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Prioritization of Flexible Pavement Sections for Maintenance Using Multi-criteria FAHP Integrated with Multi-attribute Utility Theory

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Abstract

Prioritizing maintenance activities is a common practice in pavement maintenance planning. Pavement maintenance and repair are costly activities, and the available budget for managing the pavement infrastructure is limited. In order to maintain pavement sections at acceptable service levels within the budget and resources available, maintenance must be prioritized. There were insufficient attributes and a lack of effective tools for ranking maintenance. In order to address this drawback, this study employs a fuzzy analytical hierarchy process integrated with multi-attribute utility theory (FAHP-MAUT) to create a prioritization system for pavement maintenance activities that incorporates most possible attributes. Pavement attributes refer to present pavement conditions and the expected parameters that pertain to its service life. The relative importance (weight factor) of attributes is derived from expert responses. Using Saaty's scale, a questionnaire form was designed for this purpose. The data were collected through questionnaire form and from various pavement tests. The questionnaire's detail information was collected and evaluated using FAHP, and a utility function was developed using MAUT. The utility score for each attribute was clumped together using relative weight to produce a total utility score. The total utility score was used to prioritize a network of flexible pavement. Overall pavement condition index (OPCI) has received the highest weight factor of 36.7% in the prioritization of highways. The proposed method is used to a case study of twenty-two National Highways (NH) in Bihar state (India). A sensitivity analysis is performed to investigate the impact of each attribute in the pavement prioritizing process. OPCI is observed as the most sensitive attribute and highest impact on the pavement. This study indicated the potential for prioritizing flexible pavement based on established criteria.

Keywords Prioritization · FAHP · Overall pavement condition index · MAUT · Utility score

Introduction

Road transport is of extremely a vital importance to the economic and social development of a country. Consequently, there is a high demand for better and more efficient roads around the world. Over the last few decades, there has been a massive increase in road transport and the number of vehicles in India. Even though the National Highways account for less than 2% of the total road network, they carry 40% of the total traffic (MoRTH 2019). Flexible (Bituminous) pavements constitute over 90% of the total road network

including airfield pavements in India (IRC: SP: 100–2014). Flexible pavements naturally deteriorate over time. Pavement surfaces break down naturally over time, as the materials that make up asphalt break down and become affected by the elements, including rain, sunlight, and chemicals. Although pavements are designed and constructed according to prevailing guidelines, they are deteriorating due to unexpected impacts of traffic loading (overloading of trucks, advancement of multi-axel commercial vehicles, repetitions of axel loads) and environmental conditions (temperature, rainfall intensity). The deterioration of bituminous pavements can be seen on the surface as distresses.

The Pavement Management System (PMS) is a set of tools and techniques designed to support the decisions of an agency regarding the best strategies to assess and maintain serviceable pavements over time (AASHTO 2012). The PMS consists of three distinct levels: strategic, network, and project. A PMS's main objective at the network level is to

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develop short- and long-term budget criteria, as well as a list of potential projects to ensure the network's security and operational readiness (AASHTO 2012). The PMS typically includes methods of ranking and prioritization for selecting the most high-priority pavement sections, since there are very limited funds allocated for pavement maintenance (Moazami et al. 2011). Prioritization and ranking are primarily driven by the existing prioritization model (Shah et al. 2014). Ranking models are usually concerned with solving the numerical solution of an objective function designed to optimize a network of several pavement conditions within a budget limit. The highest priority is outlined and implemented in a network of various pavement sections using these models. Ranking aims to create an efficient framework that meets the requirements of the most relevant sections without exceeding the budget. In general, prioritization models incorporate expert judgments and experience into the decision-making process (Flintsch et al. 1998). Several types of pavement defects (cracking, potholes, ravelling, etc.) observed in a particular section of pavement are considered in the prioritization model (Dessouky et al. 2011; Dabous and Al-Khayyat 2018).

Review of Existing Literatures

Commercial vehicles are the primary source of pavement erosion, although the combination of traffic and meteorological conditions is also regarded a key influence in pavement degradation (Werkmeister et al. 2004). A study looked at the impact of traffic volumes and weather conditions on pavement sections in Canada, and it was discovered that weather conditions caused 30 to 80 percent of all deterioration (Nemry and Demirel 2012). The two most important environmental criteria are the fluctuations in temperature throughout the year and the presence of water or ice in the subgrade or pavement layers (Papagiannakis and Masad 2012). The bond between the aggregates in the pavement disintegrates under excess wetness, and this condition is exacerbated by the expansion of extra aggregates (Airey and Choi 2002; Papagiannakis and Masad 2012). Climate change may have an impact on pavement efficiency in any given geographical area (Werkmeister et al. 2004). Pavement deterioration happens when the pavement is subjected to climate variations, which cause thermal cracking, roughness advancement, rutting, frost heave, and thaw weakening (Mills et al. 2009). Pavement deterioration necessitated early M&R operations, reconstructions, and a more expensive design (Mills et al. 2009).

The present serviceability index, pavement condition index, condition score, riding quality index, and riding score are used to prioritize pavement sections for maintenance and treatment (Gurganus 2011; Abu Dabous et al. 2019). Two

or more pavement performance indices are integrated with accurate weighting and reliable model techniques to form a composite index. Pavement performance indicators such as the riding comfort index (Karan et al. 1983), pavement quality index (Reza et al. 2005), and condition rating (Ruotoistenma and Seppala 2007) are used to measure pavement performance.

Globally, the multiple-criteria decision analysis (MCDA) technique is increasingly used in the management of civil infrastructure. Analytical hierarchy process (AHP) is one of the most often used MCDA methodologies for prioritizing, capable of determining the most relevant criterion from a set of conflicting criteria (Li et al. 2018). Furthermore, an AHP model is being developed for pavement maintenance management since it facilitates comparisons between decision elements (Cafiso et al. 2002). Many studies employ AHP because of its easy and quick results (Ahmed et al. 2017; Zavadskas et al. 2008; Saaty 1980); however, AHP cannot contain crisp input; hence, many researchers focus on the integration of AHP with fuzzy logic (Moazami et al. 2011; Vyas et al. 2019). By combining Gaussian membership functions with AHP, a fuzzy decision-making technique is employed to prioritize pavement (Moazami et al. 2011). Fuzzy logic is used to build MCDA utilizing complex proportional assessment (COPRAS) and AHP, and attribute weights are determined and then evaluated to assess asset maintenance plans (Fouladgar et al. 2012). An alternate study combined fuzzy AHPs with the VIKOR technique to improve decision-making by considering the pavement quality index, improvement and maintenance costs, pavement width, traffic congestion, and operation time into account (Babashamsi et al. 2016). Fuzzy weighted averages and FAHP approaches are also utilized for pavement prioritization, taking into account IRI, surface modulus, friction coefficient, and rut depth (Singh et al. 2018). Recently, the Mamdani Fuzzy Inference System with AHP has been utilized to assess runway conditions and select M&R strategies (Vyas et al. 2019). The hesitant fuzzy analytic network process (H-F-ANP) and the hesitant fuzzy preference ranking organization method for enriching evaluations II (H-F-PROMETHEE II) were combined to offer the ranking or prioritizing by decision-makers (Samanlioglu and Ayağ 2021). The fuzzy proximity index ranking (FPIR) method was created to address the problems that occur in a fuzzy environment due to ambiguous and imprecise information. To accommodate for uncertainties and ambiguities in expert judgments and user input, the proximity index was combined with fuzzy sets (Mufazzal et al. 2022).

The multi-attribute utility theory (MAUT) is one such technique that is especially advantageous since it allows for the analysis of both quantitative and qualitative criteria by considering their relative weights (Keeney and Raiffa 1976). MAUT has made transportation selections from the Tshwane

and Houston routes since various sustainable elements, such as social, economic, and environmental, are involved (Zietsman et al. 2006). MAUT was developed to assess the design of low-density residential dwellings while taking into account housing characteristics, economic issues, environmental factors, and aesthetic considerations (BuHamdan et al. 2019). The MAUT, according to the literature, is used to analyze a model with multiple attributes of varying dimensions. Based on the pavement features, the study develops an integrated FAHP and MAUT model capable of ranking and prioritizing a large network of flexible pavements. Few studies have ranked and prioritized pavement sections based on expert opinion (Vyas et al. 2019).

A road infrastructure is an essential component of the performance of all national economies, delivering a wide range of economic and social benefits. Consequently, it contributes significantly to the environmental footprint during construction, maintenance, and use (Santero and Horvath 2009). A road network that deteriorates will not only incur higher maintenance, rehabilitation, and user costs over time, but will also emit more pollutants, produce more traffic noise, and create unsafe conditions from vehicles moving over uneven pavements (Santos et al. 2017). Hence, good road pavement management is crucial for an adequate road pavement maintenance, as it is capable of providing decision-makers (DMs) with the necessary methodologies for an efficient sustainable management of road pavements (Dawson et al. 2014). A sustainable pavement can meet specific engineering goals, while also providing for basic human needs, efficiently utilizing resources, as well as conserving/restoring surrounding ecosystems. In order to ensure sustainability, non-destructive testing is used to assess pavement conditions and plan maintenance activities at the right time and place.

