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ANALYSIS OF ASPHALT PAVEMENT CONSTRUCTION QUALITY PARAMETERS AUTOMATED REGISTRATION SYSTEMS

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Abstract. Nowadays all newly paved asphalt layers are assessed and controlled by conventional destructive methodology, which does not provide data on real-time for contractors and customers. The purpose is to evaluate the methodologies used for the automated registration of quality parameters of asphalt layer installation and the possibilities for their usage. An experimental study of asphalt pavement compaction was performed, and the data obtained show the limited reliability of automated methods. A survey of specialists showed that 3 out of 8 contractors use automated registration technologies in their daily construction work. The implementation of a bonus system or lower costs of these technologies would ensure a significantly higher involvement of contractors, and automated registration technologies would significantly improve the quality of road construction but are currently too expensive to use without additional incentives. The lack of competence of technical operators of mechanisms and an unpreprared legal basis framework are the main disadvantages.

Keywords: asphalt layer, asphalt pavement, asphalt paving, automated registration, quality parameters.

1. Introduction

In recent years in Lithuania discussions about new technologies to register automatically all the quality parameters of the asphalt pavement layer on site on real-time and in the whole road section, have started. This could lead to better quality of asphalt roads, faster and probably more accurate laboratory examinations of the installed asphalt layer.

Nowadays the quality of the installation of asphalt pavement layer is evaluated only by old methods, such as extraction of the cores from the road section and comparison with the specimens made in the laboratory. This method harms the pavement layer surface quality, comfort for drivers, and the examination is foreseen at one point.

An analysis of the literature of the experience of other countries in the application of automated methods to determine the properties of constructed asphalt layers carried out. The experimental study used to determine the properties of the constructed asphalt layers by standard and automated methods. Survey of specialists conducted in order to understand general opinions.

2. Literature review regarding asphalt layers construction quality control

In the compaction process, one of the key monitoring points is position, which is collected with a high-precision positioning terminal installed in each roller. In addition, rollers are equipped with infrared temperature sensors for collecting and uploading real-time compaction temperature data. In each roller hardware, design parameters are uploaded before compaction procedure in order to ensure required quality for compaction, layer thickness, etc. For quality control throughout the compaction process despite system self-control, management personnel are in touch with real-time data, and they can change roller settings remotely and on time (Yuan et al., 2022).

Volvo prepared a system called Pave Assist, which collects data about distance covered by paver, tonnage of paved asphalt, paved area, and CO_2 emissions of paver. Vögele, the Wirtgen Group Company, introduced WITOS Paving. It is a digital system that collects real-time data of the paving process, analyses it and represents it directly to the construction company office and on. This system collects data real-time and from on-board information and automated reports, which software prepares. All data could be stored and accessed remotely in the cloud, allowing the usage of past results in the future. Furthermore, the system represents geometric and statistical parameters of the asphalt layer installed, such as layer thickness, width, amount of material, density (Vögele, n.d. b) (Volvo, n.d.).

Nowadays, majority of rollers present the compaction process data for operator separately. One of the systems, that are being tested is the compaction guidance system, which combines the temperature and number of passes through specific spot to one map, which shows areas of different importance for compaction. The case study covered three different scenarios, without any guidance system or display, only with separate displays and with a guidance system display. The results of this case study show that the guidance system, which uses real-time temperature and location data, improves the quality of compaction by 115% in total (Makarov et al., 2021).

One of the new systems that is being tested is intelligent compaction (IC). IC captures location, time, and settings used for compaction. IC process output are: IC measurement values (ICMV), roller passes, asphalt surface temperatures and roller settings (Chang et al., 2014). ICMV indicate the stiffness of the asphalt layer and are dimensionless (Nieves, 2014). Several studies have been performed to evaluate the reliability of the results of the IC system compared to the results of the core density. The results showed that correlation is inconsistent due to limited spot tests and different nature of measured properties. Also, the ICMV results were compared to the Nuclear Density Gauge (NDG) results, and the correlation between them was very low (Chang et al., 2011). According to the study authors, it is recommended to require that at least 70% of the compacted areas be compacted with the IC methodology (Chang et al., 2014). Another way of using ICMV results for acceptance is selecting points for cores extraction from IC made map of compaction degree. On the map the weakest points of the whole road section could be determined, and cores extracted at these spots. This testing methodology could ensure that in quality control and acceptance phases evaluation covers entire road section (Xu et al., 2022).

