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REVIEW

Methods and factors of prioritizing roads for maintenance: a review for sustainable flexible pavement maintenance program

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Abstract
Road construction and maintenance project involve a huge capital investment. Therefore, to be a good road transportation planner, one should give prime attention to maintenance of existing road. If a road is well maintained over the period with proper and adequate techniques its remaining service life will increase automatically. In this study, a detailed literature survey is done among the various factors, techniques and models used by various researchers in different studies, and based on literature review best factors, techniques and models are discussed. Major factors that are responsible for pavement deterioration as per study are distress, condition of pavement (measured in terms of Pavement Condition Index), the utility value of road, total traffic on road, climatic conditions of area and type of road. Finally models of pavement maintenance are categorized into three major categories Deterministic, probabilistic, and biologically inspired models and various aspects of all models are discussed in detail.

Keywords Pavement distresses · Pavement maintenance · Road utility · Maintenance prioritization

Introduction

Timely maintenance of roads offers many benefits for preservation of road asset. Good and effective road maintenance not only reduces vehicle operation cost and accident rates but also improves service life of road by reducing the rate of deterioration of pavements. Regular road maintenance activities save budgetary expenditure of restoration of roads. The economic rate of return due to timely maintenance of road can be as high as 15 to 20 percent, depending upon the traffic volume and category of road [1]. An effective pavement maintenance program becomes necessary for reducing hazardous impacts on environment because bad quality of pavements increases vehicle operation cost and energy and environmental (i.e., emissions) impacts becomes very high [2]. Figure 1 clearly shows the effect of maintenance activities on the overall pavement performance and its enhanced service life: curve with periodic maintenance activities.

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Road infrastructure's contribution to socio-economic development

The country's transportation infrastructure relies heavily on roads and vehicle transportation. Intercity, intra-city (inside metropolitan regions), and rural roads are used to transport people and products. Roads have an impact on economic growth, population distribution, city design, access to social infrastructure (such as schools and hospitals), marketplaces, and people's quality of life [3]. Good transportation infrastructure help to boost GDP (Gross Domestic Product) while also providing jobs for millions of people around the country. The following are some of the reasons why roads need to be maintained: It decreases the rate of deterioration of road infrastructure—pavement, cross drainage structures, traffic control and safety devices, protective structures—thus extending the life of various components of road assets and protecting the significant investments made in new road construction and upgrades, including capacity augmentation of existing roads [4]. This also assists the government in avoiding premature road restoration and rebuilding investments, allowing for the most efficient use of available resources. Cost of running cars and fuel consumption, as well as the pace of vehicle degradation is also reducing which benefits road users.

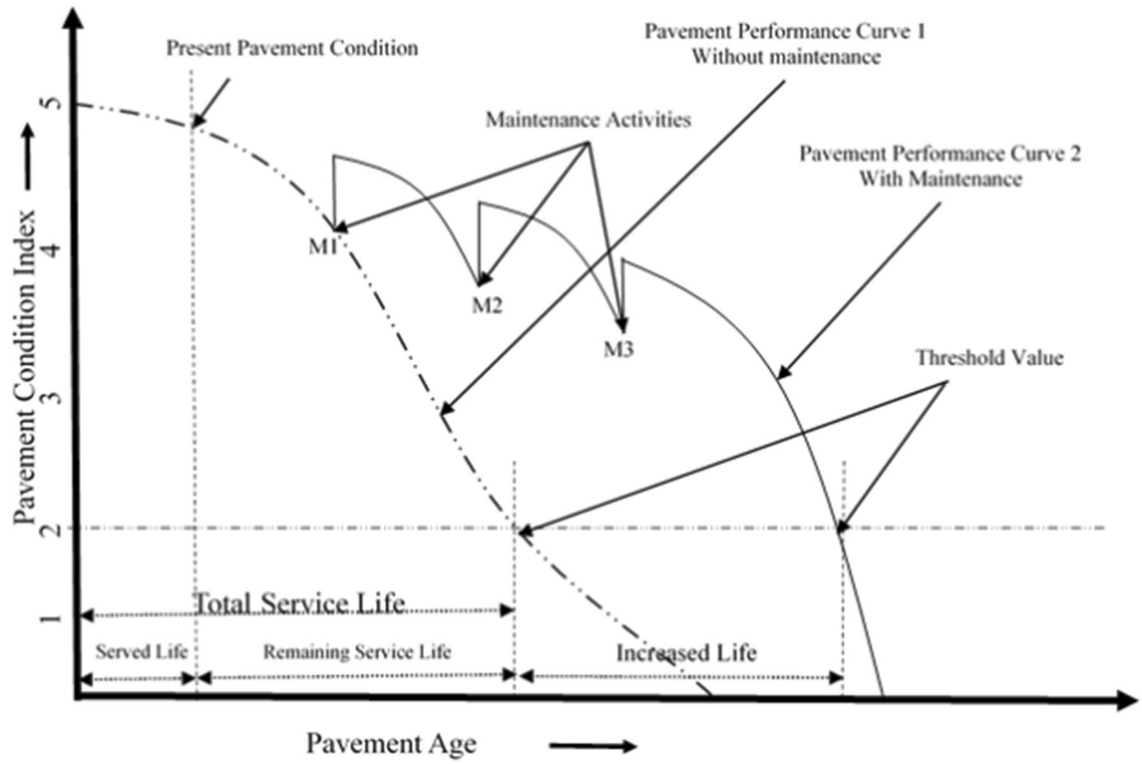

Fig. 1 Pavement performance curve with periodic maintenance activities

During the past two decades, there has been a growing interest in the modelling and optimisation of maintenance of systems consisting of multiple components. There are two major reasons for this. First, improvements in analytical techniques and the availability of fast computers have allowed more complex systems to be investigated. Second, people have realised that interactions between components in a system cannot be neglected and should be taken into account [5]. Therefore, we need technically sound scientific management systems for upkeeping of roads.