One of the issues with pavement priority is that there is no absolute attribute value beyond which the pavement fails. The acceptability of the pavement quality is mostly determined by the subjective judgement of the individual or individuals utilizing the roadway or making the decisions. A combined index should take into account both the subjective judgement of decision makers and the most essential pavement qualities.

Pavement degrading variables include traffic volume (Babashamsi et al. 2016), precipitation (Mills et al. 2009), air temperature (Nemry and Demirel 2012), pavement age, and drainage condition. Many scholars have utilized the FAHP to estimate the weight factor; however, when the number of possibilities is huge, the pairwise comparison matrix becomes complex. The study takes into account the missing characteristics as well as FAHP along with MAUT.

Objectives

There is a need for development of guideline to devise methodology for systematic data collection on the structural and functional performance including traffic and environmental conditions of highways and the data analysis to scientifically planning and judicious allocation of maintenance fund. The objectives are drawn as follows:

- To identify key attributes that influence the serviceability of the flexible pavement using factor analysis
- To determine the relative importance (weight factor) of distresses, structural capacity, roughness, and skid resistance for formulation of OPCI
- To determine the relative importance (weight factor) of selected attributes for the development of utility function
- To develop a FAHP-MAUT model to prioritize the highways for maintenance activity

Methodology

This section presents the process for carrying out this present study.

Selection of attributes

Attributes are the parameters which are responsible for affecting the deterioration process of the pavement. Nine attributes are extracted from literatures, namely, pavement condition, commercial vehicle repetitions, pavement age (Abu-Samra et al. 2017), grade of pavement (Li et al. 2018), air temperature (Mills et al. 2009), wind speed, precipitation (Nemry and Demirel 2012), relative humidity, and drainage condition. Based on the discussion among master students, research scholars, and professors, those who are working in the area of pavement maintenance, a questionnaire form was developed for pilot survey (as shown in Appendix 1). The purpose of the pilot survey is to collect the responses from the professionals in terms of rating system 1 to 5 scale, where one indicates a very low impact and five denotes a very high impact of attributes in the pavement deterioration. Factor analysis was carried out using Cronbach's alpha and the Kaiser-Meyer Olkin (KMO) test to assess the reliability of professional responses. The attributes which have Cronbach's α-value and KMO test value less than 0.5 will be discarded.

Determine the Weight Factor

Questionnaire form was designed to fulfil three different purposes: (i) to determine the relative importance of $PCI_{Distress}$, $PCI_{Structure}$, $PCI_{Roughness}$, and $PCI_{Skid\ Resistance}$ (shown in Appendix 2); (ii) to determine the weight factor for selected attributes after the pilot survey (shown in Appendix 3); and (iii) to determine the relative importance of various categories of each attribute (Appendix 4). The questionnaire form was circulated among the professionals to collect responses in terms of relative importance of attributes. Responses were

collected from professional engineers, consultant engineers, and technical experts in Saaty's scale, which is scored from 1 to 9. One signifies equal importance, whereas nine represents extremely high importance. A comparison matrix is generated using the expert responses, and the weight factor for each attribute is determined using FAHP.

Developed a Utility Function

The FAHP and MAUT combined together to develop the utility function for each attribute using collected expert responses. The utility function is used to calculate the utility score for each attribute.

Data Collection

The data collection comprises of expert responses and field data for various parameters. The expert responses were collected through designed questionnaire form as discussed in Sects. 3.1 and 3.2. Pavement distresses data, structural capacity of pavement, skid resistance, and pavement unevenness data were collected from the field. Other data such as traffic volume, amount of precipitation, variation of air temperature, date of construction of pavement, and drainage condition of pavement were collected.

Sensitivity Analysis

The sensitivity analysis is used to investigate how the ranking of pavement sections changes as utility values fluctuate within a reasonable range and to assess the optimal solution's robustness.

FAHP-MAUT Model

In this study, FAHP is integrated with MAUT in order to prioritize a pavement section network. MAUT requires a number of attributes for the implementation, which represent the major parameters for every pavement section. Each attribute value is determined by the utility function and indicated by its output in the range of 1–100. Thus, the development of utility function is MAUT's cornerstone. This proposed model incorporates highly deteriorating attributes for each pavement section, utility functions, and relative weights for each criterion in the decision-making process of pavement management, and flexibility is also built into the model for adjusting the different elements. Figure 1 outlines the process involved with the development of this model. A decision-maker can adjust the selection criteria, different attributes, and their relative weight as necessary or required.

> **Step 1.** An organizational hierarchy is developed for ranking and prioritizing pavement sections.
> **Step 2.** A pair-by-pair comparison of the different criteria is done using a transformed Saaty's scale. The original Saaty's scale is fuzzified according to fuzzy set theory (Saaty 1980) using crisp values as shown in Table 1. The expert responses are arranged in a matrix as shown in

Fig. 1 Flow chart of FAHP-MAUT model
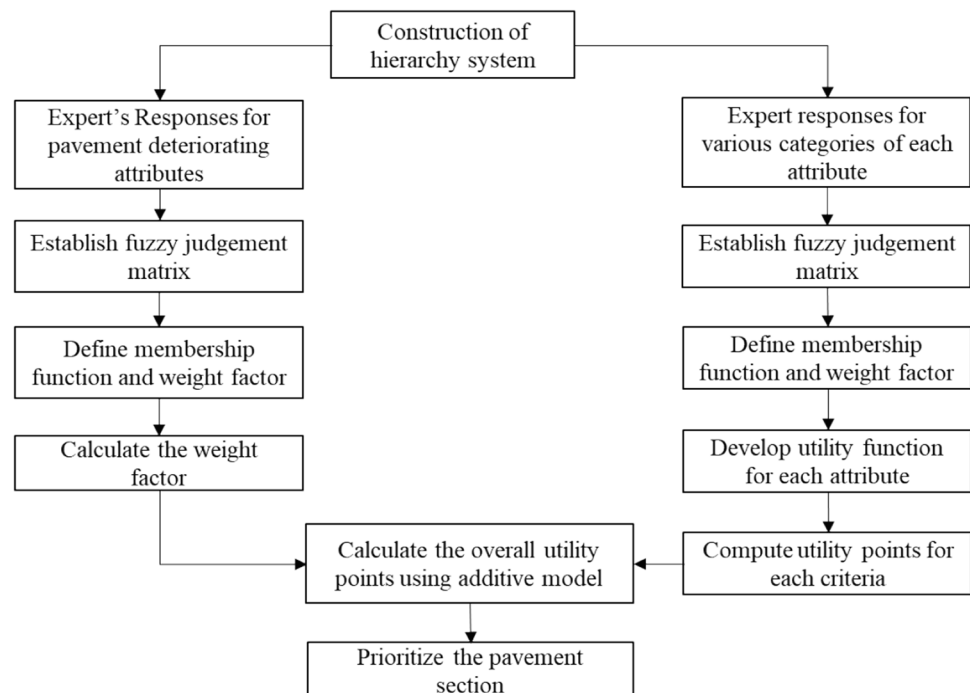
Eq. (1), and the inverse operation for the resulting matrices is illustrated by Eq. (2).

$$\tilde{A} = \left(\tilde{a}_{ij}\right)_{n \times n} = \begin{bmatrix} \tilde{a}_{11} = (1,1,1) & \tilde{a}_{12} = (l_{12}, m_{12}, u_{12}) & \cdots & \tilde{a}_{1n} = (l_{1n}, m_{1n}, u_{1n}) \\ \tilde{a}_{21} = (l_{21}, m_{21}, u_{21}) & \tilde{a}_{22} = (1,1,1) & \cdots & \tilde{a}_{2n} = (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} = (l_{n1}, m_{n1}, u_{n1}) & \tilde{a}_{n2} = (l_{n2}, m_{n2}, u_{n2}) & \cdots & \tilde{a}_{nn} = (1,1,1) \end{bmatrix}$$
(1)

whereas,

$$\tilde{a}_{ji} = \left(\tilde{a}_{ij}\right)^{-1} = \left(l_{ij}, m_{ij}, u_{ij}\right)^{-1} = \left(\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}\right)$$
(2)

Step 3. Synthetic measurements index $(\tilde{S}_i)$ is developed through Eq. (3):

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1}$$
(3)

in which

$$\sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right)$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} u_{ij}}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} m_{ij}}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} l_{ij}}\right)$$

Step 4. The pairwise comparison is performed after getting the $\tilde{S}_i$ index value. The triangular membership function has two fuzzy numbers $\tilde{S}_i = \left(l_i, m_i, u_i\right)$ and $\tilde{S}_j = \left(l_j, m_j, u_j\right)$ through which relative weight vectors is estimated by comparing them according to Eq. (4):

