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Economic Analysis and Prioritisation of Non-core Roads in India: A Case Study

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Abstract
The road network is a major asset for every developing nation. Data collection, analysis, and arriving at economical maintenance work plans are said to be major goals for every road agency. Successful implementation of Pavement Management Systems can result in ease of decision-making about investments incurred for the maintenance of road networks. Advanced pavement maintenance strategies ensure the rational utilisation of limited funds scientifically. Based on existing pavement conditions, a systematic procedure is required to analyse the impacts of different maintenance strategies based on the predicted future pavement conditions. The present study attempts to develop a prioritised work programme for an identified non-core road network in India using the Highway Development and Management tool. Pavement distress data for non-core roads with a total length of 1743.9 km were collected using a Network Survey Vehicle and stored in a customised central database. Six maintenance strategies were formulated and predicted the International Roughness Index values, and they were compared with those obtained from the conventional maintenance strategy adopted by the state agency. Furthermore, an economic analysis was carried out, and the best strategy was proposed based on optimised costs. The predicted International Roughness Index (IRI) from the proposed strategy was found to be 37% lower than the predicted IRI using a conventionally adopted maintenance strategy. Such road asset management studies should be popularised by the state public works department for non-core roads to optimise the resources.

Keywords Highway development and management tool · International Roughness Index · Net present value · Network survey vehicle and pavement management systems

1 Introduction

India is a country with a road network of about 6.2 million kilometres, which is the second-highest network in the globe. Therefore, greater importance has to be given to maintaining a sustainable road network using advanced maintenance techniques that are available in the present scenario. The road network in a country serves as a major mode of transportation for the public and goods compared to air and waterways. Once a road is constructed, its structural and functional stability starts to decrease, thereby increasing vehicle operating costs (VOC), travel time, and accidents, and thus reducing the riding comfort of the road user [1]. Lack of timely maintenance measures in the needed year leads to extensive rehabilitation or sometimes warrants re-construction, thereby escalating the maintenance cost. To overcome these drawbacks, appropriate maintenance schemes are required to know the real condition of the roads and to develop an unbiased improvement strategy for the roads based on their actual conditions [2]. This can be achieved with the help of road maintenance software for the development of effective road maintenance management systems.

Maintenance strategies to be adopted for any road depend on various factors like traffic flow patterns, existing pavement conditions, climate, accident rates, and also the funds available for implementing suitable maintenance

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strategies. Road asset anagement is one of the basic areas of the transportation sector in developing countries. Asset management mainly depends on the data of transport infrastructures like pavement management, bridge management, auxiliary structures management like signage, road furniture, drainage structures, retaining walls, etc. [3]. This paper deals with a systematic approach towards pavement distress data collection techniques using advanced data collection tools, handling of large datasets with a well-designed database management system (DBMS), and preprocessing of all the pavement-related data within DBMS to feed as input parameters to develop prioritisation schemes.

1.1 Pavement Management System (PMS)

PMS indicates a combination of a group of systematic techniques that are designed to help road engineers/decision makers in making sound and economical decisions related to the design, maintenance, and rehabilitation of pavement structures [1]. Properly designed PMS can be used for complex engineering applications such as comparing the performance of various pavements [3]. PMS models are used to predict the future condition of the pavements, which in turn helps in arriving at the necessary maintenance treatments required for the pavements [4]. The pavement deterioration prediction models are effectively utilised in pavement condition prediction, budgeting, work preparation, and scheduling of inspections [4]. The main objective of network-level PMS is to develop short- and long-term budgeting and to prepare a possible project list that can be taken up within the constrained budget [5]. Any decision-making tools may not directly result in arriving at final answers, but they can provide a comparison of alternative decisions in a scientific manner [6], cloud decision tree can also be an option for development of M&R strategies [7]. PMS configuration can be mainly categorised into two levels, namely network level, which covers the entire network of a study area and mainly helps in arriving at decisions concerning network-wide planning, budgeting, and policy-making. Golabi et al. [8] extensively worked on innovative network-level PMS for the Arizona Department of Transportation (ADOT), which can also be referred to in work done by Ferreira et al. [9] Project level analysis covers a detailed study of each section considered in the network.

The economic growth of any country is mainly dependent on the availability of transport infrastructure facilities. According to [2], road infrastructure supports approximately 20% of the gross national product (GNP). So, it is very important to retain transport infrastructure facilities in a good serviceable condition to preserve the huge investment incurred in the road network [10].

1.2 Asset Evaluation (Pavement)

Once the pavement is constructed, it starts deteriorating with respect to time. The rate of deterioration is influenced by several factors, like vehicle fleet, traffic flow pattern, environmental conditions, etc. From the historical data, it is observed that it takes about 20 years for a pavement to reach a point where it warrants major rehabilitation when the pavement is constructed as per standard specifications [11]. Haas et al. [12] proved that periodic pavement evaluation should be adopted to ensure the user demands that have to be met by pavements and also to arrive at the information required for planning and budgeting. Major parameters to be measured in the evaluation of pavements include structural adequacy, surface defects/distresses, riding comfort, skid resistance, treatment and road user costs, etc. However, many road agencies ignore the maintenance of the road network unless it reaches the level where the riding comfort reaches intolerable levels [13].

