PAVING BELOW ZERO CENTIGRADE – HOW A PROJECT EXPOSED TWO DIFFERENT APPROACHES TO INNOVATION

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ABSTRACT

In 2010 the Dutch highway agency tendered an innovation challenge. Contractors had to submit ideas and strategies to lay a 300m lane of Porous Asphalt (PA) surface layer while the outside temperature was below freezing point. Up until then, contractors were willing to repair and pave PA under such conditions, but did so without giving a guarantee on quality. The highway agency wanted to push the envelope and organized an innovation competition to prove that sufficient quality could be reached under these extreme conditions. From an original cohort of six invited contractors, two were selected to put their ideas into practice. The contractors had to [a] monitor their process (temperatures; GPS tracking of the machines), make the variability within this process explicit, and [c] determine quality parameters afterwards. Although the two selected contractors choose a similar approach in technologies, their operational approach was significantly different. One contractor treated the project as a usual job. The team saw monitoring as an added task. The other contractor treated the project as an innovative project. They deliberately selected team members and experimented with a whole package of measures and measurements to anticipate the extreme conditions. The two test sections were to be constructed simultaneously on the same night and on the same highway. This paper will describe the challenge, both approaches, and the monitoring of the important parameters during the process. It will also discuss the lessons learned related to the different approaches and related to paving under such conditions.

Keywords: paving, innovation, extreme conditions

1. INTRODUCTION

During the winters 2008-2010 more than usual surface damages did occur on the Dutch highways – specifically rutting and ravelling of the upper porous asphalt layer. The integrity of the porous asphalt seemed to suffer from the freeze – thaw cycles typical for the Dutch winter. Loose stones shattered an above average amount of car windows. Emergency road repair jobs caused traffic disruption. In some cases the damages was such that the upper layer had to be milled off completely on longer stretches. Because the Agency was reluctant to lay a new upper layer of porous asphalt at low temperatures, resurfacing was postponed to spring. Speed limitations were applied on the rough milled surface. All this did not go unnoticed to the public. The media picked up the irritation and questioned the Highways Agency's policy regarding the use of Porous Asphalt on the highways and regarding their maintenance strategies. Why was the Agency postponing the resurfacing? Were they really sure that resurfacing could not be done during the wintertime?
This paper first describes the innovation challenge that the Highway Agency put to market and the projects that followed. After selection, based on their proposed project approach, two contractors were awarded the opportunity to put their ideas into practice on two similar test sections on the highway. These approaches are explained in section 3 of this paper. Since low ambient temperature was the key in the reasoning to postpone repairs. It was important to monitor temperatures and cooling of the mix during the laying and compaction. Section 4 of the paper deals with the data gathering regarding temperatures and cooling on both test sections. Since more rapid cooling of the mix was presumed, contractors had to anticipate in their compaction strategies. Section 5 of the paper deals with the monitoring results of the movement of paver and rollers. Overall conclusions are presented in section 6 of the paper.

2. THE CHALLENGE

The contract document for the Rijkwaterstaat (RWS) project "Asfalteren onder het vriespunt" (Asphalt paving under sub-zero temperatures) summarises the purpose of the project as follows: " […] current techniques to construct Hot Mix Asphalt (HMA) paving during low temperatures are rather limited. Until now, construction companies resist to provide the same guarantees as when paved under normal conditions. In practice, most of the repairs are of a temporary nature with the permanent surfacing constructed later when the weather improves. If paving under sub-zero temperatures is a good option from quality perspectives, then it can make a difference to the traffic hindrances currently experienced." RWS therefore invited contractors to propose ideas to construct the Porous Asphalt (PA) layer under sub-zero temperatures without a loss in quality [1]. Possible improvements generated from the contractor's ideas were to be realised in two 300m long test sections to be constructed on the A58 freeway in Breda. The test sections were to be constructed simultaneously by two different construction companies on the same night.

