THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

2011
6(1): 48–58

APPLICATION OF EXPERT EVALUATION METHOD TO DETERMINE THE IMPORTANCE OF OPERATING ASPHALT MIXING PLANT QUALITY CRITERIA AND RANK CORRELATION

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Abstract. Road asphalt concrete pavement is usually laid of hot-mix asphalt (HMA) mixture. HMA mixture is produced in an asphalt mixing plant (AMP) according to the technology applied in its structure. AMP shall meet certain requirements set in the norms not only to the quality of HMA mix produced in it, but to environmental protection as well. A possibility to produce an HMA mixture of all required types and marks in it shall be available through the use of various materials and additives, including reclaimed asphalt pavement (RAP). HMA mixture production costs shall be as low as possible. AMP shall be of appropriate technical condition and with proper equipment, which mostly influence on the technological, ecological and economic parameters. Its actual productivity shall meet the required scope (HMA mixture amount) of road construction works carried out in the serviced region. The article presents 9 criteria of operating AMP quality, mathematical models of determining their significance through the application of an expert research method as well as expert opinion correlation values. Ranks of AMP quality criteria have been replaced by their weight indices through the application of two different methodologies. Quality criteria weight indices may be used according to an additive model through the calculation of operating AMP quality multi-criteria index. A numerical sample is presented at the end of the article.

Keywords: asphalt mixing plant (AMP), quality, concordance coefficient, criteria, expert, multi-attribute analysis, investment, hot mix asphalt (HMA).

1. Introduction

Bitumen mixtures are used in the pavement of roads, parking lots, terminals, airfields, and other trafficked areas. Hot mix asphalt (HMA) has become the most popular mixture. Its production volumes have constantly been increasing not only in Europe as could seen from Key Figures of the European Asphalt Industry in 2009 (European Asphalt Pavement Association (EAPA)) and other economically well-developed countries, but in Lithuania as well (Sivilevičius, Šukevičius 2009). HMA is a mixture of asphalt cement, mineral aggregates and air, and the properties of this material are significantly influenced by its components. The asphalt mixture design process generally requires a balance of various desirable mixture properties with an attempt to optimize the selection and proportions of these different components (Li *et al.* 2009).

HMA mixture is produced in a stationary or a portable asphalt mixing plant (AMP). According to their inner workings, HMA mixture manufacturing facilities are classified into batch plants, continuous mix plants and drum mix plants *(ASTM Standart D 995-95b "Standard Specification for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures").* Structural and technological requirements for all AMP equipment are presented in the Standard Specification for Mixing Plants. The builders of roads and other transport infrastructure objects have to select the operating AMP, capable of producing a suitable HMA mixture, which complies with the conditions of public procurement tender and reduces the transportation distance and cost. The best equipment shall be selected from the operating AMP available within a rational provision with HMA distance from an infrastructural object (motorway, road, street) under construction.

AMP produced by different corporations have different structure. Their clients may require and order additional equipment or reject some standard original equipment. When exploited, the facilities of AMP wear, and at the end of the working season are repaired and replaced. Therefore, operating AMP of not only different but the same company are of different structure and most probably do not accurately and precisely perform HMA mixture production technological operations, give different output and the sequence of technological processes as well as pollute the environment differently.

ISSN 1822-427X print / ISSN 1822-4288 online doi: 10.3846/bjrbe.2011.07
http://www.bjrbe.vgtu.lt

AMP is a long-life equipment. Its factual service life from the beginning of its mounting in the plant (in a separate lot) until its demounting and replacement by a more upgraded technological equipment is frequently more than 20–30 years (Sivilevičius 2003). During this AMP exploitation period requirements set in normative documents to the properties of the produced HMA mixture, technological operation parameters, pollutant emissions into the air change a lot. Thus, the quality parameters of long used AMP frequently do not meet certain requirements or meet them partially.

AMP belongs to a group of technological equipment producing asphalt mixtures to lay flexible pavement of transport infrastructure objects. HMA mixture of optimal composition designed in a laboratory from new and reclaimed materials through the application of deterministic (Asi 2007; Doh *et al.* 2008; Roberts *et al.* 1991; Sivilevičius *et al.* 2011; Widyatmoko 2008) or stochastic methods (Sivilevičius, Vislavičius 2008) shall be produced in AMP without exceeding component content deviations (tolerances). The amount of components in HMA mixture and their deviations from job mix formula (JMF) influence on its physical and mechanical parameters and the dynamic modulus (Ceylan *et al.* 2009; Liu, Cao 2009; Petkevičius *et al.* 2009; Petkevičius, Sivilevičius 2008). HMA mixture properties and asphalt concrete structure depend on the mineral materials and bitumen properties used in its production (Haryanto, Takahashi 2007; Kim 2009; Lee *et al.* 2009; Mahmoud *et al.* 2010; Pan *et al.* 2005; Radziszewski 2007).

The amount of components in the produced HMA mixture deviates from JMF (Bražiūnas, Sivilevičius 2010) and varies within a certain range (interval), which is frequently impacted by segregation processes (Brown *et al.* 1989; Stroup-Gardiner, Brown 2000). The homogeneity of HMA mixture produced with reclaimed asphalt pavement (RAP) is reduced by a huge amount of RAP in it (Aravind, Das 2007; Mučinis *et al.* 2009). The content of components in the produced HMA mixture may deviate from JMF, but not more than it is specified in guidelines *Automobilių kelių dangos konstrukcijos asfalto sluoksnių įrenginio taisyklės ĮT ASFALTAS 08* [The Installation Rules of the Roads Pavement Asphalt Layers "*ĮT ASFALTAS 08*"].

