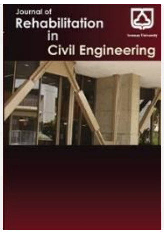
Journal of Rehabilitation in Civil Engineering 13-2 (2025) 64-74



Journal of Rehabilitation in Civil Engineering

Journal homepage: https://civiljournal.semnan.ac.ir/

Assessment of Maintenance Strategies and Performance Prediction for Urban Roads Using IRI and HDM-4 Models

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ARTICLE INFO

Article history:
Received: 04 January 2024
Revised: 05 July 2024
Accepted: 15 August 2024

Keywords:
Rutting;
Fatigue;
Pothole;
Patching;
IRI.

ABSTRACT

Globally emerging markets need a well distributed, safe, and efficient transportation system. Analyzing, pavement management and maintaining such a dense highway networks and transportation systems comes with its own complications. Out of the many available techniques globally i.e. Highway Development and Management (HDM-4) can be adopted to achieve such a daunting task. In HDM-4, pavement distress initiation and progression can be predicted using HDM-4 pavement deterioration models using different parameters like traffic, climate, pavement structure, and composition combinations. However, before implementation, such HDM-4 model should be calibrated and validated. Since, in-situ variables greatly influence the rate at which each pavement distress initiates and propagates. The paper focuses on distress factors i.e. rutting, fatigue, pothole, and patching on a highway of two and four-lanes using HDM-4 model. International Roughness Index (IRI) values are computed using MERLIN instrument. The results are given as input to HDM-4 software for the predicting initiation and progression of discomfort for the present and future traffic. Based on the IRI values, priority ranking are given for road maintenance, higher the IRI value, higher is the priority for road maintenance and vice-versa. Findings from this study can be used to improve road networks, traffic safety, and applicability for comparable road conditions.

E-ISSN: 2345-4423

How to cite this article:
D, H., Poojari, Y., Noolu, V., & Dachepalli, V. (2025). Assessment of Maintenance Strategies and Performance Prediction for Urban Roads Using IRI and HDM-4 Models. Journal of Rehabilitation in Civil Engineering, 13(2), 64-74. https://doi.org/10.22075/jrce.2024.32883.1968

