the entire selected urban road network of the Patiala city from section ID UR01 to UR09

Year	***Section***	***Works Description***	***SECTION ID***	***Capital Cost (in Rs.)***
2013	Thapar University To Bhadson Road	Patching	UR04	59
	Dukhniwaran Sahib To Passi Road	Patching	UR03	0
	Fountain To Memorial Chowk	Patching	UR09	30
	Leela Bhawan To Amar Hospital Road	Patching	UR05	0
	NIS To Fountain Chowk	Patching	UR08	303
	Samana Chungi To Bhakhra	Patching	URO6	327
	Samana Chungi To YPS Chowk	Patching	UR07	37
	Thapar University To Dukhniwaran Sahib	Patching	UR02	0
	Thapar University to Nabha Road	Patching	UR01	0
Total Annual Cost:				757
2015	Thapar University To Bhadson Road	Patching	UR04	378
	Dukhniwaran Sahib To Passi Road	Patching	UR03	0
	Fountain To Memorial Chowk	Patching	UR09	0
	Leela Bhawan To Amar Hospital Road	Patching	UR05	0
	NIS To Fountain Chowk	Patching	UR08	1,627
	Samana Chungi To Bhakhra	Patching	URO6	9,575
	Samana Chungi To YPS Chowk	Patching	UR07	0
	Thapar University To Dukhniwaran Sahib	Patching	UR02	0
	Thapar University to Nabha Road	Patching	UR01	0
Total Annual Cost:				11,579
2016	Thapar University To Bhadson Road	Patching	UR04	832
	Dukhniwaran Sahib To Passi Road	Patching	UR03	0

	Fountain To Memorial Chowk	Patching	UR09	0
	Leela Bhawan To Amar Hospital Road	Patching	UR05	0
	NIS To Fountain Chowk	Patching	UR08	3,003
	Samana Chungi To Bhakhra	Patching	UR06	19,538
	Samana Chungi To YPS Chowk	Patching	UR07	0
	Thapar University To Dukhniwaran Sahib	Patching	UR02	0
	Thapar University to Nabha Road	Patching	UR01	0
Total Annual Cost:				23,373
2017	Thapar University To Bhadson Road	Patching	UR04	904
	Dukhniwaran Sahib To Passi Road	Patching	UR03	0
	Fountain To Memorial Chowk	Patching	UR09	0
	Leela Bhawan To Amar Hospital Road	Patching	UR05	0
	NIS To Fountain Chowk	Patching	UR08	2,837
	Samana Chungi To Bhakhra	Patching	UR06	22,109
	Samana Chungi To YPS Chowk	Patching	UR07	0
	Thapar University To Dukhniwaran Sahib	Patching	UR02	0
	Thapar University to Nabha Road	Patching	UR01	0
Total Annual Cost:				25,850
2018	Thapar University To Bhadson Road	Patching	UR04	2,254
	Dukhniwaran Sahib To Passi Road	Patching	UR03	0
	Fountain To Memorial Chowk	Patching	UR09	2,949
	Leela Bhawan To Amar Hospital Road	Patching	UR05	0
	NIS To Fountain Chowk	Patching	UR08	2,462
	Samana Chungi To Bhakhra	Patching	UR06	54,639
	Samana Chungi To YPS Chowk	Patching	UR07	0
	Thapar University To Dukhniwaran Sahib	Patching	UR02	0
	Thapar University to Nabha Road	Patching	UR01	0
Total Annual Cost:				62,304