HMA mixture loaded to the hob storage hopper (storage silo) from AMP mixer be of a certain temperature, which depends on the type of HMA mixture as well as the type and mark of bitumen used in it. The actual temperature of the produced HMA mixture shall meet the requirements specified in guidelines *Automobilių kelių asfalto mišinių techninių reikalavimų aprašas TRA ASFALTAS 08* [The Specification of Technical Requirements for Automobile Road Asphalt Mixtures "*TRA ASFALTAS 08*"]. Compliance with this requirement depends not only on the moisture and temperature of mineral materials, fuel (especialy fuel oil) quality, air temperature, operator's actions, but on the AMP structure (burner, drying drum, bitumen system) as well. During the drying process more energy consumption is required to dry and heat saturated mineral materials. Mineral particles of different size absorb different amount of moisture (Ang *et al.* 1993). Fewer AMP turn offs in the production of HMA mixture also result in less energy consumption.

When producing HMA mixture, hazardous and environment polluting materials, such as dust, smoke and combustion product gases, are emitted during technological processes occurring in AMP equipment (Brock *et al.* 1995; Dupont *et al.* 1993; Hobbs 2009; Порадек 2001). In modern AMP, to separate dust from air and gas flow pulse-jet filters are used (Mukhopadhyay 2009). Pollutant concentration and their emission may be one of the most important criteria enabling to determine if AMP is suitable for use (user-friendly).

The cost price of HMA mixture produced in AMP shall be minimal. It depends on the consumed fuel amount and price, salary, electricity consumption, materials' price and is frequently calculated per one ton of HMA mixture.

An important AMP quality indicator is its physical and moral wear (amortization). The newer the AMP is, the less its equipment structural parameters change, and the better quality of HMA mixture it can produce.

Frequently, AMP is seasonal technological equipment. When the working season is over, worn-out elements are replaced (blades of the mixer (pugmill), sieves, drying drum charging place blades). It requires additional expenses, which can restore AMP structural parameters from initial to the condition similar to it.

There are few published research works on the improvement of the structure of AMP, investigation and evaluation of the technological parameters and properties of HMA mixture produced in them. Hereby, one of the reasons for this is the complexity of such research due to a huge number of samples to be taken and changing technological processes to be measured. Sometimes when changing HMA mixture production technological parameters, the process shall be detuned, stopped, deviated from JMF as well as other materials shall be used or the production process shall be disturbed.

Divinsky *et al.* (2003) calculated process capability indices *CP* and *CPK*, index *K*, quality mark *QM* values and evaluated the quality of investigated AMP according to the statistical characteristics of the HMA mixture density produced in AMP, bitumen content in it, percentages passing No 4 sieves and percentages passing No 200 sieves.

AMP quality is evaluated by the additive model (Sivilevičius *et al.* 2008) based on 9 criteria, according to which AMP quality multi-criteria index *K* is calculated. This article presents the methodology which enables to estimate the impact of every criterion of AMP quality on complex index *K*.

Recently, expert investigation methods have been applied in various management and engineering areas. The efficiency of buildings' wall structures is determined (Zavadskas *et al.* 2008) and the risk of construction projects is evaluated (Zavadskas *et al.* 2010) through the use of experimental investigation methods. To describe and solve the task model, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) grey and COPRAS-G (COmplex PRoportional ASsessment) methods are used. Project properties are described by the values of efficiency indicators defined within intervals. Expert investigation methods were applied in management by Podvezko (2007); Podvezko *et al.* (2010); Zavadskas *et al.* (2010). ARAS–F (Additive Ratio Assessment) method was used to select the location of logistic centers (Turskis, Zavadskas 2010). In 2009, Maskeliūnaitė *et al.* (2009); Sivilevičius, Maskeliūnaitė (2010) applied the Analytic Hierarchy Process (AHP) method, which was proposed by Saaty *et al.* (2003), to investigate the importance of quality criteria on passenger carriage by railway. This method was also applied by Farhan and Fwa (2009) to identify the priority of road pavement maintenance. The AHP method was used for another task by Abdelgawad, Fayek 2010; Lin *et al.* 2008; Medineckienė *et al.* 2010; Morkvėnas *et al.* 2008.

The work aims to present the system analysis of operating AMP quality criteria, the algorithm of identifying their importance through the use of an expert method, enabling to identify the weights of the quality criteria required to calculate the AMP quality complex index according to the additive model.

2. Opinion of experts on the importance of AMP quality criteria and computation of their correlation

The country's more complex management of the economy and technological processes requires a comprehensive analysis of the activity. Frequently, the impact of separate factors on the work efficiency and production quality improvement shall be determined and estimated. Sometimes, the help of specialists (experts) is required. The efficiency of taking solutions influences on the improvement of the country's economy management.

The essence of the expert evaluation method lies in the rational organization of the analysis carried out by experts of the quantitative evaluation of the problem and the processing of findings. The generalized opinion of the group of experts is taken as a problem solution (solution result). If the solution shall be taken on the basis of expert evaluation, the degree of concordance of expert opinions shall be taken into account (Kendall 1970).

