



Investigation of the Importance of Destructive Factors that Affect the Durability of Asphalt Pavement

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Abstract. Asphalt pavements are affected by a number of factors that deteriorate them. The impact of individual factors, or combinations of two or three factors, on pavement deterioration is typically investigated through costly and time-consuming laboratory and field experiments. However, it is challenging to evaluate all factors at once. Therefore, there is a lack of a study that covers all of these factors. A comprehensive assessment of how these factors affect the durability of asphalt pavements is a complex task that can be solved using expert opinion-based methods. In this paper, 18 criteria, which assess climate conditions, traffic loads, and the effects of winter maintenance materials and pollutants from vehicles, have been identified as factors deteriorating asphalt pavements at some level. The survey was conducted to identify the most significant criteria (factors), which have the greatest effect on asphalt pavement deterioration. Each of the 52 experts evaluated the significance of the criteria with ranks and percentage points. The high concordance of experts' opinions allowed to use the averages of criteria normalized weights calculated by the ARTIW-L, ARTIW-N, and DPW methods to identify the most significant criteria (factors). Changes in ambient air temperature, high annual average daily traffic flow, precipitation, high ground water level and percentage of heavy vehicles were determined to be the most important factors for the durability of asphalt pavements. The values of the criteria weights show how much one factor is more important than another.

Keywords: Asphalt Pavement · Durability · Destructive Factors · Expert Evaluation · Relative Weight · Opinion Consistency

1 Introduction

Asphalt pavements are susceptible to a variety of distress mechanisms, including rutting, thermal cracking, and fatigue cracking [1]. These failures are often accelerated by local climatic conditions and increasing traffic loads [2]. Additionally, winter maintenance materials and pollutants from vehicles contribute to the shortened lifespan of pavements.

With climate change becoming an increasingly critical concern, there is a growing interest in understanding how shifts in climate may accelerate the deterioration of flexible

pavements and impact their service lives [3]. Low ambient temperatures, typical in the winters of Northern Europe, the Baltic countries, northern USA, and Canada, increase crack formation in pavement [4]. Conversely, in warmer southern regions, high summer temperatures decrease the viscosity, adhesion, and cohesion of bituminous binders in asphalt layers [5–6], thus accelerating binder aging [7]. Oxidation and UV radiation further degrade the bitumen in the top layers and leads to cracking [8].

Moisture damage also contributes to pavement degradation through stripping, raveling, fatigue, and permanent deformation [9]. Water infiltration between the bitumen and aggregate surface causes adhesion failure [10]. Variations in groundwater levels and moisture in unbound layers significantly impact pavement stiffness, as shown by [11], while surface water flow and anti-freezing agents exacerbate deterioration [12].

Repeated traffic loads, especially from heavy vehicles, further accelerate pavement deterioration. Factors such as axle configuration [13], distance travelled [14], and vehicle speed [15] influence pavement wear. As the trucking industry grows, so do loads on existing roads, which can lead to overloaded vehicles and significant pavement damage [16].

The influence of individual factor or two-three factors on pavement deterioration is well analysed in previous studies. However, it is challenging to evaluate all factors at once. Therefore, there is a lack of a study that covers all of these factors. Multi-criteria decision-making methods with expert opinion-based methods have been successfully used in similar complex situations to prioritize different criteria (e.g., for the pavement maintenance prioritization process). Therefore, the same approach could be applied to identify the importance of different factors that affect the durability of asphalt pavement.

The aim of this study is to systematically evaluate the factors affecting asphalt pavement durability. By applying expert opinion-based methods, this work assesses the significance of these destructive factors and examines expert rankings and weights for each criterion.

2 Test Object and Methods

2.1 Destructive Factors Affecting the Durability of Asphalt Pavement

All factors affecting asphalt pavements were categorized by the authors into three groups: (i) climatic conditions (group A); (ii) winter maintenance materials and pollutants from vehicles (group B); (iii) traffic loads (group C). The first group, A, includes the effects of oxygen in binder (A1), low ambient temperature (A2), high ambient temperature (A3), sunlight and radiation (A4), precipitation (A5), high groundwater level (A6), microbes and bacteria (A7), and fluctuations in ambient temperature (A8). In practice, climate factors are not manageable, except for the groundwater level (A6).

