The influence of asphalt workmanship on pavement service life

Joralf Aurstad[1, a], Nils S. Uthus[1, b], Roar Telle[2, c], Leif J. Bakløkk[1, d]

[1] *Norwegian Public Roads Administration, Trondheim, Norway*
[2] *Veiteknisk Institutt, Høvik, Norway*

[a] joralf.aurstad@vegvesen.no
[b] nils.uthus@vegvesen.no
[c] roar@veiteknisk.no
[d] leif.baklokk@vegvesen.no

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ABSTRACT

The "Durable Roads" program 2011-2014 has been a 4-year research program conducted by the Norwegian Public Roads Administration (NPRA). The overall objective is to increase service life and reduce annual costs for the Norwegian road network.

For many years there has been a strong need in Norway for improved expertise in the area of road technology and road maintenance. Premature failures /distresses occur too often also on new roads. Focus on cost and completion time often leads to low quality work, improper use of materials is often seen, and there is a growing lack of professionals.

"Durable roads" has looked especially into how to improve asphalt pavement quality and thereby achieve longer service life. The paper shows typical damages that may occur on the road due to wrong or inadequate execution of asphalt works, and insufficient quality control. Further the paper presents initiatives and measures that have been taken in this respect and how these now are being implemented in NPRA. Among the tools that hopefully will contribute to longer lasting pavements in the future are;

- Practical control schemes/check lists/instructions for NPRA's inspectors
- New "Best practice guide" developed for both contractors, road owners and for education purposes
- New guidelines for asphalt transport by boat (up to 30 % of asphalt mix is transported by boat in Norway)
- Use of IR-cameras to promote and document homogenous conditions/temperatures during laying and compaction
- Introducing competence/skill requirements in contracts and tender documents
- Introducing a new non-destructive method for detecting deviations in quality on new asphalt pavements, based on laser measurements

Keywords: Asphalt, Bonding, Durability, Economics, Performance testing

1. INTRODUCTION

For many years, there has been a growing need in Norway for improved expertise in the area of road technology and road maintenance. Preservation of the existing road network is now strongly emphasised, both in the National Transport Plan and in the Norwegian Public Roads Administration's (NPRA) Action Plan.
The "Durable Roads" program 2011-2015 [1] has been a 4-year research program conducted by the Norwegian Public Roads Administration (NPRA). The overall objective is to increase service life and reduce annual costs for the Norwegian road network. Measures/actions that need to be taken are identified concerning the whole pavement structure, including the subgrade and the pavement layers. In addition, it is important to focus on improving the expertise both within NPRA and among other road owners, contractors, consultants and teaching and research institutes since, in general, all suffer from a growing lack of professionals.

The research program has focused on the following main topics, which form the work packages:
1. Road surfacing
2. Structural design and strengthening
3. Knowledge dissemination and implementation
More info is available on the program's web site. [2]

Premature pavement failures/distresses occur too often, as shown on figure 1. Focus on cost and completion time often leads to low quality work and improper use of materials.
If these early distresses can be avoided (eliminating the "bump" to the left on the figure), the overall pavement life will be substantially increased, moving the entire curve to the right. Even in a relatively small country like Norway, this represents a lot of money (see chapter 4).