2019	Thapar University To Bhadson Road	Patching	UR04	3,367
	Dukhniwaran Sahib To Passi Road	Patching	UR03	0
	Fountain To Memorial Chowk	Patching	UR09	5,491
	Leela Bhawan To Amar Hospital Road	Patching	UR05	2,022
	NIS To Fountain Chowk	Patching	UR08	1,880
	Samana Chungi To Bhakhra	Patching	URO6	80,898
	Samana Chungi To YPS Chowk	Patching	UR07	0
	Thapar University To Dukhniwaran Sahib	Patching	UR02	3,653
	Thapar University to Nabha Road	Patching	UR01	0
Total Annual Cost:				97,311
2020	Thapar University To Bhadson Road	Patching	UR04	4,979
	Dukhniwaran Sahib To Passi Road	Patching	UR03	2,868
	Fountain To Memorial Chowk	Patching	UR09	8,699
	Leela Bhawan To Amar Hospital Road	Patching	UR05	3,748
	NIS To Fountain Chowk	Patching	UR08	7,740
	Samana Chungi To Bhakhra	Patching	URO6	113,475
	Samana Chungi To YPS Chowk	Patching	UR07	2,032
	Thapar University To Dukhniwaran Sahib	Patching	UR02	6,832
	Thapar University to Nabha Road	Patching	UR01	0
Total Annual Cost:				150,373
2021	Thapar University To Bhadson Road	Patching	UR04	6,249
	Dukhniwaran Sahib To Passi Road	Patching	UR03	5,157
	Fountain To Memorial Chowk	Patching	UR09	11,431
	Leela Bhawan To Amar Hospital Road	Patching	UR05	6,057
	NIS To Fountain Chowk	Patching	UR08	13,634
	Samana Chungi To Bhakhra	Patching	URO6	130,580
	Samana Chungi To YPS Chowk	Patching	UR07	3,780
	Thapar University To Dukhniwaran Sahib	Patching	UR02	11,043

	Thapar University to Nabha Road	Patching	UR01	16,504
Total Annual Cost:				204,435
2022	Thapar University To Bhadson Road	Patching	UR04	7,705
	Dukhniwaran Sahib To Passi Road	Patching	UR03	7,988
	Fountain To Memorial Chowk	Patching	UR09	13,920
	Leela Bhawan To Amar Hospital Road	Patching	UR05	8,240
	NIS To Fountain Chowk	Patching	UR08	20,354
	Samana Chungi To YPS Chowk	Patching	UR07	6,136
	Thapar University To Dukhniwaran Sahib	Patching	UR02	14,590
	Thapar University to Nabha Road	Patching	UR01	30,075
Total Annual Cost:				109,008
2023	Thapar University To Bhadson Road	Patching	UR04	8,789
	Dukhniwaran Sahib To Passi Road	Patching	UR03	10,574
	Fountain To Memorial Chowk	Patching	UR09	16,194
	Leela Bhawan To Amar Hospital Road	Patching	UR05	10,002
	NIS To Fountain Chowk	Patching	UR08	26,407
	Samana Chungi To YPS Chowk	Patching	UR07	8,376
	Thapar University To Dukhniwaran Sahib	Patching	UR02	17,821
	Thapar University to Nabha Road	Patching	UR01	45,402
Total Annual Cost:				143,567
2024	Thapar University To Bhadson Road	Patching	UR04	9,806
	Dukhniwaran Sahib To Passi Road	Patching	UR03	12,467
	Leela Bhawan To Amar Hospital Road	Patching	UR05	11,376
	NIS To Fountain Chowk	Patching	UR08	31,668
	Samana Chungi To YPS Chowk	Patching	UR07	10,353
	Thapar University To Dukhniwaran Sahib	Patching	UR02	20,283
Total Annual Cost:				95,953
2025	Thapar University To Bhadson Road	Patching	UR04	10,782

	Dukhniwaran Sahib To Passi Road	Patching	UR03	14,135
	Leela Bhawan To Amar Hospital Road	Patching	UR05	12,673
	NIS To Fountain Chowk	Patching	UR08	36,068
	Samana Chungi To YPS Chowk	Patching	UR07	11,950
	Thapar University To Dukhniwaran Sahib	Patching	UR02	20,980
Total Annual Cost:				106,588
2026	Thapar University To Bhadson Road	Patching	UR04	11,746
	Dukhniwaran Sahib To Passi Road	Patching	UR03	15,486
	Leela Bhawan To Amar Hospital Road	Patching	UR05	13,926
	NIS To Fountain Chowk	Patching	UR08	39,303
	Samana Chungi To YPS Chowk	Patching	UR07	13,152
	Thapar University To Dukhniwaran Sahib	Patching	UR02	22,601
Total Annual Cost:				116,215
2027	Thapar University To Bhadson Road	Patching	UR04	12,726
	Dukhniwaran Sahib To Passi Road	Patching	UR03	16,514
	Leela Bhawan To Amar Hospital Road	Patching	UR05	15,173
	NIS To Fountain Chowk	Patching	UR08	42,582
	Samana Chungi To YPS Chowk	Patching	UR07	14,342
	Thapar University To Dukhniwaran Sahib	Patching	UR02	24,340
Total Annual Cost:				125,676
Total Costs for Alternative:				1,272,989