1. Introduction

Transportation infrastructure plays a pivotal role for any emerging nations, in achieving prosperity. Road transport holds a dominant position among all forms of transport due to its accessibility, from door-to-door service, ease of operation, and dependability. The Government of India launched a sizable National Highway Development Programme (NHDP) in 1999 to support the economic growth of the nation [1,2]. This programme includes the creation of the highway projects with high speeds routes ever undertaken. In India, most of the highways are constructed with flexible pavements (FP) and normal bitumen is used as binding material generally. In general, due to distress caused by the heavy axle loads, FP's are susceptible to frequent damages. However, bitumen is frequently substituted with polymers to increase its performance to compensate the temperature variations in the pavement, for better performance under such heavy axle loads [2,3]. Due to the increase in computing power in recent decade, pavement distress can be monitored using a pavement management system (PMS). Highway administrators have several tools for the maintenance and rehabilitation of pavements, Highway Development and Management (HDM-4) is one such tool. The HDM-4 pavement deterioration models help to predict the initiation and progression of various pavement distresses under the different combinations i.e. traffic, climate, pavement structure, and composition. It is used to determine the annual condition of the pavement over time for the FP conditions indicator. So the yearly situation of pavement structure was used to forecast pavement performance. [4] conducted a thirty-year examination of the HDM-4 programme. To create the most effective management maintenance strategies for road networks, several researchers conducted studies across nations to achieve validation, calibration, and modification of HDM-4 pavement deterioration models [5][6]. [7] attempted to use experimental data collected over 61 low-volume roads (LVR) sections over four years to calibrate and validate HDM-4 deterioration models for paved LVR's using window monitoring techniques. During the absence of the availability of any long-term historical pavement performance data and an immediate need for the development of pavement deterioration models HDM-4 pavement distress models can be used for as calibration. The governing reasons for distress and acceptable limits of distress in FP's were studied and a comparative analysis of various road sections [8]. The study investigated the HDM-4 to compute the distress developed in the pavements and the authorized limits of distress in each segment of FP [9]. Among the previous studies, pavement roughness is considered the most important parameter for user satisfaction, as it directly affects the comfort of rider. International Roughness Index (IRI) is one of the most widely used indices, among the various pavement roughness. The quality of road surface can be assessed by using the roughness index and suggests improvement measures and maintenance practices. Several maintenance-effect models were developed to examine the effects of various maintenance practices on pavement roughness. [10] developed the maintenance-effectiveness measure for two highway categories and two climate zones to facilitate comparisons between various treatments. The efficiency of various rehabilitation and maintenance techniques for quick improvements in pavement condition [11]. Impact of various maintenance and rehabilitation strategies on long-term alterations in pavement condition, effectiveness of pretreatment structural capacity, traffic volume, climate, and pretreatment conditions was also investigated. A reach a desired target IRI by maximizing net present value (NPV) and minimizing costs was obtained [12]. Right amount of capital and ongoing maintenance was needed to keep the metropolitan road network in usable shape. In addition to inventory data, IRI values are calculated by specifying the state of the road network, traffic volume, traffic data, etc. To calculate the IRI in the absence of data from previous surveys, estimates were used. Field testing are to be carried if additional parameters are needed. [13] developed a reliability-based model for selecting the planning period to do preventive maintenance. The developed model used dynamic load-related roughness threshold (RQI) and actual RQI-growth rates for preventive maintenance. [14] verified normal, repeatable and time-stable IRI measurements by several IRI providers by adopting and verifying longitudinal profile measurements made using several profiles. [15] observed a statistically significant correlation between IRI, rutting and cracking. These correlations are not enough to allow IRI to be used as a stand-in for pavement quality. [16] demonstrated the failure of road sections with and without maintenance owing to distress over a 10 year period. [17] studied the effect of geocomposites used as a reinforcement of overlays to minimise the reflective cracks. They observed that type-I geocomposite is most effective in increasing the fatigue life, while temperature rise is the negative effect on the fatigue performance. [18] investigated the rheological characteristics of modified bitumen for self-healing of asphalt concrete. Investigations were performed using bending beam and dynamic rheometer, observed that by addition of 5% of powdered activated carbon to bitumen shows a better performance against rutting. [19] investigated the effect of polycarboxylate-lignosulfonate superplasticizer (PLS), Water /Cement (W/C) ratio and cement content on the compressive strength of pervious concrete (PC) payments and analysed the performance by design of experts (DoE), observed that a PC mixture with 1.0% PLS, 0.40 W/C ratio and 350 kg/m^3 of cement content had the maximum compressive strength. [20] measured mode II fracture toughness using a double-edge notched compression graphite specimen. For the numerical simulation, the CA2 hybrid discrete-finite element computer program was utilised while for the surface displacement identification and crack propagation, digital image correction was used. Tensile kinked crack and shear crack initiation and propagation at the notch tip were observed. [21] developed a pavement performance prediction model to predict the pavement performance for maintenance and rehabilitation for future planning. The artificial Neural Networks (ANNs) approach is utilized to develop the Jointed Reinforced Concrete Pavement (JRCP) performance prediction models. [22] studied to assess the performance and maintenance on unpaved roads using HDM-4 models. The study investigated the possible scenarios that consider either the replacement or non-replacement of gravel materials on the roads.

[23] developed an IRI prediction model for the National Road Network (NRN) based on the available Laos RMS database. The Multiple Linear Regression (MLR) analysis technique was applied to develop IRI prediction models for two different surfaces of the road. [24] studied the overload of vehicles' effect on the IRI values using HDM-4 models. The study identified that the IRI value is exponentially increased due to excess load. This study is planned to suggest different maintenance strategies for different urban roads with specific conditions.

