Defects in Flexible Pavements: A Relationship Assessment of Defects for Low-Cost Pavement Management System

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Abstract

Pavement maintenance has been a key concern for any pavement management authority. Countries are facing a severe challenge of funds in maintenance schemes, especially in developing countries. The existing pavement maintenance methods are goal-specific and lack integration of various indicators that are significant for any low-cost PMS. Thus, this paper aims to investigate the possible defects which may occur in flexible pavements. It also investigates the relationship between the different defects. A detailed literature review has been done for this research to identify all possible defects in flexible pavements and key features considered in any PMS. A questionnaire was designed to seek the expert's opinion on the defects and their possible relationships to be considered for a low-cost PMS. The data was collected from 283 experts currently working in pavement management authorities and pavement maintenance schemes. Aggregated Mean Score, Box plotting and Chi-Square test are used to analyze the data. It is concluded that Bumps/Sags (3.17) are one of the major defects reported by the experts in pavements in Pakistan, followed by the fatigue cracks (3.07). Rutting (2.98) and rut depth (2.98) stand at third key defects reported in this study. Depression (2.96), potholes (2.76), longitudinal crack (2.69), edge crack (2.55), roughness (2.51) and deflection (2.50) are also regularly arising defects in pavement maintenance activities in Pakistan. The results are in the acceptance range of the three mentioned validation methods. The correlation test results show that most of the defects in structural, functional, safety and serviceability indicators reject the null hypothesis thus, there is a close relationship between these defects observed in the flexible pavements. In last stage, a PMS model is suggested to assist the road management authorities of developing countries to make low cost decision for effective pavement rehabilitation.

1. Background

Pavement maintenance has advanced from a notion in the 1960s to present common and practical implementation in many countries (Wu et al., 2012). Pavement maintenance management systems were well developed in different organizations around the world, but it did not take shape until the mid to late 1970s to incorporate all these operations into a functioning PMS. The World Bank has carried out a variety of road projects since 1968 and has established many assessment modules that include models of pavement efficiency. They have been spread worldwide in over 100 countries and need to be tailored to local conditions (Thube, 2013). Due to aging, vulnerability to weather and traffic and the rising repair backlog, road transport infrastructure deteriorates. As a consequence, a primary issue is the viability of these infrastructures. The latest developments suggest that there is a substantial and growing expense of sustainable transport networks. As a result, overall thinking regarding the method of infrastructure management that takes maintenance needs into account is gaining in importance (Uddin, 2013). From 2008 to 2028, it is projected that an annual expenditure of $101 billion would be needed to sustain all USA highways and that failure to deliver the funds will further weaken road networks (ASCE, 2013). The USA already invests over $184 billion annually to repair and expand the road network (Congressional Budget Office, 2016). More than £ 15 billion is expected to be spent in England for the primary purpose of growing the potential and the current state of road networks (Transport, 2014).

The flexible pavements experience numerous distress indicators, including cracks, potholes, erosion, etc. It is not easy to identify the existence of various distress indicators. Distress position, scale, severity and mapping is a key a problem (Hosseini & Smadi, 2021). Inspectors walking around the segment of the highway have historically carried out thorough manual checks. They are replaced by advanced distress investigation approaches owing to additional time and resources, ranging from contactless high-speed laser sensors to machines that capture video photographs of the pavement's surface (Choi, 2020). Later, processing algorithms are used to classify forms of cracks and other situations commonly focused on neural networks (Domitrović et al., 2018). Typical pavement administration faces problems such as fault classification and lengthy evaluation turnaround period (Adarkwa & Attoh-Okine, 2013)(Shabir Hussain Khahro et al., 2021). The pavement structural capability assessment shows the pavement's residual existence, i.e., the amount of load repetitions that it can still endure. The structural capacity of a road considers the structural capacity of all road layers and the soil state of the foundation (Bejan, S.; Pérez-Acebo, 2016). A comprehensive literature review has been carried out for this study and the core summaries of the selected recent work are shown in Table 1.