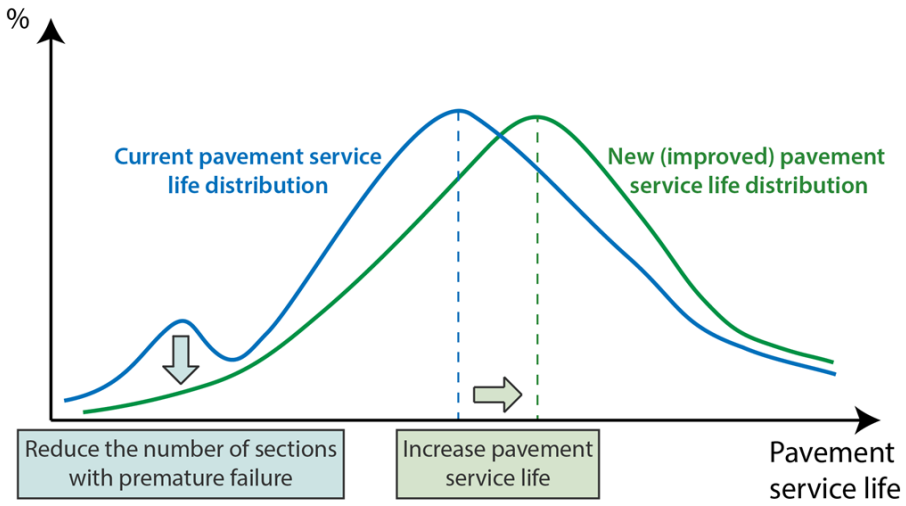

Figure 1: Asphalt pavement life distribution, effects of cutting early failures.

"Durable roads" has looked especially into how to improve asphalt pavement quality and thereby achieve longer service life. An investigation was conducted to find out what typical damages may occur on the roads due to wrong or inadequate execution of asphalt works, and due to insufficient quality control. Based on that work, a number of initiatives and measures have been taken, these are now to be implemented in NPRA's procedures and documents. Hopefully, these actions will contribute to longer lasting pavements in the future.

2. PRESENT SITUATION – PREMATURE PAVEMENT FAILURES

The length of the Norwegian main road network is about 55 000 km (10 000 km state level, 45 000 km county level). All state roads and most county roads (90 %) have asphalt pavements.
Due to increased traffic loadings, heavy winter conditions with studded tyre wear etc., the material requirements for the main roads are quite strict. Only superior aggregates are allowed in main road pavements, and binder quality is highly focused on. Polymer modified binders have shown to be beneficial regarding both deformation resistance, wear from studied tires and overall durability, ageing etc. Therefore, there has been a substantial increase in use of PMBs in Norway in recent years.

Nevertheless, it is fair to say that the overall asphalt pavement condition is far from optimal. "Durable roads" conducted a preliminary study including both field investigations and interviews with pavement engineers and professionals all

around the country. The study revealed that even though new materials and techniques have been implemented in our asphalt programmes, there are (surprisingly) many poor pavements to be seen. And much of the early deterioration seems to be caused by lack of basic knowhow, poor workmanship and insufficient control procedures.

Typical problems are lack of bonding between asphalt layers, poor longitudinal and transverse joints and inhomogeneity, as shown in figures 2-4.

Figure 2: Typical asphalt pavement failures caused by poor interlayer bonding.

In Norway only bitumen emulsions are used as tack coat materials. These materials are often described in the tender documents by type and required dosing, but in most cases, these are "dormant requirements". In reality, there is hardly any documentation and control system to ensure bonding quality.

Figure 3: Typical asphalt pavement distresses due to improper execution of longitudinal joints.

Joints are often the weakest and most vulnerable areas on asphalt pavements in Norway. High void content due to improper bonding and/or mix separation will allow water to penetrate into and under the asphalt. And combined with traffic pumping and freeze-thaw mechanisms, the pavement soon will start to deteriorate. These open joints will not only cause low driving comfort and reduced pavement life, in some cases this is clearly also a safety problem.

If one is not cautious, asphalt mix segregation can be a real problem. Given that the asphalt plant produces mix as specified, separation can take place during both loading, unloading (e.g. from boat), transport and laying. Open-textured

areas with only coarse aggregates will soon deteriorate, as showed in figure 4. But dense areas are even worse with bitumen overfilled voids leading to "bleeding", which can be dangerous spots regarding wet friction.

Figure 4: Typical asphalt pavement inhomogeneities (mix segregation, open vs. dense areas), these may cause both durability and poor friction problems.

3. ACTIONS TO PROLONG PAVEMENT LIFE

"Durable roads" has looked into different possible actions to improve the quality of asphalt works, from a practical point of view. These measures can be divided in two main categories;

- technical improvements, including clearer and more precise requirements
- competence improvements, involving both road owners and contractors

3.1 Improved bonding/tack coat requirements

As mentioned, the requirements for use of tack coat connected to repaving and asphalt maintenance have not been very precise. Also the follow-up procedures from NPRA have varied a lot.
Thus, a number of repaving projects was investigated in the project. The spraying of emulsion was controlled by laying out pads before application. By visual inspections, and by weighing the pads before and after, both the tack coat distribution and the amount spread (weight/m^2) could be determined, as shown in figures 5 and 6.

