JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT
2009
15(2): 169–179

MANUFACTURING TECHNOLOGIES AND DYNAMICS OF HOT-MIX ASPHALT MIXTURE PRODUCTION

Henrikas Sivilevičius[1], **Šarūnas Šukevičius**[2]
Dept of Transport Technological Equipment, Vilnius Gediminas Technical University, Plytinės g. 27, LT-10223 Vilnius, Lithuania
E-mail: [1]*henrikas@ti.vgtu.lt,* [2]*sarunas.sukevicius@ti.vgtu.lt*

Received 15 Jan 2009; accepted 11 May 2009

Abstract. In most countries, the pavement of motor roads, airfields and other trafficked areas is made of hot-mix asphalt (HMA) mixture prepared by asphalt mixing plants (AMP) of various designs. The total output of HMA mixtures shows the dynamics of national road transport infrastructure's development, corresponding to the increasing number of vehicles, traffic intensity and axle loading. HMA mixtures are made by using various technologies, which have some advantages and disadvantages. The paper presents technological schemes of making HMA mixtures used in Lithuania and other countries. The development of AMP and technical and technological characteristics of new computer-aided AMP models used at various asphalt production companies (APC) were analysed. Based on the data provided by the European Asphalt Pavement Association (EAPA), the correlational-regression relation between the country's area and the amount of the produced HMA mixtures was established. The data on the total output of HMA mixtures in Lithuania cannot be found in the information provided by EAPA. For the first time, the dynamics of the production of HMA mixtures by particular APC in Lithuania over the last 10 years (1998–2007) has been determined based on the data directly obtained from their manufacturers. The data were analysed and compared to the output of HMA mixtures in other countries and the dynamics of the development of AMP models used in Lithuania and changes in their numbers were determined.

Keywords: hot-mix asphalt mixture, asphalt mixing plants, batch plant, production dynamics, technological process.

1. Introduction

The sector of Lithuanian transport accounts for more than 10% of the gross domestic product (GDP), and most of which is falling on road transport. This may be explained by the density of road network as well as the state and technical parameters of roads. Asphalt pavement of the principal roads in the country makes 60.1%. Hot-mix asphalt mixture is used for this purpose.

In most countries, the layers of motor road pavement are made of bituminous mixes, with HMA mixture being the most popular material due to its numerous advantages (Hunter 1997; Asphalt … 2007; Roberts *et al.* 1991). HMA mixture: a mixture of aggregate and asphalt cement (bitumen) sometimes including modifiers, that is produced by mixing hot, dried aggregate with heated asphalt in plant designed for the process (McDaniel and Anderson 2001).

A number of researchers, e.g. Arambula *et al.* (2007), Stroup-Gardiner and Brown (2000), Chen and Liao (2002), Seo *et al.* (2007), Rybiew (Рыбьев 1969), Kotliarskij (Котлярский 2004), Szydlo and Mackiewicz (2005), Topal and Sengoz (2005), Shu and Huang (2008), Li and Metcalf (2005), studied the structure of HMA mixture and asphalt concrete, trying to find the ways for improving their properties. The researchers from the Asphalt Institute (1993), as well as Roberts *et al.* (2002), Sanchez-Leal (2007), Sivilevičius and Vislavičius (2008), Ogunro *et al.* (2004), Aravind and Das (2007), Asi (2007), used deterministic and stochastic methods to improve the design of hot asphalt mixture composition.

The investigations of Kennedy and Huber (1985), Petkevičius and Sivilevičius (2008), Wu and Romero (2005), Sivilevičius (2005) are aimed at developing methods of quality control for producing the designed HMA mixture of optimal composition. Recently, feasibility study of using reclaimed asphalt pavement (RAP) in HMA mixture production has been made by Huang *et al.* (2005), Widyatmoko (2008), Karlsson and Isacsson (2006).

The survey of the investigations shows that HMA mixture is the material with complex structural, mechanical and rheological characteristics, which has not been thoroughly investigated yet. The structure of HMA mixture and its properties are being continuously improved to achieve that the layers of road pavement made of it could withstand the increasing axle loading of heavy vehicles and traffic (Sivilevičius and Šukevičius 2007; Laurinavičius and Oginskas 2006; Radziszewski 2007; Ziari and Khabiri 2007) as well as changing climatic conditions.

In addition to developing methods of improving the quality of the materials used in the production and composition design of HMA mixture, the researchers and engineers are trying to improve the production technology and equipment. All these works allow us to produce

ISSN 1392–3730 print / ISSN 1822–3605 online
DOI: 10.3846/1392-3730.2009.15.169-179

higher quality HMA mixtures and, therefore, to obtain stronger and more durable asphalt pavement with better surface structure.

The dynamics of HMA mixture output shows the rate of development and maintenance of automobile roads, depending on the total area, population and the number of vehicles of the country as well as density of road network and the economic development of the state. According to the data provided by Asphalt Institute (2007), 1.5 million tonnes of petroleum asphalt were produced in the US in 1920, while in 1979 its amount reached a record figure of 38 million tonnes, most of which were used to build road pavement. In 1988, the amount of HMA mixture produced in this country reached 500 million tonnes, which cost 10.5 billion US dollars (Roberts *et al*. 1991). In the former USSR, about 60 million tonnes of asphalt concrete mixture were produced in 1979 (Королев 1979).

In highly developed countries, the number of vehicles is continuously growing. Therefore, new roads are being built and the old ones are being reconstructed. The demand for bituminous mixes and the requirements to their quality are also increasing, giving an incentive to engineers to create new technologies of HMA mixture production and appropriate asphalt mixing plants (AMP).

Surveying the historical development of road pavement (Jones 1986), the author indicates that, since the end of the 19th century, road engineers in Europe have begun to use for road pavement a dustless material, known now as asphalt. After the World War II, both in the United Kingdom and USA, road pavement was mainly made of hot-rolled asphalt. In the 40-ies and the 50-ies, various types of AMP were used for making HMA mixtures. However, they were not powerful enough. Later, these plants were automated and electronic systems of proportioning and control of the materials were introduced. Their capacity have grown from 20–30 tonnes of mixture per hour to 80–120 t/h, while controlled by a single operator.