Table 1: Previous research work summary

Reference	Objective	Method	Key Achievements	Remarks
(Hafez et al., 2021)	Identification of efficient pavement management systems	Case Study, Survey, mathematical programming	The transportation agencies can determine future budget needs, funding allocations and treatment policy to demonstrate the best possible use of pavement management resources	Fixed for local conditions and road condition assessment models cannot be integrated.
(Hosseini & Smadi, 2021)	The accuracy of prediction models can affect the decision-making process maintenance activities.	Recurrent Neural Networks (RNN) algorithm	Increasing the error rate also contributed to the prediction model, resulting in a higher benefit reduction rate.	Focuses on the validation of the existing model. It is an accuracy predication model.
(Momin & Hamim, 2021)	Proposed PMS for Bangladesh	Multiple Regression Analysis, SPSS,	Pavement rehabilitation using deflection value predicted by IRI and age of pavement sections.	Limited to few defects classes only.
(Roberts et al., 2020)	Identification of hotspot on the urban road network	Deep learning, ANN, Convolutional Neural Networks (CNN), camera phone, the Google Pixel 2XL	Low-cost hotspot analysis of the pavement distresses	Needs ANN expert to process the model and complex.
(Fani et al., 2020)	Developed a PMS	Multistage stochastic mixed-integer programming model, Mathematical Programming	The indices are high indicating the effectiveness of the stochastic solution.	The high computational complexity of the mixed-integer programming models hinders the practical application of the proposed stochastic pavement for large-scale networks.
(Choi, 2020)	Development of the Road Pavement Deterioration Model	Recurrent Neural Network (RNN), Deep learning, GIS	Accurate prediction of maintenance timing for pavement is achieved.	Expertise needed. A complex process, equipment's needed.
(Obunguta & Matsushima, 2020)	PMS with less data	Markov hazard model	Examines the applicability to developing countries of a PMS with less data	Needs analyses the relationship between the pavement design and estimated life expectancy.
(Santos et al., 2020)	Selecting optimal and rehabilitation strategies for pavements	Fuzzy logic, AHP,	It provides decision-makers with an easy and intuitive methodology for the selection of pavement sections.	At network level only and complex to operate.
(Montoya-alcaraz et al., 2020)	PMS for Mexico	Past data, Case Studies,	Developed a useful procedure that allows the collection, analysis, processing and updating of pavement conditions data	Limited to few defect classes. Multi Attribute analysis is lacked.
(Engineering & Almassy, 2019)	Proposed PMS for Budapest	GIS, Pareto Solution	PMS follows an multi variable optimization methods to define the rehabilitation technique	PMS system presented lacks further refinement including carrying capacity results and road structure.
(Zagvozda et al., 2019)	A database management system for a small city	GIS, QGIS,	GIS technologies applied to establish and keep better road infrastructure management.	The database was created by a manual collection of pavement condition. Their limiting factor is often the price or the scope and functions that do not necessarily correspond to the needs of a particular road administration.
(Wang & Pyle, 2019)	PaveM, PMS for the California Department of Transportation	Decision tree, H-chart,	PaveM provides a screening of system needs and total funding need estimate.	PaveM is to provide information to support decision-making, and not to make decisions.
(Pantuso et al., 2019)	Proposed PMS for Kazakhstan	GIS, GIS web, programing,	A methodology for analyzing the collected pavement data for the implementation of a network-level pavement management program.	Focuses on the survey data processing. The Decision-making model is linear.
(Santos et al., 2018)	Optimization-based decision support system (DSS) for pavement management	Pareto, Case study,	Enhance the sustainability of the road pavement maintenance decision-making process by including road users and environmental concerns.	The number of objective functions referring to indicators able to be simultaneously optimized is limited. Cost and environmental indicators are included only.
(Yan & Yuan, 2018)	A low-cost video-based pavement distress screening system	GIS, Image Sensing,	The proposed VPADS system aims to provide a computer-aided screening solution for transportation authorities	Accuracy of detecting crack and distress features yielded 80%. work can be further expanded by developing a crowd sensing inspection. Limited to image assessment only.
(Obaidat et	Pavement distress	GIS, Paver	The system was of great help in	Limited indicators are added in the model

al., 2018)	classification and maintenance priorities		identifying, collecting and displaying pavement condition data.	suggested.
(Domitrović et al., 2018)	Model to evaluate existing pavement condition	Analytical Neural Network (ANN)	High coefficient of determination and correlation between the actual data and the data assessed.	Needs ANN expert to process the model and complex.
(Vines-cavanaugh et al., 2017)	StreetScan PMS	Algorithms, Decision trees and mathematical models, PAVER, GIS	Users are able to visualize and interact with the repair suggestions and condition indices	Expertise needed. A complex process, equipment's needed
(Loprencipe et al., 2017)	Design of a PMS	Vehicle Operating Costs VOC	The traffic is directly proportional to the indirect user costs.	Develop a new PMS to include the indirect operating costs. PMS in small and mid-sized
(Picado-Santos et al., 2004)	Proposed PMS for Lisbon	GIS, Survey, GPS, VIZIROAD, Survey	Maintenance and rehabilitation decisions tends to have a more reactive attitude than a planned vision.	Such a system cannot be successfully implemented without the full commitment of the responsible authority and the appropriate know-how of the system designer.
(Issa & Abu-Eisheh, 2017)	Maintenance plans in Palestine	Survey and Case Study	Operation and Maintenance manual had a positive impact on the ten pilot municipalities.	Data driven and handled manually. Lacks to manage large plans.

It is analyzed that PMS has been the topic of key research and a sufficient number of works already carried out on PMS but it is also observed that limited attempts are made on the design of low-cost PMS. Most of the PMS are designed for developed countries, whereas limited attempts are made for developing countries where the road management agencies are facing substantial financial challenges to manage the maintenance schemes for the existing road networks.

A PMS offers a comprehensive, reliable approach for choosing maintenance and rehabilitation needs and deciding goals and the optimum repair period (Donev & Hoffmann, 2018)(Talpur et al., 2014)(Dong et al., 2021). The usefulness of every PMS depends on the data being used (*Nashville-Davidson County's Transportation Plan*, 2011). Primary data categories available include pavement quality scores, costs, the background of roadway building and repair, and traffic loading. Identifying and assessing pavement conditions and identifying the causes of erosion significantly emphasize every PMS (France-mensah et al., 2019). A PMS tends to eradicate human subjectivity from the equation when properly handled and to create impartial judgments. And the general efficiency of the road infrastructure is increased as the usable funds for the system are extended (Haas, 2007).

To preserve the pavement infrastructure and support its customers, a considerable effort is made every year, involving labour, money and other services (Zhang & Mohsen, 2018). Adaptation to global climate change is projected to generate the need for a significant rise in pavement maintenance investment (Chinowsky et al., 2013)(Qiao et al., 2015). Pavement activities need to be prioritized to minimize the cost of maintenance activities and maximize the life cycle of the network (Donev & Hoffmann, 2018). To reach this goal, a robust and accurate deterioration model is needed (Lytton, 1987). By reducing the error in deterioration models, agencies can obtain significant budget savings through timely intervention and accurate planning (George, 2000). Long-term and short-term planning that becomes possible with deterioration models is even more critical when highway agencies have limited funding (Saba, M.; Hu, 2019).

