

Runway paving: Taking a different approach

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ABSTRACT

Hot Mix Asphalt (HMA) paving of airport runways mostly requires multiple paving teams, multiple pavers, and a wide array of other equipment. The runway paving projects are typically renowned for the logistical effort and the tight margins for overruns, often requiring a relatively large part of the contractor’s resources. Due to the nature of airport operations the projects are of a fast-track nature and planned meticulously. The large-scale nature of the projects raise the attention of the media and contractors often use them as showcases. Although their project characteristics are well known and often appeal to the imagination, the projects have little attention in scientific journals from a process and operations management perspective. We present research ideas on operational matters, process and quality control issues relevant for runway HMA paving construction. It builds on our research experience in the area of highway asphalt paving. We describe the current state of the asphalt paving process and provide a brief overview of the sparse publications in the area. Based on a limited oral inquiry amongst Dutch experts – we present a first list of issues typical for runway asphalt paving operations. We hone in on variability encountered during HMA paving operations and operational strategies necessary for consistent paving and compaction. Lastly, we present technologies and approaches to improve the operational control and subsequent quality consistency during runway HMA paving operations.

KEYWORDS: runway paving, process control, logistics, compaction

1. INTRODUCTION

The current asphalt paving process depends heavily on the skills and experiences of the people working on site. 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 Hot Mix Asphalt (HMA) paving construction in The Netherlands. The experts suggested that: little or no research effort is put into the 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. Ter Huerne (2004) illustrated that often the key parameters in the pavement process – being temperature, compaction and layer thickness – are not monitored during production. Workers usually base their decisions on their intuition and experience.

Moreover, Simons (2006) interviewed 28 compactor-, paving- and screed operators actively involved in the asphalt paving process. The interview results confirmed that the compaction process largely depends on tradition and custom i.e. the knowledge and experience of the paving 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". A worrying feature is that most operators acknowledged that they hardly made use of the technology available on their machines or even simple temperature measurement instruments to assist them in the HMA paving process.

Up until now the asphalt paving companies – for both roads and airport runways - appear to lean heavily on the experience and tacit knowledge of the construction teams on site. Yet, the companies acknowledge they have to make an effort to improve product and process performance and that they now need more intricate understanding of the asphalt paving process and the interdependencies within. Therefore an important first step into developing a deeper understanding of the HMA paving process during road and airport runway construction is investigating current operational strategies and process control. This requires measuring and documenting the operational processes during HMA paving construction. This awareness led to the founding of the ASPARi (Asphalt Paving Research & Innovation) initiative - a network with a focus on innovation and performance in the asphalt paving process. The research is aimed at improving quality and consistent reduction of quality variability in the HMA paving process, and consciously working towards professionalising the process. In this paper we examine the typical characteristics of runway paving projects and explore whether it is possible and useful to use the ASPARi approach and methods for the analysis and advancement of runway paving operations.

2. STATE OF RESEARCH INTO THE ASPHALT PAVING PROCESS

Given that the asphalt paving industry is perceived to be based on tradition and custom, one would expect significant research efforts and initiatives to professionalize paving and compaction processes. However, efforts to systematically monitor, map and analyse the HMA paving process are few. A scan of literature on asphalt issues shows a well developed field of asphalt research. In the Netherlands and abroad, several agencies and organisations dedicated to asphalt research can be traced. Conferences on Bituminous Materials and Asphalt Pavement are organised annually. Several journals are dedicated to promoting asphalt pavement research including the International Journal of Pavement Engineering (IJPE ||issn 1029-8436), launched in 1999 and the International Journal of Pavements (IJP ||issn 1676-2797), launched in 2001. Approximately one hundred 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 sixty-five (approximately three percent) speaking directly to construction modelling. The search through journals and conference proceedings made clear that the majority of the research and the resulting scientific papers deal with the

characteristics of asphalt from the construction material perspective viz. mixtures, recipes and material properties. Papers on the HMA paving process from production-operation-management perspectives were only a fraction of the total of papers published on asphalt. A similar situation applies to work carried out by research institutions and agencies with much on materials and little on the asphalt paving process. It seems the process-perspective on asphalt pavements is hardly developed systematically. Research into the HMA paving process seems to be in a state of infancy.