Interestingly, the contract documents make reference to a RWS Innovation competition held in 2007 and reported on in a previous Eurobitume Congress [2]. The "Innovatie Programma Geluid – Innovation Programme for Noise reduction" competition challenged commercial parties to propose ideas to extend the service life of the dual layer PA system from seven to nine years [3]. The Asphalt Paving Research and Innovation (ASPARi) unit together with contractor BAM Wegen, introduced a number of innovations during the execution of the A35 project, including monitoring key process parameters in order to reduce quality variability in the HMA construction process i.e. the foundation of ASPARi's Process Quality Improvement (PQi) approach. HMA temperature was monitored using infrared cameras and laser linescanners, and all machine movements were tracked using a high accuracy GPS system. The result is that for the first time in The Netherlands, operational behaviour relating to key process parameters during HMA construction, could be made explicit.

For the project RWS awarded separate contracts for the two test sections to be constructed on the A58 freeway. RWS initially invited six contractors to tender for the project. Four of the six contenders – being ASPARi Founders - approached the research unit to undertake the monitoring because of its previous experience on the A35 freeway and other projects. The contract documents, in a separate "Monitoring" specification, state: "The purpose of monitoring the construction work is to determine one or more characteristics during construction, so that directly afterwards or over time, the behaviour of the test section could be explained." More specifically, the contractor was to record all construction conditions, including the condition of the existing surface, the application of the prime layer, the mix characteristics and the HMA delivery. An additional requirement was that the contractor provides reports on key process parameters including paving, compaction and temperature measurements over time. The objectives outlined in the contract specifications were mostly similar to the PQi as developed and applied in the ASPARi monitored projects (see Figure 1). The main objective of a PQi exercise is the improvement of process quality through firstly, monitoring of the HMA construction process in order to make operational behaviour explicit and secondly, using an action research approach to work towards process improvement with HMA construction teams [4].

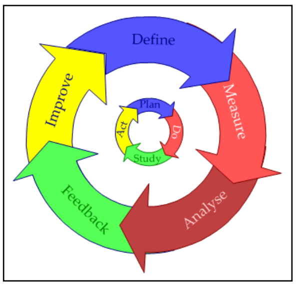

Figure 1 - The PQi cycle

Since both contractors had built a PQi into their tenders to RWS, and RWS insisted that the test sections should be constructed on the same night, the two projects had to be monitored simultaneously. The project required that specific weather conditions had to be prevalent before work could proceed. Both contractors also agreed to execute the contract within 48 hours after being given the "Frost-Go" notice.

Research perils encountered on the project

ASPARi researchers have spent a significant amount of time and effort over the past four years on developing and improving the PQi strategy and the appropriate tools, technologies and methods used to make operational behaviour explicit [5], [6], [7] & [8]. Previously, all PQi's followed a similar pattern. One asphalt team was monitored during a typical cycle, requiring one set of measurement devices and a small team of student assistants. However, the "Paving under sub-zero temperatures" project provided several challenges for the research team. The main challenge related to having sufficient resources and personnel available for following two construction teams. Monitoring two teams simultaneously meant that an additional set of measurement devices had to be hired for one night only, for both temperature profiling and GPS monitoring. Perhaps more importantly is that RWS set a very specific temperature window during which work could be carried out given their goal of wanting to study the effect of paving and compaction in sub-zero temperatures. The contract stipulated that work be carried out within a very strict (narrow) temperature window, the limits of which were set out in the contract documentation. This vital condition had four main implications:

- Firstly, it meant that data collection personnel normally drawn from Civil Engineering students at the University of Twente and usually difficult to assemble on short notice, proved even more challenging for this project. The "Frost-Go" notice for the work would be given within a two day window, effectively giving researchers forty-eight hours to assemble a rather large team that could track both test sections simultaneously.
- Secondly, despite formally booking the equipment for the PQi, researchers ran the risk of "losing" the rental equipment to other parties if the work were to be postponed.
- Thirdly, of concern to the research team was that the rental conditions and costs left no space for researchers to test and calibrate the rental equipment. The practice of rigorously testing equipment outside of PQi's ensured that previous exercises proceeded as they should have.
- Lastly, the very specific temperature requirement meant that work was postponed on two occasions because of "unfavourable" weather conditions.

Despite these challenges, two researchers accompanied by eight students, successfully conducted the data collection part of the PQi exercise. The next section will outline the different approaches contractors took in terms of operational strategies and the implications of using rental equipment in the monitoring exercises.

