IMPLEMENTATION PQi TO IMPROVE HMA CONSTRUCTION PROCESS.

H.L. ter Huerne[#1] M. Oosterveld[2,] M. Moenielal[3] and R.J. Dekkers[4]
[1] Reef-Infra bv, P.O. Box 355, 7570 AJ, Oldenzaal, The Netherlands
[2]BAM Wegen bv, P.O. Box 2419, 3500 GK, Utrecht, The Netherlands
[3]Ballast Nedam, Celsiusbaan 4c, 3439 NC Nieuwegein, The Netherlands
[4]KWS Infra bv, P.O. Box 217; 4130 EE Vianen, The Netherlands

ABSTRACT

During HMA paving and compaction roller operators rely generally on personal experience and have little information about important factors, such as asphalt temperature during operations (Miller 2010). The ASPARi research group has a set of high-end GPS rovers and an infrared linescanner available for rapid and secure data acquisition of the paving process. Within the ASPARi research a founders group of contractors (approx. 80% market share) is active, they support the research but they also learn from the measures done on their own primary process: asphalt paving and construction. Together with the Twente University they record and analyse to improve quality at the road building site. ASPARi developed the PQi circle which stands for measuring equipment movements and temperatures of the freshly paved lane. Crucial within those PQi's is feedback to the construction team, in order to reflect the asphalt paving teams with their working method and behaviour during paving. All founders do have experience with those PQi's. They monitored their own process and they learn how to monitor their own process in terms of quality control and quality assurance. This latter fact is a big leap for the road building society. As a result we will focus on the results of the PQi circles gained at different sites, different constructors, different asphalt set's and so on. We will discuss the differences in quality control systems and findings related to the different construction processes involved. We selected the main asphalt paving variables and draw conclusions on how these can affect final specifications of paved roads..

Keywords: Asphalt compaction, temperature monitoring, GPS, construction process

1. INTRODUCTION

The asphalt paving process in order to constructing roads is strongly mechanized in the last decades. Based on that, one could think that choices during the construction phase are based on research and knowledge. Unfortunately this is not the case and the whole process still strongly depends on craftsmanship and implicit knowledge. The work is carried out without instruments to monitor key process parameters and the "check" and "act" links as part of the Deming circle (plan-do-check-act) are often not applied during construction of asphalt paving works. Tradition and proven practice guides the selection of work method and the use of equipment. Public clients have introduced new contracting scheme's containing incentives for better quality of work [1] EAPA, Miller, 2008.
New types of contracts spur the road construction companies to advance in product and process improvement. The companies see themselves confronted with different "rules of the game" than what they were used to. Performance contracting and longer guarantee periods create a new set of risks and business incentives. Road construction companies seek better control over the construction process, over the planning and scheduling of resources and work, and over performance. Improved control would also reduce the risks of failure during the guarantee period. To be able to achieve these goals, the relevant on-site operational parameters need to be known and the relationships between these parameters need to be thoroughly understood. To be able to improve product and process performance, asphalt paving companies now more than ever acknowledge they need to develop intricate understanding of the asphalt paving process and the interdependencies within the process.
After first initiatives in earlier years, in 2007 nine road construction companies joined forces with the University of Twente and founded ASPARi. ASPARi - short for Asphalt Paving Research & Innovation is a cooperative network of organisations that work together in research projects and technology development to improve the performance of the asphalt road construction industry. In 2008 the ASPARi founders agreed to bundle the ongoing activities to pave the way forward to a high professionised asphalt construction industry. In 2011 a total of eleven road contractors work together in ASPARi. The ASPARi team focuses on innovation and performance in the asphalt paving process. Their research is aimed at improving quality and consistent reduction of quality variability in the hot mix asphalt (HMA) paving process, and consciously working towards professionalising the asphalt paving process. In the future the ASPARi founders aim to use the monitoring techniques and data of ASPARi to develop real time information systems on paver and roller compactors. These systems would be a big step forward in order to improve the process during construction.
This paper shows the results and experiences of some ASPARi research projects in recent years. The paper is structured as follows. After this short introduction we will discuss the questions the asphalt paving practice is dealing with. In the second paragraph we will discuss, very briefly, the ASPARI method. A method to give answers to these questions. The focus of this paper nevertheless will be on the cases that have been done using the ASPARi equipment and doing so-called PQi cycles. PQi cycles have been done by the contractors to gather data about their own primary process, asphalt paving, in order to reflect the asphalt paving teams with their working method and behaviour during paving.