Optimization techniques used to control paving are single-goal or multi-goal optimization. There are various strategies for optimizing a single goal, such as lowering expenses or optimizing the advantages of care in terms of road conditions or life span (Irfan et al., 2012). The study on pavement maintenance is becoming an appropriate field to establish methods of multi-goal optimization. Efficient road maintenance preparation is also the primary objective of every road administration to schedule maintenance operations based on available funds (Pérez-Acebo et al., 2018). The PMS is an organized procedure to administer, sustain roadways efficiently and economically, based on statistical and quantitative methodologies. Thus, this study examines the previous work done on PMS in various countries. A critical review has been done and the gap of this study is also highlighted. It investigates the methods used for decision-making in various PMS. This paper also identifies all the possible defects that may occur in a flexible pavement and evaluates the relationship between the defect classes.

2. Research Methodology

A comprehensive process is designed for this study. As there are various stages involved in the research, a complete research flow is shown in Figure 1.

A comprehensive literature review has been made for this research and the research gap was highlighted from previous research. A review of various PMS research studies was done and its input was also considered while finalizing the list of the indicators (defects). A questionnaire was designed in the next phase to seek the expert's opinion on the defects and their priority for flexible pavement maintenance plans. The questionnaire was sent to almost 350 experts via email and hard form who are working and having experience in flexible pavement maintenance schemes. A total number of 283 questionnaires were successfully received and raw data was cleaned to observe any missing data point.

Based on the nature of the study, the data was collected from experts and professionals working in the National Highway Authority (NHA), Pakistan. The data was collected in three different rounds categorized as per study objectives. Figure 2 shows the graphical representation of the study area.

A descriptive statistical analysis of the survey was conducted using SPSS, version 25. The response to each question in the survey was imported into SPSS from Google forms and hard form data in excel. The complete data of 283 respondents for each question was plotted in the SPSS interface. Aggregated Mean Score (AMS) was used as a data analysis approach. The AMS has been successfully used numerous times in such data sets (Kausar, 2018)(Ali et al., 2019). The result validation was a key milestone in this research; therefore, a two-tier approach was developed. Standard Deviation (SD) and Skewness & Kurtosis tests were conducted on the data in tier one. Both validate each question separately as a distinct entity. Whereas, in tier two, the box plotting was also conducted to observe the results' possible data outliers and fitness.

A box plot, also known as a box and whisker plot, is a type of graph that displays a summary of a large amount of data in five numbers. These numbers include the median, upper quartile, lower quartile, minimum and maximum data values (Ladkin, 2018)(Whitaker et al., 2013). The use of boxplots in place of single points in a quality control chart can effectively display the information usually given in $\bar{X}$ and R charts, show the degree of compliance with specifications, and identify outliers (Iglewicz & Hoaglin, 1987).

A boxplot is a standardized way of displaying the distribution of data based on a five-number summary ("minimum", first quartile (Q1), median, third quartile (Q3), and "maximum"). It assist in outliers identification and data grouping density (Galarnyk, 2018). A box plot is a highly visually effective way of viewing a clear summary of one or more data sets. It is beneficial for quickly summarizing and comparing different sets of results from different experiments. At a glance, a box plot allows a graphical display of the distribution of results and provides indications of symmetry within the data (Ladkin, 2018).

In the last phase, the defect relationships were analyzed using chi-square test for each primary indicator which includes; Functional Defects, Structural Defects, Safety Defects and Serviceability Defects of flexible pavements. The Chi-Square statistic is commonly used for testing relationships between categorical variables as shown in Equation 1. The null hypothesis of the Chi-Square test is that no relationship exists on the categorical variables in the population; they are independent (Statistics_Solutions, 2012)(McHugh, 2012).

$$x_c^2 = \sum \frac{(O_i - E_i)^2}{E_i} \qquad (1)$$

where c is degrees of freedom, O is observed value(s) and E is expected value(s)

This statistic can be evaluated by comparing the actual value against a critical value found in a Chi-Square distribution, but it is easier to examine the p-value provided by SPSS simply. To conclude the hypothesis with 95% confidence, the value labeled Asymp. Sig. (which is the p-value of the Chi-Square statistic) should be less than .05 (the alpha level associated with a 95% confidence level) (Statistics_Solutions, 2012). A low value for chi-square means there is a high correlation between two sets of data. (McHugh, 2012)(Glen, 2020).

3. Results And Discussion

Each indicator has been analyzed to observe the data set and the specific results of each indicator. Table 2 shows that the summary of data collected from experts for structural indicators was only considered for this study.

Table 2: Case processing summary of structural indicators

Structural Defects	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Deflection	283	100.0%	0	0.0%	283	100.0%
Fatigue (Alligator) Crack	283	100.0%	0	0.0%	283	100.0%
Longitudinal Crack	283	100.0%	0	0.0%	283	100.0%
Traverse (Thermal) Crack	283	100.0%	0	0.0%	283	100.0%
Block Crack	283	100.0%	0	0.0%	283	100.0%
Swell/Frost Heaving	283	100.0%	0	0.0%	283	100.0%

It can be observed that there is no missing data item and all data points of the expert's judgement are properly stored from raw data in SPSS. Raw data of each defect is carefully shifted in SPSS format to assess the results and correlations further. A separate box plot assessment is carried out in the next phase to observe the data distribution for all defects considered in the structural indicator category. Figure 4 shows the results of box plotting.

