Evaluation of heuristic procedures formation results to select and justify composition of defectiveness parameters of road pavement affecting reliability indicators

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Abstract. The research presents effective solution to the problem of evaluation of heuristic procedures formation results, obtained by the Delphi approach, during the selection and justification of the composition of defectiveness determining parameters of road pavement that affect the indicators of their reliability. The article presents the parameters of the defects of road surfaces of the Penza agglomeration, obtained by diagnostics in order to identify the most important of these parameters in the questionnaire of experts and a single matrix of expert assessments. The author developed the algorithm processing the results of the selection of a subgroup of experts with a close opinion, including the need to conduct expert evaluation of the rank type. According to the variance analysis (presented by the author), a statistical assessment of the significance of differences in the distribution of defectiveness parameters of road pavements affecting some generalized indicator of their reliability, the structure of their influence is determined, while the parameters of the distribution of differences of significant and insignificant differences are assigned to different groups by their degree of influence. The structure of their influence is determined, at the same time parameters that have essential and non-essential difference in the distributions according to the degree of their influence are assigned to different groups. This approach allowed leveling the significance of differences in the assessment of the distribution of defectiveness parameters of road pavements that affect some generalized indicator of their reliability, with the assessment of differences in the average values of the ranks. The comparison of the evaluation of parameters that have an insignificant difference in the average values of ranks assigned to one group, with an estimate for the parameters for the average degree of influence attributed to another group, showing their practical unambiguity. The final structure of groups of defectiveness parameters of road pavements is established, taking into account the priority of their influence on the generalized indicator of reliability of these roads. This heuristic analysis made allowed identifying the most essential parameters affecting the quality of road pavements and their reliability.

1. Introduction
One of the solutions to the task of conducting expert studies [1] on the selection and justification [2] defining defectiveness parameters of road pavements that [3] affect some generalized indicator of their reliability [4], involving heuristic procedures [5], was considered in [6].
The above mentioned works are devoted to a detailed review of the content of the main steps for the heuristic procedure implemented at Delphi’s approach: the heuristic preparation procedure, the survey of experts [7], and statistical processing of results of expert survey [8].

Therefore, in this article, the content of the quantitative assessment of the stage of implementation of the heuristic procedure for the formation of its results is considered.

2. Materials and Methods

The task is to identify the most important parameters from the questionnaire of experts (Table 1).

| No | Defectiveness parameters | Description of coating defectiveness parameters |
|----|--------------------------|-------------------------------------------------|
| $x_1$ | Pollution bands at the edges of the pavement | The presence of contamination of the pavement from dirt and debris at the edges |
| $x_2$ | Destroyed and deformed seams not filled with seal on cement concrete pavement | Damage to seams and pavements near them, presence of debris and inclusions of elements of reinforcement in damaged seams |
| $x_3$ | The grid of cracks along the bands of rolling | The destruction of the pavement without significant distortion of the profile and accompanied by small longitudinal and transverse cracks of arbitrary shape, characteristic of insufficient pavement strength |
| $x_4$ | Temperature cracks | Cracks resulting from temperature fluctuations and stress concentrations in the pavement layers |
| $x_5$ | Cracks | Violation of the integrity of the pavement without removing the material with the formation of narrow slits. Cracks of arbitrary outline and location with a width of opening more than 3 mm on the roadway |
| $x_6$ | Untreated sections of the roadway with sweating of binder | Surplus of binder on the surface of the pavement with a change in its texture and color area of more than 1 m |
| $x_7$ | Breaks | Destruction of pavement for its entire thickness with a sharp distortion of the transverse profile, accompanied by a grid of cracks |
| $x_8$ | Potholes | The destruction of the pavement in the form of depressions of various shapes with sharply defined edges (more than 3 cm deep and an area of more than 200 cm) |

To this end, there was the survey of 12 experts about 8 - and most important defectiveness parameters of road pavements, most significantly affecting their reliability indicators, the answers of which are summarized in Table 2.