2. ASPARI RESEARCH APPROACH

2.1 Research questions

Key problem within the asphalt paving process is the lack of knowledge about the ongoing process of compaction. Compaction is one of the most important steps in order to reach asphalt pavement quality [3]. However, progress in compaction strongly depends on mixture composition, mixture temperature and number of roller passes applied. During earlier studies the ASPARi team found that roller operators have too little information about those parameters that deduce compaction progress. This means that compaction in the field is mostly experienced-based and/or based on craftsmanship. When we look at it from a Deming perspective; well-designed processes should at least consists out of the four steps "plan" " do" "check" and "act". However within the road construction industry the resources to apply the check step are too poor and therefore there is no short loop for feedback, it must be said that there exists a long loop. Products become checked when contractor delivers the product to the road owner. However at that moment improvement of compaction is not possible anymore, and one can also not speak of a learning cycle of involved personnel. It is strange that under field conditions as discussed we find large variability's in compaction rates measured. The equipment as it is proposed by the ASPARi team can fill such a gap.
The ASPARi founders hold a strong conviction that changes in the industry can only happen [a] when research and technology development are driven by practice, [b] when it is guided by scientific rigor, and [c] when it involves the people working in practice in an action research and research technological development (RTD) program. In the ASPARi research program two key research questions are addressed. The first tackles the main causes of variability in the asphalt paving process whilst the second focuses on the effect of revised operational strategies on quality in the paving process.

2.2 Aspari research

As said before; the ASPARi programme foresees in equipment and methods to monitor the key process parameters of asphalt construction. Key in the ASPARi approach is:

- using new SMART Technologies (as GPS, thermography, imaging, pervasive networks)
- to create insights into the paving process and give feedback to the operators
- to reduce variability and enhance control in the paving process
- to continuously advance productivity
- to improve product quality
- to reduce risks for the paving companies

In ASPARi innovative monitoring techniques of the asphalt paving process were developed. Themographic imagery and continuous GPS (Global Positioning Systems) tracking on the paver and compactor rollers for improved process control during the asphalt paving process.

2.3 The ASPARi PQi cycle

The method used by ASPARi is called Process Quality improvement - PQi. The target of the PQi cycle (or a series of different PQi cycles) is/are to explicitly measure and store the key process parameters and the asphalt paving team behaviour. A crucial step is the communication with the crew (afterwards) about their behaviour during paving based on the explicitly monitored process. For the paving team this is crucial feedback, needed for on-going learning on the job. The PQi-cycle consists of;

- Preparations: Input location of Construction site; Fixation of tools on the paving equipment; Explanations to the machine operators
- Measurements: Temperature collection; Movements of asphalt paver and roller compactors; Weather conditions; Compaction (by nuclear gauge / core samples)
- Analysis: Processing data of measurements in graphs, plots and animations
- Feedback: Discuss results and animations with the machine operators

We here briefly introduce the two most important steps out of the PQi procedure: temperature profiling and GPS position monitoring. For a more detailed discussion about this topic we will refer to ter Huerne [4].

2.3.1 Temperature profiling

Infrared camera images and temperature probes are used to document temperature differentials during the hot mix asphalt paving operations. Temperature differentials in the asphalt mat can produce density differentials, which will affect the life of the pavement [5, 6]. Temperature segregation can easily occur during different steps of the asphalt paving process; transport of asphalt mixture in the haul truck, inside the truck box, and in the wings of the paver [5, 7, 8]. Stroup-Gardiner & Brown [9] defined segregation of such a magnitude that there is a reasonable expectation of accelerated pavement distress.

Stroup-Gardiner [10] and Read [11] were of the opinion that temperature differentials in the HMA during construction is a strong indicator of a segregated mix. Because of these reasons the ASPARi team incorporated the IR camera images to document temperature differentials during HMA paving operations within the PQi cycle. After a couple of probes this has been executed by fixing a linescanner on the paver at a height of 3 to 4 m and 1m behind the paving screed. The linescanner measures temperatures over the full lane width. Two infrared cameras are used to collect surface temperature data at fixed positions behind the paver. On these fixed spots, the in-asphalt temperature is measured by temperature probes.

The temperature data are analysed in two ways. The temperature data of the linescanner -measured behind de screed- is processed in contour maps of the paving operations. Temperatures measured by the infrared camera and the temperature probes are processed in a graph of the asphalt cooling curve, comparing cooling rates at the surface with in-asphalt cooling rates.

