

EAPA POSITION PAPER



THE IDEAL PROJECT



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EXECUTIVE SUMMARY

This paper provides tools and guidance for increasing the durability of asphalt pavements by providing good examples in all stages of the project from the design preparation stage through to maintenance.

The durability of asphalt pavements is very important because of the increasing demands for availability of the road network which means that roads need be built to last for a very long time and the amount of maintenance required has to be reduced.

Durability is not only important for the availability of the network, but it is also related to the effective use of material. Effective and efficient use of materials comes from better durability of products which in turn leads to a lower environmental impact.

To show the possibilities of building more durable roads the various stages of the process of building an “ideal” road project are described in this paper.

Maximising the durability of road pavements will:

- Reduce the delays to road users caused by maintenance
- Reduce the maintenance costs of the road authority
- Improve the sustainability of asphalt pavement construction and ultimately provides more value for the money invested.

The aim of this document is to encourage all working in the roads / highways sector from the asphalt supply industry to the road owner to contribute to making more durable asphalt pavements. It outlines techniques and procedures as well as the latest technologies.

This document presents valuable information for creating durable asphalt pavements but it cannot be totally definitive. It does not provide all the knowledge that is needed in the different steps of road design, road building and road maintenance, because that also requires experience. This document can be seen as a starting point of a whole library and as appetiser. For more information and details good reference are provided. This paper supports existing resources and seeks to bring new ideas in addition.

The starting point for increasing the durability of asphalt pavements is in ‘Project preparation’ where the road owner has to prepare the information that is needed for all parties involved in the contract. It is important that the right asphalt layers, thickness and mixtures are chosen by considering the site conditions such as traffic, climate, and ground conditions etc.

The right choice of “Tendering procedure” gives the road owner the opportunity to obtain the quality it needs. In many present tendering systems the cost is the only or dominant criteria used and the lowest bid is awarded. Awarding the lowest bid is only likely to result in the lowest permissible quality nor does it stimulate the use of the latest technology and innovation. To be able to achieve a higher quality it must be specified. This can be done in various ways, which are described in this paper. The knowledge and technology is available to deliver high quality roads and companies should be rewarded for delivering improved performance, robustness and efficiency of road infrastructure.

Good “Project planning” can reduce the risk of failures or under-achievements. To achieve a long lasting pavement good “Pavement design” is essential and the devil is always in the detail. Design also needs to consider the vital interaction of the road structure with requirements for drainage.

For selecting the appropriate “Paving materials” a wide range of asphalt mixtures is available that can be considered to meet specific (functional) requirements.

When “Preparing the project”, suppliers and contractors need to assess their requirements in order to ensure successful delivery of the contract requirements. For “Asphalt production” the importance of consistency of factors such as product compliance and especially temperature of the asphalt mixture is addressed. Consistency is also related to “Asphalt transport”, ensuring that the steady flow of materials to the project helps ensure a uniform pavement structure. Practical advice on loading and unloading delivery vehicles is described as well as systems to assist in traceability of materials.

“Paving operation” is critical to success, right from the point of paver set-up. Information technology on pavers has come a long way to assist in obtaining higher levels of pavement quality.

Similarly, the importance of “Compaction” in obtaining a durable pavement structure is highlighted. This includes the choice of rollers as well as control systems for providing important information to the roller driver.

For durable and long lasting asphalt pavements properly constructed “Joints” are essential as pavements are designed on the assumption that they are “monolithic structures”. Poor joints will lead to earlier than normal rehabilitation.

Similarly, the importance of “Bond and Tack coats” in ensuring monolithic construction and ultimately the bearing capacity of the pavement is explained. Proper bonding between the layers is also essential for waterproofing the pavement.

“Quality and process control and Assurance” are emphasised in ensuring that the efforts made in work preparation are not sacrificed during execution. New technologies to assist with quality control are also addressed.

In relation to “Operation / Maintenance” minor and major maintenance techniques are explained alongside an example of Treatment Selection Guidelines.

The “Conclusions” of this document mention that in support of the information provided and the use of Best Practices available, education, training, experience and support of staff is essential to provide them with the skills to achieve better durability in the end.

Literature references are mentioned for those who want to learn more about a certain subject mentioned above.

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1. INTRODUCTION

Roads facilitate a very important mode of transport in Europe. Road transport has the largest share of EU freight transport performance among the three inland transport modes (road, rail and inland waterways). In 2014, road transport accounted for 74.9% of the total inland freight transport (based on tonne-kilometres performed); rail had 18.2% and inland waterways had 6.7% [1.].

Passenger cars accounted for 83.2 % of inland passenger transport in the EU-28 in 2013, with motor coaches, buses and trolley buses (9.2 %) and trains (7.6 %) both accounting for less than a tenth of all traffic (as measured by the number of inland passenger-kilometres (pkm) travelled by each mode) [2.].

The European road network consists of 5.5 million km and it represents an estimated value of over € 8,000 billion, managed under local, regional and national responsibility" [3.]. Therefore the roads are an enormous national investment and require maintenance to keep them in a satisfactory condition and ensure safe passage at an appropriate speed and with low road user costs. Of this road network more than 95% of main pavement layer type in Europe are flexible (asphalt) [4.].

Roads have been built and maintained for many decades but the intensity of traffic and demands on roads is still increasing. For these reasons the availability of the road network is increasingly important and that means that roads need to be built to last for a very long time.

Road maintenance can lead to a road closure or closure of lanes which reduce the capacity of the network. For that reason it is important that roads are built in such a way that the amount of maintenance needed is reduced. In other words the durability of the roads has become a very important item.

The durability of asphalt pavements is very important because of the increasing demands for availability of the road network which means that roads need be built to last for a very long time and the amount of maintenance required has to be reduced.

Durability is not only important for the availability of the network, but it is also related to the effective use of material. Effective and efficient use of materials comes from better durability of products which in turn leads to a lower environmental impact.

The main consideration when choosing a type of asphalt for the surface course is the functional characteristics provided by the material in relation to the (whole life cycle) costs of the pavement. The main functional surface characteristics are:

- skid resistance (safety)
- evenness - transverse and longitudinal (driver comfort)
- noise reduction (health, environmental and driver comfort)
- durability (pavement performance)
- visibility (safety)
- sustainability / recyclability of the material

There are many ways to use materials in a more efficient way and there are also many ways to obtain better durability of roads and road surfaces.

To be able to show the possibilities of building more durable roads the various stages of the process of building an ideal road are described in this document.

Tools for increasing durability of asphalt pavements by providing good examples in all stages of the project from the design through to maintenance are highlighted.

Durability can have different meanings in different countries. Durability for asphalt pavements can be defined as building a product that meets long-term needs, resists damage and stays relevant to the (road) users.

Durability also has a link to “Sustainable development”, which means that it “meets the needs of the present generation without compromising the ability of future generations to meet their own needs”.

Combining both definitions could lead to the statement that present and future generations need pavements that are durable, long lasting while being material, energy and cost efficiently built.

Maximising the durability of road pavements has the benefits of [5.].

- Reducing the delays to road users caused by maintenance
- Reducing the costs of the road authority of that maintenance
- Improving the sustainability of asphalt pavement construction.

The aim of this document is to encourage all working in the roads sector to contribute to making more durable asphalt pavements. It provides current and established techniques and procedures as well as the latest technologies.

This document presents important information but refrains from providing all the knowledge that is needed in the different steps of road design, road building and road maintenance. It refrains, for instance, from addressing points of detail such as:

- What type of filler should be used
- What type of aggregate should be used
- What the shape of the aggregate should be
- Which type of binder should be used
- Etc. etc.

This document can be seen as a starting point of a whole library and as appetiser, with good references for detail provided.

This paper supports existing resources and seeks to highlight the most important parameters for an ideal project while bringing forward some additional new ideas.

This document provides examples and tools for increasing the durability of asphalt pavements. It refrains from being a Best-Practice-document as these will vary from country to country depending on, for example, political, regulatory or budgetary drivers.

2. PROJECT (CONTRACT) PREPARATION

In general a road authority is the owner of a road and it decides what has to be done. In general the road authority describes in documents what it expects will be the outcome of a project (tender documents, specifications etc.) against which suppliers and contractors have the possibility to provide an offer.

The road authority has several possibilities to describe what it needs.

- a. Describing in detail what has to be done;
- b. Describing in detail what is needed in terms of performance outcomes;

In case a. the contractor will have to do what has been explicitly described. These types of contract generally do not give many opportunities for innovation. In most cases the lowest offer gets the job.

Case b. may give more opportunities for innovative ideas.

When maintenance for a long period (e.g. 20 to 40 years) is also included in the contract, it can stimulate the contractor to pay more attention to the quality / durability of the solutions offered because he will be responsible for the project for a long period and thereby seek to avoid unnecessary or unplanned maintenance operations.

Performance specifications are often considered to recognize the relationship between construction quality and long-term performance. By rationally controlling variables that impact long-term performance, the quality of the final product can be improved. In order to achieve long (-life) performance, aspects such as these should be considered in addition to the technical demands.

The overall purpose of building more durable pavements is to achieve lower annual costs by increased pavement life and fewer and more cost effective maintenance activities. In order to assess the economic benefits of a more durable pavement, the full financial consequences should be considered using Cost/Benefit Analysis (CBA) [6.], to include:

- Initial construction costs
- The loss of asset value due to pavement deterioration
- Owner costs due to periodic maintenance and traffic management at road works
- Road user costs, primarily due to delays at road works

- The societal costs due to potential accidents involving road users and workers at road work sites
- The environmental impacts of road construction and maintenance

Intuitively, a more durable pavement probably results in an increase in construction cost compared to traditional pavements, but lower maintenance-related costs. Some of the costs included in CBA are relatively simple to determine while others are more difficult. Traditionally, in the case of pavement deterioration, only limited information regarding costs had been published. However, developments in the sophistication and accuracy of Pavement Management Systems (PMS) have helped drive better understanding of the modelling of residual value of pavements [6.]. Costs associated with road user delays can be obtained using models based on measured traffic flows and road capacities. Road safety costs are more difficult to quantify, but are likely to be significant in the case of lost lives. The main areas of concern for environmental costs are Carbon Footprint – embedded from pavement material production, potential pollutant impacts related to fuel/energy consumption of vehicles and noise impacts. The owner costs consist mainly of direct costs including maintenance and traffic management costs but also indirect costs in terms of administration.

However, even though many costs associated with CBA are abstract and difficult to establish, there are simpler ways of estimating the economic benefits of more durable pavements. Perhaps the easiest way is to compare the construction and maintenance costs of two (or more) types of pavement structures, one being a more durable one and the other being a conventional one. This in turn requires information regarding the durability of the various pavement layers. Information about the main characteristics and the durability of surface layers in Europe can be found in Appendix 1 of [7.].

Traditional Life Cycle Cost Analyses (LCCA) can be used for calculating the present costs for the pavement alternatives and is the primary tool used for economic comparisons.

For the LCCA studies the time span that is taken into account is mostly between 20 and 60 years. When dealing with Long Life Pavements (see chapter 4.1) this time span could be even longer.

Robust economic models are necessary to show the benefit of alternative designs and materials. Road owners have developed many models to identify the relationship between investment and life-cycle costs and continue to populate these with material life data to improve their accuracy for Whole Life Cost

assessment. Nonetheless, many pavements are still purchased primarily based on investment cost, which consequently, often leads to high life-cycle costs since the procurement procedure rewards the lowest bidding price.

When preparing the project contract the road authority has to prepare the relevant information that is needed for the contract. As an example: In a maintenance project where asphalt layers have to be removed / milled it is important to know what the existing pavement to be removed consists of (for potential future reuse) and whether it anything which may require specific treatment or disposal. The size of the (possible) work-zones are important for the planning and execution of the project.

For road maintenance there are examples of contracts where the contractor (consortium) is responsible for the maintenance for a long period for (a part of) a whole road network in a certain area. This gives to contractor the incentive to optimise the use of material and equipment.

For maintenance contracts it is important to consider that a range of techniques are available to deliver the desired outcomes. In some cases it may only be necessary to carry out minor interventions e.g. surface dress a road to restore skid resistance or apply a sealant technique, while cracking and potholing may be indicators of deeper structural issues requiring resurfacing or reconstruction. Robust project preparation is vital to ensuring future performance by clearly identifying the needs and expectations of the client for the road, and driving whole life cost behaviours and benefits. Contracts should encourage innovation and enable efficient delivery.

Years of financial crisis have driven tendering systems to a position where first cost is the only or dominant criteria used and the lowest bid is awarded. Awarding the lowest bid is only likely to result in the lowest permissible quality nor does it stimulate the use of the latest sustainable technologies and innovations. To be able to achieve a higher quality it must be specified by the road owner. This can be done by:

- Using Green Public Procurement criteria in public tenders to improve the sustainability of infrastructure projects and to reduce energy consumption. The Green Public Procurement (GPP) criteria for design, construction and maintenance of roads developed by the European Commission [8. stimulate the European public authorities to design, build and maintain roads in more green / sustainable way.

Raising the quality of the construction process will result in a CO₂ reduction since longer service life of road pavements means a more efficient use of available materials.

- Using functional requirements / specifications to stimulate the use of the latest technology and inspire bidders to come up with innovative solutions: sustainable materials, environmentally friendly designs and energy efficient business operations.
When selecting requirements and the appropriate values, conflicting requirements needs to be prevented. Over-specification obstructs innovation since almost all degrees of freedom will be restricted.
Functional specification can be used when the tender is awarded on any number of criteria other than just price (like Most Economically Advantageous Tender).
- Using quality / best price-quality ratio, bonus/malus-system, experience and expertise in tendering process as mentioned in the EU Public Procurement Directive (Directive 2014/24/EU) [9].

The most economically advantageous tender (MEAT) criterion enables the procuring authority to take account of criteria that reflect qualitative, technical, and sustainable aspects of the tender submission as well as price when reaching an award decision.

To determine the most economically advantageous tender, the procuring authority can use various criteria linked to the subject matter, for example quality, price, technical merit, functional or environmental characteristics, cost-effectiveness, delivery date, etc. Other criteria used in Europe are extra guaranty, technical solution, limitation of traffic nuisance during construction, risk management and quality system and construction methods [10].

