

## THE ASPHALT PAVING PROCESS: PLANS FOR ACTION RESEARCH

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### ABSTRACT

Recent significant changes in public sector procurement in the Netherlands are forcing road construction companies to professionalize one of their primary processes: on-site asphalt paving. This paper describes an initiative aimed at improving quality in the process. A literature review confirmed that research into the asphalt paving process seems to be in a state of infancy. Interviews with on-site plant operators confirmed that operational choices in the asphalt paving process depend heavily on craftsmanship and that the work methods and equipment are mainly selected on the basis of tradition and custom. Also, the operators were reluctant to use new (available) technologies. Since improving the paving process requires integrating new technologies with the learning of new work methods, this paper proposes an action research strategy. Such an approach involves operators and researchers in addressing the apparent mismatch between current technology development, work methods and the operators' (tacit) operational strategies.

### 1. INTRODUCTION

Over the last three years, since the parliamentary enquiry into the construction sector, the business environment within the road construction sector has changed dramatically in The Netherlands. 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 and Buur, 2005). These new types of contracts, tougher competition and the urge to make a distinction in the market, spur the companies to advance in product and process improvement. These changes have significantly altered the playing field for competition. The companies see themselves confronted with different "rules of the game" than what they were used to. Performance contracting and longer guarantee periods create a new set of risks and business incentives. In general, the companies experience the pressure of new types of competition and other rules and trends, but at the same time, they acknowledge the opportunity to distinguish themselves.

In an effort to outperform competitors, asphalt-paving companies seek better control over the paving process, over the planning and scheduling of resources and work, and over performance. Improved control would also reduce the risks of failure of the paving during the guarantee period. To be able to achieve these goals, the relevant operational parameters need to be known and the relationships between these

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parameters need to be thoroughly understood. For the 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.

## **2. RESEARCH OBJECTIVES**

This work forms part of an overall project focusing on the improvement of the Hot Mix Asphalt paving process aiming at improved quality and consistent reduction of quality variability. This paper reports on the development of a research strategy to address two key research questions. The first question is what are the main causes of variability in the asphalt paving process and the second is what will the effect of revised operational strategies be on quality in the process.

## **3. METHODS**

During a workshop conducted by Dorée and ter Huerne (2005), national experts and representatives of agencies in the asphalt field were confronted about the state of asphalt paving construction in The Netherlands. The experts suggested that.

- little or no research effort is put into systematic analysis and mapping of the asphalt paving process;
- the asphalt paving process depends heavily on craftsmanship;
- work is carried out without the instruments to monitor the key process parameters; and
- the selection of work methods and equipment is based on tradition and custom.

We then undertook three tasks in response to the anecdotal suggestions made during the workshop. First, we conducted an extensive literature review to assess the state of research into the asphalt paving process. Second, we conducted one-on-one on-site interviews with twenty-eight machine operators. The purpose was to gain insight into operational strategies in the asphalt paving process from operator perspectives and therefore confront the suggestions made by the national experts. Last, we developed a research strategy to move the process forward in attempting to answer the key research questions mentioned above.

## **4. STATE OF THE ART**

### **4.1 State of research into the asphalt paving process**

Several dedicated asphalt research agencies and organisations exist in The Netherlands and abroad. A scan of literature on asphalt issues showed a field of asphalt research which is well developed. One area dominates the core of our knowledge base to date viz. the characteristics of asphalt from the perspective of construction material (mixtures, recipes, strengths, elasticity, etc). However, efforts to systematically map and analyse the process of asphalt paving are few. Approximately 100 papers were published in the *International Journal of Pavement*

*Engineering* during the period 2002 to 2005 with only one being in the construction process research area. A similar situation applies to the *International Journal of Pavements* during that same period with a mere two papers out of 65 (approximately 3%) speaking directly to construction modelling. A scan of publications in the *Journal of Computing in Civil Engineering* revealed that six papers (approximately 5%) were published in the areas of modelling and simulation of construction processes. This out of 133 papers published during the same period analysed for the Pavement Engineering journals.

Abudayyeh *et al.* (2004) investigated construction research trends in technical papers published in the American Society of Civil Engineering's *Journal of Construction Engineering and Management* between 1985 and 2002. 879 technical papers were analysed. The top research topical areas were reported as scheduling, productivity, constructability, simulation and cost control. These topics formed approximately 18% of the total number of papers published during that period. It's interesting to note that the modelling of construction processes comprised less than 2% of the total number of papers published during this period and that it only ranked 17<sup>th</sup> out of a list of 29 research areas. Despite the apparent neglect of construction process research, a positive trend appeared in the period 1997 to 2002 with an increase in the number of construction simulation papers published (Sawhney *et al.*, 1998; Halpin and Martinez, 1999; Naresh and Jahren, 1999; Kartam and Flood, 2000; Halpin and Kueckmann, 2002). This trend continued after 2002 (Zayed and Halpin, 2004; Zhang and Tam, 2005) albeit with few papers published relating to the simulation of the asphalt construction process (White *et al.*, 2002; Jiang, 2003; Nassar *et al.*, 2005; Choi and Minchin, 2006).