When given a prepared questionnaire, the experts E_1, E_2, ..., E_n were asked to give quantitative weight values X_1, X_2, ..., X_m (points B_1, B_2,..., B_m) to AMP quality criteria based on their knowledge, experience and intuition. The highest point (an integer number) is given to the most important quality criterion; one point less is given to the next criterion; and the lowest point is given to the least important criterion (usually 1 point). The number value of the highest point is selected depending on number m, which shows AMP quality criteria.

Based on the questionnaires filled in and returned by experts, weight values (points) given by each expert to AMP quality criteria and presented in Table 1.

A group of selected n experts give quantitative evaluation of the operating (not newly purchased) AMP m quality indices (criteria). Rating by ranks R_{ij} (i = 1, 2,..., n; j= 1, 2,..., m) makes up n number of rows and m number of columns, see Table 2 (matrix) R. Experts may evaluate the expected value R_{ij} in a different way. Any evaluation scale may be used, for example, index units, unit parts, percent, 10 point system or AHP method pair comparison scale (Lin *et al.* 2008; Podvezko 2009; Saaty 1980, 2003). To calculate the concordance coefficient, only expert index rating can be used (Podvezko 2005).

Table 1. Weight values given by experts to AMP quality indices in points B_{ij}

	Expert's (respondent's) code	Quality criterion (index) notation and its point (j = 1, 2, ..., m)			
		X_1	X_2	…	X_m
i = 1, 2,..., n	E_1	B_{11}	B_{12}	…	B_{1m}
	E_2	B_{21}	B_{22}	…	B_{2m}
	E_3	B_{31}	B_{32}	…	B_{3m}
	⋮	⋮	⋮	⋮	⋮
	E_n	B_{n1}	B_{n2}	…	B_{nm}
Total $\sum_{i=1}^{n} B_{ij} = B_j$		B_1	B_2	…	B_m

Table 2. Experts' opinion ranks and their use in determining an average rank and value W of Kendall's coefficient of concordance

	Expert's (respondent's) code	Quality criterion (index) notation and its rank (j = 1, 2, ..., m)			
		X_1	X_2	…	X_m
i = 1,2,...,n	E_1	R_{11}	R_{12}	…	R_{1m}
	E_2	R_{21}	R_{22}	…	R_{2m}
	E_3	R_{31}	R_{32}	…	R_{3m}
	⋮	⋮	⋮	⋮	⋮
	E_n	R_{n1}	R_{n2}	…	R_{nm}
Sum of ranks $\sum_{i=1}^{n} R_{ij}$		R_1	R_2	…	R_m
Average rank $\bar{R}_j = \frac{\sum_{i=1}^{n} R_{ij}}{n}$		$\bar{R}_1$	$\bar{R}_2$	…	$\bar{R}_m$
$\sum_{i=1}^{n} R_{ij} - \frac{1}{2}n(m+1)$					
$\left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2}n(m+1)\right]^2$					

If experts' evaluation was presented in any other form, it shall be preliminary ranked. Ranking is a procedure when the most important index is given rank equal to 1, next according to its importance is given rank two, etc. The last index according to its importance is given rank m; here m is the number of compared indices.

If weight values (points) given by experts to AMP quality criteria (indices) presented in Table 1 are available, the correlation of their opinion is determined by computing the Kendall's coefficient of concordance W. For this reason, first of all, points B_{ij} given to each criterion shall be replaced by ranks R_{ij} (Table 2), showing the hierarchy (precedence), inspite of the fact that the same W is obtained using values (points) instead of ranks. Points B_{ij} may be replaced by ranks R_{ij} using Eq (1):

$$R_{ij} = (m+1) - B_{ij}, \tag{1}$$

where B_{ij} – point (j = 1, 2, ..., m) given by i expert (i = 1, 2, ..., n) to criterion i; n – the number of experts; m – the number of AMP quality criteria (indices).

For example, ranks R_{ij} of AMP each criterion out of the 9 quality criteria are obtained from Eq $R_{ij} = 10 - B_{ij}$, and out of 7 quality criteria, from Eq $R_{ij} = 8 - B_{ij}$.

The idea of Kendall's (1970) coefficient of concordance is related to AMP's each quality criterion (index) rank sum R_{ij} with respect to all experts:

$$R_j = \sum_{i=1}^{n} R_{ij} \; (j = 1, 2, ..., m), \tag{2}$$

to be precise, with values R_j deviation from the total mean $\overline{R}$ square sum S (variance analogue) is:

$$S = \sum_{j=1}^{m} (R_j - \overline{R})^2. \tag{3}$$

Total mean $\overline{R}$ is calculated according to

$$\overline{R} = \frac{\sum_{j=1}^{m} R_j}{m} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} R_{ij}}{m}. \tag{4}$$

It is convenient to calculate average rank $\overline{R}_j$ and concordance coefficient (Kendall's coefficient of concordance (Chua, Li 2000)) W by a matrix, the structure of which is presented in Table 2. Columns refer to quality criteria (j = 1, 2, ..., m), rows to experts (i = 1, 2, ..., n), and squares to ranks R_{ij} given by experts to quality criteria.

Average rank $\overline{R}_j$ of each criterion is obtained by dividing the sum of given ranks by the number of experts:

$$\overline{R}_j = \frac{\sum_{i=1}^{n} R_{ij}}{n} \; (j = 1, 2, ..., m), \tag{5}$$

where R_{ij} – rank given by i expert to j criterion, n – number of experts.