Pavement management system

Pavement management system (PMS) is an arrangement of policies and techniques that help in keeping pavements in serviceable condition over the design life [6]. The major objective of a PMS is to help highway engineers make cost effective and consistent decisions from the construction phase to the maintenance and rehabilitation phase of pavements.

Pavement maintenance management system

A component of PMS called Pavement Maintenance Management System (PMMS) is defined as technical and operational methodology for managing, directing and controlling maintenance resources, in a scientific manner for optimum benefits [1]. According to MORTH 2004 [7], the PMMS is a complex problem of matching time, labor, resources, equipment, design, funds, and material. The major function performed by PMMS is to identify the projects that need maintenance and rehabilitation (M&R) activities and then establish priorities. This is followed by identifying the type and timing of M&R required for each project. PMMS consists of two major components: (1) An information system to collect, store and manage data and (2) a decision support system to process and analyse data for decision making [8, 9]. Figure 2 illustrates the how various factors are combined simultaneously by application most suitable techniques to develop an effective PMMS via reviewing this study.

Factors affecting pavement maintenance

In the presence of a number of roads to be maintained and limited funds availability, prioritizing roads based on scientific methodology becomes critical. This prioritization must be done using various factors like pavement distresses, traffic volume and its composition, importance of road in terms of its utility, etc. There are enormous factors that affects pavement maintenance but, in this study, the major factors affecting the pavement maintenance are

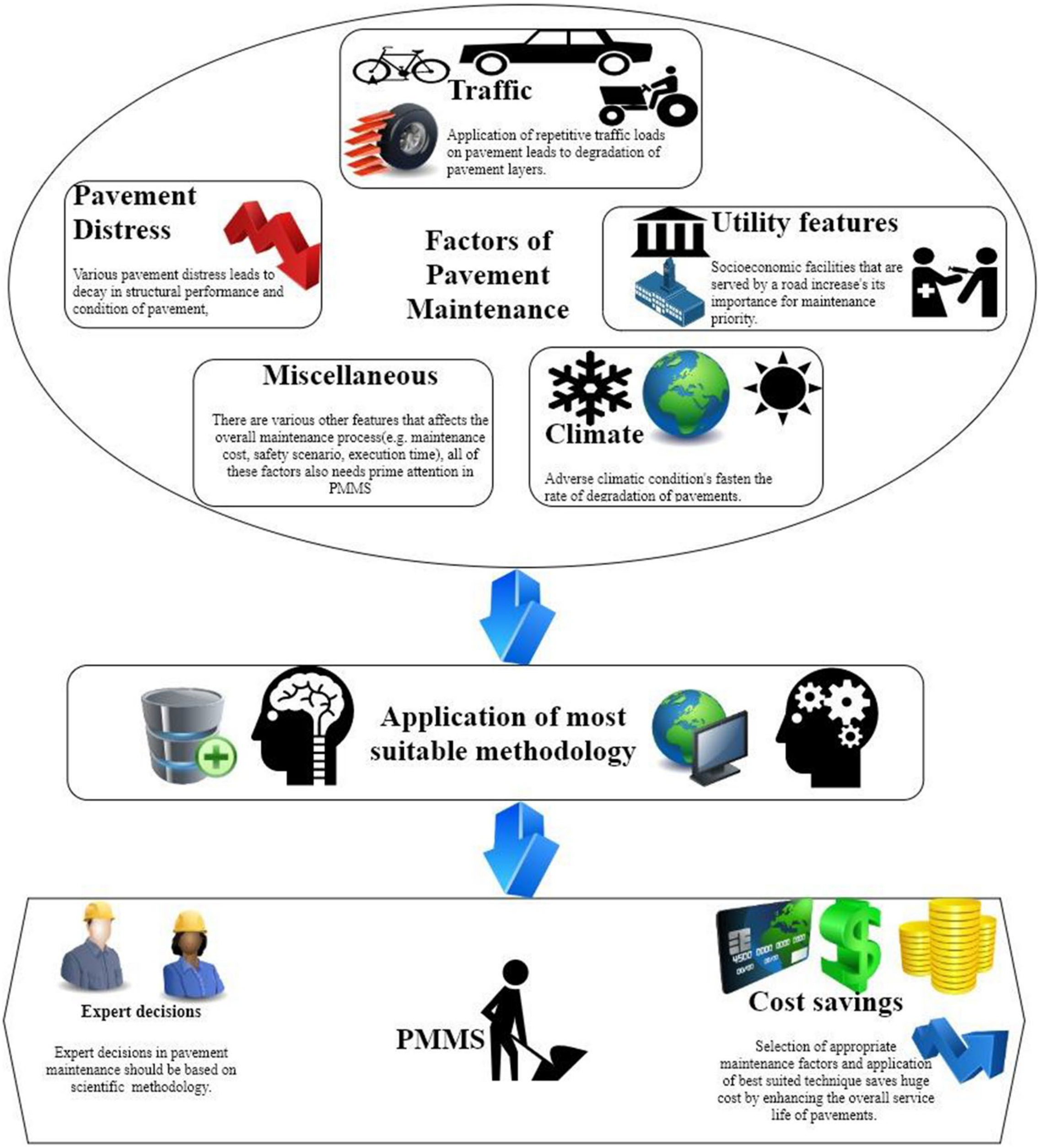

Fig. 2 Illustration of the study

selected and discussed. Selection of factors was done after reviewing various literatures of pavement maintenance planning as well as considering expert opinions of professionals as well as academicians working in the field of pavement maintenance and planning. On the basis of literature review, the factors required to be considered in road maintenance prioritization can broadly be divided into four categories as shown in Table 1. Selection of the predominant factors depends upon the social-economic condition of the country and functional performance of pavements.