We can therefore conclude that the majority of the research and the papers deal with the characteristics of asphalt from the perspective of construction materials. Research into the asphalt paving process is in a state of infancy.

## **4.2 Mapping 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 and Shi, 1994; Pampagnin *et al.*, 1998; Bouvet *et al.*, 2001; Hildreth, 2003; 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, transform the result into geometrical representations, and investigated the use of Geographic Information System (GIS) technology to develop a graphical illustration depicting the number of compactor passes. Krishnamurthy *et al.* (1998) developed an Automated Paving System (AUTOPAVE) for asphalt paving compaction operations. Peyret *et al.* (2000) reported on their Computer Integrated Road Construction (CIRC) project. This aims to develop Computer Integrated Construction systems for the real-time control and monitoring of work performed by road construction equipment, namely compactors (CIRCOM) and pavers (CIRPAV). Oloufa (2002) described the development of a GPS-based automated quality control system for tracking pavement compaction. The Compaction Tracking System (CTS) allows tracking of multiple compactors.

Several experiments to map the asphalt paving experience were conducted in recent years. However, although some of these experiments were developed into industrial applications, it appears that few have been accepted widely by industry and are frequently used on the construction sites. Although some equipment manufacturers now provide GPS as an option for clients, GPS is not yet part of operational strategies and working practice in asphalt processes. Therefore, although GPS technology has been subject of study in asphalt construction processes, and is now available on roller equipment, it is not yet adopted and integrated into operational strategies and methods.

## 5. RESULTS OF THE ON-SITE INTERVIEWS

The interviews revealed several tensions between theory and practice. One of the major practical problems roller operators deal with is that whilst they are responsible for the final compaction level of the asphalt mat, they are not able to measure the degree of compaction during the compaction process itself. When final rolling has stopped the target density should ideally have been achieved since it would be difficult to achieve further compaction when the asphalt mat cools down (Timm *et al.*, 2001). However, most roller operators interviewed indicated that they were not informed of the final density of the completed layer – not during the site operations and even not afterwards - despite its importance. This is a significant shortcoming in terms of quality control. It shows an absence of “closing the feedback loop” (Montgomery, 2005) and as such negatively affects any learning that could occur. In addition, the number of roller passes and the roller patterns directly influences compaction (Leech and Powell, 1974; NCAT, 1991). Whilst indicating that they used prescribed roller patterns during the compaction process, a concern is that most operators did not keep track of the number of passes completed during rolling. They also appear to base key operational decisions on what they “feel” and “see” since they do not know what the actual temperatures and the material characteristics are during the process of compaction. Roller operators indicated that they specifically looked for the occurrence of “cracking” and “shoving” and the rapid cooling of the asphalt during the compaction process. Interestingly, the speed of the asphalt paver was not considered an important point of discussion between screed and roller operators. This raises the issue of whether they were aware of the effect of temperature differentials if the paver was too far away from the roller’s working zone. The influence of temperature differentials on hot mix asphalt paving has been studied extensively (Chadboum *et al.*, 1998; Timm *et al.*, 2001; Stroup-Gardiner *et al.*, 2002; Willoughby *et al.*, 2002). The relevance of temperature issues seems in stark contrast with the road crews’ (lack of) attention to this parameter during the paving process.

Evidence of barriers to technology adoption was revealed in a number of ways. Most operators frankly acknowledged that they hardly made use of the available technology on the machines. Of the operators that had temperature measurement tools at their disposal, only a minority confirmed to use these. They showed an awareness of the importance of the cooling process of the asphalt and they considered weather conditions, the temperature of the asphalt mix and changes in layer thickness to be important factors to pay attention to during the paving process. Also, they understand that a change in layer thickness directly affects the cooling rate of the asphalt mat. It is easier to achieve target density in thicker layers of asphalt than in thinner layers. This is because the thicker the mat, the longer it

retains the heat and the longer the time during which compaction can be achieved (Asphalt-Institute, 1989). However, in practice the roller operators are mostly uninformed about the discontinuities because of adjustments made by the paver and screed operators – such as paver speed, layer thickness and screed vibration.