TOPCON introduced compaction systems C-53 and C-63 that are installed in rollers to get number of passes, asphalt temperature, and layer stiffness data in real time and save them in storage. The GPS sensors, mounted in the rollers generate the number of passes colourful map for the optimisation of operators work. The temperature sensors, mounted in the rollers, help the operators to be sure that compaction process is proceeded at optimum asphalt temperature. The stiffness sensors help to ensure that stiffness values of the HMA layer meet the requirements after compaction (TOPCON, n.d. a., n.d. b.).

Benefit-cost analysis was performed in 2016 in USA, where IC were compared with conventional compaction and their influence on the service life with service costs was determined. So, the construction costs determined in this research were 37% lower with IC compared to conventional compaction for the thick asphalt overlay and 54% lower in the case of a new road construction with IC. These percentages converted to money would be more than 15 thousand dollars savings each year. In addition, the road constructed with IC showed the result of 26 service life years compared to 10 years of the road constructed with conventional compaction (Savan et al., 2016).

The Compaction Monitoring System (CMS) monitors asphalt layer temperature, location and movement of the roller, vibration of the roller, and evaluates the compaction effort from these data (Kassem et al., 2012). When the system collects the number of passes of the roller through the specific spot and the temperature of it, it can calculate the compaction effort. Currently, this system is like a data analysis system after construction because it can save all the data and it could be revised later. But in the future, authors indicate a chance of this system working in real time (Kassem et al., 2015).

The Wirtgen group company HAMM introduced new technologies called Smart Compact and Compaction quality, that works together with WITOS Paving. They evaluates asphalt temperature and stiffness and selects right parameters of drums and types for compaction process. The system records the number of passes and after optimising the roller route to avoid double passes, the result is a reduction of 30% of the passes, which reduces fuel and CO_2 emissions (HAMM, n.d. a; n.d. b).

The BOMAG manufacturer introduced a new technology called Asphalt Manager. With this system, operators are required to choose only the type and thickness of the layer. This system is equipped with several different sensors and could display to the operator the stiffness, amplitude, and temperature data. The system automatically adapts the amplitude, when the stiffness and asphalt temperature reach certain values to avoid crushing the aggregate. For measuring the compaction parameters, the Evib parameter is presented and measured in real time and displayed to the roller operator (BOMAG, n.d.).

Ground penetrating radar (GPR) technology device collected density results were compared with core density and has shown a significant correlation. GPR could be used in several ways (mounted on the paver, steel wheel roller, cart, trail for the car, drone) and in several situations. Mounting on the paver is not efficient. Mounting on the roller could be the most convenient and efficient way, but roller vibrations must be eliminated. Mounting on the cart or on the trailer is possible only in situations where measurements are conducted after compaction, because it requires additional vehicles and human work. GPR mounted on drones are currently tested technology, and it has major disadvantage as it very depends on weather conditions (Wang et al., 2022).

For the compaction process, asphalt temperature data are very important and could lead to more efficient compaction. In the study performed in period 2007–2008 three different Infrared (IR) cameras and measurement methodologies were tested to determine the most efficient way of continuous temperature measurement. The first case study was conducted with a handheld IR camera. The second – with the IR camera mounted on the paver, which took images every 5 seconds. The third – with the IR line scanner mounted on the paver, which was mounted at the same location as the IR camera in the second study and images were taken every 3 seconds. The results of asphalt pavement surface temperature were more precise with the IR line scanner. Parallel with these studies, in-asphalt temperatures were also measured and compared with surface temperature measured with IR devices. The correlation between these temperatures was strong and most of R^2 values were above 0.9. These results open up the opportunity to use surface temperatures, measured with IR devices, as reliable indicators of the in-asphalt or core temperatures (ter Huerne et al., 2009).