It is observed that the data is usually distributed and there is no outlier in the data set for all defects in structural indicators category. The minimum score of deflection defect is 1, whereas its maximum score is 4 given by the experts. The defection defect has major data set scores from 2 to 3 as its mean lies at score 2 at the 25th quartile. The case of traverse cracks and block cracks is similar. Whereas, it is observed that longitudinal cracks have similar data distribution like deflection, traverse and block crack but its mean lies at 75th quartile, which is mean score 3. The case of fatigue and swell/frost heaving is different. The minimum score of a fatigue crack is 2 whereas its major data set lies between the score of 3 to 4 with a mean score of 3 at the 25th quartile.

Its maximum score is 4 and its 75th quartile has the same score. In case of swell/frost heaving, its minimum score is 1 and its maximum score is 3, which is also its 75th quartile. Swell/frost heaving has an average mean score of 2, which is its 25th quartile.

Table 3 shows the summary of data collected from experts for functional indicators considered for this study.

Table 3: Case processing summary of functional indicators

Functional Defects	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Rutting	283	100.0%	0	0.0%	283	100.0%
Corrugation	283	100.0%	0	0.0%	283	100.0%
Shoving	283	100.0%	0	0.0%	283	100.0%
Potholes	283	100.0%	0	0.0%	283	100.0%
Patching	283	100.0%	0	0.0%	283	100.0%
Raveling	283	100.0%	0	0.0%	283	100.0%
Bleeding/Flashing	283	100.0%	0	0.0%	283	100.0%
Delamination	283	100.0%	0	0.0%	283	100.0%
Drop-off	283	100.0%	0	0.0%	283	100.0%
Polished Aggregates	283	100.0%	0	0.0%	283	100.0%
Depression	283	100.0%	0	0.0%	283	100.0%
Bumps/Sags	283	100.0%	0	0.0%	283	100.0%

It can be observed that there is no missing data item and all data points of the expert’s judgement are properly stored from raw data in SPSS. Raw data of each defect is carefully shifted in SPSS format to assess the results and correlations further. A separate box plot assessment is carried out in the next phase to observe the data distribution for all defects considered in the functional indicator category. Figure 5 shows the results of box plotting.

It is observed that the data is almost normally distributed but it has few outliers. The minimum score of rutting defects is 2, whereas its maximum score is 4 given by the experts. The rutting defect major data set scores ranges from 2 to 4; therefore, its mean lies at score 3. The case of corrugation, raveling, bleeding/flashing, delamination and drop-off is very similar. Their minimum score is 1, which is also their 25th quartile score and their mean score is 2, which is also their 75th quartile score. Whereas, their maximum score is 3, given my all experts considered in this study. Shoving defect has some variations as its data is widely and there is no specific trend of its data. There can be much reason behind this outlier. It can be an expert’s misinterpretation of the defect or lack of coordination and information. Potholes and polished aggregates defects have a similar data trend as their minimum score is 1 and the maximum score is 4, whereas their maximum data sets are between 2 to 3, which are their scores at their 25th and 75th quartile. Despite such close association, it should be noted that their mean score is not similar. Pothole has higher mean score 3 as compare to polished aggregates, which have 2 mean score. Patching has different data distribution compared to all defects under functional indicators.

Patching 25th score and minimum scores are similar, whereas its 75th score and maximum score are also similar. The mean score of patching in this data set is 2 as per the data collected for this study. The defect depression has a minimum score of 2 which is also its 25th quartile. It has a maximum score of 4 but its mean score is 3, whereas its 75th quartile has 3.5 score. The last defect of this category is bumps/sags with a minimum score of 2 and a maximum of 4 at 75th quartile. Its mean score is 3 but there are two outliers observed in data set for this defect. Though, in this whole data set, it is not a big percentage of outliers it's hardly 3.8% of the collected data.

Table 4: Case processing summary of safety indicators

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Skid Resistance	283	100.0%	0	0.0%	283	100.0%
Potholes	283	100.0%	0	0.0%	283	100.0%
Edge Crack	283	100.0%	0	0.0%	283	100.0%
Rut Depth	283	100.0%	0	0.0%	283	100.0%
Rail Road Crossing	283	100.0%	0	0.0%	283	100.0%

It can be observed that there is no missing data item and all data points of the expert's judgement are properly stored from raw data in SPSS. Raw data of each defect is carefully shifted in SPSS format to assess the results and correlations further. A separate box plot assessment is carried out in the next phase to observe the data distribution for all defects considered in the safety indicator category. Figure 6 shows the results of box plotting.

It is observed that the data on defects in safety indicators varies for each defect. There is one defect with an outlier. The minimum score of skid resistance is 1, which is also its 25th quartile and its maximum score is 3. The mean score of skid resistance defect is 2, which is also its 75th quartile. The potholes minimum score is 1, and its maximum score is 4, whereas its mean score is 2, which is also its 25th quartile. The minimum score, 25th quartile and mean score of edge crack is 2, whereas its maximum score is 4. The rut depths 1, whereas its maximum score is 4 given by the experts. The defection defect has major data set scores from 2 to 3 as its mean lies at score 2 at 25th quartile. The case of traverse cracks and block crack is similar. Whereas, it is observed that longitudinal cracks have similar data distribution like deflection, traverse and block crack but its mean lies at 75th quartile which is mean score 3. The case of fatigue and swell/frost heaving is different. The minimum score of a fatigue crack is 2, whereas its major data set lies between the score of 3 to 4 with a mean score of 3 at the 25th quartile. Its maximum score is 4, and its 75th quartile has the same score. In the case of swell/frost heaving, its minimum score is 1 and its maximum score is 3, which is also its 75th quartile. Swell/frost heaving has an average mean score of 2, which is its 25th quartile.

