

## Hot Mix Asphalt – the “Paving under sub-zero temperatures” experience

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### Summary

Rijkswaterstaat’s recent “Asfalteren onder het vriespunt (Paving under sub-zero temperatures)” provided an interesting research opportunity for the Asphalt Paving Research and Innovation (ASPARi) unit. The participating contractors both chose to adopt ASPARi’s Process Quality improvement (PQi) methodology to monitor their paving and compaction work. This presented a number of challenges for the construction teams and presented an opportunity to compare the operational strategies employed by the two contractors. The conditions at the time of construction were the same for both contractors; and the goals and objectives were the same given RWS’s requirements. It would therefore be interesting to see whether the approaches to construction would be the same. The results show that whilst the contractors used similar equipment and introduced several innovations to counter the effect of the cold conditions, the adopted operational strategies and approaches are different. From a research perspective, the main challenge was being able to deal adequately with monitoring two construction teams simultaneously and being able to organise sufficient resources and personnel within the 48-hour window after the “Frost-Go” notice was given.

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## 1. *Introduction*

The contract document for the Rijkswaterstaat (RWS) project “Asfalteren onder het vriespunt” (Asphalting under sub-zero temperatures) summarises the purpose as follows: “[...] current techniques to construct Hot Mix Asphalt (HMA) paving during low temperatures is rather limited. Until now, construction companies are loathe to provide the same guarantees for paving [...]. 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 ZOAB layer under sub-zero temperatures without a loss in quality. Possible improvements generated from the contractor’s ideas were to be realised in two test sections on the A58 in Breda. These were to be constructed simultaneously by two different construction companies on the same night.

## 2. *The Process Quality improvement (PQi) exercise*

Interestingly, the contract documents make reference to the RWS Innovation competition held in 2007. The Innovatie Programma Geluid competition challenged commercial parties to propose ideas to extend the service life of the dual layer porous asphalt system from seven to nine years (Rijkswaterstaat 2007). ASPARi 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. HMA temperature was monitored using infrared imagery 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. The authors have subsequently published several follow up articles on this and other projects (Miller, Dorée et al. 2007; Miller and Dorée 2008; Miller, Dorée et al. 2008; Miller, ter Huerne et al. 2008; Miller, Dorée et al. 2009)

For the “Asfalteren onder het vriespunt” project, RWS awarded separate contracts for the two test sections to be constructed on the A58. RWS initially invited six contractors to tender for the project. Four of the six contenders – being ASPARi Founders - approached ASPARi to undertake the monitoring because of its previous experience on the A35 and other projects. Amongst the four were the two “winners”: Dura Vermeer and KWS. 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 circumstances, including the condition of the existing surface, the application of the prime layer, the mix characteristics and aspects related to 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 Process Quality improvement (PQi) method as developed and applied in the ASPARi monitored projects. The main objective of a PQi is the improvement of process quality through firstly, monitoring of the HMA con-

struction process in order to make operational behaviour explicit and secondly, using an action research approach to work towards process improvement with HMA construction teams. The aim is for HMA teams to reflect on their work post-construction using a series of plots, visualisations and animations specifically developed to make their operational behaviour explicit. In this way they are able to discuss and analyse what they have done, how they have done it and whether there are opportunities for improving their work methods. A typical PQi cycle shown Figure 1 in consists of:

- Day 1: **Preparation and definition** – site calibration, record site conditions and a preparatory meeting with the HMA team;
- Day 2: **Data collection** – temperature profiling, monitoring all HMA machine movements, monitor weather conditions, nuclear density profiling and recording all noteworthy events using the measurement devices shown in Table 1;
- Days 3 and 4: **Data analysis** – analyse all data and prepare visualisations and animations;
- Day 5 – Feedback session – discuss all results, visualisations and animations with the HMA team, laboratory technicians and others directly involved in the project.



