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Application of analytic hierarchy process (AHP) for sustainable pavement performance management in Qatar

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Abstract

Purpose – Pavement is one of the main elements of the roads network. It is extremely essential to study and understand the factors affecting its performance and highlight the most important ones for decision-makers and pavement experts to consider during the design, construction and maintenance stages. The purpose of this paper was to identify the factors affecting pavement performance and rank them according to their importance using Analytic Hierarchy Process (AHP) for decision-makers and pavement experts to consider during the design, construction and maintenance stages.
Design/methodology/approach – A survey was developed considering 29 factors found in the literature that affect pavement performance. The survey was sent to pavement professionals in Qatar to rate their perception of factors affecting pavement performance to enhance roads' sustainability. 205 responses were collected and analyzed using AHP.
Findings – The findings indicate that the factor "unconsidered heavy vehicles volume" is the most critical factor that affects pavement performance. The second most critical factor affecting the pavement performance is the "low asphalt content" due to escalating binder aging, reducing fatigue life of the pavement and decreasing the durability of roads. The third and fourth factors are "poor mechanical and thermal properties" and "unexpected high traffic volume," respectively. These two factors are strongly attached to the first and second factors since the traffic volume affects the pavement performance less but similar to the heavy vehicles and a mix with poor mechanical and thermal properties is related indirectly to the asphalt content in the mix.
Originality/value – The research provides help for decision-makers in the construction industry to improve the performance of pavements using a multi-criteria decision-making tool. This paper's outcome would help the pavement management professionals in the construction industry to improve pavement performance and management, increase the pavement's life cycle and reduce maintenance costs.

Keywords Pavement management model, Analytic hierarchy process, Pavement performance, Sustainable pavement, Pavement perspectives, Pavement condition
Paper type Research paper

1. Introduction

One of the main awareness for a road infrastructure manager is to increase its efficiency under limited resources (Moreira *et al.*, 2018). Pavement performance of asphalt is an important criterion for road engineering quality evaluation (Tiza *et al.* 2016). Pavement-management systems are important tools that planning agencies depend on to maintain their roadway systems (Swei *et al.*, 2019). Pavement performance is the ability of a road to handle the traffic load sufficiently without deformation or defects during the road's designed life. In real life, pavement performance is complicated due to various factors of different magnitude during pavement life.

The literature review indicated that previous studies concentrated on some of these factors to improve pavement performance. However, the outcomes' accuracy can be questionable because the pavement performance process is affected by many different factors at diverse rates and times. The main objective of this paper was to analyze the effect of each factor and pairwise compare them with respect to pavement performance using the analytic hierarchy process (AHP). All factors identified from the literature review were

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ranked based on the importance of their effect on pavement performance according to AHP to assist the decision-makers in specifying the most critical factors to consider during the design, construction and maintenance stages of the pavement.

2. Literature review

Pavement performance of asphalt is an essential criterion for road engineering quality evaluation (Tian *et al.* 2018). The pavement is performing fine if it is safe and comfortable for road users to drive on it during the road's designed life. A detailed literature review was conducted on previous studies related to the pavement performance to identify the factors involved in this complicated process. Several studies concentrated on traffic factors, such as the simulation models used by researchers to predict future pavement performance. These models require accurate traffic volumes input to work properly (Premkumar and Vavrik, 2016). Other studies focused on factors related to the mechanical and thermal properties of asphalt mixtures. In a recent study by Mehta *et al.* (2017), the performance of slabs built over the econocrete base and bituminous base were compared. It was found that fewer cracks formed over the econocrete base than over the bituminous base. In another study by Francois *et al.* (2019), results indicated that the portland cement-treated base was more effective than the bituminous stabilized base for fatigue cracking. Likewise, many previous researchers studied the factors related to other categories given in Table 1, such as highway design, quality and maintenance, surface condition and environmental factors. The literature review resulted in 29 factors that directly or indirectly affect pavement performance. These factors are listed into six categories, as shown in Table 1 below.

According to the factors identified by the literature review, a survey was developed and circulated to professionals in the pavement industry in Qatar. The survey aimed to capture the assessment of the professionals to assist in ranking the importance of each factor`s effect on pavement performance in Qatar.