Table 5 shows the summary of data collected from experts for serviceability indicators considered for this study.

Table 5: Case processing summary of serviceability indicators

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Roughness	283	100.0%	0	0.0%	283	100.0%
Slippage Crack	283	100.0%	0	0.0%	283	100.0%
Reflection Crack	283	100.0%	0	0.0%	283	100.0%
Draining	283	100.0%	0	0.0%	283	100.0%

It can be observed that there is no missing data item and all data points of the expert's judgement are properly stored from raw data in SPSS. Raw data of each defect is carefully shifted in SPSS format to assess the results and correlations further. A separate box plot assessment is carried out in the next phase to observe the data distribution for all defects considered in the serviceability indicator category. Figure 7 shows the results of box plotting.

Any PMS must explore the frequent defects and problems pavement is suffering from; therefore, defect identification is done and prioritize the key defects after the expert's opinion. Table 6 shows the ranking of the defects typically observed in the flexible pavements.

Table 6: Ranking of all flexible pavement defects

Defects	Statistic	Statistic	Skewness	Kurtosis	Ranking
	Mean	Std. Deviation	Statistic	Statistic	
Bumps/Sags	3.1731	0.7598	-0.863	0.952	1
Fatigue (Alligator) Crack	3.0769	0.73688	-0.123	-1.108	2
Rutting	2.9808	0.75382	0.032	-1.205	3
Rut Depth	2.9808	0.72735	0.03	-1.058	3
Depression	2.9615	0.73994	0.062	-1.129	4
Potholes	2.7692	0.83114	0.037	-0.802	5
Longitudinal Crack	2.6923	0.80534	0.158	-0.682	6
Edge Crack	2.5577	0.69771	0.867	-0.447	7
Roughness	2.5192	0.72735	0.408	-0.222	8
Deflection	2.5	0.93934	0.148	-0.826	9
Polished Aggregates	2.4615	0.82751	0.235	-0.412	10
Traverse (Thermal) Crack	2.4038	0.7478	0.05	-0.218	11
Block Crack	2.3077	0.64286	0.079	-0.048	12
Potholes	2.2692	1.01199	0.488	-0.781	13
Draining	2.1154	0.70444	-0.166	-0.92	14
Swell/Frost Heaving	2.0962	0.7478	-0.16	-1.162	15
Shoving	2	0.68599	0	-0.794	16
Patching	1.9615	0.79117	0.069	-1.385	17
Drop-off	1.9038	0.7211	0.147	-1.018	18
Slippage Crack	1.8846	0.70444	0.166	-0.92	19
Raveling	1.8077	0.71506	0.302	-0.965	20
Bleeding/Flashing	1.7692	0.67491	0.313	-0.762	21
Reflection Crack	1.7692	0.70336	0.358	-0.893	21
Delamination	1.7115	0.66676	0.404	-0.719	22
Skid Resistance	1.6731	0.67798	0.511	-0.723	23
Corrugation	1.6346	0.62713	0.457	-0.607	24
Rail Road Crossing	0.2308	0.42544	1.316	-0.28	25

It has been observed that Bumps/ Sags are one of the major defects reported by the experts in pavements in Pakistan, followed by fatigue cracks. Rutting and rut depth stands at the third key defects reported in this study. Depression, potholes, longitudinal crack, edge crack, roughness and deflection are also regularly arising defects in pavement maintenance activities in Pakistan. Similar defect ranking were also observed in the previous studies (Rashid & Gupta, 2017)(Public, 2017)(Loprencipe & Pantuso, 2017)(Gáspár, 2017)(Van Geem et al., 2016).The result validation is done using standard deviation, skewness and kurtosis test. Most of the results are in the acceptance range of the three mentioned validation methods. It is analyzed that skid resistance, corrugation, and railroad crossing are rare types of defects in flexible pavements.

In the later phase, it was essential to analyze the possible relationship between the defects considered under four PMS indicators. It is crucial to observe that "Is there any close relation occur or do not occur between the defects" considered under all indicators for this PMS. So, the Chi-Square test is conducted to assess the relationship between the defects for flexible pavements. Table 7 shows the results of the test.

Table 7: Chi-Square test results

Structural Indicators						
	Deflection	Fatigue (Alligator) Crack	Longitudinal Crack	Traverse (Thermal) Crack	Block Crack	Swell/Frost Heaving
Chi-Square	9.231a	14.308a	19.231a	25.692a	38.923a	3.500b
df	3	3	3	3	3	3
Asymp. Sig.	.026	.006	.000	.000	.000	.174
a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 13.0.						
b. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 17.3.						

Functional Indicators										
	Rutting	Corrugation	Shoving	Potholes	Raveling	Bleeding/Flashing	Delamination	Drop-off	Depression	Bumps/Sags
Chi-Square	2.808a	15.500b	9.846a	16.154b	6.731a	10.654a	11.577b	5.808b	3.962a	31.231a
df	3	3	3	3	3	3	3	3	3	3
Asymp. Sig.	.046	.067	.007	.081	.035	.033	.063	.045	.038	.041
a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 17.3.										
b. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 13.0.										