1.3 PMS Studies in India

Veeraragavan and Chakraborty [14] developed a method to prioritise the pavement sections by considering both functional and structural parameters of the highway. The benefit/cost ratio and net present value were determined in the economic analysis process. As per the highest value obtained after the economic analysis, the corresponding pavement section was given priority for maintenance treatment and ranking was done accordingly. Roy et al. [15] demonstrated the importance of HDM-4 in selecting from various available alternatives for maintenance and rehabilitation of pavements depending upon the life cycle economic cost analysis. Various sections of the State Highway of Kerela state were selected in the study and road investment programmes were prepared. Depending on the Internal Rate of Return (IRR) method and the benefit/cost ratio method, the appropriate maintenance and rehabilitation (M&R) strategies were selected. Aggarwal et al. [16] used HDM-4 to prioritise the National Highways network based on the results of Net Present Value (NPV)/Cost ratio values. The yearly M&R strategies were prioritised to utilise the maintenance funds appropriately. In HDM-4, the 'Project Analysis' component has been used to compute the NPV/cost ratio values for various national highway pavement sections that were considered under the study. A higher NPV/cost ratio of any pavement section means consideration for its maintenance. Nautiyal et al. [17–20] created a Web-based maintenance plan for rural roads at both the network and project levels that prioritised pavement maintenance based on current pavement condition and traffic.The authors also provided a scientific approach to forecast the remaining service life (RSL) of low volume rural roads using pavement age and present pavement condition (PCI) as predicting parameters. The Analytical Hierarchy Process (AHP) tool is being used effectively in Indian states to prioritise maintenance strategies for low volume roads.

Singh and Sreenivasulu [21] utilised the "programme analysis" component to arrive at the best possible M&R strategy for the pavement sections that were considered in the study. The NPV/cost ratio method was used to prioritise all the pavement sections. Shankar et al. [22] performed a rural road pavement performance study on the selected four rural road sections in the Warangal district of Telangana. Detailed data collection was done corresponding to both functional and structural parameters, and analysis was done using HDM-4 for both responsive and scheduled maintenance. The strategies were compared and the best one was selected for the application. Calibration of deterioration models was also done in the study. Shah Yogesh et al. [23] carried out an economic analysis of Indian urban roads by selecting a 60 km road stretch in Noida City near New Delhi, India. The analysis was carried out with two main goals in mind: to minimise NPV and to minimise costs to achieve the desired IRI.The road network data collection included road inventory, geometric details, structural and functional evaluation details, and vehicle fleet data. Various strategies were considered as choices, which included routine maintenance, resealing, thin overlay, thick overlay, resealing + overlay, and strengthening.

Prioritisation of maintenance strategies plays a major role in the effective utilisation of the limited funds available. Prioritisation of maintenance strategies depends on the demands of the road users in terms of traffic volume count, the existing condition of the pavement, vehicular fleet characteristics, climatic conditions, pavement material characteristics, deterioration behaviour of the pavement, etc. Proper approaches towards the ranking of pavements for maintenance will enable the public agencies to rationalise the distribution of limited funds.

In the present case study, an oracle database called EXOR is used to store road network, traffic characteristics, pavement inventory, and condition (both structural and functional) data. EXOR is a customised database to store the data modular-wise with five different customised modules, namely Road Information System (RIS), Bridge Information System (BIS), Traffic Information System (TIS), Pavement Management System (PMS), and Routine Maintenance Management System (RMMS). The corresponding data are collected, validated, and stored in a respective module. The database is also customised in such a way that the input required for HDM-4 software (i.e. 112 columns) is also generated automatically along with homogenous sections using the Transportation Intelligence Gateway (TIG) module.

2 Objectives

The main objective of the study is to develop a prioritised work programme for an identified highway network and to prepare a roll-out plan. For which the following sub-objectives were formulated:

1. Collection of pavement inventory, condition, traffic, axle load, soil characteristics, and vehicle fleet data.
2. Validation and updating of data in the central database
3. Economic analysis and preparation of prioritised road network plans

3 Methodology

For the current study, about 1744 km of non-core road network are considered for prioritisation, with annual average daily traffic (AADT) ranging from 600 to 31,000 Passenger Car Unit (PCUs). The network is identified and digitised using the ArcGIS application tool, and those shape files are imported to a central database. Pavement inventory and condition data are collected using a Network Surveying Vehicle (NSV) and a Falling Weight Deflectometer (FWD), respectively. The data collected are post-processed and stored in a central database (EXOR). A classified traffic volume count survey is carried out at pre-identified sections and the data are projected for the future as per Indian traffic projection guidelines (IRC 64). Vehicle fleet characteristics are collected as per Indian standard specifications as input for HDM software. HDM models were calibrated for Indian road conditions. Six types of strategies were formulated which are suitable for Indian non-core roads, and the predicted pavement roughness from those strategies was compared with current maintenance practices practiced by the state public works department. Detailed economic analysis is carried out to select the best strategy, and a rolling out plan is prepared for the selected strategy for the next 10 years.

The data architecture consists of the EXOR Core where the data related to road inventory and condition, pavement composition, asset tagging, traffic, axle load, and accident data are stored module wise. Similarly, it also consists of a structural manager where the data related to bridges and culverts are stored. The Spatial Manager consists of GIS maps and networks. All these modules are connected with the Transportation Intelligence Gateway