Table 5.6 Schedule of providing alternate 2 of 25 mm SDBC layer for the entire selected urban road network of the Patiala city from section ID UR01 to UR09

Year	***Section***	***Works Description***	***SECTION ID***	***Capital Cost (in Rs.)***
2013	NIS To Fountain Chowk	25 mm overlay of Dense graded Bitumen	UR08	9,009,000
	Samana Chungi To YPS Chowk	25 mm overlay of Dense graded Bitumen	UR07	4,050,000
Total Annual Cost:				13,059,000
2014	Fountain To Memorial Chowk	25 mm overlay of Dense graded Bitumen	UR09	3,537,000
Total Annual Cost:				3,537,000
2016	Thapar University To Bhadson Road	25 mm overlay of Dense graded Bitumen	UR04	4,900,500
	NIS To Fountain Chowk	25 mm overlay of Dense graded Bitumen	UR08	9,009,000
	Samana Chungi To Bhakhra	25 mm overlay of Dense graded Bitumen	UR06	29,713,500
Total Annual Cost:				43,623,000
2017	Fountain To Memorial Chowk	25 mm overlay of Dense graded Bitumen	UR09	3,537,000
	Thapar University to Nabha Road	25 mm overlay of Dense graded Bitumen	UR01	8,820,000
Total Annual Cost:				12,357,000
2018	Leela Bhawan To Amar Hospital Road	25 mm overlay of Dense graded Bitumen	URO5	3,618,000

	Samana Chungi To Bhakhra	25 mm overlay of Dense graded Bitumen	UR06	29,713,500
Total Annual C.				33,331,50
2019	Thapar University To Dukhniwaran Sahib	25 mm overlay of Dense graded Bitumen	UR02	7,296,750
Total Annual Cost:				7,296,750
2020	Fountain To Memorial Chowk	25 mm overlay of Dense graded Bitumen	UR09	3,537,000
Total Annual Cost:				3,537,000
2021	Dukhniwaran Sahib To Passi Road	25 mm overlay of Dense graded Bitumen	UR03	7,029,000
	Samana Chungi To Bhakhra	25 mm overlay of Dense graded Bitumen	UR06	29,713,500
	Thapar University to Nabha Road	25 mm overlay of Dense graded Bitumen	UR01	8,820,000
Total Annual Cost:				45,562,500
2022	Thapar University To Bhadson Road	25 mm overlay of Dense graded Bitumen	UR04	4,900,500
Total Annual Cost:				4,900,500
2023	Fountain To Memorial Chowk	25 mm overlay of Dense graded Bitumen	UR09	3,537,000
	Samana Chungi To YPS Chowk	25 mm overlay of Dense graded Bitumen	UR07	4,050,000
Total Annual Cost:				7,587,000
2024	Leela Bhawan To Amar Hospital Road	25 mm overlay of Dense graded Bitumen	UR05	3,618,000

	Thapar University To Dukhniwaran Sahib	25 mm overlay of Dense graded Bitumen	UR02	7,296,750
Total Annual Cost:				10,914,750
2026	NIS To Fountain Chowk	25 mm overlay of Dense graded Bitumen	UR08	9,009,000
Total Annual Cost:				9,009,000

Table 5.7 Schedule of providing alternate 3 of reconstruction for the entire selected urban road network of the Patiala city from section ID UR01 to UR09