Table 1 Linguistic terms and their corresponding triangular fuzzy numbers

Saaty's scale	Definition	Fuzzy triangular scale
1	Equal importance	(1, 1, 1)
3	Low importance	(2, 3, 4)
5	Average importance	(4, 5, 6)
7	Strong importance	(6, 7, 8)
9	Extremely strong importance	(9, 9, 9)
2	Intermediate values between two	(1, 2, 3)
4	adjacent scales	(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

$$V\left(\tilde{S}_i \geq \tilde{S}_j\right) = \sup\left[\min\left\{\tilde{S}_j(x_j), \tilde{S}_i(x_i)\right\}\right]$$
(4)

Which can be also represented as shown in Eq. (5):

$$V\left(\tilde{S}_i \geq \tilde{S}_j\right) = \begin{cases} 1 & if\ m_i \geq m_j \\ 0 & if\ l_j \geq u_i \\ \dfrac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & otherwise, \end{cases}$$
(5)

After comparing, the weight vectors $W'(x_i)$ is represented in terms of crisp values and is calculated by following the mathematical Eq. (6):

$$W'(x_i) = \min\left\{V\left(\tilde{S}_i \geq \tilde{S}_j\right)\right\}$$
(6)

The weight vectors are expressed as shown in Eq. (7):

$$W' = \left[W'(x_1), W'(x_2), \cdots, W'(x_n)\right]^T$$
(7)

$W'(x_i)$ is a crisp numeric value which is further normalized through Eq. (8):

$$W = \frac{W'(x_i)}{\sum\limits_{i=1}^{n} W'(x_i)}$$
(8)

Finally, normalized weights are assigned to the various attributes, and multiplying these weights by the respective attributes will yield a utility score for a pavement section. Utility scores are calculated for each attribute using the utility function. The FAHP-MAUT model is supposed to combine the utility of the attributes into one value since each of the attributes has different ranges of value. The additive index method is selected for this study because each attribute is independently evaluated for ranking and prioritizing pavement sections. The overall utility score is determined and their mathematical expression is shown in Eq. (9):

$$U\left(x_1, x_2, \ldots, x_n\right) = \sum_{i=1}^{n} k_i u_i(x_i)$$
(9)

where total utility is expressed as $U\left(x_1, x_2, x_3, \ldots \ldots x_n\right)$; k_i is represented as the scaling weight varies from 0 to 1; $\sum_{i=1}^{n} k_i = 1$; and utility value is expressed as $u_i(x_i)$ and x_i is its attribute value.

Formulation of OPCI

Highway engineers need a reliable pavement performance indicator to develop an efficient pavement management system (PMS) that can predict the rate of deterioration

(AASHTO [2012]). Numerous researchers have produced their studies regarding a serviceability index that allows for a systematic management of the road network (Shiyab [2007]). By using this OPCI, it will be possible to produce precise predictions of the pavement's efficiency and will provide a clear overview of the current surface conditions. Additionally, the life cycle cost of the selected M&R action will be enhanced using the acceptance levels of the four different condition indices. By incorporating such an index into PMS, better systems can be created, which will lead to additional road maintenance savings and improve road network service quality. It is also generally understood that if the PMS cannot schedule M&R work over a period of several years, full benefits from the PMS cannot fully be realized.

Individual indices namely pavement condition distress index ($PCI_{Distress}$), pavement condition structural capacity index ($PCI_{Structure}$), pavement condition roughness index ($PCI_{Roughness}$), and pavement condition skid resistance index ($PCI_{Skid\ Resistance}$) are first calculated; afterwards, they are added to yield one single index. The additive index approach reveals the general form of OPCI as indicated in Eq. ([10]):

$$OPCI = \sum_{i=1}^{n} PCI_i \times w_i \tag{10}$$

where *OPCI* is in 0 to 100 scales, PCI_i is the pavement condition index corresponding to i^{th} indicators (0 to 100 scales), w_i is the weightage or impact factor for various types of distresses or condition indicator (0 to 1), and *n* is the number of PCI indices. The weightage factor is determined for each index using the FAHP method. The relative weight will represent the impact of each index.

Pavement Condition Distress ndex (PCI_Distress)

An index of distress is formulated based on the major impacting defects observed in a pavement surface (Shiyab [2007]). Based on the field data and weightage values, each index is calculated individually. Finally, the multiplicative index approach is used to formulate the distress index using the weightage of individual distress as shown in Eq. ([11]):

where *ACI* is alligator cracking index, *RI* is Rutting index, *LCI* is longitudinal cracking index, *TCI* is transverse cracking index, *PI* is patching index, *RAI* is ravelling index, *PHI* is potholes index, *BI* is bleeding index, *DSI* is settlement and depression index, and *SI* is shoving index.

Pavement Condition Structural Capacity Index (PCI_Structure)

Falling weight deflectometer (FWD) is used to assess the structural capacity of pavement. FWD is a reliable and most suitable non-destructive method for this investigation. The structural condition index (Eq. ([12])) is derived by using the layer strength and carrying capacity of the pavement to calculate the structural condition:

$$PCI_{Structure} = 100 \times \left[\left\{ 1 - \left(1 - \frac{SN_{eff}}{SN_O} \right) \times w_{Structure} \right\} \right] \tag{12}$$

where SN_{eff} is the effective structural number, SN_o is the required structural number, i.e., that of a newly constructed pavement; and $w_{structure}$ is the weight factor for structural capacity.

The effective pavement structural number is calculated by using Eq. ([13]) (AASHTO [2012]) which depends on the total pavement thickness (*D*) in inch above the subgrade and effective modulus (E_P) of pavement layers above the subgrade in psi, measured using FWD (IRC:115 [2014]):

$$SN_{eff} = 0.0045 \times D \times E_p^{1/3} \tag{13}$$

$$SN_O = 0.0394 \times \sum_{K=1}^{NL} a_k d_k m_k + MSN \tag{14}$$

$$MSN = 3.57 \log_{10} CBR - 0.85 \left(\log_{10} CBR \right)^2 - 1.43 \tag{15}$$

Equation ([15]) is applicable for CBR ≥ 3%, otherwise zero.

The required structural number (SN_o) is calculated using Eqs. ([14]) and ([15]), where a_k is the strength coefficient of

$$PCI_{Distress} = 100 \times \begin{bmatrix} \left\{ 1 - \left(1 - \frac{ACI}{100} \right) \times 0.9 \right\} \times \left\{ 1 - \left(1 - \frac{RI}{100} \right) \times 0.7 \right\} \times \left\{ 1 - \left(1 - \frac{LCI}{100} \right) \times 0.7 \right\} \times \\ \left\{ 1 - \left(1 - \frac{TCI}{100} \right) \times 0.7 \right\} \times \left\{ 1 - \left(1 - \frac{PI}{100} \right) \times 0.5 \right\} \times \left\{ 1 - \left(1 - \frac{RAI}{100} \right) \times 0.3 \right\} \times \\ \left\{ 1 - \left(1 - \frac{PHI}{100} \right) \times 0.5 \right\} \times \left\{ 1 - \left(1 - \frac{BI}{100} \right) \times 0.2 \right\} \times \left\{ 1 - \left(1 - \frac{DSI}{100} \right) \times 0.2 \right\} \times \\ \left\{ 1 - \left(1 - \frac{SI}{100} \right) \times 0.1 \right\} \end{bmatrix} \tag{11}$$

a layer k, d_k is the thickness of a layer k in mm, m_k is the drainage coefficient of a layer k, and *MSN* is the modified structural number depends on CBR (%) (MoRTH 2019).

Pavement Condition Roughness Index (PCI$_{Roughness}$)

Researchers have shown that the scale of the international roughness index (IRI) is strongly correlated with the PCI scale since both measures take into account the perception of vehicle riding and the response to different modes of vehicle performance. A highly correlated relationship was found between the PCI and IRI measurements (Shiyab 2007), as shown in Eq. (16). The IRI can be expressed either in millimeter per minute or in kilometers per minute.

$$PCI_{Roughness} = 0.6 \times (IRI)^2 - (15.2 \times IRI) + 100 \qquad (16)$$

Pavement Condition Skid Resistance Index (PCI$_{Skid\ Resistance}$)

As a pavement condition indicator, the skid resistance index can be used alone or in combination with another indicator. In order to measure the Skid resistance number physically, a variety of tools are available. A pendulum skid tester can be used to determine the skid resistance from the field on a scale of 0–100. Equation (17) can be used to determine pavement conditions due to skid resistance.

$$PCI_{SkidResis\tan ce} = 100 \times \left[\left\{ 1 - \left(1 - \frac{SKN_{eff}}{SKN_O} \right) \times w_{SkidResis\tan ce} \right\} \right] \qquad (17)$$

where, SKN_o is the maximum allowable skid number corresponding to good condition (IRC:82 2015) equal to 65, SKN_{eff} is the effective skid number measured on the in-service pavement and $w_{Skid\ Resistance}$ is the weight factor for skid resistance. Equation (18) is the final formula for OPCI after assigning the weight factor to all the indicators. The weightage for PCI$_{Distress}$, PCI$_{Structural}$, PCI$_{Skid\ Resistance}$, and PCI$_{Roughness}$ is determined using FAHP.

$$OPCI = \begin{bmatrix} (PCI_{Distress} \times w_{Distress}) + (PCI_{Structure} \times w_{Structure}) + \\ (PCI_{Roughness} \times w_{Roughness}) + (PCI_{SkidResis\tan ce} \times w_{SkidResis\tan ce}) \end{bmatrix} \qquad (18)$$

Pavement Deteriorating Attributes

There are several parameters involved in decision-making on maintenance at the network level, and each may be connected in various ways to maintenance processes. Practically, it is not possible to monitor each of them. Therefore, the highly deteriorating parameters are identified for maintenance decision-making process. The maintenance and treatment of flexible pavement are determined by a number

of factors, including pavement distresses (Abu Dabous et al. 2019; Ahmed et al. 2017; Babashamsi et al. 2016; Moazami et al. 2011), traffic volume (Babashamsi et al. 2016; Moazami et al. 2011), precipitation (Dawson 2009; Mills et al. 2009; Nemry and Demirel 2012), temperature (Mills et al. 2009; Nemry and Demirel 2012), and roughness (Meegoda and Gao 2014).