If S is a real sum of squares, calculated according to Eq (3), the concordance coefficient, when there are no related ranks, is defined by the correlation of the obtained S and relevant max S_{max} (Maskeliūnaitė *et al.* 2009; Podvezko 2007; Завадскас 1987):

$$W = \frac{12S}{n^2 (m^3 - m)}. \tag{6}$$

It is convenient to calculate the sum S of AMP each criterion ranks R_{ij} deviations from average rank squares according to:

$$S = \sum_{j=1}^{m} \left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2} n(m+1) \right]^2, \tag{7}$$

where m – number of AMP quality criteria (j = 1, 2, ... m); n – number of experts (i = 1, 2, ... n).

Random value S is calculated by adding values identified for all quality criteria and presented in Table 2.

The max possible value S, when experts' opinions are absolutely compatible, i. e. when the evaluations of all experts are the same. The opposite, the worst (different) ranking would be when experts' evaluations are contradictory, i.e. all possible ranks from one to m are used to evaluate each criterion, when the sum of each criterion ranks is the same and coincides with the total mean. In this case the value of S is equal to 0, although such result may occur very rarely in practice and can be treated as theoretical and marginal.

The concordance coefficient may be used in practice if its marginal value showing when experts' evaluations can be still considered compatible is identified. Kendall (1970) proved that if the number of AMP quality criteria (indices) is $m > 7$, the weight of concordance coefficient may be identified through the use χ^2 (chi-kvadrat) Pearson's criterion.

Random value

$$\chi^2 = n(m-1)W = \frac{12S}{nm(m+1)} \tag{8}$$

is distributed according χ^2 to distribution with $v = m - 1$ degree of freedom. Critical value $\chi^2_{v;\alpha}$ is found according to the selected level of significance α (in practice, α value is taken 0.05 or even stricter 0.01) from χ^2 distribution Table with $v = m - 1$ degree of freedom. If χ^2 value calculated according to Eq (8) is higher than χ^2_{kr}, the evaluations of experts shall be considered as concordant.

When the number of compared AMP quality criteria (indices) n is from 3 to 7, χ^2 distribution should be applied carefully as distribution's critical value $\chi^2_{\upsilon,\alpha}$ may be higher than the calculated one although experts' compatibility level is still sufficient. In such case, probability Tables of concordance coefficient or critical values' S Tables (with $3 \le m \le 7$) may be used (Kendall 1970).

The min concordance coefficient value $W_{\min}$ at which it is stated that opinions of all experts n about the quality of AMP m compared quality criteria with the determined (required) weight level α and the degree of freedom $v = m - 1$ are concordant, and calculated according to Eq (9):

$$W_{\min} = \frac{\chi^2_{v,\alpha}}{n(m-1)}, \quad (9)$$

where $\chi^2_{v,\alpha}$– critical Pearson's statistics, the value of which is found in the Table (Montgomery 2009) when the degree of freedom υ and weight level α are taken.

Frequently, in practice in some calculations it is more convenient to use significance (weight 1, 2, ..., 9) indices, the best value of which is the max value.

When AMP quality is evaluated by the additive mathematical model (Sivilevičius *et al.* 2008), according to which its quality complex index is calculated, which enables to identify its quality by one number and compare it with the other analogous AMP, it is convenient to use not quality criteria average ranks $\bar{R}_j$, which do not show how one criterion is more important than the other, but their weight indices Q_j.

Weight indices in the solved sample in the research paper (Завадскас 1987) were calculated as follows: object's each criterion average rank $\bar{R}_j$ is divided by the value constant for all object's quality criteria, the sum of ranks $\sum_{j=1}^{m} R_j$, i.e. value is calculated:

$$\bar{q}_j = \frac{\bar{R}_j}{\sum_{j=1}^{m} R_j}. \quad (10)$$

The sum of values $\bar{q}_j$ calculated according to Eq (10) is equal to 1.000. Having normalized ranks, the most important quality criterion is the quality criterion the calculated value of which is the lowest (min). Final values are identified as follows. In the beginning, reciprocal quantity $\bar{q}_j$ is calculated for each quality criterion.

$$d_j = 1 - \bar{q}_j = 1 - \frac{\bar{R}_j}{\sum_{j=1}^{m} R_j}. \quad (11)$$

The sum of all calculated values d_j is equal to $m - 1$. Finally, quality criteria weight indices Q_j are calculated, the sum of which is also equal to 1:

$$Q_j = \frac{d_j}{\sum_{j=1}^{m} d_j} = \frac{d_j}{m-1}. \quad (12)$$

Max weight indices Q_j calculated like this are of the most important quality criteria when calculating additive K. Weight indices $Q_{j\max}$ calculated according to this methodology slightly differ from $Q_{j\min}$. Завадскас (1987) in the presented sample of applying this methodology points out that weight index $Q_{j\max}$ of the most important criterion identified by 35 respondents on the 5 quality criteria object equals to 0.225, and the least important $Q_{j\min}$ = 0.176, i. e. it differs only 1.278 times (27.8%), which makes this index "insensitive".

The importance of AMP quality criteria evaluated by experts by normalizing them (equating their sum to one) may be identified by calculating weight index Q_j of each quality criterion proposed by Eq (13):

$$Q_j = \frac{(m+1) - \bar{R}_j}{\sum_{j=1}^{m} \bar{R}_j}, \quad (13)$$

where m – number of quality criteria (indices) showing AMP quality (properties); $\bar{R}_j$ – average rank of j criterion, calculated according to Eq (5).