German Wibau SL developed dustless AMP, while drum mixers were only in gestation period in the USA in 1975. The drum mixer was developing by leaps and bounds in the USA (Jones 1986). In 1973, 27 % of all new AMP were of drum-mixer type and by 1985 this had grown to 98%. In 1973, 27% of all new AMP were of drum-mixer type and by 1985 this had grown to 98%. It is now estimated that there is a population of 4000 AMP in the USA: of these 1500 are drum-mixers.

Drum-mixer type AMP are being continuously improved to increase their efficiency. Zhang (1986) describes and assesses the widely used parallel-flow, single-diameter drum mixers and Venturi-type mixers, as well as comparing the design features of early single-diameter drum, double-drum and triple-drum models, including their heat transfer and capacity of heating the reclaimed asphalt pavement (RAP) to show the advantages of cylinder-type systems to HMA mixture manufacturers and contractors. He demonstrates that the smaller permissible flow rate makes the single-diameter drum mixer‘s productivity by 35% lower than that of the Venturi-type mixer. Including thermal energy carried by superheated virgin aggregate, the triple-drum mixer possesses the industry’s greatest ability for running very high percentages of RAP with moisture contents more than 5%.

The first G-1 (D-138) model of batch-type AMP with gravity drum mixer was introduced in Lithuania in 1962. According to the data provided by Petkevičius (Петкявичюс 1986), 119 AMPs were used at 45 Lithuanian APS in 1982. They produced 1.95 m tonnes of HMA mixture. 135 AMP operating at 48 APC in Lithuania produced as much as 2.284 m tons of HMA mixture in 1984. At that time, Russian AMP of low capacity (about 20–25 t/h) were replaced by German (GDR) AMP made by Teltomat-5 technological equipment with the output of 80-100 t/h. In 1982, the number of these AMP was 5, while in 1984 it reached 14 items. 99 AMP with 93 batch-type mixers were used at APC at the end of 1999 (Sivilevičius 2000). According to rough calculations of the authors, they had already produced 1.8–2.4 m tonnes of HMA mixture.

At that time (1999), HMA mixture in Lithuania was made by 64 inefficient Russian mixers (producing up to 25 t/h of HMA), 5 medium efficiency AMP (40–100 t/h) as well as by 24 Teltomat-5 AMP of higher output (up to 100 t/h) and by only 6 computer-aided AMP models AMO BS 200/RC 120, AE 150T, Teltomat-160, 160 Global H, Euro A 240, and MAP 155 E 190 L, with the production capacity ranging from 150 to 200 t/h, which were produced by the companies Machinery, Benninghoven, Maschinen GmbH, Ammann and Marini AMP. Most of these models are used now. The manufacturers of HMA mixtures used to purchase new computer-aided batch-type AMP to replace obsolete equipment.

There are currently 3 types of plant in use in the UK: batch-heater, batch asphalt plant, drum-mixer (Jones 1986). In the USA there are also 3 types of AMP, working according to the new USA standard ASTM D995-95b (2004). These are batch plant, continuous mix plant and drum-mix plant.

The statistical data provided by EAPA show that most of the countries estimate the output of HMA mixture. In the survey for 2006, Asphalt in Figures found on the EAPA website, the data of Lithuania are missing. Therefore, the authors of the present paper have attempted for the first time to estimate (based on the data elicited from manufacturers) the amounts of HMA mixture produced by all Lithuanian AMP during the last year, which could be added to the EAPA.

The present paper aims to analyse technological patterns of HMA mixture production, as well as the development of AMP in Lithuania and to provide the data on the dynamics of HMA mixture output during the last 10 years.

2. Technologies of HMA mixture production

HMA mixture production technology defined as the specified sequence of all production processes depends on AMP design. Famous world companies, concerns and corporations (Ammann, Benninghoven, Wibau, CMJ, Astec, Ermont, Marini, Lintec, Barber-Greene, Niigata, etc.) produce modern complicated and high-output computer-aided technological equipment. Most of the new AMP are versatile mixing plants, allowing the production of HMA mixtures of various types and makes. They allow us to weigh (measure) the granules of RAP and aggregates and to change the composition of the produced HMA mixture quickly. They also allow accurate weighing of materials and to improve the quality of their mixing as well as storing the produced HMA mixture, maintaining the required temperature and reducing energy consumption and emission of pollutants.

According to the European (EN 536 1999) and US (ASTM D 995-95b) standards, HMA mixture is produced by AMP of three types, i.e. batch plants, as well as drum-mix and continuous plants. They have some advantages and disadvantages (Hunter 1997), allowing manufacturers to choose technological equipment depending on particular conditions. HMA mixture's manufacturer usually wants to get a versatile AMP, allowing him/her to provide customers with bituminous mixtures of every type, as well as using RAP in HMA mixture's production.

AMP designs vary depending on manufacturer because they are adapted to a particular HMA production technology. Researchers and engineers are improving AMP design and control system, increasing their universality and reliability. In spite of great variety of AMP models, their design matches one of HMA mixture production technologies given in Figs 1–4. A dotted line denotes the available but not always performed technological operation.

In European countries (including Lithuania), batch-type AMP are most widely used for making HMA mixture. They are based on the traditional technology (Fig. 1). Batch plant is a manufacturing facility for producing bituminous paving mixtures that proportions the aggregate and bituminous constituents into the mix by weighed batches, adds bituminous material either by weight or volume, and mixes the blend. Initially, cold mineral materials are continually proportioned, and, finally, hot fractions obtained by additional screening of dried and heated mixture are batch-weighed. Additional screening of hot aggregate mixture is aimed at obtaining