Figure 1 - Typical PQi cycle

Table 1 - Measurement devices used during a typical PQi

Task	Instrument	Method	Measurement accuracy & frequency
Monitor weather conditions	Weather station (vintage pro)	Weather station set up next to the construction site to log local conditions	Ambient temperature, wind speed, relative humidity, solar radiation data logged at 5-minute intervals
Measure asphalt surface temperature behind screed	Linescanner (Raytek)	Laser linescanner mounted on the back of the HMA asphalt paver.	captures HMA surface temperature at 1-second intervals behind the paver screed
Measure surface temperature cooling rate	2 handheld infrared cameras (Flir & Fluke)	Cameras on tripods at fixed positions approx. 100m apart	Images taken manually every 30 seconds
Measure in-asphalt temperature cooling rate	2 channel digital thermometer (by contractor)	Thermo-coupler placed in the middle of asphalt layer	Temperature logged automatically every 30 seconds
Monitor movements of all asphalt paving machinery	5 GPS receivers (Trimble)	Base station set up on site & GPS receivers mounted on HMA machinery	Differential GPS accuracy of < 10 centimetres, Data logged at 1-second intervals
Measure asphalt density	Nuclear density gauge (by contractor)	Density measured after every roller pass at fixed temperature logging positions	Preferably on spot of cooling measurement after each roller pass, and afterwards
Record noteworthy incidents on site	Memo recorders (Sony)	Record incidents as they occur	Incident log; observations

Since both KWS and Dura Vermeer 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. In this regard, KWS and Dura Vermeer agreed to execute the job within 48 hours after being given the “Frost-Go” notice. The next section describes the approaches and operational strategies applied by the two contractors.

### 3. Differing approaches and operational strategies

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, ZOAB construction, a quality plan, production controls and the zero 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 2.

Table 2 - Paving and compaction equipment used on the project

	Contractor 1	Contractor 2
Paver	Self-priming paver	Self-priming paver
Breakdown & intermediate 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 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 contrast to the test section where no heating was applied which had an average surface temperature of approximately -3.9°C before the start of construction.

#### Temperature profiling

The ZOAB's surface temperature homogeneity was monitored using a laser line scanner mounted behind the paver screed to scan the entire width of the asphalt layer. The scan is set to average 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 post-construction in a movie-like format.

For *Contractor 1*, the linescanner analysis in the form of Temperature Contour Plots (TCP) provided several insights into operational practices (see typical TCP shown in Figure 2). 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 hop-

per 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 (Mahoney, Muench et al. 2000). In addition, several researchers have studied the effect of temperature differentials on density and surface smoothness (Stroup-Gardiner, Wagner et al. 2002; Willoughby, Mahoney et al. 2002). The high resolution of the linescanner enables another phenomenon to be identified. The TCP shows longitudinal thermal streaks occurring during paving operations. These thermal streaks 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 by not more than 15°C when compared to the surrounding HMA. 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 surface temperature differences of as much as 30°C when compared to the surrounding asphalt. The thermal streak phenomenon has previously been observed by this research team on other PQi’s. Lavoie (2007) found that thermal streaks represents an area of weakness that has low resistance to thermal contractions. This type of failure results in the development of longitudinal cracks, appearing in the first few winters following construction work.

