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Making the asphalt paving process explicit - A fundamental step for quality improvement

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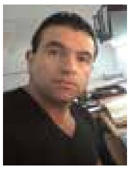

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Professional paper

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Making the asphalt paving process explicit - A fundamental step for quality improvement

The objective of the paper is to make explicit the paving operations, the related asphalt temperature and density data, and the logistic process, as a fundamental step to identify improvement opportunities. For that, temperature data, roller compactor trajectories, asphalt density, paver speed, and trucks logistics, were collected. The results, analysis, and feedback received, point to specific opportunities for improvement, including avoiding the paver start-stop cycles, uniform compaction of the entire pavement surface, and definition of roller compaction strategy.

Key words:

asphalt pavement, asphalt quality, asphalt mix temperature, paver speed, roller compactors

Stručni rad

Mauricio Pradena, Seirgei Miller, Guido Staub, Marcos Díaz, Francisco Contreras

Eksplicitno definiranje postupka asfaltiranja kolnika - temeljni preduvjet za poboljšanje kvalitete

Cilj ovog rada je jasno definiranje postupka asfaltiranja kolnika i uz njega vezane podatke o temperaturi i zbijenosti asfalta te logističkog procesa, budući da je to temeljni preduvjet za postizanje poboljšanja. U tu svrhu, prikupljeni su podatci o temperaturi asfalta, putanjama kretanja valjaka, zbijenosti asfalta, brzini kretanja finišera te o logističkoj podršci kamionima koji dopremaju asfalt. Rezultati, analize i dobivene povratne informacije upućuju na postojanje konkretnih mogućnosti za poboljšanje, koje uključuju izbjegavanje zaustavljanja finišera tijekom asfaltiranja, ujednačeno zbijanje cijele površine kolnika te izrada strategije za kretanja valjaka.

Ključne riječi:

asfaltni kolnik, kvaliteta asfalta, temperatura asfaltne mješavine, brzina kretanja finišera, valjci za zbijanje asfalta

Fachbericht

Mauricio Pradena, Seirgei Miller, Guido Staub, Marcos Díaz, Francisco Contreras

Explizite Definition des Fahrbahn-Asphaltierungsverfahrens - Grundvoraussetzung für die Qualitätsverbesserung

Ziel dieser Arbeit ist es, den Prozess der Asphaltierung der Fahrbahn und die damit verbundenen Daten zur Temperatur und Verdichtung von Asphalt sowie zum Logistikprozess klar zu definieren, da dies eine grundlegende Voraussetzung für die Erzielung von Verbesserungen ist. Zu diesem Zweck wurden Daten über die Temperatur des Asphalts, die Bewegungsbahn der Walzen, die Verdichtung des Asphalts, die Geschwindigkeit des Fertigers und die logistische Unterstützung durch die den Asphalt liefernden Lastwagen gesammelt. Die Ergebnisse, Analysen und die erhaltenen Rückmeldungen zeigen, dass konkrete Verbesserungsmöglichkeiten bestehen, darunter das Vermeiden des Anhaltens des Fertigers während des Asphaltierens, die gleichmäßige Verdichtung der gesamten Fahrbahnoberfläche und die Entwicklung einer Strategie für Walzenbewegungen.

Schlüsselwörter:

Asphaltfahrbahn, Asphaltqualität, Asphaltmischtemperatur, Fertiger-Fahrgeschwindigkeit, Asphaltverdichterwalzen

1. Introduction

1.1. Science in asphalt concrete pavements

Historically, the asphalt paving construction process has been based on tradition, craftsmanship and a variety of implicit, experience-based methods employed during construction activities. This construction model leaves many of the construction activities under a sort of "black box" model (Figure 1) in contrast to the pavement design or asphalt materials where a scientific approach has been applied. In effect, when comparing scientific articles published over the past decennia, papers on asphalt material and mix design significantly outweigh the number of papers published with regard to asphalt pavement construction. However, given the high cost to society of road in general and asphalt concrete pavements in particular, a more scientific approach is required.

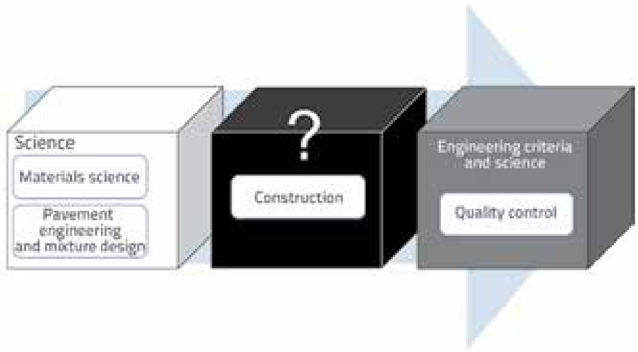

Figure 1. Science applied in different phases of asphalt concrete pavements

The situation has been aggravated by legal frameworks adopted in several countries, which prevent researchers from gaining access to actual construction projects. Yet, despite these barriers, several asphalt-construction related studies have been carried out over the past 30 years partly in response to the arrival of new technologies, such as infrared thermography and Global Positioning Systems (GPS). Two key areas have been in the focus of construction related variability studies, namely the asphalt mix temperature variability during construction, and compaction variability.