2. Need for the study and objective

The current study focuses on prioritizing and adopting the work strategies that would help decision-makers with effective maintenance, distress and roughness measurements, using the HDM-4 model. IRI values were calculated for the selected roads and compared with roughness values obtained from HDM-4 models. As understanding the existing issues in the city limits and suggesting suitable remedies to achieve the desired speed limits, on the existing routes. Prior research states the ride quality is directly proportional to the comfort of the drivers. However, to achieve high ride quality or satisfaction, pavement roughness is an important parameter. As there is a dire need for well-calibrated HDM-4 pavement deterioration models, foreseeing the present and future traffic in urban areas. Such models are crucial for developing pavement management and maintenance plans.

3. Study area and data collection

3.1. Study area

The current investigations was performed to analyse the pavement performance using the HDM-4 software in Hyderabad City. Four sections were selected from different locations in Hyderabad city, every chosen place has been given a notation for example, JNTU to Pragathi Nagar (JP), Bachupally to Nizampet (BN), Miyapur to Bachuapally (MB), Gandi Maissama to Bachupally (GB). The study area of the present study is shown in Fig. 1.

Fig. 1. Study area for data collection.

3.2. Data collection

To assess the kind of distresses of various and its severity, pavement surface quality was assessed visually. Additionally parameters like the type, width, condition of the shoulder and drainage was noted. Other crucial parameters related to the cross-section of the pavement *i.e.* pavement width, shoulder width, number of lanes, the vertical profile of the road, and vertical slopes and design speed. Typically, the design speed for this kind of road network should be 60 km/h. However, parameters such as poor geometry and low country development levels preventing improper reconstruction, caused the reduction in the speed ranges 40 - 50 km/h. The different distresses like potholes, rutting, fatigue, patches and edge drops were visually inspected and the percentage of these distresses was calculated. The rut is a common type of pavement distress that is frequently used in pavement performance modelling. The main cause of rutting on modern roads is heavily loaded trucks. Over time, these heavily loaded trucks imprint their tyre impressions on roads, causing ruts. Ruts can form as a result of wear, such as studded snow tyres, which are common in cold climate areas, or as a result of deformation of the concrete pavement or sub-base material. Fig. 2 shows the distress obtained data from each section with respective current traffic.

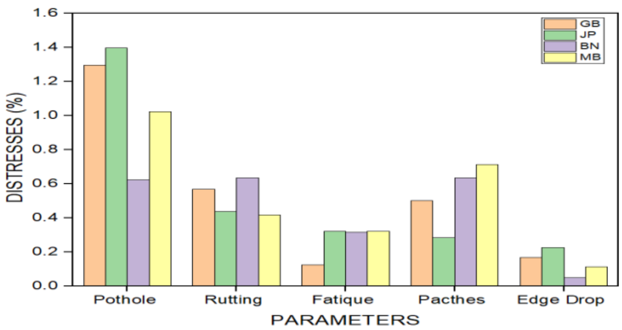

Fig. 2. Percentage of Distress data.

One can infer from Fig. 2, among all the distresses, potholes were observed common in all stretches and the percentage is higher compared to other distresses. Edge drop distress was observed very less compared to other distresses in all the stretches. Based on the percentage of distress present on the stretches, the degree of discomfort was analysed. Generally, the relation between the degree of discomfort and the percentage of distress is directly proportional. From Fig.2 it was observed that discomfort levels were more observed in the JP stretch as compared to other stretches because of the higher percentage of distresses present.

4. Methodology

Current methodology includes site selection, data collection, and extraction, HDM-4 deterioration models, average roughness, and International roughness index (RI). The distresses like rutting, potholes, fatigue and patching were analyzed using video graphic data. From the HDM-4, vehicle population growth, rutting, fatigue propagation are predicted for 2021-2035 period. The IRI was calculated using merlin instrument for the 4 stretches. Calibration and validation of HDM-4 deterioration models for four stretches were analyzed, maintenance and resurfacing strategies for the selected stretches were discussed. Fig. 3 shows the current methodology for performance prediction of existing roads.