Figure 5: Pads used for measuring tack coat (emulsion) application rates.

As seen from figure 6, only one out of ten investigated sites showed tack coating in compliance with NPRA's requirements. These results have caused the introduction of more stringent descriptions in the tender documents. The specifications are now changed from 0,30 kg *bitumen emulsion* per m^2 to 0,15 kg *bitumen* per m^2. This is due to the fact that one single type of emulsion may show considerable variations in concentration, because of storage conditions etc. and it is difficult to measure the quantity of applied emulsion precisely as some of the water is lost during spraying.

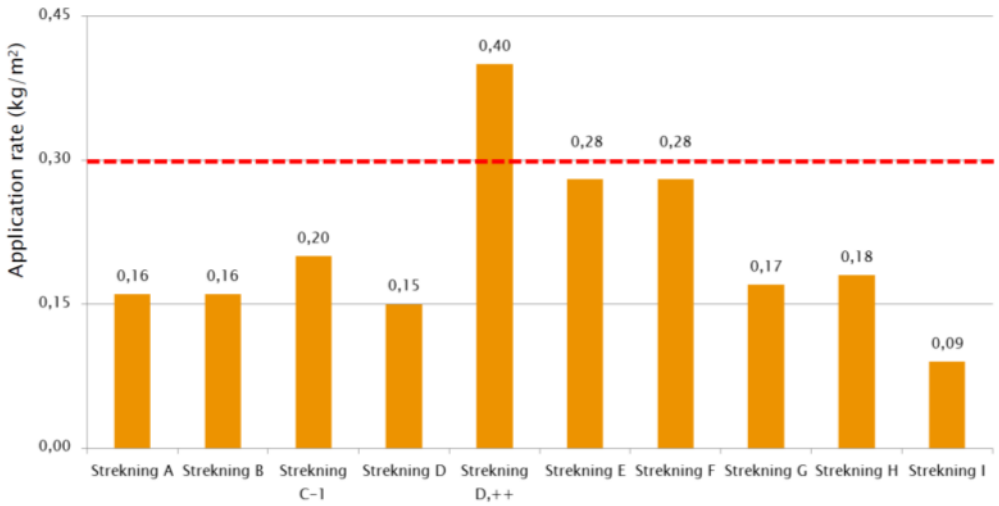

Figure 6: Amount of bonding bitumen measured on ten different road sections (dotted line indicates requirement 0,30 kg/m^2 bitumen emulsion left on surface).

However, resulting bonding not only has to do with the amount of emulsion sprayed on the old asphalt surface. Many factors will influence on the bonding properties; rain/water on the road surface, contaminants/dust, temperature, type of asphalt materials and so on. Therefore, NPRA now wants to move towards more functional requirements, also regarding asphalt bonding. Then it will be more up to the contractor to choose the right type and amount of binder. One task has been to investigate a new method (at least in Norway) for physical testing/measurement of the bonding, as shown in figure 7. This is discussed in a separate report from the project [3].

Figure 7: Shear bond test (EN 12697-48). Tested specimen; poor bonding caused by wet and dirty surface.

3.2 Improved execution of joints

Many Norwegian asphalt pavement failures has to do with poor workmanship regarding longitudinal (especially) and transverse joints. Therefore, extra emphasis has been put on this matter in the last seasons.

Specifications; void content
NPRA has traditionally only had requirements on samples/measurements taken at least 0,5 m from the joint. This procedure has shown to be insufficient regarding work quality. Therefore, asphalt contract specifications have now been updated, allowing for core sampling/void measurements directly on the joints. The void content measured on the very joint can be maximum 2 % higher than in the rest of the pavement.