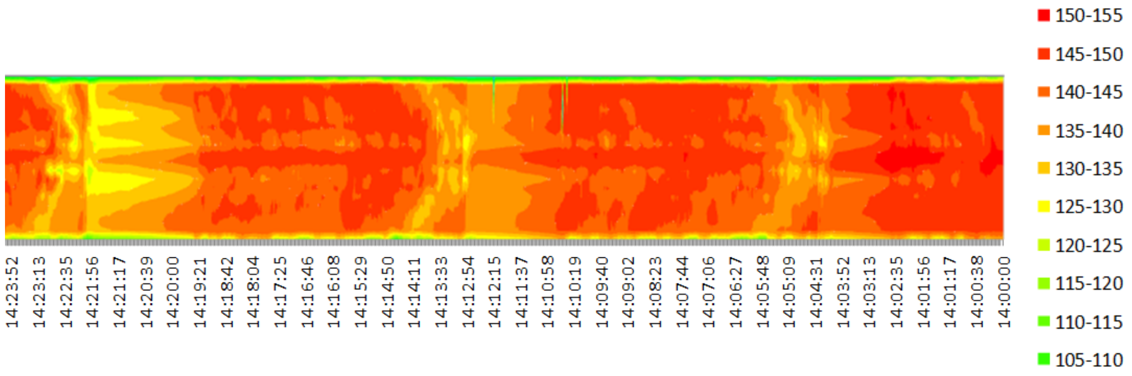

Figure 1: A typical result of temperature monitoring profiling using the IR linescanner on a just freshly paved road section. Asphalt surface temperatures just after the screed in ˚C.

2.3.2 Monitoring of paving equipment movements

The research group proposes a GPS system to collect positioning data of the asphalt paver and the compactors for measuring position of the equipment with about 10cm accuracy. There exists also other initialtives using GPS technology for coaching the asphalt paving process: Krishnamurthy et al. [12] reported about the Automated Paving System (AUTOPAVE) for asphalt compaction operations. Peyret et al. [13] discussed his Computer Integrated Road Construction (CIRC) project. This aims to develop Computer Integrated Construction systems for the real-time control and monitoring of work performed by road construction equipment, namely compactors (CIRCOM) and pavers (CIRPAV). Oloufa [14] described the development of a GPS-based automated quality control system for tracking pavement compaction. Hence, it appears that several thermographic imaging and GPS experiments to map the asphalt paving experience were conducted in recent years.
The system ASPARi used within their PQi cycle consists of a reference station set up next to the road and roving units mounted on the asphalt paver and each of the compactors. Positioning data is collected at 1-second intervals and is analysed using the MATLAB software.
Animations showing equipment movements are produced from the GPS data using the MATLAB software. In addition to being able to observe and analyse the operational behaviour of the compaction rollers using the animation video, the GPS data are used to prepare compaction coverage contour plots showing the number of passes applied to specific areas of the paved lanes. This results in a more detailed analysis of the compaction process.
The following process is to initially determine the compaction coverage separately for each roller and then calculate the overall compaction coverage for the lane. These information is compared with the core density results for the lane.

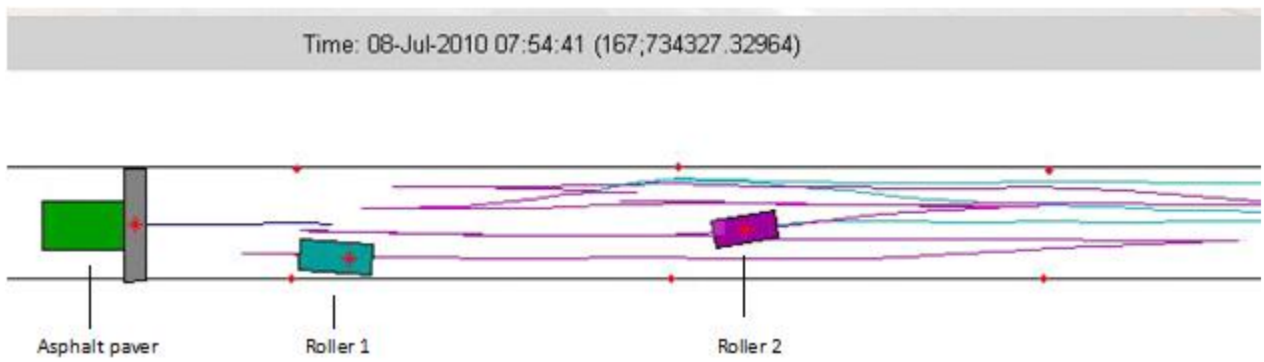

Figure 2: A typical few on the results of a MATLAB analysis Using GPS data results of an asphalt paving process. One sees the asphalt paver (green) and two rollers (blue and purple).

3. TEST SECTIONS OF THE FOUNDERS

In this paragraph we will discuss the findings and results of the PQi cycles done by different ASPARi founders. Of course, in detail, processes differ for different asphalt paving teams and contractors. However there should be a common practice and experience. We aim to gather these aspects in order to be able to draw general conclusions, not only for these founders but also everyone involved. In the following of this paragraph we discuss the next founders, period and test sections:

a. Reef Infra, 2008-2010, Heerenveen and Sneek,
b. BAM Wegen, 2007-2009, Amsterdam, Everdingen and Wageningen
c. Ballast Nedam, 2011, Gorinchem

3.1 PQi test sections Reef infra; Sneek en Heerenveen,

Reef is a middle large contractor who Works at the east side of the Netherlands. Reef is from the beginning founder of the ASPARi initiative and did until medium 2011 three test sections by using the ASPARi equipment.