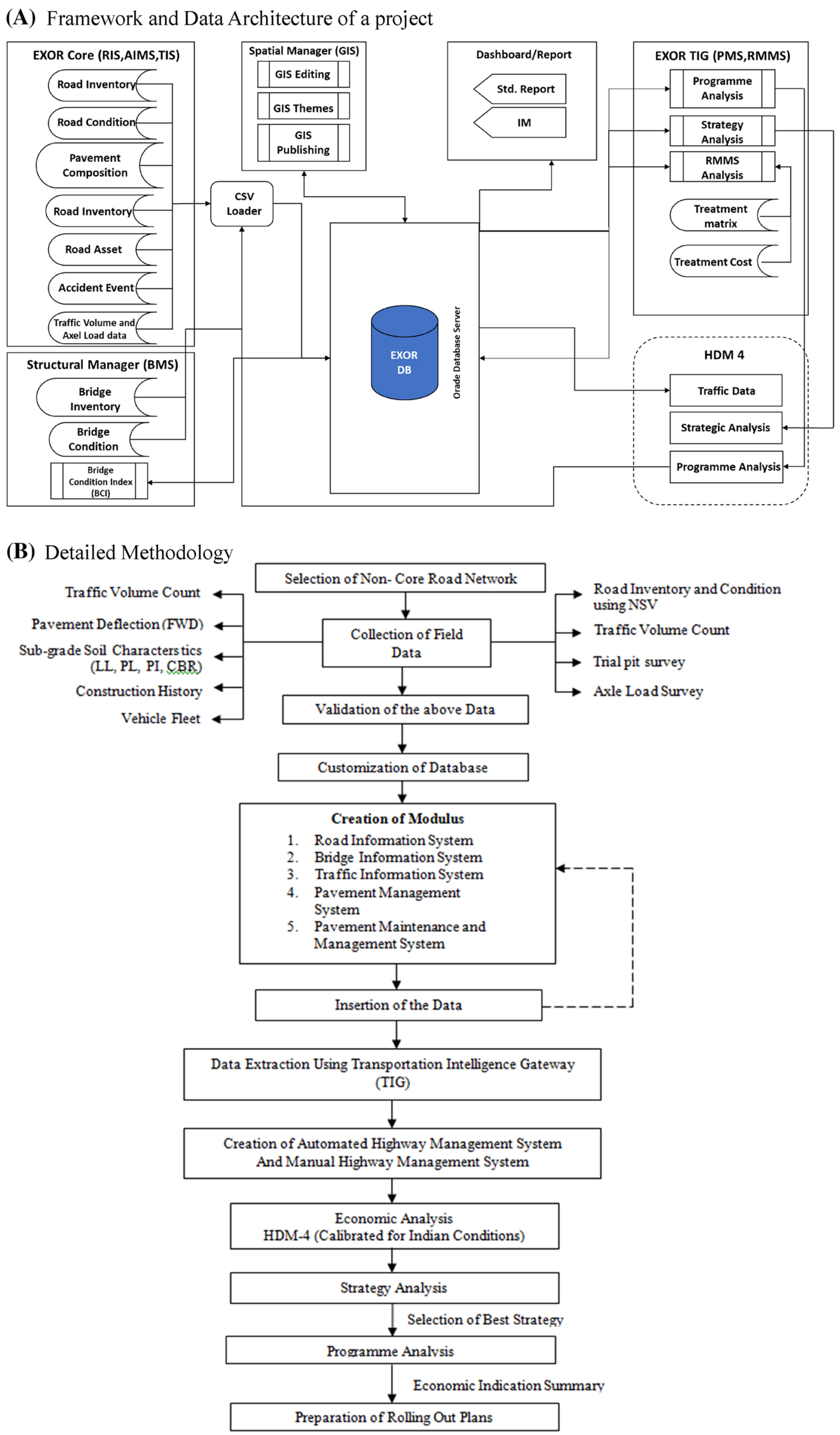

Fig. 1 (**A**) Framework and data architecture of a project. **B** Detailed Methodology

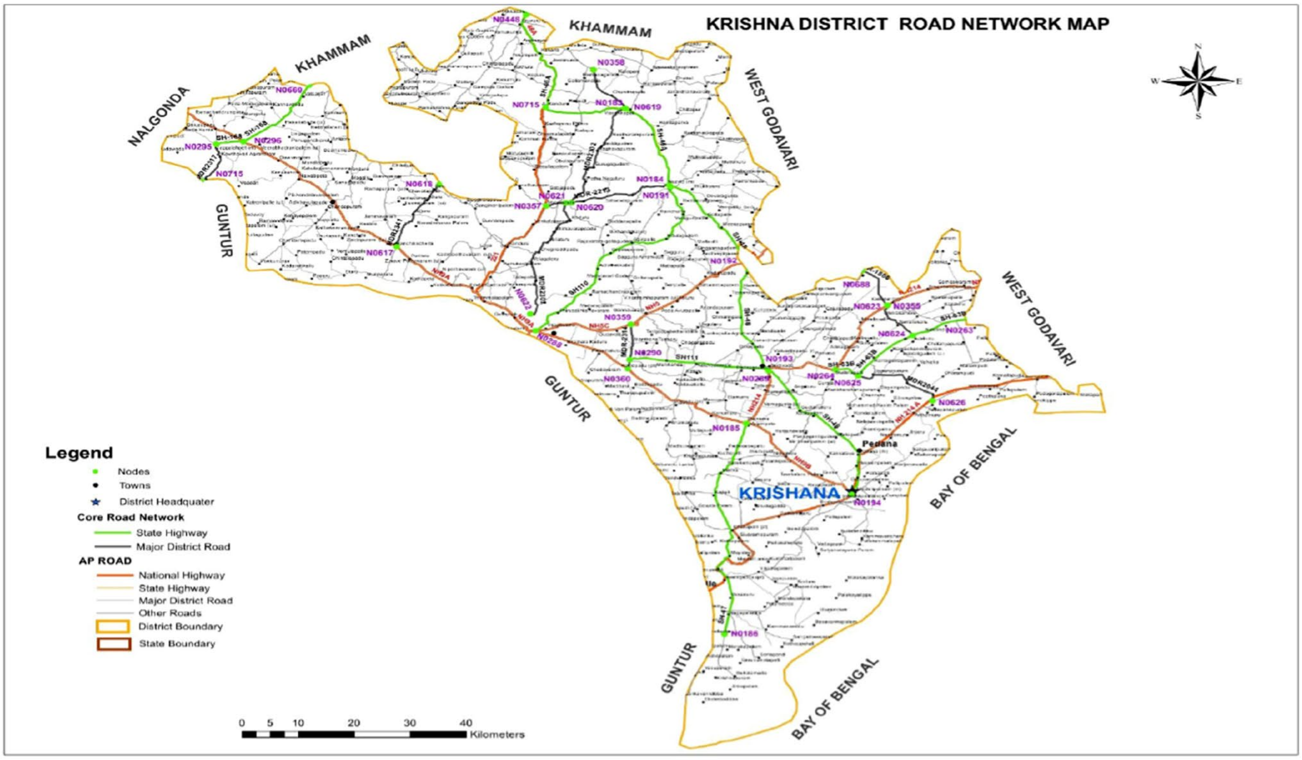

Fig. 2 Road network map of the study area

(TIG) module to generate homogenous sections which are fed into HDM-4 for the preparation of annual road maintenance plans. The output of HDM-4 can be published and stored on the dashboard. The framework and data architecture of a project are shown in Fig. 1A, and the methodology adopted is shown in Fig. 1B.