The second group, B, includes fuels and oils (B1), salt and its solution (B2), coolant and electrolyte (B3), and surface treatment to increase friction (B4). During winter, salt and its solution are spread on the road to increase the adhesion between vehicle tires and the road surface. Other pollutants from vehicles end up on the road surface due to vehicle accidents.

The third group, C, consists of horizontal static and dynamic loads from vehicles (C1), studded tires (C2), vertical static and dynamic loads from vehicles (C3), high traffic

volume (C4), low driving speed (C5), and a high number of heavy vehicles in traffic flow (C6). In practice, only factor C2 from this group can be managed (eliminated). It can be done by prohibiting studded tires in the country.

2.2 Survey

To determine the significance of these 18 hierarchically unstructured destructive factors, a survey among road construction experts was carried out. 52 experts from private and academic (scientific) sector filled the questionnaire and assigned ranks and percentage scores for each criterion. Experts were asked not to assign tied ranks or percentage scores, meaning there were no equally significant criteria.

2.3 Consensus of Experts' Opinions

To take the average of the experts assigned ranks regarding the significance of criteria as the result of the solution, it is essential to ensure the consistency of the experts' opinions. The concordance coefficient W numerically indicates the consistency of opinions, which must be greater than its minimum value $W_{\min}$. The concordance coefficient W was calculated by Eq. (1) [17] and the minimum value of concordance coefficient $W_{\min}$ was determined by Eq. (3) [18].

$$W = \frac{12S}{n^2(m^3 - m)}, \quad (1)$$

here m – is the number of criterion ($i = 1, 2, \dots, m$); n – is the number of expert ($j = 1, 2, \dots, n$); S – is the sum of the squared deviations of each m -th criterion's ranks $\sum_{j=1}^n R_{ij}$ from the average rank $\bar{R} = \frac{n(m+1)}{2}$, calculated using Eq. (2):

$$S = \sum_{i=1}^m \left[\sum_{j=1}^n R_{ij} - \frac{n(m+1)}{2} \right]^2. \quad (2)$$

$$W_{\min} = \frac{\chi_{v,\alpha}^2}{n(m-1)}, \quad (3)$$

here $\chi_{v,\alpha}^2$ – the chi-square Pearson's statistic, which depends on the degrees of freedom $v = m - 1$ at the chosen significance level α (use 0.05 or stricter 0.01).

The empirical Pearson's chi-square statistic was calculated by Eq. (4):

$$\chi^2 = \frac{12S}{nm(m+1)}. \quad (4)$$

The compatibility coefficient k_c was calculated by Eq. (5). It indicates how many times the calculated values of W and χ^2 exceed their critical values $W_{\min}$ and $\chi_{v,\alpha}^2$ [19]. When the calculated value of k_c is greater than 1, it can be reasonably assumed that the

opinions of the experts are aligned and the number of experts is sufficient for reliable results.

$$k_c = \frac{W}{W_{\min}} = \frac{\chi^2}{\chi_{v,\alpha}^2}. \quad (5)$$

2.4 Transformation of Ranks and Percentage Scores into Relative Weights

The normalized relative weight of the i -th criterion was calculated from the average ranks of each i -th criterion using the Average Rank Transformation into Weight – Linear (ARTIW-L) method (Eq. 6). The average ranks of the criterion $\bar{R}_i$ is related to the criterion weights $\omega_i^{\text{ARTIW-L}}$ by a linear inverse functional dependence.

$$\omega_i^{\text{ARTIW-L}} = \frac{(m+1) - \bar{R}_i}{\sum_{i=1}^m \bar{R}_i}, \quad (6)$$

here $\bar{R}_i$ – average rank for criterion i -th by the n experts ($\bar{R}_i = \frac{\sum_{j=1}^n R_{ij}}{n}$).