1. IBF, Heerenveen, 2008, making a area suitable to build houses and offices and industry,
2. Bypass around Sneek, 2010, top layer porous asphalt and base layer,
3. Heerenveen, 2011, NOAP (Asphalt plant) doing tests using Low Temperature Asphalt.

IBF Heerenveen gave Reef the first possibilities to experiment work together with the ASPARi team and test their equipment. At that moment also the research group ASPARi was testing getting the equipment operational. An important point is getting the paving team involved. A sceptical paving team gives not the right setting for doing such tests. We solved this potential problem by supply information about the project at an early moment and repeat the communication just in advance before starting the construction works.
The second project Sneek, the set-up of the procedure was at full strength and all elements of a PQi could be established. The next and for now last test section was at the site of the NOAP (Northern Asphalt Plant from Reef). The first time we did our full scale Low Temperature (LT) asphalt tests and therefore the temperature monitoring part of the PQi cycle were of interest for the project.

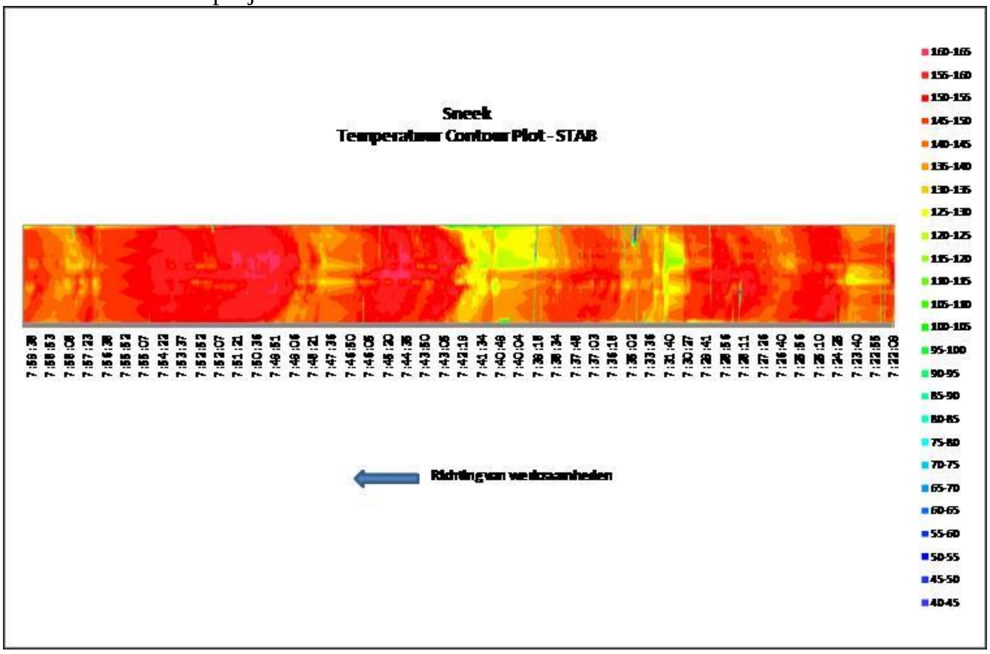

Figure 3: Typical temperature contour plot from the Sneek test site. Differences in material temperature during paving caused by truck changes are easily visible.

As working now for a certain period using the full PQi cycles or parts of the equipment for temperature monitoring we can draw the next premature conclusions:

- Changing trucks in front of the asphalt paver always leads to cool area's of the freshly paved layer which might be responsible for a quality drop. Especially this temperature drops manifest themselves when the paving process is just start up. It looks like the asphalt must heat up the paver before a more continuously temperature of the freshly paved layer can be achieved. Apart of this it is recognised that there is a lot of difference between one truck change and the other (fig 3). A specific truck change can be responsible for large temperature losses whereas another truck change almost no temperature losses at all exposes. Whether or not this is caused by (in)experience of the truck driver, bad insulation of the specific truck, longer transport times or something else was not figured out. It seems an interesting possibility for further improvements.
- The cold start gives a large area of a (too) cool paved fresh layer. Because roller operators are not fully equipped to identify such cold areas, this can lead easily to areas with insufficient compaction level. Here quality improvements can be reached by coaching the roller operator and/or give the crew additional equipment.
- During the compaction process by rolling it seems that the focus of the operators is too much on the middle part of the lane under construction. The edges of the paved lane will receive the least roller passes. This conclusion was also drawn by the ASPARi team [2].
- At four positions temperature measurement were done and afterwards cores were drilled. Based on the drilled core's and amount of roller passes applied the conclusions could be drawn that lesser roller passes leads to reduced compaction rate's. Of course this is common knowledge or intuition however, it is nice the research proves such results. A reduction of 3 to 5 roller passes lessens the compaction rate with 1 to 1.5 %. This can be the difference between accepting or not accepting the work. See figure 4.
- So far we did not draw a relationship between the temperature during applied roller passes, the number of roller passes applied and the final density of the mat, although we have a lot of information about roller passes and temperature per location. In future we will further work out this topic.