3. THE APPROACHES

Both contractors provided detailed plans of how work was to be executed on the project. The rather similar plans provide extensive detail regarding the removal of the existing surfacing, tack coat application, asphalt production at the plant, PA construction, a quality plan, production controls and the measurements required by RWS. Whilst the project goal is the same, RWS's desire to stimulate and facilitate innovation in HMA construction results in different approaches and operational strategies; and the choice of equipment shown in Table 1.

Table 1 - Paving and compaction equipment used on the project

	Contractor 1	Contractor 2
Paver	Self-priming paver	Self-priming paver
Breakdown compaction	10 ton tandem roller	10 ton tandem roller
Final compaction	14 ton tandem roller	14 ton 3-drum roller
Other	Heating the longitudinal joint and compacted with 2.5 ton tandem roller	Pre-heat milled surface with a jet blower; heating applied to the longitudinal joint

Contractor 1 chose a traditional approach for paving with no prior heating of the milled surface and used a self-priming paver for the application of the tack coat. A small area was constructed at the start of the test section to check that all equipment was working as intended and later removed before the actual start of construction. Heating was applied to the longitudinal joint and the joint was compacted using a 2.5 ton tandem roller. Contractor 2, on the other hand, chose to preheat the milled surface using a turbo jet blower and also applied heating to the longitudinal joint. Infrared images taken after the jet blowing exercise, showed the surface to be heated to a temperature of around +8°C. The average temperature just before the start of construction was found to be approximately +4°C. This is in stark contrast to the test section where no heating was applied which had an average surface temperature of approximately -4°C before the start of construction.

4. RESULTS APPROACH 1

4.1 Temperature profiling

Typically, the homogeneity of a newly constructed HMA layer can be determined by analysing the variation in temperature across the length and width of the paved lane. Paver stops are easily identifiable if the HMA cools off appreciably during the stop. The practice of allowing the paver hopper to empty completely before new truck arrivals shows up in the form of temperature differentials greater than the norm at the start of paving. New truck arrivals coincide with the paver operator appearing to empty the hopper almost completely. The result is that for paver stops and the practice of almost complete emptying the paver hopper, the HMA surface temperature drops appreciably and shows up as cyclically occurring cool areas with varying degrees of temperature differentials. Depending on the extent of the variation in temperature, these areas may be classed as being potentially or highly segregated areas (in terms of temperature) and may be prone to fatigue cracking, ravelling and other surface integration mechanisms [9]. In addition, several researchers have studied the effect of temperature differentials on density and surface smoothness [10] & [11].

The PA's surface temperature homogeneity was monitored using a laser linescanner mounted behind the paver screed to scan the entire width of the asphalt layer. Previous research shows the linescanner to be useful for monitoring temperature homogeneity [12] & [13]. The scan was set to 150 lines per second with a resolution of 256 measurement points per line. The scanner is connected to a laptop with data and stream files stored directly onto a laptop mounted close to the paver operator. The stream files can be replayed in a movie-like format.

Contractor 1

The temperature of the existing surface shortly before that start of paving was found to be an average of -3.9°C. An analysis of the linescanner data shows the newly constructed PA layer to be fairly temperature homogeneous with an average surface temperature of 136°C where the paver did not stop. No prolonged stops were experienced during construction with the paver only stopping briefly whilst waiting for every new truckload of asphalt (μ = 2,4 minutes per truck change). The truck change coincides with the paver operator appearing to empty the hopper almost completely. The result is that for these short stops, the HMA surface temperature drops to ±110°C and shows up as cyclically occurring cool areas before each new truckload. During the longest stop, the surface temperature drops from a maximum of 145°C to 100°C, over a five-minute period. This cooling of the mix during truck changes, consistently result in temperature differentials greater than 30°C.

Figure 2 Temperature Contour Plot (TCP) of the first 100m of paving, shows typical longitudinal thermal streaks occurring during paving operations. They are visible in two forms. In the first, a longitudinal streak is visible near the centre of the paver with the temperature in the streak dropping to as low as 125°C whilst the surrounding HMA is more than 140°C. In the second, longitudinal segregation is evident in thermal streaks running parallel to the centre-line in the area of the conveyor belts that transport asphalt through to the paver's augers. These temperatures differentials are greater than those in the centre with the surface temperature dropping to below 120°C (ΔT = 20°C) in some places along the test section.