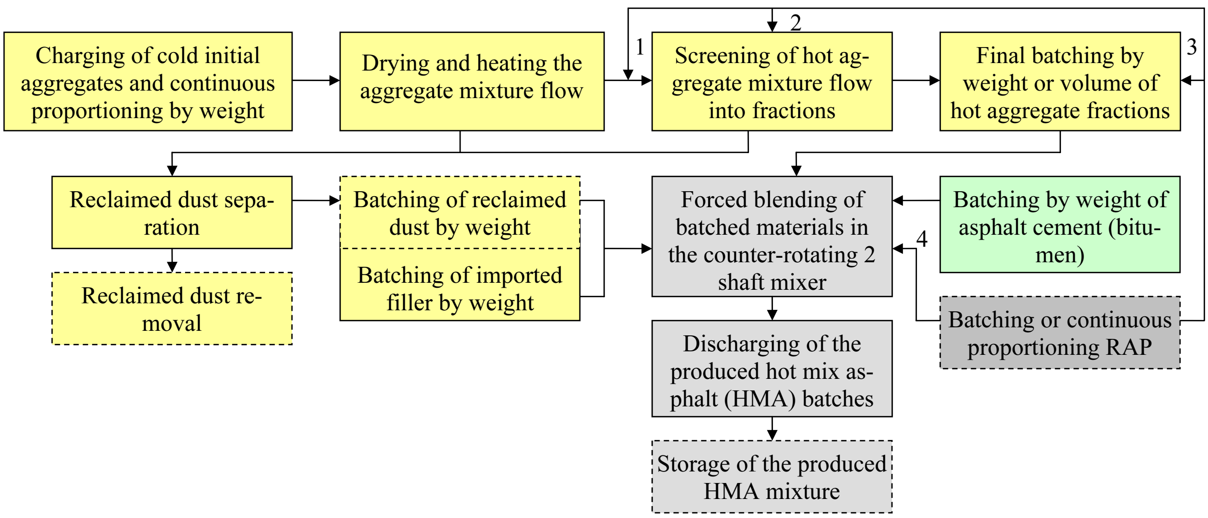

Fig. 1. A diagram of HMA mixture manufacturing in batch-type AMP with initial continuous batching of cold mineral materials and final batching of additionally screened hot fractions by forced blending with other materials

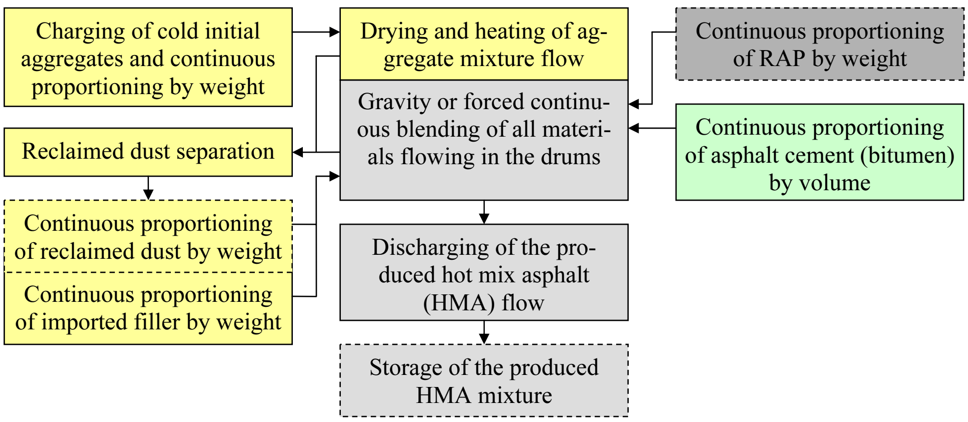

Fig. 2. A diagram of HMA mixture manufacturing in drum mix type AMP plant with gravity mixing of initially proportioned materials in the continuous flow

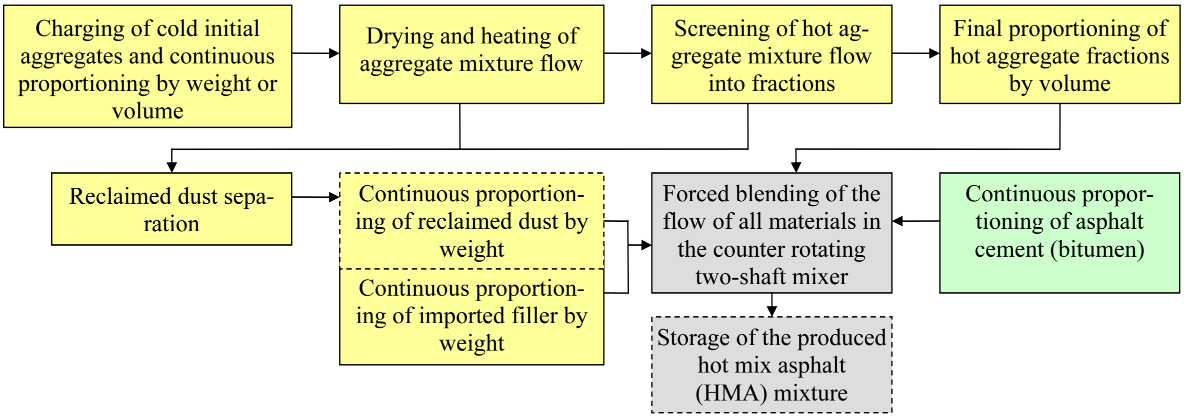

Fig. 3. A diagram of HMA mixture manufacturing in the continuous type AMP with the initial continuous proportioning of cold materials and final continuous proportioning of the screened hot mineral materials, forced to mix with other materials in the continuous flow

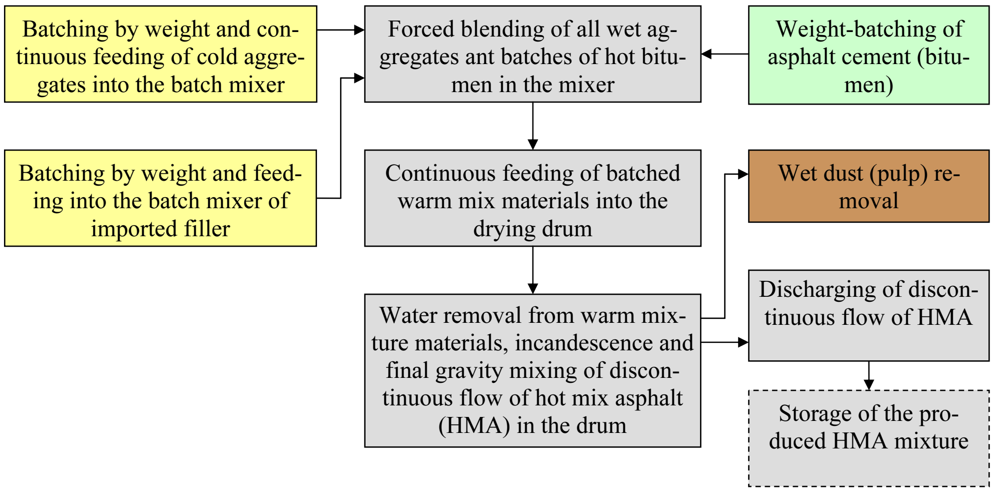

Fig. 4. A diagram of HMA mixture manufacturing in AMP of the mixed (batch-continuous) type with the forced initial and final gravity mixing of the proportioned materials in a discontinuous flow

4–6 hot fractions which are expected to be less polluted by outside granules and more homogeneous than the initial cold mineral materials. The granules of RAP in a batch plant can be fed to 4 facilities: heated elevator (1), screened hot mix hopper (2), hopper-type batch-weigher of hot fractions (3) and mixer (4). In this type of AMP, job mixing formula of HMA mixture may be changed easily and more often during the working day; actually, without any loss in quality, which is usually required when HMA mixture is made for several installations located in different places or cities.