4 Data Collection and Interpretation for Use in HDM-4

About 1743.9 km of non-core road network is considered in the present study.

4.1 Study Area

The Krishna District of Andhra Pradesh State in India is considered for the present study. The roads in the present study were classified as core road networks (CRN) and non-core road networks (NCRN). CRN roads are those which in the future will be converted into state highways, whereas NCRN roads include major district roads, other district roads, and village roads. NCRN has been considered for the analysis in the present case study. The total network consists of 237 roads, out of which 168.25 km are bituminous roads, 54.61 km are earthen roads, and 0.04 km are cement concrete pavement. The road network map is shown in Fig. 2.

4.2 Collection of Pavement Structural and Functional data using NSV and FWD

The Hawkeye 2000 professional NSV is equipped with a fully integrated Hawkeye 2000 data collection system. It consists of a multi-laser profiler, a digital imaging system, and a Gipsi-Trac unit, the output of which is accurately linked with a high-precision distance measuring instrument. Each dataset is referenced to the road running distance in accordance with the Council's current reference system, as well as its spatial position using differential GPS.

The data collected from the NSV consist of the following parameters:

1. Rise/fall (m/km), grade (%), cross slope (%), horizontal and vertical curvature (1/km);
2. Avg. profiler data: rut depth (mm), IRI (m/km), Macro texture (mm);
3. Pavement distress data: ravelling, edge break, cracks, patching, shoving, spalling, etc., (both severity and

Table 1 Predicted future traffic

Vehicle type	Economic indicator	R^2	Elasticity	$\text{Log}_e\ P = A_o + A_i{*}\text{Log}_e\text{GNP}^3$	Projected traffic in % (2017–2026)
Two wheeler	PCI[1]	0.96	1.54	$\text{Log}_e\ P = -10.8 + 1.54\ \text{Log}_e\ \text{GNP}$	9.42
Car	PCI	0.95	1.36	$\text{Log}_e\ P = -10.02 + 1.36\ \text{Log}_e\ \text{GNP}$	8.32
Three wheeler	NSDP[2]	0.97	1.56	$\text{Log}_e\ P = -13.6 + 1.56\text{Log}_e\text{GNP}$	9.55
Bus	Population	0.99	0.60	$\text{Log}^e\ P = 0.508 + 0.6\ \text{Log}_e\ \text{GNP}$	3.67
Goods vehicle	NSDP	0.98	1.00	$\text{Log}_e\ P = -4.31 + 1.0\text{Log}_e\text{GNP}$	6.12
Tractor and trailer	NSDP	0.76	1.03	$\text{Log}_e\ P = -4.59 + 1.03\text{Log}_e\text{GNP}$	6.30

[1]PCI-per capita income, [2]NSDP-net state domestic products, [2]GNP-gross national product

extent) were observed for different types of surfacing, i.e. bituminous/cement concrete surface;
4. Carriageway type, width, and number of lanes; shoulder width and type; sign boards; cross drainages etc.;
5. At various radial distances and pavement temperatures, deflections were measured.

4.3 Traffic Data

Classified traffic volume count was carried out along the predefined survey locations for 3 days (24 h), which included one weekend, one normal working day, and one market/any special day of a particular week selected. These classified volume counts were converted into PCU values as specified by the "IRC 64:1990" Guidelines for Capacity of Roads in Rural Areas [11]. Then the counts were converted into ADT and AADT by applying seasonal correction factors [12]. The predicted future traffic is presented in Table 1.

4.4 Maintenance Standards Considered for the Study

Based on the analysis of the existing road conditions, six types of strategies [13, 14] have been considered for the improvement of the riding quality of the existing road network, and they are compared with current practice being implemented by the state public works department [15, 16].

1. Road and building practice (R&B practice)
2. Best responsive
3. Fair responsive
4. Minimum responsive
5. Best schedule
6. Fair schedule
7. Minimum schedule

The work items considered in best responsive strategies include the provision of 80 mm thick dense-grade asphalt when overlay roughness (IRI) ≥ 5 m/km, two-way AADT ≥ 2000, cumulative ESAL ≥ 0.1, provision of 30 mm thin overlay when roughness (IRI) ≥ 3 m/km, two-way AADT ≥ 2000, patching of all potholes, edge repair when area of edge break ≥ 200 m^2/km, sealing of all structural crack. Similarly, the various strategies considered for the current study have been listed in Table 2. The economic cost consists of material or item costs incurred for the respective maintenance per square metre area. However, the financial cost includes additional taxes from government agencies, excise duty, VAT, and other intangible cost parameters. In the present study, the financial cost is considered to be 1.1 times higher than the economic cost. The financial cost is always the current market price of the material, which includes all taxes and is always higher than the economical cost. Generally, the financial cost is about 8–10% higher than the economic cost as per the Asian Development Bank/World Bank considerations.

5 Data Analysis

5.1 Pavement Condition Analysis

A pavement condition survey of the network of 1743.9 km was carried out using NSV. From the distress data analysis, it is found that the IRI of the network considered varies from 0 to 14 m/km. About 53% of the network has an IRI ranging between 4 and 6 m/km, which is considered to be in fair condition for a non-core road network. Also, the total area of cracking per km varies from 0 to 35%. However, about 84% of the network has a cracking area of less than 5%, which indicates that the majority of the network is in good condition. Similarly, the average rut depth varies from 0 to 30 mm. The percentage distribution of IRI, cracking area, and average rut depth is as shown in Fig. 3A–C, respectively.