Quality specifications must be sound and reliable. Test methods with a low reproducibility can generate conflicts between road administration and suppliers.

In the construction sector the knowledge and technology is available to deliver high quality products, but until now there is in most cases no incentive for the construction companies to use this and to innovate. If a construction company is rewarded for improved performance, robustness and efficiency of road infrastructure, he has the incentive needed. This will stimulate using the state of the art technologies, processes and materials across all types of networks.

Timing of tender calls can be critical to success. At a national strategy level, if multiple tenders are issued for large volumes of work across a country or region in a limited investment period, then this could lead to supply chain capacity issues as there is not sufficient time for the industry to plan new or additional resources (people, plant and equipment) to deliver to all contracts at the same time. A smooth profile or pipeline of work helps ensure continuity of delivery and to prevent “pinch points”.

Tender calls should be sent out in an early stage. Where possible, paving jobs should be sent out for tender calls early enough to allow projects to be planned to be constructed in times of favourable weather. Carrying out work in less favourable weather conditions may result in pavements with lower durability. It is also important to have paving jobs more spread over the year as in some countries the construction season is condensed to 3-4 months within a year. When parties are under extreme time pressure failures are more likely to occur. A more constant production and construction over the year (and year on year) will improve the quality.

3. PROJECT PLANNING

Good planning of work can reduce the risk of failures or under-performance.

A risk assessment should be made to identify scenarios that would have an adverse effect on durability and a reasonable probability of occurring. A decision should then be made about how to reduce the probability and / or effect to an acceptable level [5.].

Early contractor involvement (onsite and off-site in the offices) with discussions and information exchange between road owners, designers and contractors regarding the job to be done can lead to practical and adequate solutions. Sometimes this can even be achieved before detailed design is complete or contracts are awarded and can encourage innovation. Good liaisons between all parties contributes to trust and will avoid problems during the execution of the job.

In some cases it is better to close a whole road for maintenance than to maintain it in small packages. Working in small packages requires the creation of a work zone every time (which can be very costly) and it might not contribute to a durable pavement in the end, which means earlier maintenance (again).

The expected performance must be accurately described by the road authority. Before construction starts, the contractor should submit to the authority for consideration a detailed paving plan and method statement including, for example vehicle schedules for the removal and the production of all layers of asphalt with a detailed description of machine technology and transport logistics in a comprehensible form as well as what tests will be carried out to ensure consistency [5.] and [11.].

Durability also depends on the weather conditions during laying and the workmanship of the people involved in the paving operation.

When the weather is inclement greater attention to detail is needed because such conditions can have a substantial impact on the quality of the construction. Throughout the planning, the time of the day and season when the work will be undertaken should be considered. Ideally, all work should be done in daylight during daylight hours when the workers can better concentrate on their duties [5.].

For a good job a sufficient quantity of well-maintained equipment is needed and should be operated by adequately skilled, experienced and well-motivated staff.

The asphalt pavement (layers) should be completed before opening to traffic. Traffic should not be allowed on the new incomplete pavement before all asphalt layers have been paved (unless considered in the pavement design), otherwise the pavement can be seriously damaged under the traffic loadings and weather conditions.

In the planning phase attention should already be paid to future maintenance, like keeping the drainage well-functioning.

Project planning should also be extended to maintenance operations in order to guarantee proper funding. Severe delays in the maintenance projects generate misfit between the needs specified in the project and the real needs of the pavement when the work takes place.

Constant and well programmed funding is key to avoid unexpected problems.

4.PAVEMENT DESIGN

To achieve a long lasting pavement a good pavement design is essential. The thickness of the asphalt layers depends on the bearing capacity of the subgrade, the subbase and road base, the amount of traffic, the traffic loads (including projected/forecasted traffic growth in terms of axle loads) and the climatic conditions. Asphalt pavements can be relatively thin when there is a good bearing capacity of the foundation and with light traffic. They will be thicker for heavily trafficked roads and weaker foundations.

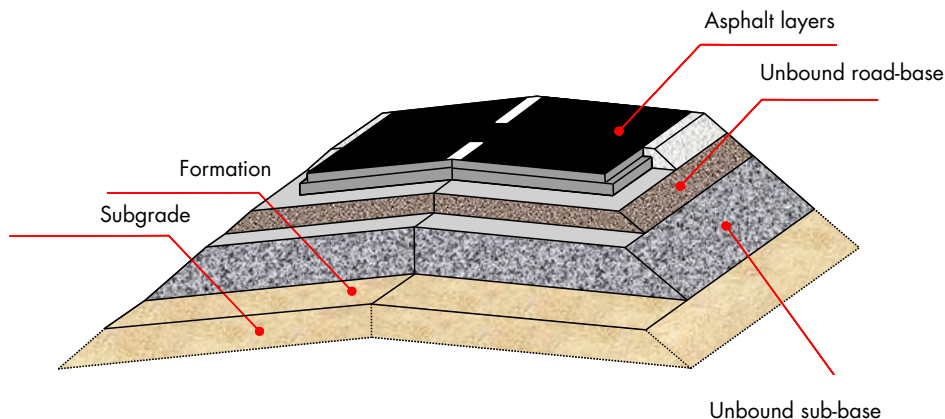


Figure 1. Schematic illustration of flexible pavement structure.

A flexible pavement consists of different layers above the subgrade, and normally consists of bituminous bound layers on a granular base layer. The granular base layer could consist of unbound aggregate or hydraulically bound aggregate. The materials used for the granular base layers can be locally available materials, imported crushed/uncrushed granular materials and re-used (secondary) material.

The bearing capacity of a road depends therefore on the bearing capacity of the subgrade. Building a good road starts with building a good foundation. Before the pavement including drainage is designed, there should be a sufficient inspection and assessment of the subgrade (also called formation level) to be able to complete a meaningful design.

The type and thickness of the materials used for the subbase layers depend on the expected traffic loading and the bearing capacity of the subgrade as well

as practical issues. Subbase requirements may be specified either in terms of a minimum strength of the (total) foundation or as a minimum compaction degree. A granular subbase also provides a good working platform for the next (bound) pavement layer.

In all cases it is very important that all layers are well compacted close to the optimum moisture content. Detailed information about soil compaction can be found in [12.].

In some countries, climatic conditions may also require relatively thick pavement structures in order to avoid frost-related heaves. Furthermore, economic factors, such as availability and transportation costs, also have a significant impact on the amount of unbound materials desired in a pavement. In some cases adequate bearing capacity can be achieved using different stabilization techniques. For example, different types of cement- or lime- stabilization can be used to improve different soils.

It is important to keep water out of the pavement both during construction and during the service life of the pavement. If there is not enough attention paid to drainage, moisture will affect the material properties and it will have a direct influence on the durability of the asphalt pavement. Therefore there should be two way dialogue between drainage and pavement designer in order to ensure that the drainage scheme and materials selected are mutually compatible [5.].

4.1. PAVEMENT DESIGN METHOD

Most pavement designs use the so-called semi-mechanistic or “mechanistic- empirical” methods, partly based on fundamental engineering principles. Semi-mechanistic procedures consist of a structural response model and associated performance models. The response models relate traffic loading to stresses and strains in the pavement structure. The performance models relate calculated stresses and strains to a rate of deterioration.

The two main (classical) distress mechanisms considered in semi-mechanistic methods are rutting (in the top of the subgrade only; the risk of rutting in bituminous materials is taken care of in the asphalt mixture design procedure) and fatigue cracking (initiated in the bottom of the asphalt layer). Structural rutting originating at the subgrade can be controlled by limiting the compressive strain induced at the top of the subgrade, which is normally a function of the expected number of load applications during the design period and the thickness and the stiffness of the upper pavement layers [7.] and [13.].

Traditionally, pavement cracking is thought to be initiated at the bottom of the asphalt layers where the tensile bending stresses are the greatest and then progress up to the surface (bottom-up cracking). Most design methods are based on this concept. Another type of cracking that can occur is "top-down cracking". Top down cracking appears to be a mode of distress in several countries and since the mid-1980s has got more attention. Although not fully understood there are some basic views on the top-down cracking mechanism:

- High surface horizontal tensile stresses due to truck tires (wide-based tires and high inflation pressures are cited as causing the highest tensile stresses).
- Age hardening of the asphalt binder

More information about top-down cracking can be found in [14.]. "Some recent calculation models are described by way of example in [15.].

Pavements are normally designed for a certain period, related to the estimated amount of heavy traffic over that period. In the past a design life of 20 years was often used, but nowadays pavements are designed for longer periods, sometimes in excess of 40 years [6.]. In cases where structural maintenance is not favourable, because the road cannot be closed even for one whole day, the Long Life Pavement concept is often used. Details for designing a Long Life Pavement can be found in [7.].

When an asphalt pavement structure is well designed with a sufficient thickness (Long Life Pavement, in the USA called 'Perpetual Pavements'), the pavement achieves an indeterminate or infinite life by just periodically removing and replacing the surface layer only ("mill and fill") [7.] and [16.]. The material that is milled, the reclaimed asphalt pavement (RAP), can be re-used to produce a surface layer. In this way limited new material is needed to maintain the pavement structure.

A Long Life Pavement requires that the structure is designed and constructed from the bottom-up and that it has a combination of thicknesses and asphalt mixture characteristics which preclude fatigue cracking and durability problems. Good design in the past also enables long life pavements to evolve from existing pavements. A 'standard' pavements can only be upgraded to a perpetual pavements if the existing structure has a very low damage level.

The renewable pavement surface must be designed to resist rutting and needs to be tailored for its specific applications.

In the end, a Long Life pavement can provide a uniform, smooth and safe driving surface, and it will avoid huge expenses associated with reconstruction.

4.2. ASPHALT PAVEMENT STRUCTURE

An asphalt pavement can consist of several different types of asphalt layers. In general there are three types of asphalt layers used. Of course there are more ways to build an asphalt pavement. The number of layer types could be more and could even be less, depending on the type of road, the type of traffic, etc.

In general the following types are used:

4.2.1. ASPHALT SURFACE COURSE

The surface course is the top layer of the pavement and it should be able to withstand high traffic- and environmental/climate-induced stresses without exhibiting unsatisfactory cracking or rutting. It needs to provide an even profile to avoid additional dynamic loads and for the comfort of the user, while at the same time it should possess a texture ensuring adequate resistance to skidding. Depending on local conditions, functional characteristics such as spray and noise reduction are additionally required for surface courses. In most cases, rapid drainage of surface water is desired in order to keep water out of the pavement structure while in other cases, the surface course can be permeable to permit water flow through the pavement.

The functional requirements of the surface layer can change in time because of (new) demands from society. An example is noise reduction where the old surface layer can be replaced by a noise reducing surface layer (when maintenance is needed or even in an earlier stage if reduction of traffic noise has a higher priority).

In most cases a surface layer will be replaced when the surface characteristics of this surface layer no longer meet the requirements, and it can be removed and replaced by a new one of the same type (or another of a different type), or it could be overlaid. In some cases, surface characteristics may be compromised as a result, or as an indication of issues deeper in the pavement e.g. bottom-up cracking and those will need to address those as well as the surface problems. Durable surface layers will therefore help reduce the frequency of maintenance interventions and costs [17.].

Information about the durability of surface layers in Europe can be found in Appendix 1 of [7.].

4.2.2. BINDER COURSE

Binder courses are frequently used between surface and base courses to primarily prevent or reduce rutting by combining stability and durability. This is because the highest shear stresses in the pavement will generally occur about 50 – 70 mm below the asphalt surface. In some climates the maximum deformation can be located at a shallower depth. According to Lenker [18. and 19.] the maximum stresses can occur at a depth between 20 and 50 mm.

For a durable pavement it is therefore essential that the surface layer and the binder layer (mixtures) are designed to prevent permanent deformation in these layers.

4.2.3. BASE COURSE

The base course is intended to distribute traffic and environmental/climate loading in such a way that underlying (un)bound layers are not exposed to excessive stresses and strains.

Following the principle of performance-specific design of each layer, the base course should primarily show adequate fatigue resistance.

Traditionally, fatigue cracking has been viewed as being initiated in the bottom of the asphalt layer to propagate up through the layer (bottom-up cracking). Since fatigue cracking is assumed to be related to the magnitude of tensile strains in the bottom of the base course, it is therefore necessary to minimise these strains by designing the pavement structure correctly. In general it means that the thicker the pavement, the lower the stresses at the bottom of the pavement, and consequently, the longer the pavement will last.

Stresses and strains can also be reduced by increasing the stiffness of the base layers. There are several techniques to obtain high stiffness layers.

It can be seen that designing pavements is often about finding the optimum solution to a number of influencing factors. The resistance to fatigue can be improved in different ways, for instance by using a (polymer) modified binder, or a more dense mixture. An optimal recipe should also result in a homogenous material which facilitates adequate compaction. Low voids and high binder contents improve the fatigue resistance (Rich Bottom Layer concept) and also enhance the resistance against moisture-related damage, which is important since the base course layer is often in prolonged contact with water. However, a too low void content and too high binder content should be avoided in order to ensure retention of stability of the mixture and rutting resistance of pavement layer.

4.3. ADDITIONAL REMARKS

Some additional remarks regarding pavement design:

- Building good road pavements starts at the design stage. A high bearing capacity of the subgrade and the subbase is preferred [20.] and [14.]. If the bearing capacity of the subgrade is poor, there might be a need to improve it by replacing a part of the (top) subgrade or by in-situ stabilisation / soil treatment to improve its load bearing properties. Old pavements could offer good subgrade conditions; if a new road is to be built at the same place, it could be recommended in some cases to keep the subgrade as it is.
- An old concrete pavement can provide a good road base for an asphalt overlay. However, cracks and joints in the old concrete pavement to be overlaid can lead to reflective cracking in the asphalt overlay. To avoid this reflective cracking the concrete slabs should be fractured before applying an appropriate thickness of asphalt overlay [21.] and [22.].
- Weak subgrades might also lead to settlements and unequally distributed settlements. A good geotechnical investigation ahead of construction is always recommended.
- For a good bearing capacity of the whole road structure it is important that there is a good bond and interlock between all asphalt layers as well as between the asphalt layers and any hydraulically bound or unbound layers [20.], [23.] and [24.]. In [25.] and [26.] a thin prime coat applied on the untreated aggregate base layer is mentioned to promote a good interface bond and aggregate interlocking.
- Pavements should be designed wide enough to avoid traffic edge loading [24.].
- A good drainage of the whole pavement structure (surface layer, interlayers, subgrade and soil) is important [24.] and [27.] to keep the (unbound) pavement layers dry [23.]. Asphalt should perform its role of adequately protecting the base against traffic and environment [23.]. The pavement and materials should be well designed and constructed to avoid ingress of water into the lower layers [23.].
- In climates with frost penetration, frost resistant road-base and sub-base material needs to be used to avoid frost heave if it is used in or close to the freezing zone [24.].

