# IS TECHNOLOGY A NEW CHALLENGE FOR THE FIELD OF CONSTRUCTION MANAGEMENT?

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The central theme in Construction Management (CM) and CM research is improving the performance of construction industry. Much effort and thought is given to improving project performance. Within CM there is a natural inclination to focus on projects and project management (PM). Companies in the construction industry also see project management as their key competence. Both have little appreciation for technologies other than those that support project management tasks. Technology – other than PM support – is often seen as an outside resource that is "contracted in". By taking such a neutral position regarding technology, CM and construction companies not only disregard the potential of these technologies, but also fail to notice the adverse effects when new technologies are "contracted in". This paper argues that CM as well as companies in construction can gain by reconsidering their stance towards technology. This argument is built on the case of road construction – in particular the asphalt paving process. The case shows that development of the new technologies and the development of the skills and operational practice of the people that are expected to use the technologies are not in harmony. Projections for the upcoming decade indicate a sharp rise and proliferation of SMART technologies – this too for the construction industry. Construction companies need to take a more proactive and involved stance towards these technologies to be able to reap the benefits. If not, then the gap between technologies and construction will grow and the risks for the companies increase with it. CM and CM research needs to address this gap, support the introduction of new technologies and the synchronisation of new technology development and the development of skills and working. If it fails to do so CM and CM research will struggle to maintain its meaningful contribution in the improvement of the construction industry.

Keywords: asphalt, construction management, GPS technology, process control.

## INTRODUCTION

The strength and vitality of the field of CM is visible in the attendance of and number of papers for the ARCOM conferences, the pressure on the CM journals to increase the number of annual issues (e.g. Construction management and Economics), and the growing delay and number of papers "accepted in print" (e.g. Construction Innovation). The field of CM originated as a reaction to an academic tradition skewed towards Engineering and Technology. The introduction of CM journals was a logic response to the near impenetrability of the technical journal for CM issues. A first generation of rather mathematical approaches to scheduling, planning, resource allocation and project management opened up the new fields of project management and subsequently CM. The evolvement and growth of the more general management studies – with areas such as marketing, strategic management, production operation

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management, organisation design, organisation behaviour, human resource management, etc – brought new angles into the field of CM and into the CM journals. Nevertheless, the new influx of issues from a project performance perspective still dominates the field of CM as one of the recurring angles. This of course is a mirror and consequence of construction industry's focus on projects and project management (Pries *et al.* 2004). Given the origin of the CM journals, it is not unusual that CM has an orientation that is rather unsympathetic towards technology. This situation is seldom challenged because authors that write papers on technology and engineering rather publish in the earlier established engineering journals. These older journals not only provide them feedback from their selected peers, but often also offer better impact factors. As such, a trajectory once logical and explicable is perpetuated. Just as the QWERTY layout once sensible in the era of the mechanical typewriter is still the dominant layout on computer keyboards. This even though the initial reasons for this layout are all eliminated.

In this paper, we argue that the neglect of technology in the field of CM must be challenged. This is particularly so because we can expect an influx of new SMART technologies into the construction industry and into the construction practice. To illustrate this argument we present an innovation project in road construction that took place in 2007 in the Netherlands. The observations made related to this case study underline the growing gap between the trajectories of new technologies on the one hand, and the skills and explicit process insights on the other. New technologies are developed and introduced into the construction industry without in-depth knowledge of the construction practice and operational strategies. The operators and site crews involved are not able to use the new technologies. The technologies do not match their operational strategies. On the other hand, the operators and site crews, who mainly work on intuition and implicit routines, are not able to explain what their operational strategies are. As such, they can hardly play a role in shaping the scope and direction for the development of new technology.

This paper is structured as follows. After the introduction, we provide a short literature review of technology and the asphalt paving process. Thereafter we explain the background to the Dutch Ministry of Transport sponsored innovation project, BAM Wegen’s innovation role and objectives for the project. This is followed by a description of the data collection using new technology, the analysis and a discussion of the results. Finally, we outline the challenges we see ahead for CM and CM research in the context of a changing business environment for the construction industry.