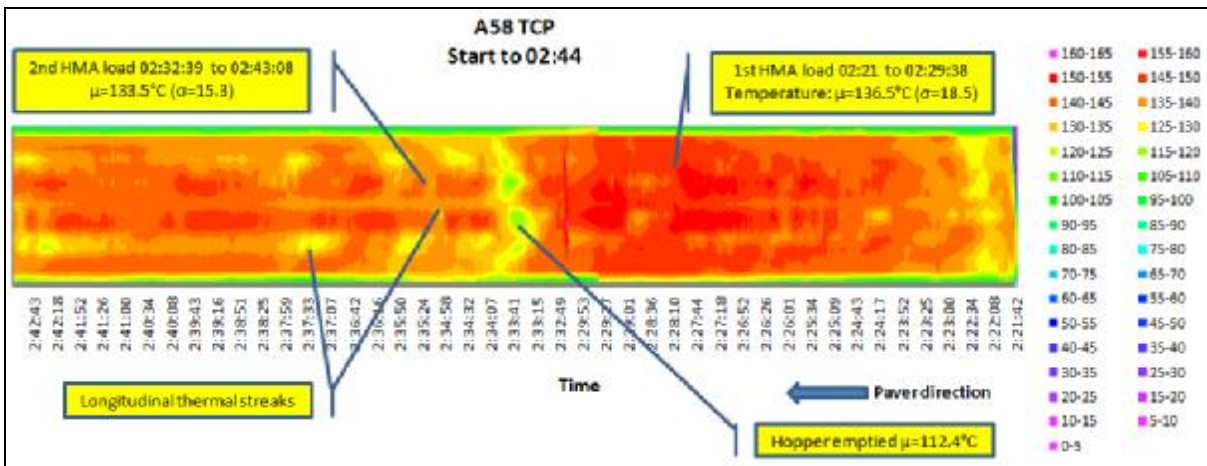


Figure 2 - Typical Temperature Contour Plot for Contractor 1 – first 100m

The linescanner data was also used to compare joint warming mechanisms employed by Contractor 1 to improve the joining of the existing (cold layer) and newly laid HMA surfacing. The joint warming resulted in the heated longitudinal joint area having a surface temperature approximately 25°C higher (on average) than the non-heated side (see Figure 3).

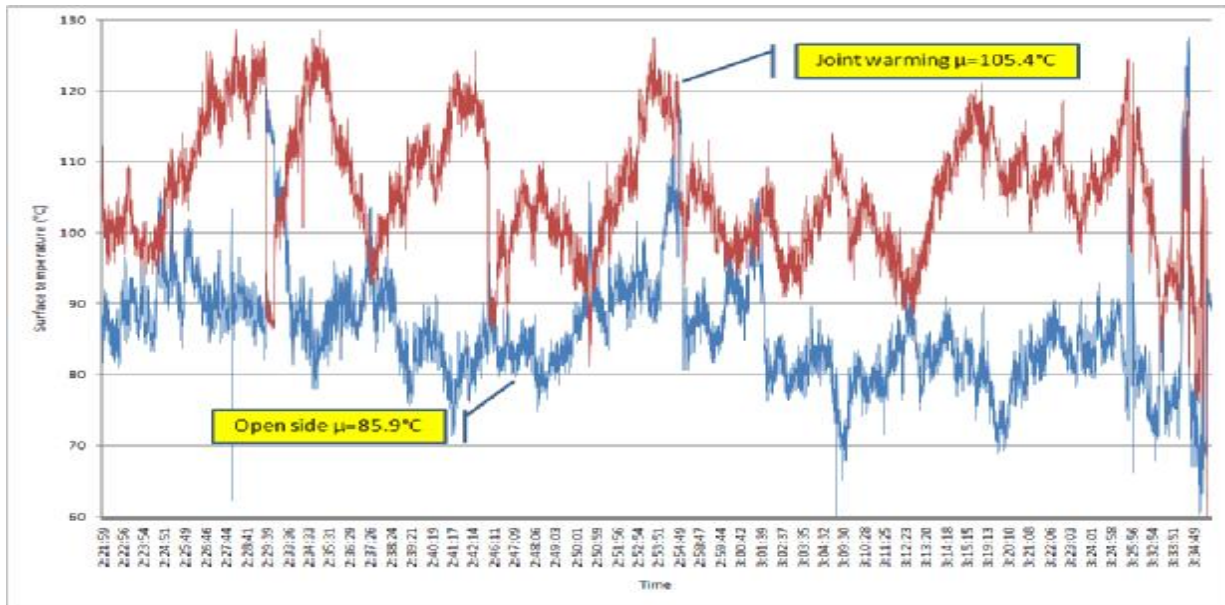


Figure 3 - Joint warming analysis

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 (Miller, ter Huerne et al. 2008; Miller, Dorée et al. 2009), 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 (see Figure 4) 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 depending on the length of the stop. The incident log and paver GPS data showed that no prolonged stops occurred ( $\mu = 1.8$  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.