5.2 Use Strategy Analysis to Optimise Using Funding Scenarios, and Service Level

The objective of optimisation is to provide greater efficiency in selecting maintenance and improvement alternatives to

Table 2 Work standards (maintenance standards)

Sl no	Work item	Operation	Intervention	Effects	Economic cost (Rs)	Financial cost (Rs)
R&B practice						
1	Overlay @ 80 mm	Overlay dense-grade asphalt	Roughness (IRI) ≥ 8 m/km	–	783	870
2	Resealing @ 30 mm	Thin overlay	Roughness (IRI) ≥ 6 m/km	–	311	345
3	Patching (Pothole)	Patching	Every Year	100%	311	345
4	Edge repair	Edge repair		60%	315	350
5	Cracking	Cracking		50%	38	42
6	Ravelling	Patching		50%	55	61
Best responsive						
1	Overlay @ 80 mm	Overlay dense-grade asphalt	Roughness (IRI) ≥ 5 m/km, two-way AADT ≥ 2000, cumulative ESAL ≥ 0.1	–	783	870
2	Resealing @ 30 mm	Thin overlay	Roughness (IRI) ≥ 3 m/km, two-way AADT ≥ 1000	–	311	345
3	Rutting	Inlay	Mean Rut Depth > = 1 mm	10%	783	870
4	Digout	Inlay	Wide structural cracks ≥ 5%, IRI ≥ 3, two-way AADT ≥ 2000	10%	783	870
5	Patching (Pothole)	Patching	Pothole Numbers > = 1 No's	100%	311	345
6	Edge repair	Edge repair	Edge break ≥ 200 m^2/km	50%	315	350
7	Cracking	Cracking	All structural cracking ≥ 1%	100%	38	42
8	Ravelling	Patching	Ravelling ≥ 1%	100%	55	61
Fair responsive						
1	Overlay @ 80 mm	Overlay dense grade asphalt	Roughness (IRI) ≥ 6 m/km, two-way AADT ≥ 1500, cumulative ESAL ≥ 0.05	–	783	870
2	Resealing @ 30 mm	Thin overlay	Roughness (IRI) ≥ 4 m/km, two-way AADT ≥ 1000	–	311	345
3	Rutting	Inlay	Mean rut depth ≥ 3 mm	20%	783	870
4	Digout	Inlay	Wide structural cracks ≥ 8%, IRI ≥ 4, two-way AADT ≥ 3000	20%	783	870
5	Patching (Pothole)	Patching	Pothole numbers ≥ 3 No's	80%	311	345
6	Edge repair	Edge repair	Edge break ≥ 400 m^2/km	30%	315	350
7	Cracking	Cracking	All structural cracking ≥ 3%	80%	38	42
8	Ravelling	Patching	Ravelling ≥ 5%	80%	55	61
Minimum responsive						
1	Overlay @ 80 mm	Overlay dense-grade asphalt	Roughness (IRI) ≥ 7 m/km, two-way AADT ≥ 1000, cumulative ESAL ≥ 0.05	–	783	870
2	Resealing @ 30 mm	Thin overlay	Roughness (IRI) ≥ 5 m/km, two-way AADT ≥ 1000	–	311	345
3	Rutting	Inlay	Mean rut depth ≥ 5 mm	30%	783	870
4	Digout	Inlay	Wide structural cracks ≥ 10%, IRI ≥ 5, two-way AADT ≥ 4000	30%	783	870
5	Patching (Pothole)	Patching	Pothole numbers ≥ 5 No's	70%	311	345
6	Edge Repair	Edge repair	Edge break ≥ 600 m^2/km	10%	315	350
7	Cracking	Cracking	All structural cracking ≥ 5%	70%	38	42
8	Ravelling	Patching	Ravelling ≥ 10%	70%	55	61
Best schedule						
1	Overlay @ 80 mm	Overlay dense-grade asphalt	Roughness (IRI) ≥6 m/km, two-way AADT ≥ 2000, cumulative ESAL ≥ 0.1	–	783	870
2	Resealing @ 30 mm	Thin overlay	Initial year + 5 years	–	311	345

Table 2 (continued)

Sl no	Work item	Operation	Intervention	Effects	Economic cost (Rs)	Financial cost (Rs)
3	Rutting	Inlay	Every year	10%	783	870
4	Digout	Inlay		6%	783	870
5	Patching (Pothole)	Patching		100%	311	345
6	Edge repair	Edge repair		100%	315	350
7	Cracking	Cracking		100%	38	42
8	Ravelling	Patching		100%	55	61
Fair schedule						
1	Overlay @ 80 mm	Overlay dense-grade asphalt	Roughness (IRI) ≥ 7 m/km, two-way AADT ≥ 1500, cumulative ESAL ≥ 0.05	–	783	870
2	Resealing @ 30 mm	Thin overlay	Initial year + 6 years	–	311	345
3	Rutting	Inlay	Every year	7%	783	870
4	Digout	Inlay		4%	783	870
5	Patching (Pothole)	Patching		80%	311	345
6	Edge repair	Edge repair		80%	315	350
7	Cracking	Cracking		80%	38	42
8	Ravelling	Patching		80%	55	61
Minimum schedule						
1	Overlay @ 80 mm	Overlay dense grade asphalt	Roughness (IRI) ≥ 8 m/km, two-way AADT ≥ 1000, cumulative ESAL ≥ 0.05	–	783	870
2	Resealing @ 30 mm	Thin overlay	Initial year + 7 years	–	311	345
3	Rutting	Inlay	Every year	5%	783	870
4	Digout	Inlay		2%	783	870
5	Patching (Pothole)	Patching		70%	311	345
6	Edge repair	Edge repair		70%	315	350
7	Cracking	Cracking		70%	38	42
8	Ravelling	Patching		70%	55	61

achieve laid down performance levels at an overall network level. Work selections may be optimised within the government's funding commitment to achieve the desired service. HDM-4 provides for maximising the benefit in terms of NPV and minimising the cost for a target IRI (service level) in selecting the appropriate alternatives and different funding scenarios for a long-term analysis period. State agency suggestions may be used to undertake analysis for various scenarios before finalising the overall budget and service level. The final optimised PMS/HDM4 output regarding future maintenance programmes and costs must be imported into the Road Asset Management Systems (RAMS) database for reporting. The information can then be disseminated to decision makers using standard reports.