According to Table 2, we check the equality condition for the sums of all its individual columns

$$
\sum_{j=1}^{m} x_{ij} = \sum_{i=1}^{n} x_{ij} \quad \ldots \quad \sum_{i=1}^{n} x_{ij} = 432. 
$$

Satisfaction of the condition (1) indicates the correct completion of the summary table of expert answers (Table 2) [10].
Table 2. Summary table of experts’ answers

| Experts’ numbers | Defectiveness parameters of road pavements, most significantly affecting indicators of their reliability \(x_1, x_2, \ldots, x_8\) | \(\sum_{j=1}^{8} x_{ij}\) |
|------------------|---------------------------------------------------------------------------------|------------------|
| 1                | 3 4 2 5 1 6 7,5 7,5                                                           | 36               |
| 2                | 3 5,5 2 4 5,5 7,5 1 7,5                                                       | 36               |
| 3                | 2 5 1 6 3 4 7,5 7,5                                                           | 36               |
| 4                | 3,5 5 1 3,5 2 6 7 8                                                          | 36               |
| 5                | 1 2,5 4,5 4,5 7 2,5 8 6                                                     | 36               |
| 6                | 3 4 1,5 5 1,5 6 7 8                                                          | 36               |
| 7                | 7 5 4 1 2,5 2,5 6 8                                                          | 36               |
| 8                | 5 6 2,5 1 4 2,5 7 8                                                          | 36               |
| 9                | 3,5 2 1 7,5 5 3,5 6 7,5                                                       | 36               |
| 10               | 5 8 3 2 4 7 1 6                                                                | 36               |
| 11               | 2,5 5 1 8 4 2,5 6 7                                                           | 36               |
| 12               | 2,5 3 1 8,5 2,5 7,5 5 6                                                        | 36               |

\[ \sum_{i=1}^{12} x_{ij} \]

On the values of the sums of the columns \(\sum_{j=1}^{8} x_{ij}\), we make a conclusion about the degree of influence of the considered defining parameters, which are distributed in this way:

1. \(X_3 \sum_{i=1}^{3} X_{i3} = 24,5\); 3. \(X_5 \sum_{i=1}^{5} X_{i5} = 42\); 5. \(X_4 \sum_{i=1}^{4} X_{i4} = 56\); 7. \(X_7 \sum_{i=1}^{7} X_{i7} = 69\);

2. \(X_1 \sum_{i=1}^{1} X_{i1} = 41\); 4. \(X_2 \sum_{i=1}^{2} X_{i2} = 55\); 6. \(X_6 \sum_{i=1}^{6} X_{i6} = 57,5\); 8. \(X_8 \sum_{i=1}^{8} X_{i8} = 87\).

Thus, among the investigated defectiveness parameters of road pavements [11], the most essentially influencing indices of their reliability [12], the greatest influence is exerted by the determining parameter \(X_8\), and the last \(X_3\).

We will evaluate the degree of consistency of the interviewed experts using the concordance [13] coefficient according to formula (2), provided that the ranks in the matrix (see Table 2) have equal rank values for different parameters \(u\) the same specialist [14].

\[
W = \frac{S}{1 - \frac{1}{12}(m^3 - m) - \sum_{i=1}^{n} T_i} ,
\]

where \(S = \sum_{j=1}^{m} \left[ \sum_{i=1}^{n} X_{ij} - \frac{1}{m} \sum_{j=1}^{m} \sum_{i=1}^{n} X_{ij} \right]^2 \)

\[
T_i = \frac{1}{12} \sum_{j=1}^{n} (t_{ij}^3 - t_{ij}) ;
\]

\(t_{ij}\) - the number of ranks \(j\)-th parameter in each row of the rank matrix.
\( m \) - number of experts; 
\( n \) - number of ranks; 
\( X_{ij} \) - evaluation of \( j \) - th rank of \( i \) - th expert.