Drum mix plant – a manufacturing facility for producing bituminous paving mixtures that continuously proportions aggregates, heats and dries them in a rotating drum, and simultaneously mixes them with a controlled amount of bituminous material. The same plant may produce cold-mixed bituminous paving mixtures without heating and drying the aggregates.

A drum-mix plant is by 20% more efficient (400 t/h or more) than a batch plant. It is also lower, though occupying a larger area. The production pattern of HMA mixture used in it (see Fig. 2) shows that the operation is continuous, while the cylinder drum is used as a drier, heater, receptacle of aggregates, bitumen, mineral powders and RAP, as well as a forced (e.g. double-drum type) or gravity (e.g. Venturi, triple-drum type) mixer. To use a drum-mix plant for producing a homogeneous HMA mixture, non-segregated mineral materials of stable gradation should be employed, which is not always possible in production. Without the additional screening of the mixture of mineral materials, high-quality HMA mixture can hardly be made, even if inhomogeneous hot aggregates are very accurately proportioned. It may be assumed that, for this reason, drum-mix plants are not widely used in Lithuania and other European countries. Very often, when HMA mixing is interrupted during the working day, the quality of the mixture is slightly decreased.

A continuous plant is used for making HMA mixture according to the technological pattern shown in Fig. 3. Continuous mix plant is a manufacturing facility for producing bituminous paving mixtures that continuously proportions the aggregate and bituminous constituents into the mix by a continuous volumetric proportioning system without definite batch intervals. It is of simpler design than a batch plant because the proportioning of cold and hot aggregate screened fractions are bitumen is usually performed by volume systems (e.g. AMP D-645-3). According to LST EN 536 (2000), the mixture of hot aggregates should not be always screened into fractions. A system of continuous proportioning of materials by volume can hardly ensure the accuracy and stability of this significant process. Batches of materials are mixed by twin-shaft continuous forced mix plant.

In Lithuania, continuous plants are not used. They are not popular in other countries either because of constantly increasing requirements to the quality of HMA mixture production.

Since 1987, AMP of the type AMO BS 200/RC 120 has been used in Lithuania to make HMA mixture according to the mixed batch-continuous plant dustless technology (Fig. 4). This model was particularly useful in the first years after the regaining of independence by Lithuania, when the requirements to the environment protection had been increased. Weighed batches of cold (and wet) mineral materials, imported filler and hot bitumen are fed to the rotating twin-shaft mixer of forced mix type, where HMA mixture batch is made and then poured into the intermediate hopper. Then, by the flow of specified intensity, it is directed to the parallel flow drying hopper from the intermediate hopper. When the water is evaporating, the mixture is getting warmer, the bitumen between the grains is fluidifying and turning into the films preventing from separating and raising of dust and grains stuck to the mineral constituents of the material. When cold wet mineral materials are mixed with hot bitumen, the water which had not evaporated from grain surface prevents from the binder's sticking to particle surface by strong adhesive forces, covering the particles completely or partially with films. HMA mixture made by AMP of the mixed (batch-continuous) type can be used only for the lower layers of the pavement and the base. The upper pavement layer of urban streets made of HMA mixture prepared at this AMP proved to be not sufficiently strong and frost-resistant.

The quality of the considered AMP performance may be determined by using multicriteria complex quality indicator K (Sivilevičius *et al*. 2008). The significance coefficients of its 9 criteria were determined by expert methods, while the values of variable parameters were taken from the laboratory tests, production reports and standards and specifications.

3. The dynamics of HMA mixture production in the ES member-states and other countries

In planning and managing the development of automobile transport it is necessary not only to estimate annually the total number of vehicles and the number of trucks, in particular, as well as the number of road accidents and traffic intensity on particular road sections, but also to determine the length of the roads used, changes in the type of pavement, costs of road maintenance, repair and other indicators. The statistical analysis of these data and their comparison to similar data of other countries or periods of time allow us to determine the major trends of development and to forecast to what extent road capacity corresponds to the continuously growing number of vehicles.

In addition to the above indicators, most of the countries estimate the amounts of materials used to build and maintain roads, showing the dynamics of road transport development and improvement. The most expensive materials include bituminous mixtures, with hot HMA mixture making the largest part. The amounts of the mixture produced are calculated every year and presented by the European Asphalt Pavement Association (EAPA) (Table 1).

Table 1. The abbreviations of 27 EU member-states according to ISO-3166-1 and the data on HMA mixture production provided by EAPA

AT	Austria	**Yes**	**LV**	Latvia	Yes
BE	Belgium	**Yes**	**LT**	Lithuania	No
BG	Bulgaria	**No**	**LU**	Luxemburg	No
CY	Cyprus	**No**	**MT**	Malta	No
CZ	Czech Republic	**Yes**	**NL**	Netherlands	Yes
DK	Denmark	**Yes**	**PL**	Poland	Yes
EE	Estonia	**Yes**	**PT**	Portugal	Yes
FI	Finland	**Yes**	**RO**	Romania	Yes
FR	France	**Yes**	**SK**	Slovakia	Yes
DE	Germany	**Yes**	**SI**	Slovenia	Yes
GR	Greece	**Yes**	**ES**	Spain	Yes
HU	Hungary	**Yes**	**SE**	Sweden	Yes
IE	Ireland	**Yes**	**UK**	United Kingdom	Yes
IT	Italy	**Yes**			

The analysis of HMA mixture production in the last 10 years in various countries shows the annual increase of this mixture only in the EU member-states. In some countries, HMA mixture output is not stable, with the production ranging considerably (USA, Germany, Poland, Portugal). The annual increase of HMA mixture production in the EU member-states may be accounted for by the financial support provided to the development of various production areas, including programmes and projects of road network development. Great differences (range) between the average annual amounts of HMA mixture produced in 10-year period (1998–2007) as well as maximum and minimum amounts, and in the data on its production in 2007 could be observed in various countries (Fig. 5).