3.1.1 General findings REEF:

Comparing the findings from the different test sections the main tings that we conclude are that;

- ➢ Although communication with the paving team has been achieved rolling patterns are still the result of craftsmanship and experience. This is generally leading to large variability's in compaction rates at different locations.
- ➢ Cooling and maybe even more information about the cooling process is still quite important in order to reach the correct density rate as a result of the rolling process. Roller operators do not have Infra Red glasses, so management with help of the ASPARi team should give them the necessary tools to get this information at the right time (real time), at the right place (inside the roller) and at the right way available.

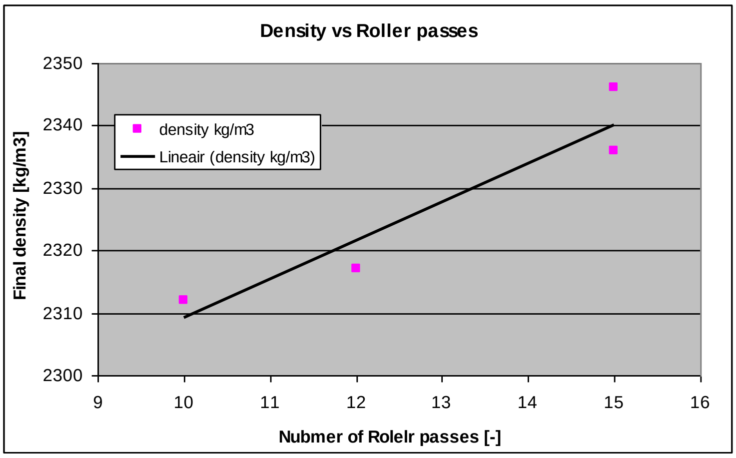

Figure 4: The final density achieved related to the amount of roller passes applied, test section Sneek 2010.

3.2 PQi Test Section – BAM Wegen; Amsterdam, Wageningen, Everdingen,

BAM Wegen is one of the two largest contractors in the Netherlands. BAM is form the beginning founder of the ASPARi initiative and did until medium 2011 three test sections by using the ASPARi equipment.

1. May 2007: ZOAB top layer on highway A35, nearby Hengelo
2. Oct 2008 : AC binder and SMA surface-layer at industry-road “Aziëhavenweg” in Amsterdam
3. Sep 2009 : LEAB base-layers on highway A2 in Everdingen
4. Sep 2009 : AC bind and surface-layer on rural road “Bennekomsteeg” in Wageningen

The Aziëhavenweg in Amsterdam was for both BAM and the ASPARi-team the second experiment with temperature-monitoring and GPS-monitoring. Apart from registering and monitoring the paving-process the focus was on trying-out the feasibility of different measuring-techniques. On the Aziëhavenweg BAM used a industrial infrared camera mounted at the back side of the paver. The camera took pictures at 5-seconds interval. The data-analysis was very time-consuming so temperature could not be viewed real-time to the paving team.
BAM used the infrared linescanner for the first time in September 2009. This gave the paving-team the opportunity to see the asphalt-temperatures in real-time through a laptop connection with the linescanner. Another large step forward was the use of an wireless connection between the linescanner and laptop on the second day of that test section. This can be seen as a next step in the future in bringing the measured temperature data directly to the roller-operators.
Also in September 2009 BAM performed a PQi- cycle in Wageningen on a small rural road. Due to (planned) inconsistent layer thickness the use of a infrared camera to monitor the cooling was very valuable (fig. 5).

Figure 5; An example of inhomogeneous cooling of the asphalt due to (planned) inconsistent layer thickness

Another important lesson learned in Wageningen was the bad GPS-reception caused by reflection of the trees. Despite the professional GPS-equipment with Glonass and GPS-satellite reception, it appeared very hard to filter the GPS-paths to a comprehensible standard.
On all three projects, the paving teams were eager to see their experience and craftsmanship being confirmed by explicit data. It gave them further insight at, under normal conditions, invisible aspects as roller-passes applied, cooling from the asphalt mat and variability's of asphalt-temperatures. In the discussions afterwards, it became clear that paving teams are willing to incorporate new techniques.
In general, BAM draws the following conclusions about the experience by following the ASPARi PQi-cycle