## TECHNOLOGY AND THE ASPHALT PAVING PROCESS

There have been several organized industry-aided research efforts for the development of state-of-the-art technologies for real-time locating and positioning systems for construction operations (Abourizk *et al.* 1994, Pampagnin *et al.* 1998, Bouvet *et al.* 2001, Navon *et al.* 2004). They include efforts to develop automated methods for monitoring asphalt laying and compaction using GPS and other IT technologies. Li *et al.* (1996) reported on a system to map moving compaction equipment. Krishnamurthy *et al.* (1998) developed an Automated Paving System (AUTOPAVE) for asphalt compaction operations. Peyret *et al.* (2000) developed the Computer Integrated Construction systems for the real-time control and monitoring of work performed by road construction equipment, namely compactors (CIRCOM) and pavers (CIRPAV). Oloufa (2002) described the development of a GPS-based automated quality control system for tracking pavement compaction. Hence, it appears that several GPS experiments to map the asphalt paving experience were conducted in recent years. However, although some of these technological experiments were developed into industrial applications, it appears that it is not yet part of operational strategies and working practice in asphalt processes. Also, several authors argue that the construction industry typically lags behind other industries in adopting technology (AbouRizk *et al.* 1992, Halpin *et al.* 1999, Halpin *et al.* 2002, Bowden *et al.* 2006). For his MSc thesis Simons (2007) interviewed 28 compactor-, paver- and screed operators actively involved in the asphalt paving process. The interview results confirmed that the paving process largely depends on tradition and custom i.e. the knowledge and experience of the compaction team. Machine settings are mainly done based on "feeling and experience". Compactor operators visually note the behaviour of the mix to determine if the desired density has been achieved. Although the interviewees all refer to common and proven practice in machine setting, the actual settings and operational strategies varied widely from team to team. Therefore, there is not really one common practice, but a wide array of "common practices". In addition, most operators acknowledged that they hardly made use of the technology available on the compactor or even simple temperature measurement instruments to assist them in the compaction process. The interviews conducted with operators confirmed anecdotal evidence, which suggested that in The Netherlands, work in the asphalt paving process depends heavily on craftsmanship, that work is being carried out without measuring the key process parameters (temperature, density and layer thickness), and that the work methods and equipment are selected based on tradition and custom (Dorée *et al.* 2005). This "business as usual" scenario occurs despite road construction companies having an array of new technologies at their disposal.

## THE INNOVATION PROJECT

In 2006, the Dutch Ministry of Transport organized an innovation competition, challenging commercial parties to put forward ideas to extend the mean service life of the dual layer porous asphalt system from seven to nine years. The porous asphalt system consists of a 25 mm thick upper layer with a maximum grain size of 8 mm and a 45 mm thick lower layer with a maximum grain size of 16 mm. It is specially designed for high reductions of traffic noise (5-7 dB (A) at normal traffic speed). BAM Wegen joined forces with the University of Twente and various other parties to enter the innovation competition. The group's focus was on extending the service life of the dual layer porous asphalt and involved improving the whole process from the choice of raw materials and mix design, to monitoring of the finished product. The aim of this project was to improve the homogeneity of the asphalt mix during production, transport and application. The realisation phase of the project was a 460m long section of resurfacing of the A35 highway in the east of The Netherlands. BAM Wegen developed, planned and carried out the construction of the test section. The scope of the project required the removal of the existing surfacing layer followed by repaving with the dual layer porous asphalt system. The layers were laid simultaneously with a special machine, the Twin-lay asphalt paver (Dutch abbreviation TAS). The 12m wide highway was divided into three paving lanes viz. 5m, 4m and 3m wide. Construction work was carried out over two nights during April 2007.