3. Methodology

29 factors affecting pavement performance were identified through a detailed literature review. To analyze the importance of these factors, professional opinions were needed from specialists working in the pavement field. Thus, a survey was developed to observe the respondents' judgments on the importance of each factor`s effect on pavement performance. The first part of the survey was related to data demography such as organization type, job designation, field of experience, years of experience and companies` size. The second part of the survey asked the respondents to judge the importance of each factor`s effect on pavement performance according to a (1–9) scale, as shown in Table 2 below.

A total of 205 surveys were collected from the respondents in Qatar, and the Relative Importance Index (RII) was applied to the collected data prior to the AHP model. An AHP model was built using the Super Decisions software fed by the survey data. Figure 1 summarizes the methodology used in this study and similar previous studies on AHP.

4. Data characteristics

To develop and distribute the survey and collect the responses, an online website application called "SurveyMonkey.com" was used in this study. In addition, some responses were collected from experts as hardcopies and manual input during conferences and professional events related to pavement performance. Incomplete responses were disregarded to avoid ambiguous results. A total of 205 completed responses were received from professionals. The largest portion of respondents worked for construction contractors (37%), followed by

#	Category	Factor name	References
1	Environment	Extreme weather conditions	Wayne Lee *et al.* (2017), Yang *et al.* (2016)
2		High rainy seasons	Premkumar and Vavrik (2016), Xiao and Wu (2016)
3		High repetition of freeze thaw cycles	Meegoda and Gao (2015), McGhee and Flintsch (2003), Galambos (1997)
4	Mix design properties	Low asphalt content	Xiao and Wu (2016), Wayne Lee *et al.* (2017), Premkumar and Vavrik (2016)
5		Poor mechanical and thermal properties	Yang *et al.* (2016)
6		Using additives in hot mix asphalt	Wayne Lee *et al.* (2017), Zhang *et al.* (2018), Behl *et al.* (2013)
7		Excessive use of recycled aggregate	Mehta *et al.* (2017), Tian *et al.* (2018), Premkumar and Vavrik (2016)
8	Highway design	Substandard curvature degree	Wayne Lee *et al.* (2017)
9		Excessive use of rumble strips	Wayne Lee *et al.* (2017), Mehta *et al.* (2017), Tao and Mallick (2009)
10		Improper crosswalk location	Mehta *et al.* (2017), Shirzad *et al.* (2018), Tran *et al.* (2012)
11		Absence of safety edge	Yi (2017), Erlichson (1991), Crisman and Roberti (2012)
12		Steep slope	Coffey and Park (2016), Daniel (2007), Watson *et al.* (2008)
13		Thin asphalt layers	Xiaodi *et al.* (2017), Duncan-Jones (1998)
14		Low structural capacity	Mehta *et al.* (2017), Tawalare and Raju (2016), Lau and Popik (2014)
15		Short design life	Li *et al.* (2015), Medl *et al.* (2017), Zheng (2017)
16		Absence of drainage system	Premkumar and Vavrik (2016), Yang *et al.* (2016), Wayne Lee *et al.* (2017)
17		Insufficient drainage system	Premkumar and Vavrik (2016), Wayne Lee *et al.* (2017), Yang *et al.* (2016)
18	Surface condition	Extremely rough road surface	Premkumar and Vavrik (2016), Tian *et al.* (2018), Yang *et al.* (2016)
19		Low skid resistance	Tawalare and Raju (2016), Tiza *et al.* (2016), Agbonkhese *et al.* (2013)
20		High rut depth	Tawalare and Raju (2016), Tiza *et al.* (2016), Agbonkhese *et al.* (2013)
21		High percentage of cracks	Li *et al.* (2017), Newland (2015), Guarin (2013)
22	Quality and maintenance	Lack of quality assurance (QA) procedures	Li *et al.* (2017), Mishalani and Gong (1999), Wayne Lee *et al.* (2017)
23		Poor quality material used in road construction	Hamdar *et al.* (2015), Ding *et al.* (2017), Newland (2015), Guarin (2013)
24		Noncompliance with specification requirements	Bretreger (2015), Hamdar *et al.* (2015), Guarin (2013), Hughes (1984)
25		Improper field compaction	Tawalare and Raju (2016), Tiza *et al.* (2016), Agbonkhese *et al.* (2013), Newland (2015)
26		Lack of maintenance of the drainage system	Yang *et al.* (2016), Premkumar and Vavrik (2016), Wayne Lee *et al.* (2017)
27	Traffic	Unexpected high traffic volume	Tawalare and Raju (2016), Yang *et al.* (2016), Meegoda and Gao (2015), McGhee and Flintsch (2003), Galambos (1997)
28		Higher operating speed than posted speed	Tawalare and Raju (2016), Premkumar and Vavrik (2016), Wayne Lee *et al.* (2017), Yang *et al.* (2016)
29		Unconsidered heavy vehicles volume	Premkumar and Vavrik (2016), Coffey and Park (2016), Tawalare and Raju (2016), Tian *et al.* (2018), Wayne Lee *et al.* (2017)