Vögele presents a device, called Vogele RoadScan, which uses the IR line-scanner mounted on the paver. This device could measure temperature at 10 m width road section and scan temperature immediately behind the screed. Measurement results are displayed in 25×25 cm tiles, each of these tiles containing up to 16 measuring points (see Figure 1) (Vögele, n.d. a).

The Teede Tehnokeskus, has another device, called TGS Pavement. This equipment scans temperature and its uniformity of the asphalt pavement layer that has been paved immediately after the paver and represents these data on real-time in situ and in some background company facilities or even for the Customer. This measurement helps to react in real time with the compaction processes if some cooler spots are located, and also for the Customer it is sufficient data for quality assurance phase. This technology works consistently to provide continuous data flow. Also, this device could be used for bonus motivational systems (Teede Tehnokeskus, n.d.).

Figure 1. Temperature registration behind the paver with thermal camera

3. Automated registration of quality parameters of asphalt layer installation

To compare asphalt parameters registered in standard and automated manners, the experimental investigation needed to be performed. The Ammann ARX 90 Tandem roller was chosen, which could be connected to special remote program, called QPoint for automated asphalt layer parameters registration. This roller was used for wearing asphalt layer paving process in national significance highway road A5 Kaunas–Marijampolė–Suvalkai. The experiment was performed on 20 September 2023. The main focus of this experiment was to compare the data that the QPoint program shows in real time and records with the system for future analysis of the paving works with the data, which are received after the cores are extracted and analysed. In addition, Nuclear Density Gauge (NDG) and infrared thermometer were included in the experiment to get more widely available experimental data for comparison.

Before the tests, a special tablet was mounted in the roller operator cabin (see Figure 2) and the special module of sensors and devices mounted in the top of the roller.

At the first phase of the testing, IR thermometer registered temperature after each pass of the roller, NDG device registered compaction level, density and temperature of the layer and the Qpoint data were extracted from the system afterwards at this specific point. The same procedure was repeated at the second point. At the second phase of the testing, the map of the asphalt layer compaction was analysed and two spots were chosen for the cores extraction (one, that showed the best

Figure 2. Tablet of QPoint program in roller cabin

result of the compaction and one, that showed the worst result). In addition, several points were chosen only for the NDG analysis, to compare the data presented by the NDG and QPoint software.

When compared infrared thermometer output with QPoint system output, results showed that only in 3 measurements (from 9) temperature was the same with some deviation (±3 °C), which consists of only 33% of reliability. The rest of the measurements registered a bigger difference between different registry devices – from 8 to 19 ° C difference. Both of these points temperature registration data is presented in Figures 3 and Figure 4.

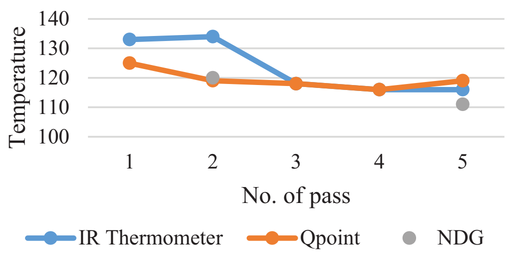

Figure 3. Temperature measurements at the first inspection point with different devices

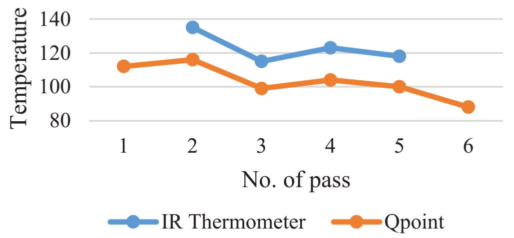

Figure 4. Temperature measurements at the second inspection point with different devices