- The thickness of asphalt pavement is a very important parameter for the pavement life. A conservative design giving an extra thickness added to the theoretical design will lead to a much longer pavement life [20.] and [27.]. An extra thickness can also be regarded as an extra safety margin in the design.

Successful durable pavement design relies on considering the relevant influences and requirements of the road both today and in the future. The design should seek to ensure that it is practicable to effectively construct a monolithic structure. Design requirements come not only from imposed traffic stresses but also the effects of climate and weather.

5. PAVING MATERIALS

When selecting the appropriate paving material a wide range of asphalt mixtures is available that can be considered depending on specific (functional) requirements.

The general asphalt mixtures are:

- | | |
|--|--------------|
| • Asphalt Concrete (AC) | (EN 13108-1) |
| • Asphalt Concrete for Very Thin Layers (BBTM) | (EN 13108-2) |
| • Soft Asphalt (SA) | (EN 13108-3) |
| • Hot Rolled Asphalt (HRA) | (EN 13108-4) |
| • Stone Mastic Asphalt (SMA) | (EN 13108-5) |
| • Mastic Asphalt (MA) | (EN 13108-6) |
| • Porous Asphalt (PA) | (EN 13108-7) |
| • Double layered Porous Asphalt (2L PA) | (EN 13108-7) |
| • Asphalt for Ultra-Thin Layer (AUTL) | (EN 13108-9) |

The characteristics of the asphalt mixtures are described in the above mentioned harmonised European Standards (hENs) of the EN 13108 series. Asphalt materials are traditionally produced as hot materials ($>140^{\circ}\text{C}$), but in recent years sustainability drivers have encouraged the use of lower mixing and installation temperatures. The hENs permit the use of so-called Warm Mix Asphalt technologies.

5.1. ASPHALT MIXTURE DESIGN

The bituminous binder should be chosen taking into consideration the prevailing conditions concerning aggregate type and regional climate since they collectively influence mixture performance.

In addition to binder properties, binder content shows a major impact on mechanical properties of asphalt mixtures.

Asphalt binder and mixture properties can be improved using certain additives, e.g. polymers. The use of modified bitumen can be justified in the case of severe conditions (climatic, traffic) [28.]. In addition to binder properties, binder content shows a major impact on mechanical properties of asphalt mixtures. The binder content in surface layer mixtures should not be too low in order to promote durability and reduce permeability, but should not be too high as to have a negative influence on texture, skid resistance and rutting.

For good durability of the road it could be desirable to minimise ageing of the pavement by reducing the air void content of the mixture and by selecting an appropriate binder [23.] and [24.] that does not age quickly. This will also contribute to preventing (fatigue, top-down and low temperature) cracking in the surface layer.

Over recent years there has been a tendency to reduce the binder content, and increase the use of more viscous binders, in mixtures to improve the resistance to permanent deformation and to improve the stiffness. This tendency might compromise durability and therefore it is better not to reduce the binder content too much but to adapt the aggregate properties and grading curve (e.g. by using a higher percentage of crushed aggregates) and to increase the degree of compaction to increase stiffness and resistance against permanent deformation. An increase in binder content can increase the resistance to fatigue and the water resistance, as mentioned before [5.].

A mixture can be designed to have a low air void content (when compacted), but that mixture also needs the ability to be well compacted on site. Therefore in the mixture design workability is important to be able to achieve adequate compaction in the end. Adequate compaction is also important when the weather conditions are not favourable. In some cases Warm Mix Asphalt additives for the mixes produced at standard temperatures might help in these cases. (In general, Warm Mix Asphalt reduces the viscosity and/or surface tension of the bitumen at a lower temperature, allowing for mix production at lower temperatures as well as allowing more time available for compaction in cooler ambient conditions. There are two basic processes to produce Warm Mix; chemical additives and controlled bitumen foaming during the mixing process at the asphalt production plant).

A good asphalt mix gradation is essential for obtaining a rut resistant asphalt mixture [28.].

Smaller nominal sizes of aggregate are good to avoid segregation and improve packing of the aggregate skeleton and it therefore improves the durability without compromising the resistance against permanent deformation [5.]. In addition smaller nominal sizes of aggregate may also lead to a lower rolling resistance of surface layers. However the relation with skid resistance and noise reduction should not be forgotten.

The aggregate should exhibit adequate properties in relation to their strength and wear resistance. Asphalt is a uniquely 100% recyclable construction product and old materials can be re-used in new mixtures. Careful consideration is

however required when using high percentage additions of Reclaimed Asphalt (classified by EN 13108 Part 8), with particular attention to recovered binder properties and content.

Some demands for the mixture properties are contradictory so a good compromise is always sought. The European Asphalt Standards require a process of Type Testing through which asphalt producers assess and validate the properties and performance of both mixtures and their ingredients. That is why the mixture design should be carried out by experienced technicians and carefully controlled by robust testing.

The test conditions for mixture design are generally specified in standards or contract documents.

Laboratory procedures for mix design should be done in such a way that the obtained densities are as close as possible to those obtained under work conditions to avoid over-compaction or under-compaction.

In some cases, higher void content could be prescribed to check the mixture behaviour under worse conditions (e.g. for water sensitivity).

5.2. JOB MIXTURE TRIALS

With novel or uncertain aspects of a mixture, a requirement for job mixture trials can be used to demonstrate their practicability (in addition to Type Testing). Job mixture trials can be used to assess the workability of mixtures and the effectiveness of equipment and/or roller patterns [5.]. See also 11.1.3 Test strips / trial sections.

6. PREPARING THE JOB

Items that could be part of the job preparation can be found in the following check-list:

- Safety and Safety Equipment checklist
- Traffic control plan
- Surface preparation
 - In case of applying an asphalt overlay on an existing concrete pavement future reflective cracking above cracks and joints of the existing concrete pavement (to be overlaid) should be avoided. The best way to control reflection / reflective cracking in an asphalt overlay over a concrete pavement is to fracture the slabs prior to placement of the asphalt overlay [21.] and [22.].
- Filling dips and ruts (if needed)
- Alignment and grade
- Asphalt production plan
- Asphalt transport plan
- Temperatures
- Paving operation plan
- Paving and compaction widths/sequences,
- Compaction; Types and amount of rollers needed and specification of rolling pattern
- Equipment pre-check
- Application of tack / bond coat
- Location of joints
- Preparing the area to be paved
- Milling and fine milling if needed.

7. ASPHALT PRODUCTION

During the production of an asphalt mixture, the right procedures should be followed as described in the Factory Production Control Standard (EN 13108-21). FPC aims to ensure that asphalt mixtures are produced to the correct and consistent recipe or design. Consistent production promotes consistent properties of the asphalt mixture, both in terms of final characteristics and in workability for the installation processes. In particular too high or low production temperatures can have a negative influence on the durability of an asphalt layer.

The production temperature has to be at such a level that a proper coating of the aggregates can be obtained as well as the required compaction level during paving and compaction (which depends on: ambient temperature, transport distance, type of mixture, thickness of the layer). Once those requirements have been met, the production temperature should be kept as low as possible to reduce aging of the binder and bitumen fumes, besides of avoiding Green House Gas emissions.

A constant temperature of the asphalt mixture produced and delivered is important for obtaining a good evenness of the asphalt layer. The asphalt mixture temperature of large production volumes coherently produced for a type of asphalt can be made in coordination with the construction site in a controllable temperature range. A critical point for temperature fluctuations is due to the quantities and the subsequent mixing of residual quantities and the production of small quantity of an asphalt mixture. By grouping "similar" asphalt mixture varieties of small quantities in the production process can minimise temperature fluctuations.

Other items that can contribute to fluctuating asphalt mixture performance are:

- Production of small asphalt mix quantities,
- Frequent changes of asphalt mixture type,
- Variable moisture content of the aggregates used (particularly fine aggregate),
- Different levels of Reclaimed Asphalt

In order to help ensure uniform production, the asphalt mixing plant requires timely and accurate information regarding production volumes from customers [11.].

Some types of asphalt mixtures may be prone to segregation (particularly those of larger aggregate size) and ways to avoid this during production are illustrated in [29.].

Technical specifications should avoid any reference to the configuration of the asphalt plant or how it should be operated. Specifications should be intended to keep constant and reliable quality of asphalt mixes.

8. ASPHALT TRANSPORT

The transportation of the asphalt mixture from the asphalt plant to the construction site is important for consistent paving operations and the durability of the pavement. Transportation should be designed to prevent temperature loss or differentials in the mixture and/or mixture segregation. Vehicles for transporting asphalt must be insulated and sheeted to minimise heat loss through the body and to the atmosphere. They should have smooth beds (without irregularities such as welded joints and dents) to prevent products sticking and ensure smooth flow of product and need to be kept clean. Ideally vehicles should be dedicated to asphalt transport but it is likely that they will also transport unbouand materials and bring returned loads of reclaimed asphalt (which is a more efficient use of transport as they do not run empty). In recent years, developments in asphalt vehicles have included the adoption of curved beds, heated bodies and “walking floors” (so that the vehicle body is not tipped for safety) technologies.

Planning tools [30.] are available to assist with asphalt production and transport planning that calculate the number of trucks required based on known inputs of mix tonnage available, paving width, depth and truck cycle times.

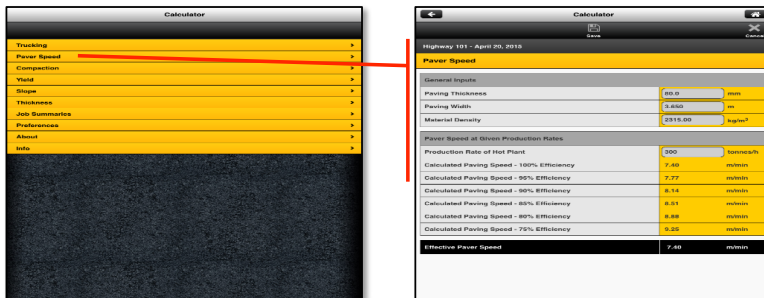


Figure 2: Example of planning tool to calculate the number of trucks required and paver speed [30.].

8.1. RELEASE AGENT

Release agents are applied to the bed of haulage vehicles to prevent the asphalt product from sticking and /or potentially segregating. Many products have been used as release agents, including water, vegetable oils and other proprie-

tary liquids. It is important not to permit the use of solvents or fuel oils such as diesel as a release agent as these will affect the quality of the asphalt. In some cases a very thin layer of lightly coated fine sand has been shown to inhibit asphalt sticking to truck beds.

Plant delays may arise from waiting for truck bed release agent application prior to loading as this was often carried out by hand. Automated systems now exist which spray controlled volumes of water or release agents from overhead gantries. The application time is reduced and the release agent is applied more consistently and with less waste.

Modern ultra-high-molecular weight bed liners are available, which eliminate the use of release agents. These liners may initially be expensive but can save the time previously required to spray the release agent in the truck bed [31.].

8.2. LOADING

Asphalt transport starts with loading the truck correctly and is necessary to eliminate truckload segregation. This means that a normal truck needs to be loaded with at least three different drops, with the first drop being very near the front of the truck bed, the second drop extremely close to the tail gate, and the third drop in the centre [29.]. This type of loading is shown in Figure 3. This process reduces the distance that the coarse aggregate particles can roll and thus significantly reduces the amount of segregation that will occur during the loading operation. This also helps ensure a balanced load across the vehicle axles.

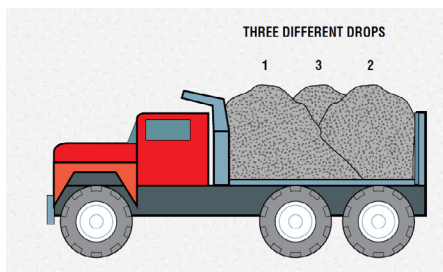


Figure 3: Proper truck loading [29.].

Segregation might also occur when the mixture is poured too slowly into the truck.

8.3. TRANSPORT LOGISTICS

Long haulage distances make it more difficult to achieve a continuous supply because of potentially differing traffic conditions and delays which increase any temperature losses which will reduce the time available for compaction. When long haulage distances are involved, additional care must be taken to ensure continuity of supply and avoid material being stored in delivery vehicles for excessive periods [5].

In the case of long haulage distances and / or time-consuming material delivery on specific sites then the use of asphalt produced with a viscosity reducing additive has advantages.

Information technology can increasingly be used to inform the paving crew where the asphalt trucks are, which material they are transporting, how much and what their Estimated Time of Arrival (ETA) is. See Figure 4 for an example. This technology is able to enhance a smooth operation and/or e.g. initiate alternative supply.



Figure 4: display with information about the asphalt trucks (Source: KWS (NL): ALIS: Asphalt Logistic Information System)

8.4. UNLOADING

Management of delivery vehicles on site is critical to help ensure a consistent flow of material to the paving team, as well as overseeing the safety of personnel on site. Movement of reversing vehicles should be controlled by a specifically trained operative (banksman) in communication with both the driver and paver crew. Reversing cameras on trucks can assist with driver visibility but should not be the only method, particularly at night.

It is important to ensure that the trucks approach the paver without bumping or interrupting the constant speed of the paver as this causes irregularities in the asphalt mat. When tipping directly into the paver hopper, the truck should always stop short of the push rollers on the paver and allow the paver to pick up the truck. The truck and paver need to maintain contact during tipping and it may be necessary for the truck driver to apply light brake pressure on a downhill grade.

When unloading a truck into the paver hopper it is important to discharge the material such that the hopper remains as full as possible at all times, rather than 'dribbling' the material into a paver. In essence the rate of discharge from the truck needs to match the rate of laydown of the paver.