1.2. Asphalt mix temperature variability during pavement construction

Read [1] highlighted the temperature differential problem with the use of infrared thermography. Several studies have since been conducted showing the extent of temperature variability during paving operations, and its influence on the performance of asphalt layers in terms of density, voids and other properties [2-5]. Early studies into the effect of cooling of asphalt mixes during compaction [6] highlighted the need to conduct compaction activities within an "ideal window of opportunity" i.e. a suitable temperature range during which the target density could be reached with ease and without stress to the asphalt layer being compacted. In order to support contractors during compaction activities, researchers initially developed hand calculations and spreadsheet-based calculations relying on heat conductivity and heat transfer in asphalt layers as described in [7], the aim being to predict asphalt layer cooling during compaction. The first software tools (PaveCool, CalCool, and MultiCool) for temperature prediction during construction were then developed by [8, 9].

1.3. Compaction variability of asphalt pavement layers

Early studies aimed at determining variability in compaction were mainly conducted without the use of new technologies [10-12]. These studies showed that compaction was not uniform across the road width and length, and thus highlighted the complexity of the compaction process. In an attempt to assist operators, reduce complexity of compaction task, and work towards more method-based compaction strategies, several researchers explored possibilities of utilizing GPS to automate the compaction process [13-19]. These studies focused on an appropriate use of GPS technology to monitor and steer the compaction process with several prototypes developed during this period. Subsequent research focused on development of integrated solutions that took into account more than just compaction and attempted to monitor the entire asphalt construction process [20, 21]. The early GPS compaction prototypes have since been further developed into Intelligent compaction applications to assist roller operators in their compaction tasks [22-26]. It is currently common for machine manufacturers to provide GPS solutions on their roller compactors and also to equip them with a range of sensors for measuring the asphalt surface temperature and other parameters during compaction activities

2. Obstacles to technology adoption

Despite the current availability of many GPS-based compaction technologies and the availability of tailor-made infrared thermography, it can still be said that technology adoption in asphalt construction has been slow. This is in line with research suggesting that, in general, construction industry has been slow to adopt new technologies [27-29]. Several arguments have been made in support of this claim, including that the technology does not meet specific needs of construction industry and that the technology is too complex for construction workers who are generally low-skilled. The adoption of advanced technological processes can also be hindered by scepticism and reluctance of operators - who feel that their workmanship is being devalued or that management could use the technology to track their movements and possibly use it punitively [30]. Despite the adoption problem, it would appear that machine manufacturers are continuing to develop new technologies and add sophisticated sensors to their machines. Should this trend continue, it would widen the gap between technology development and the skills of the operators. To prevent this from happening, there is a need to address the "human factor". This means that the technology and, more importantly, the qualitative and quantitative data coming from the technologies, should be integrated into the asphalt construction team´s work methods and processes.

2.1. ASPARi approach

While the above-mentioned studies have focused on either the temperature variability or the compaction variability problem, researchers of the ASPARi (Asphalt Pavement Research & Innovation) research group of the University of Twente in the Netherlands have taken a more holistic view regarding the problem of variability in asphalt construction by studying the entire asphalt construction process and including the ethnographic factor, i.e. by working with asphalt construction teams and their managers.

It is worth noting that changes to the industry and the collaboration with researchers was forced on the construction industry by a chain of events starting with the finding of wide-scale construction fraud and collusion prevalent in the late 1990's [31, 32]. In response to that, major public clients changed contractual conditions by extending guarantee periods from 3 years to between 7 and 10 years for standard contracts and introducing several integrated type (non-traditional) contract forms where risks are shared between contractors and public client [33, 34]. Contractors were also to take responsibility for designing their own asphalt mixes. The combination of changing market dynamics and the fact that little was known about the asphalt construction process from a scientific perspective, resulted in an urgent need to improve the contractors' primary processes, so as to ensure that the constructed asphalt layers will last for the specified guarantee periods. Researchers responded by developing an action research methodology to work with asphalt construction teams and their managers to improve their primary processes [35]. This ethnographic approach, coupled with iterative reflective learning cycles [36, 37], enabled researchers to engage with asphalt teams at the construction site level. Researchers developed the Process Quality improvement (PQi) methodology, which was aimed at making operational behaviour explicit using off-the-shelf new technologies including GPS, infrared cameras, laser line scanners, and other sensors. The sensors are used to create appropriate visualizations that operators are able to understand and interpret. As mentioned earlier, the PQi methodology includes elements of feedback and reflective learning so as to enable operators and the rest of asphalt construction crews to reflect on their work using hard data and visuals. The operators identify opportunities for process improvement and make decisions with their managers on which improvements should be implemented. This is a departure from the traditional construction industry "top-down" approach. Quite interesting is that the data is not used to punish the operators and construction teams in any way. The data is used as a mirror for process improvement and results in (small) step-wise, systematic, sustainable process improvements. Public clients also do not use the data to punish contractors for non-compliance.

This bottom-up approach has led to some interesting developments. Firstly, the scientific approach to making operational behaviour explicit through the use of new technologies and sensors and appropriate visualisations has enabled sustainable process improvement discussions with the asphalt construction teams, since they are closest to the process and are responsible for the final quality of asphalt pavement [38]. It appears that the action strategy approach and the feedback loops built into the PQi methodology have resulted in process improvement that takes place in a more sustainable manner [39]. Researchers, construction teams, laboratory personnel, and managers appear to have a better understanding of the complexities and variability inherent in the asphalt construction process. Hence, by adopting an ethnographic approach [35], i.e. by explicitly including the "human factor" in the research (understanding the challenges and the way of learning of the paving teams), the ASPARi group has been able to overcome the historical reluctance of the construction industry to adopt innovation and novel technologies.