According to the annual output of HMA mixture, all the countries may be divided into 2 groups: large producers, making more than 5 m tonnes of the mixture per year (Fig. 6a) and small producers making less than 5 m tonnes per year (Fig. 6b). The data on HMA output (in million tonnes) in some countries, which are not the EU member-states, are given for comparison in Table 2.

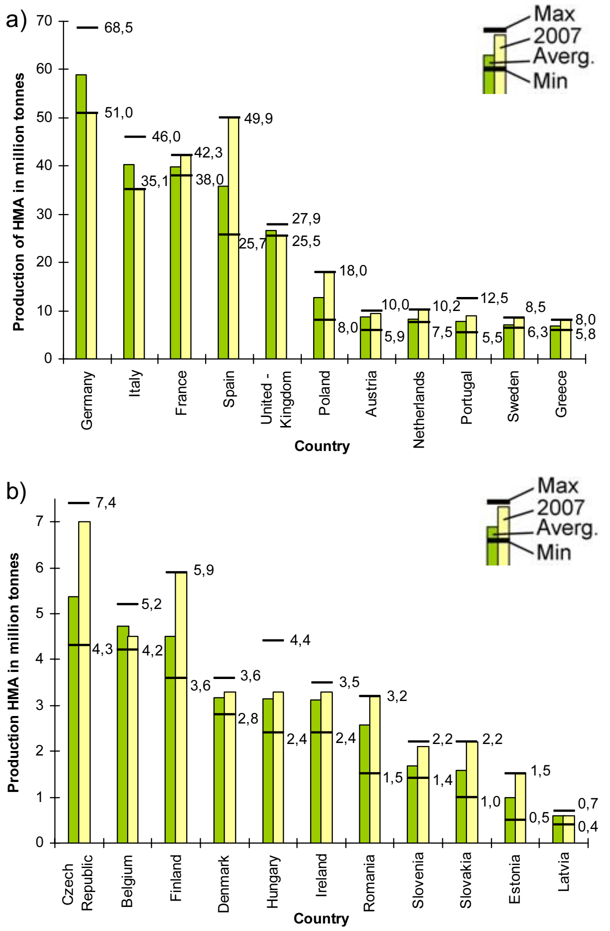

Fig. 5. Minimum, average annual and maximum output of HMA mixture in 1998–2007 in the EU member-states and the amount obtained in 2007 in the countries: a) producing more than 5 m tonnes of HMA mixture on average; b) producing less than 5 m tonnes of HMA mixture on average

Table 2. The dynamics of HMA mixture production in the EU and other countries, m tonnes

Country	1998–2007 period			2007
	Min	Avg	Max	
USA	465	504.0	545	500
Japan	54.9	64.27	71.4	54.9
Turkey	9.5	14.06	22.2	22.2
Australia	6.5	7.07	7.7	7.7
Norway	3.9	4.67	5.9	5.9
Canada (Ontario)	11	13.24	14.5	13.2
European Union	238.8	284.5	341.6	304.1

The linear correlation between the output of HMA mixture in 2007 in the EU member-states and their area (Fig. 6) was obtained from the data provided by EAPA. It is expressed by the regression equation as follows:

$$Q = 0.073 \cdot 10^{-3} \cdot A - 0.157, \quad R^2 = 0.586, \tag{1}$$

where Q is HMA mixture output, tonnes; A is the state area, km^2; R^2 is determination coefficient.

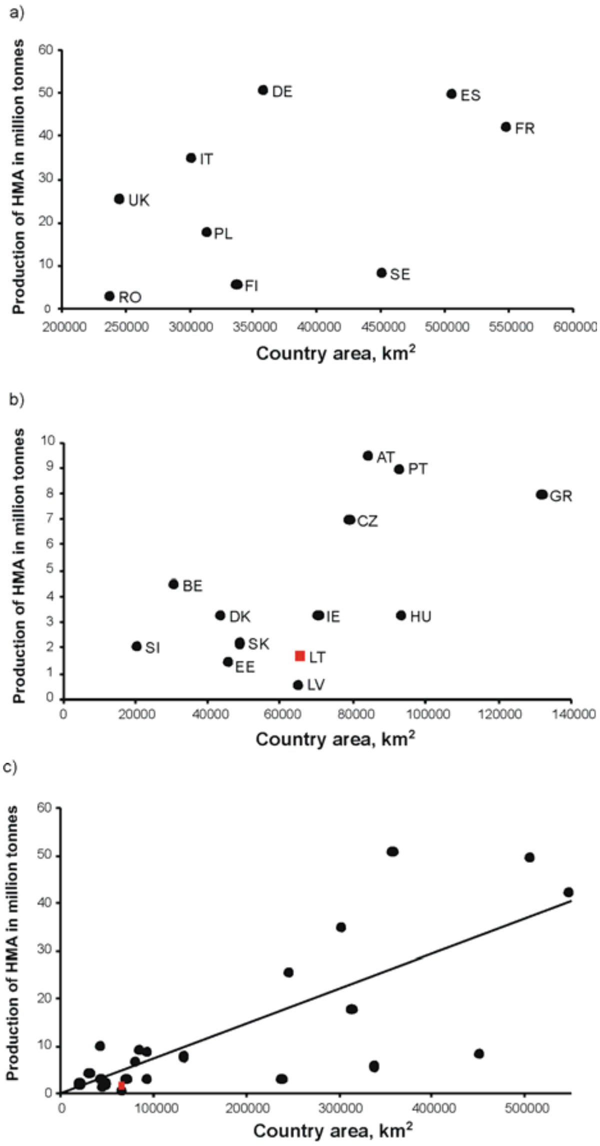

Fig. 6. The relationship between HMA mixture output by AMP of the EU member-states (2007) and their areas: a) countries with the area more than 200 000 km^2; b) countries with the area less than 200 000 km^2; c) correlational regression dependence of HMA output in all the countries

The analysis made does not include the data on HMA mixture output in small EU countries (e.g. Cyprus, Luxemburg, Malta) and some larger countries (Bulgaria, Lithuania), the data on which are missing in EAPA survey in 2007.