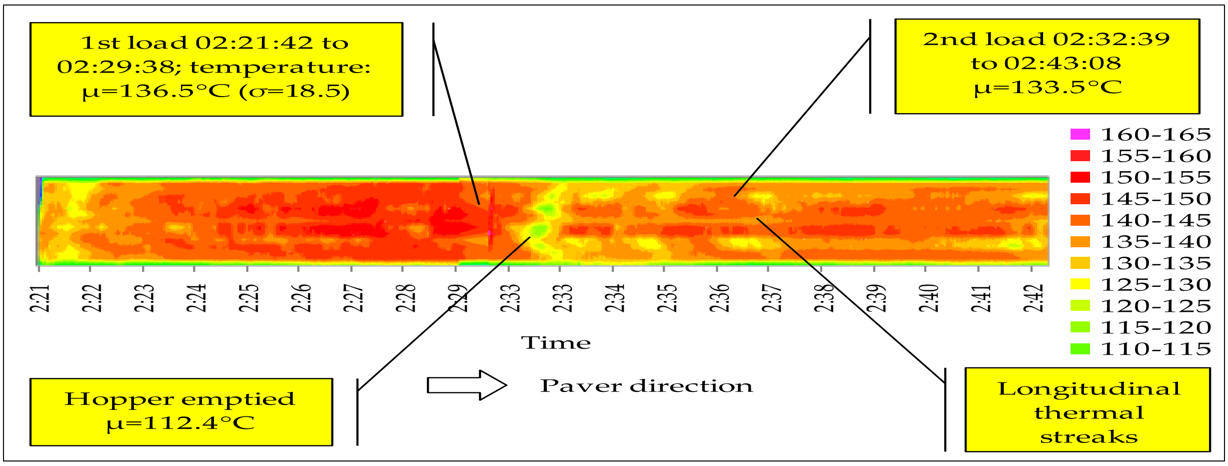

Figure 2 - Typical Temperature Plot for the first 100m - Contractor 1

The linescanner data was also used to compare joint warming mechanisms employed by the contractor to improve the joining of the existing (cold layer) and the newly laid PA surfacing. This practice was undertaken successfully with the joint warming resulting in an average temperature of 105°C next to the existing surfacing compared to the open side's average of 85°C where no additional heating was applied (for the effect of the heating of the joint see Figure 3).