Traffic Volume

Pavement distresses are mainly caused by pavement condition and traffic moving through it, so pavement maintenance is mainly a function of these factors. According to IRC:37 (2018), traffic volume is the sum total of vehicles that pass through an individual road segment, expressed in the form of the number of vehicles passing per day. The number of vehicles per day is converted to millions standard axles (msa). It is generally accepted that in India, NH are designed with high traffic volume factors (TVF) of 50 msa, whereas 20 msa is used for some highways. For non-highways, traffic volumes are assumed to be less than 20 msa. In planning highways, IRC: 37, 2018 estimates the annual growth rate of commercial vehicles at 5%. In view of the fact that msas differ for different roads, it is necessary to characterize traffic volume in terms of msa (Table 2).

Precipitation

Precipitation in the form of rain, fog, and snow causes the level of moisture in the pavement to change and, consequently, distresses in the pavement result from this change. Dawson (2009) examines how moisture affects pavements in various ways. Precipitation is usually drained from pavement by gullies, drains, and pipes built along with road drainage, while surface runoff enters pavement by cracks and potholes (distress). A local water table also plays a critical role in the development of pavement distresses. The bond between pavement layers and subgrade layers is negatively impacted by the water table, leading to a weaker bond between aggregates. The flood has also damaged the pavements. The India Meteorological Department (IMD) defines a rainy day as having precipitation of 2.5 mm or more, while an extremely heavy rainy day occurs when rainfall exceeds 650 mm (IMD

Table 2 Traffic volume factors (IRC:37 2018)

Traffic volume (msa)	Condition
< 10	Very low
10–20	Low
20–30	Medium
30–40	Heavy
> 40	Very heavy

Table 3 Categories of rainfall departure from normal (IMD 2019)

Category	Departure from normal	Rainfall amount (in mm)
Large excess rainfall	60% or more	>1900
Excess rainfall	20% to 59%	1425–1887
Normal rainfall	-19% to +19%	962–1413
Deficient rainfall	-20% to -59%	950–487
Large deficient rainfall	-60% to -99%	475–12

2019). From June to September, India received approximately 86% (102.08 cm) of its annual rainfall during the monsoon season. There are six categories of rainfall in India (Table 3): large excess, excess, normal, deficient, large deficient, and no rainfall.

Air temperature

Because of the high temperatures in tropical climate zones, the pavement surface becomes hot (up to 64 °C) which dilutes the bond between bitumen and fine aggregate, creating the phenomenon of ravelling, whereas the freezing temperatures render the surface brittle and prone to cracking. The stress–strain response of pavements is heavily influenced by pavement temperature. It is the stress–strain response that spreads the wheel loads over the surface, and limiting this response may result in load-related deterioration (Dawson et al. 2014). The elevated pavement temperature reduces the pavement material's resistance to permanent deformation. Thermal stress develops in asphalt layers during this situation, which leads to thermal cracking (Dave and Hoplin 2015). According to the Indian Meteorological Department, the winter season is marked by air temperatures between 0 and 5 °C, while the summer season is marked by temperatures between 39 and 42 °C. The utility scores were developed using the IMD report on air temperature variation.

Pavement age

National Highways with a design period of 20 years, as well as corridors with a design period of 30 years, are under consideration. IRC: 37 (2018) prescribes detailed design periods for different categories of roads.

Drainage condition

One of the most important criteria for a good pavement design is its ability to drain water or liquid precipitation (Shah et al. 2014). In some pavement sections, there is no internal drainage system. This is due to the fact that these pavement sections have greater infiltration values than the drainage capacity of base and subbase layers. Most often, water seeps into the pavement through the surface cracks, joints, and shoulders. In some cases, water may enter the pavement structure because of a high groundwater level. Since improper drainage conditions may cause damage to flexible pavement, drainage condition should also be taken into account when designing the pavement (IRC: SP: 42 2014). The drainage condition is therefore also considered a key factor for prioritizing criteria in this study, as shown in Table 4.

Data Collection and Analysis

The data collection was separated into two components: (1) field data and (2) expert responses. The first part discussed the selection of a national highway section, pavement distresses, precipitation amounts, traffic volume, pavement age, air temperature, and the pavement's drainage condition. The second part contained data obtained via a questionnaire distributed among the pavement engineers and pavement maintenance experts.

Selection of Decision Attributes (Questionnaire Form for Pilot Survey)

The specific attributes were selected based on the literature survey and a discussion with 15 master students, 6 research scholars, and 4 professors. All participants such as master students, research scholars, and professors are from the transportation engineering department, NIT Patna, and have a thorough understanding of the pavement maintenance and

Table 4 Categorization of drainage condition (IRC:SP:42 2014)

Drainage condition	Rating	Condition
Good	1	A well-designed drain system without obstructing the surface drainage
Fair	2	High ground vegetation (within 10-m shoulder) and with poor drain system
Satisfactory	3	High ground vegetation (within 2-m shoulder) with poor surface drainage due to inadequate shoulder and improper alignment
Poor	4	Inadequate shoulder or high shoulder without drain which obstructing the surface drainage, high water table (< 1 m from surface) and a raised median with pool of water

treatment process. The attributes collected from the literature reviews is also discussed. After discussion, a total of nine parameters such as OPCI, traffic volume, pavement age, grade of pavement, air temperature, wind speed, precipitation, relative humidity, and drainage condition were proposed that have the greatest influence on pavement condition. A pilot survey was conducted through developed questionnaire to determine the most influencing attributes in the pavement deterioration. For the multivariate analysis, the number of expert responses should be at least four to five times the number of independent variables (Tabachnick and Fidell 1996). The questionnaire form was sent by email to 40 professional engineers, 20 consultant engineers, and 20 technical experts. Out of 80 questionnaire forms, only 57 forms were received which was useful for analysis. OPCI, traffic volume, precipitation, air temperature, pavement age, and drainage condition were determined as the six most influential attributes after analyzing the pilot study.

Determination of Weight Factor

Three questionnaire survey is carried out for the model implementation. First survey form was designed to obtain the relative weight for $PCI_{Distress}$, $PCI_{Structure}$, $PCI_{Roughness}$, and PCI_{Skid} used in the formulation of OPCI (discussed in Eq. (10)). In the second survey form, the relative weight of different parameters such as OPCI, traffic volume, precipitation, air temperature, pavement age, and drainage condition have been estimated. The third survey form was used to develop utility function for the proposed model. All developed survey form was sent by mail to 80 professionals having experience in the field of pavement construction and maintenance. Of these, 57 professionals completed and returned the survey form. Twenty-five respondents (44%) are working as government engineer, 14 (25%) are consultant engineer, and remaining 18 (31%) are researchers. All expert's responses are arranged in a Microsoft Excel sheet to determine the relative importance for each parameter using FAHP technique.

Selection of Study Area

There are more than 5.898 million kilometers of roads in India, making it the second largest road network in the world. Over 40% of the total traffic in India uses the wide 132,500-km roadway network of expressways and highways; however, Bihar State has a total of 5358 km of NH (MoRTH 2019). This study selects a road network based on the road network's importance in relation to adjacent states and countries (Nepal). This study focused on the following roads: NH-19, NH-28, NH-30, NH-31, NH-57, NH-83, NH-84, NH-85, NH-102, and NH-104 as shown in Fig. 2.

The different distress data were collected by visual inspection in both directions of the pavement. Using Eq. (13), the effective modulus of the pavement over the subgrade can be calculated. Pavement unevenness is thus determined with the bump integrator, while skid resistance is evaluated with a pendulum skid tester. Traffic volume is gathered between August to November 2019 and converted to million standard axles (msa) according to (IRC:37 2018). Data on construction started and completed for NH pavement is collected from the National Highway Development Program (NHDP) and the Road Construction Department, Bihar, and the age of the pavement is estimated. The precipitation and air temperature data are drawn from the India Meteorological Department (IMD) annual report 2019, and the drainage condition of the pavement is determined through the field investigation. The drain system, the vegetation near the shoulders, the shoulder height, the waterlogging in the median, and the groundwater level are examined for each NH pavement section.