Table 1 Factors for road maintenance

Distress [1]	Traffic [10–13]	Utility value [14]	Miscellaneous [15–19]
Rutting Ravelling Patching Pothole Cracking	Total traffic Commercial vehicles Total truck traffic Total no of accidents	Medical Educational Demographic Law and order Economic Infrastructure	Climatic conditions Maintenance cost Safety scenario Execution time

Pavement distress

Deficiency or imperfection in the current state of pavement with respect to its original state is known as pavement distress. There are many types of distresses in pavements which need to be grouped together into similar characteristics groups. For this purpose, Indian Roads Congress [1]. in its guidelines has grouped pavement distresses into four major categories as shown in Table 2.

Surface distress, cracks, deformation, and disintegration are four major categories of pavement distresses. Surface distresses are limited to the surface and might be caused by insufficient bitumen quality or quantity. A bleeding or fatty bituminous surface has a thin coating of excess or free bituminous binder on it, which forms a bright, glass-like reflecting surface that tends to become soft in hot weather and slippery in cold and wet weather, eventually developing low skid resistance. When wet, a smooth surface has little skid resistance and becomes extremely slippery [20]. This creates risks, particularly on grades, curves, and crossings. The emergence of alternate lean and heavy lines of bitumen in a longitudinal or transverse direction is referred to as streaking. Loss of tiny particles from the surface or the appearance of a dry surface with fine cracks characterises a hungry surface.

Bituminous surfacing cracking is a prevalent problem with the passage of time. Cracks on bituminous surfaces are divided into many groups based on their severity [21]. Hairline cracks are found in a small region and are less than one mm wide. Hairline cracks are usually discrete, and they are not usually interconnected. Short and tiny fractures emerge at regular intervals over the surface. During the summer, such cracks frequently vanish. Alligator or map cracking is defined as a network of linked cracks in the pavement surface with tiny irregular blocks that resemble alligator skin. Longitudinal cracks are those that appear parallel to the centreline or along the road. Alligator cracking can occasionally be triggered by longitudinal cracks. Transverse cracks emerge in transverse directions or as a sequence of linked cracks producing big blocks perpendicular to the road's direction. Edge cracking is described as cracks that form parallel to the pavements outside edge. Reflection cracks are sympathetic fractures in bituminous surface that occur over joints and beneath fractured pavement. It might be a longitudinal, transverse, diagonal, or block pattern.

Deformation can occur in one or more layers of bituminous layers, or it might affect the entire pavement and subgrade. Deformation is defined as a change in the original shape of the pavement surface. Slippage, rutting, corrugation, pushing, shallow depression, and settling are all signs of it. The relative movement between the wearing course and the layer underneath the bituminous surface is referred to as slippage. It is characterised by the formation of crescent-shaped fractures on the pavement surface that point in the direction of the wheels' push. Rutting is a dip or groove in the pavement that runs parallel to the wheel path [22]. The production of regular undulations (ripples) over the bituminous surface is known as corrugation. These are generally minor depressions, as opposed to bigger depressions created by weakness in the pavement's bottom layers or sub-grade. Shoving is a type of plastic movement inside the bituminous layers that causes the pavement surface to bulge. Shallow depressions are small, isolated low regions that dip approximately 25 mm or more below the profile where water normally get trapped. Shallow depressions may cause further deterioration of the surface, as well as pain and a potentially dangerous condition for traffic.

When compared to shallow depressions, settlements and upheavals are marked by comparatively substantial deformations of the pavement. There are certain distresses in the pavement that, if not addressed soon, will cause it to disintegrate into small, loose bits. If disintegration is not stopped in its early stages, the pavement may need to be completely rebuilt. The presence of moisture causes the bitumen layer to separate off the aggregate particle surfaces, which is known as stripping [23]. This may result in a loss of link between the bitumen and the aggregate, as well as a loss of cohesiveness in the mixture. Raveling is the separation and dissociation of fine aggregate particles and binder from a bituminous surface over time [24]. Potholes are varying-sized bowl-shaped voids in a bituminous surface or extending into the binder/base course produced by localised material breakdown [25]. Edge breaking is a typical defect in bituminous surfaces, when the edge of the bituminous surface breaks in an uneven pattern. Extent and severity levels of all distress varies regionally therefore IRC 82 2015 has provided all details regarding the extent and severity levels of all above

Table 2 Classification of pavement distress [1]

Surface distress	Cracks	Deformations	Disintegrations
Fatty surfaces	Hairline cracks	Rutting	Upheavals
Smooth surfaces	Alligator cracking	Corrugations	Stripping
Streaking	Longitudinal cracking	Shoving	Loss of aggregates
Hungry surfaces	Transverse cracking	Layer slippage	Ravelling
	Edge cracking	Shallow depressions	Potholes
	Reflection cracking	Settlements	Edge breaking

distress for Indian roads. Knowledge of all above distress plays an important role in developing a combined severity level indexes of any road for its maintenance priority.

