



QUALITY ATTRIBUTES AND COMPLEX ASSESSMENT METHODOLOGY OF THE ASPHALT MIXING PLANT

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Abstract. Multi-attribute methods in road construction can be used on the national, organization and project levels. However, most assessment methods are seeking to find how to make the most economic construction decisions, and most of all these decisions are intended only for economic objectives. Computerised Asphalt Mixing Plants (AMP) are one of the most expensive and complicated equipments for construction of road pavements. Modern AMP is controlled by computer program, but there are still some problems. Properties of the AMP not always satisfy demands and requirements of road constructors. Quality of the asphalt hot mixtures, environmental contamination, pollution, firm economic well-being and possibility to satisfy demands of hot asphalt mixture users depend on the AMP quality. This paper proposes a multi-attribute model for efficient quality assessment of the AMP. For this problem were selected 9 main quality attributes and weighted by expert ranking method. The problem is solved by applying additive assessment. Also, a case study is presented.

Keywords: asphalt mixing plant (AMP), hot mix asphalt (HMA), quality, attribute, assessment, additive.

1. Introduction

Asphalt has been used as a construction material from the earliest days of civilization, but though it has long been used as a waterproofing material in shipbuilding and hydraulics, its use in roadway construction is much more recent. About 96% of the roads in the United States have asphalt surfaces (Roberts *et al.* 2002). While in Lithuania, more than 60% (Petkevičius, Christauskas 2006) of the roads have asphalt surface. The gravel pavements will be covered by an asphalt layer in the near future.

Permanent deformations (Radziszewski 2007), primarily in the form of ruts, are one of the basic asphalt pavement damages impairing its service properties. Application of appropriate asphalt mixtures and binder modification are effective methods for improving asphalt courses resistance. While being manufactured, stored, fitted into a road pavement and during long-term service, bitumen binders and asphalt mixtures are subject to continuous unfavourable ageing processes during which pavement courses characteristics change considerably, resistance to permanent deformations being among them.

The largest damage to the road pavements is caused by heavy goods vehicles (Sivilevičius, Šukevičius 2007). Due to large axle loads, which often assume a dynamic effect, the

heavy goods vehicles account for almost the total destructive impact on the road pavement. A continuous increase in the transit heavy goods vehicles on the roads of Lithuania causes the permanent deformations of road pavements, which are further progressing. Due to an insufficient pavement strength the ruts, waves, displacements and potholes are initiated. Based on the analysis of traffic volume it could be stated that the amount of vehicles on our roads has been annually growing. The largest loads are caused by heavy goods vehicles, the average annual increase is 17%.

The behaviour of pavements indicates that the condition of the bonding between pavement layers plays an important role (Ziari, Khabiri 2007) in the road structures performance. Premature failure of road sections due to layer separation, leading to redistribution of stresses and strains in the pavement structure, is often encountered, especially in areas, where the vehicles are more likely to apply horizontal forces.

Čygas *et al.* (2008) stated that the rapid growth of heavy traffic, the increase in the standard axle load make scientists to look forward for new durable road constructing materials and their mixes. The continuously increasing need for strengthening the road pavement structures induces to use new road reconstruction technologies, to

search for new methods in constructing pavement structural layers and investigate pavement structures under real conditions. The authors presented investigation of experimental pavement structures and described the installation process of stress and strain transducers in different layers of experimental pavement structures and initial results of stress and strain measurements.

The performance of hot mix asphalt (HMA) is largely determined by the characteristics of its constituents: asphalt binder and aggregate. Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

The needs for highway research are many. HMA is used for roads and motorways pavements' laying. It is produced in central or mobile asphalt mixing plants (AMP). These technological equipment are named asphalt mixing plants. HMA paving materials can be manufactured by:

- batch mix plants,
- continuous mix (mix outside dryer drum) plants,
- parallel flow drum mix plants, and
- counter flow drum mix plants.