Results and Discussions

Reliability Test and Factor Analysis of Selected Attributes

The reliability of expert responses is assessed using two tests: the Cronbach's alpha coefficient and the Kaiser-Meyer Olkin (KMO) test. Cronbach and Shavelson (2004) provided a model based on α-coefficient value that lies in the interval of 0.5 to 1, with the lowest approved value for lying between 0.5 and 0.6. The α-coefficient value and KMO test result were used to assess the reliability and significance of expert responses. The result greater than 0.5 allows to identify the most deteriorating characteristics (explained in Fig. 3). However, if the test result does not meet the KMO and Cronbach's alpha requirements, the process should be looped again to identify the appropriate expert responses. The irrelevant expert responses have been excluded from the study; the entire method is repeated to determine the KMO and Cronbach's alpha test results. The closer the value of α-coefficient and KMO is to one, the better the consistency of the attributes being evaluated.

Cronbach's α-coefficient was determined to be 0.826 for the expert responses collected for nine attributes, as shown in Table 5. The α-coefficient test result is larger than 0.5, indicating that the expert responses are reliable. The purpose of factor analysis is to minimize the dimension of attributes. The KMO and Barlett's test are used to determine the sampling adequacy. The test result complied with KMO and Barlett's requirements and yielded a value of 0.766 (shown in Table 6), which is more than 0.5.
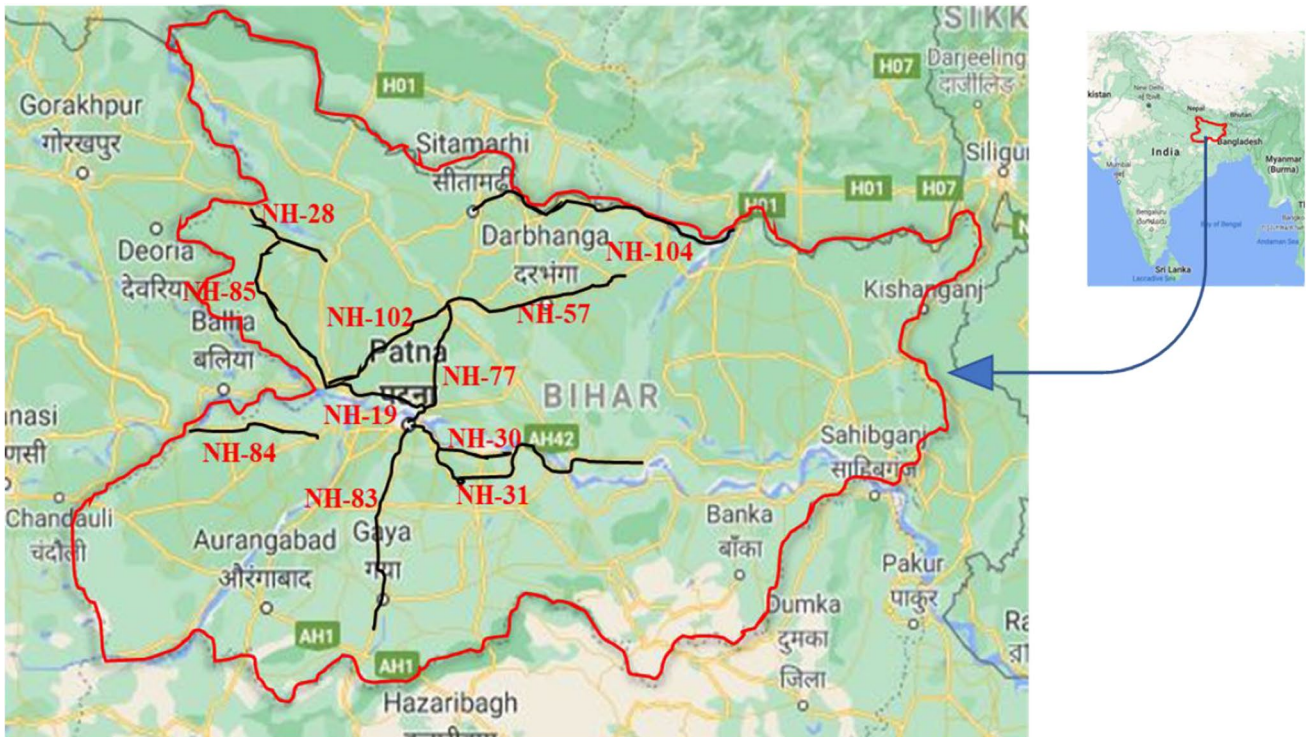
Fig. 2 fDetails of pavement section selected as study area

Fig. 3 Flow chart for selection of attributes
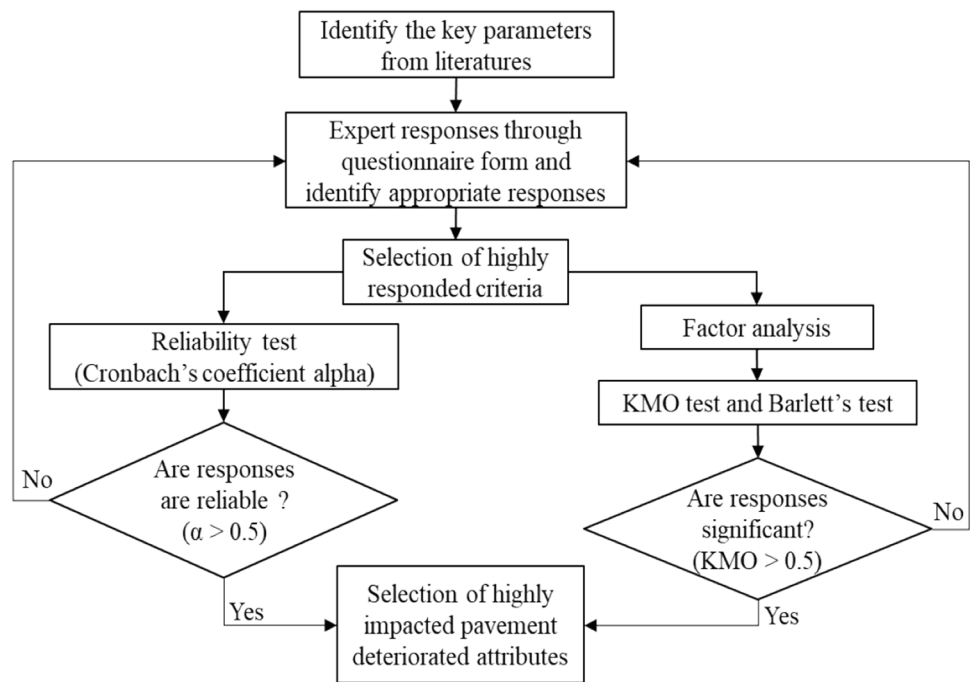
The factor analysis was done to reduce the attributes that were superfluous or had a minor impact on pavement deterioration. The grade of the pavement, wind speed, and relative humidity are identified attributes that show a low impact on NH deterioration. The remaining six parameters are taken into account for further investigation. The significant attributes are examined using KMO and Barlett's test of sphericity. The significance value closest to zero discloses the most relevance, while the significance value closest to one shows the lowest significance.

Table 5 Cronbach's alpha test result

Cronbach's Alpha α	Number of Items
0.826	9

Table 6 KMO and Barlett's test result for the usability model

KMO measure of sampling adequacy		0.766
Barlett's test of sphericity	Chi-square (approximate)	180.433
	Degree of freedom (Df)	36
	Significance (Sig.)	.000

Calculation of OPCI

A network of 22 NH is selected for implying priorities for maintenance. The field data for all highways are collected and converted into an index value as explained in Sect. 3. The index value for distresses, structural capacity, roughness, and skid resistance are tabulated in Table 7. Based on the expert responses, a comparison matrix was created, and the weight factor was determined. The relative importance of all four pavement condition indices was determined independently using the FAHP technique, and the average weight of all 57 responses was utilized as the final weight. Distresses,

structure, roughness, and skid resistance all have weight factors of 0.525, 0.28, 0.134, and 0.061, respectively. According to the weight factor of different PCI values provided in Table 7, 52% of respondents prioritize $PCI_{Distress}$, 28% prefer $PCI_{Structure}$, 13% prefer $PCI_{Roughness}$, and the remaining 6% choose $PCI_{Skid Resistance}$. The OPCI is calculated by multiplying all PCI indices by their proportional weight using an additive index technique. $OPCI = ((81 \times 0.525) + (64 \times 0.28) + (80 \times 0.134) + (83 \times 0.061)) = 76.23$ is an example of calculating the OPCI for NH-19 in the east as shown in Table 7. The remaining NH is computed in the same manner.