Evaluation of PCI

One of the most significant aspects of pavement design, rehabilitation, and maintenance is evaluating the state of the pavement, which includes distress, roughness, friction, and structure. Because of precise pavement evaluation, most of the cost-effective maintenance and rehabilitation (M&R) methods designed using the Pavement Management System (PMS) are cost-effective [26].

The results of several previous research on evaluating pavement performance using condition indicators are discussed. AASHO conducted pavement performance research for 123 test Sects. (74 flexible and 49 rigid pavement sections) to produce the Present Serviceability Index (PSI) model, which is based on subjective ratings and objective ground measurements. A statistical criterion was developed and verified using multiple regression analysis, allowing pavement ratings to be properly calculated from objective measurements gathered on the pavements [27]. The United States Army Corps of Engineers created the pavement condition index (PCI) [28]. A cumulative deduct value score is applied to the PCI value depending on the type, quantity, and severity level of distress as well as the type of pavement. Karan et al., 1983 [29] proposed the pavement quality index (PQI) as a method of statistically gathering data from an expert panel. It was created by a review of 40 sections that were scored on a scale of 0 to 10 for riding comfort index (RCI), structural adequacy index (SAI), and surface distress index (SDI). The Federal Highway Administration (FHWA) defined an index in 1990 that represented an overall aggregate of several pavement condition metrics [30].

IRC: 130–2020 [31] guidelines give important details on pavement performance assessment, pavement condition assessment using multiple data collection systems, assessment tools for data analysis to estimate road network condition using alternative management approaches. Data collecting may be classified into one of three levels in this guideline as: The overall planning, programming, and policy choices supported by the network-level RMS should be answered by **"network-level data"**. **"Project-level data"** should be used to help determine the appropriate treatment for a specific section of road. These data may be gathered and preserved over time to build a more comprehensive database. However, a technique for keeping the data updated must be established. And data at the **"research level"** should be developed to collect thorough information on certain qualities to answer specific queries.

Moazami et al. [32] converted 19 different type of distress to a single equivalent called Pavement condition Index (PCI)) to make evaluation easier. Zhang et al. [33] considered pavement defects, roughness, skid resistance and structural capacity as four major factors for ranking of pavements for maintenance. Jackson et al. [34] considered fatigue, rut depth, pavement age and pavement condition index as the major factors for pavement maintenance. Ahmed et al. [35] considered five major distresses namely: cracking, pothole, patching, ravelling, and rutting to determine the pavement condition index. Farhan and Fwa [36] considered Ravelling, Rutting and Cracking as the three major distresses, and the collected data were categorized into: pavement section data (highway class, section, length, and geometric data) and pavement distress data (distress type, severity, extent, and location).

A number of other studies [36–41] suggest that alligator cracking, longitudinal cracking, transverse cracking, edge cracking, rutting, ravelling and potholes are prominent distresses to be considered while developing pavement maintenance models. However, to assign a unique value to overall pavement condition, these distresses should be converted to a common index value such as PCI. Pavement roughness which measures unevenness of the pavement surface is another distress expressed usually in terms of International Roughness Index (IRI) or Skidding Resistance Index (SRI). Permanent depressions on the road surface called ruts are measured in terms of Rutting Depth Index (RDI). Chan et al. [42] considered Rut Depth (RD), International Roughness Index (IRI), and Present Serviceability Index (PSI) as main performance indices. Ouma et al. (2015) [17] considered Surface condition Rating (SCR), Pavement Quality Index (PQI), and Pavement Smoothness and Roughness Index (SRI) as prime indices.

Traffic volume and its composition

A number of studies have demonstrated the use of traffic as an important aspect of pavement maintenance studies [10–13]. Shrestha and Pradhananga [43] selected six roads in Las Vegas to make a GIS-based road maintenance system considering traffic as a prime factor along with road condition and safety. Velaga and Dhingra [44] used traffic data along with road condition data and road inventory data to develop a GIS and GPS-based road maintenance and rehabilitation system. Traffic parameters, structural parameters, climatic parameters and performance parameters were considered as prime factors by Sollazzo et al. [45]. Short-term traffic demand can be easily estimated but long-term traffic on the road is difficult to estimate due to which pavement performance prediction can be inaccurate [46]. Many more studies considered traffic characteristics as important aspect for road maintenance prioritization [47–49]. Traffic was taken as an important factor along with physical factors, climate, management factors and social aspects by De Oliveira et al. [47] in his study. Babashamsi et al. [48] uses five main factors, i.e., traffic congestion, PCI, pavement width, improvement and maintenance cost and time required to operate to develop their maintenance model. The various factors that considered important for maintenance of rural roads as per study conducted by Dhamaniya [49] are: 1. Village data 2. Road network 3. Traffic data 4. Utility value 5. PCI.

Road utility value

Traditionally, priority for all-weather-roads was established on the basis of pavement condition only, but there are several other criteria such as demographic and socio-economic conditions that need to be considered for maintenance prioritization (Table 3). These criteria can be converted into a unique value known as road utility value [14]. Demographic features include total population and population density while socio-economic features include hospitals, schools, police stations, banks, etc. Presence or absence of one or more of these features determines the utility value of a road [50]. A computation sheet has been prepared to assign weights to various features for calculating the utility value on the basis of a chart provided by Indian Roads Congress [14].