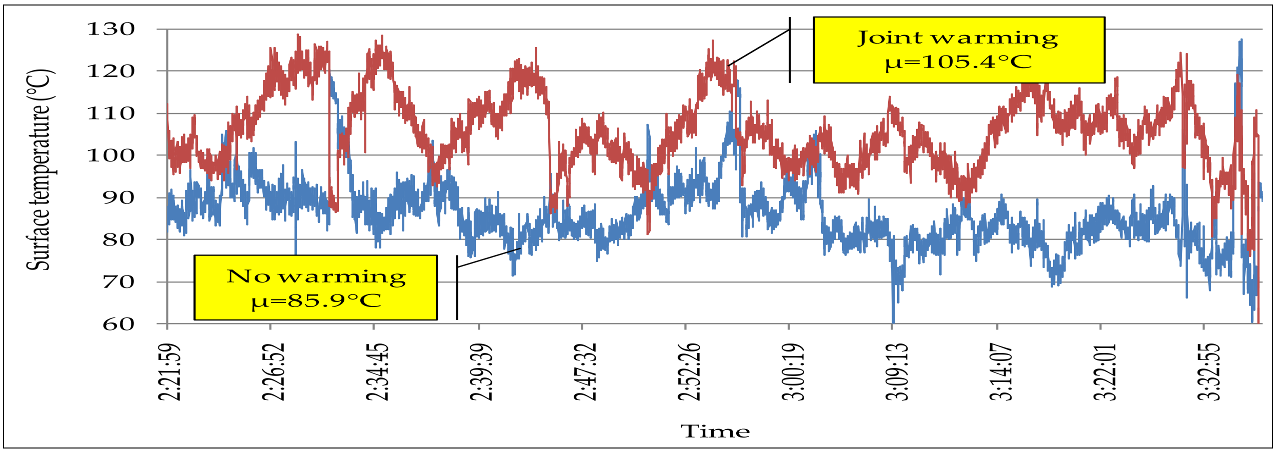

Figure 3 - Contractor 1 - joint warming analysis

4.2 Monitoring machinery movements

Three rollers were used for compaction operations, each fulfilling distinctly different roles. A small 2.5ton tandem roller was used for joint compaction, a 10ton tandem roller for breakdown rolling and a 14ton tandem roller for final rolling. The small tandem roller was not equipped with a GPS receiver and could therefore not be tracked during its operations. This roller was not part of the original operational plan devised by the contractor prior to construction operations being carried out. The decision to use it was taken shortly before construction commenced. The primary reason for its usage was that the contractor intended limiting the damage to the adjoining existing PA layer. No echelon movements were used during compaction operations. The decision to purposely not use the roller's echelons capabilities was taken by the contractor a few weeks before construction commenced.

The Compaction Contour Plot (CCP) shows the number of roller passes. The accumulated passes of breakdown roller is given in the top of Figure 4. GPS data loss occurred between 02:43 and 03:03 resulting in an incomplete view of the roller's compaction operations. It is clear from the CCP, that from position 180m onwards, the operator tended to concentrate on the middle of the paved lane and applied an average of 11.5 passes compared to the sides where only 5.5 passes were applied on average. A similar pattern to that observed for breakdown rolling emerges for the 14 ton tandem roller used for finishing operations (see bottom of Figure 4). An average of 8.8 roller passes was applied to the middle of the lane compared to an average of 4.5 passes applied to the sides. Also, two zones of compaction are clearly visible over the length of the test section. The first 100m has received significantly less compaction passes (3.2 on average) compared to the rest of the test section (8.2 passes on average). The lack of compaction passes on the longitudinal joint side has been compensated by using the 2.5 ton small tandem roller for joint compaction. It is difficult to determine whether this additional joint compaction was adequate given the absence of GPS data.