Table 1. Summary of the factors affecting pavement performance in the literature

professionals who work for clients and owners like public authorities (22%), as shown in Figure 2.

Reference is made to the job designation; most of the respondents were project managers and project engineers (33% and 31% respectively). More than a third of the participants were involved in construction projects (35%), while a fifth of them was involved in design (21). According to the experience, participants with 6–10 years of experience and 11–15 years of experience made (32%) and (32%) of the total responses, respectively. Finally, yet importantly, half of the participant were from large companies (54%), while the minority worked for small companies (9%)

Table 2.
(1–9) scale for evaluating the importance of each factor`s effect

Score	1	2	3	4	5	6	7	8	9
Importance of effect	Minor	↔	Moderate	↔	Strong	↔	Very strong	↔	Extremely strong

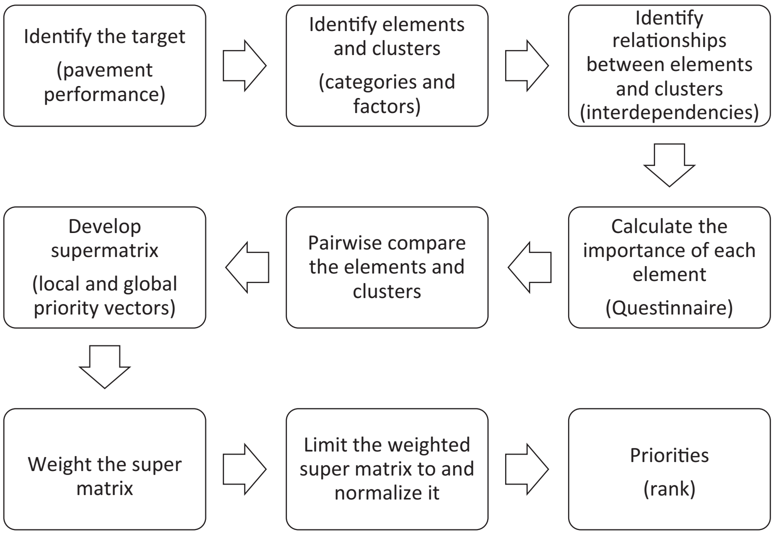

Figure 1.
Research methodology

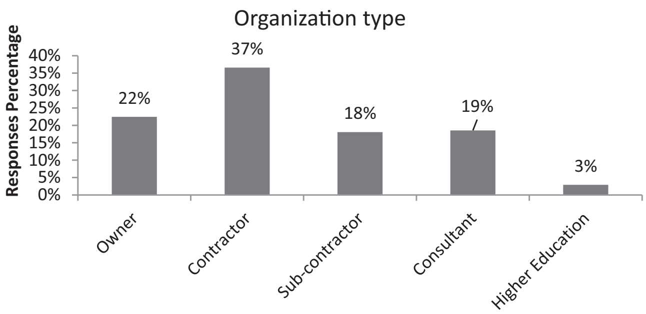

Figure 2.
Percentage of respondents according to organization type

5. Data analysis

Professionals in the pavement industry were tasked to evaluate the importance of the effect for each factor according to (1–9) scale. For example, for each factor, the question was, "How important is the impact of this factor on the pavement performance?" , and the respondents answered this question as shown in Table 3 below for each factor.

5.1 Relative Importance Index (RII)

Relative Importance Index is a well-known and sufficient ranking strategy adopted in this study, and it is the average importance score for each factor, as shown in Eqn 1 below.

$$\mathrm{RII}(\%) = \frac{\sum S}{H * N} \tag{1}$$

Where,

ΣS = the summation of each importance score multiplied by its number of responses.