Execution of work; coating and compaction
In general, NPRA will not go too much into procedure/equipment requirements, since that should be up to the contractor. But in some contracts, where the traffic or climatic conditions are severe, use of extra compaction equipment has been

specified, like the edge restraining devise shown on figure 8. Also, extra tack coating of the edge is demanded in some contracts, as it has been on airfields for several years.

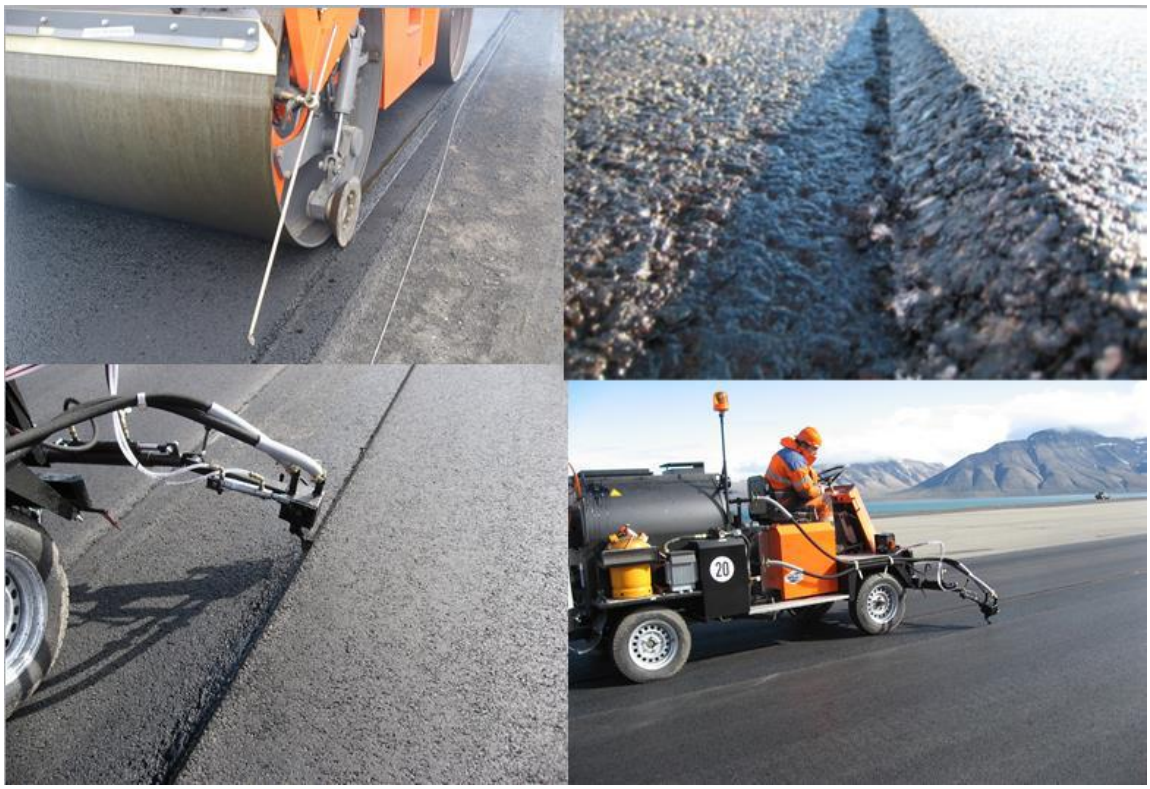

Figure 8: Perfecting joints by use of edge compacting equipment and extra binder application.

3.3 Surface control

IR scanning

It is known from various studies on asphalt pavements that there is a correlation between temperature variations on the newly laid mix and the compacted density. Colder areas will, given the same work of compaction (number of roller passes), reveal higher void contents and thereby be more vulnerable for early distresses.

NPRA has, in the last years in some contracts, tried out continuous temperature registration by use of infrared scanners. The IR cameras are mounted on the paver and give immediate pictures of temperature variations of the newly laid asphalt behind the screed.