Miscellaneous factors

There are other factors like safety scenario, climatic conditions, maintenance cost and execution time that need to be considered to make an effective pavement maintenance and management system. Climatic conditions of a place play an important role in the rate of deterioration of pavement surface. Temperature, snowfall, and precipitation affect pavement performance as pavement materials deteriorate faster in more severe climatic conditions. Chandran et al. [15] considered safety scenario of roads as an important parameter of road maintenance prioritization as unsafe roads should be maintained first. Pavement condition, IRI of pavement sections and land-slide susceptibility were considered to make a maintenance model for roads by Pantha et al. [16]. Ouma et al. [17] considered road safety, pavement surface condition, road operational status and road aesthetics in decreasing order of significance. Climatic factors, traffic and social aspects were considered by De Oliveira et al. [47] for the development of pavement maintenance system. Ramadhanh et al. [18] highlighted that maintenance cost along with road class, operating speed, pavement condition, riding quality, importance to community, and safety condition are the main factors that should be considered for rating of maintenance priority of roads. Shrestha et al. [19] considered road length, population served, average cross section and improvement

Table 3 Utility value evaluation sheet

Variables of the habitation		Weightage of variable					Maximum Weightage
		0	2	4	6	8	
Demographic	Population	< 250	251–500	501–1000	1001–2000	> 2000	8
	SC/ST population	< 25	26–50	51–200	201–300	> 300	8
Educational	Primary school	Nil	1	> 1			4
	Middle school	Nil		1	> 1		6
	High school	Nil			1	> 1	8
	Intermediate College	No				Yes	8
	Vocational School	No				Yes	8
Medical	Dispensary	No		Yes			4
	Maternity and child welfare centers	No			Yes		6
	Primary health centers Veterinary	No				Yes	8
Law & Order	Police station Fire station	No			Yes		6
Infrastructure	Hilly area Coastal area	No		Yes			4
	Electrified	No			Yes		6
Economic activities	Post office Bank	No		Yes			4
	Panchayat Headquarter	No			Yes		6
	No. of markets	Nil	One day		Two or more days		6
	Total						100

cost, number of settlements, population, and area covered by the Village Development Committees (VDCs) to develop their maintenance model. Pavement maintenance and rehabilitation projects involve limited budget and time frame to complete. Considering this, a large number of studies have included execution time and maintenance cost as prime factors in the development of maintenance prioritization models [48].

Methods of pavement maintenance prioritization

A method for maintenance prioritization should make use of all the factors assigning suitable importance to each. A number of methods and models have been developed as part of PMMS. These models can be broadly categorized into deterministic, probabilistic, and biologically inspired models as shown in Fig. 3.

Deterministic models

In pavement condition prediction, deterministic regression models are most popular. In these models, a regression equation is developed with the dependent variable being pavement condition index and the independent variables being pavement type, pavement age and other factors that are influencing pavement condition. Many regression equations can be developed for a pavement but only one regression equation is selected for each family of pavements that shows similar conditions and are expected to deteriorate in the same manner [51]. Deterministic models can be sub-divided into three major categories: (1) Pure Empirical Models, (2) Mechanistic-Empirical Models, and (3) Expert System Models.

Pure empirical models

Pure Empirical models are the most commonly used deterministic models for predicting pavement performance. However, these models need a massive database for making a reliable model. A typical example of equations formed in this model can be:

$$PCI = a + bx + cy \quad (1)$$

where, PCI = Pavement Condition Index, x and y = Pavement age (in years) and a, b and c are regression parameters. For assuring accuracy of these models, pavements need to be grouped into families and individually each family will have distinctive set of criteria and parameters [52].

Mechanistic—empirical models

Pavement performance under the effect of traffic loading is generally analysed by mechanistic approach. To include mechanistic approach, a number of empirical models have been developed in combination with mechanistic knowledge. The mechanistic relationship between loading, deflection, stresses and strains is the basis for developing these models. Mechanistic models are used to compute pavement response (strains, deflections and stresses) under traffic loading and an empirical function linking pavement response with pavement performance is formed. Mechanistic-empirical models

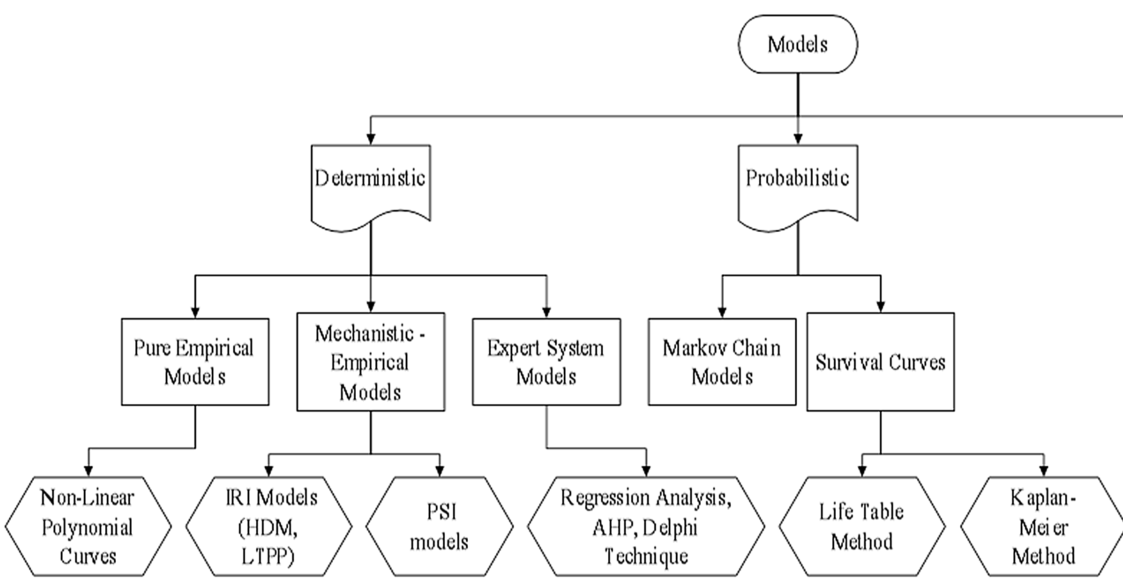

Fig. 3 Categorisation of models

take mechanistic properties of pavement into account which makes them more reliable than pure empirical models. However, more effort is needed in the acquisition of data which is a major drawback of these models. Some common mechanistic—empirical models are:

International roughness index models International Roughness Index (IRI) was developed by World Bank in 1980 for standardizing measurement of roughness [53]. IRI is defined as the ratio of a standard vehicle's accumulated suspension motion to the total distance travelled by the vehicle in inches per mile. The determination of IRI values differ from country to country. In INDIA, Central Road Research Institute (CRRI) recommends fifth wheel bump integrator to measure road surface roughness or unevenness for computing IRI. The relationship given by CRRI to calculate IRI is:

$$IRI = \frac{UI}{720} \quad (2)$$

where, UI = Unevenness Index (mm/km), IRI = International Roughness Index (m/km). Huang [54] defined three levels for IRI: Poor (IRI > 170), Fair (95 < IRI < 170) and good (IRI < 95). The study concluded that poor and fair pavement conditions lead to more traffic accidents. Park et al. [55] established a relationship between surface distresses of an asphalt pavement and its roughness and showed that roughness is an important factor in PMMS. Dalla et al. [12] developed a pavement maintenance model considering prime factors as pavement age and IRI values just after completion of pavement construction or treatment. Mubaraki [56] investigated pavement sections using IRI and pavement damage. The study concluded that there is a significant relationship between IRI and cracking.

Highway development and management model (HDM) and Long-Term Pavement Performance Study (LTPP) are the major roughness index-based prediction models used worldwide. HDM is a type of roughness prediction model developed by the World Bank. World Bank highway decision model HDM-4 is an advanced version of HDM which is the most popularly used model worldwide by various road agencies for the last many years. These models were developed by an international collaborative study known as an International Study of Highway Development and Management (ISOHDM) [57]. A number of studies used HDM and concluded that HDM is effective in pavement performance [58–64].

In 1987, Strategic Highway Research Project (SHRP) initiated the LTPP program and then it was expanded to a 20-year program under the coordination of the Federal Highway Administration (FHWA). The prime objective of LTPP program was to develop and improve the design process for new and existing pavements, estimate existing pavement conditions, making effective methodologies to improve existing design and maintenance process, and determine effect of environmental criteria, traffic, construction processes and material properties on the structural performance of pavements [65]. The data were stored in seven segments: Inventory, Traffic, Monitoring, Maintenance, Material testing, Rehabilitation, and Climate data [66]. One of the important studies in this field is the pattern recognition model developed by Kargah-Ostadi et al. [67] for prediction of IRI in flexible pavement. Von Quintusand and Killingsworth [68] developed a relationship between pavement conditions such as IRI and deflection time history data using the LTPP data. Rada et al. [69] tried to correlate structural adequacy and ride quality of pavement structures using LTPP database.

Present serviceability index (PSI) models Functional condition of pavement with respect to its ride quality is expressed as its present serviceability index (PSI). Cracking, slope variance (SV), patching, and rutting depth are various pavement condition measurements which are correlated with PSI [70]. It plays an important role in assessment of pavement for improvement in safety [71]. PSI and IRI are currently used in assessment of comprehensive pavement conditions in practice and the correlation between these two quantities can enable engineers to transfer one quantity to the other [42].

Expert system models

Development of mechanistic-empirical and pure empirical models needs a lot of information to be collected. If this information is not accurate, these models will not be much reliable. To overcome this difficulty, expert opinion can supplement the available data. In case of road maintenance models, opinion of the experienced engineers who are familiar with the pavement performance and deterioration patterns is valuable [13, 38, 72, 73]. Opinion is taken from the experts of the field who are highly skilled and have in-depth knowledge of the subject.

TxDOT PMIS developed by the Texas Department of Transportation [74], SDDOT PMS developed by South Dakota Department of Transportation [34] and Tennessee Pavement Management system (TPMS) [42] are some of the PMS developed by various agencies where expert opinion was taken into account [52]. Dalal et al. [50] used TxDOT database to develop an empirical model for predicting IRI. The model was validated by comparing IRI data observed in 2015 with the predicted IRI. Another study by Jackson et al. [34] was conducted under the supervision of 12 engineers from construction support, materials, and planning to develop pavement performance curves using both individual and composite pavement indices of SDDOT. Opinion taken from the experts is not directly used but analysed to reach a unique solution. Commonly used techniques to carry out analysis of expert opinion are delphi technique, fuzzy set theory, and Analytic Hierarchy Process (AHP).

Delphi technique Delphi technique is an organized and structured correspondence procedure, created as an interactive technique with a group of experts [75–78]. The experts answer questionnaires in at least two rounds [79]. After each round, a facilitator gives a synopsis of the experts' opinion and the reasons of their judgments. The experts are then asked to re-examine their opinion in the light of opinions of other experts in the panel. In subsequent rounds, the opinion of the gathering merges towards a unique and unanimous solution. The procedure is stopped after a predefined stop criterion like number of rounds, accomplishment of the accord, or dependability of results [80, 81].

Khademi and Sheikholeslami [82] used the delphi technique as a multi-criteria group decision technique for maintenance of low-class roads. The results of the model showed significant contrast between conventional individualistic decision and those made by incorporating systematic specialist comment. Dhamaniya [49] used Delphi technique to calculate the utility value of roads in the state of Gujarat in India for network level planning of maintenance of rural roads constructed under Prime Minister Village Roads scheme (PMGSY) of the Government of India.