1. Temperature- as well as Compaction Contour plots increase understanding among personnel and are very suitable for training-purposes.
2. The number of roller passes differs significantly in transversal and longitudinal direction.
3. Roller-operators can hardly notice temperature-variability. Under normal circumstances, they do not use infrared techniques and temperature differences are not noticeable. It is recommended to develop a method that makes asphalt temperatures for the roller operators easily visible and translates this data directly in directions.
4. Pavecool and Multicool are software tools for calculation of the expected cooling of the asphalt layer. These tools turn out to be reliable predictors for estimating the time-window for compaction.
5. Paver stops do almost always lead to extra temperature-cooling of the asphalt mat. . The severity of that cooling depends of the length of the paver-stop
6. Roller-operators can improve their effectiveness and the quality of their work when they can use reliable temperature contour-plots in their cabins
7. Roller-operators can improve the effectiveness and the quality of their work when they can use compaction-characteristics of asphalt mixtures

These conclusions triggered BAM Wegen to invest more effort in investigating the compaction-characteristics of asphalt-mixtures and the behaviour of the paving team. BAM developed an experiments in the laboratory with which the compaction possibilities of an asphalt mixture can be tested in a gyrator [16].
Together with the ASPARi-team BAM developed a visualisation-tool for getting the asphalt-temperature for the roller operator. Other than commercial available solutions from roller-manufactures (such as the HCQ from Hamm or the Asphaltmanager from BOMAG) their aim is to develop a tool that visualises the asphalt-temperature of the paved area directly in the surrounding of the roller. At September 2011 a first draw-version of the visualization-tool was tested in

Wijhe. The ASPARi-team succeeded making a wireless connection between the linescanner and the roller. This connection made it possible to show real time the asphalt temperature information to the roller operators. This can be of great help for roller operators in doing their work.
Finally BAM will closely monitor the first PQi-test-project on the A35 near Hengelo. This test section was paved in 2007 and now reaches the end of the predicted lifetime of the surface-layer [4]. BAM sees this as a full scale test of the relationship between on the one side compaction temperature and compaction effort and on the other side pavement performance of the compacted material. When any damage to the surface layer is detected, this damage will be compared with the temperature- and compaction-contourplots to see if there is any special connection between the damage and the paving and rolling conditions. Such a positive relation would give a boost for putting further effort into the ASPARi-program.

3.3 PQi Test Section – Ballast Nedam; Kok-Lexmond area at Gorinchem

Ballast Nedam is one of the five largest contractors of the Netherlands and is one of the founders of the ASPARi initiative. Ballast Nedam performed one test section using the ASPARi-equipment at April 13 2011 at an industrial area in Gorinchem
The Ballast Nedam project consisted of the realisation of an impermeable pavement for an industrial area. The paving area was outside surrounded by a factory-hall, large concrete blocks and a large pile of backfill-material. The pavement construction is made impermeable by using a SAMI (Stress Absorbing Membrane Interlayer) underneath the first asphalt-layer. The PQi-measurements were performed on the Asphalt Concrete binder and the Asphalt Concrete surface layer.

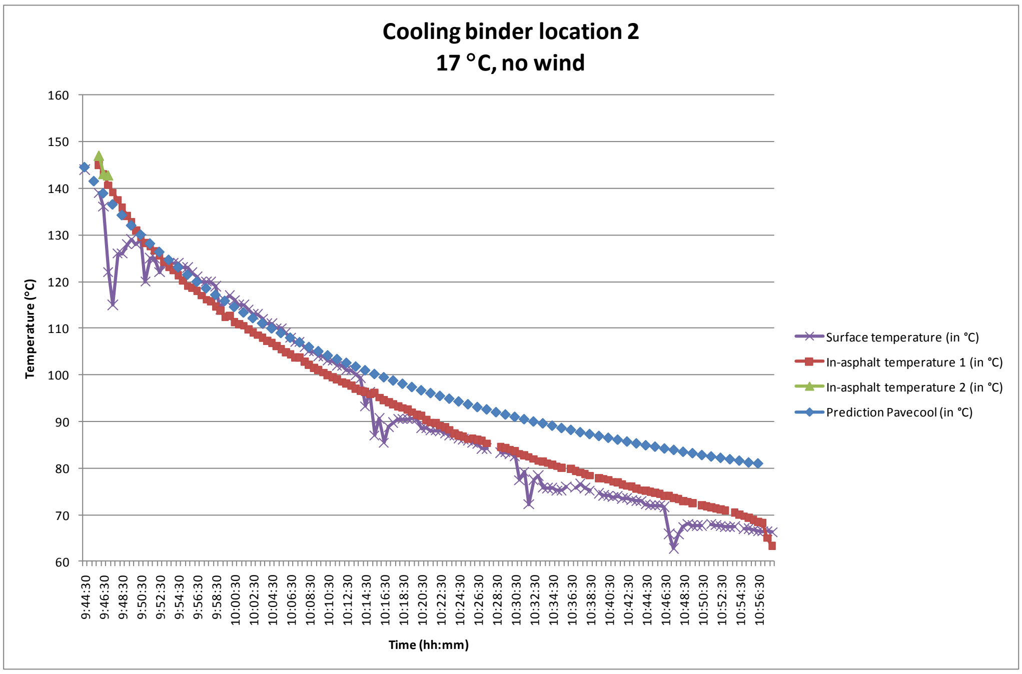

Figure 6: Real asphalt cooling data compared to cooling figures predicted by Pavecool.