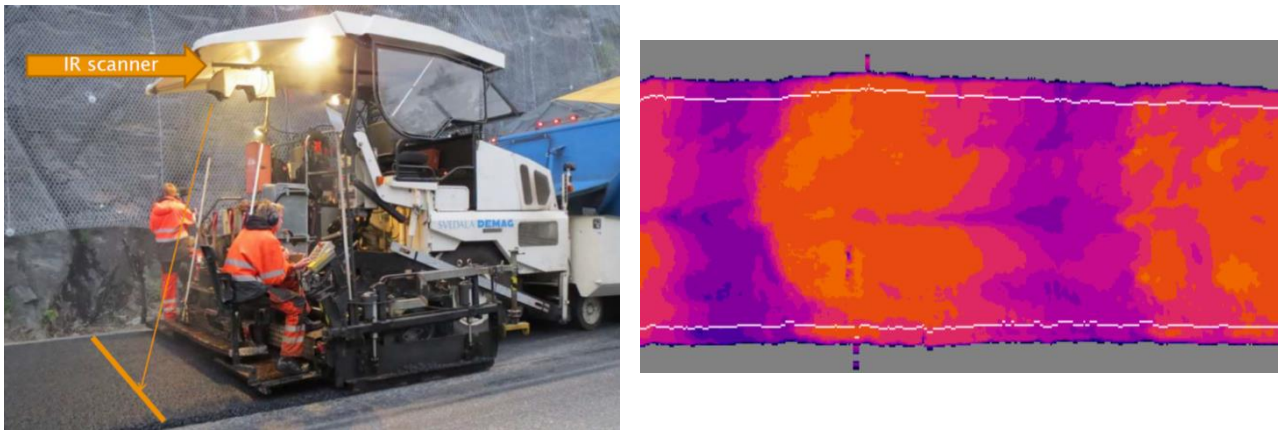

Figure 9: IR cameras give an immediate and continuous scanning of the surface temperature.

These pictures can be used by both the contractor and the builder/NPRA's local project leader. The advantage is that the contractor can take immediate action during the asphalt works and make necessary corrections. At the same time, the road owner can locate precisely possible weak spots that might need to be followed up more closely. For both sides, this has proved to be a very useful, educational and motivating tool.

NPRA has in the last three years designed special contracts where the contractor can obtain bonus for homogeneous pavements, documented by this type of scanning data (paved area within specified temperature limits).

Surface texture

ViaPPS (Pavement Profile Scanner) is a Norwegian system designed to examine the condition of road pavements. The system is developed in close cooperation with NPRA. ViaPPS is based on laser scanner technology, measuring the entire width of the lane with high resolution, driving with traffic speed. The transversal profile is measured 140 times per second in 580 points, generating 3D picture of the pavement. A normal mounting height of 2 meters gives a measurement width of 4 meters. This enables the ViaPPS to detect a number of parameters such as the centre line of the road, the side line, the width of the road, the road marking and the asphalt edge. ViaPPS conforms to the European standard EN 13036-8 Road and Airfield surface characteristics.

The main surface characteristics measured are

- rut depth and rut width
- cross fall
- curve radius
- longitudinal evenness (International Roughness Index, IRI)
- macro texture (mean profile depth, MPD)
- crack detection

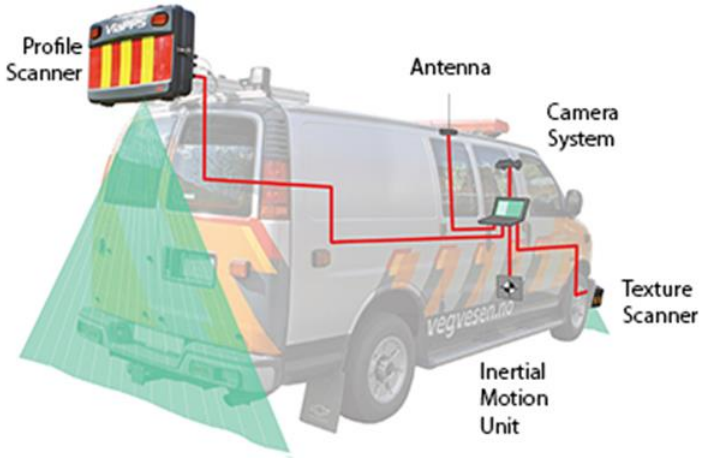

Figure 10: ViaPPS mounted on an NPRA road-monitoring vehicle.