The normalized relative weight of the i -th criterion was also calculated from the average ranks each i -th criterion using the Average Rank Transformation into Weight – Non-linear (ARTIW-N) method (Eq. 7). The average ranks of the criterion is linked to the criterion weights $\omega_i^{\text{ARTIW-N}}$ by a nonlinear correlation.

$$\omega_i^{\text{ARTIW-N}} = \frac{\min_i \bar{R}_i}{\bar{R}_i \cdot \sum_{i=1}^m \frac{\min_i \bar{R}_i}{\bar{R}_i}}. \quad (7)$$

Based on the percentage scores P_{ij} given by the experts to the criteria, the relative weight of each criterion $\bar{P}_i$ was determined by Direct Percentage Weight (DPW) method (Eq. 8). Using this method, the weights of the criteria ω_i^{DPW} are linked by an inverse nonlinear correlation to the average ranks of the criteria $\bar{R}_i$.

$$\omega_i^{\text{DPW}} = \frac{\sum_{j=1}^n P_{ij}}{100n}. \quad (8)$$

2.5 The General Subjective Weight

None of the methods used to transform ranks and percentage scores into relative weights (ARTIW-L, ARTIW-N and DPW) has an advantage (benefit) compared to others. Therefore, without applying a preference for specific method, the general subjective weight of each criterion is calculated using Eq. (9).

$$\bar{\omega}_i = \frac{\omega_i^{\text{ARTIW-L}} + \omega_i^{\text{ARTIW-N}} + \omega_i^{\text{DPW}}}{3}. \quad (9)$$

The general subjective weight $\bar{\omega}_i$ is more reliable than the weight of the criterion determined by any single method.

2.6 Variations in Ranks and the Relationship with Averages

As discussed previously, the consistency of the experts' opinions regarding the significance of all destructive factors (criteria) that affect the durability of asphalt pavement is indicated by the concordance coefficient W . The higher it is, the more similar the experts' evaluations are. The consistency of each individual criterion's assessment is indicated by the standard deviation of its ranks σ_{Ri} (Eq. 10).

$$\sigma_{Ri} = \sqrt{\frac{\sum_{j=1}^n (R_{ij} - \bar{R}_i)^2}{n - 1}}. \quad (10)$$

It is likely that different experts give different ranks for the same criterion. Therefore, when the standard deviation of ranks for i -th criterion σ_{Ri} is lower, the opinions among the experts are similar to each other. However, when the standard deviation of ranks for i -th criterion σ_{Ri} is high, the opinions among the experts can differ significantly.

3 Results and Discussion

The summarized data for each criterion based on the survey results are given in Table 1. It represents the significance of factors that affect the durability of asphalt pavement. The relative weight for each criterion was determined by three different methods (ARTIW-L, ARTIW-N and DPW).

The concordance coefficient W , calculated according to Eq. (1), is equal to 0.598 while its minimum value $W_{\min}$, calculated according to Eq. (3) and taking into account that $v = m - 1 = 17$ and $\alpha = 0.05$, is equal to 0.031. $W_{\min}$ indicates when the opinions of the experts can still be considered as aligned.

The empirical Pearson's chi-square statistic χ^2 , calculated according to Eq. (4), is equal to 528.76. Its critical value when $v = m - 1 = 17$ and $\alpha = 0.05$ is $\chi_{17,005}^2 = 27.59$.

The compatibility coefficient k_c from Eq. (5) is equal to 19.2. Since the concordance coefficient W and the empirical Pearson's chi-square statistic χ^2 is almost 19.2 times higher than its minimum value $W_{\min}$ and $\chi_{v,\alpha}^2$, there is a general consensus among experts on the factors affecting the durability of asphalt pavements and the number of experts is sufficient for reliable results and conclusion.

The normalized relative weights of each criterion were calculated using the ARTIW-L, ARTIW-N, and DPW methods according to Eq. (6), (7) and (8). As can be seen from Table 1, their values are similar and indicate almost identical priorities for the criteria.

The general subjective weights of each criterion $\bar{\omega}_{C4} =$, calculated according to Eq. (9), are presented in Fig. 1 in decreasing order of priority: $A8 > C4 > A5 > A6 > C6 > A2 > A3 > C3 > C1 > C2 > C5 > A1 > B2 > B1 > A4 > B4 > B3 > A7$. Research data show that in the Baltic region (since experts were from this region), the changes (fluctuations) in ambient temperature ($\bar{\omega}_{A8} = 0.1206$), high traffic volume ($\bar{\omega}_{C4} = 0.0978$), precipitation ($\bar{\omega}_{A5} = 0.0887$), high groundwater level ($\bar{\omega}_{A6} = 0.0790$), and a high number of heavy vehicles in traffic flow ($\bar{\omega}_{C4} = 0.0771$) are the most crucial factors that reduce the durability of asphalt pavements.

