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Low-Cost Pavement Management System for Developing Countries

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Abstract: Governments face numerous challenges in sustaining road network conditions. This is attributed to road authorities' shortages of financial and physical infrastructure. As a result, low-cost automated solutions are being pursued to solve these problems and provide people with appropriate road conditions. Several attempts have been made to improve these technologies and incorporate them into a Pavement Management System (PMS) but limited attempts are made for developing countries. This study aimed to design a low-cost pavement management system for flexible pavement maintenance. A detailed literature review has been carried out, followed by a qualitative assessment of the various indicators considered for PMS. The priority ranks of the PMS indicators were made using an Analytical Network Process (ANP) and each rank was validated by a sensitivity assessment test using the Super Decision-Making tool. This paper also provides the conceptual framework for the low-cost PMS, followed by a fishbone diagram of the indicators and sub-indicators. It is concluded that an emergency maintenance plan with an ANP weight of (0.41) is one of the most significant plans for a low-cost PMS, followed by a routine with an ANP weight of (0.39) and periodic maintenance plans with a (0.20) ANP weight. Moreover, the functional indicators with an ANP weight of (0.32) are the most significant indicators for a low-cost PMS, followed by structural (0.26), safety (0.24), and serviceability(0.18) indicators. This model will assist the road planners in making better decisions on pavement maintenance management plans. The model will suggest the pavement sections on a higher priority to be added in the maintenance plans, especially where the maintenance budget is limited.

Keywords: pavement management system; pavement maintenance; low-cost maintenance; analytical network process; multi-criteria decision making

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1. Introduction

Roads form an integral part of transport infrastructure. All other modes of transportation require road connectivity to supplement them. Maintaining roads and their better condition will improve rapid access between regional and rural communities, help in reducing poverty and, ultimately, enhance the socio-economic growth and development of any country [1,2]. Pakistan's transport sector contributes around 10% to its Gross Domestic Product (GDP) annually. It creates around 2.3 million jobs (5.9% of the employed labor force). It is reported that due to the deprived conditions of roads, reckless driving, avoiding safety guidelines, and few other reasons, the fatality rate is 38 in 10,000 in Pakistan, which is very high compared with other countries [3].

Road reliability refers to a road's ability to meet traffic and environmental demands over the course of its operation and serviceability to users. Road maintenance plans include road repair and rehabilitation to keep a healthy condition of roads within budgetary constraints. As a result of declines in road maintenance funding and growing environmental challenges, road management authorities are in tough circumstances to make road repair and reconstruction decisions [4]. To meet this gap, the concept of a Pavement Management System (PMS) has been introduced. A PMS is a system used by road authorities to prioritize road sections for repair and reconstruction [5–8]. It can be defined as a systematic tool for managing, planning, and allocating budgets and scheduling all pavement maintenance work to help road agencies make decisions [9–11].

It is reported that roads are subjected to environmental and traffic load degradation, which requires regular and periodic maintenance of roads to keep them running. These processes must be improved based on upcoming challenges [12,13]. All the asphalted roads deteriorate with time, mainly due to the load of traffic and inclement weather [14]. Maintenance programs are administered using a criterion of challenges that includes commercial intervention based on limited resources, the local climate, the type of road classification, and political considerations. Normally, the level of roughness and the useful life of the surface indicators determines the time and type of maintenance work [5]. It has also been reported in recent studies that developing countries' road authorities have shifted their focus from the design and construction of new roads to the repair and control of the existing roads [15]. In contrast, other countries prefer to spend on modern infrastructure, but their pace has been slow in the last decade. While it is commonly known that road maintenance funds will be spent excessively on improving road performance, every country, nevertheless, dedicates considerable resources to keep the roads functional and running [16,17]. If roads are not properly and timely repaired, then the repair costs may increase. Road maintenance plans are either overlooked or given low importance [18]. The environmental and social effects of deferred maintenance are considerable because it affects the costs of maintenance.

The maintenance and recovery of roads are expensive. In 2008, the United States invested an estimated USD 182 billion in federal highway infrastructure upgrades and upkeep. Although billions are invested per year, many people believe it is inadequate [19]. According to reports, between 2008 and 2028, USD 101 billion in annual infrastructure investments would be required to maintain all of the United States' highways in their current conditions. Therefore, road networks are declining further every year [20]. Early identification of pavement distresses and preventative repair can be achieved with the aid of technology, rather than the costlier corrective maintenance activities that would be expected after the pavement has collapsed [21,22]. With road management authorities, a pre-determined maintenance schedule for the life cycle of the pavement is typically defined, depending on the area's survey and available funds. As a consequence, limited preventive maintenance is done to prolong the pavement life cycle, saving money for the authority. They essentially choose the worst-case scenario, allowing the pavements to deteriorate to the point of collapse without any preventative steps in place. To support good decision-making, a PMS requires an accurate and efficient pavement deterioration prediction model [23]. In addition to the prediction model, an optimization process is needed as a basic component of a PMS to guarantee the best possible pavement conditions. Thus, prediction models forecast future pavement conditions, allowing for the design of optimal maintenance strategies during the service life, and thereby reducing life-cycle costs [24].

A good PMS must be able to gather data in a reliable and repeatable way. Manual surveys were used in the past for data collection, which was time-consuming and ineffective. Automated data collection technologies, on the other hand, have been developed and continue to be a significant field of study [25]. As a deterministic regression prediction model, regression analysis is one of the most commonly utilized instruments in several research fields. It is also possible that many explanatory factors control the process of pavement degradation. The usage of a multiple regression model for pavement deterioration would be more useful [26].

The low-cost models placed tremendous stress on PMSs, which aim to align budgets with the optimum conditions for road users. PMSs are extremely data-dependent and it can be expensive and time-consuming to collect this data unless it can be efficiently automated. As a consequence, road agencies are usually limited to the use of traditional manual conditional surveys for identifying and tracking road network conditions [3]. This contributes to inefficient interventions in procedures and policies. There is a clear correlation between the number of injuries and the surface conditions [27]; hence, a common goal for all maintenance activities is to extend the life of the pavement. Pavement preservation activities used to improve pavement performance prolong the life of the pavement and improve safety. The collection and coordination of maintenance tasks is an important feature of cost-effective maintenance during the pavement life cycle. As a multi-attribute problem, such cases can be solved using an Analytical Hierarchy Process (AHP), a Fuzzy Analytical Hierarchy Process (FAHP), an Analytical Network Process (ANP), and an Analytical Neural Network (ANN) as Multi-Criteria Decision-Making Aids (MCDAs) [28].