3. RUNWAY PAVING – THE DUTCH EXPERIENCE

To collect the main operational issues for airport paving, we conducted telephonic interviews with airport paving project experts of the larger Dutch contractors. Three main issues were focussed on viz. [1] typical characteristics of the airport paving projects, [2] the main operational issues, and [3] the main operational strategies employed during construction.

Typical for the airport projects are the amount of resources that need to be mobilized, the attention to logistics, and the planning effort to secure the continuity and pace of the paving process. All experts see the logistics as the main area of concern. It is especially the case for the overhaul of existing runway pavements. Clients often set stringent requirements including an elimination of joints due to environmental requirements and restrictions concerning penetration of any spillage to the ground. This in turn, means that warm joints should always be used during construction. Also, the projects are executed in a tight timeframe to restrict the downtime of the runway. It is the combination of these two latter requirements that shape the typical effort of airport paving relative to “normal” highway projects: more resources to mobilize and control, more detailed planning, more focus on logistics, and securing pace by creating more slack, maintaining more spare recourses, more monitoring effort and taking more notice and care of external influences.

In the last decade a typical overhaul runway project on a commercial airfield required four to eight milling machines, eight or nine pavers, about twenty compaction rollers, four to five asphalt producing plants, between 120-150 trucks, and a dozen miscellaneous pieces of equipment for cleaning, sweeping, blowing, drying and other tasks. Often artificial lighting has to be arranged for work carried out at night. The work may involve over 250 people and laying approximately 10 000 tons of asphalt a day. Some operational issues typical for runway paving include:

- Contractors prefer to execute the work over weekends. In the weekend the traffic is less dense and the transport between plant and site more predictable and regular. Moreover, the plants are not constrained by producing asphalt for other projects;
- All asphalt plants are supplied with the exactly the same materials from the same sources. In that way trucks can be directed to any of the pavers on the runway;
- The pavers are put in line or in V-formation depending on cross-section requirements of the runway;
- Accurate milling is the key to control the smoothness of the surface. The centreline’s construction is crucial because of the landing of the plane’s nose wheel. The smoother centerline the more comfortable the landing;

- People issues: On airports people often have to be screened before they can enter the airside of the airport. The projects often require working in shifts. Interestingly, the projects require relatively few “handworkers” since they are only required for the two outer pavers of the formation;
- The supervision task is typically split into three: logistics, paving operations and compaction operations;
- Before the work starts a buffer of loaded trucks is built up. This buffer is to cushion fluctuations in the arrival of asphalt from the plants. Changes to the number of trucks in the buffer are used as a trigger to change the speed of the pavers. The target amount of trucks in the buffer is based on previous experiences and expert judgment;
- Paver operators are instructed to follow the leader (the paver up front). Whilst paving the teams need to be guarded against sudden or considerable adjustments of the screed. The objective is to work as smoothly and continuously as possible. In case of changes in logistics the speed of the pavers is adjusted to prevent stop-and-go events.
- The roller operators get little specific instructions, but are expected to stay behind “their” pavers and not cross more than half of the lane next to them;

When comparing the operational choices and strategies of runway paving projects and the “normal” highway projects, we observe similarities and differences. The similarities are of course in the resources used and the structure of the paving process. Runway paving projects are executed by the same people, using the same equipment and machines, working in the same sequence of actions – as on other paving projects. In essence runway projects can be perceived as scaled-up paving jobs in a deliberately tight time frame. The large scale and high intensity of runway projects are the key characteristics that set these projects apart from the normal paving projects. Therefore it comes as no surprise that the contractors see the logistics as the key area of concern for runway paving. All other matters are treated in a “business as usual” manner.