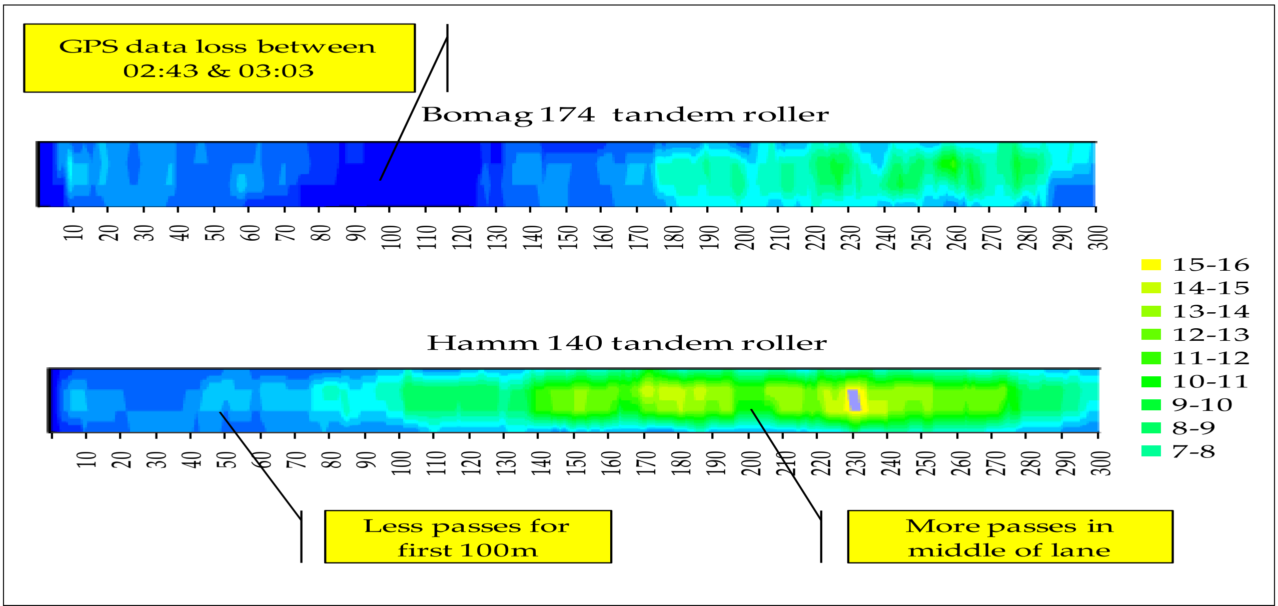

Figure 4 - Compaction Contour Plots (CCP) for Contractor 1

5. RESULTS APPROACH 2

5.1 Temperature profiling

Unfortunately, the research team was unable to gain the same range of insights for Contractor 2 whose paver was fitted with the rental linescanner. With no prior testing of the linescanner, the success of the temperature homogeneity measurements was left to the roll of the dice, so to speak. Regrettably, the combination of a rental linescanner and a "foreign" laptop not normally used on PQi's, resulted in problems for the Direct Data Exchange facility that allows automatic data transfer and thus, no linescanner data or data stream files could be recorded. Fortunately, a backup methodology used on earlier PQi's during the formative stages of this research [8] was put in place just in case using the rental linescanner proved problematic. Images taken with a hand-held infrared camera, every five metres behind the paver screed, provided sufficient data to determine the extent of temperature homogeneity of the test section (Figure 5) and to visualise the truck changes. The incident log compiled during construction operations revealed the same operational behaviour found with Contractor 1, that the paver stopped every time a new load of asphalt arrived with the result that the surface temperature dropped to approximately 120°C depending on the length of the stop. The incident log and paver GPS data showed that no prolonged stops occurred (μ = 1.8 minutes) and hence the stops had little effect on the overall cooling of the mix. In addition, the contractor limited the mixing of colder HMA that normally falls from the sides of the hopper and remixed with the warmer mix, by keeping the hopper flaps open. An additional strategy employed by the contractor was to remove the first 2 to 3 tons of HMA from the truck flap area and dispose of it, before unloading the rest of the mix into the hopper. Joint warming was also employed for this test section. However, the resolution of the hand-held infrared camera is rather limited when compared to the linescanner and hence does not show the same level of detail. Hence, no inferences could be made regarding the joint warming or the presence of the thermal streak phenomenon found with Contractor 1.

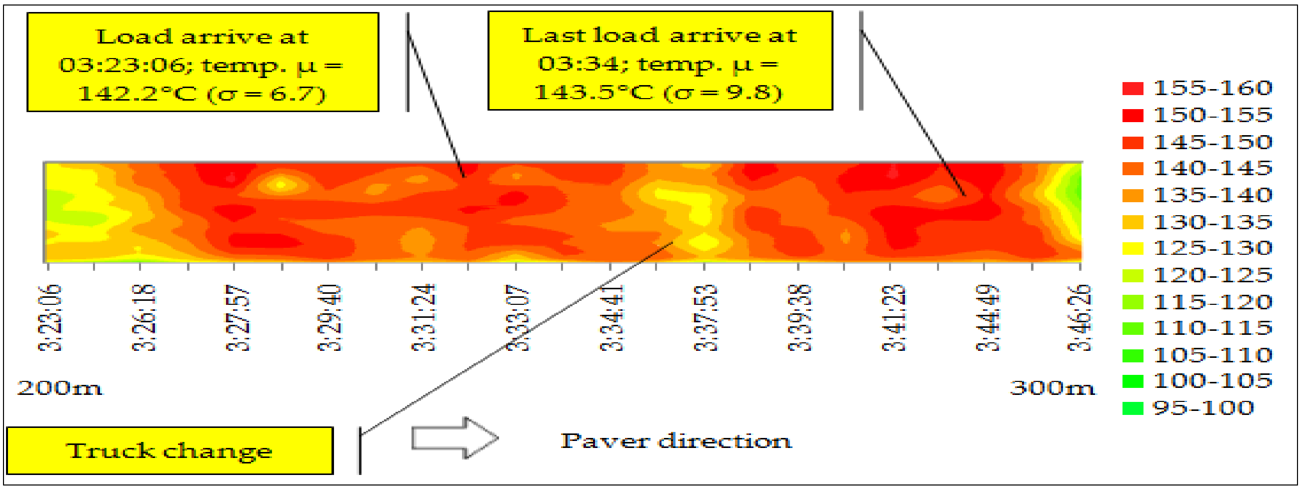

Figure 5 - Typical Temperature Contour Plot (TCP) for the last 100m - Contractor 2