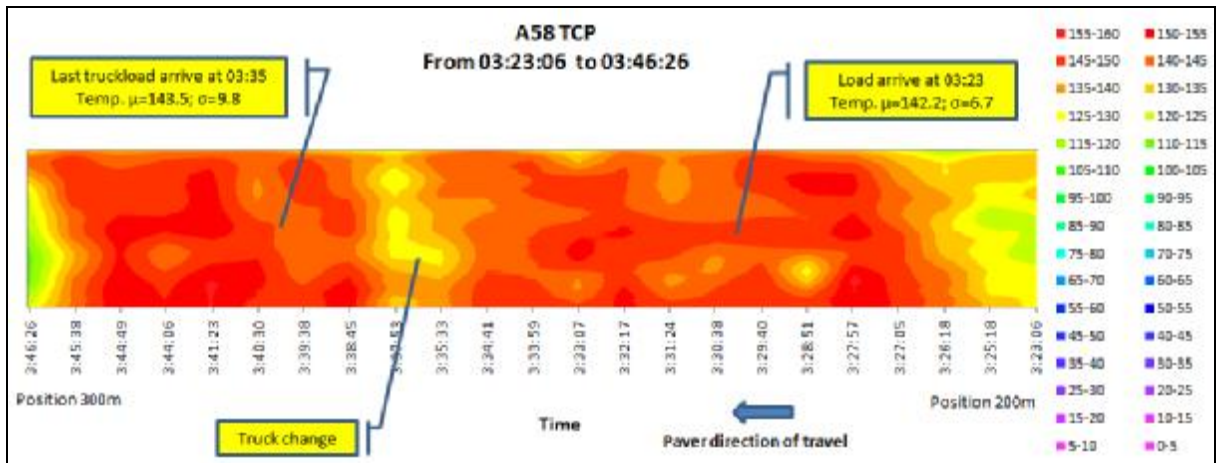


Figure 4 – Typical Temperature Contour Plot for Contractor 2 - last 100m

### Monitoring machine movements

The paver speeds were derived from the GPS data. Both paver operators maintained constant speeds during paving of 5m/min and 5.8m/min for their respective sections. In both cases, the only exception is that the pavers stopped for an average of  $\pm 2$  minutes for each new load. These stops were verified using the incident log compiled by the team during paving operations.

**Contractor 1** used three rollers for compaction operations, each fulfilling distinctly different roles. A small 2.5 ton tandem roller was used for joint compaction, a 10 ton tandem roller for breakdown rolling and a 14 ton tandem roller for final rolling. Regrettably the small tandem roller was not equipped with a GPS receiver and could therefore not be tracked during its operations. This small roller was not part of the original operational plan devised by the contractor prior to construction operations being carried out. The decision to use the small roller was taken shortly after construction commenced. The initial strategy to use a special single drum mounted on the 10 ton tandem for the joint, was abandoned in order to limit the damage to the adjoining existing surfacing layer. The construction team was not happy with the result and therefore mobilised the small tandem roller. The Compaction Contour Plots (CCP) for the two heavier tandem rollers is given in Figure 5. Note that 20 minutes of GPS data loss occurred between 02:43 and 03:03 resulting in an incomplete view of the Bomag tandem roller's compaction operations. It is clear from the CCP, that from position 180m onwards, the operator has tended to concentrate on the middle of the paved lane where the average number of passes are almost double that of the sides (see top of Figure 5).

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. A similar pattern to that observed for breakdown rolling emerges for the Hamm 14 ton tandem roller used for finishing operations (see bottom of Figure 5). Also, two zones of compaction are clearly visible over the length of the test section. The first 100m has received significantly less compaction passes compared to the rest of the test section.