Fuzzy set theory Fuzzy set theory (FST) is very effective in handling uncertainty, imprecision, and subjectivity in a decision-making process. On comparing FST with probabilistic approach, FST is inclined towards formalizing the subjective and imprecise nature of human behaviour whereas probabilistic approach focuses on stochastic behaviour of the decision-making process. In terms of pavement failure and deterioration, where pavement conditions change with time, there are no predictive data in the future state [83]. Chandran et al. [15] used Fuzzy Logic for prioritization of low volume roads of PMGSY. To deal with subjectivity in judgment, fuzzy pair-wise correlation derivation procedure should be coordinated with AHP [84].

Analytic hierarchy process Analytic hierarchy process (AHP) was developed in the 1970s by Saaty [85]. It is a multi-criteria decision-making mathematical technique which uses a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives [86]. It allows qualitative information in addition to quantitative information to be incorporated. A matrix expressing the relative value of a set of attributes is constructed using pair-wise comparisons between all factors. The next step is to calculate the relative weights, importance, or value, of the factors. The final step is to calculate a Consistency Ratio (CR) to measure how consistent the judgments have been relative to large samples of purely random judgments [87, 88].

De Oliveira [47] used AHP to prioritize the earth roads for maintenance activities by considering several factors that were affecting the performance of roads like physical factors, climatic factors, social factors, and traffic characteristics. Expert advice was used from five major groups: civil servants, consultants, professors, and master's degree students in transportation engineering. Khademi and Sheikholeslami [82] prioritized the maintenance of roads using a combination of delphi technique and AHP. The list of experts for AHP was decided from surveys using delphi technique. Ahmed et al. [35] used AHP to prioritize maintenance of 28 pavement sections in the city of Mumbai in INDIA. Terrestrial laser scanner was used for surface distress data collection. A number of other studies also demonstrated the usefulness of AHP in road maintenance prioritization [17, 18, 32, 36, 41, 48, 50, 89]

Probabilistic models

In probabilistic models, future pavement condition is predicted with certain probability. The results from these models are usually not in the form of fixed numbers but in the form of probability distribution. Current condition is predicted based on previous conditions [90]. In case of overlays on existing pavements, probabilistic models have a huge advantage over deterministic models. Markov-chain model and survival time analysis are two commonly used probabilistic models.

Markov-chain model

Markov model is a stochastic model describing a sequence of possible events in which the probability of each event depends only on the state attained in the previous event [91]. In simple words, a process will satisfy the Markov Property if on the basis of its present state one can predict the future of the process and also know the full history of the process. Butt et al. [92] used Markov model to predict future pavement conditions on the basis of their present condition. Carnahan et al. [93] used Markov chain model to develop a cumulative damage-based model for pavement deterioration and concluded that if we use multiple distresses rather than a single distress to make Markov chains it becomes more effective in pavement studies. Yang et al. [94] uses recurrent Markov chain to model the performance of cracks in flexible pavements and concluded that this process provides more applicable, appropriate and computationally efficient methodology for predicting pavement deterioration with respect to cracks.

Survival time analysis

Survival time analysis attempts to compute time that a pavement will take to reach failure. The failure can be termed when pavement reaches a specified limit of serviceability. In case of flexible pavements, present serviceability index (PSI) is used to define this threshold value. When PSI falls below 2.5, the pavement is assumed to have reached its limit of serviceability. Some other composite indices such as Pavement Condition Rating (PCR) and Pavement Condition Index (PCI) are frequently used in pavement maintenance systems. Remaining Service Life (RSL) of an existing pavement is popularly estimated by survival time analysis. In 1940's, United States used this method for RSL evaluation of flexible pavements to plan their maintenance activities [95]. Life table method was used to develop survival curves of pavements built between years 1903 and 1937 in 46 states. Probability versus Time intervals were drawn in chronological order to obtain survival curves. Life table method has been widely utilized for RSL investigation of pavements [96].

Biologically inspired models

Biologically inspired models are rapidly becoming popular in the development of pavement condition prediction models. Artificial Neural Network (ANN) [97], Genetic Algorithms (GA) [98], Gene Expression Programming (GEP) [98], and Adaptive Neuro-Fuzzy Inference System (ANFIS) [99], are most commonly used biologically inspired techniques in the field of pavement maintenance prioritization. Artificial neural network (ANN) is a computational tool based upon functioning of human brain through neurons. It simulates the structure and decision-making process of human brain. Formulation of an ANN comprises of two phases: (1) learning phase, in which adaptation of ANN's internal parameters is performed using training data and (2) evaluation phase in which testing is performed using testing data based on learning in the first phase. ANN exhibits learning capability, non-linearity, memorization and adaptability. Learning means neural network learns with each pass of training; non-linearity means neural network can perform nonlinear multi-dimensional mapping; memorization means it can retain information and re-establish the fragmented patterns; and adaptability means it can adjust to the environment by learning during training. These features are useful in approximation and estimation of multi-faceted relationship between a number of numeric input and output values [100].

Bosurgi and Trifirò [11] used ANN and GA to effectively use the available economic resources for maintenance of flexible pavements. The study showed that ANN provided one optimal solution among many possible solutions over a short period of time. Kirbas and Karaşahin [101] used three prediction models based on: (1) ANN, (2) deterministic regression analysis, and (3) Multivariate Adaptive Splines (MARS) for future performance of pavements. The results showed that ANN was the most accurate to predict pavement conditions in future. Sollazzo et al. [45] used LTTP database to develop an ANN model and the outcome of the study showed that adopting a large set of database gives better results with ANN compared to linear regression.