5.2 Monitoring machinery movements

For Contractor 2, the compaction operational strategy appears to be quite different (Figure 6). The contractor uses similar weighted rollers (to that of the other contractor) with breakdown rolling undertaken using a 10ton tandem roller and final rolling using a 14ton three-drum deadweight roller. The tandem roller operator covers the entire test section tending to concentrate on the middle of the lane. Three zones of compaction are visible with the start of the test section receiving less passes than the end and the number of compaction passes steadily increases from the start to the end (μ = 4.3, 8.7 and 13 passes for the three zones). Whilst the operating strategy of the tandem roller operator appears to be clear, the role of the three-drum roller is unclear. The operator starts off compacting the whole width of the lane (μ = 7.2 passes), then after approximately 90m tends to only compact the longitudinal join area (μ = 2.9 passes). This operator has probably changed strategy after observing a change in the behaviour of the PA layer. The overall result is that there is significant variability in the number of compaction passes applied to the test section with the area next to the longitudinal join having received the most compaction passes.

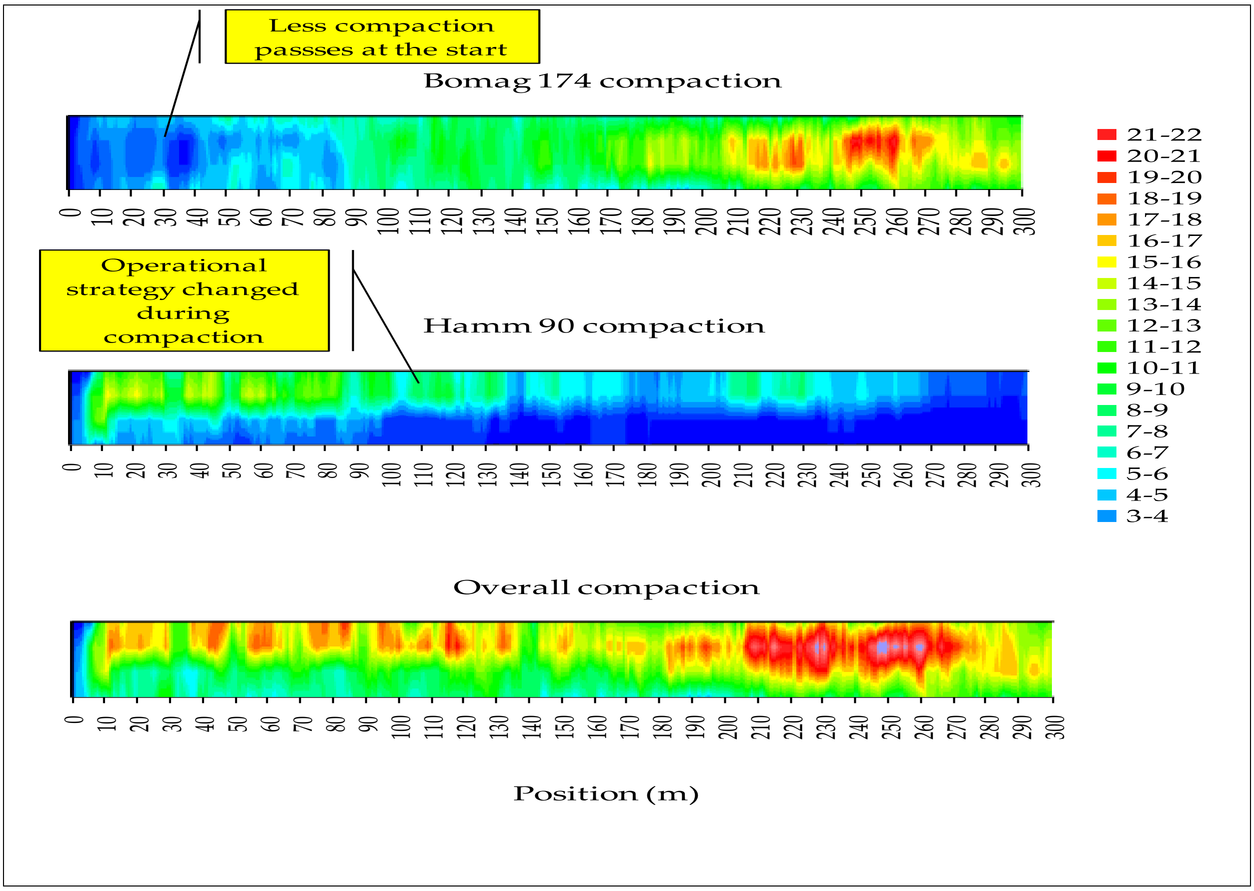

Figure 6 - Compaction Contour Plots for Contractor 2

6. CONCLUSIONS

This paper documented an innovation challenge set by the Dutch highway agency: "paving porous asphalt below zero centigrade". Contractors had to come up with methods and technologies to ensure the quality of the porous asphalt layer. This paper honed in on the way the contractors picked up the innovation challenge. The paper written by Voskuilen et al [14] documents the quality parameters of the paved layer. That paper argues that it is possible the lay porous asphalt under sub zero centigrade and the reach sufficient layer quality, given appropriate measures are taken.

For the innovation challenge: The contractors' operational strategies were quite similar. Both used self-priming pavers, and their choice of roller weights are the same for the PA layer. One contractor used a small 2.5 ton roller to specifically compact the longitudinal joint area, but that was the fall-back option. To counter some of the effects of cold weather, both applied heating to the longitudinal joint area. In addition, one made innovative use of a jet blower to heat the rather cold milled surface. As a result of which, the heated surface was approximately 8°C warmer than the unheated surface. Some other differences between the two contractors were observed. One contractor spread small sized aggregate for improving texture (skid resistance) onto the PA layer, using a contraption bolted on the roller. The other used a low-tech approach: a worker with a wheel-barrow and spade to spread sand onto the surface from the side of the road. The most distinct difference however was the overall approach the two took to the project. One contractor treated the project as a normal project with some extra monitoring and hardly any extra measures and objectives. For its construction team, it was "business as usual". The entrenched routines of the team secured coordination and a smooth process. The other contractor took a different approach and embraced the task as an innovation project. They handpicked a team with people from different regions and mobilised technologists to monitor even more than required by the RWS contract. In this way they gathered more detailed insights into the several aspects of paving at low temperatures. However the more complicated context and the ad hoc formation of the team created extra coordination pressures for the actual paving process and measurement procedures.