Based on the experiences during the PQi-session and the analysis afterwards Ballast Nedam draws the following conclusions:

1. The temperature variability's induced by truck changes are significant (within 20-25ºC). However the paving team considers these variability's as normal.
2. The real asphalt-cooling is stronger than predicted by the Pavecool-software (fig 6). Even on a hot-day as when the measurements took place. It appears that the cooling-time from start to app. 100ºC is constant for different circumstances but between 100-60ºC the cooling lasts remarkably longer.
3. There is a surprisingly large difference in cooling between location in full wind and locations in the lee. It is hardly impossible for the operators to notice these differences, so it raises the question how they would be able to take these effects into account. Normally the operator will work based on his observation of the colour and the shine of the asphalt surface and the effect of his roller on the hot layer. It would help the paver operator if he is helped by information about the temperature of the asphalt layer.
4. The spread of the number of roller passes along the mat differs strongly. According to the paving team a large variation is caused due to the confinement of concrete blocks and the factory hall, which results in less space for the roller compactor operators. This leaded to short tracks. Operators refer to laying asphalt on a highway, where the tracks are longer and the variation in the number of roller passes will be smaller.

5. The nuclear measured densities differ strongly from the density measured on the drilled cores: 45-120 kg/m^3 for the surface layer and 60-65 kg/m^3 for the binder. A possible explanation is that the thickness of the surface layer differs significantly from the thickness of the base layer. The paving team suggests that more cores should be drilled and investigated in order to getting more reliable results for comparing the nuclear measured densities with the densities of the drilled cores.
6. At the location of a paver-stop the number of roller passes is less compared to positions not located at a paver stop.

At the beginning the paving team was somewhat skeptical, but get excited and are willing to cooperative after they saw the movements of paver and the rollers in the animations. They looked at the work of themselves and their colleagues. Normally they only got density information measured with nuclear gauges and from drilled cores. They were not familiar with explicitly monitored data of moving equipment and explicit data form the cooling asphalt layer. Especially for thin asphalt surface layers the paving team is eager to know how the cooling and compaction goes especially when weather conditions are far from optimum. Furthermore, it is important to emphasize that the main goal of the PQi is to tool to learn and improve their own primary process; asphalt paving. It must not be used as a tool for the management or the client to give penalties to the paving team.

Figure 7: Measuring nuclear density and asphalt temperature by infrared camera and temperature probes in surface layer in track next to factory hall

4. CONCLUSIONS PROCESS QUALITY IMPROVEMENT – SESSIONS

In the past four years several contractors performed about ten Process Quality improvement-sessions. In these sessions the asphalt-temperature was measured with the Infrared-linescanner, cooling curves were predicted with Pavecool and measured with thermocouples and infrared cameras. The movements of paving equipment were monitored with high accuracy-GPS and the compaction-progress was measured with a nuclear-density-instrument.
After the measurements the data was analysed and presented to the paving-teams. Together with the paving-teams the results were discussed and the focus for future analyses was shifted. Where in the first two years the focus was on “measuring-instruments” and “finding possibilities for improvement”, the last two years the focus was shifted to “speeding up data-analysis”, “pointing out variability’s of the process and product” and “learning from paving-teams”.