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. There is also evidence that no direct feedback is given to machine operators. Machine settings are done mainly on the basis of “feeling and experience”. 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. Asphalt paving in many ways still is a process driven by craftsmanship, heavily dependent on tradition, and on operators' experience, gut feeling and tacit knowledge. Therefore, there is not really one common practice, but a wide array of “common practices”. This wide array must lead to extensive variability in the quality of final product.

## 6. ACTION RESEARCH STRATEGY

Given that craftsmanship still rules the operational choices in the paving process and that the operational strategies are typically tacit; Can new technologies provide an impetus towards a more professional approach? This is not a straightforward “yes” as often assumed. Our interviews indicated that operators are not comfortable with new technologies. Over the last decennia several technologies were developed to improve process information and process control (see the previous section). New features and functions were added to the equipment. Most operators acknowledged that they hardly made use of the available technology. They just do not know how or why to use the new “gadgets”. Another new technology is GPS. Although equipment manufacturers now provide GPS as an option for clients, it is not yet adopted and integrated into operational strategies and methods. The data provided by GPS systems does not help the operators because they do not know that these data might be relevant for their operational choices and work methods.

The adoption of technology process may also be hindered by scepticism and reluctance of the 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 (Simons, 2006). Several authors argue that the construction industry typically lags behind other industries in adopting technology (AbouRizk *et al.*, 1992; Halpin and Martinez, 1999; Halpin and Kueckmann, 2002; Bowden *et al.*, 2006).

For evaluating the adoption of technology one could use the innovation adoption factors as given by Rogers (Rogers, 2003). When the data produced by the GPS systems do not match with the operators' operational reasoning, at least three of Rogers' five attributes will not be fulfilled – and adoption will be problematic. At the same time, tailoring the GPS solutions to overcome this mismatch is difficult because the operational reasoning of the operators is tacit and implicit.

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| Factors for likelihood innovation adoption (Rogers 2003) <ul style="list-style-type: none"><li>• relative advantage</li><li>• compatibility</li><li>• complexity</li><li>• trialability</li><li>• observability</li></ul> |
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## 6.1 New research approach

Developing better operational strategies requires adoption of new technologies, but new technologies are not adopted due to insufficient understanding of current operational strategies (the common practice). This resembles a chicken or egg problem, a causality dilemma. Against that background, the research project follows an action research strategy alternating steps of technology introduction and mapping of operational strategies (see Figure 1). Through monitoring of the learning processes of the operators, and evaluating the operational choices with them, the tacit knowledge of the "common practice" will become explicit. This provides the opening for further development of process understanding, tools and operational strategies. Qualitative heuristics will be confronted with quantitative process data.

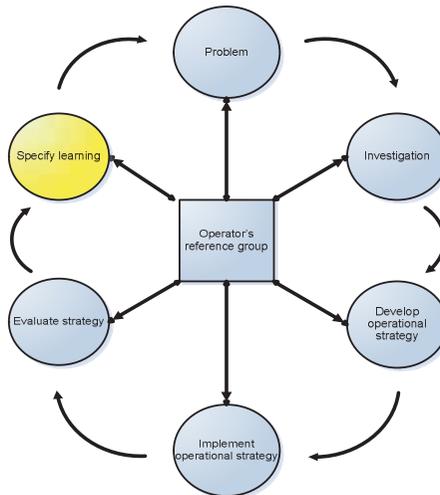


Figure 1. Action research strategy for the asphalt paving process

The proposed strategy implies that it firstly, involves the asphalt machine operators directly in the research project and secondly, it includes a statistical modelling and computer simulation component that aims to test and validate models developed during the research. The explicit models will facilitate the practitioners in synthesizing their tacit knowledge and promote learning processes. Trochim (2001) suggests that "there is so much value in mixing quantitative and qualitative research. Quantitative research excels at summarising large amounts of data and reaching generalisations based on statistical projections. Qualitative research excels at telling the story from the participants viewpoint, providing the rich descriptive detail that sets quantitative results into their human context".

The aim is for operators and researchers to jointly develop operational strategies using an iterative process (see Figures 2 and 3) of problem definition, operational strategy development, implementation, evaluation, and consciously specifying the learning taking place. This is expected to lead to:

- better understanding of the asphalt paving process;
- the development of innovative tools and technologies to assist understanding of the paving process; and
- adoption and wider acceptance of innovative tools and technologies and its associated benefits.