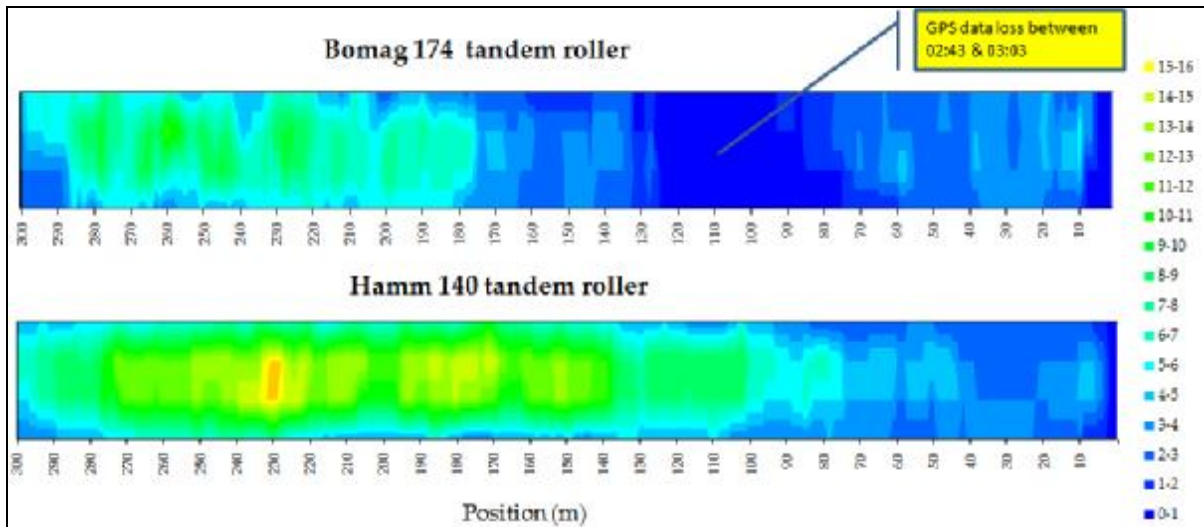


Figure 5 - Compaction Contour Plots for Contractor 1

For *Contractor 2*, the compaction operational strategy appears to be quite different (see Figure 6). The contractor uses similar weighted rollers (to that of the other contractor) with breakdown rolling undertaken using a Bomag 10 ton tandem roller and final rolling using a Hamm 14 ton three-drum deadweight roller. The tandem roller operator covers the entire test section tending to concentrate on the middle of the lane. Two 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. 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, then after approximately 90m tends to only compact the longitudinal joint area. 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 joint having received the most compaction passes.