Truck tipping needs to be as quick as possible but controlled to avoid "bumping" of the paver. Particularly for first loads, rapid truck discharge 'floods' the paver hopper and minimizes material-run-around that often occurs at the tail gate. Rapid discharge prevents also an accumulation of coarse material at the outside portion of the paver wings [29].

The truck body should not be raised too steep at the beginning of the discharge, so as to prevent overfilling the hopper and to avoid segregation of coarse aggregate, which may run on the surface of the mix and accumulate in a contiguous block in the hopper [18]. The tipping angle should be slowly increased to ensure a smooth flow of material. Subsequent loads need to be brought to the paver before the hopper is emptied.

An additional method used to deliver the asphalt mixture to the paver is a material transfer vehicle (MTV). An MTV that remixes reduces any segregation and temperature variation that may have occurred in the mixture as a result of the poor truck-loading procedures or transport delays by remixing the product prior to discharging into the paver.

The MTV should allow the paver to operate almost continuously, without stop-

ping between truckloads of mixtures, as long as a continuous supply of the mixture is available from the asphalt plant. Therefore, the paver operator can keep the head of material in front of the screed constant by supplying a continuous amount of mixture back to the screed and obtain a smoother asphalt layer. Use of an MTV also eliminates the problems of bumping the paver and truck driver braking as the units are not in contact and the paver does not push the MTV or delivery truck.

When using a Material Transfer Vehicle an extra hopper (with a large storing capacity) can be placed in the hopper of the paver. Such an extra hopper is insulated to prevent cooling of the asphalt mixture and can be partly heated to maintain a constant temperature of the mixture even for a prolonged period of time and to prevent the mix from sticking.

9. PAVING OPERATION

To obtain a durable pavement the paving operation is very important. With the same basic materials a better performance and a better durability can be obtained if their installation is enhanced.

It is key to balance plant production, transport, paving and compaction in such a way that a constantly moving paving operation (paver) is possible without stops and starts. Stops can lead to uneven temperatures, material segregation and ultimately an uneven surface of the paved material. As previously noted, a Material Transfer Vehicle (MTV) can assist to achieve no stops and starts.

A paver or asphalt finisher is used to spread the asphalt mixture (received from the truck or MTV and to provide an even (surface) layer and homogeneous pre-compaction to give sufficient mix stability so that rollers can start the compaction process.

A paver has three basic components – a hopper and material transfer system, the tractor and the screed. The tractor unit provides the forward energy for the whole operation, pushing the hopper, the delivery vehicles and the loads, and pulling the screed behind. The hopper and transfer system move and distribute the materials to be in front of and across the width of the screed. The screed levels and partly compacts the material to a controlled thickness and profile.

During the paving process improper operation of a paver can cause segregation, unevenness, and/or inconsistent thickness in varying degrees, which can affect pavement durability. In [29.] suggestions are given that should be considered when segregation occurs at the paver.

A heated screed should be used. This is particularly important at the start up every day. A cold screed will affect both the mixture and the (joint) density. The end gates of the screed should always be down and they should always be in contact with the substrate layer. The end gates provide confinement to the mix and aid in compaction of the asphalt at the edges of the layer being paved.

For paving base courses and binder courses use a string line or other electronic devices as a guide for the paver in order to produce a straight and smooth surface.

Basically, the top layer should be paved without leveling, because the unevenness of the base over an extended paving path (5 tow arm lengths = 3 paver

lengths) are compensated.

In case of paving of a top layer that must be at the same level as an already paved asphalt layer or when being connected to a building, the use of a suitable height sensor is recommended. In exceptional cases where the evenness of the over-building base (e.g. asphalt binder) can no longer be improved, the use of a suitable reference for paving with automatic leveling system is required [11.] and [18.].

With a long ski (up to 13 meters) with ultrasonic sensors a very good evenness can be obtained. With up to four sensors, even large area unevenness, such as road waves, are compensated for. The individual sensors can each be positioned separately.

With these measurements, the system calculates an average, and provides a virtual reference level. With four sensors, long unevenness that occur in regular intervals of five to seven meters, can be detected. Such a long ski can provide a very stable and accurate height information (see figure 5).

Coordinate paver and auger speed to allow for a uniform head of material across the entire width of the paver. Maintain paver and auger speed. The driving speed of the paver should be constant but not be too high. If the paver is not able to keep a constant speed, it should stop.

A range of paving machines exist of varying (and variable) widths, different tractor weights and power outputs, different screed weights and compaction capacity, different hopper volume and with a range of operating and control systems. Careful selection of the right paver for the job is a first important stage in delivering a good pavement.

The paving crew has control of various elements of the equipment – the paver direction and speed, the auger (material transfer) speed and height, the screed tow point height and angle of attack, screed profile and vibration. The operators require the skill and experience to balance all of these for the materials being delivered to produce the best pavement mat to be compacted.

The evenness of the surface of the asphalt layer relies on balancing the forces acting on the screed when paving. The traction force (forward movement) must be sufficient to tow the screed against the weight (or head) of material delivered across the auger. The weight and forward movement of the screed will act to squeeze the material underneath, as it is slightly angled. The screed essentially “floats” on (is supported by) the material passing under it.

The most important control of the paver is on the tow point height as this determines the thickness of the asphalt layer by changing the angle of attack of the screed and hence the volume of material passing underneath. However, the angle of attack is also affected by other factors such as the auger speed or height, paver speed, stability and stiffness of the asphalt materials. When these factors fall out of balance or are regularly changed then it can result in irregular thickness, unevenness, or poor texture.

With so many factors influencing the balance of the screed it is therefore most desirable to ensure that changes are not regularly required – the best jobs are those where the paver starts up and the operators do not need to change any of the controls!

Control systems for pavers vary hugely in complexity, from a string line between levelling pins to contact or sonic skis and averaging beams through to fully automated 3D and millimetre accurate sensor systems. In essence their operation is based on the same principles in that when variations from the target level or thickness are measured or detected then the paver settings are adjusted – either manually or automatically. With sufficient data of conditions ahead of the paver, the time and distance required for adjustment can be increased in order to smooth out and minimise the impact of any changes.

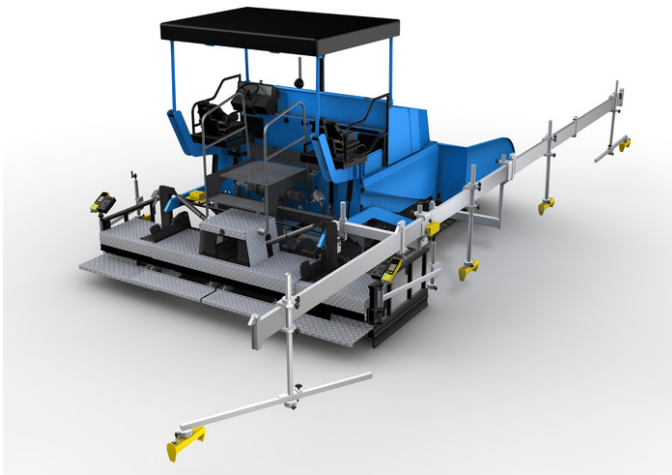


Figure 5: Example of big sonic ski to eliminate long waves (source: Moba)

Use extend augers and tunnels where needed to ensure a continual supply of fresh material.

Hand raking should not be done unless absolutely necessary. The most uniform surface texture can be obtained by keeping the handwork behind the screed to a minimum.

Excess material should not be spread over the fresh paved material compacted by the screed.

The raker should be alert to a crooked edge on the mat so he can straighten it immediately. He does this by either removing or discarding the mix that bows outside the edge line or by adding mix from the hopper if the edge of the mat is indented. He will occasionally need to work along the longitudinal joint. If the paver follows the guideline, the back work will not be necessary.

Surplus of asphalt should not be spread across the asphalt surface as this will result in non-uniformity of the surface texture, even after proper compaction is obtained [32.].

Some other very important issues are:

- Shifting truck in front of the paver: If the paver stops and the truck is backing into the paver there is a risk of creating a bump.
- Emptying the hopper when shifting truck should be prohibited because of cold material in the edges of the hopper. Serious variations in the surface are observed.
- If the trucks are delayed (because of traffic) the best solution could be to lift the screed and make a transversal joint.

9.1 PAVER SETUP

The task of the paver or asphalt finisher is to provide an even (surface) layer and homogeneous pre-compaction to give sufficient mix stability so that rollers can start the compaction process. It also has to provide a homogeneous surface texture [33.].

The screed levels and pre-compacts the asphalt mixture to a specified thickness, grade, cross-slope and crone profile. The tow points of the screed are set to give the required thickness of the asphalt layer. In case of using an automatic levelling system, their position may then be continuously adjusted by electronic systems. A grade controller automatically maintains the surface level against a reference surface such as a control ski, a string line or an mm GPS system. The slope controller is used to maintain the transverse inclination of the screed [33.].

The angle between the bottom plate of the screed and the surface being paved is known as the 'angle of attack'. The desired surface evenness is obtained if all the forces acting on the screed are in equilibrium (see Figure 6). Only then the screed will settle into its proper angle of attack.

The angle of attack may be increased or decreased by raising or lowering the tow point level. Any movement of the tow points disturbs the equilibrium and results in a rise or fall of the screed. Once the screed has attained the new level, the angle of attack is restored and the forces revert to a state of equilibrium [33.].

The main parameter affecting the pre-compacting by the screed is its weight. A heavier screed will result in a better pre-compaction than a lighter one. Compaction systems such as tampers and vibration units are attached to assist in pre-compaction of the mixture. For special applications such as base layers special high-compaction screeds have been developed [33.].

The height of the auger is very important. If the high auger is set too high it can cause traction problems and a material overflow, if it is set too low the auger can lead to an increase of the pre-compaction and to waves. Both incorrect settings affect both the bulk density and the evenness of the asphalt layer. The distance between the bottom edge of the auger blade to the base depends essentially of the largest aggregate diameter of the asphalt mixture:

- Maximum aggregate diameter ≤ 16 mm: layer thickness + 50 mm
- Maximum aggregate diameter > 16 mm: layer thickness + 80 mm [11.] and [18.].

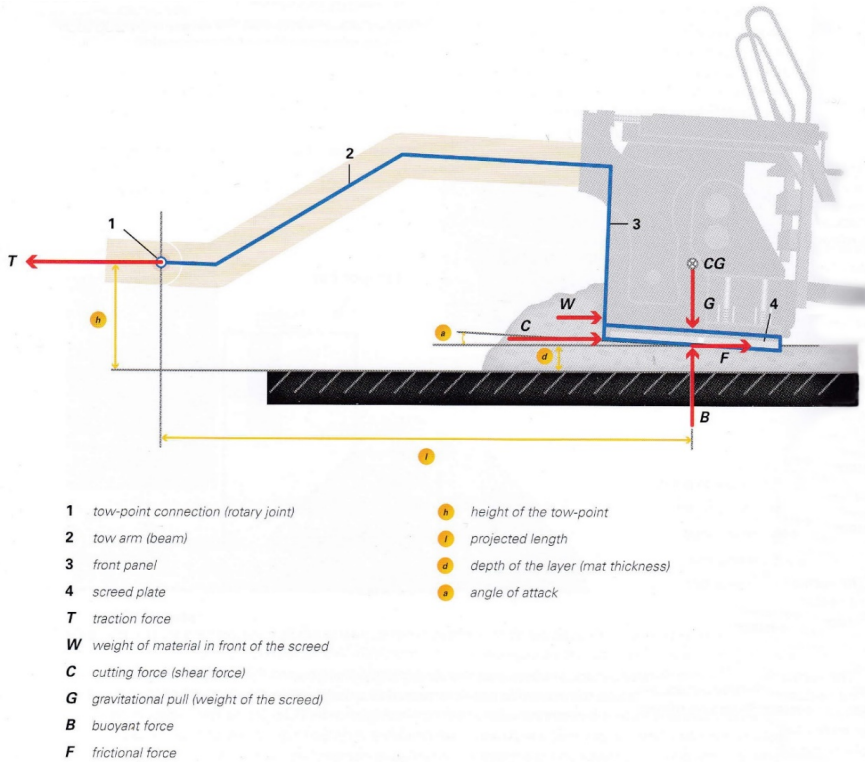


Figure 6: Factors that affect how the floating screed maintains its vertical position [34.].

The choice of a paving unit starts with the screed. It has to be able to lay the asphalt at the desired width. The choice of the screed also depends on the type of asphalt mixture and layer thickness. The choice of the tractor will depend on the choice of the screed. It must be powerful enough to tow and to support the screed at the specified widths [33.].

The paving speed should be as constant as possible. Variations will result in an uneven surface. An automated system to pre-set and maintain speeds under varying load conditions is recommended. Stops may not only blemish the surface, they will also result in temperature differentials (often called 'temperature segregation'). Every time the paver stops, the screed tends to sink in the asphalt mixture and will result in three distinct

temperature zones (auger chamber, under screed plate, uncompacted area under the catwalk on the back of the screed) that could result in unevenness after the paver moves and the breakdown roller compacts the area where the paver stopped.

9.2. INFORMATION TECHNOLOGY ON THE PAVER

For asphalt paving without string lines or for an accurate reference surface but with stringent elevation, cross slope and/or smoothness specifications (like e.g. on airports) and for asphalt paving with frequent cross slope changes (on e.g. highway exits and curves, parking lots, sports surfaces) 3D technology can assist during milling operations and asphalt paving operations.

The 3D technology is using the 3D design together with a Global Navigation Satellite System (using GPS or Galileo).



Figure 7: Example of use of GPS.

When controlled via GPS or by a local station with tracking mode, the current position of the screed is permanently indicated and compared to a ground (design) model, which has been loaded into the on-board computer. If the comparison results in a deviation in grade or cross slope, it will automatically be levelled out by the system.

In this way it is possible to integrate automatic changes in the cross slope during one project. With this machine guidance system an automatic height control and cross-slope regulation can be achieved.

So in short:

- The position of the paver (screed) is measured remotely
- The project data are compared to the actual screed position
- Deviations between design and actual position are adjusted by the levelling controller
- It adds the accuracy and the flexibility of 3D technology and allows to also pave with variable depth and slope based on the 3D design.
- The 3D technology eliminates the use of string lines.