H = highest possible number (nine in this study)

N = total number of respondents (205 in this study)

For example, the RII for the factor "Improper field compaction" $\mathrm{RII}_{(\text{factor } 21)}$ is calculated from Table 3 as below:

$$\mathrm{RII}_{(\text{factor } 21)} = \frac{\sum (1*1) + (2*2) + (3*1) + (4*3) + (5*16) + (6*7) + (7*54) + (8*90) + (9*31)}{9*205}$$

$$\mathrm{RII}_{(\text{factor } 21)} = 0.8233$$

The RII values for each factor were calculated. After that, the factors were ranked based on their RII values resulted from 205 completed surveys, and the factors were listed in Table 4.

The factor "absence of drainage system" ranked first according to the RII, and the factor "unconsidered heavy vehicles volume" ranked second, followed by the factor "improper field compaction" and the factor "insufficient drainage system," respectively. Oppositely, the factor "improper crosswalk location" ranked last right after the factor "excessive use of rumble strips" and the factor "higher operation speed than posted speed."

5.2 (1–9) scale conversion

It is recommended to convert the RII rank into (1–9) scale for easy use in AHP. The comparison analysis in AHP will depend on the ranking of RII factors. Thus, the rank in Table 4 was distributed among each category. The difference between the maximum RII rank and the minimum RII rank was calculated to be used in the conversion function to develop the conversion table. According to the AHP procedure given in prior studies, the value 1 in the (1–9) scale reflects the comparison of a factor to itself only. This means the minimum value for comparing two different factors in (1–9) scale is two, and the maximum value is nine.

Thus, the maximum local difference in any category is 28 since the first RII rank (1) and the last RII rank (29) was found in the "highway design" category, as shown in Table 5 below. The "RII rank" is the factor rank according to the RII, "Max" is the maximum RII rank in the category, "Min" is the minimum RII rank in the category and "Difference" is "Max-Min."

From the above, the linear trend line equation can be simply developed from the maximum and minimum difference between RII rank by the point (1–28) and highest and lowest values in the (1–9) scale by the point (2–9) as shown in Eqn 2 below:

Factor	1 Minor	2 ↔	3 Moderate	4 ↔	5 Strong	6 ↔	7 Very strong	8 ↔	9 Extremely strong	Total
	Number of responses for each importance score									
Unexpected high traffic volume	1	3	19	47	27	19	37	28	24	205
Higher operating speed than posted speed	35	70	26	20	24	9	16	2	3	205
Unconsidered heavy vehicles volume	0	1	2	2	16	20	48	60	56	205
Low asphalt content	1	2	6	13	21	44	80	28	10	205
Poor mechanical and thermal properties	2	2	5	17	34	43	47	46	9	205
Using additives in hot mix asphalt	4	2	7	17	38	45	57	28	7	205
Excessive use of recycled aggregate	2	5	10	27	35	50	41	27	8	205
Substandard curvature degree	14	52	67	22	12	15	11	8	4	205
Excessive use of rumble strips	18	82	45	20	20	8	10	2	0	205
Improper crosswalk location	64	55	29	20	9	7	13	1	7	205
Absence of safety edge	19	26	37	48	26	25	11	8	5	205
Steep slope	10	20	59	53	24	18	12	7	2	205
Thin asphalt layers	1	8	7	19	19	34	70	35	12	205
Low structural capacity	3	1	8	10	27	35	48	56	17	205
Short design life	3	3	6	10	26	40	66	38	13	205
Absence of drainage system	1	0	3	3	16	12	37	78	55	205
Insufficient drainage system	2	0	1	3	11	37	65	53	33	205
Lack of quality assurance (QA) procedures	1	3	2	1	12	19	93	55	19	205
Poor quality material used in road construction	2	2	0	8	15	31	65	58	24	205
Non-conformance with specification requirements	3	29	52	31	22	22	21	15	10	205
Improper field compaction	1	2	1	3	16	7	54	90	31	205
Lack of maintenance of the drainage system	0	2	8	3	12	16	84	59	21	205
Extremely rough road surface	4	4	31	64	31	27	24	15	5	205
Low skid resistance	4	39	45	32	26	22	22	10	5	205
High rut depth	2	10	15	36	39	47	32	15	9	205