Although the quality improvement of asphalt concrete pavements is a common challenge, it is very important to realize that Dutch experience should not be transferred directly given different contexts. These include different contractual arrangements, levels of access to and experiences with new technologies, different governance structures and, most importantly, a difference in the work methods and approaches to construction tasks and uses of technology.

In fact, the Netherlands has favourable conditions because of the integrated contract systems, affordable off-the-shelf technologies, and due to the fact that construction workers are immersed daily in a technology-driven society (for instance, through use of the country's sophisticated public transport system). Hence, instead of direct application of the PQi methodology, it is necessary to adapt it to the specific working context in (small) step-wise, systematic, sustainable process-improvement phases.

2.2. The Chilean application

The objective of this article is to make the asphalt pavement construction process explicit as a fundamental step for identifying quality-improvement opportunities in the Chilean context. For that, actually, the basics of the PQi methodology are applied on a pilot project in Chile, where the methodology is adapted to a context that is different from the Dutch one. As alluded to earlier, the Chilean construction context is characterized by lower access to affordable technology and by different human related factors since construction workers are less immersed in technology on a daily basis [40].

Also, approximately 60 % of the Chilean rural road network is unpaved [41]. In this scenario, although there are different types of contractual agreements for pavement construction, the traditional contract system still plays a major role. Even though there are concessionary agreements, level of service agreements (mainly oriented to road maintenance), DBOT (Design, Build, Operate, and Transfer) and BOT (Build, Operate, and Transfer) type agreements, the type of contract where contractors execute construction activities given in the form of technical specifications, is the one most often used in Chilean pavement construction. In this kind of traditional agreements, there is a quality assurance system with public and private components, where the responsibility for the overall quality of pavement construction is assumed by the public National Highway Laboratory (NHL). Also, every contract has a public supervisor who is assisted by a private company and the public Regional Highway Laboratory (RHL). Being responsible for the quality of pavement construction in Chile, the NHL has supported different research and innovation initiatives to improve the quality of Chilean pavements. The NHL is also included in the present research. While the research referred to in the present article is still on-going, the first phase presented in this paper deals with a pilot project entitled "Rehabilitation of the Route F-50 Lo Orozco – Quilpue, 3rd phase" situated in the Valparaiso Region. It is a traditional contract, and the project site is located 80 km from the capital city of Santiago. The 3rd phase of this project includes construction of 12 km of asphalt pavement with three hot mix asphalt layers (base, binder, surface layer) over granular base.

3. Methodology

The methodology applied in this research is basically the PQi methodology adapted to the Chilean context (Figure 2).

Phase 1: *Preparation and definition* – check construction site design, record site conditions and hold a preparatory meeting with the asphalt team. The Figure 3 (left) shows the meeting with the field asphalt team held on 24 April 2017, i.e. one day before actual measurements. Previous coordination meetings were performed between the scientific team (authors of the present article) and the NHL staff, namely the engineers Rodrigo Uribe and Gabriela Muñoz, the former being the head of the Asphalt Pavements Area of NHL.

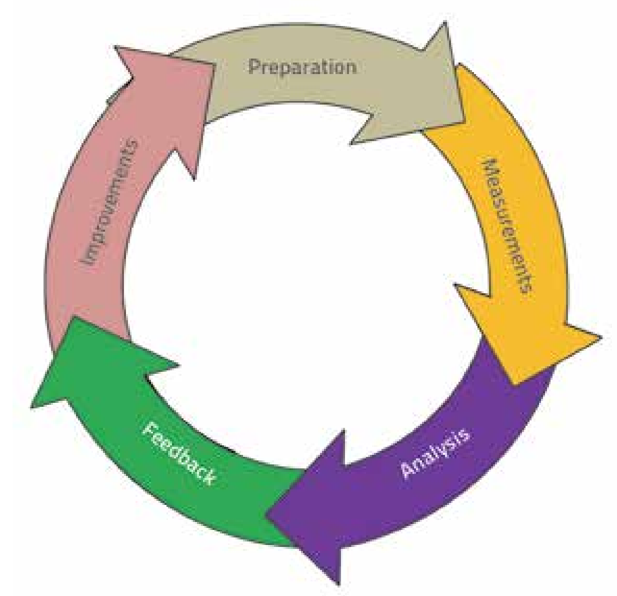

Figure 2. The process quality improvement cycle, PQi [42]

Phase 2: *Data collection* – temperature profiling, monitoring all asphalt machine movements, monitoring weather conditions, nuclear density profiling, and recording all noteworthy events. The collection of temperature, density and geodetic data is shown in Figure 4.

The data were collected over 2 days viz. 25 and 26 April 2017. On the first day, a section of surface asphalt layer 290 (m) in length was monitored, while a section of asphalt base layer 150 (m) in length was monitored on the second day.

Phase 3: *Data analysis* – analyse all data and prepare visualisations and animations.

Phase 4: *Feedback session* – discuss all results, conduct visualisations and animations with the HMA team and others directly involved in the project.