Second, the compaction could be evaluated. But insofar as the QPoint system registers only dynamic modulus of the compacted layer and the NDG device gives compaction degree value, it is not efficient to compare this data directly. Only comparison could be made between 2 of passes at the first detection point. In both of these passes NDG registered slightly more than 99% compaction degree, but the QPoint system showed drastically different results, dynamic modulus at the fifth pass was almost twice as big as in the second pass. Another point worth noting is the comparison of the results of the NDG device at the same location at the moment of the paving and the next day after the compaction. The degree of compaction and the density results were slightly lower the next day and the content of the air voids was higher as there is an inverse dependency between density with compaction and the content of the air voids. This measurement means that the NDG device is more reliable with the colder layer.

The same misalignment with the dimensions of QPoint and NDG device results (and extracted cores) have been in a second phase of the experiment. The results show that in every possible way, there is no visible connection between all compaction and modulus values.

At the two points (No. 1 and No. 5) cores were chosen to be extracted to evaluate their data in comparison with the NDG device and QPoint. No. 1 from QPoint was chosen as it showed the highest modulus value and No. 5 as it was the lowest modulus value. The results of the NDG device showed a similar connection, but the extracted core results were drastically inverse, as in No. 1 it registered a lower value (97.40%) than in No. 5 (100.20%). The air void content was inverse and in case No. 1 in extracted core it was 9.2 times higher than NDG showed. But in the the No. 5 case – 0.7 times less than NDG showed. This comparison shows that evaluation of the content of air voids is not reliable with NDG at the moment, but it is worth to mention that only two measurements were performed, and it is not sufficient amount of data to perform comparison. The same comparisons were carried out with density parameters, and in case No. 1 it was less than registered with the NDG device. In case no. 5, it was equal to registered with the NDG device. So, one of the two measurements shows significantly reliable results between NDG and extracted core values, as the other was with 6% deviation of tolerance.

4. Contractors' motivation systems based on automated registration systems data

Bonus methodology systems are created in several countries in North Europe to provide quality in asphalt laying processes. The focus of these methodologies nowadays is concentrated on continuous temperature and paving process registration. Furthermore, certain quality parameters must meet at least minimum values compared to the total paved area, in order to receive the bonus. Contractors can get up to 5% of the whole contract fee.

The main indicators for the bonuses are the amount of stops of the paver (not more than 5 stops of more than 2 min length at the 1000 m distance), area of the cold spots (not more than 0.1% of the paved area; required only in Finland) and the area of the risk zones (zones in which the asphalt layer temperature is lower than the average temperature and that consists not more than 5% of the paved area). The main focus of the system is on temperature registration behind the paver (measured with thermal cameras on real-time), compaction of the asphalt layer (measured with GPR after the asphalt layer installation) and pavement roughness (measured 2–4 weeks after the installation of the asphalt). After tests performed in Finland, the results of this bonus system usage showed that contractors try to put maximum effort in order to reach maximum bonus value and as a secondary result, the asphalt layer installation quality increases (Nevalainen & Pellinen, 2016). According to Estonian Transport Administration estimations, the bonus system in their country led to longer pavement life, saving natural resources, and minimising waste. All these results require only minor investments to set up such a bonus system, and the result of longer pavement life enables saving the public budget for other investments in the future. An average bonus of 3.5% of the cost of the contract works on a specific road result in 20–50% less expenses in the next 20 years for the repairing works of the same road section (Palmi & Truu, 2023).

In the performed survey of specialists (scientists, contractors and customers/builders), results showed drastical changes from the answers, when the bonus system is not introduced and when it is. They believe that it would help Contractors to save a lot of expenses with the bonus payments. The statement about benefits of the real-time data for Contractors to monitor the real situation, was one of the most important factors for the Contractors and less interesting for Customers and Scientists. This logic shows that when there are no additional motivational systems, the automated technologies are helping for Contractors to adapt on real-time with the data on the spot.