Therefore, this study uses an ANP due to its appropriateness and finesse for such decision-making problems. This research focuses on the design of a low-cost pavement management system to make better decisions based on various flexible pavement health indicators and sub-indicators discussed in the coming sections of this paper. This model can be used in both conditions of data collection—either auto or manual road health detection. This model will guide the decision-maker in developing countries to make rapid decisions on pavement maintenance management work with the optimal treatment approach.

2. Research Methodology

A thorough literature review has been made for this research. The possible types of defects that normally occur during flexible pavement maintenance management were identified through the literature. A questionnaire was designed to get the experts' feedback on the most common types of defects that occur in flexible pavements. The reason for expert input was to access the performance of the literature and field experience and to prioritize the defects based on local conditions. In the next phase, the possible pavement maintenance approach was also identified and reviewed by an expert in the same process for defects. The data was collected from experts working with the National Highway Authorities in Pakistan and the data covers all provinces of Pakistan. The questionnaire was distributed to 65 experts via email and hard copy. Around 52 questionnaires were successfully received from experts. Based on the nature of questions and scope, this is quite an acceptable number for data analysis [29]. There are limited experienced staff working on road maintenance plans and the questions were in the nature of who needs qualified experienced staff to respond. Most of the experts were project managers, program directors, program coordinators, directors, and site engineers. The questionnaire has three sections. In the first section, the experts were requested to share their feedback on the PMS criteria and alternatives using an ANP Scale, as shown in Table 1, in a pairwise matrix format.

Table 1. Scale for pairwise comparison [30].

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between adjacent scale values

In the second and third sections, the experts were requested to share their feedback on the most commonly occurring defects and their possible low-cost treatments, respectively, using two different scales, as shown in Figures 1 and 2.

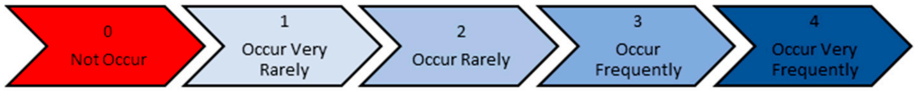

Figure 1. Scale for defect frequency of occurrence.

Figure 2. Scale for defect low-cost treatment type.

2.1. Data Collection and Sample Size

The significance of calculating sample sizes is underrated. The core population is a community of experts engaged with numerous pavement maintenance schemes [27]. The estimation of a sample size is often an important phase in the preparation of research studies. Insufficient or limited sampling sizes can make it difficult to show the desired difference or to reliably predict the occurrence of the event of interest. A broad sample size could increase the study's complexity and related costs, making it unfeasible. Any of these scenarios are inappropriate and can be stopped by the investigator. Table 2 shows the confidence level of the sample size collection for this research.

Table 2. Sample size with confidence levels [31].

Population Size	Confidence = 95% Margin of Error				Confidence = 96% Margin of Error			
	5.0%	3.5%	2.5%	1.0%	5.0%	3.5%	2.5%	1.0%
10	10	10	10	10	10	10	10	10
20	19	20	20	20	19	20	20	20
30	28	29	29	30	29	29	30	30
50	44	47	48	50	47	48	49	50
75	63	69	72	74	67	71	73	75
100	80	89	94	99	87	93	96	99
150	108	126	137	148	122	135	142	149
200	132	160	177	196	154	174	186	198
250	152	190	215	244	182	211	229	246
300	169	217	251	291	207	246	270	295

The data has been analyzed by an ANP using Super Decisions Version 2.10. The ANP analysis details are given in the next sections.

2.2. Analytic Network Process (ANP)

The ANP is an extension of T. Saaty's well-known decision-making tool, the AHP. The ANP is a dependencies-focused generalized form of the AHP. The ANP approach is a more generalized version of the AHP, which takes into account internal and external dependencies among the decision model's elements and alternatives. The ANP deals with all forms of dependencies and inputs in the output framework in a structured manner. The well-known AHP method is a subset of the ANP, which can be extremely helpful in integrating linkages into a system. The ANP model's composition is made up of clusters of elements that are connected by their interdependence. A cluster is a collection of elements that share a set of characteristics. Each of these clusters has at least one variable that is linked to another cluster. The movement of control between the elements is shown by these relations [32]. Since it can cope with all sorts of input and dependency while modeling a dynamic decision environment, the ANP model can offer a more precise tool for better understanding the essence of trade-offs between different parameters than traditional selection approaches. In a multi-objective and multi-stakeholder context, the ANP is useful for dealing with interdependent relationships [33]. Modeling dependencies and feedback between network components is rendered more easily with the ANP. As a result, the ANP is one of the most effective decision-making tools [34]. These dependencies, also known as feedbacks, may be modeled using the ANP method; they are more realistic and, as a result, provide more reliable outcomes. Since dependencies will exist between all of the elements in the judgment problem (i.e., alternatives, parameters, sub-criteria, and the goal), the model is no longer linear like the AHP (Figure 3), which arranges the elements in tiers. The ANP model does not need a hierarchy since clusters replace levels and each cluster includes nodes or components. The clusters are linked by a line, indicating that the elements or nodes inside them are linked.

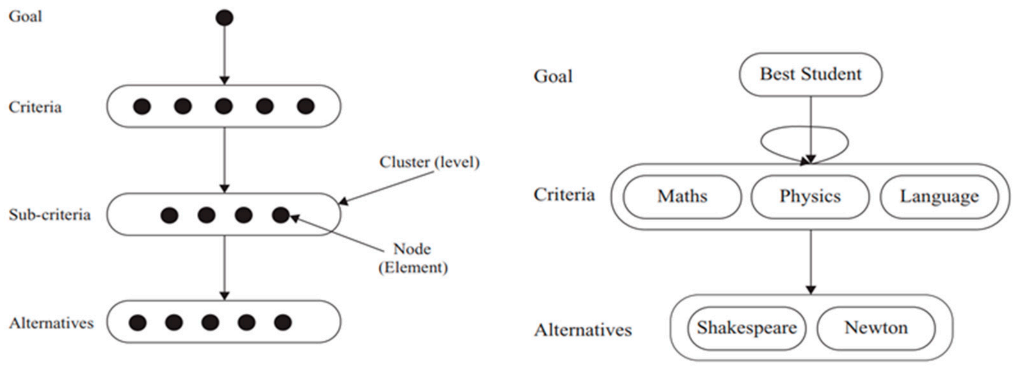

Figure 3. AHP and ANP decision processes [35].