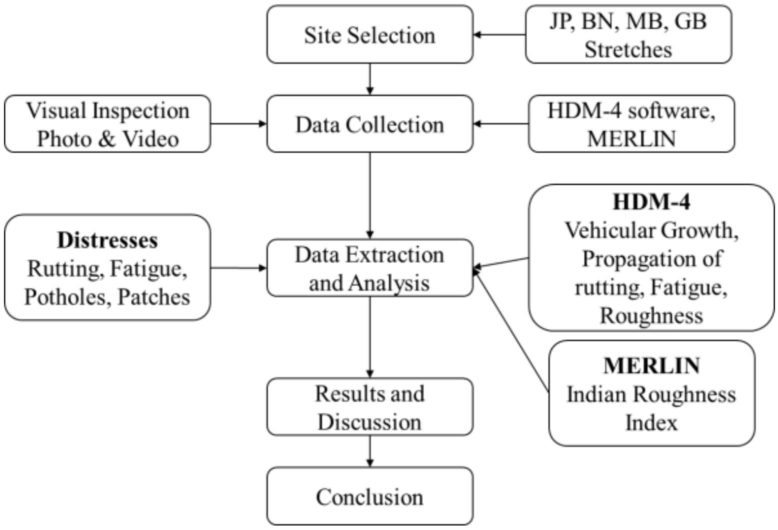

Fig. 3. Detailed methodology.

5. Calibration and validation of HDM-4 deterioration models

The interplay between cars, environment, and pavement structure is modeled by the structured mechanistic-empirical pavement distress models integrated into HDM-4. Several HDM-4 distress models are used to estimate and predict the pavement deterioration over time and with traffic. Pavement deterioration manifests itself in numerous ways. Calibration and validation of the HDM-4 degradation models before localizing is necessary. The data from the first and second years of the time series were used to calibrate HDM-4 deterioration models. While, using HDM-4 default calibration settings first years' time series data were run through. The outcomes of the obtained distress were then contrasted with those found in the time series from the second year. The calibrated HDM-4 pavement deterioration models must be validated to determine whether the calibration factors or calibrated models are adequate and to guarantee the effectiveness of the created models. Validation is crucial before the model is effectively used for the next applications for its adaptation. Validation entails contrasting the predicted levels of distress with the calibrated deterioration models, while the actual levels are seen on the chosen pavement sections. The validation of the distress progression models are listed below; rutting progression model, fatigue progression model, roughness progression model.

5.1. Maintenance and resurfacing strategies in the HDM-4 model

The average section roughness (IRI) and the average daily dosage (AADT) were used to define the maintenance/improvement therapies. In the current investigation age, condition of the asphalt layers and paved areas, cracking was not taken into consideration. Given the significance of the road and annual average daily traffic (AADT), designs are carried to calculate the suitable road width and recommendation are suggested to restore the roads to the desired operational speeds. This primarily pertains to paving and enlarging unpaved highways' road profiles. Table 1 provides an overview of the maintenance and improvement treatments.

Table 1. Work strategies to enhancement the urban road network.

Work Strategies	AADT	Initiation	Type of work
Routine maintenance of paved roads	All	Annual	Repairing, patching, edges, potholes etc.
Resurfacing treatment			
a) with a 4 cm layer of AC	200–1000	IRI= 3.5–5.5 m/km	Resurfacing
b) with a 5 cm layer of AC	1000–3000	IRI= 3.0–5.0 m/km	Resurfacing
c) with a 6 cm layer of AC	>3000	IRI= 2.5–4.5 m/km	Resurfacing

6. Analysis of data and discussion

6.1. Vehicle growth

Vehicle growth anticipated over the years until 2035 Fig. 4. The AADT of each vehicle was considered at peak hours only. It was observed that from 2021 - 2035 there was a rapid growth of the two-wheeler (2W) vehicular population followed by car, bus, three-wheeler (3W), HCV and light commercial vehicles (LCV) population. The 2W population increased from 9000 to 19000 during the 2021 to 2035 period due to a spike in electric vehicles market. The growth of LCV was observed very less compared to other vehicles.