According to the results in Table 7, Sec-13 has the best pavement condition, with a $PCI_{Distress}$ value of 96 since road has either newly constructed or well maintain, while Sec-12 has the worst, with a distress value of 59. Sec-21 of the National Highway is structurally sound, with a $PCI_{Structure}$ value of 95, while Sec-16 has the lowest structural value of 65 which need to be maintained based on the available resources. The pavement Sec-21 has highest roughness index value of 95, while Sec-16 has the most undulation and lowest roughness index value of 65. The highest $PCI_{Roughness}$ rating corresponds to a smooth or recently created pavement surface. Sec-19 and 21 have the highest skid resistance index values of 96, while Sec-12 has the lowest skid resistance index value of 75. All index values are merged to evaluate pavement condition, using the weight factor to generate a

Table 7 OPCI for different NH in Bihar

Road name	Highway number	Direction towards	Section number	$PCI_{Distress}$	$PCI_{Structure}$	$PCI_{Roughness}$	$PCI_{Skid Resistance}$	OPCI
Patna-Hazipur-Chhapra	NH-19	East	Sec-1	81	64	80	83	76.23
	NH-19	West	Sec-2	75	61	82	84	72.57
Gopalganj	NH-28	East	Sec-3	82	64	84	88	77.59
	NH-28	West	Sec-4	78	61	83	89	74.58
Bakhtiyarpur-Fatuha-Patna	NH-30	East	Sec-5	75	68	71	89	73.36
	NH-30	West	Sec-6	77	67	73	82	73.97
Begusarai-Barh-Bakhtiyarpur	NH-31	East	Sec-7	86	74	77	85	81.37
	NH-31	West	Sec-8	79	65	80	82	75.40
Darbhanga	NH-57	East	Sec-9	73	72	81	81	74.28
	NH-57	West	Sec-10	83	69	85	80	79.17
Hazipur-Muzaffarpur	NH-77	North	Sec-11	68	52	74	82	65.18
	NH-77	South	Sec-12	59	46	70	75	57.81
Patna-Gaya-Dhobi	NH-83	North	Sec-13	96	86	94	94	92.81
	NH-83	South	Sec-14	93	88	90	94	91.26
Ara-Buxar	NH-84	East	Sec-15	87	70	73	91	80.61
	NH-84	West	Sec-16	76	64	65	90	72.02
Chhapra-Gopalganj	NH-85	North	Sec-17	73	58	72	86	69.46
	NH-85	South	Sec-18	65	59	81	82	66.50
Chhapra-Rewaghat-Muzaffarpur	NH-102	East	Sec-19	92	80	91	96	88.75
	NH-102	West	Sec-20	89	77	90	95	86.14
Sitamarhi-Jaynagar	NH-104	East	Sec-21	94	77	95	96	89.50
	NH-104	West	Sec-22	90	84	90	92	88.44

Table 8 Comparison of weight factor between FAHP and AHP

Attributes	No. of samples	Mean weight factor		Standard deviation		Coefficient of variance	
		FAHP	AHP	FAHP	AHP	FAHP	AHP
OPCI	57	0.367	0.367	0.0392	0.0405	0.107	0.110
TVF	57	0.264	0.257	0.0343	0.0370	0.130	0.144
Precipitation	57	0.188	0.184	0.0262	0.0266	0.139	0.145
Air temperature	57	0.099	0.102	0.0123	0.0130	0.124	0.128
Pavement age	57	0.056	0.061	0.0065	0.0070	0.118	0.113
Drainage condition	57	0.025	0.028	0.0033	0.0026	0.129	0.092

single value called OPCI. Section 13 has the highest OPCI at 92.81 which is in good condition, while Section 12 has the lowest at 57.81. Therefore, there is a great need to provide the maintenance to Sec-12 based on the available fund.

Comparison Between FAHP and AHP

Weight factor for each attribute was determined using the FAHP and AHP. A total of 57 responses were received, and weight factor has been calculated individually and determined the average value. The standard deviation and coefficient of variation (COV) were calculated for FAHP and AHP and determine the degree of variation between them. Based on the results discussed in Table 8, FAHP has shown the lower coefficient of variation for OPCI, TVF, precipitation, and air temperature. Pavement age and drainage condition of NH have produced higher value, since very few experts have prioritized them. The lower the ratio of standard deviation and mean, the better the result. As a result, FAHP is more realistic than AHP (Khashei-Siuki et al. 2020).

Calculation of Total Utility Score

The relative weight for different attributes was determined using the analysis of second questionnaire survey form. The weight factor for different attributes such as OPCI, traffic volume, precipitation, air temperature, pavement age, and drainage condition obtained after the evaluation of expert responses using FAHP technique are 0.367, 0.264, 0.188, 0.1, 0.056, and 0.025 respectively. The expert responses of third questionnaire form were evaluated using FAHP technique to obtain the utility score in the range of 1–100. The utility score is determined for each response and average them. The average value of utility score is used to extract the utility function for each attribute. The attributes value and utility score are shown in Fig. 4, and utility functions for each attribute are explained. The illustration of the utility function is explained for the precipitation attribute in Table 9.

The lowest rainfall amount is considered 0 mm, whereas the highest rainfall amount is selected as more than 1900 mm. The expert responses have been used to create a pairwise matrix, which is then assessed using the FAHP technique, as stated in Sect. 3. Finally, the utility points for precipitation attributes are computed as indicated in Table 8. Figure 4c depicts the utility function for precipitation. Similarly, utility points for other attributes such as OPCI, traffic volume, air temperature, pavement age, and drainage condition are also evaluated, and utility function is developed as shown in Fig. 4.

According to the results in Table 10, each attribute has a varied priority for NH depending on its value. The obtained attribute values for each NH pavement are fed into their associated utility functions to generate the final utility score.

Table 9 Pairwise comparison matrix and utility points for precipitation

		Rainfall amount (in mm)						Utility points
		0	244	719	1188	1656	1900	
Rainfall amount (in mm)	0	1	1/2	1/3	¼	1/5	1/7	100
	244	2	1	1/2	¼	1/4	1/5	96
	719	3	2	1	1/3	1/2	1/5	90
	1188	4	4	3	1	1/4	1/6	81
	1656	5	4	2	4	1	1/3	66
	1900	7	5	5	6	3	1	44

Sec-12 receives the highest priority with utility score of 47 from OPCI, whereas Sec-13 receives the highest utility score of 99.24. The utility score assigned by OPCI represents the pavement condition of NH. Sec-7 demonstrates the highest priority in terms of TVF due to the highest commercial vehicle load repetition. Sec-13 has a utility value of 95.69, indicating that it is the least important in terms of TVF. Sec-9 and Sec-10 had the highest priority due to being the oldest NH among the 22 NH, whereas Sec-13, Sec-14, and Sec-18–22 received the highest utility score of 97.94 since

OPCI utility Function

Utility Score = $0.008(OPCI)^2$ + $0.2866(OPCI) + 3.7319$

$R^2 = 0.9998$

Traffic Volume Utility Function

Utility Score = $-0.0348(TVF)^2$ + $0.5536(TVF) + 97.002$

$R^2 = 0.9916$

Precipitation Utility Function

Utility Score = $-2E{-}05(Precipitation)^2$ + $0.0039(Precipitation) + 97.9$

$R^2 = 0.9748$

Air Temperature Utility Function

Utility Score = $-0.0019(Temperature)^3 + 0.0919$ $(Temperature)^2 - 1.5587(Temperature) + 100.1$

$R^2 = 0.9976$

Age Utility Function

Utility Score = $-0.0909(Age)^2$ $- 2.2877Age) + 99.783$

$R^2 = 0.999$

Drainage Condition Utility Function

Utility Score = $3.5634(Drainage\ Condition)^2$ $- 46.921(Drainage\ Condition) + 143$

$R^2 = 0.9994$

Fig. 4 Utility function for **a** OPCI; **b** TVF; **c** precipitation; **d** air temperature; **e** pavement age; **f** drainage condition

Table 10 Utility score for various parameters

Section number	OPCI	Utility for OPCI	TVF (msa)	Utility for TVF	Pavement age	Utility for age	Precipitation (in mm)	Utility for precipitation	Air temperature	Utility for air temperature	Drainage condition	Utility for drainage condition	Total utility	Priority ranking
Sec-1	76.23	72.06	28	85.22	9	86.68	824.88	87.51	33	80.46	2	63.41	80.00	15
Sec-2	72.57	66.66	26	87.87	9	86.68	824.88	87.51	33	80.46	2	63.41	78.71	14
Sec-3	77.59	74.14	51	34.72	11	81.52	864.65	86.32	36	74.44	1	99.64	66.91	5
Sec-4	74.58	69.61	48	43.40	11	81.52	864.65	86.32	36	74.44	1	99.64	67.53	8
Sec-5	73.36	67.81	46	48.83	11	81.52	866.90	86.25	36	74.44	2	63.41	67.40	6
Sec-6	73.97	68.70	49	40.57	11	81.52	866.90	86.25	36	74.44	2	63.41	65.54	2
Sec-7	81.37	80.03	53	28.59	8	88.94	1071.50	79.12	34	78.66	2	63.41	67.46	7
Sec-8	75.40	70.82	50	37.68	8	88.94	1071.50	79.12	34	78.66	2	63.41	66.48	4
Sec-9	74.28	69.16	35	73.75	12	78.61	1020.77	81.04	35	76.66	2	63.41	73.53	11
Sec-10	79.17	76.56	35	73.75	12	78.61	1020.77	81.04	35	76.66	2	63.41	76.25	13
Sec-11	65.18	56.40	43	56.46	11	81.52	822.38	87.58	32	82.07	2	63.41	65.78	3
Sec-12	57.81	47.04	41	61.20	11	81.52	822.38	87.58	32	82.07	1	99.64	64.50	1
Sec-13	92.81	99.24	18	95.69	2	97.94	992.04	82.09	39	66.38	1	99.64	94.43	22
Sec-14	91.26	96.51	19	94.96	2	97.94	992.04	82.09	39	66.38	1	99.64	93.24	21
Sec-15	80.61	78.82	32	79.08	9	86.68	852.48	86.69	32	82.07	2	63.41	80.86	16
Sec-16	72.02	65.87	33	77.37	9	86.68	852.48	86.69	32	82.07	2	63.41	75.66	12
Sec-17	69.46	62.24	37	69.84	10	84.21	785.81	88.61	35	76.66	2	63.41	71.76	10
Sec-18	66.50	58.17	38	67.79	10	84.21	785.81	88.61	35	76.66	2	63.41	69.73	9
Sec-19	88.75	92.18	30	82.29	2	97.94	822.38	87.58	35	76.66	1	99.64	89.42	20
Sec-20	86.14	87.78	30	82.29	2	97.94	822.38	87.58	35	76.66	1	99.64	87.81	19
Sec-21	89.50	93.46	39	65.66	2	97.94	893.78	85.41	33	80.46	1	99.64	85.50	18
Sec-22	88.44	91.66	40	63.47	2	97.94	893.78	85.41	33	80.46	1	99.64	84.26	17