The University of Twente research team monitored a number of key process parameters during construction. The team focuses on innovation and performance in the asphalt paving process, having recently consulted key role players in the industry

(Dorée *et al.* 2003, Dorée *et al.* 2005) and subsequently publishing a number of conference papers in this research area (Huerne ter *et al.* 2007, Miller *et al.* 2007, Miller *et al.* 2007). Their research is aimed at improving quality and consistent reduction of quality variability in the hot mix asphalt (HMA) paving process. Two key research questions are addressed. The first tackles the main causes of variability in the asphalt paving process whilst the second focuses on the effect of revised operational strategies on quality in the paving process.

So, what triggered the research into monitoring of key process parameters? Why did BAM Wegen involve the "academics"? For BAM Wegen this was the second serious project for their Twin-lay asphalt paving machine. The first project was not problem-free. The surface was corrugated unacceptably and had to be milled off and repaved, a time-consuming and costly repair operation. Analysis of the project raised the suspicion that the roller operators had not waited long enough for the fresh layer to cool to temperatures suitable for compaction. Compaction of the too hot asphalt was seen as the cause of the corrugations. The question then was why the roller operators started compacting the too hot layer? This question was particularly puzzling since the rollers were equipped with temperature sensors that produce continuous temperature readings. What was happening and why did it happen? These questions needed answers before the TAS machine could be used again with some degree of confidence. Therefore, BAM Wegen invited the researchers to participate in the tender for the innovation project. Together it was decided to focus on extensive asphalt temperature measurements and GPS monitoring of the paving machine and the two rollers.

## OBJECTIVES

Contractor BAM Wegen set two main objectives for the project. First, to work towards a 25% increase of the service life of the dual layer porous asphalt by improving the total process from choice of raw materials and mix design to the monitoring of the finished product. Second, to develop innovative monitoring techniques of the asphalt paving process since major developments in road paving are often hampered by insufficient feedback from finished products. The latter objective led to the contractor introducing two innovations for the project. Firstly, to use a Twin-lay asphalt paving machine in combination with a shuttle buggy for improved temperature homogeneity; and secondly, to use thermographic imagery and continuous GPS (Global Positioning Systems) tracking on the paver and compactor rollers for improved process control during the asphalt paving process.

## USING TECHNOLOGY TO ANALYSE OPERATIONS

Infrared camera images were used to document temperature differentials during the hot mix asphalt paving operations with more than 400 photographs taken in a predetermined regime. A GPS system with 10cm accuracy was used to collect positioning data for all equipment movements over the two-night period.

### Temperature profiling

The temperature profiling enabled the contractor to measure the extent of variability in surface temperature and hence draw a number of conclusions about temperature homogeneity. There is evidence of a distinct lack of consistent repetitive temperature contours during continuous paving operations for all lanes and the surface temperature varies appreciably both longitudinally and transversely leading to extensive variability in temperature homogeneity (see the typical Temperature Contour Plot in Figure 1). Operational discontinuities affecting the paving process were identified. The rate of cooling of the asphalt mat is clearly visible when the paver stops during continuous paving operations and at the end of paved lanes; and the initial movement of the paver and subsequent initial coolness of the mix are clearly visible through narrow bands of contours at the start of paving operations. Also, in-asphalt temperature and surface temperature measurements were compared.

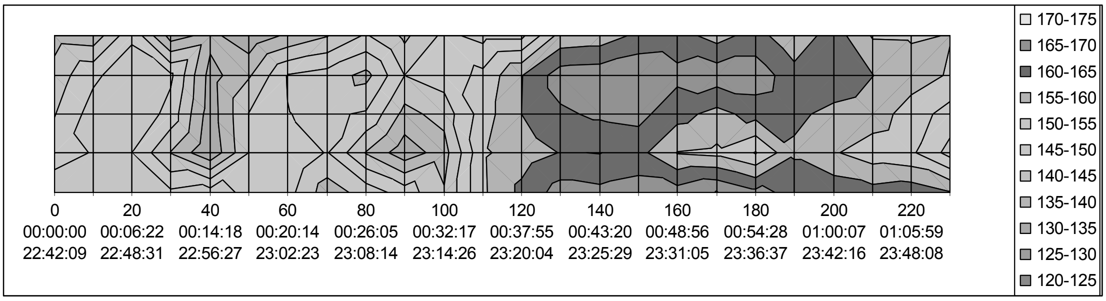


*Figure1: Temperature contour plot (TCP) for Wed Lane 1*

**GPS monitoring**

The monitoring of equipment movements using GPS systems highlighted a number of operational issues. The paver speeds vary between 3,5m/min to 5,5m/min. The time between the start of paving and the start of compaction varies with rollers starting compaction activities between 2 minutes and 41 minutes after paving operations.