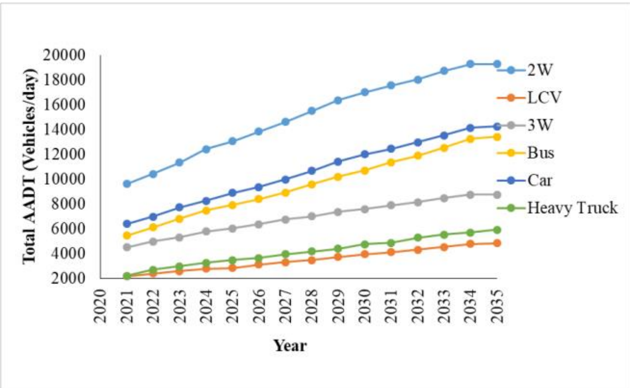

Fig. 4. Vehicle growth anticipated by the HDM-4 model over the year.

6.2. Rutting

The progression of rut depth from 2021 to 2035 is shown in Fig. 5. The two plots in the Fig.5 represent the mean rut depth (RDM) and standard rut depth (RDS). From the fig-5 an increase in RDM and RDS values are from 2021 to 2035. The rut value is 35mm in 2021 and it will be extended up to 85mm in 2030. It was found that the obtained and progress rutting performance is beyond the permissible limits as per the IRC standard (IRC: 82-2015). Further, maintenance has been required within the stipulated time so that pavement performance can be improved.

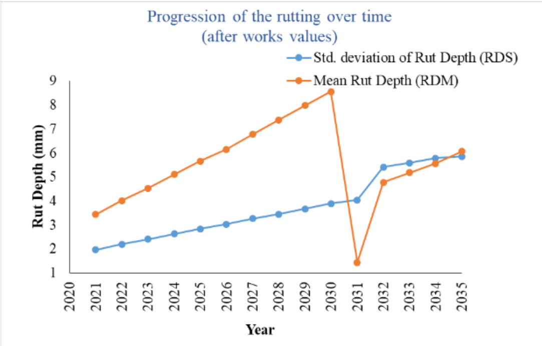

Fig. 5. Progression of the rutting for the analysis period.

6.3. Fatigue

The cracking percentage from 2021 to 2035 is shown in Fig. 6, the fatigue proportion was less than 20 percentage which is within the permissible limits, as observed in 2021. However, from the 4-year interval, increase in the permissible limits are exceeded gradually extended over the years. A renewal coat is required to prolong the pavement's performance and to reduce the fatigue, from the observed data.

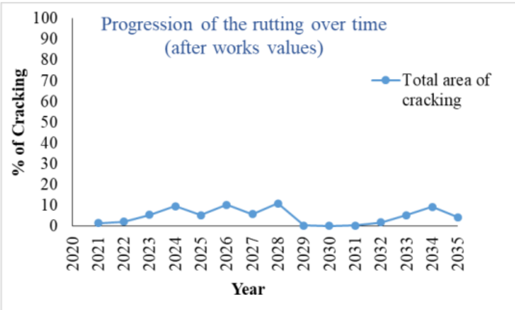

Fig. 6. Cracking progression over time resulting from the HDM-4 model.

6.4. International roughness index

The ratio of a vehicle's collected suspension motion divided by the test distance is represented by the reference average corrected slope. The IRI is often stated in meters/kilometer.

6.41 Machine for Evaluating Roughness using low-cost Instrumentation: MERLIN

MERLIN parameter is used to measure the unevenness of road *i.e.* roughness. MERLIN will produce the standard roughness scales established to measure the roughness. The probe is positioned in the center of the 1.8-metre-long foot to measure the roughness. The spots on which the device measures the vertical displacement are the road surface beneath the probe and imaginary line connecting the two locations *i.e.* center point where the road surface touches. Fig. 7 shows the data collection using MERLIN, while roughness data collection Fig. 8.

Fig. 7. Rohgness data collection using merlin equipment.