Figure 3. Meeting with the asphalt pavement team (left) and installation of GPS (right)

Figure 4. Collection of temperature and density data (left and centre) and geodetic data (right)

Phase 5: *Proposal of improvements* – define improvements for working methods and future projects.

4. Results and analysis

4.1. Logistic support for asphalt delivery

The arrival and departure times of trucks were monitored and good coordination was observed in truck logistics.

4.2. Paver speed

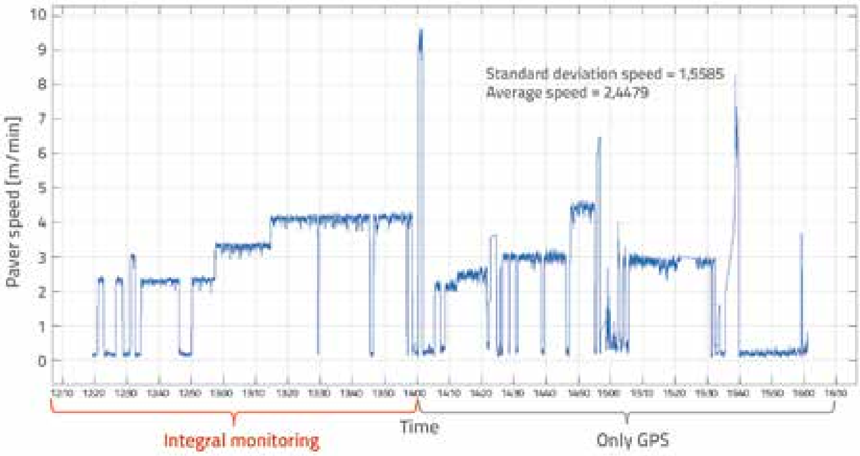

Figure 5. Paver speed – GPS based, first day of measurements

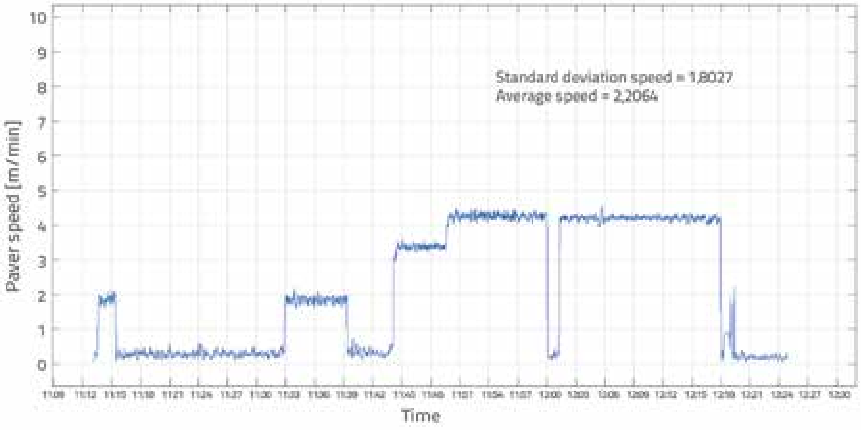

Figure 6. Paver speed – GPS based, second day of measurements

Paver speed results for the first and second day of measurements are shown in Figures 5 and 6. On the second day, the entire scientific team made integral measurements during construction of the 150 (m) of pavement. On the first day, the scientific team made integral measurements during the first 290 (m) of pavement. As indicated in Figure 5, only GPS measurements were made for the last 110 (m). A slow start can be observed in both figures, which is due to the need to warm up the screed plate of the paver. On the first day, the slow beginning includes a start-stop cycle of the paver for about 15 (m), which can produce potential discontinuities of the pavement. On the second day, this cycle is about 20 (m) but it has less changes compared to the first day. It is clear from Figures 5 and 6 that the speed of the paver varies considerably on the first measurement day. This variability is less prevalent on the second day but may still result in a less than desirable end quality of the asphalt pavement. To avoid potential discontinuities of the pavement, it is necessary to ensure that the screed plate of the paver is heated before the start of pavement construction work.

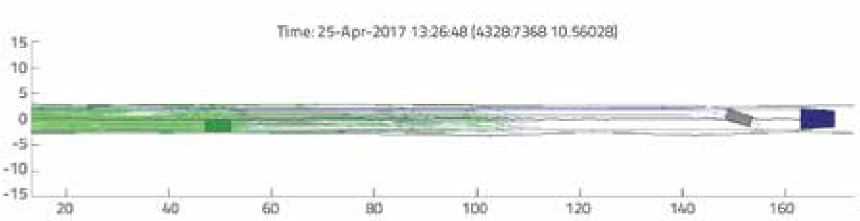

Figure 8. 2D animation on the first day of measurements

4.3. Compaction contour plots (CCP)

An example of compaction strategies used on the second day of measurements, i.e. for the 150 (m) of the asphalt base layer, is shown in Figure 7. In particular, the upper part of Figure 7 shows the number of passes of the steel-drum roller. The lower part of the figure presents the number of passes of one of the tired-wheel rollers because, although the compaction was performed with three tired-wheel rollers, only one of them was monitored in this pilot project. Some interesting trends were nevertheless observed. While the CCP's of both roller compactors presented in Figure 7 show a generally consistent behaviour, several possibilities for the reduction of variability are evident. The maximum number of passes for both compactors is 14. In the case of the steel-drum roller, the average number of passes is 9.8 and the standard deviation is 3.3. The average number of passes of the tired-wheel roller is 10.3 with the standard deviation of 2.3.