Strategy and programme analysis were done using the HDM-4 tool. An economic analysis was carried out for the selected sections to develop a pavement management programme based on the existing performance of the sections. The budget forecasting was done for the next 10 years by considering a 12% discount rate (as suggested in Indian guidelines, IRC SP 30 [10], "Manual on Economic Evaluation of Highway Projects in India") with the objective of an unconstrained work programme for the next 10 years for the selected sections and predicting the funding levels that are required for the improvement standards that are adopted. Non-motorised vehicles were not considered during the analysis as they were negligible. Strategy analysis was done by considering various strategies, including R&B practice. The economic analysis was done based on the benefit-to-cost ratio and savings in VOC. A best-possible strategy was thus selected, and a programme analysis was carried out for that strategy. Figure 4 shows the variation of IRI values, and Table 3 indicates the strategic analysis economic indicators summary.

5.3 Programme Analysis to Prepare Multi-Year Maintenance Plan

Once the strategy is finalised, a programme analysis using HDM-4 or a simplified maintenance and programming tool will be used to generate a long-term improvement and maintenance plan. This will require the latest road network and

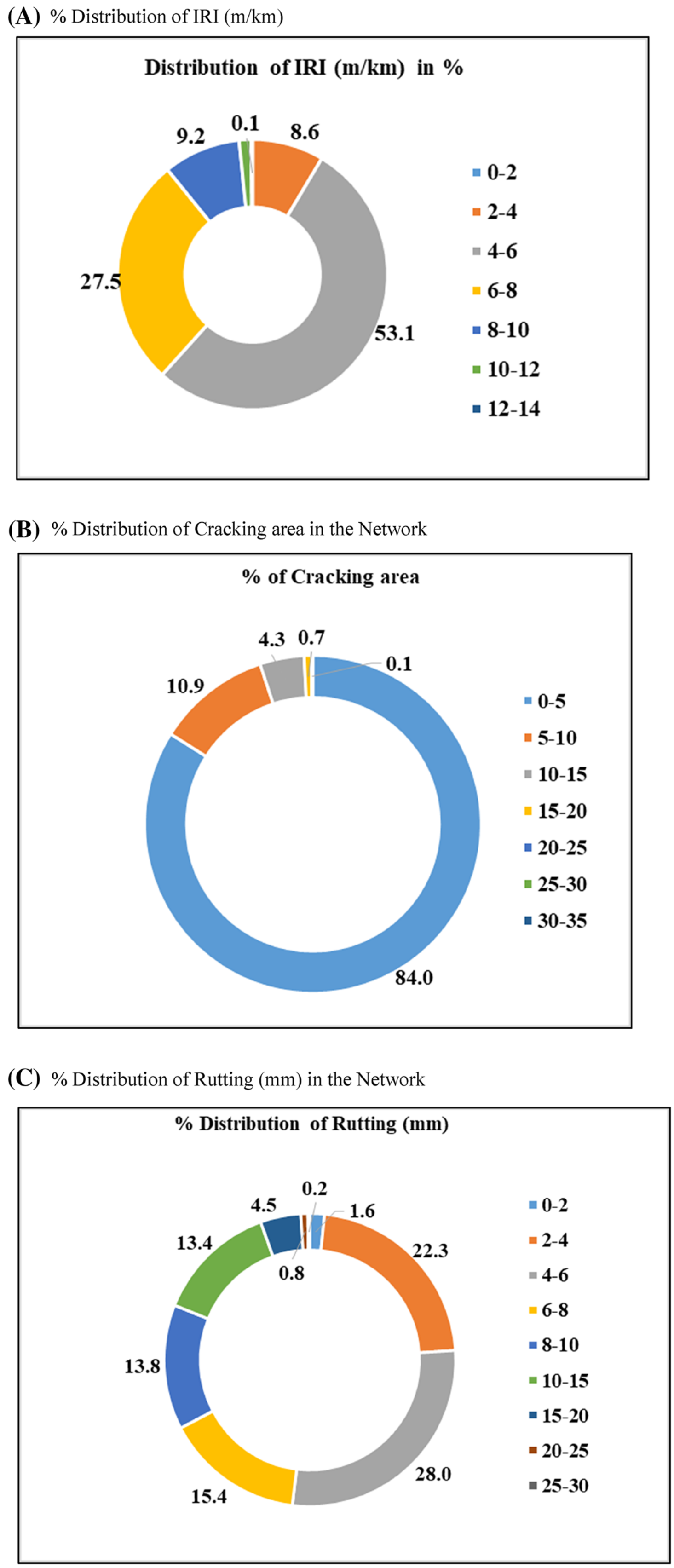

Fig. 3 (A) % Distribution of IRI (m/km). **B** % Distribution of cracking area in the network. **C** % Distribution of rutting (mm) in the network