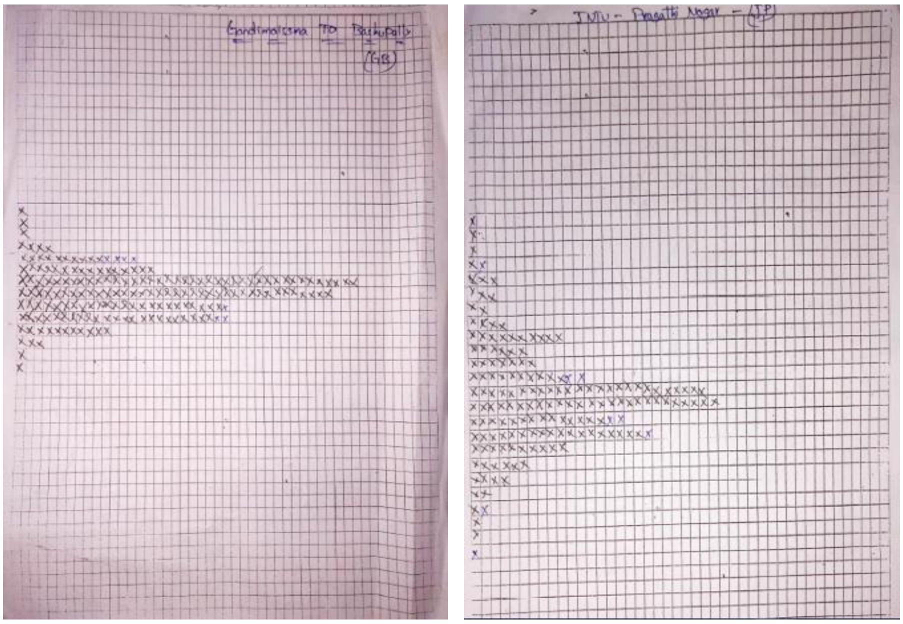

Fig. 8. Measured rohgness values.

The roughness of each route was measured by using the MERLIN and roughness values were evaluated for various routes. The IRI values were calculated using the measured roughness values. The obtained roughness and IRI values relation, represented in Table 2.

Table 2. The relationship between Merlin and IRI scale.

S.No	Route Name	D = Roughness in terms of the Merlin scale (mm)	IRI Values (m/Km) IRI = 0.593+0.0471D
	JP	D = 167.876	IRI = 0.593+0.0471*(167.876) IRI= 8.50 m/Km
	MB	D = 104.18	IRI = 0.593+0.0471*(167.876) IRI= 5.48 m/Km
	BN	D = 123.290	IRI = 0.593+0.0471*(123.290) IRI = 6.39 m/Km
	GB	D = 102.059	IRI = 0.593+0.0471*(102.059) IRI = 5.42 m/Km

Table 2 shows the obtained IRI values of each section. The ideal road should have an IRI value of less than 3.5 to minimize the wear and tear effect. However, in order to elimate slipping the value should be greater than 0 for better gripping of tires on roads. Majority of the sections are at the brink of reaching the permissible limit of IRI values, as observed form table-2. The current paved road network's IRI value obtained is 8.5 m/km and could be increased in the future, that leads to structural damage. Hence, new road construction or overlay is recommended from the investigations, so that the overall condition of the road network will be improved significantly.

7. Maintenance of pavement using HDM-4

Numerous HDM-4 distress models are used to predict the pavement deterioration over time and with traffic. Pavement deterioration manifests itself in numerous ways. However, the current study is confined to only two characteristics *i.e.* rutting and roughness and other parameters for future scope of study. The maintenance effects on rutting and roughness can be seen in Fig.9.

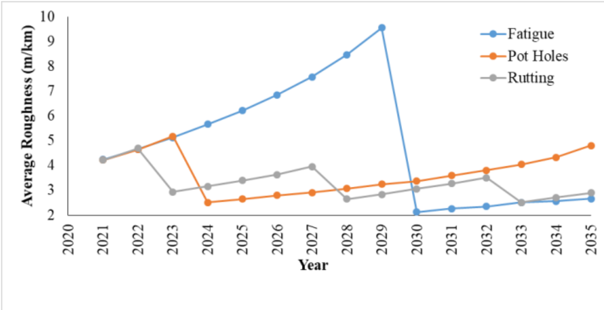

Fig. 9. Predicted roughness of pavement using HDM-4.