This order of listing generally reflects the chronological order of development and use within the HMA industry. Construction of AMP is adopted for certain production technology of HMA. Technological process of HMA contains preparing (initial proportioning of cold aggregates, drying and heating, hot mix aggregate screening to 3 or 4 hot fractions, hot fractions, imported filler, required dust and asphalt cement proportioning by weight) and main operations (hot mixing of overall prepared materials). It is necessary to distinguish between the HMA quality and the HMA production quality. The quality of HMA production is characterised by % of its mass meeting the job mix formula or normative documentation quality (componential composition, temperature etc.) requirements (Petkevičius, Sivilevičius 2008). The quality of produced HMA depends as on quality of applied materials as well as on manufacturing quality. High of HMA making quality can be reached by automatising of processes and computerised, properly controlling them. But the main role plays operator. He must properly use possibilities supplied by modern technologies (Sivilevičius 2005).

The modernisation history and evolution of AMP constructions are investigated and presented in many works (Jones 1986; Zhang 1996). The HMA producing technology and appropriate construction of AMP is in continuous modernisation process. The aim of modernisation is seeking for the best HMA quality, productivity, reliability, technological universality, for less pollution of environment etc.

A lot of HMA quality guarantee problems produced in AMP of different construction and automatising

processes according to many aspects were analysed and investigated. These problems are presented in Sivilevičius (2005) works. Robers *et al.* (2002) presented history of HMA composition design methods. The modern and usage in practice methods are presented by Asphalt Institute (2007). Sivilevičius (2003), investigated the influence of mineral materials grading homogeneity on the stability of the asphalt concrete mixture composition. Sivilevičius and Vislavičius (2008) presented a study of the evaluation of the random errors influence on the stochastic technological process occurring in a batch-type plant on the homogeneity of the HMA. They present the algorithm of prognosing mineral part composition of HMA, which takes into consideration a variation of mineral material cumulative percent age passing through control sieves, as well as errors of mineral material dose weight in the finite dosing.

Dosing of materials is one of the most important part of the HMA producing process. The quality of HMA making rising as systematical and random proportioning errors decreasing. The making quality rises when segregation of hot aggregate fractions is diminishing (Sivilevičius 2003).

HMA is produced by batches applying classical technology as in Lithuania as in most European countries. Quality of HMA produced by batch type AMP is assessed by applying proposed statistical methodology of control and operating (Petkevičius, Sivilevičius 2008).

AMP must satisfy all set required properties. It must produce mixture of appropriate componential composition, temperature and homogeneity, without pollution of environment, be able to produce different groups and marks of mixtures. The produced mixtures must not be expensive, and etc. AMP quality can be evaluated by applying multi-criteria additive complex model. The AMP model is described by 9 discrete criteria. Number of criteria can be changed. In civil engineering practice for multi-criteria problems, solutions can be applied by different methods: game theory (Antuchevičienė *et al.* 2006; Zavadskas, Turskis 2008), TOPSIS (Zavadskas, Kaklauskas 2007), COPRAS (Kaklauskas *et al.* 2007; Viteikienė, Zavadskas 2007), VIKOR (Zavadskas, Antuchevičienė 2007), AHP (Su *et al.* 2006), ELECTRE (Zavadskas, Kaklauskas 2007) etc.

There are many multi-attribute decision-making methods that can be applied for civil engineering problems. The authors of this research propose problem solution, based on multi-attribute additive function, taking into account that AMP multi-functional equipment and quality assessment are very complicated in this investigation.

2. AMP multi-attribute quality assessment

AMP is very complicated modern and expensive technological equipment (Fig. 1).

The main operations are controlled by installed computer programs. These programs enable the AMP operators achieve high quality of HMA. For this reason an operator must use min tolerances of materials weights, temperature of materials and select a required mixing time. When operator is working in regime of min tolerances, the time of materials proportioning is very long that reduces the productivity



Fig. 1. Construction of batch-type asphalt mixing plant (AMP): 1 – cold feed with integrated collector belt; 2 – drying drum with burner; 3 – filter-type dust collector with centrifugal force coarse dust separator; 4 – chain elevator; 5 – hot screen with bypass changeover flap; 6 – hot aggregate silo with 6 mineral compartments plus a bypass; 7 – weighing platform with scales for mineral materials, imported fillers, reclaimed dust, bitumen and special materials; 8 – mixing platform twin-shaft paddle mixer; 9 – movable hopper, optional horizontal skip; 10 – hot mix silo; 11 – truck loading; 12 – silo tower for reclaimed dust and imported filler; 13 – electrically heated bitumen tank installation; 14 – command container with control system (Available from Internet: <<http://www.ammann-group.ch/content/documents/d200404051516458690.pdf>> [accessed 2008, May])

of AMP. Operators are not always setting min tolerances of material weight and this causes a decrease of HMA quality. From this point of view, HMA computerised operating only allows to achieve a high quality only when operator uses a proper operating regime. Operator can select and set different regime of AMP work: narrow-ranging, medium-ranging or wide-ranging tolerance of mass doses. The quality of produced HMA in AMP is subjective and mostly depends on operators' qualification and conscience. It depends also on controlling programs and personal.