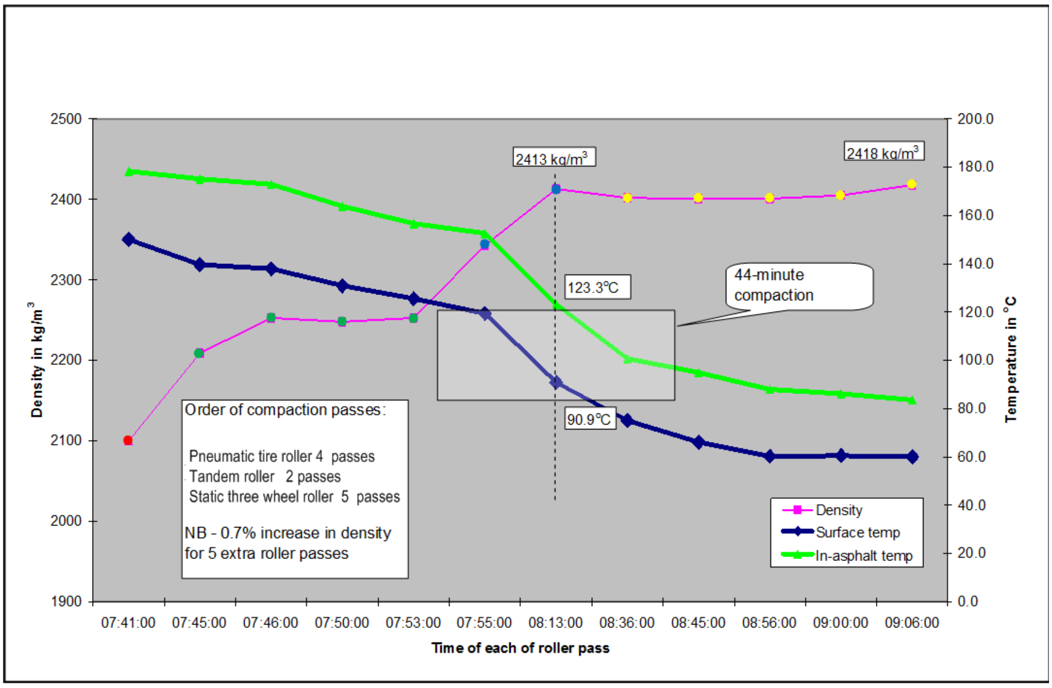

Figure 8: Improving background knowledge based on explicit data from the paving process: progression of the compaction rate related to number of roller passed applied on the mat.

The most important lessons we draw from the performed PQi-cycles done at different projects and by different contractors:

- Temperature- and compaction contour-plots are very useful for the insight in the homogeneity of the paving process; by making invisible aspects as asphalt-temperature and number of roller-passes visible, it is possible to make applied roller passes and variability in material temperature during compaction explicit. Temperature-differences of 20º-40ºC over less than 10 meters are normal. The influence of such variability's on final specs of the pavement should be investigated in the near future so the risks on not meeting asked specifications can be calculated.
- From the processes analysed it can be concluded that truck changes in front of the paper may often lead to temperature variability's of the freshly paved layer. Temperature of the paved layer however, is not explicitly visible for the roller operators so they cannot anticipate on them. This means that when such temperature variability's do occur during paving a lane, easily significant variability's in final density rate may occur.
- Paver stops (for instance due to a lack of asphalt transport), do easily lead to a strong variability in material temperature of the freshly paved lane. This easily can lead to variability in compaction rate as discussed above. Deployment of a shuttle buggy or extra trucks will help to reduce paver-stops. It is recommended to complete the project after the effect of logistics as a part of paving operations.
- Compaction at different temperatures (caused by cooling) and with different roller-types is not always effective. The monitoring of the compaction progress learns that there is a need for more insight in the compaction-behaviour of different asphalt-mixtures at different temperatures.
- From the compaction contour plots we got clear that there exists a large variability in spread of roller passes applied. It might be that roller operators have to little notion about how often they have been rolled at different locations. It seems they have too much focus on some area's whereas other area's got too little attention and too little passes. By doing PQi cycles, making data more explicit and giving feedback to operators we work towards improvement and optimisation of the asphalt paving process.
- Feedback of the PQi-cycles to the asphalt paving team is crucial for understanding the variability in compaction and temperature due to followed working method. This also enlarges the commitment for the paver and roller operators for using new tools.

During the PQi-sessions we became also aware of the fact that there exists a lack of knowledge about the compaction-characteristics of the Dutch asphalt mixtures. In the near future we will investigate the effectiveness of compaction at different temperatures in the laboratory. This will give us the necessary information to guide our paving-teams in when to start and stop compaction.

5. STATE OF ART 2ND HALF 2011

In 2008 at the Eurasphalt and Eurobitime conference we discussed our first approach in monitoring the asphalt paving process [1]. At that moment we had our first prototypes in temperature and GPS monitoring run. As a result, a lot of hand labour and time was needed to analyse the data before feedback to the paving team could be given. In 2008 the ASPARi executed only a couple of PQi cycles whereas at medio 2011 the process is far more automated and about 22 PQi cycles are scheduled. ASPARi did her first real-time pilot feedback cycles. Also other applications like Asphalt Open, Propave and the Cooling rate Calibration Curve (CCC) has been developed [16]. Those applications make the whole process of monitoring more easy and quick. Another important step is that in 2011 the first PQi cycles are executed by the contractors themself whereas before these cycles where done by the scientific staff of the university. The implications of the fact that now we as contractors use the equipment ourselves, is that we become more and more aware of our quality assurance and quality control processes, of course this is quite an improvement. Furthermore, the awareness of us as contractors increases when we have more often contact with the whole feedback system (reed more frequent PQi cycles).

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