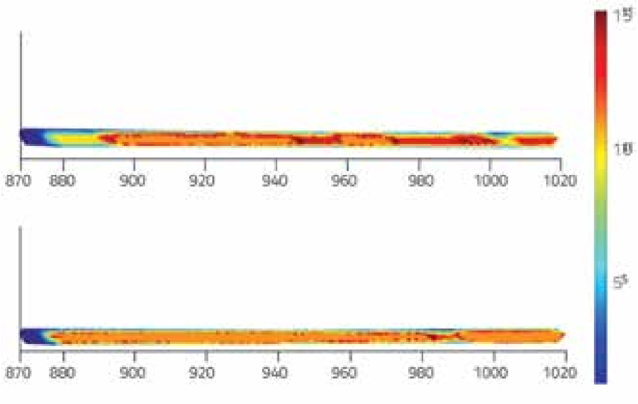

Figure 7. Compaction contour plot of the steel-drum roller (upper part) and a tired-wheel roller (lower part of the figure)

Both CCP's show evidence of compaction variability in a number of ways. It appears that operators tend to concentrate on the middle of the road, as it has received more compaction passes than the edges. Pavement edges are important due to close vicinity to the wheel paths where most loading will take place. At different sectors of the monitored section, both compactors reduce their number of passes at the pavement edges, normally areas of the pavement that are difficult to compact. However, the compaction contour plots also reveal technical possibility for improvement. In effect, it is also possible to observe sectors in which pavement edges have more passes than the pavement centre. At the compaction contour plot of the steel-drum roller, this happens at around the 960 (m) at the exterior edge and around the 900 (m) at the interior edge. On the other hand, the tired-wheel roller compaction contour plot shows more passes during the first 20 (m) of compaction and between the 920 (m) and 940 (m). In both cases that happens at the interior edge of the lane.

The compaction direction was against the kilometre increase and it is evident that the number of passes of both compactors is significantly less at the last 8 (m) of the monitored section. Even more, the steel drum roller starts the passes reduction 25 (m) before the end. All of the aforementioned problems of variability can be addressed and improved by the roller compactor operators.

The trends detected from the CCP's are confirmed by 2D animations of compactor movements developed from the data measured on this project. A moment of animations made on the first day of measurements, where the compaction was performed in the same direction as the kilometre increase, is shown in Figure 8.

A common pattern was observed in animations made for both days. Roller operators start with short path lengths (about 40 to 50 m) and increase them (about 80 m) as the paver speed increases. Roller patterns used by the steel drum roller operator can clearly be seen in the animation.

4.4. Asphalt temperature – nuclear density – roller compactor passes

Specific points were selected in situ along the length of the pavement to measure asphalt cooling rates (surface and core temperature), nuclear density, and the number of roller compactor passes. The purpose of these specific measurements was to visualize their relationships. In this respect, Figures 9 and 10 present examples of points monitored during these two days. In both cases, the target density (97% of the Marshall density) was reached in a short time and after a maximum of 8 compactor passes. However, on the second day, the target density was reached at a mix temperature of 87 °C. This is close

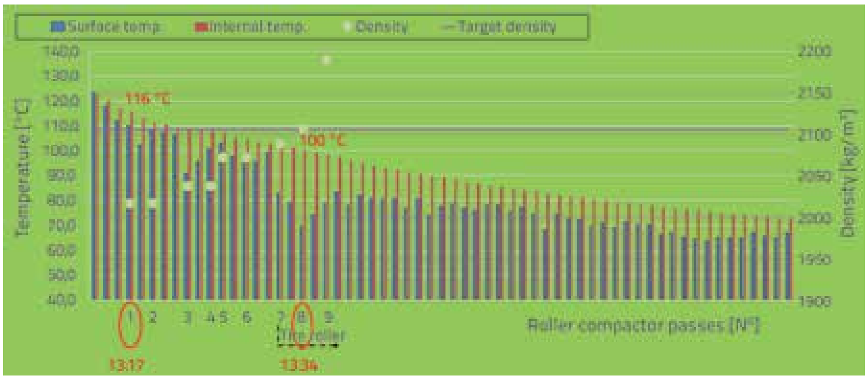

Figure 9. Asphalt temperature (surface and core), nuclear density and roller compactor passes at Km 1520, the first day of measurements (25 April 2017)

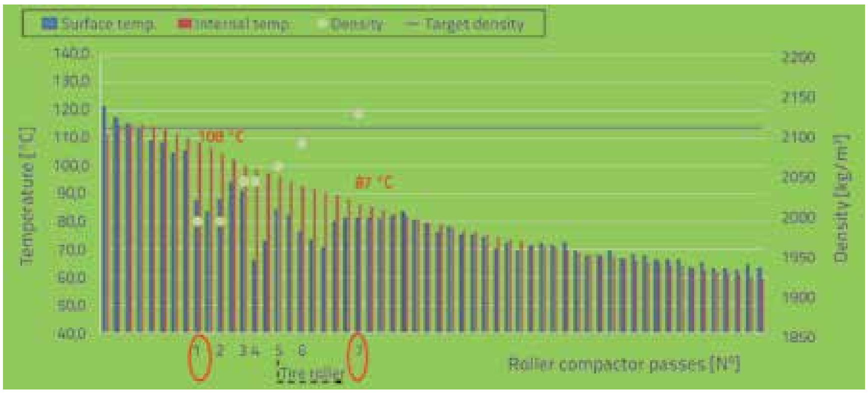

Figure 10. Asphalt temperature (surface and core), nuclear density and roller compactor passes at Km 980, the second day of measurements (26 April 2017)

to the lower temperature limit at which micro cracks could be produced in the asphalt layer if compaction were to continue. In this case, a feasible and simple possibility to improve is to start the compaction process earlier in a more desirable temperature range.