Control is obtained for j quality criterion given by all experts n (i = 1, 2 ,..., n) by dividing the sum of given weight values (points) from AMP for all m quality criteria (j = 1, 2, ..., m) by the sum of all points given by the same experts, taken from Table 1:

$$\tilde{Q}_j = \frac{\sum_{i=1}^{n} B_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{m} B_{ij}}. \quad (14)$$

Weight index Q_j enables to determine not only that AMP one quality criterion is more important than the other (average ranks $\bar{R}_j$ prove this as well), but how many times each is more important than the other.

Independent quality criteria weight indices Q_j enable to calculate K from the additive model:

$$K = \sum_{j=1}^{m} Q_j \times x_j = Q_1 x_1 + Q_2 x_2 + \ldots + Q_m x_m, \quad (15)$$

where x_j – normalized (non-dimensional) variable of AMP j criterion calculated from factual and permitted or marginal values, the best value of which is approximate to 1, and the worst is approximate to 0.

3. Numerical illiustration

Forty three specialists (experts) having knowledge of HMA mixture properties, quality requirements, production technology, AMP structure and technical parameters of the equipment were given questionnaires on the evaluation of weight values of 9 indices (quality criteria) showing the quality of the operating AMP.

The form and structure of the questionnaire as well as the quality criteria weight points given by the 1st expert to the operating AMP are presented in Table 3.

According to Eq (1) points B_{ij} of AMP quality indices‘ are converted into relevant ranks R_{ij}. For example, the weight value (point) 9 given by the 1st expert (E_1) to the 1st criterion (*C*) corresponds to rank 1. Values of all points B_{ij} replaced by ranks R_{ij}, are presented in Table 4.

The sum of ranks R_j given by all 43 experts of each criterion (j = 1, 2, ..., m) is calculated (Eq (2)). The sum of ranks of the 1st criterion is (*C*) $R_j = R_1 = 60$, the 2nd criterion (T) $R_j = R_2 = 116$, the 3rd criterion (H) $R_j = R_2 = 104$, etc.

Table 3. Questionnaire of determining the weight of the operating AMP quality complex evaluation quality criteria (points B_{1j} given by the 1st expert E_1 and calculated ranks R_{1j})

Number of criterion	Indices (quality criteria) showing AMP quality		Weight values in points B_{1j}	Ranks R_{1j}
1	Quality of HMA mixture production	Compliance of the produced HMA mixture composition (amount of components in it) with the job mix formula (JMF) requirement (*C*)	9	1
2		Compliance of the produced HMA mixture temperature with the temperature specified in *TRA ASFALTAS 08* (*T*)	7	3
3		Homogeneity of the produced HMA mixture (in mix batch), expressed by the quality of its mixing (*H*)	8	2
4	Environmental protection when polluting atmospheric air with the pollutants emitted from AMP (*E*)		1	9
5	Costs of HMA mixture production per 1 ton (cost price of producing 1 ton of HMA mixture) (*P*)		6	4
6	The degree of physical and moral wear (depreciation) of the operating AMP (*W*)		4	6
7	AMP repair and reconstruction costs (*R*)		5	5
8	The use (exploitation) of AMP capacity to produce HMA or other asphalt mixtures (*B*)		2	8
9	AMP technological versatility (capability to produce mixtures of various kinds, types and marks) (*U*)		3	7

Table 4. Ranks R_{ij} of the operating (not newly purchased) AMP quality criterion (indices) and values calculated from them

Expert‘s code, i = 1, 2, ..., n	AMP quality criterion (index) notation; j = 1, 2, ..., m								
	C	*T*	*H*	*E*	*P*	*W*	*R*	*B*	*U*
E_1	1	3	2	9	4	6	5	8	7
E_2	1	3	2	4	9	7	8	5	6
E_3	2	3	1	7	8	5	6	9	4
E_4	1	2	4	3	9	5	6	8	7
E_5	1	2	3	4	5	6	7	8	9
E_6	1	2	3	4	5	6	7	8	9
E_7	1	3	2	4	7	5	8	9	6
E_8	1	3	4	2	7	8	9	6	5
E_9	1	5	2	4	7	6	8	9	3
E_{10}	1	3	2	4	7	9	5	6	8
E_{11}	1	3	2	5	7	9	8	6	4
E_{12}	3	1	5	4	8	7	9	6	2
E_{13}	1	3	2	6	8	5	9	7	4
E_{14}	2	1	3	5	6	8	7	9	4
E_{15}	1	3	2	4	6	7	9	8	5
E_{16}	1	4	3	6	8	7	9	5	2
E_{17}	1	3	2	9	6	4	5	8	7
E_{18}	1	4	2	5	6	7	8	9	3
E_{19}	3	1	2	5	9	8	7	6	4
E_{20}	1	2	3	5	6	4	8	9	7
E_{21}	1	2	3	5	4	8	6	7	9