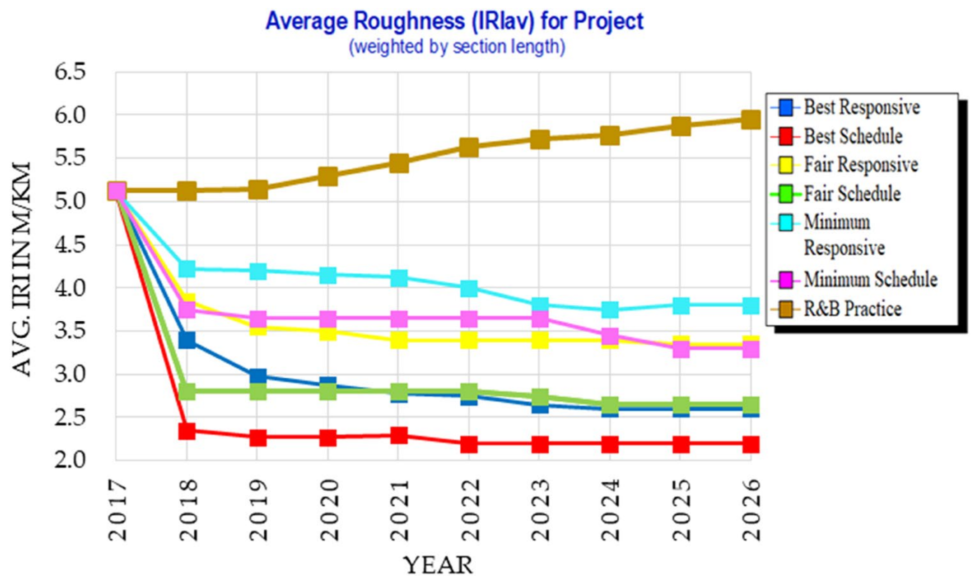

Fig. 4 Strategy analysis results (2017–2026)

Table 3 Strategic analysis economic indicators summary (crore rupees.)

Alternative	Agency capital costs (CAP)	Recurrent cost	Total agency costs (RAC)	Benefits (savings in VOC & time cost)	Benefit/RAC ratio	Benefit/capital cost ratio	Average internal rate of return (IRR)	Targeted IRI in m/km
R&B practice	266.33	59.63	325.97	–	–	–	–	5.95
Best responsive	374.33	62.89	437.22	358.15	0.82	0.96	43.18	2.60
Best schedule	451.26	306.60	757.86	198.47	0.26	0.44	32.38	2.20
Fair responsive	370.90	62.60	433.50	384.87	0.89	1.04	53.18	3.35
Fair schedule	378.84	237.04	615.88	300.97	0.49	0.79	42.79	2.65
Minimum responsive	239.45	61.26	300.71	423.26	1.41	1.77	119.63	3.80
Minimum schedule	336.54	189.90	526.43	268.27	0.51	0.80	29.73	3.65

traffic data and updates with costs of maintenance and rehabilitation alternatives. Budgets finalised for different years will be fed as inputs for constraints to short-list sections. This, being the final objective of an asset management system, will require deliberation with the field staff, technical heads, and the government. The PMS/HDM-4 maintenance programme output, along with costs, must be imported into the RAMS database for reporting. The information can then be disseminated to decision makers using standard reports.

Programme analysis was carried out for the minimum responsive strategy due to the higher B/C ratio and IRR. Suitable treatments were provided as per the results obtained from HDM-4 software. Though the targeted IRI for the best responsive strategy is lower, it is not considered a suitable maintenance strategy from the economic analysis point of view (i.e. due to the lower B/C ratio and IRR). Figure 5 shows the variation of IRI values, and Table 4 indicates the programme analysis economic indicators summary for minimum responsive strategy.

5.4 Rolling Out Plan Summary

For the preparation of the rolling plan summary, all types of surfacing, i.e., bituminous or cement concrete, were considered. The bituminous surface is proposed with four types of treatments, viz., overlay@80 mm, resurfacing@30 mm, overlay (BC 30 mm + DBM 50 mm), overlay (bituminous concrete (BC) 30 mm + dense bituminous concrete (DBM) 50 mm + wet mix macadam (WMM) 100 mm). In the present case, the IRI of earthen roads was assumed as 20 mm/km due to their priority for reconstruction. Hence, all sections were considered for reconstruction. For cement concrete roads, surface cement concrete repairs were provisioned. A rolling out plan summary for a minimum responsive strategy is indicated in Table 5.

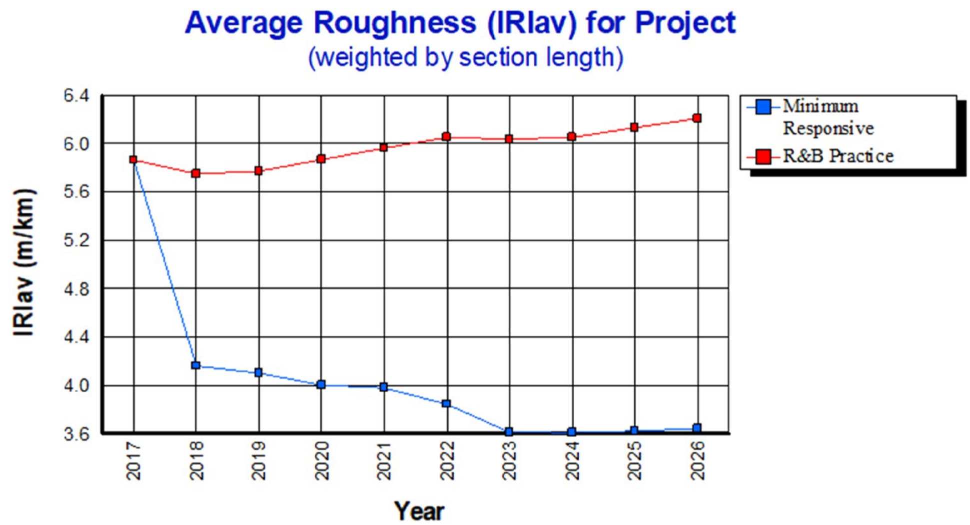

Fig. 5 Programme analysis results (2017–2026)

Table 4 Programme analysis economic indicators summary for minimum responsive strategy (crore rupees.)