The effort put into the logistics on runway projects shows that contractors [a] understand the importance of timely and sufficient supply of HMA for a smooth continuous paving process, [b] are able to organise and secure sufficient supply of mix to the site, [c] understand logistical linkages within the process (mix supply related to paver speed), and [d] understand logistical concepts as buffers (storage in the chain of the process). Above all the contractors show they are able to deal with the logistics on this scale. The effort and dedication put into the logistical planning for runway projects seems in stark contrast to the effort and dedication put into logistical planning on “normal” projects. Whilst on runway projects the contractors make sure to be in *control* of the logistics, it is not unusual on “normal” paving projects that the paving team has to *cope* with the supplies as they arrive on site. The paving and compaction process of a runway is guided by “simple” instructions imposed on the assumption that all involved know what to do based on their experience and common practice. The paver operators must “follow the leader”. The screed operators are instructed to be cautious and silky in the screed adjustment. The roller operators may only overlap as far as the centre of the lane next to the one assigned to them. The strength of this superimposing of instructions on common practice is the clarity. The weakness is the assumption that the practices within are similar and constant. Our work shows that operational strategies and practices vary significantly for “normal” HMA paving projects (Miller, Doree et al. 2007; Miller and Dorée 2008; Miller, Dorée et

al. 2008). Thus, in spite of the more controlled logistics, we can assume that for runway paving and compaction there is some unaddressed variability. Two examples are used to illustrate the point:

- Sourcing from several plants often means differences in distance and time travelled. Subsequently the temperatures of the arrived HMA mixes may also be significantly different. What effect does that have on the variability in temperatures on both sides of the hot joints?
- There seems no dominant strategy/instruction for the roller operators. Evidence gathered on highway projects shows that there is quite some variation in operational strategies in compaction. As a consequence the compactions strategies - and results - may vary from lane to lane.

Although relevant these issues were never addressed by contractors and data are not available. With the technologies now emerging – and the methods we developed - we can now start to open up these and other operational “black boxes” to reduce variability and improve consistency.

4. IMPACT OF TEMPERATURE & COMPACTION ON THE PAVING PROCESS

Two of the most important factors affecting the quality of the HMA layer are the temperature of the HMA during paving operations and the final density achieved after laydown and roller compaction (Asphalt-Institute 1983; 1989). Compaction of the HMA mat is an important task during laydown operations aiming to produce a mat of specific density. Although the compaction process appears rather simple and straightforward, it is, in reality, a procedure requiring skill and knowledge on the part of the roller operator (Roberts, Kandhal et al. 1996). Several industry-aided research initiatives exist to assist construction machine operators perform their tasks. These include methods to monitor HMA paving and compaction using GPS and other IT technologies (Peyret, Jurasz et al. 2000; Oloufa 2002).

Factors affecting the maximum compaction (density) attainable by a set of compactor rollers in the field are the physical properties of the HMA and the surrounding environmental conditions (Asphalt-Institute 1989). Physical properties include mix characteristics, the temperature at laydown, layer thickness and firmness of the founding layer. Environmental conditions comprise air temperature, wind velocity and humidity, and solar radiation levels. Most of these factors directly affect the cooling rate of the HMA and the time available for compaction. In addition, temperature differentials in the HMA layer produce density differentials, which affect the life of the pavement (Read 1997; Willoughby, Mahoney et al. 2002). Infrared cameras are used to document temperature differentials and for detecting, locating and measuring segregation during HMA paving operations (Stroup-Gardiner, Wagner et al. 2002; Stroup-Gardiner, Nixon et al. 2004).

Some of these temperature and compaction research initiatives made the transition to industrial applications. However, it appears that few are widely accepted by industry and frequently used on the HMA paving construction sites. Against that background, this research follows an action research strategy where we alternate steps of technology introduction and mapping of operational strategies (Chisholm and Elden 1993; Hartmann, Fischer et al. 2008). It involves the machine operators directly in the research pro-

ject by making behaviour explicit using visualizations (Akenine-Moeller & Haines 2002; Foley et al. 1997). We expect that such visualizations will help machine operators synthesize their tacit knowledge and promote learning and improvement processes within the HMA paving process.