The correlation between the standard deviations of criterion ranks σ_{Ri} , calculated using Eq. (10), and the average ranks of criterion $\bar{R}_i$ is given in Fig. 2. Five different regression models were applied. The second order polynomial function fitted the best. its coefficient of determination is $R^2 = 0.6833$.

The regression curve in Fig. 2 shows that experts evaluated more uniformly the most and least significant criteria. Criteria of medium significance had a greater variation in ranks, meaning the experts' opinions differed more. The coefficient of determination indicates that the change in 68.3% of standard deviations of criterion ranks depends on the change in the average ranks of criterion, while 31.7% – depends on other factors not considered in the model.

Table 1. The significance of factors that affect the durability of asphalt pavements

Destructive factor (criterion)		Statistics of ranks			ARTIW methods		DPW method		
		$\sum_{j=1}^n R_{ij}$	$\bar{R}_i$	σ_{Ri}	$\omega_i^{ARTIW-L}$	$\omega_i^{ARTIW-N}$	$\bar{P}_i$	σ_{Pi}	ω_i^{DPW}
A1	Effect of oxygen on binder	613	11.79	4.04	0.0422	0.0353	3.58	2.94	0.0358
A2	Low ambient temperature	340	6.54	3.68	0.0729	0.0637	7.88	3.83	0.0788
A3	High ambient temperature	378	7.27	3.19	0.0686	0.0573	6.76	2.88	0.0676
A4	Sunlight and radiation	660	12.69	3.39	0.0369	0.0329	2.86	2.16	0.0286
A5	Precipitation	242	4.65	3.09	0.0839	0.0896	9.27	3.28	0.0927
A6	High groundwater level	301	5.79	3.93	0.0773	0.0720	8.77	3.82	0.0877
A7	Microbes and bacteria	883	16.98	1.72	0.0118	0.0246	0.80	0.70	0.0080

(continued)

Table 1. (continued)

Destructive factor (criterion)		Statistics of ranks			ARTIW methods		DPW method		
		$\sum_{j=1}^n R_{ij}$	$\bar{R}_i$	σ_{Ri}	$\omega_i^{\text{ARTIW-L}}$	$\omega_i^{\text{ARTIW-N}}$	$\bar{P}_i$	σ_{Pi}	ω_i^{DPW}
A8	Fluctuations in ambient temperature	146	2.81	2.03	0.0947	0.1483	11.90	3.65	0.1190
B1	Fuels and oils	652	12.54	3.33	0.0378	0.0332	2.87	2.17	0.0287
B2	Salt and its solution	647	12.44	3.11	0.0384	0.0335	2.91	1.74	0.0291
B3	Coolant and electrolyte	767	14.75	2.42	0.0248	0.0283	1.77	1.28	0.0177
B4	Surface treatment to increase friction	739	14.21	2.94	0.0280	0.0293	1.85	1.47	0.0185
C1	Horizontal static and dynamic loads from vehicles	430	8.27	3.11	0.0627	0.0504	5.88	2.59	0.0588
C2	Studded tires	587	11.29	3.58	0.0451	0.0369	3.73	2.35	0.0373
C3	Vertical static and dynamic loads from vehicles	392	7.54	3.78	0.0670	0.0553	6.87	3.39	0.0687
C4	High traffic volume	212	4.08	2.91	0.0872	0.1022	10.40	3.51	0.1040
C5	Low driving speed	597	11.48	3.81	0.0440	0.0363	3.51	2.36	0.0351
C6	High number of heavy vehicles in traffic flow	306	5.88	4.47	0.0767	0.0709	8.38	4.04	0.0838
Total:		8892	171	–	1	1	100	–	1