Animations showing equipment movements were produced from the GPS data. Several views were developed to provide perspectives from those closest to the process i.e. from the seats of the paver operator, roller operators and the close-up "freecam" view shown in Figure 2. The animations provide accurate explicit evidence of all paving and compaction activities on distance and time-lines and the extent of co-operation between the paver and the roller compactors.

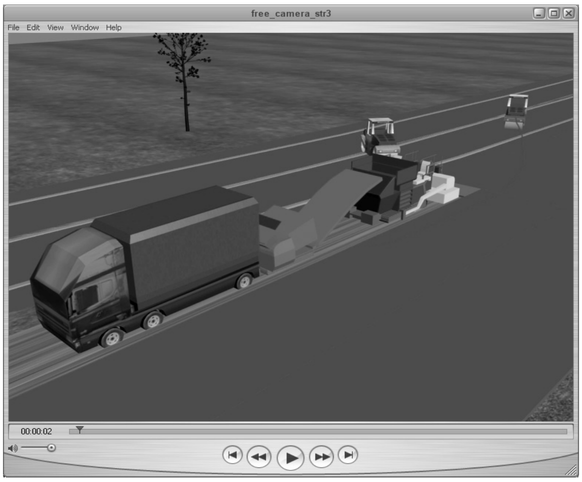


*Figure 2:"Freecam" view for Wednesday Lane 3*

In addition to being able to analyse the operational behaviour of the compaction rollers using the animations, the GPS data were used to prepare Compaction Contour Plots (CCP) showing the number of passes applied to specific areas of the paved lanes. Scrutiny of the total number of passes shows compaction inconsistencies for all paved lanes. For Thursday's lane 1, the Compaction Contour plot shows that number of compaction passes tends to decrease as you move from the left to the right side of the lane as shown in Figure 3.

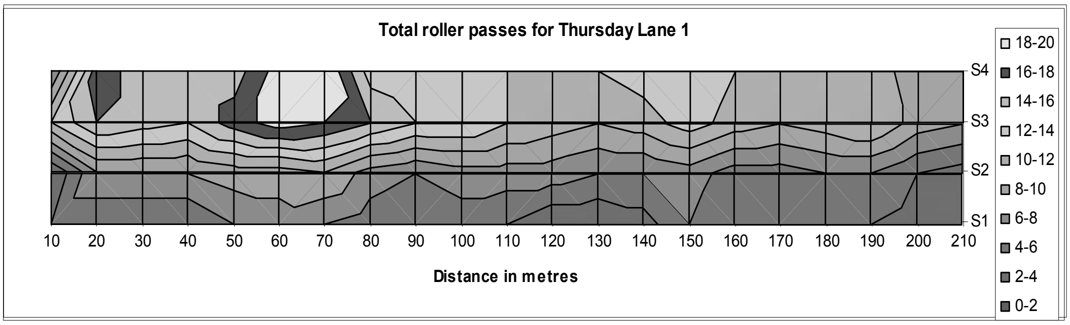


*Figure 1: Compaction Contour Plot (CCP) for Thursday Lane 1*

## OBSERVATIONS AND FIRST ANALYSIS

The described A35 project resulted in several new ways to picture and present the temperature data, the cooling process of the asphalt layer (at the surface as well as "in-asphalt"), the movements of paver and rollers, and the process of compaction. It also confirmed a strong correlation between surface and in-asphalt temperature. For a more extensive description of the A35 project and the results see Miller et al (2008).