The predicted roughness is shown in Fig. 9 for the 2021 to 2035 period. The average roughness for 4 stretches was evaluated in terms of rutting, fatigue, potholes and patches. The roughness was observed as 4.5m/km in the 2021 year for all types of distresses. Among all the distresses, fatigue distress increased rapidly from 2021 to 2029 and after that it decreased. The fatigue distress values predicted from 2030 to 2035 were less than the previous period (2021-2029) but more than the permissible limits. This study indicates that maintenance is required with respective fatigue crack prevention. Further, the investigation has to be conducted to maintain the roads effectively.

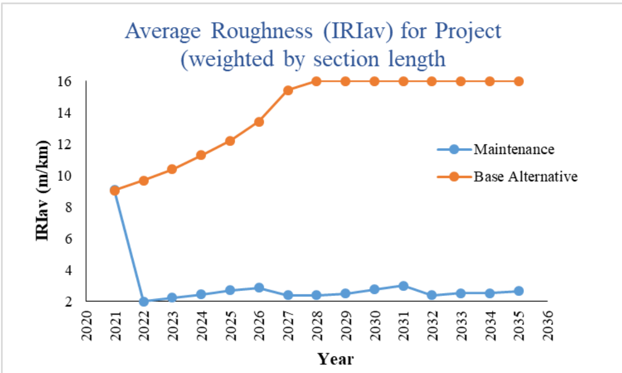

Fig. 10. Average roughness of the projects.

The average roughness for the project in terms of maintenance and base alternative is shown in Fig. 10. The roughness measurement was done for all the stretches from 2021 to 2035 time period. From the figure it was observed that year by year there are few adjustments made to the maintenance. The maintenance requirement was raised in 2021 and lowered in 2022 as the base alternative increased from 2022 to 2028. From 2028 onwards the roughness values were the same for the base alternative case. It indicates that a new coat is to be placed at all the stretches instead of repairs.

8. Conculsion

The current study was to implies to improvement of urban roads using HDM-4 deterioration models by considering the following distresses: Rutting, fatigues, roughness, patches and pothole etc. The IRI values were also computed using Merlin for all the streches. These are the conclusions that are derived from the results and analyses.

- The vehicular population growth was predicted from 2021 to 2035. The order of vehicular growth was 2W, Car, Bus, 3W, HCV and LCV. The 2W population increased rapidly due to the electric vehicle market expansion and also to minimise the travel delays in urban areas.
- The progression of rut depth in the period was beyond the permissible limits. This is mainly due to the rapid increase in vehicular population. Proper maintenance is required in a stipulated time to increase the pavement performance.

- The fatigue proportion in 2021 was within the permisssible limit but it was graduallay extended over the years. This is mainly because of the rapid increase in vehicular population. Renewal of the coat is necessary to stop the fatigue propagation.
- The IRI values obtained in 2022 exceeded the allowable limits and a maximum of 16 k/Km in 2028. The strategic plan may use to control pavement discomfort in the future by considering loading and weather conditions.
- The average roughness values obatined for fatigue were not in the permissble limits and increased rapidly up to 2029 and decreased further period. Periodic maintenance was required to minimise the fatigue distress.
- As the selected stretches had different traffic, loading conditions, climatic factors, the developed progression models were different. It was discovered that to improve pavement performance through maintenance, various strategies were required.
- The outcomes of the suggested performance model guidelines will also be helpful in Indian regions with comparable topography and climates.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors contribution statement

Harinder. D: Conceptualization, Formal analysis, Supervision,

Poojari Yugendar: Methodology, Resources, Visualization, review & editing

N. Venkatesh: Project administration, Software,

D. Vamshi: Data curation, Investigation, Validation, original draft

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