We would like to prove the assumption that the larger the country, the greater the demand for HMA mixture for road building and reconstruction, which, in turn, requires a larger amount of HMA mixture. The regression line was drawn, and the determination coefficient R^2 = 0.586 proved the validity of the assumption made. The regression line shows the amounts of HMA mixture to be produced by particular countries to match the average output figures. Only the data on Slovenia's and Denmark's output correspond to the above straight line, while the output data of Czech Republic, Greece and France are approaching them. Other EU member states produce larger (points above the straight line) or smaller (points below the straight line) amounts of HMA mixture. The leaders in HMA mixture production are Germany, Italy, UK and Spain, i.e. the largest EU member states.

Among the largest EU member states, the smallest output of HMA mixture was found in Romania, Finland and Sweden. The data on asphalt production in Romania are not surprising because it is the least economically developed European country. On the contrary, Scandinavian states belong to the most highly developed countries both in Europe and the world. Therefore, low HMA mixture output in these states may be accounted for by their extended territories.

The leader in HMA mixture output in the EU member states is Germany. Taking into account high quality of its motor roads and highways, it is evident that, if other countries like to achieve the same level, they should produce several times more HMA mixture than the average EU amount, corresponding to the regression line. Only highly developed countries (except Finland and Sweden) produce more HMA mixture than the EU average output, thereby ensuring high quality pavement of their roads. The analysis made has confirmed that high-quality motor roads are the indicator of a highly economically developed state.

4. The dynamics of HMA mixture production at Lithuanian plants

The data on HMA mixture production in Lithuania (and in 4 other EU member-states) are not provided in the EAPA survey. In order to correct this careless error, the authors of the present paper collected the information about the output of HMA mixture at all Lithuanian AMP in the last 10 years (Table 3). It was a hard work to collect these data because not all manufacturers were eager to provide the information. Now, 16 private (joint-stock) companies produce HMA mixture in Lithuania. In 2007, they produced 98.6% of this mixture used for road pavement layers out of the total amount of 1731 m tonnes. State-owned enterprises produce only 1.4% of the total amount of this mixture.

The dynamics of HMA mixture output at all Lithuanian enterprises, given in Fig. 7, shows that during the last 10 years it has increased twice (from 0.8 m tonnes in 1998–2001 to 1.7 m tonnes in 2006–2008). Taking into account that the whole amount of the produced HMA mixture was used for road and airfield pavement, the growth of its output may be associated with improving the existing and the construction of new roads.

Table 3. The dynamics of HMA mixture production at Lithuanian enterprises in the last 10 years

	Hot mix asphalt production per year by thousand tonnes									
Code	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Joint Stock companies										
AK	112.5	134.0	87.5	92.0	130.1	124.5	165.8	142.0	159.5	188.0
AT	24.8	34.2	36.9	19.6	25.9	55.6	52.9	56.2	43.4	63.2
EL	–	30.0	25.0	35.0	40.0	48.0	59.0	82.0	85.0	105.0
FG	21.0	85.6	75.0	71.2	75.3	115.9	136.0	145.3	189.6	164.5
KD	42.8	61.3	72.6	32.3	36.1	52.3	62.5	72.0	68.7	94.3
KK	–	–	–	40.9	39.2	48.1	62.1	58.7	46.4	62.8
KT	122.0	101.0	158.0	151.0	170.0	180.0	180.0	211.0	230.0	180.0
LL	77.9	39.7	32.7	57.3	67.4	105.9	112.2	150.6	165.5	196.7
MK	–	–	–	15.4	22.4	26.5	42.5	47.5	46.6	44.9
PK	149.4	155.5	134.2	67.7	98.0	138.1	163.9	187.4	190.3	194.6
PR	–	–	–	–	–	–	–	–	42.7	80.0
SG	46.0	28.0	27.0	19.0	17.0	16.0	18.0	26.0	30.0	36.0
SP	–	–	84.1	40.3	92.4	93.3	160.1	165.3	170.3	130.3
TK	–	–	6.0	13.3	17.4	17.0	21.4	34.2	23.2	19.3
UK	70.8	59.3	28.3	16.8	18.7	30.5	55.0	64.1	47.3	55.2
ZK	65.5	53.6	58.1	14.5	51.6	36.8	53.7	69.4	94.1	92.7
State-owned companies										
AR	3.4	4.7	1.5	1.7	1.8	1.8	2.7	2.5	2.1	1.7
KR	14.2	18.1	7.2	5.7	11.4	14.8	11.2	8.1	17.5	11.1
SR	8.0	8.8	5.5	9.1	16.0	16.3	11.3	13.8	11.6	11.1
Total	758.3	813.8	839.4	703.0	930.7	1121.6	1370.2	1536.1	1663.7	1731.4

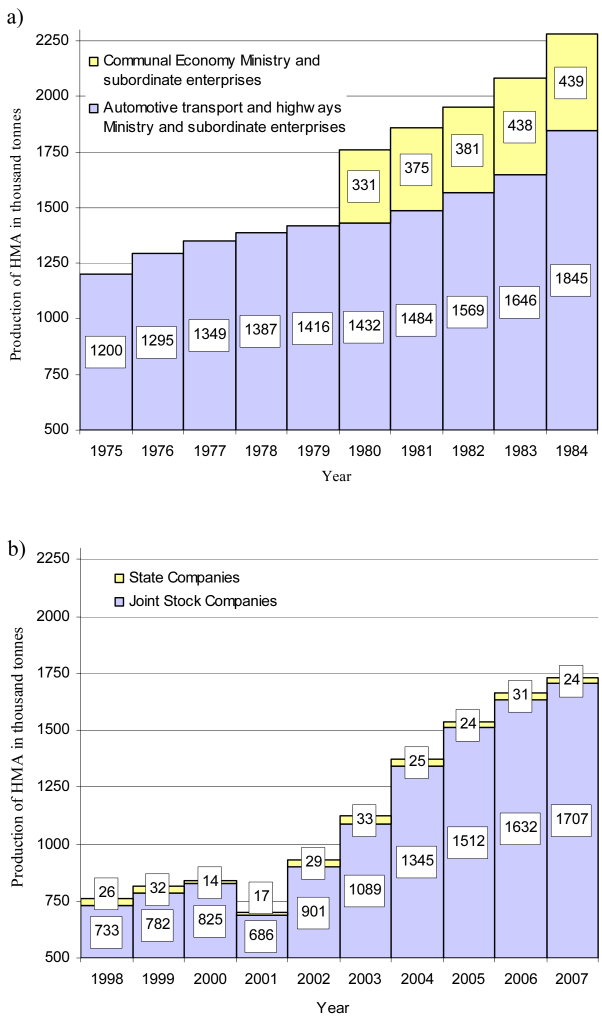

Fig. 7. The dynamics of HMA mixture production at various periods of time in Lithuanian Republic: a – 1975–1984, b – 1998–2007