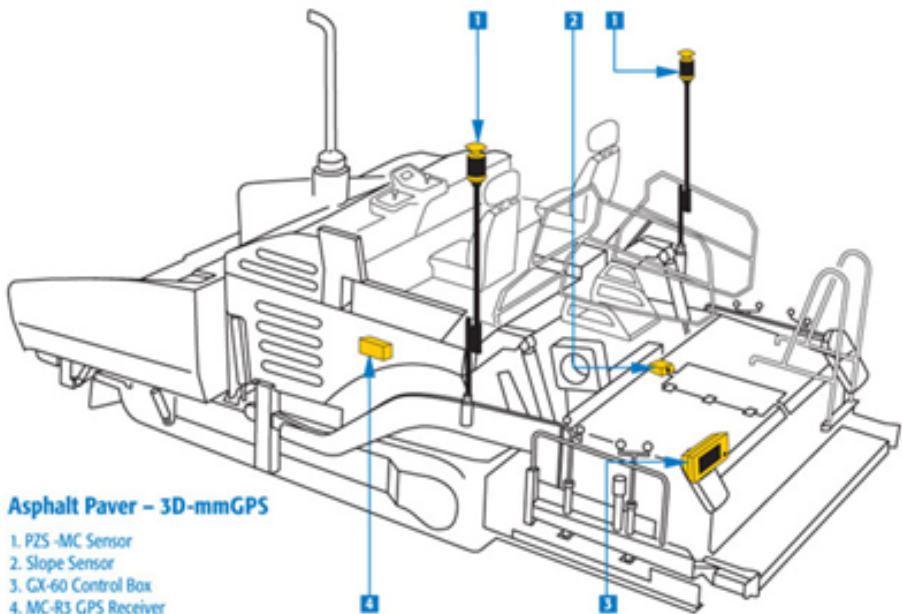


Figure 8: Schematic view of 3D on the paver [25.]

For the paving process it is important to have the relevant information available. There is information technology to inform the paving crew about the asphalt supply by trucks (see 9.1. track and trace systems).

Next to that it is important to know the weather conditions (wind speed, air temperature and humidity) to be able to calculate the cooling speed of the asphalt mixture. A weather station can be added to the paver to provide those data on a display.

Next to the weather station other devices can be used to assist the paving crew, like (see also Figure 9):

- Electronic leveling and slope control systems
- GPS
- millimetre GPS for height of finished product
- Temperature / IR (Infrared) line scanner just behind the screed for the asphalt temperature just behind the screed

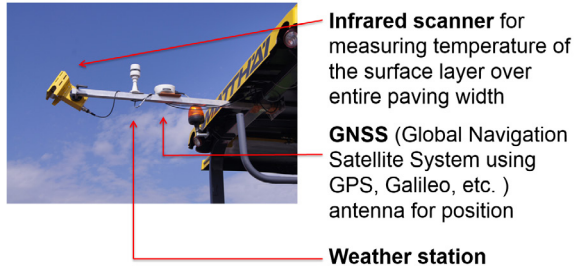


Figure 9: Sensors built on a paver

Information technology makes it also possible to store many data that can be used (in a later stage) to analyse the paving process. Figure 10 gives a schematic overview of the data exchange possibilities for an asphalt paving project.

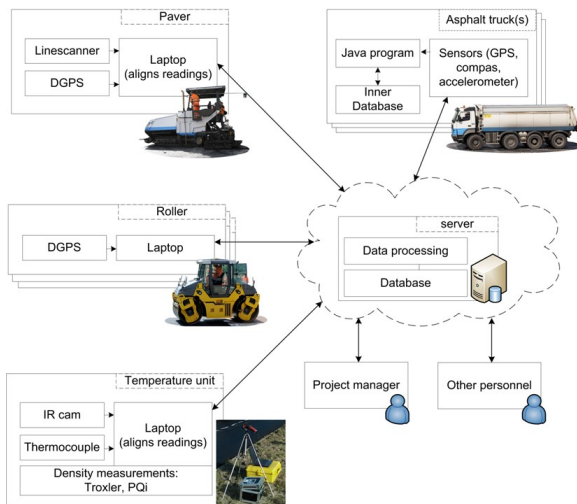


Figure 10: Overview of data exchange possibilities [35.]

9.3. SEGREGATION

For asphalt there are two types of segregation that can occur. That are temperature segregation (also called 'Temperature Differentials') and mixture segregation.

9.3.1. TEMPERATURE SEGREGATION / TEMPERATURE DIFFERENTIALS

Measuring the asphalt temperature behind the screed is important see the homogeneity of the asphalt temperature. This temperature should be uniform to be able to compact the asphalt uniformly. (Colder spot are more difficult to compact; that results in a lower compaction degree and that can result in stone loss (in surface layers) and early ravelling.

When the asphalt temperature behind the screed is not uniform the asphalt crew can look for the cause and correct that when possible.

There can be many reasons why the temperature behind the screed is not uniform. It can be due to cooling of the asphalt in the truck, cold(er) asphalt in the hopper, etc. Each step in the process should be checked. The temperature distribution as shown on the temperature display (Figure 11) or on a mobile device (figure 12) might also give directions. The use of an infrared camera might be useful to find the reason of the temperature segregation / temperature differentials.

More information about finding the reasons of temperature segregation (temperature differentials) can be found in [36.].

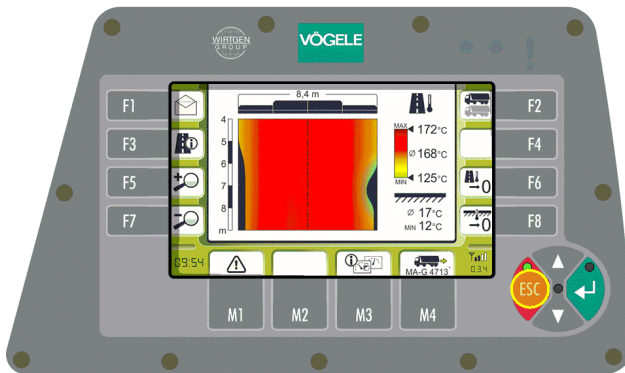


Figure 11: Asphalt temperature displayed on the paver

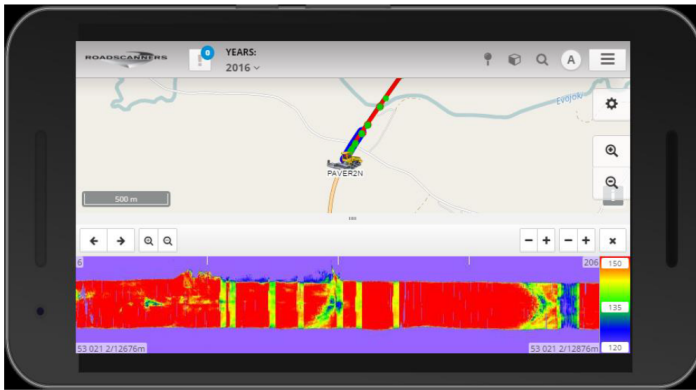


Figure 12: Asphalt temperature displayed on a 4G mobile phone [37].

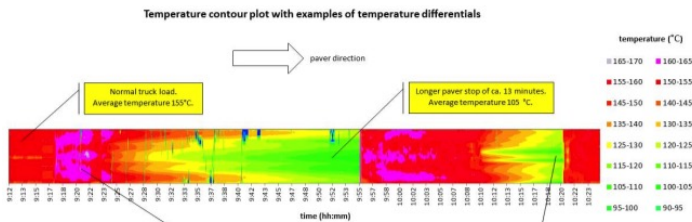


Figure 13: Example of Temperature Contour Plot [38.]

In Sweden and Norway the Infrared (IR) scanning technique is used in contracts to measure the uniformity of the asphalt temperature just behind the screed. The contractor can get a bonus when the temperature of the asphalt behind the screed is uniform and he has to pay a penalty when it is not uniform; the call those non-uniform areas: "Risk areas" (see figure 25). Since the 1990's Sweden and Norway are using bonuses for good quality too instead of having penalties only. The argument is "splitting the profit".

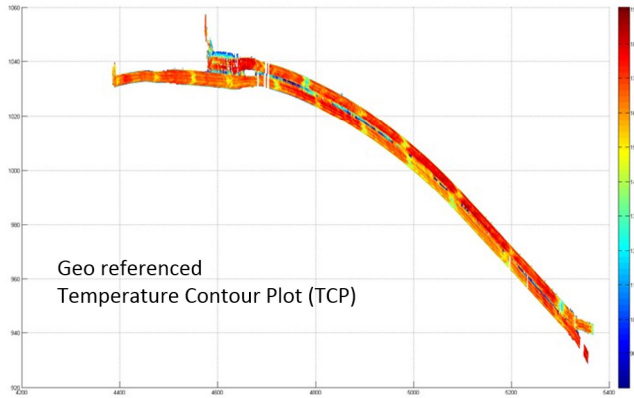


Figure 14: Example of geo referenced Temperature Contour Plot [38.]

9.3.2. MIXTURE SEGREGATION

Next to the temperature differentials / temperature segregation there is mixture segregation.

Mixture segregation may occur in the truck-loading stage (see 9.2 Loading). Mixture segregation at the edges of the lane being paved may be caused by stone segregation along the sides of the truck and incorrect mixture distribution in front of the screed. For example, if the material level is too high, it will slope towards the outer edges where stones can segregate. This can be avoided by using truck beds designed for asphalt transport (formed like a bathtub).

The distance between the side plate of the screed and the end of the auger shaft preferably should not exceed 65 cm [11.] and [18.]. The height setting of the auger is another important factor in this respect.

A segregated strip in the middle of the lane is caused by the auger drive unit located at the centre of the augers. Depending of the type of paver auger drivers at the inner ends of the shafts will prevent this from occurring. To prevent the development of segregation and unevenness's, an enlarged distance between auger and tamper shield has proven to be effective when large paving thickness's, large paving widths and at critical materials (e.g. AC 22). This does, however, increase the power demand of the paver, which also adversely can affect the evenness at an unfavorable ratio machine performance / paving width [18.]. Transversal segregation zones normally arise from the separation of material at the front and back ends of the truck [33.].

10. COMPACTION

One of the most important parts of good road construction is a good compaction of all pavement layers. It increases the stiffness of the layers, hardly without any additional material cost.

The aim of compaction is to achieve the appropriate air voids content of the asphalt mixture.

It is important to have a good homogeneity within the individual pavement layers in all directions, by using homogeneous materials and equal (homogeneous) compaction levels. A chain is as strong as the weakest element [24.]. By creating homogeneity / uniformity the spreading of material characteristics reduce. That also means that the spreading in residual pavement life / durability reduces and that the early pavement failures are reduced (see Figure 15).

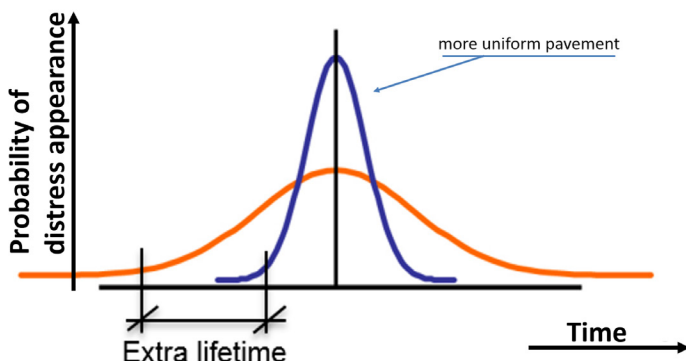


Figure 15: Influence of reduction of spreading / uniformity on pavement durability, shown as probability density function

Good compaction of asphalt layers is essential. Good compaction will increase the resistance to permanent deformation, improve the fatigue behaviour [39.] and reduce water permeability of the asphalt layer and minimise or prevent moisture damage.

Higher compaction of the asphalt mixture can result in lower pavement thickness needed due to improved fatigue behaviour (for example decrease from 8% air voids to 5% air voids can lead to 15 % less thickness [40.]). Better compaction of the asphalt layer also results in a better stiffness and it will enhance the resistance against moisture-related damage.

In order to be able to compact the asphalt mixture in an optimal way it is essential to have a good mixture composition. An optimal recipe will result in a homogenous material structure which facilitates adequate compaction. Compaction technology can be adopted to optimise compaction efficiency via heat mapping, GNSS (Global Navigation Satellite System) mapping [30.].

Well-constructed flexible pavements show very long service lives provided that distress mechanisms such as rutting and cracking are confined to the pavement surface, which significantly facilitates maintenance [41.] and [42.].

In some cases it is more difficult to obtain the required density. Examples are compacting around iron works, bridge joints and other disruptions. In these case practical solutions have to be found.

It is also difficult to compact free edges. There are several methods to improve the compaction at free edges, including the use of temporary restraints and cutting back of less well-compacted material. In chapter 11 'Joints' several techniques are described.

Adequate compaction is essential and has to be undertaken before the asphalt mixture cools. The time available for compaction will depend on the properties of the mixture (particularly the binder), the layer thickness and the weather conditions (temperature and wind-speed) [5.]. The compaction starts with the pre-compaction by the screed of the paver. Sufficient rollers should be available for the job to complete the compaction everywhere the time available to compact [5.]. If the time required for a demand oriented compaction time is larger than the weather conditions and built-in related time available, the built-in process should be adjusted accordingly or be terminated [11.] and [18.].

10.1. CHOICE OF ROLLERS

For the compaction of the asphalt behind the paver generally two or three types of rollers are used.

10.1.1 TYPES OF ROLLERS

Various types of rollers can be used and the mostly used types are:

- Steel wheel rollers
- Vibratory rollers (generally steel drum rollers)
- Pneumatic tyre rollers

The actual choice of the rollers depends on the type and size of the job and the mixture to be compacted and is often largely based on local preferences [33.].

The compaction effort of the static wheel roller is primarily dependent on its static weight and the width of the drums, but also influenced by the drum diameter. In addition, the drum diameter affects the flatness/evenness.

Pneumatic tyre rollers rely on static weight and the tyre pressure for their compaction effort.