Overall, a number of monitoring benefits are apparent. The consequences of on-site operational behaviour and discontinuities are made explicit. The temperature profiling highlights the resultant variability in temperature homogeneity and identifies potentially segregated areas. Temperature contour maps and compaction coverage plots are digitally “geo-referenced in layers” and saved in permanent records. Thus, future reviewing and matching with on-site pavement distress and failure is possible. Logging the movements of the equipment using GPS captures the results of the operational choices made by the paver and roller operators. The animations of the moving equipment provide evidence of the rolling patterns and of how rolling is undertaken during the construction process. Mapping the heuristics the operators use allows a deeper understanding of the on-site paving process. This systematic analysis and mapping of the asphalt paving process should lead to firstly, addressing the important issue of reducing variability in operational behaviour and secondly, to an improvement in consistency and quality in the final product.

Let's revisit the problem that started off the research project on the A35: The corrugations in the first Twin-lay project and the questions of why the roller operators started compaction the asphalt while it was still too hot. In a post analysis based on the insights gained in the A35 project and three related MSc projects, a number of possible scenario's was put forward. First of all the asphalt layer was thicker than the crew was used to. The thicker the layer the longer the cooling takes (Asphalt-Institute 1989, NCAT 1996). The roller operators generally base their operational choices on the distance to the paver (interviews). Their rationale: the closer to the paver, the closer to the initial temperature. How far the roller operator drives towards the paver is based on experience and intuition. However, with the thicker layer their experience and intuition failed them. They drove too close to the paver. The temperature sensor is not accurate either. The sensor measures the surface temperature which is consistently lower than the in-asphalt temperature. The difference between these two temperatures depends on several parameters - thickness of the layer being one. The temperature contour plots of the A35 show quite a variety in initial surface temperature (up to 35 degrees Celsius within 10 metres). For the operators the temperature indication must be quite erratic. In the interviews the majority of roller operators confess to ignore the temperature sensor anyway. The information provided by their new instruments is not relevant for them since it does not fit into their operational reasoning and strategies. They rather trust their intuition and experience. For a more extensive discussion on craftsmanship in the road construction industry see Miller et al (2007).

The interesting observation that this paper focuses on is the mismatch between the new technologies put onto the machinery and the operational strategies of the operators. In the interviews some operators praised their equipment but declared the new technologies pointless ("you can remove this stuff"). This gap between the sophistication of the equipment and the practice guided by intuition and experience is due to two separate market dynamics. On the one hand, there is the market driven technology trajectory of the equipment manufacturers. The companies are subsidiaries of multinational conglomerates. The equipment manufacturers compete and operate on global scale. Their main areas of advancement are [a] new technologies (sensors, telecom, and intelligence) and [b] comfort for the operator. The new technologies are mostly selected and developed without in-depth knowledge of the construction process, and certainly without considering local (regional) practice. The advancements in comfort for the operator have improved the working environment for the operators, but have also created a distance between the operator and work in progress. Ergonomic chairs take away the feedback (bumps) normally received from surface irregularities. Air-conditioned cabins take away the feel for heat radiating from the asphalt surface and the feel for ambient temperature and wind speed. Stereos in the cabins reduce opportunities to communicate with other team members.

The road construction industry - on the other hand - still operates with a market strategy that pivots around (high) volume and (low) costs. Consequently, the contractors are reluctant to spend money on higher wages, education and training. At the same time, the actual construction work is shifted to nights and weekends. These working conditions do not attract the best equipped and educated personnel. People that are able to do calculations and more abstract tasks rather work in the office during the day than on site during the night. This process of self-selection results in a situation where the average operator on site has difficulties in dealing with abstract information. The new technologies on the equipment create an information overload for the operators, who solve this situation by just disregarding the "bells and whistles" on their new machines. Intuition and past experience becomes their prime source for operational choices. Subsequently learning becomes a lengthy process of trial and error. When the asphalt mixtures and the designs are frequently changed, this learning process cannot keep up with the changes and as a result, the quality of the paving work will suffer. This is demonstrated in both twin-lay projects.