5. MONITORING AND MAPPING THE HMA PAVING PROCESS

This section describes mobile measurement devices we use to firstly, collect HMA temperature data in a temperature profiling exercise and secondly, to monitor the movements of paving and compaction equipment. Table 1 summarizes the measurement setup utilized during typical Temperature and GPS monitoring exercises.

Table 1: Mobile measuring devices used in the HMA process monitoring

Task	Instrument	Method	Output
Measure asphalt surface temperature behind paver screed	Thermal camera or line scanner mounted on the paver	Infrared images taken behind the paver screed	Temperature Contour Plot (TCP) showing surface temperature of the asphalt as the mix leaves the paver
Measure surface temperature cooling rate	Handheld thermal cameras	Cameras set up on tripods at fixed positions with operators taking images every 30 seconds	Cooling rate curves for asphalt surface temperature
Measure in-asphalt temperature cooling rate	2-channel digital thermometers	Thermo coupler placed in the middle of the asphalt layer with the thermometer logging temperature automatically every 5 seconds	Cooling rate curves for in-asphalt temperature
Monitor weather conditions	Weather station	Set up next to the construction site	Plot local weather conditions over time
Monitor the movements of the paver and compaction rollers	GPS receivers	Receivers mounted on the paver and all compaction rollers.	Animations showing the machine movements and Compaction Contour Plots (CCP) showing the extent of compaction for each layer
Measure asphalt density	Nuclear density gauges	Density measured after every roller pass at fixed temperature logging positions	Plot density/roller passes/asphalt temperature comparisons
Monitor the movements of the trucks supplying asphalt	Off the shelf GPS loggers	GPS logger placed into the trucks for the duration of the asphalt paving operations	Analysis of the truck logistics
Record noteworthy incidents on site	Voice recorder	All research personnel record incidents as they occur	Incident logs

5.1 Temperature monitoring

Typical outputs include Temperature Contour Plots (TCP) showing the surface temperature of the asphalt as the mix leaves the paver and cooling rate curves for asphalt surface temperature and in-asphalt temperature. The thermal images and resultant TCPs enables a contractor to measure the extent of variability in HMA temperature and hence draw a number of conclusions about temperature homogeneity. A distinct lack of consistent repetitive temperature contours during HMA paving operations shows up in the surface temperature varying appreciably both longitudinally and transversely as shown in

Figure 1. The presence of cyclic cool areas is evidence of mix segregation. Operational discontinuities affecting the paving process can be 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 (Figure 2); 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.

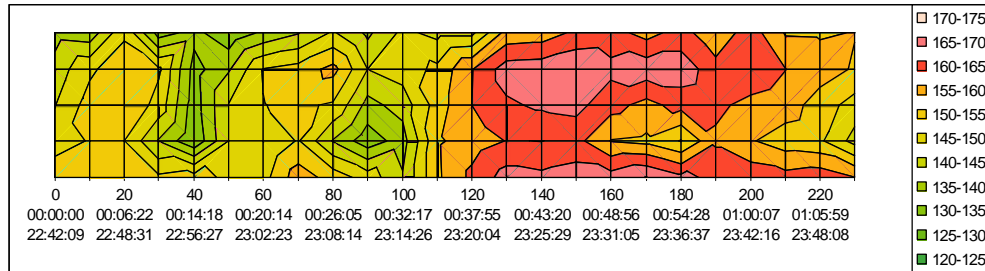


Figure 1: Typical Temperature Contour Plot (TCP)