Year	***Section***	***Works Description***	***Capital Cost (in Rs.)***
2017	Samana Chungi To Bhakhra	RECONSTRUCTION	148,567,488
Total Annual Cost:			148,567,488
2019	Fountain To Memorial Chowk	RECONSTRUCTION	17,685,000
	NIS To Fountain Chowk	RECONSTRUCTION	45,045,000
Total Annual Cost:			62,730,000
2020	Thapar University To Bhadson Road	RECONSTRUCTION	24,502,500
Total Annual Cost:			24,502,500
2021	Leela Bhawan To Amar Hospital Road	RECONSTRUCTION	18,090,000
Total Annual Cost:			18,090,000
2022	Samana Chungi To YPS Chowk	RECONSTRUCTION	20,250,000
	Thapar University To Dukhniwaran Sahib	RECONSTRUCTION	36,483,748
	Thapar University to Nabha Road	RECONSTRUCTION	44,100,000
Total Annual Cost:			100,833,748
2023	Dukhniwaran Sahib To Passi Road	RECONSTRUCTION	35,145,000
Total Annual Cost:			35,145,000

Table 5.8 Total cost of maintenance for the entire Patiala city road network for section ID UR01 to UR09 from 2013-2027

Year	Alternative 1	Alternative 2	Alternative 3	Base Alternative	Total
2013	504.39	8,706,000.00	0.00	95,000.00	8,801,504.39
2014	0.00	2,358,000.00	0.00	95,000.00	2,453,000.00
2015	7,719.20	0.00	0.00	95,000.00	102,719.20
2016	15,582.21	29,082,000.00	0.00	95,000.00	29,192,582.21
2017	17,233.68	8,238,000.00	99,044,992.00	95,000.00	107,395,225.68
2018	41,536.19	22,221,000.00	0.00	95,000.00	22,357,536.19
2019	64,873.95	4,864,500.00	41,820,000.00	95,000.00	46,844,373.95
2020	100,248.81	2,358,000.00	16,335,000.00	95,000.00	18,888,248.81
2021	136,290.13	30,375,000.00	12,060,000.00	95,000.00	42,666,290.13
2022	72,672.09	3,267,000.00	67,222,496.00	95,000.00	70,657,168.09
2023	95,711.01	5,058,000.00	23,430,000.00	95,000.00	28,678,711.01
2024	63,968.78	7,276,500.00	0.00	95,000.00	7,435,468.78
2025	71,058.49	0.00	0.00	95,000.00	166,058.49
2026	77,476.35	6,006,000.00	0.00	95,000.00	6,178,476.35
2027	83,784.31	0.00	0.00	95,000.00	178,784.31
Total	848,659.59	129,810,000.00	259,912,488.00	1,425,000.00	391,996,147.59

5.7 REMAINING SERVICE LIFE OF THE PAVEMENT

Based upon the network analysis of the HDM-4, the Remaining service life of all the pavement sections was determined, if at all no maintenance activity will be provided to the pavements. The remaining service life of all the selected roads of Patiala city is as per Table 5.9 and Fig 5.21. The time year of providing the overlay for all the section ID's was also calculate and is shown in Table 5.10.

Table 5.9 Remaining life of the pavement of different road sections

Section ID	Section Name	REMAINING SERVICE LIFE OF PAVEMENT
UR01	From Thapar University to Nabha Road	10 years (2022)
UR02	From Thapar University Chowk to Dukhniwaran Sahib	10 years (2022)
UR03	From Dukhniwaran Sahib to Passey Road	11 years (2023)
UR04	From Thapar University to Bhadson Road	8 years (2020)
UR05	From Leela Bhawan Chowk to Amar Hospital Road.	9 years (2021)
UR06	From Samana Chungi to Bhakra.	5 years (2017)
UR07	From Samana Chungi to YPS Chowk.	10 years (2022)
UR08	From NIS Chowk to Fountain Chowk.	7 years (2019)
UR09	From Fountain Chowk to Memorial Chowk.	7 years (2019)