Finally, as expected, it is also possible to observe the difference between the surface and core temperatures. It is important to establish relationships between these two types of temperatures considering the practicality of measuring the surface temperature, and the fact that it may be influenced by ambient weather conditions. However, a broader mix of temperature measurements is required to establish these relationships, due to the many variables involved.

4.5. Feedback session

The explicit consideration of the "human factor" (referred to in Section 1) is an important element for overcoming historical reluctance of the construction industry to innovate and adopt new technology. Hence, the organization of a workshop with the Chilean asphalt team, including discussions and feedback, was considered a fundamental part of the research. Given the Chilean context, and particularly as the pilot project was a part of a traditional contract, the team participating in the workshop was composed of members of the construction company, NHL, the public supervisor, the private company assisting him, and the RHL. The non-punitive character of measurement results was highlighted to this audience.

In the course of the workshop, visualizations and animations (such as the ones presented in Figures 5 to 10) were presented to the asphalt paving team in a way they could understand and interpret. For the first time, these experienced asphalt crew members were able to actually see their own working strategies and the related results in an explicit, objective, and impartial way. After the noticeable first impression (and the related silence), they slowly started to reflect on their own work. In fact, they started to actively participate answering questions of the research team and giving their opinions about the information shown in the visualizations and animations. In this way, the contractor team explained the reasons for the paver stops (Section 4.2) or they manifested their surprise by some low temperature levels in the asphalt layer at the time the target density was reached (Section 4.3). The differences between the temperature inside the asphalt layer and on the surface were brought to their attention. Yet, the clearest engagement came with the compaction strategies shown by the visualizations (as Figure 7) and animations in Figure 8. The contractor´s site manager reacted sharply when he realized (after having observed the results) the need to adopt an explicit compaction strategy. He immediately started to share this need with his team and the manner to implement it in the field. In order to

Figure 11. Feedback session with asphalt paving team at construction site

concretize that, the contractor´s site manager asked the research team for the visualizations and animations.

Finally, improvement opportunities presented in Sections 4.1 to 4.4 basically came from reflective nature of the workshop, i.e. the learning took place though interaction between people [39]. It is important to highlight that, in order to identify improvement opportunities, it was necessary to make the asphalt pavement construction process explicit, and that was only possible by measuring, applying useful technology, obtaining hard data, processing and presenting these data in a significant and useful way to the asphalt crew, as described in this section. In this way, the science and technology were made useful at the team level, resulting in an enhanced experience of the asphalt team.

This is fundamentally important because it enables the transition from implicit to explicit knowledge. In terms of single and double loop learning concepts [43], it elevates the learning from single to double loop where strategies are modified in such a way that a new construction strategy is considered when a similar situation arises [39]. This is in contrast to single loop learning where a practitioner continues to rely on current strategies even after errors have repeatedly been registered. Without making the operational strategies and key parameters of the construction process explicit, it is hard to move from single to double loop learning [39].

Moreover, a reflective experience, such as feedback session, enables moving forward in the Kolb's experiential learning model [37] represented in Figure 12. In fact, typical phases of this model present in the traditional construction process are only the "concrete experience" and "active experimentation". However, when the process is monitored and a reflective experience, such as feedback session, is included, then it is possible to add phases of "reflective observation" and "abstract conceptualisation" of the experiential learning cycle [37]. Through this process, the asphalt crew engages with the quality improvement of their work and they see technology adoption as a useful tool. Consequently, structured and systematic learning steps based on explicit data become possible, and historical reluctance of the construction industry to innovate and adopt technology is thus overcome [39].

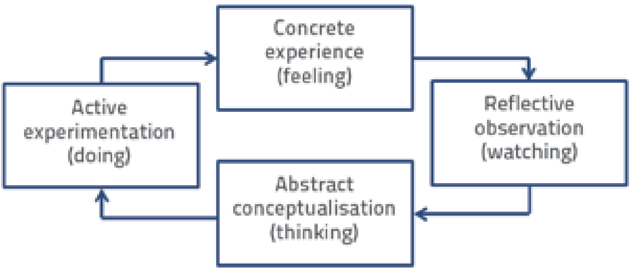

Figure 12. Kolb´s Experiential learning cycle [37]

Another workshop was organised at the NHL premises for a large delegation of the NHL staff involved in quality assurance of the asphalt pavement construction process. A high level of interaction was also experienced in this workshop, where the NHL staff found value in the application of science and technology at the user level. They acknowledged this potential of having hard data on the construction process and a good insight into the operational strategies, which can be used a means to optimize and support their quality assurance activities in limited time frame and on multiple projects. What's more, they requested an extension of the research beyond this pilot project. As this is an on-going research, the required opportunities are certainly available.