(*continued*)

Table 3.
Evaluation score for all factors

Factor	1 Minor	2 ↔	3 Moderate	4 ↔	5 Strong	6 ↔	7 Very strong	8 ↔	9 Extremely strong	Total
	Number of responses for each importance score									
High percentage of cracks	3	6	9	18	48	32	50	29	10	205
Extreme weather conditions	0	7	54	54	25	25	21	11	8	205
High rainy seasons	1	17	27	21	31	34	39	27	8	205
High repetition of freeze thaw cycles	7	4	6	6	19	19	54	55	35	205
Substandard curvature degree	14	52	67	22	12	15	11	8	4	205

Importance score

Table 3.

Factor	RII value	RII rank
Absence of drainage system	0.8412	1
Unconsidered heavy vehicles volume	0.8325	2
Improper field compaction	0.8233	3
Insufficient drainage system	0.7967	4
Lack of quality assurance (QA) procedures	0.7875	5
Lack of maintenance of the drainage system	0.7832	6
Poor quality material used in road construction	0.7772	7
High repetition of freeze thaw cycles	0.7583	8
Low structural capacity	0.7322	9
Short design life	0.7154	10
Low asphalt content	0.7144	11
Poor mechanical and thermal properties	0.7019	12
Thin asphalt layers	0.6997	13
Using additives in hot mix asphalt	0.6737	14
High percentage of cracks	0.6602	15
Unexpected high traffic volume	0.6504	16
Excessive use of recycled aggregate	0.6504	17
High rainy seasons	0.6070	18
High rut depth	0.6033	19
Extremely rough road surface	0.5480	20
Extreme weather conditions	0.5279	21
Non-conformance with spec. requirements	0.5095	22
Low skid resistance	0.4802	23
Absence of safety edge	0.4553	24
Steep slope	0.4472	25
Substandard curvature degree	0.3978	26
Higher operating speed than posted speed	0.3588	27
Excessive use of rumble strips	0.3420	28
Improper crosswalk location	0.3198	29

Table 4.
RII ranking for factors affecting pavement performance

$$y = 0.2593x + 1.7404 \tag{2}$$

After that, the conversion scale shown in Table 6 is developed based on the conversion function. For example, multiplying the RII rank difference 4 by 0.2593 and adding 1.7404 equals 2.7779 and could be rounded up to be 3, which is the corresponding (1–9) scale difference.

5.3 Pairwise comparison

The first step in AHP is developing the unweighted super matrixes. This can be done by pairwise comparison between factors within the same category in (1–9) scale. Score 1 results only when comparing the factor to itself. When comparing two different factors, the higher value will get the score, and the factor with the lower value will get the opposite of the score. For example, comparing factor number 6 and factor number 4 in the mix design properties category resulted in 3 for factor number 6 and 1/3 for factor number 4. This means the effect of factor 6 is "very important to extremely important" more than the effect of the factor number 4 on the pavement performance. Tables 7 and 8 below show the super matrix for each category.

5.4 Categories comparison

The next step in the AHP is to have a pairwise comparison at the categories' level to include their importance in the calculations. Thus, it is mandatory to calculate the RII (%) for every

Table 5.
RII rank for the highway design category

Factors	RII rank	Local	Values
Substandard curvature degree	26		
Excessive use of rumble strips	28	Max	29
Improper crosswalk location	29	Min	1
Absence of safety edge	24	Difference	28
Steep slope	25		
Thin asphalt layers	13		
Low structural capacity	9		
Short design life	10		
Absence of drainage system	1		
Insufficient drainage system	4		

Table 6.
Conversion of RII rank difference into (1–9) scale

RII rank difference	Difference in (1–9) scale
1–2	2
3–6	3
7–10	4
11–14	5
15–18	6
19–22	7
23–26	8
27–28	9

Table 7.
Pairwise comparison between factors in the environment category

Factors number	1	2	3
1	1	1/3	1/5
2	3	1	1/4
3	5	4	1

category based on each importance score's number of responses. The categories were ranked according to the computed RII values from the importance score gathered from the survey, as shown in Table 9. Finally, categories are pairwise compared, likewise the pairwise comparison of the factors, as shown in Table 10 below.