Safety Indicators					
	Skid Resistance	Potholes	Edge Crack	Rut Depth	Rail Road Crossing
Chi-Square	11.115a	10.923a	15.269a	5.115a	15.077b
df	2	3	2	2	1
Asymp. Sig.	.004	.012	.000	.007	.000
a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 17.3.					
b. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 26.0.					

Serviceability Indicators				
	Roughness	Slippage Crack	Reflection Crack	Draining
Chi-Square	30.000a	7.538a	8.000b	7.538a
df	3	3	3	3
Asymp. Sig.	.000	.023	.068	.023
a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 13.0.				
b. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 17.3.				

The correlation test results of structural indicators show that the defection, fatigue crack, longitudinal crack, traverse crack and block cracks rejects the null hypothesis thus, there is a close relationship between these defects in flexible pavements. There are possible chances that where deflection is observed in flexible pavements, there can also be fatigue crack, longitudinal crack, traverse crack, and block cracks. A similar relationship is also possible between these defects, which rejects the null hypotheses. Whereas, only frost heaving has no relationship observed between the defect types in structural indicator of the flexible pavement’s maintenance management. The correlation test results of functional indicators show that rutting, shoving, raveling, bleeding, depression and bumps rejects the null hypothesis and there is a close relationship between these defects There are possible chances that where rutting is observed, there can also be shoving, raveling, bleeding, depression, and bumps. Whereas, corrugation, potholes, delamination and drop off has no relationship observed between the defect types in functional indicator.

Similarly, safety indicators including skid resistance, potholes, edge crack and rut depth reject the null hypothesis. Hence, there is a close relationship between these defects There are possible chances that where skid resistance is observed then there can also be potholes, edge crack and rut depth. The serviceability indicators show that roughness, slippage crack and poor drainage reject the null hypothesis so, there is a close relationship between these defects There are possible chances that where roughness is observed in flexible pavements, then there can also be slippage crack and poor drainage.

In the end based on the results of the study, a PMS framework is proposed for developing countries as shown in figure 8.

The proposed PMS has three tier decision making approach. In tier one, the case selection is made. There can be possible three cases for any pavement maintenance scheme which includes; Emergency Case (Need based, Non predictable), Routine Case (Short term plans, require less time, efforts and funds) and Periodic Case (Long term plans, require more time, efforts and funds). Each case has its own implications and significance. Therefore, this framework will select the case first. In second tier, the indicators will be selected based on the feedback of tier one. Like for emergency case, road safety indicators have top most priority followed for functional and serviceability indicators as part of the similar suggestion is given by previous studies (Shabir Hussain Khahro et al., 2021)(Ding et al., 2013)(Heyns et al., 2012)(Manosalvas-Paredes et al., 2020)(Hamim et al., 2021). Similarly, the indicator selection for other cases is different as shown in the framework. In the third tier, the model will select the sub-indicators based on the second-tier results. Like for safety the sub indicators are different and the sub indicators will be selected based on their score. The sub-indicators are classified based on their scores in the expert's feedback as shown in the Table 6 above. In class one sub indicator category, the defects with score more than 3 will be selected by the model. It is based on frequency and significance of the defect as per the scenario rated by the experts. Likewise, the defects with score between 2.5 to 3.0 are classified as class two. There are different defects which lie in class two as shown in the framework. In class three sub indicator category, the defects with score between 2.0 and 2.5 will be selected and the defects with score below 2.0 will be classified as last category by the model.

The model will group the tiers based on the different scenario required by the pavement maintenance management authority. The model will optimize the decision based on pavement defect type, its frequency and low-cost solution.

4. Conclusion

It is concluded that PMS has been the topic of key interest but limited attempts are made for low-cost PMS globally and none of such attempts made earlier in Pakistan where existing models cannot work efficiently due to varying local conditions. GIS is mainly used for graphical representation of the pavement maintenances schemes with the combination of surveys, case studies, machine learning, deep learning, SPSS and PLS as a decision-making tool for PMS indicators. Whereas limited attempts are made using PLS.

It is concluded that Bumps/Sags (3.17) are one of the major defect reported by the experts in pavements in Pakistan followed by the fatigue cracks (3.07). Rutting (2.98) and rut depth (2.98) stand at third key defects reported in this study. Depression (2.96), potholes (2.76), longitudinal crack (2.69), edge crack (2.55), roughness (2.51) and deflection (2.50) are also regularly arising defects in pavement maintenance activities in Pakistan.

The correlation test of structural indicators shows that the defection, fatigue crack, longitudinal crack, traverse crack and block cracks reject the null hypothesis thus, there is a close relationship between these defects in flexible pavements. There are possible chances that where deflection is observed in flexible pavements, there can also be fatigue crack, longitudinal crack, traverse crack, and block cracks. Similarly, the correlation test of functional indicators shows that rutting, shoving, raveling, bleeding, depression and bumps reject the null hypothesis under one category thus, there is a close relationship between these defects in flexible pavements.

The correlation test of safety indicators shows that skid resistance, potholes, edge crack and rut depth reject the null hypothesis under one category thus, there is a close relationship between these defects in flexible pavements. Likewise, the correlation test of serviceability indicators shows that roughness, slippage crack and poor drainage reject the null hypothesis thus, there is a close relationship between these defects in flexible pavements.

The proposed model works in three stages including case selection, indicator selection followed by sub indicator selection. Each case represents a different real practical scenario and cost is the key feature in defect selection criteria and its possible treatment selection. The model has simple operating method which is user friendly and limited numeric calculations are involved in the model. This model will assist the decision makers of pavement maintenance authorities to make condition-based decision and utilizing limited funds they can assure the functionality and serviceability of the road for the users.