Continued

Continued Table 4

Expert's code, $i = 1, 2, ..., n$	AMP quality criterion (index) notation; $j = 1, 2, ..., m$								
	C	T	H	E	P	W	R	B	U
E_{22}	1	2	3	6	5	7	8	9	4
E_{23}	1	3	4	5	8	7	6	9	2
E_{24}	3	2	1	4	5	6	8	7	9
E_{25}	1	3	2	6	5	9	8	7	4
E_{26}	1	3	2	4	7	6	8	9	5
E_{27}	3	2	1	6	5	9	7	8	4
E_{28}	1	3	2	4	5	8	9	7	6
E_{29}	1	3	2	5	6	7	8	9	4
E_{30}	1	2	3	4	6	5	7	8	9
E_{31}	1	3	2	6	5	7	9	8	4
E_{32}	1	3	8	5	6	7	8	9	4
E_{33}	1	2	3	6	8	4	9	7	5
E_{34}	1	2	3	5	4	7	6	9	8
E_{35}	1	2	3	5	4	7	9	8	6
E_{36}	1	3	2	9	4	6	8	7	5
E_{37}	1	3	2	5	6	8	9	7	4
E_{38}	1	2	3	4	7	6	8	9	5
E_{39}	6	7	2	4	1	8	5	9	3
E_{40}	1	3	2	4	6	5	7	9	8
E_{41}	3	2	1	4	6	7	8	9	5
E_{42}	1	2	3	5	6	4	7	8	9
E_{43}	1	3	2	7	5	4	9	8	6
Sum of ranks $\sum_{i=1}^{n} R_{ij} = R_j$	60	116	104	217	262	281	325	336	234
Average rank $\overline{R}_j = \frac{\sum_{i=1}^{n} R_{ij}}{n}$	1.395	2.698	2.419	5.046	6.093	6.535	7.558	7.814	5.442
Difference $\sum_{i=1}^{n} R_{ij} - \frac{n(m+1)}{2}$	–155	–99	–111	2	47	66	110	121	19
$\left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2} n(m+1)\right]^2$	24 025	9801	12 321	4	2209	4356	12 100	14 641	361

Constant quantity is found

$$\frac{1}{2}n(m+1) = \frac{1}{2}43(9+1) = 215,$$

which is required when calculating the sum of average rank square S of criterion rank R_{ij} deviations from average rank squares according to Eq (7).

The difference between sum $\sum_{i=1}^{n} R_{ij}$ of ranks R_{ij} and constant quantity $\frac{1}{2}n(m+1)$ is calculated for each criterion. For example, this difference of the 1st criterion S is as follows:

$$\sum_{i=1}^{n} R_{ij} - \frac{n(m+1)}{2} = 60 - \frac{43(9+1)}{2} = -155.$$

This calculated difference of other quality criteria is presented in Table 4. The sum of all 9 quality criteria differences is equal to 0.

The square of the difference between ranks' sum $\sum_{i=1}^{n} R_{ij}$ and constant quantity $\frac{n(m+1)}{2}$ is calculated, which is presented in the last row of Table 4. For example, the square of this difference of the 1st criterion *C* is

$$\left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2}n(m+1)\right]^2 = [60-215]^2 = 24\ 025.$$

The squares of differences are written in the last row of Table 4 and according to Eq (7) quantity *S* is summed. Their sum *S* is solved in sample 79 818.

Concordance coefficient *W* is calculated according to Eq (6) when ranks are not related:

$$W = \frac{12S}{n^2(m^3-m)} = \frac{12\times 79\ 818}{43^2(9^3-9)} = 0.719.$$

It is larger than 0.5; therefore, it can be approx stated that experts‘ opinions are compatible.

As the number of quality criteria in the solved task is $m > 7$, the weight of the concordance coefficient is determined through the use of criterion χ^2, for which according to Eq (8) the random quantity is calculated

$$\chi^2 = n(m-1)W = \frac{12S}{nm(m+1)} = 43(9-1)0.719 = \frac{12\times 79\ 818}{43\times 9(9+1)} = 247.5.$$

The number of the degrees of freedom $\upsilon = m - 1 = 9 - 1 = 8$ is calculated for the number of experts $n = 43$ and the number of compared quality criteria $m = 9$ and a rather strict importance level $\alpha = 0.01$ is selected. Critical value $\chi^2_{\upsilon,\alpha}$ is found from the statistical Table (Montgomery 2009; Айвазян, Мхитарян 2001), which corresponds with the number of degrees of freedom and the selected importance level $\chi^2_{\nu,\alpha}$, which equals to 20.0902, i.e. it is much larger than the calculated value χ^2 , which is equal to 247.5. As value χ^2 calculated according to Eq (11) is larger than $\chi^2_{\upsilon,\alpha}$, it can be stated that the opinions of all experts are concordant when evaluating the weight of AMP quality criteria, and the the calculated average ranks show a common opinion.

Min value of the concordance coefficient W_{min} is calculated from formula (9), at the presence of which with the significance level $\alpha = 0.01$ and the number of the degree of freedom $\upsilon = m - 1 = 9 - 1 = 8$, it could be still stated that experts‘ opinions are concordant:

$$W_{\min} = \frac{\chi^2_{\nu,\alpha}}{n(m-1)} = \frac{20.0902}{43(9-1)} = 0.0584 << 0.719.$$

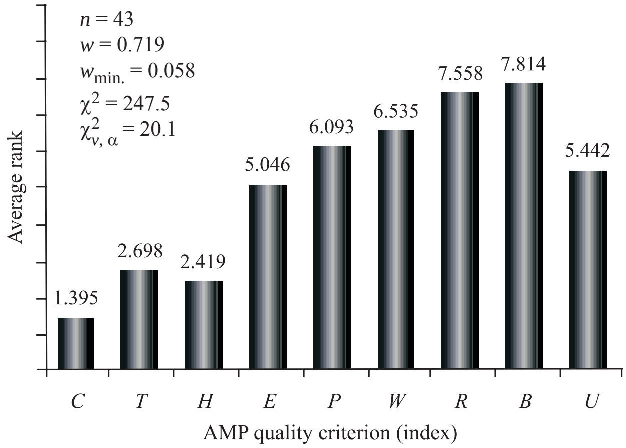

Fig. 1. Average ranks of operating AMP quality criteria (indices)

Column diagram of all 9 quality criteria average ranks $\overline{R}_j$ calculated values of AMP is drawn (Fig. 1) and values *n*, *W*, χ^2 and $\chi^2_{\nu,\alpha}$ are presented.