## CHANGES IN THE BUSINESS ENVIRONMENT

The mismatch between the intuition and the experience-based operational approach of the operators and the technology trajectories of the equipment manufacturers inevitably leads to quality control issues. Given the development of new sensors, improved communication (pervasive internet), increasing micro computing powers, RFID tagging, track and tracing, GPS application, etc., the equipment will become more sophisticated. This trend is not stoppable. The road construction industry will have to cope with this trend and at the same time reduce the variability as exposed by the A35 project. The seriousness of this issue is underlined by changes in the public procurement strategies that lead to higher risk profiles for the road builders.

Over the last four years since the Dutch parliamentary enquiry into the construction sector, the business environment within the road construction sector has changed dramatically. According to Dorée (2004) the collusion structure that regulated competition has fallen apart. Public clients have introduced new contracting schemes containing incentives for better quality of work (Sijpersma *et al.* 2005) and therefore play a critical role in the construction innovation process. This prominent role allows them to stimulate and support the implementation of innovative solutions such as process performance (Manley and Karen 2006, Ling *et al.* 2007). The new public sector procurement is about performance contracting and longer guarantee periods. No longer is the asphalt mix and surfacing design specified by the client. The contractor now has to develop a solution that fits the performance specifications. The guarantee period is stretched from three years up to seven years with ten years as maximum. Contractors needing to close roads for repair work can face lane rental agreements scenarios or even severe penalties for causing traffic congestion. This new condition creates a new set of risks and business incentives (Ang *et al.* 2005). Road construction companies, therefore, seek better control over the construction process, over the planning and scheduling of resources and work, and over performance. Improved control would also reduce the risks of failure during the guarantee period. The observations related to the A35 project, the interviews and the participation in asphalt teams, show that adding more technologies to the machinery is not necessary the viable route for risk reduction. To be able to achieve these goals, the relevant on-site operational parameters need to be known and the relationships between these parameters need to be thoroughly understood. For asphalt paving companies to be able to improve product and process performance, they now more than ever acknowledge they need to develop intricate understanding of the asphalt paving process and the interdependencies within the process. The ideal route would be to co-develop the insights into process, skills & education of operators, and supporting (SMART) technologies on site and on the equipment. It seems a task suited to CM and CM research.

## CM TO MATCH TECHNOLOGY AND PRACTICE

In the sections above, the argument is that technology and construction practice grows apart in a way that adding new technology for process control rather increases than mitigates risks. New technology should be co-developed with skills, education and in-depth process knowledge. So why is CM suited for this task? It fits perfectly with the objective of CM - improving project performance. Given the claim that CM improves the performance of the project and the construction industry, it is even obliged to involve itself in this co-development. Otherwise, the success of CM will be spoilt by quality problems due to new technologies that are disrupting the construction practice rather than supporting it. Furthermore: no other field of research will be able or urged to bring the three areas together in a co-developing manner for the field of construction. CM and CM research needs to bridge the gap between the new upcoming SMART technologies and the construction processes.

## CONCLUSIONS

This paper dealt with the complexity of technology adoption and innovation in a changing construction industry. Road construction is a typical segment of the construction industry that faces new risks and business opportunities due to more challenging public procurement strategies. The research showed that seeking competitive advantage in new products and new technologies may go against practices, cultures and resources that are shaped in a certain (market) tradition. Reducing the variability and improving quality consistency is the key to risk management. Now that the companies are aware of the higher risk profiles they acknowledge the need to make explicit the implicit working practice and operational strategies. To really take advantage of the new SMART technologies the introduction must be in co-development with in-depth process knowledge, skills, training & education. This particularly is an area for CM and CM research to contribute and flourish. In our case: BAM Wegen, through this innovation project, has shown courage and a conscious desire to adopt and integrate new technology for firstly, monitoring the equipment movements and secondly, to interrogate and change their operational strategies and methods. They now acknowledge that explicit knowledge, systematic and easily communicated in the form of hard data provides support for and a deeper understanding of the operational process being followed. For them the documented operations provide the lever to discuss and confront the operational choices made by management and more importantly, those choices made by the paving team during construction operations.

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