these NH are newly constructed. Sec-7 and Sec-8 have the lowest utility score of 79.12 due to the fact that these NH have got the most precipitation, whereas Sec-17 and Sec-18 have the greatest utility score of 88.61 due to the fact that these NH have received the least precipitation. Sec-11 and Sec-12 have the highest utility score in terms of air temperature, whereas Sec-13 and Sec-14 have the highest utility score in terms of priority, with a 66.38 utility score. The drainage condition of NH has been identified through visual inspection, and a utility score has been generated. National Highways with a utility value of 63.41 received the highest priority, while those with a utility score of 99.64 received the lowest.

Finally, the total utility score for each NH pavement is estimated and shown in Table 10. As an example of the additive utility model's ability to provide an estimate of total utility, the following calculations are for Sec-1. The other 21 National Highways follow the same type of calculation. Total utility score for Sec-1 $= ((72.06 \times 0.367) + (85.22 \times 0.264) + (86.68 \times 0.188) + (87.51 \times 0.1) + (80.46 \times 0.056) + (63.41 \times 0.025)) = 80$.

Sec-12 has the highest priority with total utility score of 64.5, while Sec-13 has the highest utility score of 94.43. The National Highway with lowest utility score has the highest priority, while highest utility score has the lowest priority. Based on the analysis, it is observed that OPCI has highest impact on the network of 22 NH while calculating the total utility score. The TVF, pavement age, and precipitation have shown the significant effect during estimating the total utility score. Air temperature and drainage condition have very little effect. This analysis is able to include any number of pavements for ranking or prioritization. The investigation showed that the suggested method is capable of capturing numerous attributes reflecting essential criteria, including sustainability criteria and of prioritizing the most highly impact NH. At the same time, the technique gave less importance to areas with relatively less social and environmental consequence. The sensitivity of the suggested method should be studied.

Sensitivity Analysis

Insua and French (1991) presented a method for sensitivity analysis by scrutinizing the previous work in the field of multi-objective decision-making problems. The determination of weight for different attributes is a deterministic approach in which utility scores are determined but the data of decision-making problems are changing in reality. So,

Table 11 Simulation output for total utility score

Section number	Total utility	10 Simulation run				100 Simulation run			
		Min	Max	Avg	% Change	Min	Max	Avg	% Change
Sec-1	80.00	78.06	82.74	80.45	0.567	73.402	86.917	80.171	0.217
Sec-2	78.71	77.19	82.97	79.11	0.506	73.194	83.298	78.726	0.017
Sec-3	66.91	64.98	68.82	66.92	0.015	63.812	71.233	67.088	0.273
Sec-4	67.53	66.11	71.08	68.09	0.818	63.278	71.594	67.596	0.094
Sec-5	67.40	66.01	68.76	67.62	0.336	65.397	69.369	67.316	-0.118
Sec-6	65.54	63.58	66.66	64.49	-1.613	63.579	67.355	65.357	-0.286
Sec-7	67.46	65.53	69.04	67.53	0.106	65.477	69.104	67.299	-0.240
Sec-8	66.48	65.60	67.90	66.55	0.096	65.206	68.459	66.893	0.617
Sec-9	73.53	72.92	75.62	74.28	1.022	69.561	78.013	73.711	0.243
Sec-10	76.25	74.56	77.59	76.55	0.393	73.964	77.743	75.959	-0.377
Sec-11	65.78	64.01	68.08	65.52	-0.390	63.832	68.079	66.234	0.689
Sec-12	64.50	62.70	66.42	64.85	0.538	62.621	66.417	64.484	-0.029
Sec-13	94.43	92.72	96.10	94.35	-0.090	92.632	96.241	94.464	0.034
Sec-14	93.24	91.51	95.95	93.60	0.387	91.426	96.034	93.734	0.534
Sec-15	80.86	78.84	82.58	81.04	0.216	78.462	83.187	80.913	0.062
Sec-16	75.66	73.40	78.01	75.08	-0.767	73.397	78.213	75.824	0.217
Sec-17	71.76	70.71	73.80	72.25	0.680	69.671	73.875	71.889	0.178
Sec-18	69.73	68.41	71.04	69.79	0.091	68.002	71.369	69.709	-0.025
Sec-19	89.42	87.59	90.88	89.58	0.181	87.189	91.655	89.538	0.130
Sec-20	87.81	85.92	89.95	87.50	-0.347	85.438	90.431	87.926	0.135
Sec-21	85.50	83.05	87.97	85.08	-0.492	82.966	88.031	85.404	-0.110
Sec-22	84.26	81.84	86.21	83.96	-0.348	81.741	86.752	84.316	0.070

once decision-making issues have been addressed, a sensitivity analysis has to be performed with them (Memariani et al. 2009).

This study used sensitivity analysis to investigate variations in the NH based on the results of utility score, which varies within an acceptable range, and to assess the effectiveness of the optimal solution. The ranking and prioritization of 22 NH is determined in this study utilizing FAHP in conjunction with the MAUT model based on expert responses used in the development of utility functions. A sensitivity analysis, on the other hand, is used to assess the dependability of the findings. This research includes two types of sensitivity analysis. The first is intended to assess the sensitivity of each attribute all at once, while the second is used to study the sensitivity of individual parameters. For each NH, the first strategy considers the combination of all attributes. The entire utility score is simulated for 10 and 100 simulation runs, and a random number in the range of ± 10% of the total utility score is generated using the Matlab-2015. Table 11 explains how the minimum and maximum utility score for each NH are calculated. As indicated in Table 11, the average value of 10 and 100 simulation runs is produced, and the percentage change is determined in relation to the original total utility score.

The 100 simulation run produced a lower percentage change than the ten-simulation run. Only five of the 22 NH demonstrated a greater percentage change, but all values were less than 1%, whereas Sec-6 demonstrated the highest percentage change of -1.613 percent in ten simulations run, and this is the only value that demonstrated a percentage change greater than 1%. In the case of 100 simulation runs, all twenty-two NH demonstrated a percentage change of less than 1%, with Sec-11 exhibiting the biggest percentage change of 0.689 percent. Sec-5 and Sec-7 have switched positions in both 10 and 100 simulations run, despite the fact that the initial utility score is quite close to 67.4 and 67.46. Sec-6 and Sec-12 have likewise shifted positions in the ten simulation runs, since the average of the simulated utility score is very near to the output values of 64.49 and 64.85, indicating a very minor preference. The longer simulation run indicates that the model is more accurate and resilient.

Similarly, the sensitivity of each attribute is specified individually in the second case. Using Matlab-2015, a random attribute value in the range of ± 10% of the original utility score is generated. In comparison to the original utility score, the percentage change is assessed for 10 and 100 simulation runs. The average and % change of each attribute is calculated for 10 and 100 simulation runs, respectively. It is observed that 100 simulation runs result in a lesser percentage change than 10 simulation runs. The sensitivity analysis also revealed that the OPCI had the greatest variation of 4.6 percent for Sec-3 in 10 simulation runs, while the smallest change was 0.12 percent for Sec-20 in 100 simulation runs.

According to the second case of sensitivity analysis, OPCI has the most variation when compared to other variables, whereas drainage condition has the least variation.

Conclusions

The MCDA strategy includes numerous objectives that must be met in order to achieve different pavement management requirements. It is a decision support system that is used to determine based on limited attributes and subjective judgment. The FAHP approach was used to determine the weight factor for decision-making attributes. MAUT was combined with FAHP to create utility functions for each attribute and calculate utility scores. A road network's rating or prioritization has been determined.