2.1. Attributes of AMP quality assessment

According to the authors' opinion, the AMP is of excellent condition when:

- 1) Tolerances of actual components (coarse aggregate, fine aggregate, fillers, and bitumen) quantities

in lot of made HMA by AMP differs less than is allowable according to the statistical tolerances that are provided by national norms (standards). An ideal case is when quantities deviations from job mix formula equals 0.

- 2) Temperature of produced HMA is in interval between max and min values defined to the used bitumen mark. Ideal temperature is in case when it is equal to the mediocre value between max and min values. Ideal temperature depends on the used bitumen mark.
- 3) Components of batch of flow HMA are smoothly distributed. That means that HMA is homogeneous. The components quantity is equal in samples, which are taken from different places of the batch.

- 4) Pollution (dust particles, burning products gases) emission is lower than the highest permitted concentration (HPC).
- 5) Production costs of HMA made in AMP are min. This can be achieved by minimising time, energy, electricity and heat wastes, optimising the number of personal and working rhythmically.
- 6) Single parts of AMP are taut, ordered, and properly regulated and min ratted. In ideal case AMP can right work without replacing parts and elements, without technical maintenance and reparation.
- 7) The awarded repair and reconstruction costs ratio to the needed repair and reconstruction costs. In ideal case the awarded costs must be not less than needed ones.
- 8) The actual produce capability of AMP must almost be equal or less more than it is needed for production amount in service area. In an ideal case rhythmically working AMP produced amount of HMA is used for roads, highways and other pavements.
- 9) AMP according to the national standards *LST EN 13108* can produce 7 types of HMA. 13108-Part 1 – Asphalt Concrete (AC); Part 2 – Asphalt Concrete for very thin layers (BBTM); Part 3- Soft Asphalt (SA); Part 4 – Hot Rolled Asphalt (HRA); Part 5 – Stone Mastic Asphalt (SMA); Part 6 – Mastic Asphalt (MA) and Part 7 – Porous Asphalt (PA). Reclaimed Asphalt (RA) compatible to national standards *LST EN 13108-8* can be used in these mixtures. Cold Asphalt Mixture (CAM) and Surface Dressing (SD) can be produced too. An ideal case is when AMP can produce all 10 HMA types.

2.2. Multi-attribute mathematical model of AMP complex quality assessment

A multi-attribute mathematical model was developed to assess technological equipment quality. At first after investigation and expert questioning it was determined to set the most significant AMP quality criteria. The additive assessment AMP quality function is as follows:

$$K = \sum_{v=1}^h R_v x_v = Cx_1 + Tx_2 + Hx_3 + Ex_4 + Px_5 + Wx_6 + Rx_7 + Bx_8 + Ux_9, \quad (1)$$

where R_v – v criterion average range numerical value; h – a number of criteria in the model; x_v – variable depending on AMP v criterion factual and standard or limit parameters; C, T, H, E, P, W, R, B and U – loose terms showing the importance of HMA composition (C), temperature (T), homogeneity (H), production costs (P), HMA environmental protection (E), AMP physical and moral wear (W), repair and reconstruction costs (R), capabilities (B) and technological universality (U) criteria; x_1, \dots, x_9 – variable arguments ($v = 1, \dots, 9$) making up the model, which are used when evaluating parameters ($x_v = 0, \dots, 1$) influencing the value of each criterion.