We determine \( T_i \) \((i = 1, 2, \ldots, 12)\) by the formula (4) and \( S \) by the formula (3). For the first line, rank 8 occurs twice. In this case
\[
T_1 = \frac{1}{12} (2^3 - 2) = 1/2.
\]
For the second row, ranks 5 and 6 occur twice. Thus we obtain
\[
T_2 = \frac{1}{12} (2^3 - 2) + (2^3 - 2) = 1.
\]
For the third row, rank 7 occurs twice. Then
\[
T_3 = \frac{1}{12} (2^3 - 2) = 1/2.
\]
For the rest of the lines, by analogy, we find
\[
T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12} = 0.5, 1, 0, 0, 5, 1, 0, 0, 5, 1, 0, 0, 5, 1, 0, 0, 5, 1, 0.
\]
The value \( S \) is found from formula (3)
\[
S = \sum (41 - 432)^2 + \sum (56 - 432)^2 + \ldots + (87 - 432)^2 = 2289.5
\]
We determine the concordance coefficient according to formula (2)
\[
W = \frac{1}{12} (8^3 - 8) - 12(0.5 + 1.0 + 0.5 + \ldots + 1.0) = 0.43
\]
The significance of the difference in the concordance coefficient from zero we test with the help of the Fisher’s \( z \)-criterion [15] by the formula:
\[
Z = \frac{1}{2} \ln \frac{(n-1)W}{(1-W)},
\]
and the number of degrees of freedom \( \gamma_1 \) and \( \gamma_2 \) by formulas
\[
\gamma_1 = \frac{(m-1) \cdot 2}{n}, \quad \gamma_2 = (n-1) \gamma_1.
\]
To do this, we find by the formula (5) a numerical value \( Z \):
\[
Z = \frac{1}{2} \ln \frac{(12-1)0.43}{0.43} = 0.87
\]
and degrees of freedom \( \gamma_1 \) and \( \gamma_2 \) according to formulas (6) and (7)
\[
\gamma_1 = (8-1) \frac{2}{12} \approx 7 \quad \text{and} \quad \gamma_2 = (12-1)7 \approx 75.
\]
At the significance level \( \alpha = 0.05 \) for \( \gamma_1 = 7 \) and \( \gamma_2 = 75 \) from Table. VI of work [15] we find that
\[
Z_\alpha = 0.35.
\]
Since the obtained $Z = 0.87$ is greater than $Z_{\alpha} = 0.35$, then with probability $P \geq 0.95$ it can be asserted that there is a non-random agreement on the strength of the influence on the quality and indicators reliability covers of the motor road [16], selected indicators [17] among experts.

An evaluation of the difference in the influence of the investigated indicators and the significance of the influence in the analysis of the investigated indicators is carried out by comparing the variances between the $S_1^2$, with the residual dispersion $S_{res}^2$, which are determined by formulas (8).

$$S_1^2 = \frac{1}{(m-1)} \sum_{i=1}^{n} \sum_{j=1}^{m} (\bar{X}_j - \bar{X}_i)^2 = \frac{1}{(m-1)} \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} (\bar{X}_j)^2 - mn(\bar{X}_i)^2 \right]$$  \hspace{1cm} (8)

$$S_{res}^2 = \frac{1}{(m-1)(n-1)} \sum_{i=1}^{n} \sum_{j=1}^{m} (\bar{X}_j - \bar{X}_i - \bar{X}_j + \bar{X}_y)^2 = \frac{1}{(m-1)(n-1)} \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} (\bar{X}_j)^2 - m \sum_{i=1}^{n} (\bar{X}_i)^2 - n \sum_{j=1}^{m} (\bar{X}_j)^2 + mn(\bar{X}_y)^2 \right]$$  \hspace{1cm} (9)

where $X_{ij}$ - evaluation of $j$ - th parameter $i$ - th expert;

- $m$ - number of parameter;
- $n$ - number of experts.

Using formulas (8) and (9), we calculate $S_1^2 = 26.1$ and $S_{res}^2 = 3.1$. The average values of ranks according to the defining parameters are $\bar{X}_1 = 3.42$, $\bar{X}_2 = 4.58$, $\bar{X}_3 = 2.04$, $\bar{X}_4 = 4.67$, $\bar{X}_5 = 3.5$, $\bar{X}_6 = 4.79$, $\bar{X}_7 = 5.75$, $\bar{X}_8 = 7.25$.

The average values, by definition of the experts, are:

$\bar{X}_1 = 4.5$, $\bar{X}_5 = 4.5$, $\bar{X}_9 = 4.5$
$\bar{X}_2 = 4.5$, $\bar{X}_6 = 4.5$, $\bar{X}_{10} = 4.5$
$\bar{X}_3 = 4.5$, $\bar{X}_7 = 4.5$, $\bar{X}_{11} = 4.5$
$\bar{X}_4 = 4.5$, $\bar{X}_8 = 4.5$, $\bar{X}_{12} = 4.5$

The general average rank by definition of experts $\bar{X}_{ij} = 4.5$.

The significance of the difference between variances $S_1^2$ and $S_{res}^2$ is verified by the Fisher’s $z$-criterion using formula (10).

$$Z = \frac{1}{2} \ln \frac{S_1^2}{S_{res}^2}.$$  \hspace{1cm} (10)

As a result, we obtain

$$Z = \frac{1}{2} \ln \frac{26.1}{3.1} = 1.06.$$ 

According to the number of degrees of freedom (which were obtained earlier) $\nu_1 = 7$ and $\nu_2 = 75$ at $\alpha = 0.05$ according to Table 5, we find $Z_{\alpha} = 0.35$.