Vibratory rollers combine the static load of the drum with dynamic loads. The vibration largely reduces the internal friction in the mix and improves compaction effect even when used with comparative low static linear loads [33.].

Static force exerted by a steel drum roller or pneumatic tyre roller is affected by the speed of the roller. The faster the working speed, the lower the density. So if a higher density behind a static compactor is needed, first lower the working speed. More passes can be added but a slower working speed is the first variable to be considered [30.].

10.1.2. COMPACTION PHASES

The rolling process can be divided in the phases:

- Initial compaction
- Intermediate compaction
- Finish compaction

THE INITIAL COMPACTION PHASE is the first step in the compaction process and should produce the majority of the target density in the asphalt layer. Initial compaction should begin at the highest possible asphalt temperature that supports the weight of the roller without distorting the asphalt mixture.

Steel drum vibratory rollers are commonly selected for the initial phase of compaction because vibratory rollers combine weight and impact. The normally have the highest production rates.

Vibratory rollers normally start with vibrating passes. On tender and unstable mixtures, it may be more suitable to start with one or two static passes at low rolling speed (1-2 km/h). The roller should follow as close as possible behind the paver so that the compaction can take place at temperatures above the

minimum compaction temperature ensuring adequate compaction levels [30.] and [33.].

Pneumatic tyre rollers are sometimes used in the initial compaction phase on base or binder layers.

Selecting the correct roller for the initial phase of compaction is critical to achieve consistent and acceptable density. Pre-compaction planning is needed to confirm that the roller will be able to match the paving speed (see also 11.1.3. "Test strips / Trial Sections").

THE INTERMEDIATE COMPACTION PHASE follows immediately after the initial phase on most mixtures. The goals of intermediate compaction are to create the final density in the asphalt and to begin the process of cleaning up marks left by the initial phase roller. The asphalt should be hot enough to allow some aggregate movement so usually intermediate rollers work in the temperature zone just behind the initial phase temperature zone. In the intermediate phase the density will be increased until the required degree of compaction.

Pneumatic tyre rollers are a common choice for intermediate compaction because they can exert high static pressure without delivering impact forces [30.]. For thin wearing courses pneumatic rollers do not have any effect on the compaction degree on. Here oscillating rollers are better.

THE FINISH COMPACTION PHASE is the final phase. The main purpose of the finish compaction phase is to remove roller marks or pneumatic tyre marks and other surface imperfections. The finish compaction phase is usually accomplished by a steel drum / steel wheel roller set in the static mode. Finish rolling may also increase density, especially if the asphalt is relatively hot. A roller with a higher linear load will clean up drum stops marks. The static line load should be at least 25 kg/cm for smoothing. The use of smooth rollers with a linear load of about 35 kg/cm will make smoothing much easier [11.] and [18.]. If the finish roller is leaving its own stop marks, the asphalt is still too warm and the finish rolling should be delayed. An on-board temperature scanner helps the roller driver to stay in the correct temperature zone [30.] and [33.].

On large jobs, the tonnage paved per hour is usually governed by the capacity of the asphalt plant. The delivered asphalt, the paving width and the layer thickness determine the speed of the paver. The lay-down speed (in square meters paved per hour) serves as a basis for the required roller input [33.]. Note that the delivery, paving and compaction of the asphalt mix must be coordinated; the mixing capacity is not equal to built-in performance! [11.].

Several App's (tools) are available for iOS and Android devices for asphalt paving professionals to plan their paving jobs by helping to estimate trucking needs, paving speeds, compaction and other factors. The calculator can help optimize the job site, reducing inefficiency and contributing to smoothness [30.].

10.1.3 TEST STRIPS / TRIAL SECTIONS

On many projects, a test strip / trial section is required to be successfully completed before the start of full production.

In general the test strip / trial section verifies that the asphalt production meets the job mix formula, that the paving equipment lays down a satisfactory asphalt, and that the selected compaction equipment achieves the required / specified density [30.].

10.2. ASPHALT TEMPERATURE INFORMATION

The roller can be provided with an asphalt temperature sensor, so he can see the actual temperature of the asphalt surface he is compaction.

It is also possible to send the data of the temperature scanner on the paver to the roller. In this way he knows the asphalt temperature behind the screed. When the roller driver knows the temperature window within he can to compact the asphalt he can adjust his compaction scheme. In this way all asphalt will be compacted at the same temperature range (assuming that the asphalt temperature and the procedure for the roller compaction are correct and correctly applied) which gives a very homogeneous compaction / density. In the end this results in a better durability.

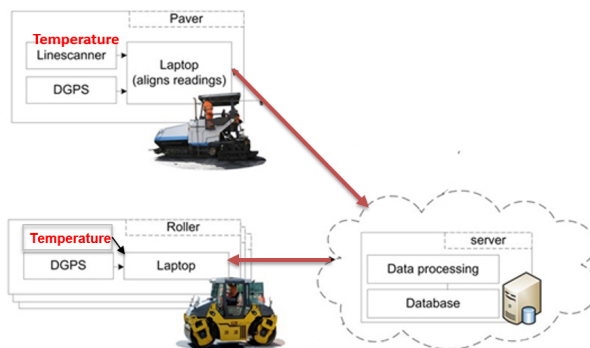


Figure 16: Temperature information transfer to roller driver (Based on [35.])

10.3. CONTINUOUS COMPACTION CONTROL SYSTEMS

To assist the roller driver and to improve the compaction process Continuous Compaction Control systems can be used.

There are various systems for Continuous Compaction Control. Some systems measures a kind of stiffness value of the material being compacted. These values measured do not correlate well with the compaction degree but they are very useful for obtaining a uniform compaction (level) of the asphalt.

A Continuous Compaction Control system without GPS can show to the operator:

- Temperature of asphalt
- Stiffness values
- Speed of roller
- Amplitude
- Frequency

A Continuous Compaction Control System with GPS can also show:

- Stiffness values as a map
- Values of temperature of asphalt, speed of roller, amplitude & frequency as a map
- Trend of stiffness values
- Exact geographical position
- Number of passes
- Date and time of passes

The information shown can be stored or transmitted and used for office analysing in a later stage.

Figure 17 shows an example of a display on a roller.



Figure 17: Number of roller passes and asphalt temperate shown as map.

System shows the number of roller passes in longitudinal and transverse direction. Shows also asphalt surface temperatures and when it is too cold to be compacted.

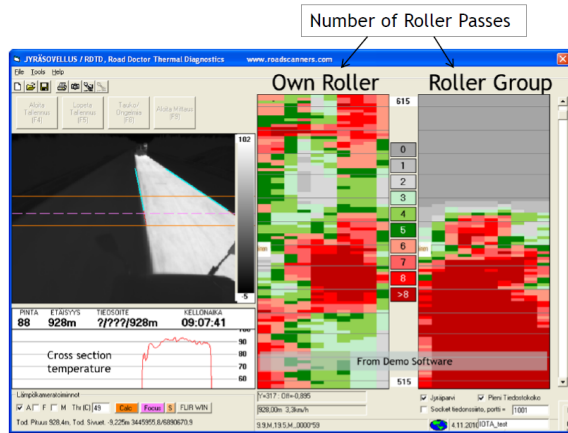


Figure 18: Display showing number of roller passes of 'Own Roller' and 'Roller group' [37].

Figure 19 is showing a Compaction Contour plot of a certain project, created after having finished the project.

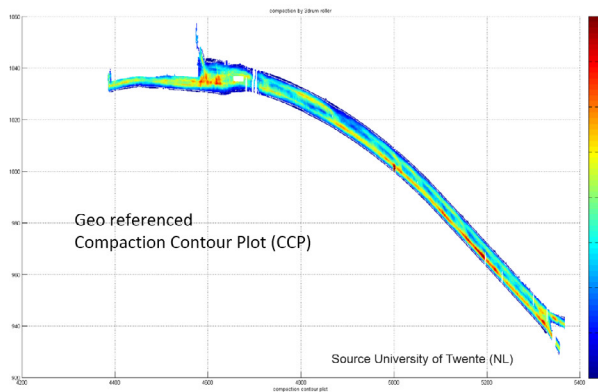


Figure 19: A geo referenced Compaction Contour Plot [38].

The roller driver is last one in process. So if he does things wrong, the contractor might be forced to remove the asphalt layer and to start again. So his work is crucial.

A Continuous Compaction Control System can assist the roller driver as guidance, but cannot replace his knowledge. The roller driver can see whether his rolling strategy is working well and it can be used as proof that the roller driver did good job.

The "measured Compaction Value" cannot predict the asphalt core densities accurately.

10.4. SITE VEHICLES

Be careful with early trafficking with site vehicles.

Corners and edges are always vulnerable, particular when the asphalt has not cooled down completely. Therefore routes should be identified and, when necessary, barriers erected to avoid traffic over-running the edges of freshly laid asphalt. Care should be taken to ensure that those routes are followed. So as few vehicles as possible should be allowed to run on pavements before they have been completed [5.].

11. JOINTS

For durable and long lasting asphalt pavements good performing longitudinal joints are essential, otherwise they will lead to earlier than normal rehabilitation because the material at the joints is likely to be less compacted. So properly constructed longitudinal joints are necessary to ensure acceptable long term performance.

The best way to eliminate joints is not to have them. Echelon paving places adjacent layers at the same time (generally the distance between two pavers should be not more than one paver length [11.], [18.] and [43.]) so that the two layers can be compacted as one operation. When this practice is used, cold joints and their inherent problems are avoided [44.]. Echelon paving requires preparation and commitment from the owner (i.e. full lane closure of the roadway is required). This techniques (also called 'hot to hot paving') is often used for the surface layers of runways.

If it is not possible to eliminate cold joints, the amount of joints should be minimised.

When longitudinal joints are required due to the nature of the job the location of the longitudinal joints is important. There should be no longitudinal joints in the wheel paths.

The joints in different pavement layers should not coincide in order to avoid having potential 'weaker' spots on top of each other. The minimum distance between joints in adjacent layers is often specified as 300 mm or at least 150 mm, but the distance should be as practical as possible [5.].

If 'cold' joints are permitted, provision should be made to ensure that the vertical face of the joint can be adequately bonded to the new material and that joints are compacted to a level similar to that of the rest of the asphalt layer.

11.1. TECHNIQUES TO CREATE JOINTS

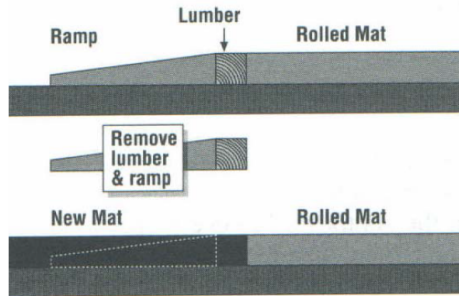
There are various techniques that can be used to create good or better joints.

11.1.1 TRANSVERSE JOINTS

When paving operations are to be discontinued for an extended period (e.g., end of day), it is necessary to construct a transverse joint across the pavement being placed. This can be accomplished in a number of ways.

Normally sand is applied to the substrate area (of which the asphalt will be removed the next day), complete the paving process without leveling, compact it with the rollers, cut back on the following day.

It is also possible to create a butt joint as illustrated in Figure 20.



a) Butt Joint

Figure 20: Transverse joint formation [45.].

Saw-cut faces may be required by project specifications. They are made in cold mats just before the new pavement is laid.

The fresh mix at the joint should be “loose depth” (thicker than the previously compacted pavement). Inexperienced rakers may try to rake the hot asphalt concrete to the thickness of the cold mat. This may look better before the joint is rolled but results in a low spot along the joint after compaction [32.].

Transverse joints should be rolled parallel to the joint (crosswise to the paving direction) before any other rolling begins on the new mat. Transverse joints must be compacted in static mode (with the vibrator off) since the vibrator may crack cold pavement [32.].

11.1.2 LONGITUDINAL JOINTS

Joint heaters can be used to improve joint density and bonding.



Figure 21: Example of joint heater

Practice has shown that Warm mix asphalt (WMA) has the potential to improve the performance of a cold longitudinal joint [44.].

It could be that the ease of compaction for these materials raises the density of the joint. It also could be that the differential in temperature between the mix being placed and the temperature at which the previously placed material regains a bit of workability is sufficient to provide higher joint density and better adhesion between the materials.

Proprietary pre-applied joint sealants can be used. There are methodologies for applying a sealant to the exposed surface of the cold joint prior to paving. Pre-formed joint tape can be rolled onto the joint. All of these materials soften and penetrate voids in the existing mat when heated by the application of hot mix in the adjacent lanes. While these compounds do not improve joint density, they significantly reduce the permeability of the joint and also increase adhesion, thus enhancing the durability of the joint [44.].

In some cases 'Inlay paving' can be used. The existing surface is milled for one lane only to the extent of the day's paving operation. The inlay is placed against the vertical longitudinal faces. When they first lane was paved, (the next day)

the other lane will be milled and filled. This lane is milled a bit wider than necessary to remove some of the recently place asphalt [44.].

Rolling from the cold side / from the hot side: Rolling of the longitudinal joint should be done from the hot side with a vibratory roller as soon as possible. The objective should be to obtain the highest possible density at the joint to ensure best performance [46.].

Use of 'edge restraining devices'. This technique uses an edge-compacting device which provides restraint at the edge of the first lane constructed. The restraining device consists of a hydraulically powered wheel which rolls alongside the compactors drum simultaneously pinching the unconfined edge of the first lane towards the drum providing lateral resistance (See Figure 22).



Figure 22: Use of an edge restraining devices

This technique is believed to increase the density of the unconfined edge. The adjacent lane is then abuted against the initial lane edge [47.].

The cutting wheel technique involves cutting 40-50 mm of the unconfined, low density edge of the initial lane after compaction, while the mixture is still flexible (see Figure 23). The width of the asphalt strip to be removed depends on the thickness of the layer.



Figure 23: Roller with cutting wheel (Bomag)

An other technique is the use of edges formers attached inside of the side shield of the screed, when paving in larger layer thicknesses or with easily compressible and very hot mixed asphalt [11.] and [18.].

Best Practices for Construction and Specifying HMA Longitudinal Joints (of the Asphalt Institute, USA) can be found in [48.].