The significance index was identified by the calculation formula of mathematical model (2), arguments x_v was extended through an experimental research of the data from the survey of 43 competent respondents, according to a 9-point system enabled to write the final AMP quality complex multi-criteria index K expression:

$$K = 0.1911 \left[1 - \frac{\sum_{i=1}^k \frac{|\Delta k_{fi}|}{|\Delta k_{ni}|}}{k} \right] + 0.1622 \left[1 - \frac{|\Delta T_f|}{\Delta T_n} \right] + 0.1685 \left[1 - \frac{\sum_{i=1}^k \frac{\Delta \sigma_{fi}}{\sigma_{fik}}}{k} \right] + 0.1100 \left[1 - \frac{\sum_{j=1}^m \frac{c_j}{HPC_j}}{m} \right] + 0.0869 \left[\frac{b(s_{\max} - s_f)}{s_{\max}} \right] + 0.0771 \left[1 - \frac{a_f}{100} \right] + 0.0542 \frac{r_f}{r_{\max}} + 0.0487 \frac{p_f}{p_{\max}} + 0.1013 \times [HMA_{AC} + HMA_{BBTM} + HMA_{SA} + HMA_{HRA} + HMA_{SMA} + HMA_{MA} + HMA_{PA} + HMA_{RA} + CAM + SD], \quad (2)$$

where $|\Delta k_{fi}|$ – modulus of factual quantity means \bar{k}_{fi} deviation of i component, contained in HMA, coarse aggregate – CA, fine aggregate – FA, fillers – F or bitumen – B from job mix formula k_{pi} of this component, mass % $|\Delta k_{fi}| = |\bar{k}_{fi} - k_{pi}|$; $|\Delta k_{ni}|$ – value of i component quantity regulated deviation modulus, mass %; k – component quantity in the produced HMA (usually 4, sometimes 3); $|\Delta T_f|$ – modulus of HMA factual temperature mean \bar{T}_f deviation from temperature's upper T_u and lower T_l values (tolerances) mean $0.5(T_u + T_l)$ set in the norms, °C; ΔT_n – HMA regulated temperature tolerance, depending on the brand of the used bitumen, $\Delta T_n = T_u - T_b$, °C; $\Delta \sigma_{fi}$ – difference between the produced i component quantity standard deviation σ_{30i} in HMA mixture, obtained when mixing in HMA mixing plant for 30 s, and this component's quantity standard deviation $\Delta \sigma_{fik}$, indicating constructional capacities of a mixing plant to reach max HMA homogeneity according to i component, when mixing the mixture for a rather long time ($\Delta \sigma_{fi} = \sigma_{30i} - \sigma_{fik}$), mass %; c_j – factual concentration of j pollutant emitted from AMP equipment to environment, mg/m^3 ; HPC_j – highest permitted concentration of j pollutant mg/m^3 ; m – a number of pollutant, according to which AMP quality is identified; b – coefficient, depending on the considered as the best set ratio between the lowest s_{\min} and the highest (considered as the worst) s_{\max} net prices; s_f – factual net price of HMA in the investigated AMP, €/t; a_f – (total) value of AMP factual wear and tear, %; r_f – monetary costs allocated for AMP repair and reconstruction, €; r_{\max} – highest expenses allocated for AMP repair and reconstruction, necessary to adjust it

properly to carry out all functions, €; p_f – factual exploitation of AMP capacities during the working season (usually 8 months) to produce HMA of all types and brands, t/season; p_{max} – the largest possible quantity of HMA to be produced during the working season in AMP working at nominal work regime, t/season; HMA_{AC} , HMA_{BBTM} , HMA_{SA} , HMA_{HRA} , HMA_{SMA} , HMA_{MA} , HMA_{PA} , HMA_{RA} , CAM , SD – show the possibilities to produce bituminous mixtures of relevant brands in AMP, evaluating each of them 0.1.

Factual values of evaluated AMP arguments x_1, \dots, x_9 calculated from the data of HMA laboratory investigations, production accounting documents, pollutant emissions and financial reports. Allowable, defined by the normative country documents, values or optimal values also use for calculation of actual values of the arguments x_1, \dots, x_9 . According to the investigated attribute, the bigger value x_v means that AMP it is better and is more close to ideal device. The value of the best (ideal) AMP multi-criteria complex quality index K is 1, average: 0.5, and the worst: 0.

2.3. Case study

The proposed assessment of AMP quality methodology was applied in practice. 8 AMP were selected for assessment. The criteria values were calculated according to AMP technical characteristics. These means are presented in Table 1. According to initial calculated values, we state

that some of criteria are better in one alternative, while some others are better in another one.