The data of the carried out research show that the evaluations of 43 experts of AMP 9 quality criteria weight correlate and may be justly taken as their generalized opinion.

Calculated average ranks $\overline{R}_j$ of AMP quality criteria show that index *C* is more important than *H*, *T*, *E*, *U*, *P*, *W*, *R* and *B*, i. e. the following hierarchy is obtained: $C \succ H \succ T \succ E \succ U \succ P \succ W \succ R \succ B$. The calculated $\overline{R}_j$ do not show how each of them is more important than the other.

When applying the methodology of Zavadskas (Завадскас 1987), AMP quality criteria weight indices Q_j are identified. For this purpose, Eqs (10)–(12) are used, when in the beginning $\overline{q}_j$ and d_j, and finally Q_j are computed from them. Calculation data are presented in Table 5 and Fig. 2.

Table 5. The results of AMP quality criteria (indices) significance (weight) and priority calculation, obtained when applying different methodologies

Quantity (Eq)	AMP quality criterion (index) notation									Sum
	C	*T*	*H*	*E*	*P*	*W*	*R*	*B*	*U*	
$\overline{q}_j$ (10)	0.031	0.060	0.054	0.112	0.135	0.145	0.168	0.174	0.121	1.000
d_j (11)	0.969	0.940	0.946	0.888	0.865	0.855	0.832	0.826	0.879	8.000
Q_j (12)	0.1211	0.1175	0.1183	0.1110	0.1081	0.1069	0.1040	0.1032	0.1099	1.0000
Q_j (13) and $\tilde{Q}_j$ (14)	0.1912	0.1622	0.1685	0.1101	0.0868	0.0770	0.0543	0.0486	0.1013	1.0000
Priority	1	3	2	4	6	7	8	9	5	

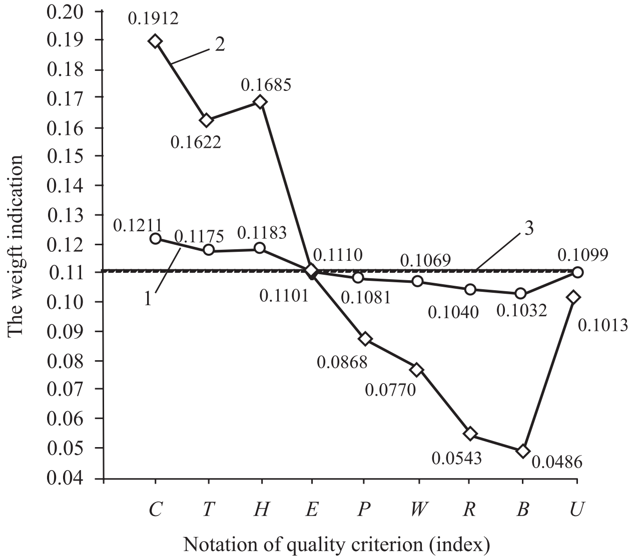

Fig. 2. Values of AMP quality criteria significance (weight) indices Q_j calculated through the use of methods: 1 – Zavadskas (Завадскас 1987); 2 – author's; 3 – average value of criteria

Correlation of the 1st criterion (C) average rank and the sum of ranks of all quality criteria is computed from the Eq 10):

$$\overline{q}_1 = \frac{\overline{R}_1}{\sum_{j=1}^{m} R_j} = \frac{1.395}{45.000} = 0.031.$$

Reciprocal quantity is obtained when the calculated correlation of ranks $\overline{q}_1$ of this criterion is subtracted from one according to Eq (11):

$$d_1 = 1 - \overline{q}_1 = 1 - 0.031 = 0.969,$$

which, according to formula (12) is divided by the sum of all quality criteria d_j, which is equal to $m - 1$, weight index is obtained:

$$Q_1 = \frac{d_1}{\sum_{j=1}^{m} d_j} = \frac{d_1}{m-1} = \frac{0.969}{8.000} = 0.1211.$$

Weight index of the 2nd quality criterion (T) is Q_2 = 0.1175, the 3rd quality criterion (H) – Q_3 = 0.1183, the 4th quality criterion (E) – Q_4 = 0.1110, the 5th quality criterion (P) – Q_5 = 0.108, the 6th quality criterion (W) – Q_6 = 0.1069, the 7th quality criterion (R) – Q_7 = 0.1040, the 8th quality criterion (B) – Q_8 = 0.1032 and the 9th quality criterion (U) – Q_9 = 0.1099

The sum of AMP quality criteria weight indices calculated according to the methodology of Zavadskas (Завадскас 1987) is equal to 1.0000. The difference between the max weight index Q_1 = 0.1211 and the min Q_8 = 0.1032 is equal to 0.0179. Their ratio 1.17 shows a slight (approx 15%) change of max and min values.