62.5% of respondents answered, that they, as Contractors, would definitely use automated technologies if the bonus system would be introduced in Lithuania. 44% of the respondents would encourage their companies to take some steps towards the usage of such technologies. Most of the respondents answered that the 1–2% bonus system value would be appropriate expression to motivate to use automated technologies. Survey showed, that only 3 from 8 Contractors use automated technologies in their daily construction works, although 100% of respondents answered, that they would use such technologies if they would be free of charge or in the case of implementation of additional motivational systems for Contractors.

5. Conclusions

1. According to the literature review, temperature monitoring and specified limits assurance during asphalt layer installation is one of the most important factors effecting durability of the pavement. Several studies are focused on recording temperatures behind the paver. In most cases, Infrared (IR) cameras and scanners are commonly employed and tested to obtain accurate real-time temperature data, which could be used for the quality acceptance phase.
2. Usually, the level of asphalt layer compaction is controlled by destructive testing, extracting cores and performing specimens density tests in the laboratory. Currently, technologies for automated compaction registration are under testing and optimisation.
3. The experiment results were subjected to a cautious comparison and analysis due to varied data dimensions and lack of data. Despite these challenges, the data exhibited limited reliability. Only a minority of points (up to 30%) demonstrated alignment between separate devices and measurements. Currently, these technologies lack the reliability to ensure pavement quality by measuring only one or two points throughout the road section.
4. Bonus methodology systems, implemented in several North European countries to improve the quality of asphalt installation, focus primarily on continuous temperature and paving process monitoring. Contractors can apply for bonuses by exceeding minimum quality parameters, earning up to 5% of the total contract price. The results from Finland indicate improved quality of asphalt installation. Minimal investments in the establishment of such systems contribute to the long service life of the pavement, reducing future public budget expenses for road repairs by 20–50% over 20 years.

Recommendations

In order to encourage the Contractors in Lithuania to use the automated registration technologies, the Customers are suggested to begin the legal basis framework adjustment in order to accept such technologies usage in road construction works. Also bonus systems are working efficiently in other North Europe countries in order to expand and motivate Contractors to begin the usage of automated registration technologies to understand its principles of operation, gain knowledge, experience for operators and get used to usage and to see its benefits. Later, bonus system could be adapted and expanded with the requirements for Contractors and the quality parameters, but the first step has to be only habituation to use such technologies in every asphalt paving operation.

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ASFALTO DANGOS ĮRENGIMO KOKYBĖS PARAMETRŲ AUTOMATIZUOTŲ REGISTRAVIMO SISTEMŲ ANALIZĖ

I. KAVECKAS, A. VAITKUS

Santrauka. Šiais laikais visi naujai pakloti asfalto sluoksniai yra vertinami ir kontroliuojami įprastiniu ardančiuoju, duomenų nesuteikiančiu būdu, t. y. realiu laiku. Tankinimo ir temperatūros registravimo sistemos šiuo metu yra labiausiai pažengusios, bet vis dar testavimo stadijose. Šiaurės Europos šalys pristatė premijų sistemos metodiką, skatinančią rangovus naudotis automatizuotomis registravimo sistemomis bei didinti atliekamų darbų kokybę. Atliktas eksperimentinis paklоto asfalto sutankinimo tyrimas, kurio metu gauti duomenys, palyginti su ardančiųjų bandymų rezultatais, rodo ribotą automatizuotų metodų patikimumą. Specialistų apklausa parodė, kad 3 iš 8 rangovų kasdieniuose statybos darbuose naudoja automatizuoto registravimo technologijas. Specialistai teigia, kad ženkliai didesnį rangovų įsitraukimą laiduotų premijų sistemos įdiegimas arba mažesni minėtų technologijų kaštai. Respondentų nuomone, automatizuotos registracijos technologijos žymiai padidintų kelių tiesimo kokybę, tačiau šiuo metu jos yra per brangios naudoti be papildomo skatinimo.

Reikšminiai žodžiai: asfalto sluoksnis, asfalto danga, asfalto klojimas, automatizuotas registravimas, kokybiniai parametrai.