It is unclear, what is the best AMP. The ranking and assessing alternatives is setting by applying the proposed methodology. The ranking and assessment results are presented in Table 2. The results show that the best alternative is the 8th alternative.

We can state that the 8th alternative is better than 5th one, the 5th alternative is better than 7th alternative, the 7th alternative is better than 4th alternative, the 1st alter-

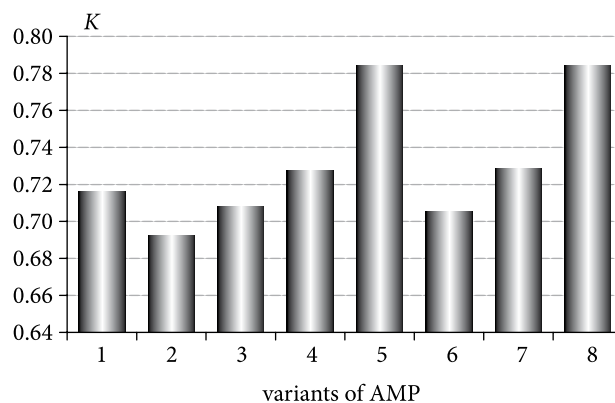


Fig. 2. Graphical view of AMP's performance criterion K values

Table 1. Decision-making matrix for quality assessment of AMP

Variant	Criteria under consideration								
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
1	0.69	0.75	0.61	0.66	0.64	0.90	0.73	0.85	0.80
2	0.72	0.69	0.69	0.61	0.58	0.88	0.67	0.91	0.60
3	0.61	0.79	0.57	0.72	0.68	0.71	0.82	0.79	0.90
4	0.67	0.84	0.67	0.58	0.72	0.98	0.75	0.76	0.70
5	0.84	0.92	0.73	0.60	0.83	0.72	0.61	0.90	0.80
6	0.72	0.84	0.57	0.58	0.68	0.90	0.75	0.85	0.60
7	0.61	0.75	0.67	0.61	0.68	0.98	0.67	0.79	1.00
8	0.75	0.82	0.91	0.88	0.63	0.77	0.79	0.62	0.70
Opt.	max	max	max	max	max	max	max	max	max
Significance	$C = 0.191$	$T = 0.162$	$H = 0.168$	$E = 0.110$	$P = 0.087$	$W = 0.077$	$R = 0.055$	$B = 0.049$	$U = 0.101$

Table 2. Results of AMP quality assessment

Variant	Criteria under consideration									Result K
	Cx_1	Tx_2	Hx_3	Ex_4	Px_5	Wx_6	Rx_7	Bx_8	Ux_9	
1	0.1318	0.1215	0.1025	0.0726	0.0557	0.0693	0.0402	0.0416	0.0808	0.7160
2	0.1375	0.1118	0.1159	0.0671	0.0505	0.0678	0.0369	0.0446	0.0606	0.6926
3	0.1165	0.1280	0.0958	0.0792	0.0592	0.0547	0.0451	0.0387	0.0909	0.7080
4	0.1280	0.1361	0.1126	0.0638	0.0626	0.0755	0.0412	0.0372	0.0707	0.7277
5	0.1604	0.1490	0.1226	0.0660	0.0722	0.0554	0.0336	0.0441	0.0808	0.7842
6	0.1375	0.1361	0.0958	0.0638	0.0592	0.0693	0.0413	0.0416	0.0606	0.7051
7	0.1165	0.1215	0.1126	0.0671	0.0592	0.0755	0.0368	0.0387	0.1010	0.7288
8	0.1432	0.1328	0.1529	0.0968	0.0548	0.0593	0.0434	0.0304	0.0707	0.7844

native is better than 3rd alternative, the 3rd alternative is better than 6th alternative, and finally the 6th alternative is better than 2nd one. The alternatives rank: $8 > 5 > 7 > 4 > 1 > 3 > 6 > 2$.

3. Conclusions

In this research work the methodology for assessing quality of AMP is proposed. The model and selected assessment criteria set are presented, too. This model allows to compare and evaluate the state and condition of AMP. The practical example shows that the model is appropriate for practical use.

It is rational to select the general contractor to national road construction by applying AMP quality complex multi-attribute index K . The selected contractor in bidding process must have the appropriate and proper quality AMP.

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