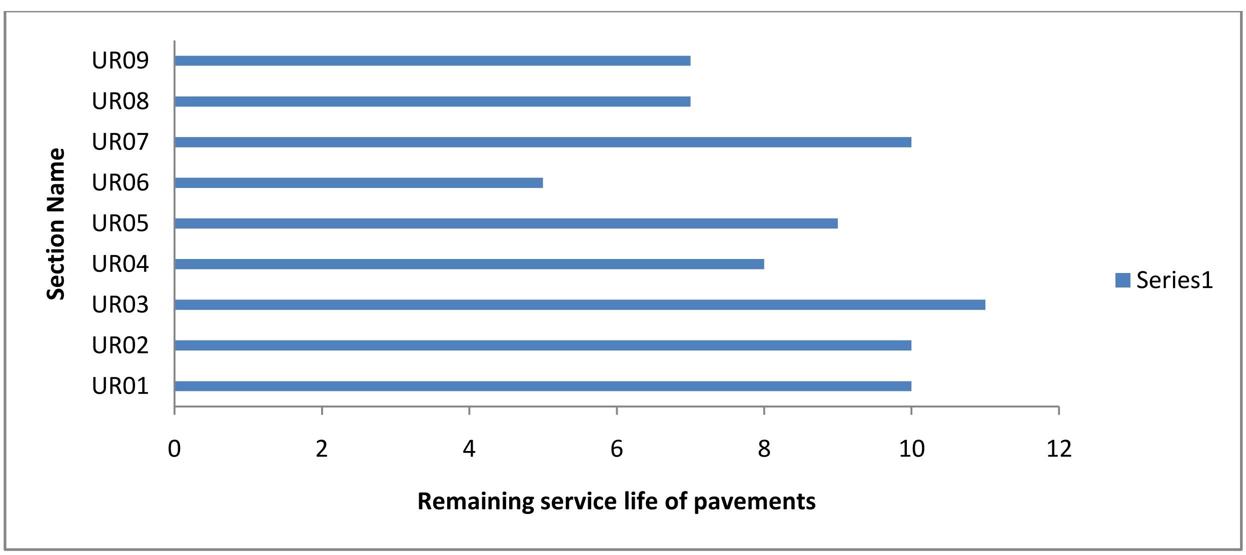

Fig: 5.21 Remaining years left for all the section ID's of the network.

Table 5.10 Overlay time for different sections

Section ID	Section Name	Year of 25mm SDBC overlay
UR01	From Thapar University to Nabha Road	2017, 2021
UR02	From Thapar University Chowk to Dukhniwaran Sahib	2019, 2024
UR03	From Dukhniwaran Sahib to Passey Road	2021
UR04	From Thapar University to Bhadson Road	2016, 2022
UR05	From Leela Bhawan Chowk to Amar Hospital Road.	2018, 2024
UR06	From Samana Chungi to Bhakra.	2016, 2018, 2021
UR07	From Samana Chungi to YPS Chowk.	2013, 2023
UR08	From NIS Chowk to Fountain Chowk.	2013, 2016, 2026
UR09	From Fountain Chowk to Memorial Chowk.	2014, 2017, 2020, 2023