The NPRA has 15 ViaPPS systems in use for documentation of the road condition. The data are typically used for road maintenance planning, optimizing the overall costs. When a new pavement is laid, the ViaPPS is also used to examine the surface in order to verify that it meets the required standard.

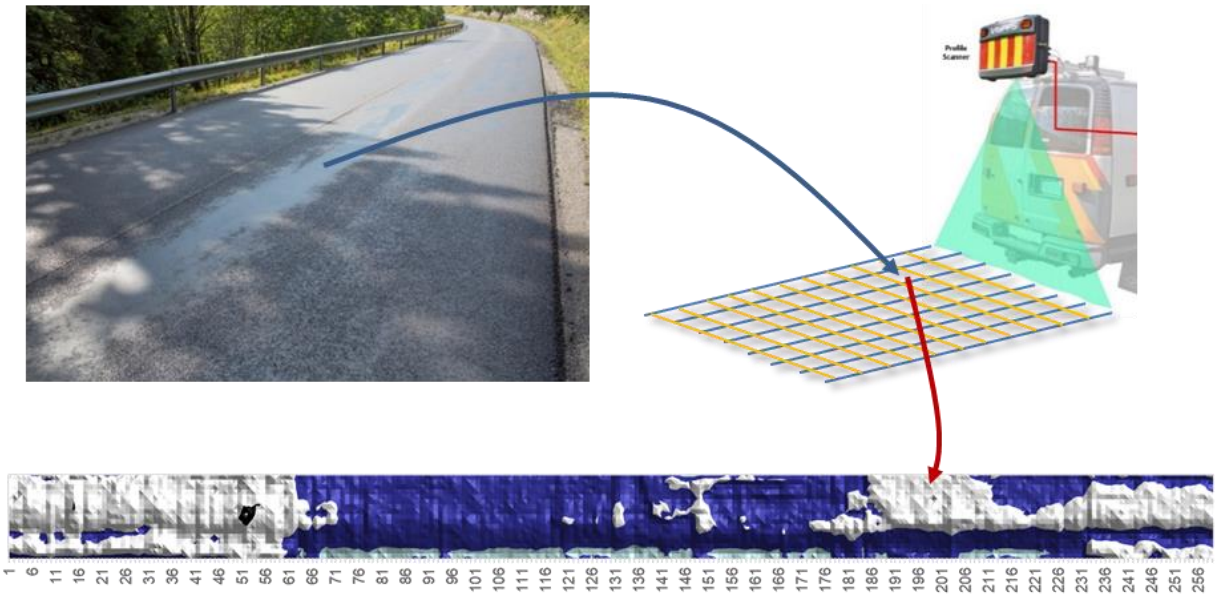

Figure 11: Homogeneity mapping from ViaPPS data; dense areas in white.

Based on statistical treatment of ViaPPS data, a new "homogeneity module" has been developed during "Durable roads". This makes it possible to detect very dense (possible slippery) or very open (possible water sensitive, wear sensitive) areas on an early stage, as shown on figure 11. This module is about to be implemented in NPRA's procedures. [4].

3.4 Training of professionals

Best practice guide

To emphasise the importance of good workmanship, a new "Best practice guide" has been developed. There are several so-called "Best practice guides" developed already, but many of these are quite comprehensive, describing a number of things that many local Norwegian inspectors do not recognise. The idea with this new publication is to point out a more limited number of factors that have proved to be crucial for Norwegian conditions. The guide highlights in short text and clear photos things to be aware of concerning planning and preparatory works, transport (by truck and by boat), laying and compaction. The publication is intended to be used actively by both contractors and road owners. Hopefully it will also be a useful tool for educational purposes. [5]

Figure 12: Example from Best practice guide; use of tack coat. Correct (left) and wrong (right) application.