Similarly, Figure 4 shows the influence matrix of the ANP model. It is the generic thorium that shows the numeric calculation matrices of the ANP model.

		Goal	Alternatives				Criteria		
			A_1	A_2	A_3	A_4	C_2	C_3	C_4
Goal									
Alternatives	A_1						x	x	x
	A_2						x	x	x
	A_3						x	x	x
	A_4						x	x	x
Criteria	C_1	x							
	C_2	x							
	C_3	x							

Figure 4. ANP influence matrix [35].

There are two layers of pairwise contrast. The cluster weights are determined using the eigenvector derived from the cluster level comparison for the control criteria. As a consequence, each of the matrix's columns adds up to unity. If every block in the supermatrix comprises a column of zero elements, the column must be normalized after being weighted by the cluster's weights to guarantee that the column sum is unity. The concept is similar to the Markov Chain, in which the sum of the probabilities of all states is equal to one. This matrix is called the stochastic matrix or weighted supermatrix. The weighted supermatrix is raised to a limiting power, such as in Equation (1), to get the global priority vectors [33].

$$\lim_{k \to \infty} W^k \tag{1}$$

If the supermatrix has the effect of cyclicity, there may be two or more N limiting supermatrices. In this case, the Cesaro sum is calculated as in Equation (2) to get the average priority weights [33].

$$\lim_{k\to\infty}\left(\frac{1}{N}\right)\sum_{i=1}^{n} Wi^{k} \tag{2}$$

3. Pavement Maintenance Management Categories of the Proposed PMS

The PMS offers reliable evidence and valuable data interpretation to render clear, cost-effective, and defensible decisions at the level of the network and project on pavement protection. The main component of the PMS is the pavement's functional, structural, safety, and serviceability assessments utilizing performance metrics. As shown in Figure 5, this model incorporates all forms of maintenance features needed in a comprehensive pavement maintenance program.

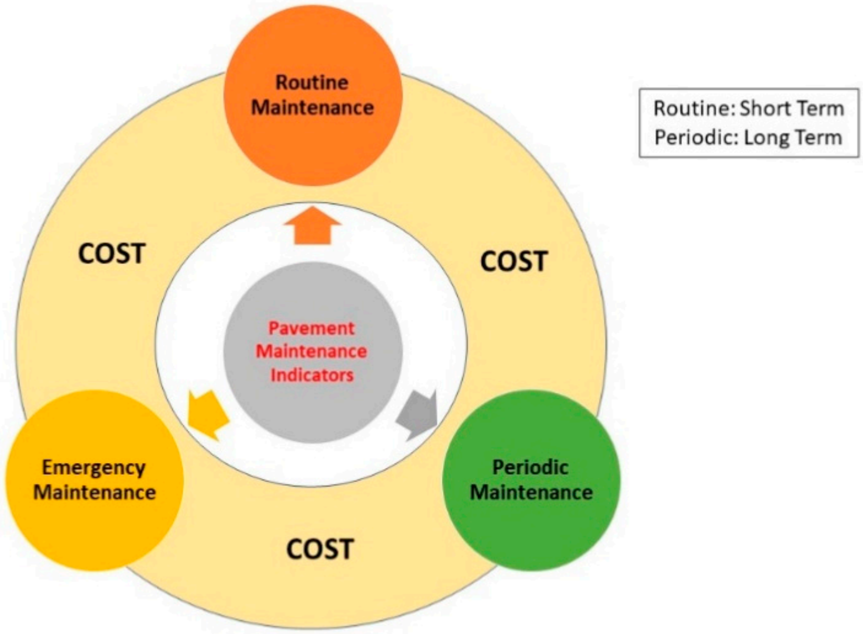

Figure 5. PMS framework for the PMM.

3.1. Routine Maintenance (RM)

The RM refers to a process of maintaining the foundations of pavements, shoulders, embankments, hydraulic frameworks, drainage systems, and road furniture against the combined effects of traffic, climate, and topography to avoid premature failures by ensuring the duration of road project construction existence and by providing the proactive maintenance activities needed every year before deterioration [36]. Most preventive maintenance is regular maintenance. It is carried out to enhance or increase a pavement's usable existence. It is a surface treatment and operational technique planned to delay incremental deficiencies and to reduce the need for regular repair and service operations.

3.2. Periodic Maintenance (PM)

The PM indicates the procedure of rebuilding pavement structures, shoulders, embankments, hydraulic structures, drainage systems, and road surfaces to some minimum appropriate structural, functional, and safety standards. It requires the remedial maintenance activities specified in the standard operating procedure required in any given year following structural, functional, and safety deficiencies [36]. Periodic repair is often a corrective treatment, and it is long-term. It is carried out after a pavement deteriorates, such as friction failure, mild to extreme rutting, or significant cracking occurs.

3.3. *Emergency Maintenance (EM)*

Maintenance for emergencies is often unplanned, serious, and often detrimental. It is always a mere act of design that causes the need for maintenance in an emergency. The whole transport network may be affected by extreme rain, mudslides, floods, hurricanes, or tropical storms. Emergencies are life-threatening and road maintenance agencies need to provide an evacuation plan for when they arise, but they do not arise often. It may also be an emergency condition that requires urgent repair, such as a blowout or a serious pothole. Temporary procedures intended to keep the surface together before more extensive repairs can be performed are often identified.

A success model for total discomfort is used in several of the pavement management schemes produced by numerous highway organizations. This is largely attributable to knowledge scarcity and data unavailability in each pavement segment relevant to the past results of the distress. Similarly, a PMS also depends on the classes and severity levels of various defects the pavement encounters. In this study, we designed a fishbone indicator and sub-indicator diagram for various categories of defects considered in this PMS, as shown in Figure 6.