Alternative	Agency capital costs (CAP)	Recurrent cost	Total agency costs (RAC)	Benefits (savings in VOC & time cost)	Benefit/RAC ratio	Benefit/capital cost ratio	Average internal rate of return (IRR)	Targeted IRI in m/km
R&B practice	267.14	59.63	326.77	0.00	0.00	0.00	0.00	6.20
Minimum responsive	293.45	61.26	300.71	424.12	1.41	1.77	115.60	3.65

6 Discussion

Road assets are expensive to construct and maintain to meet user demands. Though many state agencies have implemented road asset management systems to maintain their network and correspondent assets, there is a gap towards systematic approaches for implementation. The present case study clearly depicts the process of asset management in a well-ordered structure, starting from data collection methodology using globally accepted procedures; conceptualization of a database management system to handle a wide variety of data; data validation procedures; and modular arrangement of data as it pertains to road inventory, road condition, traffic, cross-drainage structure, accidental data, etc. The customised database used will help ease dealing with magnified data. The cloud system (EXOR) implementation will help in concerning authorised authorities for easy data access. The modular arrangement of datasets will enhance the user-friendly interface.

Since the priority is for unpaved surfaces, all earthen roads are recommended for re-construction in the first year itself. From the strategy analysis, it can be clearly seen that by adopting the conventional strategy, the targeted IRI is reaching about 5.95 m/km, which causes discomfort to road users. Though the IRI of 2.20 m/km is achieved by adopting the best schedule strategy, from the economic point of view it is not viable since the B/C ratio is only 4.40, which indicates the returns are less than the investment. By considering economic viability, a minimum responsive strategy is adopted for the preparation of prioritised maintenance work plans due to the higher B/C ratio (1.77) and IRR (119.63 crore rupees). From the economic analysis summary of the considered network, it is clear that the majority of the network length surveyed needs immediate maintenance (i.e. 70.3%) in the first year, which costs about 68% of the total cost required for 10 years. Also, from the strategy and programme analysis, the predicted IRI by adopting the minimum responsive schedule is 37% less than the conventional strategies adopted by state agencies, which plays a vital role in reducing VOC and thereby increasing road users' comfort.

7 Conclusions

Development of RAMS for network level is a highly complex task which requires a data cloud system, state-of-art equipment for data collection, and qualified engineers to meet the requirements of stakeholders. The greatest advantage of the implementation of RAMS is the availability of data in a structured manner, ease of optimization procedures, and quick access of the data at network level. The

Table 5 Rolling out plan summary

Year	Surface type	Length (km)	Proposed treatments	Cost for treatments (Crore Rs.)	Total cost (Crore Rs.)
2017	Bituminous	275.5	Overlay@80 mm	88.84	259.29
		540.43	Resealing@30 mm	71.26	
		114.3	Overlay (BC 30 mm + DBM 50 mm)	36.91	
		18.24	Overlay (BC 30 mm + DBM 50 mm + WMM 100 mm)	7.63	
	Earthen	44.88	Reconstruction	54.61	
	CC pavement	30.64	CC Repair	0.04	
2018	Bituminous	12.26	Overlay@80 mm	3.68	15.32
		58.79	Resealing@30 mm	7.75	
		8.88	Overlay (BC 30 mm + DBM 50 mm)	3.15	
		1.84	Overlay (BC 30 mm + DBM 50 mm + WMM 100 mm)	0.74	
2019	Bituminous	19.44	Overlay@80 mm	3.49	21.56
		10.74	Resealing@30 mm	12.53	
		0.80	Overlay (BC 30 mm + DBM 50 mm)	4.90	
		19.44	Overlay (BC 30 mm + DBM 50 mm + WMM 100 mm)	0.64	
2020	Bituminous	87.85	Resealing@30 mm	12.11	12.65
		1.01	Overlay (BC 30 mm + DBM 50 mm)	0.54	
2021	Bituminous	12.03	Overlay@80 mm	3.71	27.49
		151.48	Resealing@30 mm	21.05	
		0.17	Overlay (BC 30 mm + DBM 50 mm)	0.196	
		3.29	Overlay (BC 30 mm + DBM 50 mm + WMM 100 mm)	2.53	
2022	Bituminous	40.27	Overlay@80 mm	12.69	27.59
		100.88	Resealing@30 mm	14.9	
2023	Bituminous	40.28	Resealing@30 mm	6.35	7.90
		2.01	Overlay (BC 30 mm + DBM 50 mm + WMM 100 mm)	1.55	
2024	Bituminous	20.15	Resealing@30 mm	4.63	4.63
2025	Bituminous	14.03	Resealing@30 mm	2.89	2.89
2026	Bituminous	7.99	Resealing@30 mm	1.95	1.95
	Total length	1628.72		Total cost =	381.27

right treatment for the roads at the right time will not only help in reducing future investments; it also brings down VOC, the probability of accidents and high emissions during rehabilitation. Hence, pavement performance prediction modelling plays a vital role in prediction of pavement condition and possible treatments at the right time. PMS is a key tool to manage existing road assets in a better way to provide optimum operation and maintenance (O&M) strategies. The proposed study on network-level analysis not only simplifies the O&M strategies; it also helps in the prediction of future budget allocation requirements for the road sector. The major drawback of this approach is that it can only assess the network through fundamental input parameters, whereas the other road assets like traffic signs, street lights, and other road furniture are being neglected. Also, asset valuation is being neglected in the present study, which enables the stakeholders to report the assets in terms of monetary value. The further scope will be mainly focussed on a simplified analysis of the network at the project level with the inclusion of all road assets, which are being neglected in the present study.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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