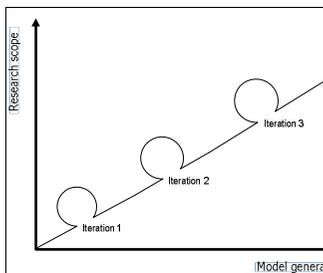


Figure 2. Iteration process

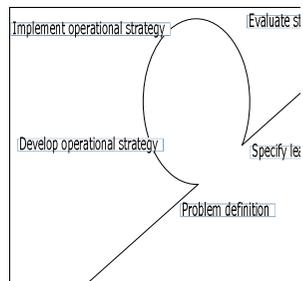


Figure 3. Typical iteration

A qualitative paradigm should provide insight and understanding from the perspective of those actually involved in the asphalt construction process. One of the major distinguishing characteristics of qualitative research is that the researcher attempts to understand people in terms of the own definition of their world (Mouton, 2001). By utilising a qualitative approach, an attempt will be made to understand the asphalt construction process, from the subjective perspective of the individuals involved. These individuals include the operators involved in the actual paving process. The complexities can only be captured by describing what really happens when they are doing their job, incorporating the context in which they operate, as well as their frame of reference. In other words, there needs to be a commitment to the empowerment of participants and the transfer of knowledge. Chisholm and Elden (1993) advises that one should strive for the full involvement of the client (in this case the machine operators) and researcher. The involvement of participants enhances the chances of high construct validity, low refusal rates and “ownership” of findings. The validity should also benefit by several iterations and expansion of the research scope across iterations. This is shown in Figure 2.

A qualitative approach therefore has the potential to supplement and reorient our current understanding of the asphalt paving process. Key research questions using an action research strategy are normally of an exploratory and descriptive nature. Exploratory in that you are attempting to firstly, assess what is happening during the asphalt paving process and secondly, to identify the key factors that affect the process. Descriptive questions also provide opportunities for finding correlations between variables affecting the paving process.

The quantitative paradigm is aimed at developing and validating accurate models of the somewhat complex asphalt paving process. The overall objective is to build process models of the asphalt paving process and to bring these models together in an event scheduling system. The models to be developed need to be checked and validated in practice. This requires the involvement of stakeholders closest to the

asphalt construction process. Several causal and predictive questions have to be addressed during this modelling phase. What are the main causes of variability in the paving process? Is variability the main cause of reduced quality, productivity and efficiency within the paving process? What will the effect of a revised operational strategy be on the asphalt paving process? Will a revised operational strategy lead to improved quality, productivity and efficiency?

With this action research strategy, the chicken-or-egg problem (the causality dilemma of technology development and adoption) is side-stepped by progressing in small steps involving the practitioners. The described action research strategy has an added benefit. Since progress in the research project coincides with actual learning and growth of operational knowledge and capabilities, the companies are happy to take part in the research - instead of just being the object of study. It breaches the classical divide between science and practice. It not only challenges the practitioners' presumption of the paving process, but also their opinions of the value of academics and academic work.

## **7. CONCLUSIONS**

A parliamentary inquiry into collusion in the Dutch construction industry sparked new public procurement strategies and altered the business environment for road paving companies. Performance contracting and extended guarantee periods drive the companies towards the improvement of product quality and process control. Since the density of the pavement is a key factor in the strength and durability of the road surface, operational strategies are a cardinal focus for research. The attention for these issues exposed that site operations and operational strategies are driven by "common practice" – the tacit knowledge and heuristics of the site crew built on years of personal experience (and often idiosyncratic). Building an objective picture of site operations is difficult since site operations are not documented. Knowing the exact location of asphalt construction vehicles, their speed and their motion characteristics, can provide essential information for the understanding of asphalt pavement construction processes. This can be done using GPS technology. That is not straightforward. Experiments of such technology introduction show problems of adoption. To be adopted the technology should be tailored to the prevailing operational strategies, but at the same time the technology has to be adopted to make the prevailing operational strategies tangible. To overcome this causal dilemma we propose an action research approach.

This action research approach provides opportunities for developing a framework to capture the operational characteristics of the asphalt paving process in a more holistic manner. It diverts from previous process modelling studies where key role players have been left out of the process. Latham as cited in (Blockley and Godfrey, 2000) observed that "there is an acceptance that a greater interdisciplinary approach is necessary, without losing the expertise of individual professions." He recognised that all concerned with construction are interdependent and need to behave as a team. Blockley and Godfrey (2000) also argue that "we need to have a whole new view of process" and in order "to do that we need to include factors that are particularly needed when co-operation between people is important". The key issue here is that the operators need to be involved in, and take responsibility for the process. They are in fact largely responsible for the success of the process.

The selected action research methodology involves the researcher, innovative technologies and most importantly, the machine operators "driving" the asphalt construction process. The first steps in this project show that the approach selected, taps into the enormous wealth of tacit knowledge and experience of operators – it provides insights necessary in analysing important operational characteristics in the asphalt paving process. The unravelling and confronting of the practitioners view is expected to lead to improved control during the asphalt paving process and consequently to improved product and process performance.

## 8. ACKNOWLEDGEMENT

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