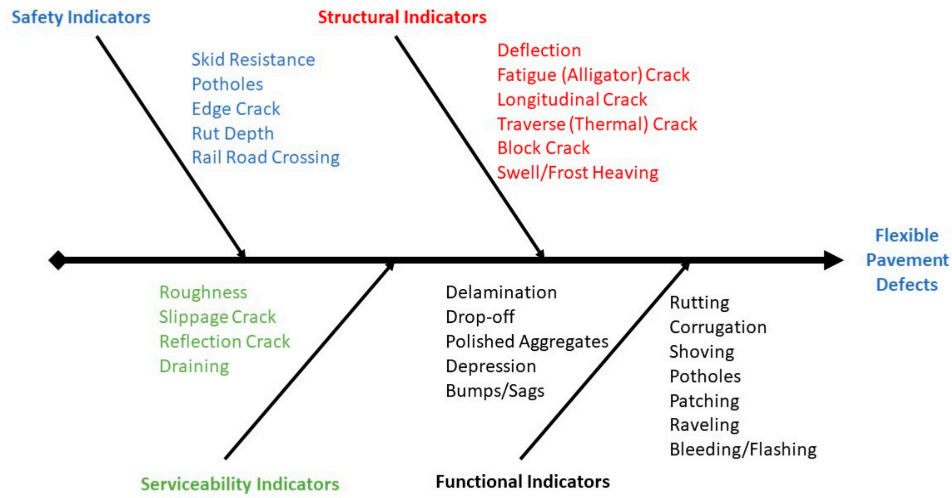

Figure 6. Pavement maintenance indicators fishbone diagram.

4. Design of ANP Decision Model for PMS

The basic ANP model is completed by specific sub-networks. The sub-networks are used to model the key features of the problem. The most important features of the PMS for maintenance management of this study are shown in an ANP-based framework with criteria and alternatives, as shown in Figure 7.

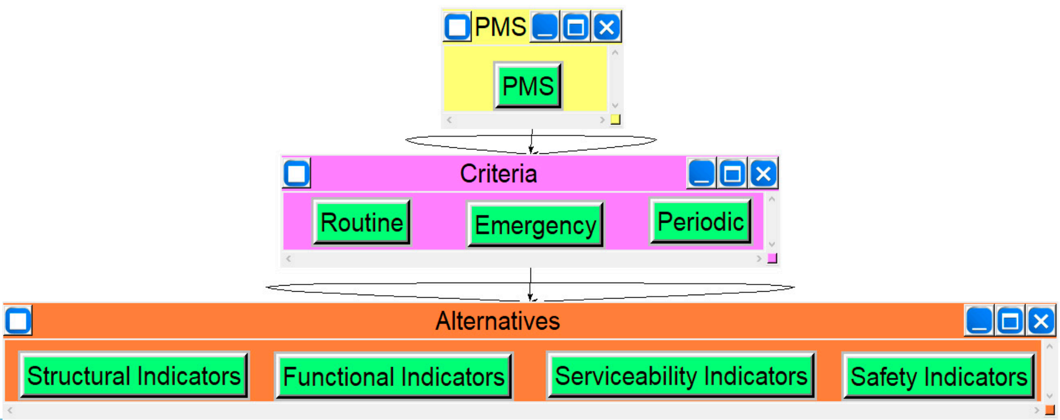

Figure 7. ANP model for the proposed PMS.

5. Results and Discussion

As discussed in the last sections, we assessed and evaluated each respondent's feedback in this research. Based on a similar methodology, each respondent's feedback was assessed in an ANP using the Super Decisions software tool, and the final ranking tables were generated for criteria and alternatives. Table 3 shows the synthesized results of each respondent's feedback.

Table 3. Synthesized indicator values of each respondent.

Normalized Cluster Values of Each Respondent	Indicators						
	Functional Indicators	Safety Indicators	Serviceability Indicators	Structural Indicators	Emergency	Periodic	Routine
Q1	0.2381	0.5038	0.1478	0.1102	0.4230	0.17313	0.4038
Q2	0.6101	0.2302	0.0601	0.0996	0.3012	0.3868	0.3120
Q3	0.5123	0.1502	0.0194	0.3181	0.5520	0.0338	0.4142
Q4	0.2910	0.2112	0.1067	0.3911	0.2914	0.0965	0.6121
Q5	0.2120	0.4367	0.1101	0.2412	0.3021	0.1872	0.5107
Q6	0.2381	0.5038	0.1478	0.1102	0.4230	0.21037	0.3665
Q7	0.3130	0.2101	0.1478	0.3290	0.4931	0.1513	0.355
Q8	0.2910	0.2112	0.2712	0.2266	0.5119	0.1523	0.3358
Q9	0.4123	0.1502	0.0613	0.3762	0.3389	0.2601	0.4010
Q10	0.3130	0.2101	0.1478	0.3290	0.4021	0.1891	0.4088
Q11	0.4101	0.2302	0.0601	0.2996	0.3899	0.1594	0.4507
Q12	0.2381	0.3038	0.1478	0.3102	0.4479	0.1847	0.3674
Q13	0.5123	0.1502	0.3120	0.0255	0.6033	0.0934	0.3033
Q14	0.4381	0.3038	0.1478	0.1102	0.5581	0.1204	0.3215
Q15	0.3356	0.2112	0.2975	0.1557	0.4230	0.17313	0.4038
Q16	0.2381	0.2038	0.1478	0.4102	0.5076	0.1035	0.3889
Q17	0.3905	0.1105	0.2408	0.2582	0.7142	0.0347	0.2511
Q18	0.5123	0.1502	0.3120	0.0255	0.4495	0.1277	0.4228
Q19	0.2381	0.0714	0.1784	0.5120	0.4230	0.1731	0.4038
Q20	0.2910	0.2112	0.0986	0.3992	0.2148	0.2040	0.5812
Q21	0.6101	0.2302	0.0601	0.0996	0.3330	0.2815	0.3855
Q22	0.3913	0.1502	0.3120	0.1465	0.4495	0.1277	0.4228
Q23	0.3130	0.2101	0.1478	0.3290	0.5581	0.1204	0.3215
Q24	0.5123	0.1502	0.104	0.2328	0.3899	0.1594	0.4507
Q25	0.6101	0.2302	0.0601	0.0996	0.4230	0.1731	0.4038
Q26	0.1770	0.2873	0.1556	0.3800	0.3012	0.3868	0.3120
Q27	0.2910	0.2112	0.0266	0.4712	0.6033	0.0934	0.3033
Q28	0.3939	0.3124	0.0206	0.2731	0.4230	0.1731	0.4038
Q29	0.4101	0.2302	0.0601	0.2996	0.7142	0.0347	0.2511
Q30	0.2381	0.2038	0.1962	0.3618	0.4230	0.1731	0.4038
Q31	0.4950	0.1502	0.0428	0.312	0.2914	0.0965	0.6121
Q32	0.2018	0.2401	0.1478	0.4102	0.3389	0.2601	0.4010
Q33	0.2910	0.2112	0.4712	0.0266	0.3330	0.2815	0.3855
Q34	0.2381	0.2017	0.1478	0.4123	0.3012	0.3868	0.3120
Q35	0.6101	0.2302	0.0601	0.0996	0.6033	0.0934	0.3033
Q36	0.2381	0.2804	0.1478	0.3336	0.2914	0.0965	0.6121
Q37	0.3770	0.2873	0.1556	0.1800	0.4230	0.2103	0.3665
Q38	0.5123	0.1502	0.3120	0.0255	0.2914	0.0965	0.6121
Q39	0.2381	0.2686	0.1478	0.3454	0.5119	0.1523	0.3358
Q40	0.6101	0.2302	0.0601	0.0996	0.4479	0.1847	0.3674
Q41	0.2381	0.2038	0.1478	0.4102	0.6033	0.0934	0.3033
Q42	0.2910	0.2112	0.0712	0.4266	0.7142	0.1204	0.1654
Q43	0.2381	0.3038	0.1478	0.3102	0.4495	0.1277	0.4228
Q44	0.5123	0.1502	0.3120	0.0255	0.2148	0.2040	0.5812
Q45	0.3881	0.2302	0.0601	0.3216	0.2914	0.0965	0.6121
Q46	0.3770	0.2873	0.1556	0.1800	0.4230	0.1847	0.3922
Q47	0.2910	0.2112	0.3732	0.1246	0.5210	0.0493	0.4297
Q48	0.2381	0.2907	0.1478	0.3233	0.3012	0.3868	0.3120
Q49	0.2381	0.2038	0.1478	0.4102	0.4230	0.2103	0.3665
Q50	0.2193	0.1502	0.3120	0.3185	0.7142	0.0347	0.2511
Q51	0.2700	0.2112	0.1287	0.3901	0.2148	0.2040	0.5812
Q52	0.3101	0.2302	0.1423	0.3174	0.4423	0.1204	0.4373
Overall Average	0.3539	0.2291	0.1566	0.2602	0.4333	0.1659	0.4006
Overall Average in %	35.39	22.91	15.66	26.02	43.33	16.59	40.06