This project has also shown that there are several technology pitfalls to be aware of. Acquiring new technologies (GPS, laser linescanners) does not mean that it can be integrated directly into work processes. It takes time to test, set up and calibrate. It takes time to ensure that data transfer mechanisms work. It takes time to get personnel used to the technology. These are lessons for contractors wanting to adopt the PQi methodology, invest in these new technologies and wanting to monitor their own HMA construction processes in the future. The obligation to monitor the process on the “Asphalt paving under sub-zero temperatures” project – as discussed in this paper – can be seen as a precursor for a future documentation and verification regime. So, can we expect contractors to start investing and installing GPS and thermographic instruments on their paving and compaction equipment soon? It will probably be a gradual process with the larger contractors being the first adopters. Key in this will the contractors’ effort to train their personnel to conduct and analyse the PQi’s themselves. This also implies new roles and a broader array of tasks for the technologists: not just focusing on mix quality and end-result control but also on process control and process improvement i.e. bridging the gap between laboratory testing and process control.

This PQi was a good opportunity to gather temperature, cooling and compaction process data for paving under sub-zero temperature conditions. The fact that both “winning” contractors, and two other contenders, proposed to follow the PQi format, is an acknowledgement of the practicality and robustness of the methodology developed by the ASPARi research unit. The combination of [1] uncertain mobilisation depending on the weather predictions, and [2] running both projects simultaneously, created the biggest challenge for the monitoring. Although not all monitoring and data gathering worked out as is intended in a PQi, the methods and back up procedures generated the data required by the RWS contract. The different ambitions and approaches the contractors took to the project also exposed the effects of entrenched routines and how this created coordination pressure. This, in turn, had consequences for process smoothness. For the contractors the information gathered, graphs, visuals and animations proved to be a new window to view the process and provided a mirror that could be used by the paving team to reflect on their construction work. In addition, this project shows that monitoring process parameters has several advantages, for contractors as well as road agencies, including that key process parameters are kept in control leading to a more consistent product, and that the data-rich environment means that both contractor and road agency are able to use permanently geo-referenced data for the future monitoring of pavement distress and premature failure.

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