There are six dominant attributes identified, namely, OPCI, TVF, precipitation, air temperature, pavement age, and drainage condition. It is determined that these variables have the greatest impact on highway deterioration after the analysis of the pilot survey. OPCI incorporates structural and functional performance, including distresses, to provide a more accurate representation of pavement condition. $PCI_{Distress}$ has received the most relative importance, while $PCI_{Skid\ Resistance}$ has received the least. However, all four indices are interrelated, so all performance measures are considered.

The FAHP and AHP are used to calculate the relative weights for all six selected attributes. FAHP is superior to AHP technique as per the COV results. OPCI has received the highest weight factor, whereas drainage condition has the least effect on highway deterioration. It has also been discovered that commercial vehicle load repetition, precipitation amount, and temperature variation all have a significant effect on the highway deterioration. As a result, the utility score of highways is determined by taking into account all six attributes. The developed FAHP-MAUT model is a highly efficient model for ranking or prioritizing highways. In the network-level decision-making process, the total utility score determines the maintenance priority for NH. A small change in its value affects the entire network's ranking since OPCI is the most sensitive attribute.

The proposed methodology is sustainable towards using non-destructive test (NDT) and plan for maintenance activities. The decision-maker can have used methodology based on engineer's experience and NDT to provide effective maintenance activities and restore pavement condition on time at right place.

Availability of Data

Pilot survey data, PCI survey data, pavement deteriorating attributes responses and used models during the study are available from the corresponding author by request.

Appendix 1

__National Institute of Technology – Patna__
__Department of Civil Engineering – Transportation Engineering Group__
__Pavement Maintenance Questionnaire Survey__

Date - ……/……. / 2021

Interviewee Details:

Name: ………………………………………………   **Age:** ………… **years**

Designation: ………………………………..   **Educational Qualification:** ……………...

Experience in Pavement Construction and Maintenance: …………………………………

Survey for Determination of Highly Impacted Distresses on Pavement

Rating Scale	Definition
1	Very Low Impact
2	Low Impact
3	Average Impact
4	High Impact
5	Very High Impact

Kindly Provide Rating Points for The Following Parameters for Maintenance as Per Your Experience and Judgement.

Sl. No.	Parameters	Rating Point
1	OPCI	
2	Traffic Load	
3	Pavement Age	
4	Temperature	
5	Wind Speed	
6	Grade	
7	Relative Humidity	
8	Precipitation	
9	Drainage Condition	

Appendix 2

National Institute of Technology – Patna

Department of Civil Engineering – Transportation Engineering Group

Pavement Maintenance Questionnaire Survey

Date - ……/……. / 2021

Interviewee Details:

Name: …………………………………………………   **Age: ………… years**

Designation: ……………….…………………..   **Educational Qualification: ………………………..**

Experience in Pavement Construction and Maintenance: ……………years

Survey for Determination of Weightage Factors in Pavement Condition Index:

Intensity of Importance	Definition
1	Equal Importance
3	Moderate importance of one over other
5	Essential or strong importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate values between two adjacent judgements

Please check the square by (X) for the relative importance between the Group 1 and Group 2 parameters.

Example: If your judgement PCI$_{Distress}$ is 5 times more important than PCI$_{Structure}$ then put (X) on left side towards PCI$_{Distress}$

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
PCI$_{Distress}$					X													PCI$_{Structure}$

OR, if your judgement PCI$_{Structure}$ is 5 times more important than PCI$_{Distress}$ then put (X) on right side towards PCI$_{Structure}$

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
PCI$_{Distress}$													X					PCI$_{Structure}$

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
PCI$_{Distress}$																		PCI$_{Structure}$
PCI$_{Distress}$																		PCI$_{Roughness}$
PCI$_{Distress}$																		PCI$_{Skid Resistance}$
PCI$_{Structure}$																		PCI$_{Roughness}$
PCI$_{Structure}$																		PCI$_{Skid Resistance}$
PCI$_{Roughness}$																		PCI$_{Skid Resistance}$

Appendix 3

<u>*National Institute of Technology – Patna*</u>

<u>*Department of Civil Engineering – Transportation Engineering Group*</u>

<u>*Pavement Maintenance Questionnaire Survey*</u>

Date – ……/……. / 2021

Interviewee Details:

Name: …………………………………………………   **Age: ………… years**

Designation: ………………………………………..   **Educational Qualification: ………………………..**

Experience in Pavement Construction and Maintenance: ……………years

Survey for Determination of Weightage Factors:

Intensity of Importance	Definition
1	Equal Importance
3	Moderate importance of one over other
5	Essential or strong importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate values between two adjacent judgements

Please check the square by (X) for the relative importance between the Group 1 and Group 2 parameters.

Example: If your judgement OPCI is 5 times more important than Traffic Load then put (X) on left side towards OPCI

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
OPCI					X													Traffic Load

OR, if your judgement Traffic Load is 5 times more important than OPCI then put (X) on right side towards Traffic Load

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
OPCI													X					Traffic Load

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
OPCI																		Traffic Load
OPCI																		Precipitation
OPCI																		Temperature
OPCI																		Pavement Age
OPCI																		Drainage Condition
Traffic Load																		Precipitation
Traffic Load																		Temperature
Traffic Load																		Pavement Age
Traffic Load																		Drainage Condition
Precipitation																		Temperature
Precipitation																		Pavement Age
Precipitation																		Drainage Condition
Temperature																		Pavement Age
Temperature																		Drainage Condition
Pavement Age																		Drainage Condition

Appendix 4

Interviewee Details:

Name: …………………………………………………   Age: ………… years

Designation: ……………….…………………..   Educational Qualification: ………………………..

Experience in Pavement Construction and Maintenance: ……………years

Survey for Determination of Weightage Factors in Pavement Condition Index:

Intensity of Importance	Definition
1	Equal Importance
3	Moderate importance of one over other
5	Essential or strong importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate values between two adjacent judgements

Condition	PCI Range
Good	85-100
Satisfactory	70-85
Fair	55-70
Poor	40-55
Very Poor	25-40
Serious	10-25
Failed	0-10

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Good																		Satisfactory
Good																		Fair
Good																		Poor
Good																		Very Poor
Good																		Serious
Good																		Failed
Satisfactory																		Fair
Satisfactory																		Poor
Satisfactory																		Very Poor
Satisfactory																		Serious
Satisfactory																		Failed
Fair																		Poor
Fair																		Very Poor
Fair																		Serious
Fair																		Failed
Poor																		Very Poor

Poor																	Serious
Poor																	Failed
Very Poor																	Serious
Very Poor																	Failed
Serious																	Failed

Condition	Traffic Volume Factor																
Very Heavy	< 40																
Heavy	30-40																
Medium	20-30																
Low	10-20																
Very Low	>10																
Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Very Heavy																		Heavy
Very Heavy																		Medium
Very Heavy																		Low
Very Heavy																		Very Low
Heavy																		Medium
Heavy																		Low
Heavy																		Very Low
Medium																		Low
Medium																		Very Low
Low																		Very Low

Category	Rainfall amount (in mm)																
Large Excess Rainfall	>1900																
Excess Rainfall	1425 - 1887																
Normal Rainfall	962 - 1413																
Deficient Rainfall	950 - 487																
Large Deficient Rainfall	475 - 12																
Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Large Excess Rainfall																		Excess Rainfall
Large Excess Rainfall																		Normal Rainfall
Large Excess Rainfall																		Deficient Rainfall
Large Excess Rainfall																		Large Deficient Rainfall
Excess Rainfall																		Normal Rainfall
Excess Rainfall																		Deficient Rainfall
Excess Rainfall																		Large Deficient Rainfall
Normal Rainfall																		Deficient Rainfall
Normal Rainfall																		Large Deficient Rainfall
Deficient Rainfall																		Large Deficient Rainfall

Condition	Air Temperature (in ^0C)																
Very High	<45																
High	37-45																
Moderate	27-37																
Low	11-27																
Very Low	>10																
Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Very High																		High
Very High																		Moderate

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Very High																		Low
Very High																		Very Low
High																		Moderate
High																		Low
High																		Very Low
Moderate																		Low
Moderate																		Very Low
Low																		Very Low

Category	Pavement Age (in years)
Category I	<20
Category II	15-20
Category III	10-15
Category IV	5-10
Category V	>5

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Category I																		Category II
Category I																		Category III
Category I																		Category IV
Category I																		Category V
Category II																		Category III
Category II																		Category IV
Category II																		Category V
Category III																		Category IV
Category III																		Category V
Category IV																		Category V

Drainage Condition	Condition
Good	A well-designed drain system without obstructing the surface drainage
Fair	High ground vegetation (within 10 m shoulder) and with poor drain system
Satisfactory	High ground vegetation (within 2 m shoulder) with poor surface drainage due to inadequate shoulder and improper alignment
Poor	Inadequate shoulder or high shoulder without drain which obstructing the surface drainage, high water table (<1 m from surface) and a raised median with pool of water

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Good																		Fair
Good																		Satisfactory
Good																		Poor
Fair																		Satisfactory
Fair																		Poor
Satisfactory																		Poor

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Declarations

Conflict of Interest The authors declare no competing interests.

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