The above table shows the 52 respondents' feedback on the criteria and indicators for the PMS. Cumulative aggregated weights were generated for each category separately using the Micro Soft Excel tool. Table 4 shows the synthesized weights of each criterion and alternative considered in this study for the PMS.

Table 4. Final synthesized weights of the PMS.

Goal	PMS Indicators	Normalized by Cluster	Normalized by Cluster %
Criteria	Emergency	0.40727	40.727
	Periodic	0.20424	20.424
	Routine	0.38849	38.849
	Criterion Weight Sum	1	100%
Alternative	Functional Indicators	0.323934442	32.39344423
	Safety Indicators	0.23799	23.799
	Serviceability Indicators	0.17797	17.797
	Structural Indicators	0.26011	26.011
	Alternative Weight Sum	1	100%

It was determined that the emergency plan is a significant plan for any low-cost pavement management system for a developing country because it assures safe traffic flow, as it is also reported by [37–39]. Due to road conditions, numerous accidents take place, and, in such cases, the road network gets blocked and prompt emergency response is required from all the state service-providing agencies, including the road management authority. Such cases should be covered under emergency pavement maintenance management plans. The recommencement of traffic flow is the key consideration of any road management authority in such cases, and therefore, emergency pavement maintenance management plans are given higher preferences by the experts. Second, routine maintenance plans are given priority, as also reported by [37,38]. The routine maintenance plans are short-term plans and can be managed within limited finances, as the pavement maintenance activities are normal, low-cost, and their scale is also limited. The periodic maintenance plans are third in priority; they are long-term plans and they require higher finances because pavement maintenance activities are of higher scope, time, and cost, as reported in [37,38]. These are long-term plans that include major rehabilitation of the affected sections and other activities.

6. Sensitivity Analysis of the Ranks

The objective of sensitivity analysis is to determine how changes in the numerical information of an ANP decision model affect the weight of the model's alternatives. The numerical data involved could be information directly supplied to the model, such as pairwise data [40]. The ANP's sensitivity study is more sophisticated and accurate than the AHP's. Each node in the ANP may be connected to another node, while in the AHP, only one criterion weight can be changed; an isolated node must be specified to a parent node. Sensitivity tests look at how a model responds to various sources of variance, such as the input dataset, the parameters chosen, and the predictions created [41]. Such assessments enable decision-makers to assess a degree of trust in the model performance, allowing them to consider and calculate confidence intervals in the modeling results [42]. In a multi-criteria decision problem, they may also expose the relationships between input and output parameters [43]. Sensitivity analysis can be done by Super Decision. The sensitivity test is conducted phase-wise and the different incremental percentage is added in the decision to observe the possible variations in the overall decision indicators. As per the ANP sensitivity thorium, the variations in the indicators should be observed at different percentage increments in the main indicator, which is the PMS in this case. Figure 8 shows the results of 10% and 20% increments in the model.

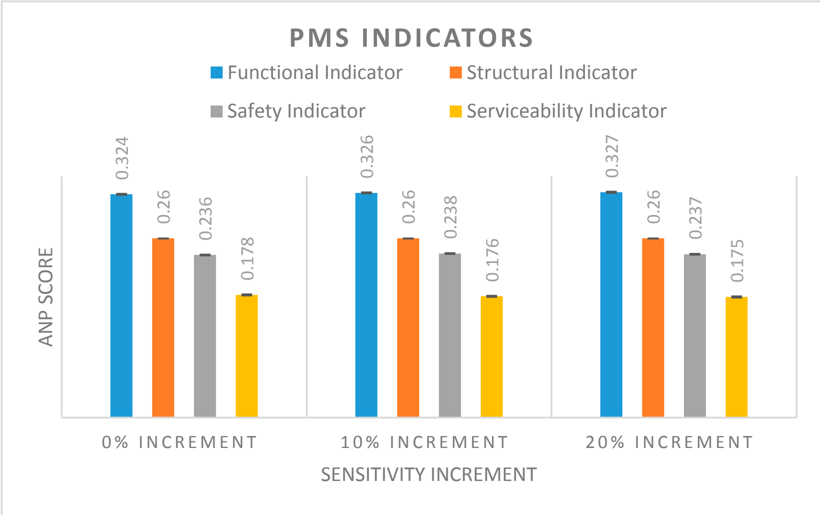

Figure 8. Sensitivity assessment of the PMS.