Lithuania pursues a policy of enhancing the infrastructure of road network, allowing the roads to adapt to the continuously growing number of vehicles and highly increased percentage of heavy trucks in the flow of transport. The increased output of HMA mixture helped to build new roads, by-pass highways and urban motorways. Moreover, dirt roads were paved with asphalt, while the pavement of principal roads was strengthened, thereby increasing their toughness index.

The average value of the pavement toughness index of Lithuanian principal roads had been decreasing since 1992 to 2002–2003. It had decreased from 1.00 to 0.83 for country roads and from 1.00 to 0.92 on the main roads. The lowest index value was observed in 2002–2003, though traffic intensity on Lithuanian roads had increased by 253% in the period of 1992–2007 (Sivilevičius and Šukevičius 2007). Then, the toughness index value began to grow, reaching 0.88 for country roads and 0.96 for the main roads in 2007. However, the value of 1992 had not been reached yet. The growth of pavement toughness index was partly accounted for by the increasing output of HMA mixture.

One of the Lithuanian joint-stock companies annually produces the average amount of HMA mixture which can be calculated by the formula:

$$\overline{Q}_j = \frac{\sum_{i=1}^{n} Q_{ij}}{n_j}, \tag{2}$$

where Q_{ij} is the amount of HMA mixture produced by *i-th* enterprise in the considered year, thousand tonnes; n_j is the number of enterprises considered ($n_j \leq 16$), j is the year of HMA mixture production.

To check if the amount of HMA mixture produced by particular enterprises is evenly distributed, standard deviation is calculated as follows:

$$s_{Qj} = \sqrt{\frac{\sum_{i=1}^{n} (Q_{ij} - \overline{Q}_j)^2}{n_j - 1}}. \tag{3}$$

The calculated values of $\overline{Q}_j$ and s_{Qj} (Fig. 8.) show that one Lithuanian joint-stock company annually produced on the average $\overline{Q}_j = 46 - 73$ thous. tonnes (1998–2002) and $\overline{Q}_j = 73 - 107$ thous. tonnes (2003–2007) of HMA mixture. The output of this mixture at particular enterprises varies considerably. The spread is shown by $s_{Qj} = 38 - 46$ thous. tonnes (1998–2002) and $s_{Qj} = 50 - 70$ thous. tonnes (2003–2007). During the second 5-year period (2003–2007), not only the average output of HMA mixture at a particular enterprise, $\overline{Q}_j$, but their ranging (s_Q) has also increased. This indicates the domination of large manufacturers of HMA mixture on the market. Longer experience of these companies, better equipment, higher qualification of their workers and, often, lower cost of HMA mixture ensure a better quality of asphalt pavement of the roads built. Usually, the workers of the AMP producing HMA mixture place and compact it on the road to make the pavement. The amounts of HMA mixture sold to other customers are very small.

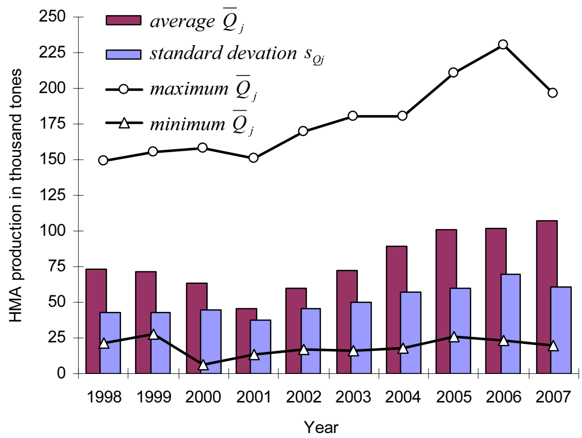

Fig. 8. The dynamics of HMA mixture production by Lithuanian enterprises in 1998–2007

5. The dynamics of quality improvement of asphalt mixing plants in Lithuania

Records of AMP, producing HMA mixture at Lithuanian APC, and the analysis of their performance have not been regularly performed. Actually, they were made only by the initiative of some researchers. When the requirements to HMA mixture quality and environment protection were getting more rigorous and efforts were being made to increase AMP efficiency and the control of technological operations, while making the mixing process continuous, old AMP models were being replaced by the new ones according to the development plans and depending on financing.

Before Lithuania had regained independence in 1990, only Russian AMP models (D-597A, D-508-2A, DS-117-2K, DS-117-2E, DS-158, D-617-2 and D-645-2) and GDR (Teltomat-5) (Table 4) were used. In 1987, AMP of the type AMO BS 300/RC 120 made in Finland, producing HMA mixture according to dustless technology (Fig. 4), was purchased. Later they were replaced by new AMP made in Finland, Germany and Italy. In 1998, a new generation computer-aided AMP EURO A-240 made by Ammann company was installed in Vilnius. Since then, various joint-stock companies have been regularly replacing old AMP with new powerful facilities (with the output of 160-320 t/h) for making HMA mixture. Some of them are provided with RAP batch weighing facilities (Table 5). They are mainly installed in large cities of Lithuania, e.g., Vilnius, Kaunas, Klaipėda, Šiauliai, Panevėžys, Alytus, and are batch-type AMP.