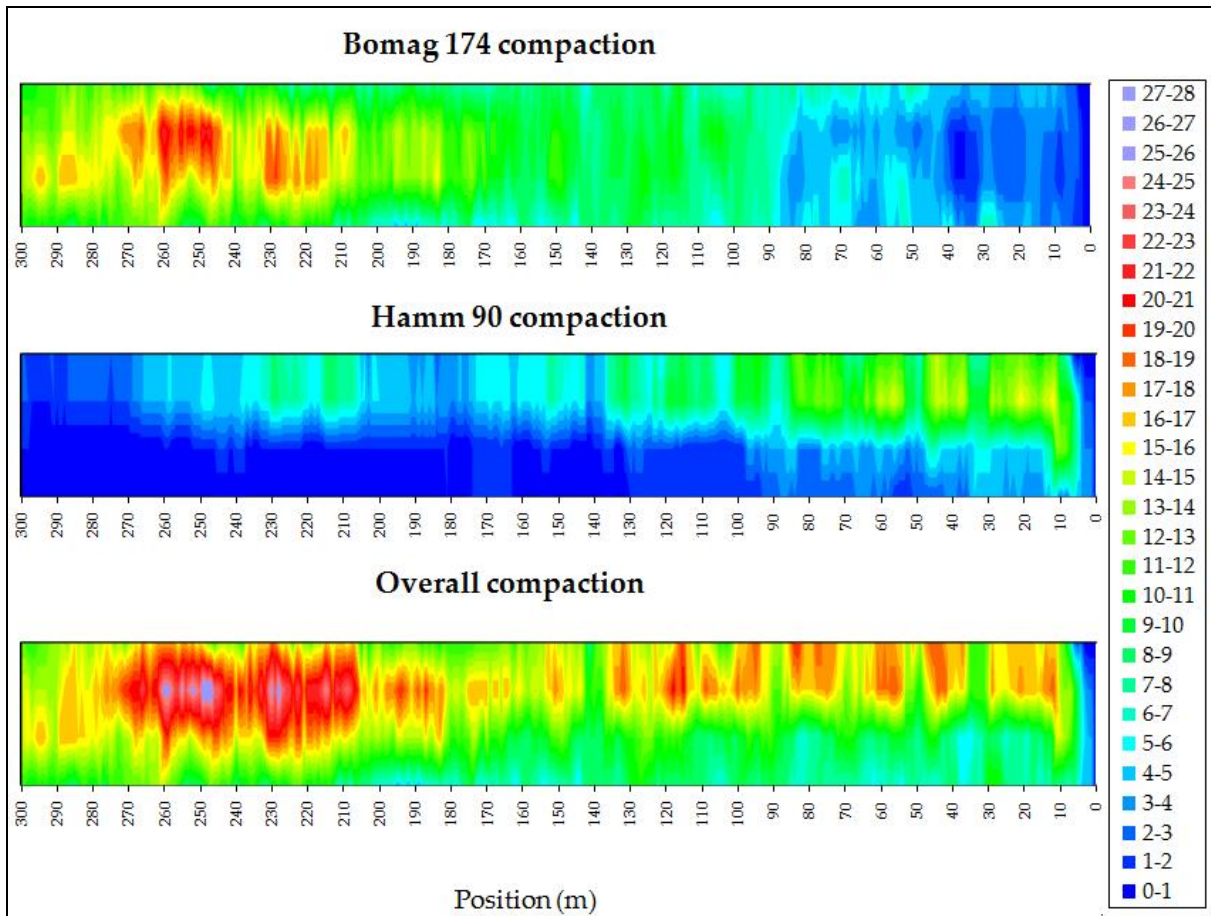


Figure 6 - Compaction Contour Plots for Contractor 2

#### 4. Observations

The contractors’ operational strategies were quite similar. Both used self-priming pavers, and their choice of roller weights are the same for the ZOAB 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, the result of which is that the heated surface is approximately 8°C warmer than the unheated surface. Next to these there were some differences between the two. One contractor spread small sized aggregate for improving texture onto the ZOAB 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 what was 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.

### 5. *Research perils encountered on the project*

Previously, all PQi's followed the same pattern. One asphalt team was monitored during a typical cycle, requiring one set of measurement devices and a small research team. However, the "Asfalteren onder het vriespunt" 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 construction 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. An additional laser linescanner proved difficult to procure on short notice. The linescanner vendor is a sole supplier and does not as a rule, keep additional scanners in stock given its high cost. This meant that a loan linescanner had to be collected from neighbouring Belgium and taken directly to the contractor for fitting to the paver. Finding additional infrared cameras, although less complicated, was also not without its problems. The only cameras available on short notice were older models unfamiliar to the research team. An additional problem surfaced during rental discussions. The cost of hiring the linescanner and infrared cameras became problematic given vendor rules for renting their equipment. Hire periods normally range from a few days to a week or more. Since the equipment was only needed for one night's measurement, this would increase costs without having the benefit of using the equipment for the entire rental period. Also, the uncertain date for use sparked discussions about the cost of "reserving" the cameras. Regarding GPS equipment, the research team has five receivers, enough to track the machine movements of one HMA construction team at a time. Tracking two teams meant that an additional GPS set needed to be rented. Securing additional GPS receivers proved even more complex than the temperature equipment. Few companies in The Netherlands supply the high accuracy GPS receivers and calls to them were futile with no suppliers keeping additional receivers in stock. One of the contractors was eventually able to hire an entire land surveying team with their own GPS equipment, to monitor its paving and compaction equipment on the night.

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.

- ú 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.
- ú Secondly, despite formally booking the equipment for the PQi, researchers ran the risk of "losing" the equipment to other parties if the work were to be postponed.

- ú 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 smoothly.
- ú Lastly, the very specific temperature requirement meant that work was postponed on two occasions because of unfavourable weather conditions. Despite these challenges, two ASPARi researchers accompanied by eight students successfully conducted the data collection exercise on the night of 20 February 2010.

So what is the point of discussing these perils? Surely procuring equipment should not have been a problem in the first place? Once equipment was found, it should have been quite easy to calibrate the equipment and conduct successful measurements on the project. Surely this is what everyone expected? However, this project has shown that there are several pitfalls to be aware of. Acquiring the equipment 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 A58 – as discussed in this paper – can be seen as a precursor for a future documentation and verification regime. In the short term, we can expect contractors to start investing and installing GPS and thermographic instruments on their paving and compaction equipment. It will be a gradual process with the larger contractors being the first adopters. Key is the contractor training their personnel to conduct 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.

## 6. Conclusions

For ASPARi it was a good opportunity to gather temperature, cooling and compaction process data for paving under freezing conditions. The fact that both “winning” contractors, and two other contenders, proposed to follow the PQi format for monitoring is an acknowledgement of the practicality and robustness of the methodology. 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, the A58 project shows that monitoring process parameters has several advantages for contractors and road agencies alike 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 is able to use permanently georeferenced data for the future monitoring of pavement distress and premature failure.

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