The generic sensitivity overall model for the PMS is a normalized model, as the parameter is zero. So, in the first phase, a 10% increment was added in the main indicator and the possible variations in the sub-indicators were observed. It has been observed that there was no variation in the decisions. In contrast, it was determined that the functional and serviceability indicators had some changes in the weights, which were minor because there was no change in the ranks. All the ranks were the same and there was no change in the indicator ranks, so it can be concluded that the decision was fine, as there was no variation observed in the sub-indicators. At a 20% increment, there was no major variation observed. It was determined that the functional, safety, and serviceability indicators had some minor changes in the weights but there was no change in the ranks. All final ranks were the same and there was no change in the sub-indicator ranks. Figure 9 shows the ANP model for the emergency phase.

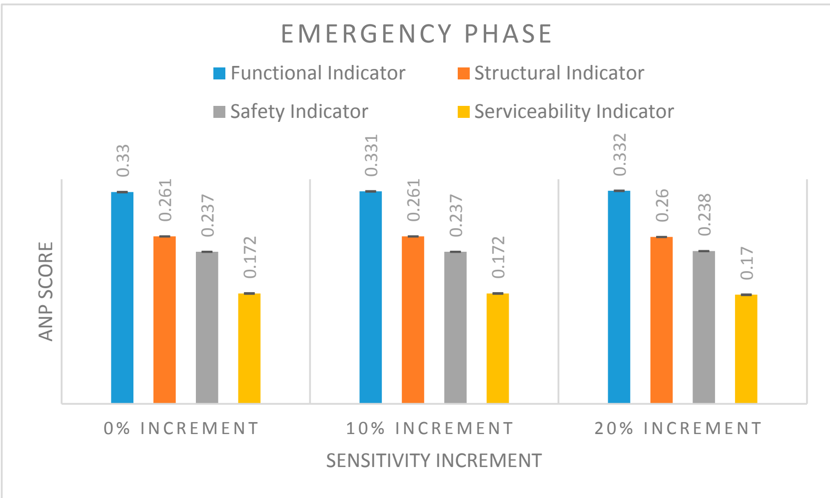

Figure 9. Sensitivity assessment of the emergency phase.

The generic sensitivity overall model for the emergency phase is a normalized model, as the parameter is zero. So, in the first phase, a 10% increment was added in the main indicator and the possible variations in the sub-indicators were observed. It has been observed that there was no variation in the decisions. In contrast, it was determined that the functional and serviceability indicators had some changes in the weights, which were minor because there was no change in the ranks. All the ranks were the same and there was no change in the indicator ranks, so it can be concluded that the decision was fine, as there was no variation observed in the sub-indicators. At a 20% increment, there was no major variation observed. It was determined that the functional, safety, and serviceability indicators had some minor changes in the weights but there was no change in the ranks. All final ranks were the same and there was no change in the sub-indicators rank. Figure 10 shows the ANP model for the periodic phase.

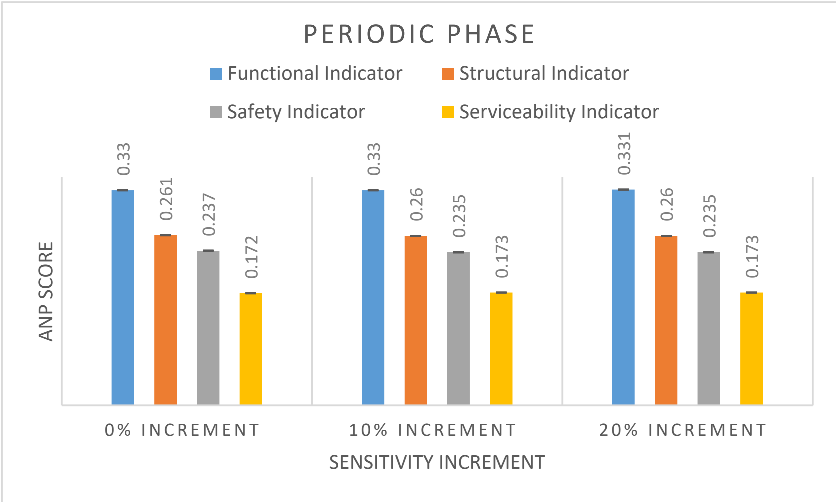

Figure 10. Sensitivity assessment of the periodic phase.

The generic sensitivity overall model for the periodic phase is a normalized model, as the parameter is at zero. It has been observed that there was no variation in the decisions at a 10% increment. In contrast, it was determined that only the functional indicators had some changes in the weights, which were minor and, thus, there was no change in the ranks. All the ranks were the same and there was no change in the indicator ranks, so there was no variation observed in the sub-indicators. It has been observed that there was no major variation in the decisions at a 20% increment. In contrast, it was determined that the functional and serviceability indicators had some changes in the weights, which were minor and, thus, there was no change in the ranks. All the ranks were the same and there was no change in the sub-indicators ranks. Figure 11 shows the ANP model for the routine phase.

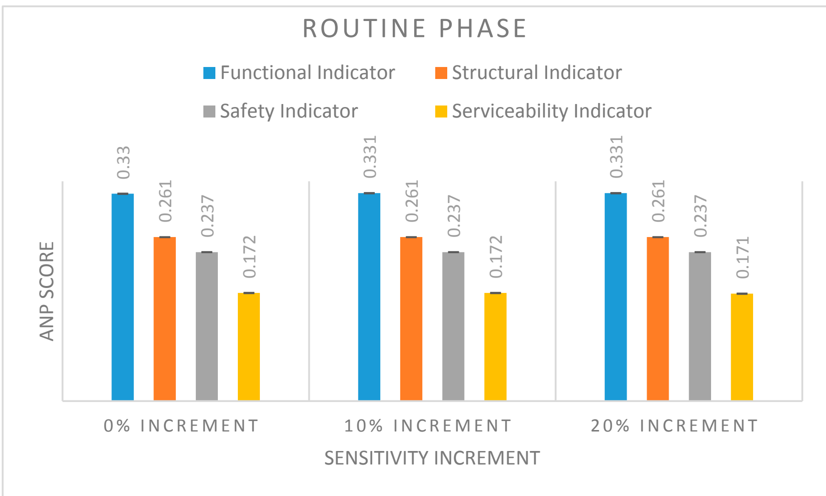

Figure 11. Sensitivity assessment of the routine phase.