Table 4. Types and number of asphalt mixing plants operating in Lithuania in 1999 (Sivilevičius 2000)

Model of AMP mixer	Manufacturer	Output t/h	Number
D-138 (G-1)	Russia	12-18	5
D-597A	Russia	25	12
D-508-2A	Russia	25	26
DS-117-2K	Russia	32	9
DS-117-2E	Russia	25	12
DS-158	Russia	40	3
D-617-2	Russia	50	1
Teltomat-5	GDR	100	24
AMO BS 200/RC120	Finland	200	1
D-645-2	Russia	100	1
Benninghoven AE 150T	Germany	150	1
Teltomat-160	Germany	160	1
Ammann 160 Global H	Germany	160	1
Ammann Euro A-240	Germany	240	1
Marini MAP 155E 190L	Italy	155	1
		Total:	99

Lithuania has principal roads of the total length of 21 328 km and a dense network (6.3 km for 1000 inhabitants; 326.6 km for 1000 km^2), which requires the continuous improvement and strengthening of pavement, as well as asphalting the dirty roads, building of by-pass highways and reconstructing of the existing roads. The volume of annually performed asphalting work depends on the investments in road network development. The capacity of the available AMP allows us to produce much more HMA mixture than required by the projects developed for annual work. AMP of the new types are capable of producing HMA mixtures of all 19 grades specified by the regulation R 35-01 and TRA ASFALTAS 08.

Table 5. Types and numbers of central mixing plants operating in Lithuania in 2008

Model of AMP	Manufacturer	Output t/h	Number
D-597	Russia	25	1
DC-117-2K	Russia	32	3
D-645-2	Russia	100	1
Teltomat-5/3S	GDR	100	9
Teltomat-160	Germany	160	1
Marini MAP 155E 190L	Italy	155	1
Ammann Euro A 240	Germany	240	1
Ammann Global 160	Germany	160	2
Amomatic VS 180 S	Finland	180	2
Benninghoven TBA-160-K	Germany	160	1
Benninghoven Compact TBA - 160-K	Germany	160	1
Benninghoven TBA-160	Germany	160	1
Benninghoven Concept TBA 240/3	Germany	240	1
Benninghoven Concept TBA 200 - 240U	Germany	240	1
Benninghoven Concept TBA - 240U	Germany	240	1
Benninghoven TBA-320	Germany	320	1
		Total:	28

AMP operating in the largest Lithuanian cities fully satisfy the need for HMA mixture required for paving motor roads to be built in the areas of their service. In Lithuanian regions, the old type AMP are also being replaced with new mixing facilities, allowing the quality of HMA mixture to be improved considerably.

6. Conclusions

1. For managing the national transport system, as well as assessing and improving its performance and predicting future trends of development, statistical data are collected, analysed and generalized. Most of the countries provided the data on HMA mixture output in recent years to the European Asphalt Pavement Association (EAPA). However, these data had not been collected in Lithuania, therefore, they are missing in the EAPA survey (along with the data on 3 other European countries). The authors of the present paper were the pioneers in collecting the information about the amounts of HMA mixture produced by particular Lithuanian enterprises

and the total amount of this mixture produced in the last 10 years (1997–2007). The data collected could be added to the information provided on the EAPA website.

2. Over the last 10 years, the number of AMP operating in Lithuania has been reduced to one-third of the former value. However, their capacity and technological features were greatly improved, while processes associated with HMA mixture production became more stable and accurate, and their harmful effect on the environment has been decreased. Some decades ago, 4 or 5 AMP of low capacity (25 t/h) were used at an asphalt production companies (APC). Now, most of these APC use only one, or, sometimes, 2 powerful batch-type facilities (producing 160–320 t/h of HMA mixture). They are usually located near big cities, producing HMA mixture, when it is needed for asphalt paving of new roads, urban highways and airfields in the areas served by them.

Acknowledgements

The authors wish to thank Zigmantas Perveneckas, the head of the road department of the Board of Directors of Lithuanian Automobile Roads at the Ministry of Means of Communication, for his help in getting from manufacturers the data on the dynamics of HMA mixture production.

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KARŠTOJO MAIŠYMO ASFALTO MIŠINIO GAMYBOS TECHNOLOGIJOS IR KIEKIO DINAMIKA

H. Sivilevičius, Š. Šukevičius

S a n t r a u k a

Daugelyje šalių automobilių kelių, skridimo aikštelių ir kitų eismo zonų danga įrengiama iš karšto maišymo asfalto (KMA) mišinio, pagaminto skirtingos konstrukcijos asfaltbetonio maišytuvuose (ABM). KMA mišinio gamybos apimtys rodo šalies kelių transporto infrastruktūros plėtros dinamiką ir atitiktį didėjantį automobilių skaičių, jų eismo intensyvumą ir ašies apkrovas. KMA mišinys gaminamas taikant skirtingas technologijas, turinčias privalumų ir trūkumų. Darbe pateiktos Lietuvos Respublikos ir kitų šalių KMA mišinių gamybos technologijos schemos. Išanalizuota ABM tobulinimo raida ir įmonėse veikiančių naujų modelių kompiuteriais valdomų ABM techninės ir technologinės charakteristikos. Naudojant *European Asphalt Pavement Association* (*EAPA*) duomenis, gauta koreliacinė-regresinė šalies ploto ir pagaminto KMA mišinio kiekio sietis. *EAPA* skelbiamoje informacijoje nėra duomenų, rodančių suminius Lietuvoje pagaminto KMA mišinių kiekius. Pirmą kartą iš asfalto mišinių gamintojų surinkus ir susisteminus duomenis, tiesiogiai gauta 10 metų (1998–2007) Lietuvos Respublikos asfaltbetonio gamyklose (ABG) pagaminto KMA mišinių kiekio dinamika ir ji palyginta su kitose šalyse pagaminto KMA mišinio kiekiais. Atlikta Lietuvoje veikiančių ABM modelių ir skaičiaus kaitos dinamika.

Reikšminiai žodžiai: karštai maišytas asfaltas, asfaltbetonio maišytuvas, asfaltbetonio gamykla, periodinio veikimo maišytuvas, produkcijos dinamika, technologiniai procesai.

Henrikas SIVILEVIČIUS, Doctor Habil, Professor at Transport Technological Equipment Department, Vilnius Gediminas Technical University. Member of Lithuanian Scientific Society (LSS), chairman at LSS department “Technika”. Author of more than 150 scientific articles. Field of research: modeling of hot mix asphalt (HMA) homogeneity, HMA production quality control methods improvement, HMA composition optimization and control statistical methods also asphalt pavement recycling technologies development.

Šarūnas ŠUKEVIČIUS, PhD student from 2005 at Transport Technological Equipment Department, Vilnius Gediminas Technical University. Field of research: modeling of hot mix asphalt (HMA) homogeneity and HMA composition optimization.