AMP quality criteria significances (weights) are determined according to the methodology developed by the author. For this purpose, the new Eq (13) developed by the author is used, from which the significance of AMP's 1st quality criterion C (produced HMA mixture composition compliance with JMF) is computed:

$$Q_1 = \frac{(m+1) - \overline{R}_1}{\sum_{j=1}^{9} \overline{R}_j} = \frac{(9+1) - 1.395}{45.000} = 0.1912.$$

Weight index of the 2nd (T) quality criterion is Q_2 = 0.1622, the 3rd (H) – quality criterion Q_3 = 0.1685, the 4th (E) quality criterion Q_4 = 0.1101, the 5th (P) – quality criterion Q_5 = 0.0868, the 6th (W) – quality criterion Q_6 = 0.0770, the 7th (R) – quality criterion Q_7 = 0.0543, the 8th (B) – quality criterion Q_8 = 0.0486 and the 9th (U) – quality criterion Q_9 = 0.1013. The sum of all quality criteria coefficients is equal to 1. The difference between the max Q_1 = 0.1912 and the min Q_8 = 0.0486 weight indices is equal to 0.1426, and ratio 3.93 shows a significant change (approx 75%) of max and min values (Table 5, Fig. 2.). A dotted horizontal line shows average weight index $\overline{Q}_j = 1:9 = 0.1111$ of all AMP quality criteria.

Having used weight indices Q_j of independent quality criteria, AMP quality complex index is obtained:

$$K = Q_1 \times x_1 + Q_2 \times x_2 + Q_3 \times x_3 + Q_4 \times x_4 + Q_5 \times x_5 +$$
$$Q_6 \times x_6 + Q_7 \times x_7 + Q_8 \times x_8 + Q_9 \times x_9 =$$
$$0.1912x_1 + 0.1622x_2 + 0.1685x_3 + 0.1101x_4 +$$
$$0.0868x_5 + 0.0770x_6 + 0.00543x_7 + 0.0486x_8 + 0.1013x_9.$$

Normalized values of variable quantities x_1, x_2, ..., x_9 of each AMP differ and vary from 0 to 1. The higher they are, the better quality of the operating AMP is.

4. Conclusions

AMP quality is evaluated according to 9 independent quality criteria showing the compliance of HMA mixture properties produced in it with JMF (C, T and H); its capabilities to meet the environmental protection requirements (E) according to the pollutants' concentration emitted from its equipment; its economy, expressed by production manufacturing costs per one ton of the produced HMA (P); its technical condition (degree of depreciation) and investments allocated to its improvement (W and R); the use of its capacity (technical productivity) when producing HMA mixture, required to lay transport roads, streets, airfields pavement structure courses in the servicing rational zone (B) and its technological versatility, defined by a possibility to produce in it all groups, kinds and types of asphalt mixtures (U) presented in "*TRA ASFALTAS 08*". The importance of these quality criteria to the quality were evaluated by 43 experts according to a 9-point scale.

Average ranks $\overline{R}_j$ obtained by replacing points given to criteria by ranks enabled to identify their hierarchy showing that the most important quality criteria for AMP quality are influenced by the properties of HMA mixture produced in it (C = 1.395, H = 2.419, T = 2.698). The less important quality criteria are influenced by environmental protection and technological versatility (E = 5.046, U = 5.442); the next less important quality criteria are those showing the mixture production cost price and AMP depreciation degree (P = 6.093, W = 6.353), and the least important quality criteria are those reflecting the scope of investments allocated to AMP repair and reconstruction and the degree of their capacity to produce HMA mixture (R = 7.558, B = 7.814). It is logical that indices of the produced HMA mixture properties mostly influence on the quality of the technological equipment complex. Experts almost do not care that most of the time AMP will not produce HMA mixture (will not generate income, benefit and added value). It may be considered that due to long idle time the company will not incur huge losses and generate sufficient benefit during the HMA mixture production period.

The opinion of all 43 experts are concordant as the calculated concordance coefficient is W = 0.719, Pearson's chi-kvadrat statistics χ^2 = 247.5 is much higher than critical value $\chi^2_{\upsilon,\alpha}$, which corresponds to the number of the degree of freedom ν = 8 and significance level α = 0.01 ($\chi^2_{\nu,\alpha}$ = 20.0902). Min concordance coefficient is $W_{\min}$ = 0.0584, at which it could be still stated (when ν = 8 and α = 0.01) that the opinions of all experts are concordant.

AMP quality criteria normalized significance (weight) indices calculated according to Zavadskas methodology max value $Q_{\max}$ = 0.1211 (C quality criterion) and min $Q_{\min}$ = 0.1032 (B quality criterion) show their slight difference equal to 0.0179, i.e. it differs 1.17 times (approx 15%). The max value of these quality criteria weight indices calculated according to the author's methodology is $Q_{\max}$ = 0.1912, and the min value is $Q_{\min}$ = 0.0486: the difference is 0.1426, i.e. 3.93 times (approx 75%). Quality criteria weight indices calculated according to the 2nd method are more different; therefore they are more "sensitive" and have greater impact on the weight of quality criteria when used to calculate the values of AMP complex quantity index K additive model components.

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Received 8 September 2010; accepted 20 January 2011