The generic sensitivity overall model for the routine phase is a normalized model, as the parameter is zero. It has been observed that there was no variation in the decisions at a 10% increment. In contrast, it was determined that only the functional indicators had some changes in the weights, which were minor and, thus, there was no change in the ranks. It has been observed that there was no major variation in the decisions at a 20% increment. In contrast, it was determined that the functional and serviceability indicators had some change in the weights, which was minor and, thus, there was no change in the ranks. All the ranks were the same and there was no change in the sub-indicators ranks. It is concluded that the decision is valid.

In the next phase, the assessment of decision was analyzed with indicators by keeping one indicator as zero, and the effects on other indicators were observed at 10% and 20% variations in the decision weights on the selected indicators. Figure 12 shows the ANP model for the functional indicators.

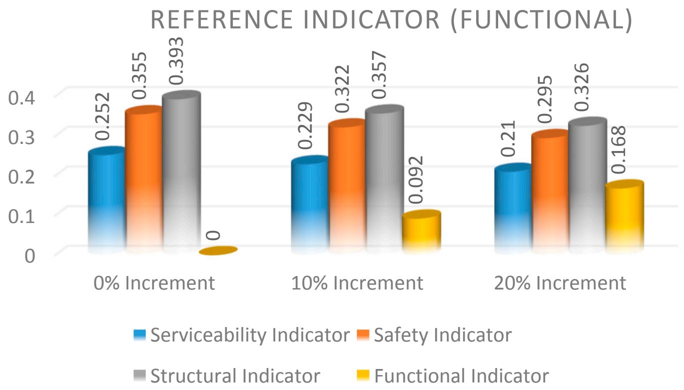

Figure 12. Sensitivity assessment of the functional indicators.

The generic sensitivity model for the PMS with specific reference to one selected indicator and the normalized model with weights of other indicators is given. The selected indicator will be zero, as its effect will be observed over the other indicators. As per the ANP sensitivity thorium, the variations in the indicators will be observed at different percentage increments in the selected indicator, which was the functional indicator in this case. So, in the first phase, a 10% increment followed by 20% increment was added in the selected indicator and the possible variations in the other indicators were observed. It was observed that there was no major variation in the decisions observed. In contrast, it was evaluated that there was a minor change in the weights of the indicators but these new weights do not influence the indicator ranks. All the ranks were the same and there was no change in the indicator ranks. After looking at the results of the 10% and 20% increments, it can be concluded that the decision is validated. Figure 13 shows the increment results for the serviceability indicator.

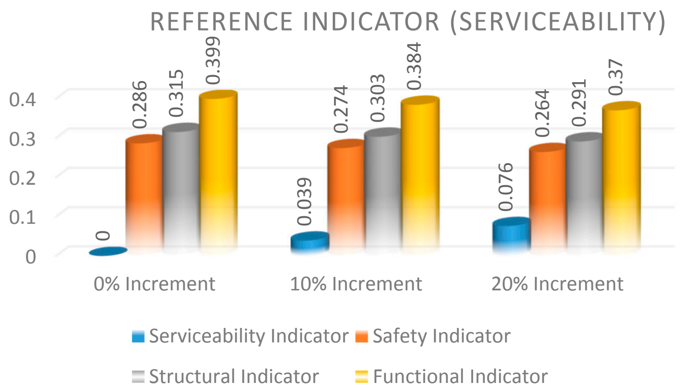

Figure 13. Sensitivity assessment of the serviceability indicators.

So, in the first phase, a 10% increment was added, followed by 20% in the selected indicator, and the possible variations in the other indicators were observed. It was observed that there was no variation in the decisions. In contrast, it was evaluated that all indicators had some changes in the weights, which were minor. All the ranks were the same and there was no change in the indicator ranks, so it can be concluded that the decision is normalized. Figure 14 shows the ANP model for the safety indicators.

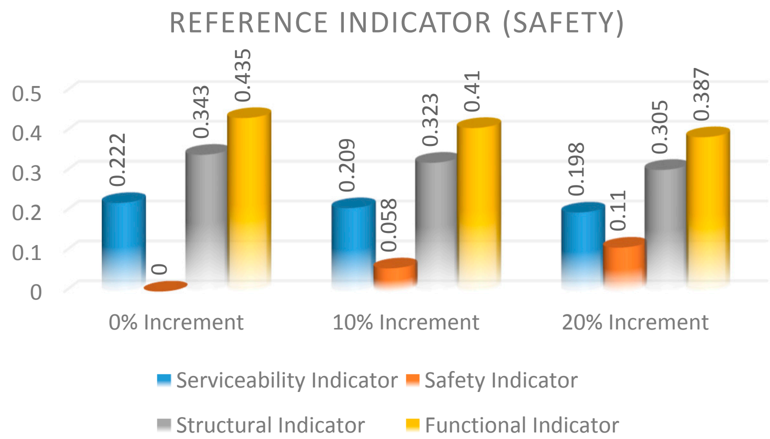

Figure 14. Sensitivity assessment of the safety indicators.

So, in the first phase, a 10% increment was added, followed by 20% in the selected indicator, and the possible variations in the other indicators were observed. It was observed that there was no major variation observed in the decisions. In contrast, it was evaluated that all indicators had some changes in the weights but all ranks were the same. Hence, it can be concluded that the decision is normalized. Figure 15 shows the ANP model for the structural indicators.

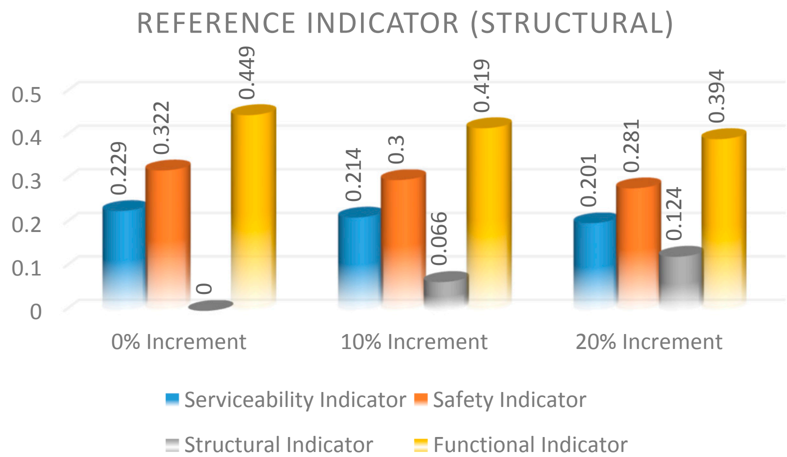

Figure 15. Sensitivity assessment of the structural indicators.