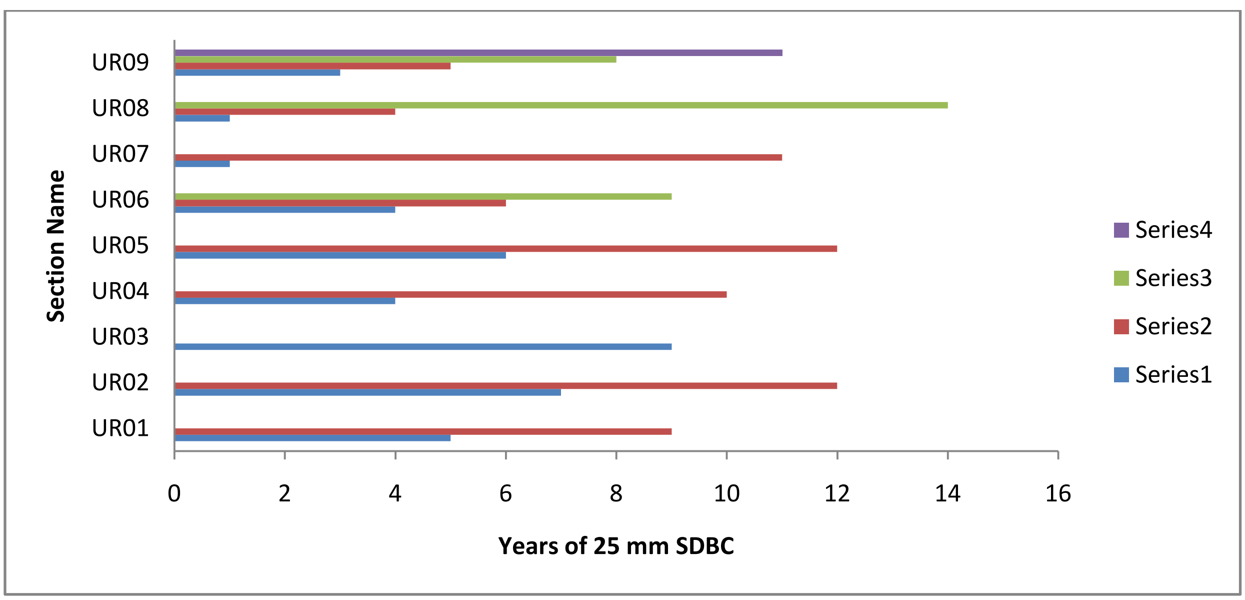

Figure 5.22 Time of overlay for the entire network roads.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The main aim of the study was to develop a Pavement Management System for urban road network maintenance, of Patiala city, to serve as a decision support tool to assist in improving the efficiency of decision making, provide feedback about the consequences of these decisions, ensure consistency of decisions made at different levels and improve the effectiveness of all decisions in terms of efficiency of results. The specific objective was to evaluate the pavements, structurally as well as functionally, and to identify the main contributory factors in the road deterioration. Furthermore, it is proposed to use these inputs into HDM4 for developing a cost effective management system to be used as a decision support tool for maintenance activities of Patiala City.

As a result of these analyses the following conclusions have been derived:

1. The Growth rate of the traffic in the urban roads is varying from 5.5 % to 8.5 % for different categories of vehicles. With the increase in volume of traffic, the condition of pavement degrades. Hence a large amount of funds are required to maintain such an urban road network. When the funds are limited, the PMMS can be used to prioritize the maintenance activities for the urban roads as per the available resources.
2. Local agencies are quite interested in saving money on their urban road network preservation. However, these agencies often act in a corrective rather than preventive manner by repairing roads once they have fallen into a poor category. By better knowing how pavement behaves and by having appropriate pavement management system these agencies can better transition from a corrective to a preventive way of preserving their road network, thus saving money to their already limited budget.
3. If only reconstruction alternative is to be adopted then the remaining service life for a number of pavement sections varies from 5 to 10 years, indicating that reconstruction

on most of the pavement sections would be inevitable in the near future in the absence of any sound pavement maintenance management policy.

4. In the study all three alternatives of pavement maintenance are compared to each other on economic analysis. The alternative 2 which comprises of providing 25 mm SDBC has been found as the optimum pavement maintenance management strategy.
5. As per the analysis of a section ID UR04 from Thapar University to Bhadson, based upon calculated PSI value for the pavement, the alternative 1 shows poor condition of road sections, whereas, alternative 2 shows good condition and alternative 3 again shows very poor condition at 2020 year. Hence, future condition of the road section can be predicted using the PMMS tool developed.
6. The use of pavement management maintenance management techniques can lead to a coordinated, cost-effective strategy for maintaining pavements.
7. The developed prioritization model in this study is based on the joint effect of important factors like pavement condition index, traffic volume, road width as well as rehabilitation and maintenance cost. Since, prioritization is a decision making process; statistical models are not very responsive. Therefore, designers must use decision making processes.
8. It is recommended that before starting any analysis the HDM-4 software should be calibrated for Indian conditions of road network.

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