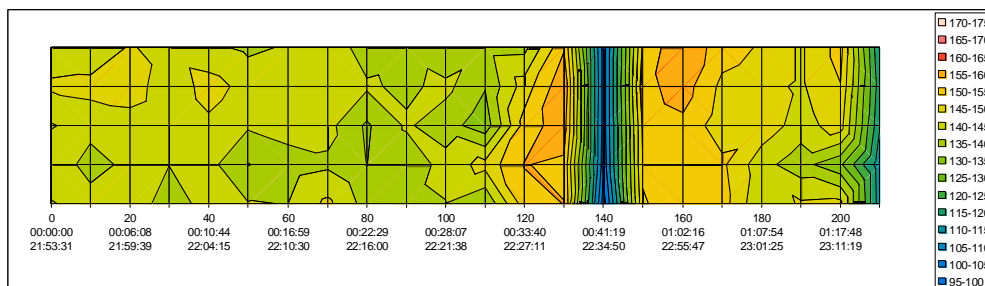


Figure 2: Temperature Contour Plot (TCP) showing a typical paver stop

5.2 GPS monitoring

During GPS data collection, we set up a stationary GPS base station next to the construction site. The base station receiver sends out Differential GPS corrections in real-time to GPS receivers mounted on the cabins of the HMA asphalt paver and roller compactors. We use the mobile GPS receivers to monitor the individual movements of all asphalt paving machinery on the construction site and generate two visualizations. First, we produce animations showing the equipment movements during HMA paving operations. Several views are 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 3. The animations provide 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 operators.

Second, we use the filtered GPS data to produce pictorial representations of the vehicles at the appropriate locations i.e. the extent of compaction. We divide the road into rectangular tiles and, for each roller compactor, we calculate the number of times the vehicle's road contact surface touches each tile. This process yields a matrix for each roller compactor with the number of passes over each tile i.e. each roller compactor's compaction effort. A typical Compaction Contour Plot is shown in Figure 4.

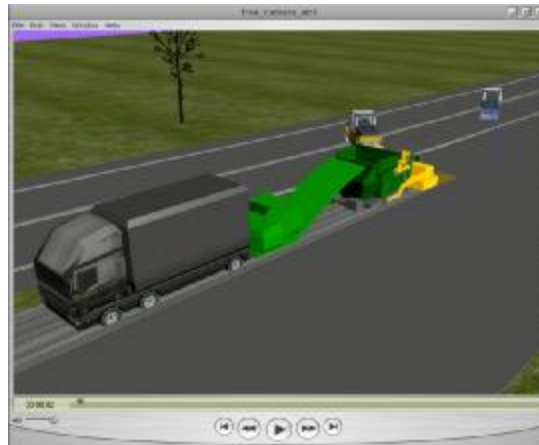


Figure 3: Typical animation produced from GPS data

The monitoring of equipment movements using GPS systems provides insights into actual paving practices. Several operational issues are highlighted and more importantly, are made explicit. These include but, are not limited to (1) an analysis of the variability of the paver speed during construction, (2) the time between the start of paving and the start of compaction given the temperature of the asphalt on arrival and the influence of weather conditions, and (3) an analysis of the extent of compaction for all lanes using the Compaction Contour Plots which shows the result of the compaction undertaken during construction. The latter is compared with asphalt temperature, nuclear densities and final core densities to investigate compaction inconsistencies for all paved lanes.

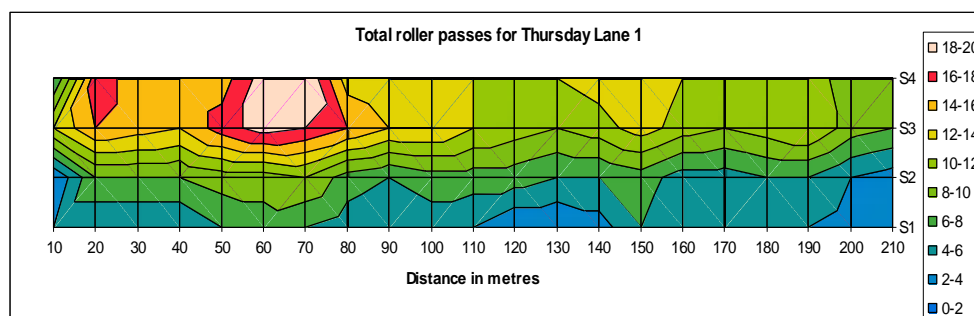


Figure 4: Typical Compaction Contour Plot (CCP)

Overall, a number of benefits of the monitoring exercises are evident. The consequences of on-site operational behaviour and discontinuities are made explicit. The temperature profiling highlights the resultant variability in temperature homogeneity and helps identifying potentially segregated areas. Temperature Contour Plots and Compaction Contour 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 opera-

tional choices made by the paver and roller operators. The animations provide evidence of the rolling patterns and of how compaction 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.