So, in the first phase, a 10% increment was added, followed by 20% in the selected indicator, and the possible variations in the other indicators were observed. It was observed that there were no major variations observed in the decisions. In contrast, it was evaluated that all indicators had some changes in the weights but all ranks were the same. Hence, it can be concluded that the decision is normalized.

As in all possible cases and comparisons, there was no major change observed in the weight, hence the final decision was fine after the detailed sensitivity assessment, so the final ANP decision ranks were final and validated for the model.

After the ranks validation, the final synchronized model is shown in Figure 16 for the low-cost PMS for pavement maintenance management proposed in this study.

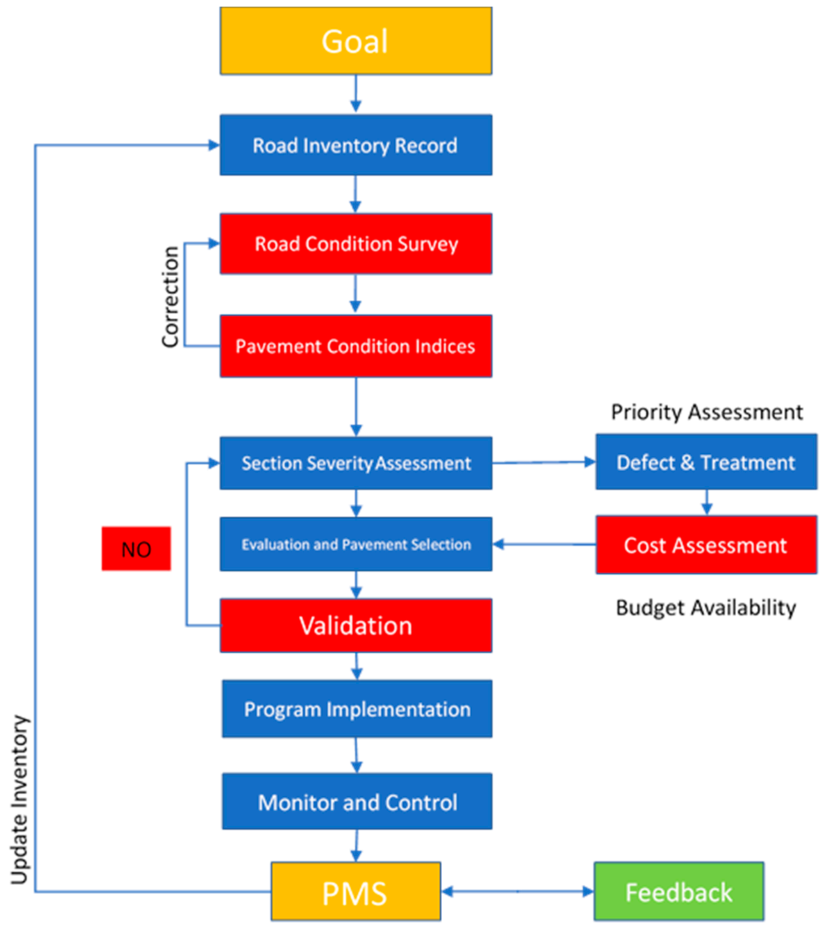

Figure 16. The proposed PMS framework.

The model was initiated with a clear goal to achieve the optimal decision on the priority of the pavement section to be placed first, based on the various indicators and sub-indicators discussed in the earlier sections of this paper. An updated pavement investor is very important to execute this model. The updated pavement section details will assist the decision-maker to make the pavement section health assessment and, based on the pavement condition, indices will be created. The pavement condition indices' ranks will be aligned with the indicators and sub-indicators suggested in the model in this paper. The pavement sections will be prioritized based on the defect type and financial assessment of the required possible treatment types of the identified defect. In the next phase, the decision validation will take place and if there are major variations observed, the decision will be referred back to the section severity assessment phase to revise the sections and treatment strategies. In the case of no major change, the pavement decision will be validated and forwarded for implementation. It is also fundamental for any decision support model to observe the performance of the decision, so it is significant to monitor the decision during the implementation phase and in case of any change, proper remedial action should be taken to avoid any major problems on the project. Similarly, if one pavement section is properly finalized, it is decent to record the feedback from various key stakeholders on the project to improve the performance of the decision support model.

7. Conclusions and Recommendations

An efficient pavement management system has the potential to support pavement management authorities to make optimal decisions in developed countries. This paper suggests a PMS for making optimal decisions on pavement section selection. The indicators and sub-indicators in the model are prioritized for low cost and the model will assist in prioritizing the pavement sections, especially in developing countries like Pakistan. It is concluded in this paper that for a low-cost PMS, the emergency plan is a substantial plan for any low-cost pavement management scheme for the developing world, as it ensures safer traffic flow. Numerous accidents occur as a result of poor road conditions, and in such situations, the road network becomes blocked, necessitating an immediate emergency response from all state service companies, including the road management authority. Emergency pavement maintenance control programs should cover all situations. In such situations, the resumption of traffic flow is the most important concern for any road management authority, so emergency pavement maintenance management proposals are given higher priority by experts.

It is also concluded that routine maintenance plans stand as the second main indicator. Routine maintenance plans are short-term plans and can be managed within limited finances, as the pavement maintenance activities are normal and low cost, and their scale is also limited. The periodic maintenance programs, on the other hand, stand third in priority, and these are long-term plans. They need more funds because pavement maintenance operations are larger in scale, time, and expense. There are long-term programs that require a significant portion of recovery as well as other operations. A detailed sensitivity assessment was carried out for this study and it is concluded that the final ranks of the indicators and sub-indicators used in the PMS are validated, as there were no significant differences in the weights observed. So, the final ranks derived from the ANP model are absolute.

It is recommended that this model is utilized in low-income countries where pavement management authorities are facing financial challenges to maintain the existing road network in any country. The indicators of the proposed PMS were selected solely on their occurrence and the repair techniques or their cost. The repair techniques suggested in the decisions will be based on the defects and their possible cheap treatments to maintain road functionality and services. The indicator and sub-indicator ranks may slightly vary from country to country, but this PMS will assist the decision-makers in prioritizing the pavement sections in any maintenance plan.

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