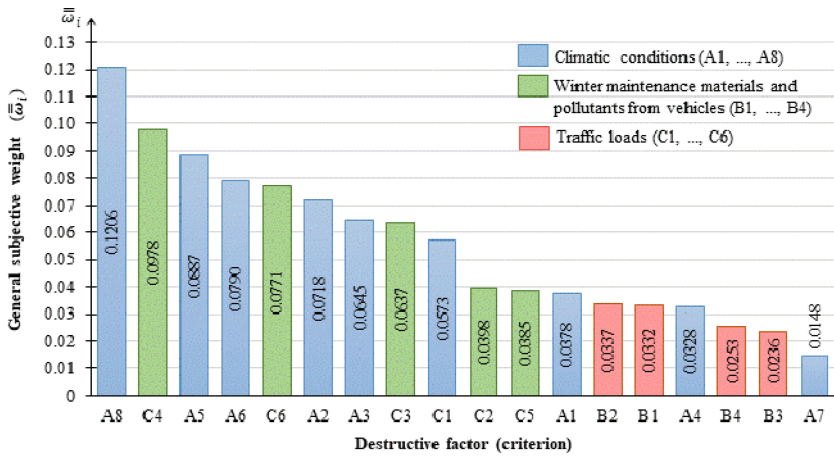


Fig. 1. The significance of factors that affect the durability of asphalt pavements according to the general subjective weights

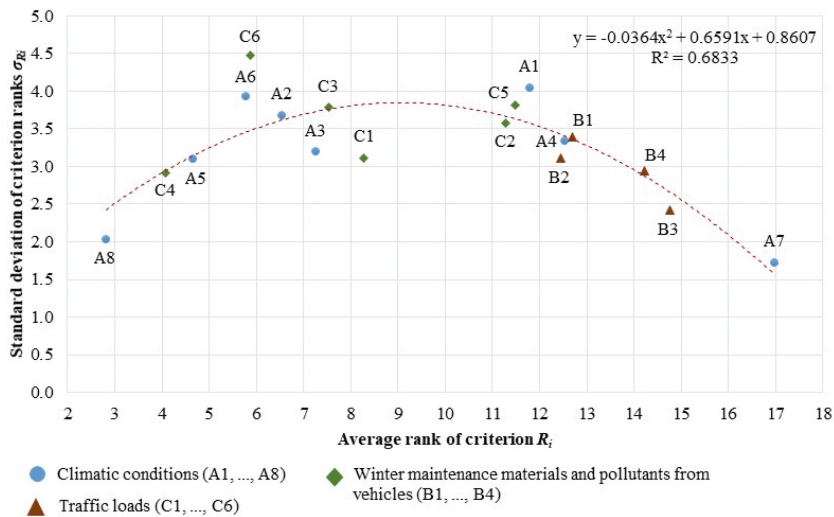


Fig. 2. Correlation between the standard deviations of criterion ranks σ_{R_i} , calculated using Eq. (10), and the average ranks of criterion $\bar{R}_i$

4 Conclusions

1. This research demonstrates that the durability of asphalt pavements can be assessed not only through expensive and time-consuming experimental laboratory and field studies, but also by utilizing expert opinion-based methods. These methods leverage the knowledge, competence, and experience of specialists, making their quantitative assessments both reliable and practical.

2. The concordance coefficient of 0.598, which is 19.2 times higher than its minimum value, demonstrates a strong agreement among experts regarding the significance of 18 factors influencing the durability of asphalt pavements. This result underscores the robustness of the study's findings, highlighting the reliability of the expert consensus. Additionally, the participation of 52 experts ensures that the sample size is statistically adequate, further validating the conclusions drawn from this research.
3. The general subjective weights of the criteria, calculated as the average of normalized relative weights based on three different methods (ARTIW-L, ARTIW-N, and DPW), enhanced the reliability of the results. The most significant criteria identified by the experts were: changes (fluctuations) in ambient temperature (0.1206), high traffic volume (0.0978), precipitation (0.0887), high groundwater levels (0.0796), and a high number of heavy vehicles in the traffic flow (0.0771). Conversely, the least important criteria were: microbes and bacteria (0.0148), coolant and electrolyte (0.0236), surface treatment to increase friction (0.0253), sunlight and radiation (0.0328), and fuels and oils (0.0332). These findings provide valuable insights into the prioritization of environmental and traffic-related factors.
4. The expert assessments of various factors influencing asphalt pavement durability revealed some differences in rankings. The standard deviations for the most and least significant factors were significantly smaller compared to those for factors of intermediate importance, indicating a stronger consensus on the factors that cause the greatest and least damage to asphalt pavements. This outcome aligns with expectations, as road engineers and researchers are generally well-acquainted with the factors that have the most pronounced and least impact on pavement performance.

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