All joints should be sealed with a thin film of bituminous binder. The sealant is intended to ensure some bond between the adjacent sections as well as to fill any access of voids. The sealant is also applied to cover the joint. If this method is used for surface layers, the longitudinal joint is usually placed offset from the centreline as these materials are not always compatible with road marking materials [44.]. This techniques does not apply to Porous Asphalt surface layers because it would block the horizontal movement of water though the Porous Asphalt layers.

12. BOND / TACK COATS

The role of the bond coat / tack coat is to ensure a proper bonding between the layers. This bond is essential for the bearing capacity of the pavement. Where an insufficient bond between layers is provided the pavement layers can bend individually under loading and not act as one thick layer. This leads to higher stresses at the bottom of each of the layers and that will lead to premature cracking.

An inadequate bond can also allow water to penetrate between the layers by coming from the side or from longitudinal joints. If water penetrates between the surface and binder layers, the binder layer can start to disintegrate.

To prevent delamination and ingress of water a good bonding layer is needed. Care in the application and curing rate of bond coat/tack coat is essential to prevent slippage of the asphalt layers during the compaction process, which could lead to longitudinal cracking and difficulty in achieving compaction in the field.

The tack / bond coat should be adequately and uniform applied to the full width of the lane to be paved and should result in a good surface coverage.

A bond coat is a spray application of bitumen emulsion to create stronger bonds between two asphalt layers. Bond coat is usually based on a polymer modified bitumen. It gives also some waterproofing.

A tack coat as a very light spray application of bitumen emulsion to create a bond between an asphalt overlay being placed and the existing surface. A Tack coat is thinner than a Bond coat.

In Europe in general an (unmodified) bitumen emulsion is used. In some European countries a Polymer Modified Bitumen (PMB) is used for the emulsion e.g. in case of very thin or ultra-thin asphalt concrete and for high traffic areas. In some European countries there is a specification that emulsion from PMB has to be used, if both asphalt layers are with PMB.

It is mostly applied with a (separate) bitumen (emulsion) spray bar.

Some pavers have a spray bar (distributor) attached to the paver, just in front of the screed. This technique prevents that (asphalt) trucks destroy the tack coat. The applied rate (of emulsion) and the residual bitumen rate is different from country to country [49].

In some cases a “Hot in hot” paving technique is used. With this technique the binder course and the surface course are paved directly after each other and the binder layer is not (separately) compacted by rollers. The rollers compact both layers at the same time. This “hot in hot” technique is sometimes called InLine Pave. There are also pavers with two creeks after each other in one paver, paving the binder layer first and directly after that the surface layer. This “Hot in hot” technique is called “compact asphalt”. When using these “hot in hot” techniques no emulsion is needed as tack / bond coat.

Vertical or near-vertical faces of existing pavements, ironwork, curbs, gutters and joints should be required to have an application of bituminous material to enhance adhesion to newly laid asphalt [5.].

Before applying any tack or bond coat, the previous layer must be clean and free from dust, leaves or other detritus in order to be able to ensure good adhesion. Once the tack coat is applied, precautions should be taken that the coat remain clean until the asphalt is laid. General traffic should not be allowed on the tack/bond coat [5.].

Tack or bond coats should be applied to that area that can be paved the same day.

Tack or bond coats should not be applied to surfaces that already have an excess of binder on its surface.

Tack or bond coats should be applied between all pavement layers.

13. QUALITY CONTROL / QUALITY ASSURANCE / PROCESS CONTROL

Highways agencies have traditionally used method specifications for specifying and accepting asphalt pavement materials and construction. With this type of specification, the methods to be used in constructing a section of pavement are stated by the agency. If the contractor adheres to the methods prescribed and adherence is verified by the inspector, materials and method specifications are specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material. With the use of method specifications, the burden for quality control and inspection, both labour-intensive activities, is the hands of the owner agency.

13.1. QUALITY CONTROL / QUALITY ASSURANCE

In recent years, many of highways agencies have adopted quality control/quality assurance (QC/QA) specification programs for the construction of asphalt pavements. This new specification is meant to improve the quality of the pavements through frequent testing and monitoring throughout the production and placement of asphalt mixtures. With a QC/QA specification, the Contractor is responsible for the quality of the pavement, while the highways agency is responsible for the acceptance, rejection and/or price adjustment with the degree of compliance with the specifications.

QC/QA specifications are a combination of end result specifications, and materials and methods specifications. End result specifications are specifications that require the contractor to take the entire responsibility for supplying a product or an item of construction.

QC/QA specifications typically are statistically based specifications that use methods such as random sampling and lot-by-lot testing, the promise of QC/QA is that better quality can be achieved by allowing the contractor more direct control over his or her operation.

QA may be viewed as a three-legged stool, note that "QC", "acceptance", and "independent assurance" all support the QA operation. Independent assurance encompasses those activities that combine to produce an unbiased and independent evaluation of all the sampling and testing procedures used in the acceptance program.

Method specifications offer an advantage when a measure of quality is particularly difficult to define. Asphalt-mix segregation is one such case. Segregation is an undesirable feature, but the allowable degree of segregation is difficult to

measure or to specify. Thus, method specifications can be used to specify what a contractor must do to prevent segregation.

Method specifications have a number of disadvantages, however:

- Contractors may not be allowed to use the most economical or innovative procedures to produce the product.
- Inspection is labour-intensive.
- If the quality of the product is measured and found to be less than desirable, the contractor has no legal responsibility to improve it.
- The agency assumes the bulk of the specification risk.
- The quality attained is difficult to relate to the performance of the finished product.

The major weakness of this type of specification is that there is no assurance it will produce the desired quality of construction. Most important, by explicitly specifying the material and procedures, the owner or agency obligates itself to a large degree to accept the end product. Such a specification is also very difficult to enforce uniformly. The terms “reasonably close conformity” and “substantial compliance” cannot be precisely defined. In the absence of a clearly established quality level and a uniform means of measuring compliance, decisions become arbitrary, and acceptance procedures become inconsistent in their application. Limits are usually based solely on subjective judgment or experience and are often difficult to meet because of the lack of definition of the capabilities of the production process and the desired product.

ADVANTAGES AND DISADVANTAGES OF QC/QA SPECIFICATIONS

The greatest advantage of QC/QA specifications to agencies is that they place responsibility for quality of materials and construction on the contractor or producer. Other advantages include more complete, as-built records; statistically defensible acceptance decisions; and savings in labour costs for agency technical personnel when features of the QC/QA specifications are fully implemented. Advantages of QC/QA specifications to contractors and producers stem from greater latitude in the choice of materials and equipment and in the design of the most economical mixtures that meet the specified requirements. Perhaps the greatest benefit is derived from the lot-by-lot acceptance procedures that are incorporated in most QC/QA specifications. When lots are immediately accepted, conditionally accepted with a reduction in payment, or rejected, contractors or producers understand their position. An enforced reduction in price is almost certain to attract the attention of management at higher levels. Management

then has the opportunity to take corrective action before large quantities of out-of-specification material or construction are produced and to avoid

RESPONSIBILITY OF CONTRACTOR

The Contractor is generally responsible for monitoring quality continuously throughout the paving process and reporting results to the Road Authority. The Contractor is ultimately responsible for the quality of the final product.

RESPONSIBILITY OF ROAD AUTHORITY

The Road Authority will typically verify the quality of paving materials and processes at a lower frequency than the Contractor, to verify that Contractor is accurately testing materials in the laboratory and achieving density and evenness on the roadway during paving.

SUPERVISION

There is typically a Quality Control Manager who is responsible to ensure that all materials testing is completed per specification and complies with the job specifications. It is usually the Quality Control Manager's responsibility to report test results to the Road Authority on a daily basis. The Quality Control Manager normally has several quality control technicians working for him in the laboratory and in the field.

IRI

International Roughness Index (IRI) is a measure of pavement smoothness. IRI is measured using a road vehicle with special laser equipment and a computer on board that runs down the road at normal travelling speed (maximum 110 km/h) to measure evenness of the pavement.

3D PAVING TECHNOLOGY TO ENSURE EVENNESS

As noted in Section 10.2, 3D Paving technology is used on some paving jobs to produce exceptionally accurate yield quantities and to pave challenging longitudinal profiles. An electronic design file is loaded into the 3D system, which in turn controls the elevation and cross-slope of the screed using Global Navigation Satellite System (GNSS) data as the paver moves down the road.

PAVING CALCULATOR

Paving calculators can be used to automate the calculation of number of trucks required, paver speed, roller speed, yield quantities, etc. based on some known inputs. Typically, the basic inputs to calculate all other variables, are: tons of mix per hour available from the asphalt plant, paving width, paving depth,

uncompacted mix density (loose density), average truck capacity, paving hours and truck cycle time. The calculator then outputs a recommended number of trucks to use and an ideal paver speed to maintain continuous, non-stop paving all day that will result in the best evenness. This calculation is a static calculation suitable for the jobsite manager. The goal is a continuous paving operation that uses the amount of mix the plant can produce for that job. The industry is now moving to shorter responses times and updating the planning real time.

A good Quality Control System during construction is essential to monitor the relevant issues.

The quality of asphalt can be defined in terms of the characteristics (e.g., asphalt content, air voids, density) required to achieve a specific level of excellence. In the case of highway asphalt materials or construction, excellence is measured according to a certain level of performance, expressed in terms of such features as durability, ride quality, and safety. Quality control, or process control, of asphalt denotes mixing and placing the asphalt ingredients (aggregates and bitumen) in a prescribed manner, so that it is reasonable to expect the pavement to perform properly.

Most important, Quality Control (QC) involves constant testing and evaluation of test results to determine whether production is in control. QC also includes the actions of plant personnel in making necessary changes and adjustments in day-to-day operations.

Here it should be emphasised the role of work preparation is essential; 85% of all problems are due to a lack of work preparation [18.].

Next to the work preparation, education and training of the staff is essential to skill them as professionals fulfilling the expectations of all involved in the usage of the road.

Prior to any paving project, a good Quality Control Plan (QCP) is essential to a successful paving project. The QCP brings together the project planning such as paver speed, roller speeds, amplitude and frequency settings, rolling pattern and final, measured density results. Similarly, a good QCP will outline a procedure for achieving desired evenness (smoothness) on the job. In addition to measuring results of density and smoothness, the paving crew must be aware of the QCP and work closely with Quality Control personnel to fine-tune operations to ensure a successful project. Another critical element of any QCP is to adapt to changing conditions of weather, plant output, trucking and equipment changes without sacrificing the final pavement quality results.

13.2. PROCESS CONTROL

Process control is the means of providing adequate checks during production (or construction) to minimise the contractor's or producer's risk of having the lot rejected. A process is said to be in control when all removable variations have been brought into tolerance. In fact, a primary purpose of process control is to eliminate assignable causes of variance so that the overall variability of the finished lot will approximate the variation used to design the sampling plan for lot acceptance.

With information technology available many data are collected and available for project evaluation (see example in figure 24).

These results are also important for the planning and preparation of similar or future projects.

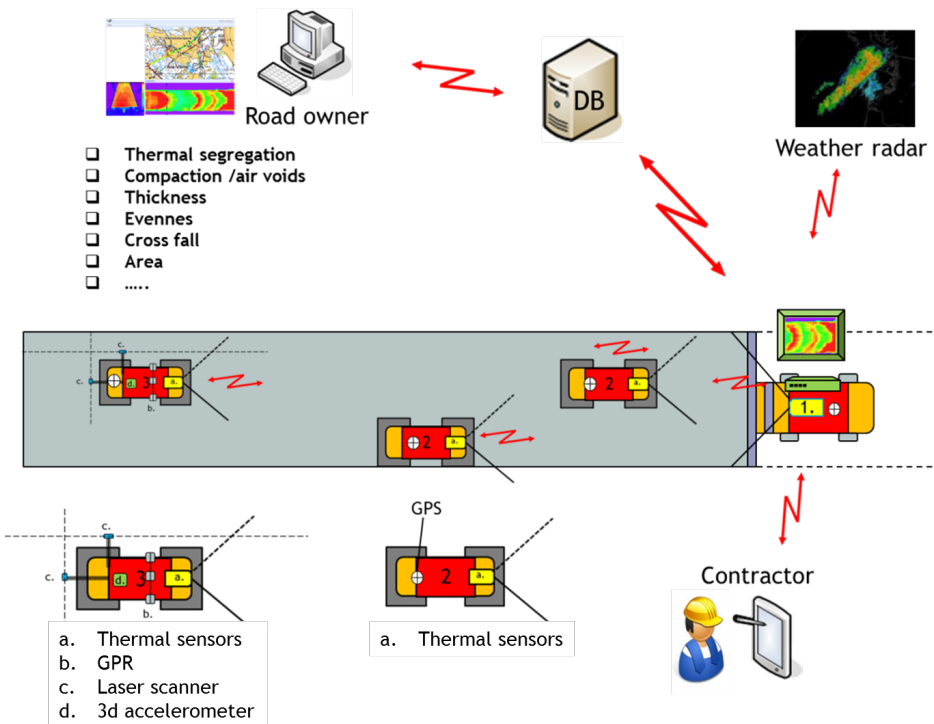


Figure 24: Example of DATA Management Process in Paving Site [37].

All data that are collected can be used to analyse the project with real data. All machine data can be recorded for fleet management. The data like delivery quantities, loading times, arrival times, etc. can be used to check whether the right material is delivered at right time at right place and the collected data can be used to improve planning and calculation tools. Last but not least these data can be used as a controlling, documentation and reporting tool.

In figure 25 the results of a temperature line scanner are shown in the temperature contour plot ("Temperaturkarta"). In the graph the maximum temperature measured during one line scan is shown (Maxtemp) as well as the minimum temperature measured in that scan (Mintemp). Tid = Time. At the top of the example the calculated "Riskandel" is shown. That is the "Risk area" / "Risk part".