Since $Z > Z_{\alpha}$, then with a probability of $P \geq 0.95$ it can be argued that the difference in the influence of the parameters’ under study is statistically significant [18], and their effect on the quality and indicators reliability of road covers of the motor road is most significant [19].
Define the structure of the influence of defectiveness parameters of road pavements, which most significantly affect their reliability indicators. The groups of indicators can be found by evaluating the difference in the average values of the ranks between the parameters.

Let us consider an evaluation of a difference in average values of ranks between parameters \[20\].

The ranks for each of the parameters form random samples \[21\], each of which has its own average \(X_j\) and the mean square deviation \(S_j\), defined by the formula

\[
S_j = \frac{1}{n-1} \sum_{i=1}^{n} (x_{ij} - \bar{X}_j)^2, \quad (j=1, 2, \ldots, m; \quad (i=1, 2, \ldots, n) \tag{11}
\]

We determine the mean square deviations of the parameters by formula (11):

\[
S_1 = 1.59, \quad S_3 = 1.23, \quad S_5 = 1.76, \quad S_7 = 2.37
\]

\[
S_2 = 1.64, \quad S_4 = 2.55, \quad S_6 = 2.10, \quad S_8 = 0.81.
\]

The experts gave the highest average rating to parameter \(X_8\) with \(\bar{X}_8 = 7.25\) and \(S_8 = 0.81\). Further, the value of \(X_7\) with \(\bar{X}_7 = 5.75\) and \(S_7 = 2.37\) follows.

The significance of the difference in the mean values of the ranks between the parameters is checked by the Student's t-criterion \[22\] by a successive comparison of the average values of the ranks of the parameters:

\[
t = \frac{\bar{X}_r - \bar{X}_l}{S_{Xr - Xl}} (k, \quad l = 1, \ldots, m; \quad k \neq l) \tag{12}
\]

\[
S_{Xr - Xl} = \left( S_{Xk}^2 + S_{Xl}^2 \right)^{1/2} \tag{13}
\]

\[
S_{Xj} = \frac{1}{\sqrt{n}} S_j \quad (j = 1, 2, \ldots, m). \tag{14}
\]

In this case, the number of degrees of freedom \(\nu = 2(n-1)\). \(15\)

If \(t > t_\alpha\), taken from tables (see, for example, [22], for \(t_\alpha = 0.05\), the \(t_\alpha\) values are presented in Table 4.6b of [22], then with the probability \(P \approx 1 - \alpha\) it can be asserted that the difference in mean values is insignificant and these parameters about the average degree of influence are not different and they can be attributed to one group.

Using formulas (13) and (14), we find

\[
S_{X8 - X7} = \sqrt{\frac{0.81^2 + 2.37^2}{12}} = 0.72
\]

\[
S_{Xj} = \frac{1}{\sqrt{n}} S_j \quad (j = 1, 2, \ldots, m).
\]

Using formulas (12) and (15), we respectively find the value of \(t_{X8 - X7}\) and the number of degrees of freedom \(\nu\):

\[
t_{X8 - X7} = \frac{7.25 - 5.75}{0.72} = 2.08 ;
\]

\[
\nu = 2(12 - 1) = 22.
\]

According to Table 4.6b [22], for \(\alpha = 0.05\) and \(\nu = 22\) we find \(t_\alpha = 1.72\).
Since \( t_{X_8 - X_7} = 2.08 > t_{\alpha} = 1.72 \), then with probability \( P \geq 0.95 \) it can be argued that the difference in the means is statistically significant, therefore the parameters \( x_8 \) and \( x_7 \) can be attributed to different groups by the average degree of influence.

Similarly, we calculate the following values:

\[
\begin{align*}
\frac{5.75 - 4.79}{0.91} &= 1.05, \\
\frac{4.79 - 3.5}{0.79} &= 1.63, \\
\frac{1.05}{0.91} &= 1.13, \\
\frac{0.79}{0.91} &= 0.87.
\end{align*}
\]

3. Outcomes

From the comparison of the calculated values of \( t_{X_k - X_l} \) with \( t_{\alpha} = 0.05 = 1.72 \), we can distinguish the following groups: \( X_6, X_4, X_2, X_1, X_5, X_1, X_3 \).