6. DISCUSSION

In previous sections we addressed the typical characteristics of runway paving projects, and we presented recent research on more “normal” HMA paving projects. This paper explores whether such an approach is possible and useful for runway projects. Key in that approach is improving process control and homogeneity by reducing variability. For that we employ new technologies to gather more information on the process and the process conditions. To enable understanding, discussion and learning, the gathered data is transformed into visualizations. The visualizations make the information accessible to practitioners. The process and operational choices are more exposed and explicit. Discussion amongst the practitioners is the first step from tacit practice, based on experience and feeling, toward more method-based operational strategies.

The investigation into the runway paving operations exposed the focus put on logistics as the key operational concern. The paving and compaction processes were also coordinated with productivity and continuous throughput in mind. The methods and experiences developed for the runway project logistics and throughput can be used as a stepping stone for improving the logistics for other paving jobs. This can be further enhanced by more detailed GPS monitoring and computer simulation of the trucks supplying asphalt (Miller and Dorée 2008). It can also include exploring the relationships between trip distances; drivers conduct and mix segregation using GPS and inertial sensors.

Furthermore: Since contractors perceive runway paving and compaction similar to highway paving, and treat these operations in a “business as usual” way, we can confidently assert that variability issues acknowledged for “normal” paving projects will also pertain to runway paving. Given the scale of the projects, the ASPARi approach might be a logistical challenge to choose, mobilize and control the measurement equipment for a runway paving monitoring regime. That said, the operational issues at stake are not that different for runway projects.

Although the work on runways is still perceived as a type requiring a rather specific approach, it seems this specificity is decreasing. This is not because the work on the runways changes, but it is due to the changes in the “normal” work on highways. More and more highways are multiple lanes. The highways are not as wide as runways but it is no longer uncommon to pave highways with multiple pavers in a line formation. More stringent requirements about the closing and opening of highways – incentives by penalties – also raises the effort put into planning and into securing the supply of asphalt and the pace of the paving process. One of the experts already changed his perspective in characterizing the runways as just ultra-wide highways. So operational approaches and practices once typical for runway paving projects now cross over to the mainstream road paving projects.

7. CONCLUSIONS

The scale and time pressure make runway paving projects stand out from other paving jobs. Runway projects raise the imagination and serve as great examples to showcase the industry. They inspire contractors to raise their planning efforts and capabilities above their normal standards. Therefore, one would expect that literature, research and scholars on airport paving would also focus on operational issues. This is not the case. The operational perspective is often overlooked. In runway projects, logistics is regarded as the main feature of operational concern. Paving and compaction are loosely coordinated by primarily trusting in the operational experience and tacit practices of the involved workers. Variability in those processes is still unexplored. Now new technologies make it possible to monitor, analyse and present the operations in a way that the practitioners can relate to it. The ASPARi work already shows that research and practice can benefit from an action research approach combining monitoring, learning, process improvement and technology development. We expect that the pressure to move in that direction will rise. As in other areas of road construction, new contract types have also made their way into runway maintenance and paving. In 2006 Schiphol Airport awarded an integrated maintenance contract based on performance specifications to contractors Dura Vermeer Infra, KWS Infra, Heijmans Infra and Imtech. This gives the contractors more freedom in operational choices – what to do and when to do it. The operational choices are regulated with penalties and bonuses. Also, performance guarantees raise the risk profile for the contractors. This risk awareness is the key driver for industry to change operations, to learn and develop from tacit experience-based ways towards explicit method-based approaches – regardless of the type of project.

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