6. AHP procedure

AHP in this study is a hierarchy headed by pavement performance and consists of factors within categories. This method simplifies complex problems and improves the real-life situation (Aragones-Beltran *et al.* 2010).

AHP requires identifying the main target, elements and clusters of the problem in real life to build the problem as a hierarchy headed by the main goal. After that, a pairwise comparison was made between each pair of elements in every cluster to develop a priority vector for each cluster. The priority vectors will then be used in the matrixes. Likewise, pairwise comparison between the clusters was made to provide the eigenvectors, which will be used in weighting the super matrixes.

Next, the super matrix is developed by combining the priority vectors. It is weighted by summing the columns to unity by multiplying the matrix by the cluster's eigenvector. Finally,

Factors number	4	5	6	7
4	1	1/2	1/3	1/3
5	2	1	1/2	1/3
6	3	2	1	1/3
7	3	3	3	1

Table 8. Pairwise comparison between factors in the mix design properties category

Categories	RII rank
Quality and maintenance	1
Traffic	2
Mix design properties	3
Highway design	4
Surface condition	5
Environment	6

Table 9. RII rank for the categories

Categories	Traffic	Mix design properties	Highway design	Quality and maintenance	Surface condition	Environment
Traffic	1	2	2	3	3	3
Mix design properties	1/2	1	2	2	3	4
Highway design	1/2	1/2	1	2	2	3
Quality and maintenance	1/3	1/2	1/2	1	2	2
Surface condition	1/3	1/3	1/2	2	1	2
Environment	1/3	1/4	1/3	1/2	1/2	1

Table 10. Pairwise comparison between categories

the weighted super matrix is raised to the power of a large number to achieve convergence to form the limiting matrix where the AHP values are determined.

7. AHP analysis

Figure 3 below shows the AHP model built for this study.

After preparing this model, pairwise comparing the factors within the same category to develop the local priority, pairwise comparing the categories to develop the eigenvector, multiplying all local priority vectors with eigenvector provided the limit matrix (see TablesA1 and A2). Finally, the limit matrix is converted to the AHP values for the factors shown in Table 11.