As a result we have obtained that the parameter \( X_1 \) belongs to two groups. However, comparing the \( t_{X_5 - X_1} \) and \( t_{X_2 - X_1} \) values, it is more preferable to relate a parameter \( X_1 \) to a parameter \( X_5 \).

The final structure of the influence of the defining parameter will be as follows: \( X_8 \) - the first group; \( X_7, X_6, X_4, X_2 \) - the second group; \( X_5, X_1 \) - the third group; \( X_3 \) - the fourth group.

According to the statistical analysis carried out on the degrees of influence, the determining parameter can be arranged as follows: \( X_3, X_5, X_1, X_2, X_4, X_6, X_7, X_8 \).

4. Conclusion

In general, the heuristic analysis made it possible to identify the most significant parameters \( X_4, X_6, X_7, X_8 \) affecting the quality of road pavements and their reliability indicators.

References

[1] Kurakina E V 2013 Expert characteristics of the road in road transport expertise Modern problems of science and education 5.
[2] Hayati E, Majnounian B 2013 An expert-based approach to forest road network planning by combining Delphi and spatial multi-criteria evaluation Environ Monit Assess 185(2)1767-76. doi: 10.1007/s10661-012-2666-1.
[3] Kokodeeva N E 2009 Evaluation of the quality of existing non-rigid-type road clothes taking into account the variation in humidity Dorozhnaya Sfera 19 72-75.
[4] Stolyarov V V 1994 The design of highways taking into account the theory of risk (Saratov: Sarat. state. tech. University), part 2.
[5] Kural I A, Kural Z, Çomu S 2014 Risk identification in construction projects: using the Delphi method. In Proc. of 11th International Congress on Advances in Civil Engineering (Istanbul Technical University).
[6] Outhred G P 1981 The Delphi method: a demonstration of its use for specific research types. In Proc. of Construction & Building Research Conference (Melbourne: RICS Foundation).
[7] Bazhanov A P, Saxonova E S 2018 The method of carrying out heuristic procedures in the selection and justification of the composition of the determining indicators of the quality of pavements that affect the reliability of roads. Preparation of a heuristic procedure and a survey of experts Transport engineering 5(1) 18.

[8] Bazhanov A P, Saksonova E S, Kochetkov A V, Schegoleva N V 2018 The method of carrying out heuristic procedures in the selection and justification of the composition of the determining indicators of the quality of pavements that affect the reliability of roads. Statistical processing and formation of the results of an expert survey Transport engineering 5(2) 14.

[9] Methodological recommendations for the study of socio-psychological climate in teams 2011 (Moscow: Center for emergency psychological assistance MZS of Russia).

[10] Yousuf M I 2007 Opinions through Delphi technique Practical Assessment, Research & Evaluation University of Arid Agriculture 5(2) 14.

[11] Kochetkov A V, Gladkov V Yu, Nemchinov D M 2013 Designing the structure of information support for the quality management system of road economy Internet Journal of Science 16(3).

[12] Bliznichenko S S 1992 Simplified methodology for rapid assessment of the transport and operational state of the road network Izvestiya Vuzov. Construction 5-6 126-130.

[13] Borodachev S M 2009 Multivariate statistical episodes (Ekaterinburg: USTU-UPI).

[14] Sidenko V M, Rokas S Y 1981 Quality management in road construction (Moscow: Transport).

[15] Fisher R A 1958 Statistical methods for researchers (Moscow: Gosstatizdat).

[16] Online collection of technical regulations and policies 2011 Use of the peer review method in the deployment of the quality function. Available at: https://studfiles.net/preview/1967369/page:5.

[17] Online collection of technical regulations and policies 2011 Industrial products and indicators of its quality. Available at: http://texnlit.ru/kachestvo/5.html/.

[18] Kobzar A I 2006 Applied mathematical statistics (Moscow: Fizmatlit).

[19] Jorge D, Ferreira A 2011 Road network pavement maintenance optimization using the HDM-4 pavement performance prediction models International Journal of Pavement Engineering 13(1) 39-51.

[20] Emma K 2014 Matching GPS data to a road network In Mathematical modeling and solution algorithms (Gothenburg: Chalmers University of Technology).

[21] Arzhanukhina S P, Sukhov A A, Kochetkov A V, Yankovsky L V 2012 Organizational and economic mechanism of innovative activity of road economy Innovative Regional Herald 4 40 - 45.

[22] Bolshev L N, Smirnov I V 1983 Tables of mathematical statistics (Moscow: Nauka).