GA has also been successfully applied and implemented to solve the multi-objective optimization problem of pavement maintenance prioritization. Bosurgi and Trifirò [11] proposed resurfacing interventions on flexible pavements using GA-based optimization. Mathew and Isaac [102] selected 15 road sections of rural-road network in the state of Kerala in India to optimize their maintenance using GA and the results showed that the technique was satisfactory for pavement maintenance program.

Summary and conclusions

Pavement distresses, utility value of road, and traffic characteristics are the three major factors that need to be considered for prioritization of any road maintenance program. Secondary factors which are equally important are length of road, safety level, cost of maintenance, and climatic conditions. Deterministic, probabilistic, and biologically inspired methods are the three broad categories of methods used in prioritization of pavement maintenance based on these factors. The main advantage of deterministic models is that for a single family of pavements we can draw several regression equations as it is easy to draw a regression equation in which pavement condition index is taken as dependent variable and pavement type, pavement age and other influencing factors are considered as independent variable. However, regression models have a drawback that prior awareness of the factors is essential for developing the regression equations. Involvement of a number of criteria makes AHP a useful tool for reaching a unique and transparent solution. In case of probabilistic methods, present condition of pavements is utilized to predict their future state. These methods are especially suitable for planning overlays on existing pavements. However, unlike deterministic methods, probabilistic methods produce result in the form of probability distribution which may be difficult to understand and apply. Biologically inspired methods like ANN are capable of solving nonlinear and complex problems but their main disadvantage is that determination of number of neurons and hidden layers can become tedious. Advantages, disadvantages, and research conducted with utilizing each method is discussed in Table 4 below:

Table 4 Advantage and disadvantages of all methods

Technique/method			Advantages	Disadvantages	References
Deterministic	Pure empirical	Non liner polynomial curves	The procedure is adaptable. As needed, you may alter the sample size, sampling type, data collection techniques, and analysis methodologies	Empirical research takes a long time to complete. large dataset is needed Outcome may be uncertain. This situation can be avoided if appropriate precautions are made ahead of time	[52]
	Mechanistic empirical models	IRI Models (HDM, LTTP)	Forecasts the performance of road networks and quantifies the benefits to road users effectively	Provides limited estimation of environmental impacts, pavement texture and skid resistance, road safety costs, congestions costs etc	[53–69]
		PSI models	For a small system, a people-based rating that can be done quickly and cheaply without the use of expensive technology is done	Instrument measurements, rather than human measurements, are often thought to be more repeatable, trustworthy, reproducible, and so on, and hence "better."	[42, 70, 71]
	Expert system models	Regression analysis	All of the variables that one wants to include in the model may be included in regression models Regression modelling software is widely used. Statistical programmes are included in almost all data mining products, as are regression tools. MS Excel spreadsheets may also be used to do simple regression modelling	If the supplied data contain mistakes, regression models will not operate effectively (that is poor quality data) The regression models' reliability falls as the number of variables increases. When you have a small number of variables, regression models operate well	[52]
		AHP	Utilize qualitative as well as quantitative information simultaneously Excel may be used to calculate the results	Pair-wise comparison is a rather arbitrary method of comparing a group of elements If the consistency index is greater than 10%, there are issues to justify the request to review the inputs sheet	[47, 85–89]
		Delphi technique	There's not a lot of space for bias or inaccuracy Delphi does not necessitate the use of just experts. Even concerned people and stakeholders might be randomly picked The Delphi approach is simple to understand and apply	Because method is dependent on opinion, consensus does not imply that it is the best solution when compared to alternative approaches The procedure is simple, and there is not much known about its internal validity	[49, 75–82]
Probabilistic	Markov chain model		Allow for uniform handling of insertion and deletion penalties in the form of locally learnable	There are a lot of unstructured parameters	[91–94]
	Survival curves	Life table method Kalpan meier method	If historical data is available, it is less expensive than the mechanical technique The impacts of the influential elements may be approximated	It is necessary to have a sufficient volume of historical data	[95, 96]

Table 4 (continued)

Technique/method		Advantages	Disadvantages	References
Biologically inspired models	ANN	Distortion in the training data is not a problem for ANN learning algorithms. There may be faults in the training samples, but they will have no effect on the final result It's employed when a quick assessment of the learnt target function is necessary	When ANN provides a probing answer, it does not explain why or how it was chosen Before introducing ANN to a problem, it must be transformed into numerical values	[11, 45, 97, 101]
	GA	The concept is simple to grasp. Works effectively for pavement repair concerns that are both discrete and continuous	Although GA needs less knowledge about the issue, it can be challenging to design an objective function and get the representation and operators right	[11, 98, 102]
	ANFIS	This allows freedom for applications with precise inputs and outputs	ANFIS has a significant processing cost because to its complicated structure and gradient learning	[99]

Future scope and recommendations

To construct effective and useful prediction models, the following components of pavement performance must be carefully considered: what to forecast, at what level to predict, what type of prediction model to use, how to deal with uncertainty, static versus dynamic decision models and how to spot major model deviation.

In his study, we assess the past, present, and future of certain major features of a PMS in this research. Factors and methods regarding purposes, data management and gathering, prediction of pavement performance and prioritization assessment are the important PMS aspects discussed in this paper. As an extension to this study, one can utilize economic evaluation, institutional considerations, information, and communication technologies for a pavement maintenance programs.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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