5. Conclusion

Using off-the-shelf technologies, the asphalt pavement construction process on a project in Chile was made explicit through collection of data on trucks logistics, paver speed, asphalt layer cooling temperature, nuclear density, and operational compaction strategies. Besides the collection and processing of data, various graphs, visualizations and animations of the construction process were designed and presented in such a way that enabled their use by the asphalt crew members. In this way, they were able to reflect on their own work, identify opportunities for improvements related to the adequate heating of the paver plate screed, or reducing the variability of roller compactor passes applying a compaction strategy, or starting the compaction sooner to avoid being close to the (lower) temperature limit when the target density is reached. In fact, this learning process took place through interaction between people in a feedback session, where individual members of the asphalt pavement crew were actively engaged in the learning process. During the reflective process, the learning was produced at different levels and individual members of the crew learned and experienced things differently. It is important to highlight that a fundamental first step had to be taken in order to identify improvement opportunities, i.e. it was necessary to make the asphalt pavement construction process explicit.

Making the construction process explicit in a contract system such as the traditional Chilean one contributes positively to the control of the contractor's process, optimizes the quality control performed by the private company supporting the public supervisor, supports the direct quality control made by the RHL, as well as the function of the public supervisor. Hence, by making the asphalt pavement construction process explicit, by identifying opportunities for improvement, and by developing the related quality improvement strategies, an appropriate contribution is made to the quality assurance role of the NHL.

It is important to highlight the key role of the NHL in the present study as an agent of innovation towards better quality pavements. In fact, the NHL has not only understood the potential, but also the risks related with making the asphalt pavement construction process explicit. The NHL staff directly involved in the project has adopted a constructive approach rather than a punitive one, stimulating quality improvement with the final objective of obtaining better pavements.

Favourable conditions in the Netherlands, the success of (small) step-wise, systematic, sustainable process quality improvements is related to the ASPARi researchers understanding the causes of the historical resistance of the pavement construction industry to innovation and technology adoption. This understanding has allowed them to apply a user-oriented research approach. A similar approach has been applied by the research team in the Chilean context. The experience presented in this article, making the asphalt pavement process explicit, is a fundamental step in the on-going research about quality improvement of the asphalt construction process in Chile.

Pavement quality is a common challenge for various types of contract systems involving pavement construction. Although this article presents examples of the Netherlands and especially Chile, the methodology, results, and lessons learnt, can be generalised to other regions or countries but, whilst doing so, it is always necessary to take into account particular reality of each specific context.

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REFERENCES

[1] Read, S.A.: Construction Related Temperature Differential Damage in Asphalt Concrete Pavements, University of Washington, Seattle, 1997.

[2] Brock, J.D., Jakob, H.: Temperature Segregation/Temperature Differential Damage, Technical Paper T-134, 1999.

[3] Mahoney, J.P., Muench, S.T., Pierce, L.M., Read, S.A., Jakob, H., Moore, R.: Construction-related temperature differentials in asphalt concrete pavement - Identification and assessment, Construction, 1712 (2000), pp. 93-100

[4] Stroup-Gardiner, M., Nixon, J., Das, P.: Automated temperature profiling during hot-mix asphalt construction, Transport Research Record, 1900 (2004), pp. 41

[5] Willoughby, K.A., Mahoney, J.P., Pierce, L.M., Uhlmeyer, J.S., Anderson, K.W.: Construction-related asphalt concrete pavement temperature and density differentials, Construction, 1813 (2002), pp. 68-76

[6] Corlew, J.S., Dickson, P.S.: Methods for calculating temperature profiles of hot-mix asphalt concrete as related to the construction of asphalt pavements, Proceedings of the Association of Asphalt Paving Technologists, Technical session, 37, 1968.

[7] Van Dee, R.: Modelling of the compaction of asphalt layers, Master Thesis, Technical University of Delft, Delft, 1999.

[8] Chadboum, B.A., Newcomb, D., Voller, V.R., DeSombre, R.A., Luoma, J.A., Timm, D.: An Asphalt Paving Tool for Adverse Conditions, Final Report MN/RC - 1998 - 18, University of Minnesota, Minneapolis, Minnesota, 1998.

[9] Timm, D., Voller, V., Lee, R., Harvey, E., Calcool, J.: A multi-layer asphalt pavement cooling tool for temperature prediction during construction, The International journal of Pavement Engineering, 2 (2001), pp. 169 - 185

[10] Leech, D., Powell, W.D.: Levels of Compaction of dense coated macadam achieved during pavement construction, TRRL laboratory Report No. 619, 1974.

[11] Leech, D., Selves, N.W.: Modified rolling to improve compaction of dense coated macadam, 1976., pp. 724

[12] Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D.Y., Kennedy, T.W.: Hot Mix Asphalt Materials, Mixture Design and Construction, Second edition, NAPA Research and Education Foundation, 1996.

[13] Bouvet, D., Froumentin, M., Garcia, G.: A real-time localization system for compactors, Automation in Construction, 10 (2001) 4, pp. 417-428

[14] Froumentin, M.H., Peyret, F.G.: Method of and auxiliary equipment for guiding a compaction machine, 1997.