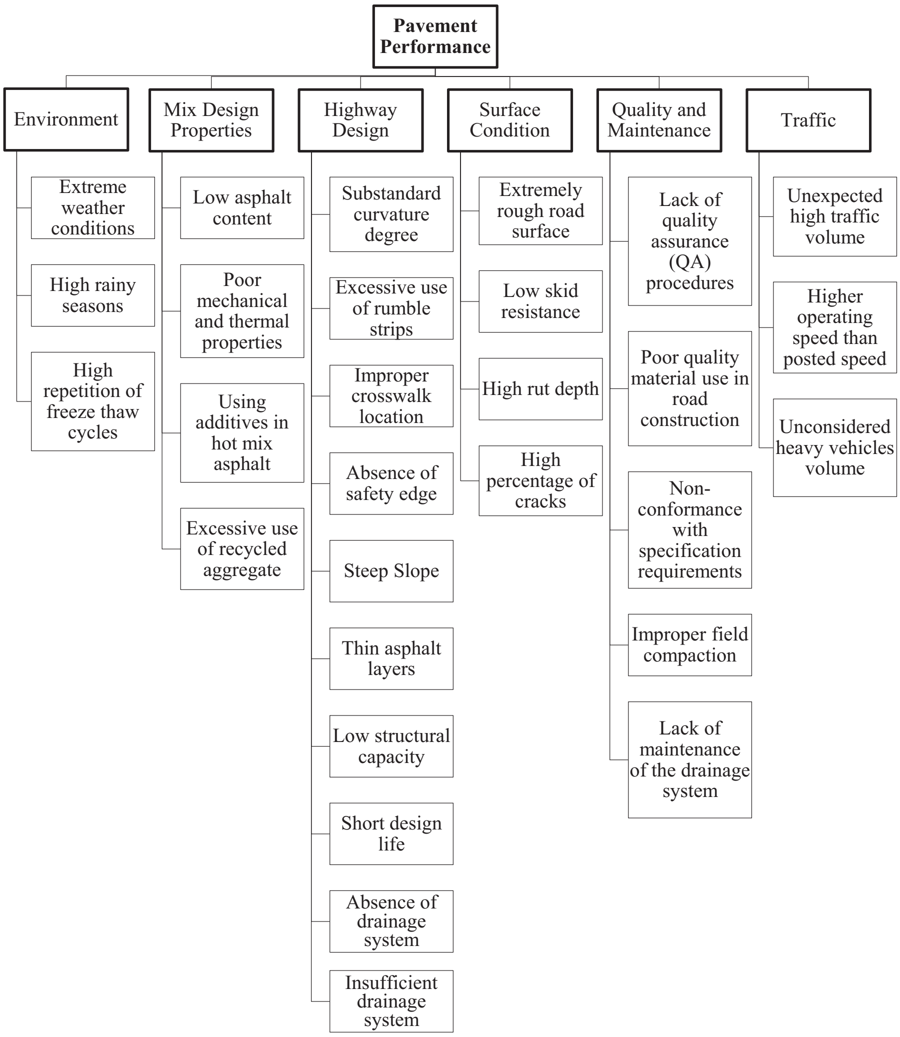

Figure 3.
The AHP model

Factors	AHP value	AHP rank
Unconsidered heavy vehicles volume	0.2297	1
Low asphalt content	0.1074	2
Poor mechanical and thermal properties	0.0675	3
Unexpected high traffic volume	0.0672	4
Absence of drainage system	0.0528	5
Improper field compaction	0.0479	6
High percentage of cracks	0.0444	7
Using additives in hot mix asphalt	0.0443	8
High repetition of freeze thaw cycles	0.0425	9
Insufficient drainage system	0.0368	10
Lack of quality assurance (QA) procedures	0.0296	11
Low structural capacity	0.0245	12
Excessive use of recycled aggregate	0.0233	13
High rut depth	0.0214	14
Lack of maintenance of the drainage system	0.0211	15
Short design life	0.0207	16
Higher operating speed than posted speed	0.0196	17
Poor quality material used in road construction	0.0160	18
Extremely rough road surface	0.0152	19
Thin asphalt layers	0.0149	20
High rainy seasons	0.0142	21
Low skid resistance	0.0074	22
Extreme weather conditions	0.0064	23
Steep slope	0.0059	24
Absence of safety edge	0.0052	25
Noncompliance with specification requirements	0.0043	26
Substandard curvature degree	0.0042	27
Excessive use of rumble strips	0.0031	28
Improper crosswalk location	0.0026	29

Table 11. AHP values and AHP rank of factors affecting pavement performance

It can be seen from Table 11 that AHP ranks 3–4 and 7–8 are very close to each other even though their ranks are different. It is important to note that the ranking was purely carried out based on the quantitative values of AHP. The table also shows that factors from 22 to 29 have AHP values lower than 1 %, indicating that their effect on pavement performance is limited.

7.1 Discussion of results

One of the aims of this study was to determine the most significant factors affecting pavement performance. Based on the detailed literature review on pavement performance, 29 factors were identified, and a survey was established to collect the professionals` judgment on each factor's effect. 205 completed responses were analyzed using the Relative Importance Index. An AHP model was developed. The limiting matrix was developed by running the software model, and the AHP values for each factor were determined. All factors affecting pavement performance were ranked based on the experts' judgment using AHP values as given in Table 10.

According to the AHP rank, the factor "unconsidered heavy vehicle volume" has the most important effect on pavement performance, emphasizing the findings of (Xiao and Wu, 2016), who related the accumulative truck volume, cumulative truck load and equivalent single axle load to the pavement performance. It also endorses the recommendations to restrict the overloading in India (Sharma *et al.*, 1995). Having this factor at the top of the AHP rank, it raises a flag for the authorities to enforce the weighting law and restrict the heavy vehicles' routes as well as requires the planning authorities to pay extra attention in predicting the future heavy vehicles volumes and the designers to consider the factor of safety for the structure of the pavement.

The second most critical factor affecting the pavement performance is the "low asphalt content" due to escalating binder aging, reducing fatigue life of the pavement and decreasing the durability of the roads. This factor's effect was a concern of many previous studies and endorses of the relationship between asphalt content, air voids and compaction with the pavement performance and expected life (Linden *et al.*, 2014). This raises a flag to pavement designers and construction contractors during laying the asphalt and compacting the pavement.