The model can also be used for rigid pavement with some modification in the sub indicators only whereas the cases and indicators can be same for both classes of pavements. The model can be extended to any mobile application for easy and rapid decision making for the users.

Declarations

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Ethical Approval

Not applicable.

Consent to participate

Not applicable.

Consent to Publish

Not applicable.

Authors Contributions

Shabir Hussain Khahro: Conceptualization, Data Collection, and Analysis, Writing

Zubair Ahmed Memon: Project Administration

Nur Izzi Md. Yusoff: Supervisor and Review

Lillian Gungat: Research methodology and data collection

Muhamad Razuhanafi Mat Yazid: Questionnaire design and validation

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Conflict of Interest

The authors declare that there is no conflict of interest.

Availability of data and material

Not applicable.

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Figures

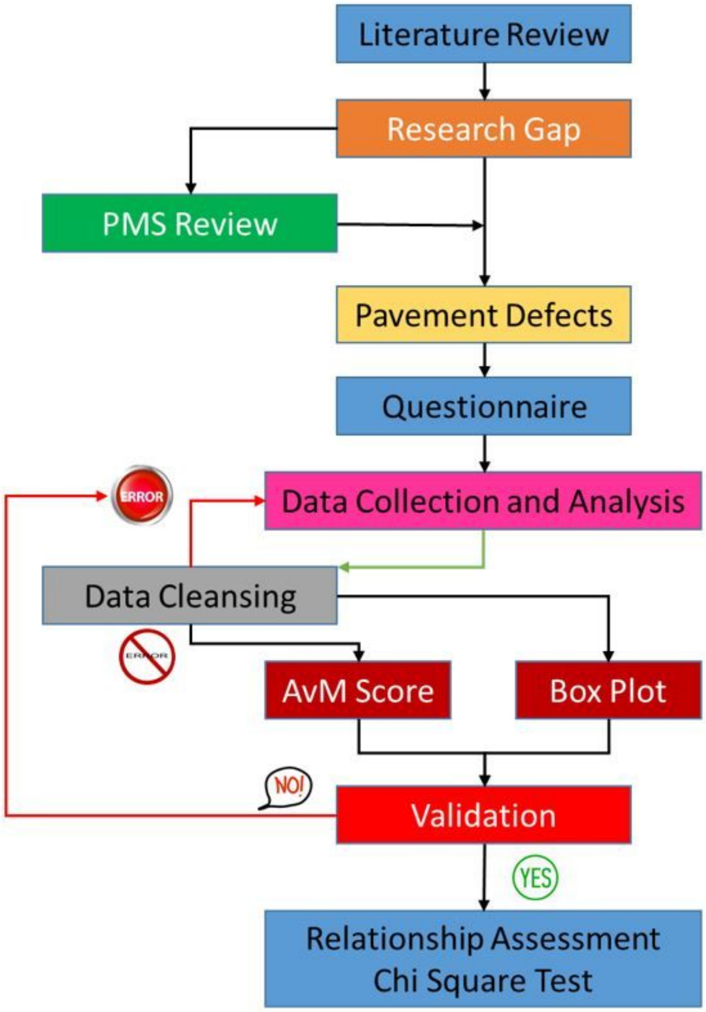

Figure 1

Research methodology

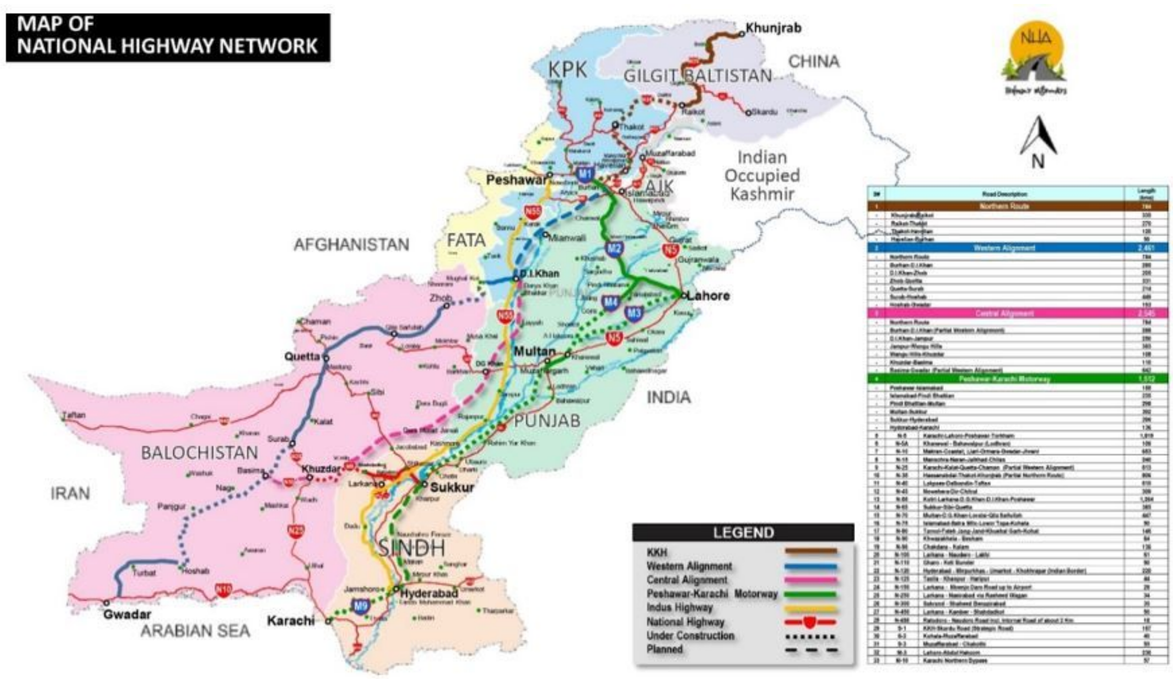

Figure 2

National Highway Network in Pakistan

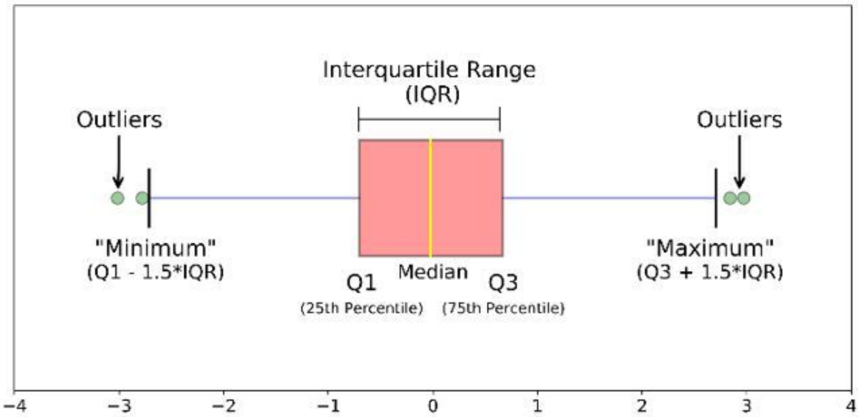

Figure 3

Box plot and its structure (Iglewicz & Hoaglin, 1987)

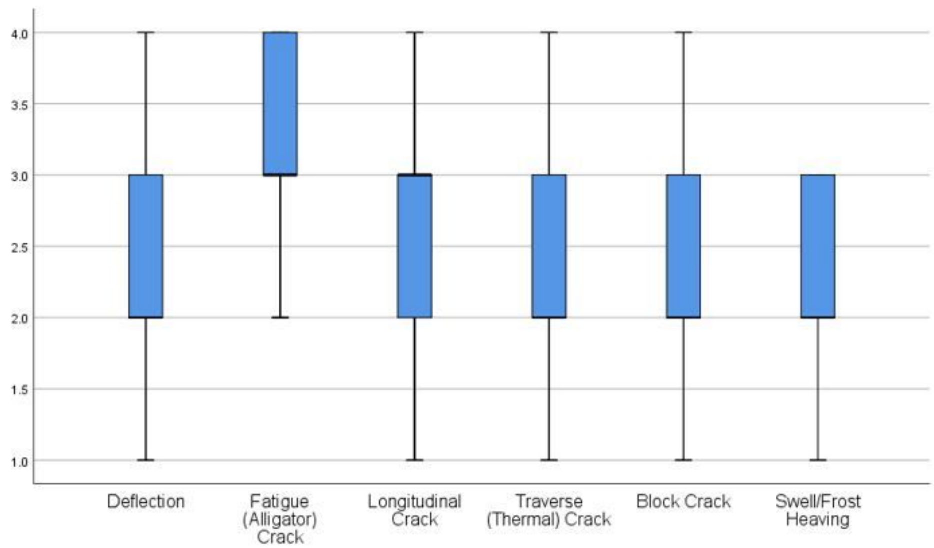

Figure 4

Boxplot assessment for structural indicators

Figure 5

Boxplot assessment for functional indicators

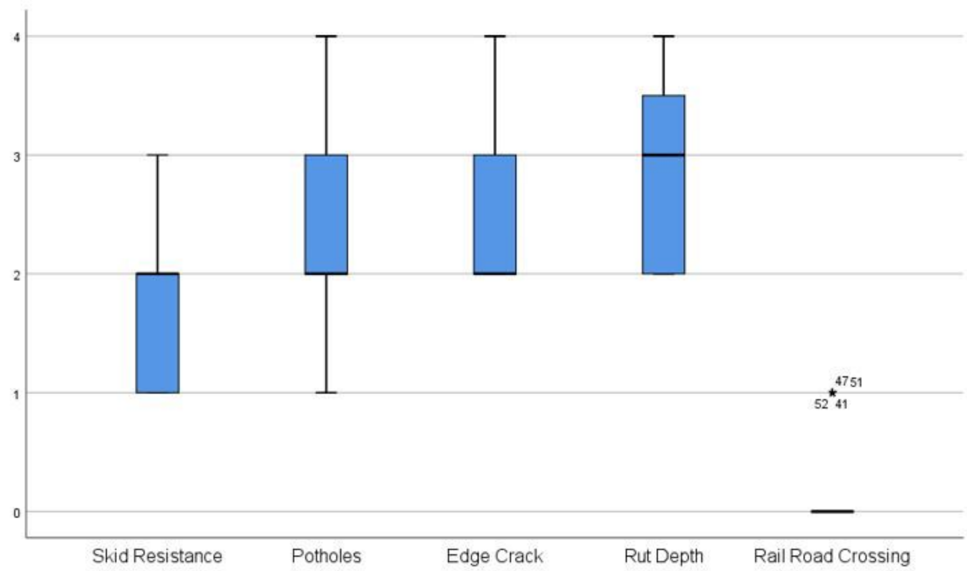

Figure 6

Boxplot assessment for safety indicators

Figure 7

Boxplot assessment for serviceability indicators

Figure 8

PMS Framework