[15] Krishnamurthy, B.K., Tserng, H.P., Schmitt, R.L., Russell, J.S., Bahia, H.U., Hanna, A.S.: AutoPave: Towards an automated paving system for asphalt pavement compaction operations, Automation in Construction, 8 (1999), pp. 165

[16] Li, C.C., Oloufa, A.A., Thomas, H.R.: A GIS-based system for tracking pavement compaction, Automation in Construction, 5 (1996) 1, pp. 51

[17] Oloufa, A.: Quality control of asphalt compaction using GPS-based system architecture, IEEE Robotics & Automation Magazine, 9 (2002) 1, pp. 29-35

[18] Pampagnin, L.H., Peyret, F., Garcia, G.: Architecture of a GPS-based guiding system for road compaction, Proceedings of the IEEE International Conference on Robotics and Automation, Leuven, Belgium, 1998.

[19] Peyret, F., Bestaille, D., Hintzy, G.: High-precision application of GPS in the field of real-time equipment positioning Automation in Construction, 9 (2000) 3, pp. 299

[20] Peyret, F., Jurasz, J., Carrel, A., Zekri, E.,Gorham, B.: The Computer Integrated Road Construction project, Automation in Construction 9 (2000) 5, pp. 447-461

[21] Peyret, F., Tasky, R.: A traceability system between plant and work site for asphalt pavements, Computer-Aided Civil and Infrastructure Engineering, 19 (2004) 1, pp. 54

[22] Anderegg, R., Kaufmann, K.: Intelligent Compaction with Vibratory Rollers: Feedback Control Systems in Automatic Compaction and Compaction Control, Transport Research Record: Journal of the Transport Research Board, 1868 (2004) 1, pp. 124-134.

[23] Briaud, J.L., Seo, J.: Intelligent Compaction: Overview and research need. Retrieved from, 2003.

[24] Camargo, F., Larsen, B., Chadbourn, B., Roberson, R., Siekmeier, J.: Intelligent Compaction: A Minnesota Case History, Paper presented at the 54th Annual University of Minnesota Geotechnical Conference, Minnesota, 2006.

[25] Horan, B., Ferragut, T.: Intelligent Compaction Strategic Plan, Retrieved from, 2005.

[26] Starry, D.W: Recent advances in compaction equipment, including intelligent compaction - Vibratory Rollers. transport Research Circular, (Number E-C105), 2006.

[27] Bowden, S., Dorr, A., Thorpe, T., Anumba, C.: Mobile ICT support for construction process improvement, Automation in Construction, 15 (2006) 5, pp. 664-676.

[28] Panagiotis, M., Tatum, C.B.: Technology Adoption Decisions in Construction Organizations, Journal of Construction Engineering and Management, 125 (1999) 5, pp. 330-338.

[29] Slaughter, E.S.: Models of Construction Innovation, Journal of Construction Engineering and Management, 124 (1998) 3, pp. 3226.

[30] Simons, B.J.A.G.: Towards a more controlled asphalt paving process, (M.Sc. Thesis), University of Twente, Enschede, 2007.

[31] Ang, G., Groosman, M., Scholten, N.P.M.: Dutch performance-based approach to building regulations and public procurement, Building Research; Information, 33 (2005) 2, pp. 3107-119, https://doi.org/10.1080/0961321042000325345

[32] Dorée, A., ter Huerne, H.: Workshop proceedings - Development of Tools and Models for the Improvement of Asphalt Paving Process, Unpublished workshop proceedings. University of Twente, 2005.

[33] Caerteling, J.S., Halman, J.I.M., Dorée, A.G.: Technology development in road infrastructure: the relevance of governmental championing behaviour, Research Policy, 2008.

[34] Hoezen, M.E.L., Dorée, A.G.: First Dutch competitive dialogue projects: a procurement route caught between competition and collaboration, Paper presented at the 24th Annual ARCOM Conference, Cardiff, UK, 2008.

[35] Miller, S.R., Dorée, A.G., ter Huerne, H.L.: The asphalt paving process: plans for action research, Paper presented at the 4th Nordic Conference in Construction Economics and Organisation, Luleå, Sweden, 2007.

[36] Harrison, M., Short, C., Roberts, C.: Reflecting on reflective learning: the case of geography, earth and environmental sciences, Journal of Geography in Higher Education, 27 (2003) 2, pp. 3133-152.

[37] Kolb, D.A.: Experiential Learning: Experience as the Source of Learning and Development, Englewood Cliffs, New Jersey: Prentice-Hall, 1984.

[38] Miller, S.R.: Hot Mix Asphalt Construction - Towards a more professional approach, (PhD), University of Twente, Enschede, The Netherlands, 2010.

[39] Bijleveld, F.: Professionalising the asphalt construction process: aligning information technologies, operators' knowledge and laboratory practices. (PhD), University of Twente, Enschede, the Netherlands, 2015.

[40] The Economist: Pockets World in Figures. London: Economist Books, 2017.

[41] Ministry of Publc Works of Chile: National Road Network: Dimensions and Characteristics (in Spanish), Santiago, Chile, 2016.

[42] Bijleveld, F.R., Vasenev, A., Doree, A.G., Hartmann, T.: Aspari is for paving, network to professionalise the paving industry, ConcepTueel, 21 (2012), pp.17-21

[43] Argyris, C., Schon, D.: Organization learning: A theory of Action perspective. Reading, Mass: Addison Wesley, ISBN 0-201-00174-8, 1978.