The third and fourth factors are "poor mechanical and thermal properties" and "unexpected high traffic volume," respectively. These two factors are strongly attached to the first and second factors since the traffic volume affects the pavement performance less but similar to the heavy vehicles, and a mix with poor mechanical and thermal properties is related indirectly to the asphalt content in the mix. Having these two factors ranked high also validates the previous recommendations and concerns. Even though factor 1 is related to factor 4 (similarly factor 2 to factor 3 or factor 7 to factor 8), these factors' ranking was based on the respondents' view in the AHP analysis. According to the AHP, the least significant factor is "improper crosswalk location" because its effect is indirect and the pavement performance is reduced by the deformation of the vehicle's braking or aggressively maneuvering due to unexpected pedestrians crossing the road (Jin *et al.*, 2015). Besides, the effect of this factor can be eliminated by simple measures was suggested in many previous studies (Duncan-Jones, 1998).

Last but not least, the second least significant factor is "Excessive use of rumble strips," which agrees with previous studies claimed the safety benefits of rumble strips supersede its minor effect on pavement performance.

By looking at the AHP total weight, it can be seen that the first four factors share almost 50% of the AHP total weight, while the remaining 25 factors share the other half. Also, the lowest 12 ranked factors shared less than 10% of total AHP weight. This finding encourages the decision-makers to focus on these two factors rather than the others because it reflects the magnitude of these two factors' effect on the pavement performance.

8. Conclusion

This paper aimed to identify the importance of all factors found in the literature affecting pavement performance to guide the decision-makers and highlight the critical issues for professionals to consider during design, construction and maintenance stages.

The literature review in this paper recognized 29 factors affecting pavement performance. A survey was developed to gather professional judgments in the pavement industry on the importance of each factor`s effect. AHP model was built and fed by RII results.

The results confirm that AHP fairly represents the complex real-life problems and simplify making decisions. In this study, the AHP rank indicated the most critical factors affecting the pavement performance are "unconsidered heavy vehicle volume," followed by the factor "low asphalt content." The factors "poor mechanical and thermal properties" and "unexpected high traffic volume" ranked third and fourth, respectively, which raises flags to authorities to concentrate on future traffic requirements and consider extra safety factors in designing asphalt pavements.

Moreover, the least influential factors on pavement performance are "improper walk location" and "excessive use of rumble strips." This endorses previous studies' findings that claimed a minimum or ignorable impact of these factors on the pavement performance.

As a future study, the pavement performance factors could be used with analytical models to measure the pavement performance in a real case study.

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Appendix

Factors number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	1	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1/5	1	1/8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1/5	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	1/2	1/3	1/3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	2	1	1/2	1/3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	3	2	1	1/3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	3	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	1/2	1/6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	2	1	1/6	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	6	6	1	7	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	1/2	1/3	1/7	1	1/2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	2	1/2	1/6	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1	1/2	1/3	2	2	5	6	6	8	7	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1/2	3	3	6	7	6	9	8	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	3	2	1	3	3	6	7	7	9	8	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	1/2	1/3	1/3	1	2	5	6	5	8	7	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	1/2	1/3	1/3	2	1	5	6	6	8	7	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	1/5	1/6	1/6	1/5	1/5	1	3	3	5	4	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	1/6	1/7	1/7	1/6	1/6	1/3	1	1/2	4	3	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	1/6	1/6	1/7	1/5	1/6	1/3	2	1	4	3	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	1/8	1/9	1/9	1/8	1/8	1/5	1/4	1/4	1	1/3	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	1/7	1/8	1/8	1/7	1/7	1/4	1/3	1/3	3	1	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1/3	2	3	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	3	4	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1/2	1/3	1	3	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1/3	1/4	1/3	1	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1/3	1/5
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1/4
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4	1

Table A1.
AHP limit matrix for all factors

Category number	1	2	3	4	5	6
1	1	2	2	3	3	3
2	1/2	1	2	2	3	4
3	1/2	1/2	1	2	2	3
4	1/3	1/2	1/2	1	2	2
5	1/3	1/3	1/2	2	1	2
6	1/3	1/4	1/3	1/2	1/2	1

Table A2.
AHP super matrix for categories

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