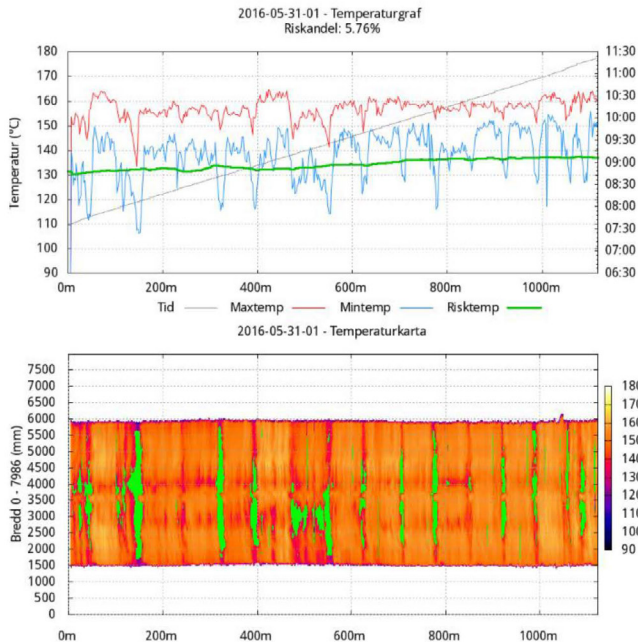
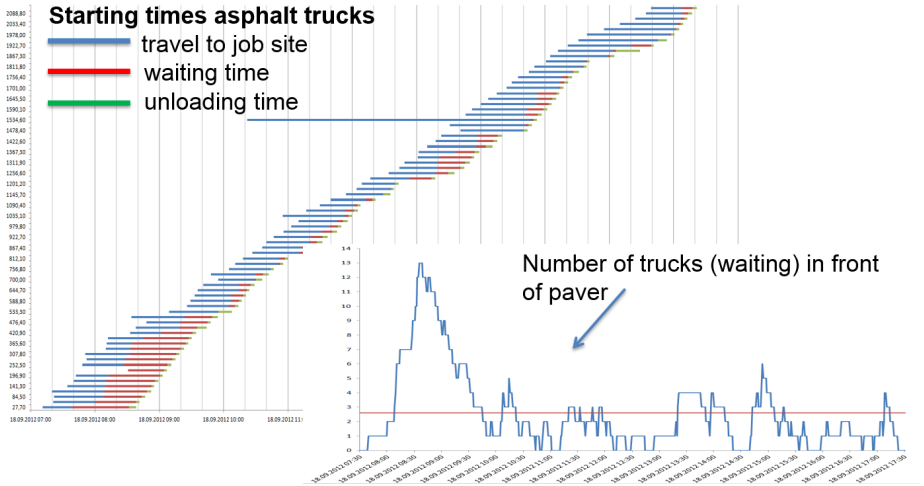


Figure 25: Example of asphalt temperature graph and temperature contour plot

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14. OPERATION / MAINTENANCE

During the operation of the road regular maintenance is important to ensure that deterioration does not occur. In particular the drainage system should be maintained well so the pavement keeps dry.

Roughness is most frequently the triggering factor which identifies a roadway as a candidate for rehabilitation or reconstruction [50.].

Road asset management / maintenance procedures should be implemented as soon as the pavement is completed [5.]. In fact maintenance should be addressed in the pavement design stage. Building roads is a long time investment and in the design stage maintenance should be taken into account. In some cases roads are built in a two stage approach. That means that the reinforcement of the road is already planned in the design stage; this could e.g. be the case where road are being built in an area where uneven settlements are expected.

Before maintaining a pavement, which has a distress, it is important to understand the cause of the distresses that appeared. In some cases the problems are caused by lower pavement layers or insufficient bearing capacity. In these cases a cosmetic solutions are not effective.

Many maintenance techniques are available. The choice of the right maintenance techniques depend on the cause of the distress, the traffic volume, the lifetime extension needed, etc.

The maintenance techniques can be divided in two types of maintenance: local maintenance and major maintenance [50.].

14.1. LOCAL MAINTENANCE

Local maintenance can be:

- minor (pothole) patching
- filling cracks
- crack sealing

Filling cracks and crack sealing are done primarily to prevent water penetration and further damage to the pavement structure. Water is very damaging to the base and subbase material, especially if it undermines the base and creates voids underneath that will lead to potholes and larger failures.

14.1.1. MINOR PATCHING / POTHOLE REPAIR

Before repairing a pothole it is essential to understand the cause of the pothole. If it is a (very) local problem pothole repair might be the solution.

There are various pothole repair techniques available [51.].

For a permanent or more durable pothole repair the procedure is [51.]:

- preparation of the area to be repaired including edge formation (by saw cutting)
- cleaning / excavation with removing all debris, loose material and water (drying)
- application of bond coat to base (the bottom) and sides
- infilling with asphalt material (mostly hot-mix, also cold-mix asphalt is used)
- compaction with vibrating plates, drum vibratory rollers or tamper

The proper preparation of potholes is essential for a good repair. No matter how good quality and durable the material that is used for pothole infilling is, it will not perform well and not last long enough if it is applied in inappropriate circumstances.

The prepared patch area (normally rectangular shape) must include the whole area affected by the pothole and any associated distress in surroundings. The cut edges should be clean and neat. All unsound and debonded material should be removed. Cationic emulsion is normally used for bond coating and it must be evenly applied. Every type of infill material should be fully compacted. Attention must be paid to the proper mixture temperature when warm / hot asphalt is used. Special care should be devoted to the pothole edges and corners of rectangular patches. Because the joints between the patch and the adjacent pavement are the areas that fail most frequently (open cracks), sealing the joints is advisable for better durability (geosynthetic crack-sealing strip over the joints, using a layer of bitumen emulsion to stick the strip and a second layer on top of the strip to 'waterproof' the geosynthetic). Finally, blinding with some coarse sand over the second layer of emulsion ensures that the bitumen does not stick to vehicle tyres. For deeper potholes (more than 40 mm), the asphalt should be installed in more layers (each compacted separately). This method using hot-mix asphalt represents the most durable solution for pothole repair and it should ensure the service life as of surrounding pavement [51.].

14.2. MAJOR MAINTENANCE

The major maintenance techniques apply to the whole surface of the pavement. The mostly used techniques are:

- surface treatment
- non-structural asphalt overlay
- structural asphalt overlay

To be able to choose the right maintenance technique it is important to understand the cause of the distress(es). For choosing the right structural overlay a structural pavement analysis with bearing capacity measurements might be needed.

14.2.1 SURFACE TREATMENT

A surface treatment is applied to an asphalt pavement surface to restore or protect the surface characteristics. It includes a spray application of bitumen (or emulsion) and may include the application of aggregate cover. The thickness of a surface treatments is typically less than 25 mm. Surface treatment are also called surface seals, or seal coats or chip seals. There are many types of surface treatment. Examples are:

- Surface dressing
- Fog seal
- Chip seal
- Slurry seal
- Surface rejuvenation
- Micro surfacing
- Surface correction like re-texturing

14.2.2. OVERLAYS

Asphalt overlays are commonly applied on existing flexible and rigid pavements when the pavement condition (structural and functional) has reached an unacceptable level of service. Overlays are designed to resist fatigue and/or rutting failure mechanisms; however, overlays may still show cracking patterns - "Reflective cracking" - similar to the ones, which existed in the old pavement after a short period of time due to continuous movement at the discontinuity prompted by thermal expansion and traffic loading. Reflective cracking is a serious challenge associated with pavement rehabilitation as it leads to premature failure of the overlay and allows water infiltration through the cracks, which causes

stripping in asphalt layers and weakening and deterioration in the base and/or subgrade. Different treatment methods have been suggested for controlling reflective cracking including metallic grids, different types of geosynthetics, asphalt-based interlayers as stress absorbing membrane interlayer (SAMI) or stress absorbing layer (SAL), and fractured-slab approaches [52.].

Advantages and inconveniences of some methods are:
[52.]:

- Crack sealing and overlay (pros: low cost and suitable for cracked asphalt pavements; cons: reflective cracking may still appear).
- Chip seal interlayer (pros: low cost and adequate control of reflective cracking).
- Full-depth reclamation (pros: prevent reflective cracking, suitable for heavily cracked pavements, environmentally-friendly; cons: cost).
- Cold-in place recycling (pros: prevent reflective cracking; cons: not suitable for heavily cracked pavements with fatigue cracking) [52.].

Before applying a new overlay it might be needed to apply a regulating (binder) course first to be able to obtain the required evenness and the required compaction level. It is also important to have a well prepared substrate before applying an overlay. That means that certain areas have a need to be milled and filled first in order to get a homogeneous substrate.

When milling these small areas (e.g. one wheel track or patches) before applying a road wide overlay, these areas have to be paved (filled) before applying the road wide overlay; otherwise the (extra) milled areas contain a higher thickness of asphalt, which will result in a depressions after compacting the whole thickness. An alternative could be milling the full width.

Sometimes fine milling with a level averaging system is adopted to ensure an even substrate.

14.2.3. OTHER MAINTENANCE TECHNIQUES

There are also several other maintenance techniques like:

- Mill and fill
- Micro surfacing (filling ruts)
- Asphalt reinforcement
- Rejuvenating Porous Asphalt
- In situ recycling
- Repave – reshape

14.3 TREATMENT SELECTION GUIDELINES

To assist in selecting the right treatment, several guides or guidelines are available.

Reference [53.] provides a Pavement Treatment Selection Guide for the right (surface) treatment to the right pavement at the right time (See Figure 27).

Reference [54.] provides a good overview of the maintenance techniques available.

Reference [55.] provides asphalt surfacing treatment selection guidelines and has flow charts which guide the practitioner through:

- Step 1: Existing pavement forensics, for new surfacing on existing pavements
- Step 2: Selection of preferred surfacing type for new or existing pavements
- Step 3: Asphalt considerations that influence preferred surfacing type
- Step 4: Bonding of surfacing to substrate, sealing the surface

Reference [56.] provides the guidelines for assessing pavement preservation treatments and strategies of Alberta, Canada.

Reference [57.] provides Pavement preservation manual (of Mn DOT) with a Treatment Selection Guidelines for Flexible Pavements

Pavement Condition	Parameters	Treatment								
		Thin Hot Mix Overlay	Fog Seal	Crack Sealing	Sand Seal	Chip Seals	Slurry Seal	Micro-surfacing	Cold In-Place Recycling ²	Hot In-Place Recycling ²
Traffic (ADT) ^{1, 2}	<1000	●	●	●	●	●	●	●	●	●
	1000 — 4000	●	●	●	●	●	●	●	●	●
	>4000	●	●	●	○	●	●	●	●	●
Ruts	<5mm	●	●	●	●	●	●	●	●	●
	5mm — 25mm	●	○	●	●	●	●	●	●	●
	>25mm	○	○	○	○	○	○	●	●	●
Cracking Fatigue	Low	●	●	●	●	●	○	●	●	○
	Moderate	●	○	●	●	●	○	●	●	●
	High	●	○	○	○	○	○	○	●	●
Cracking Longitudinal	Low	●	●	●	●	●	●	●	●	●
	Moderate	●	○	●	●	●	●	●	●	●
	High	●	○	●	○	○	○	○	●	●
Cracking Transverse	Low	●	●	●	●	●	●	●	●	●
	Moderate	●	○	●	●	●	●	●	●	●
	High	●	○	●	○	○	○	○	●	○
Surface Condition	Dry	●	●	○	●	●	●	●	●	○
	Flushing	●	○	○	●	●	○	●	●	●
	Bleeding	●	○	○	○	●	●	●	●	●
	Variable	●	●	○	●	●	●	Variable	●	●
	Portland Cement Concrete pavement	●	○	●	●	●	●	●	○	○
Ravelling	Low	●	●	○	●	●	●	●	●	●
	Moderate	●	●	○	●	●	●	●	●	●
	High	●	●	○	●	●	●	●	●	●
Potholes	Low	●	○	●	●	●	●	●	○	○
	Moderate	●	○	●	●	●	●	●	○	○
	High	●	○	●	○	○	○	○	○	○
Texture	Rough	●	○	○	●	●	●	●	●	●
Ride	Poor	●	○	○	○	○	●	●	●	●
Drainage	Poor	○	○	○	○	○	○	○	○	○
Snow Plow Damage	High	●	●	●	●	●	●	●	○	○
Skid Resistance	Low	●	○	○	●	●	●	●	○	○

- = Recommended
 ● = Provisionally recommended (dependant on road conditions)
 ○ = Not recommended

Figure 27: Example of Pavement Treatment Selection Guide [53.].

15. CONCLUSIONS

Increasing importance is being placed on the efficiency and quality of delivery of road infrastructure projects to meet the demands of road users to have a safe, efficient and reliable network on which to travel and transport goods.

To meet these demands of the road users it is important to deliver a (very) high quality road infrastructure to reduce maintenance activities. That means there is a need for more durable asphalt pavements.

The road construction and maintenance community has the skills, personnel and methodologies to be able to deliver projects in an efficient, safe and cost effective manner, however, this does not always happen in the real world.

The technologies are available to build more durable pavements, but the contracts often do not stimulate innovations and do not contribute to the use of the latest technology.

The aim of this document is to encourage all working in the asphalt industry and at the road authority side to contribute to making more durable asphalt pavements. It provides techniques and procedures as well as the latest technologies.

This document presents information everybody should know for creating durable asphalt pavements. It is not providing all the knowledge that is needed in the different steps of road design, road building and road maintenance, because it is totally impossible to have all that information in one paper. This document can be seen as a starting point of a whole library and as appetiser. For more information and details good reference are provided. This paper goes further than the standard books; it is meant to bring new ideas that go on top of that.

Next to the use of Best Practices available, education and training of the staff is essential to skill them to fulfil the expectations of all involved in the usage of the road in the end.

Last but not least: The use of modern technology in the paving sector might also lead to attracting new young workers in the asphalt industry.

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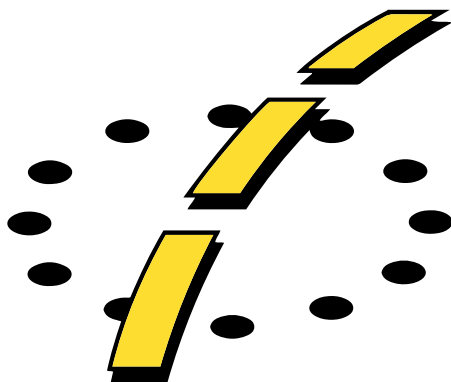
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