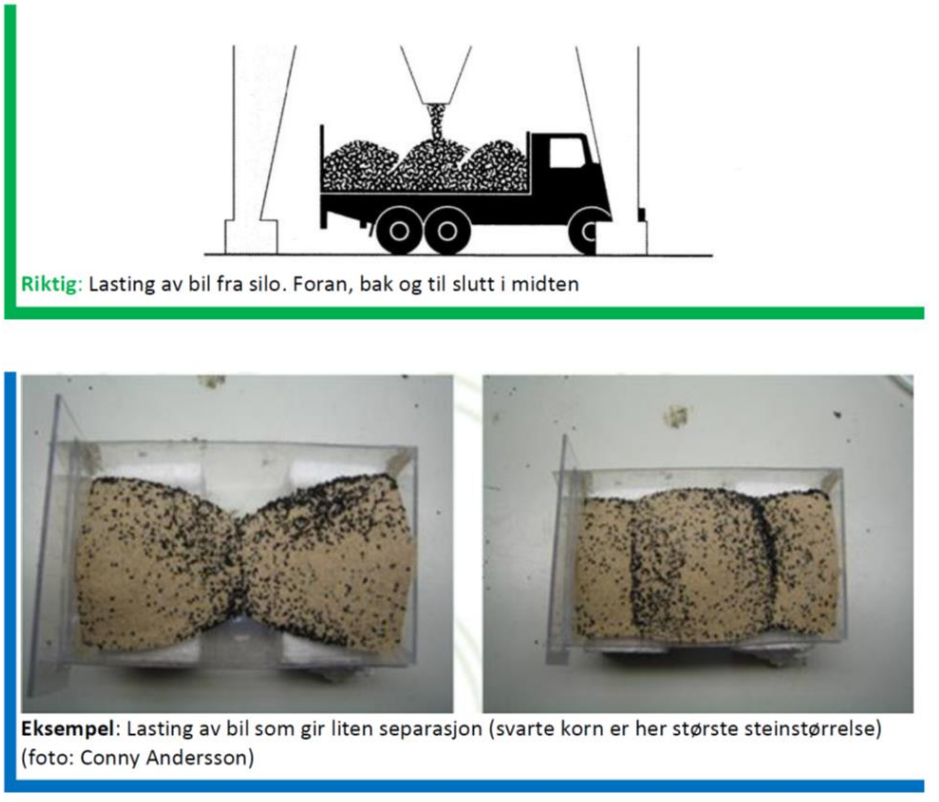

Figure 13: Example from Best practice guide; loading of truck to avoid segregation. Load in three piles; front, rear and middle (black grains illustrate coarse aggregates).

Guidelines for asphalt transport by boat

About 30 % of asphalt transport in Norway is carried out on sea, often over long distances. In the western and northern regions, the major volume goes by boat. There have been few studies on how boat transport, including needed reloadings, may influence the final pavement. Clearly, it is a big challenge to prevent quality reduction (temperature loss, segregation etc.). So far, the transporters have had very little guidelines and support on this matter.

"Durable roads" has done a number of follow-up studies on asphalt transport by boat, including infrared monitoring of the mix all the way from the plant, via loading on the boat, boat transport, reloading from boat to trucks, truck transport, and on to the paver at the final destination. It has been proved that loading and discharging procedures, together with how the mixes are insulated during transport, clearly influence the pavement's homogeneity, and thereby life expectancy. Based on these studies, some easy-to-read guidelines have been developed and spread to the transporters, in cooperation with the asphalt contractors. [6]

Figure 14: Examples from guidelines of asphalt transport by boat: Cold asphalt from bottom and edges of the loading room must not be loaded on one single truck. And the truck should be perpendicular to the side of the boat during unloading to prevent segregation.

Asphalt control instructions

Following the best practice guide, a separate guide "Control of asphalt works" has been carried out. This publication includes some practical control schemes/check lists describing the key factors that NPRA's asphalt inspectors should follow up in their work.

Figure 15: Examples from "Control of asphalt works"; spills from asphalt trucks shall be removed immediately, otherwise these will cause potholes.

Often unskilled and/or inexperienced inspectors have to discuss with skilled and very experienced persons from the contractor. A common list of parameters to be controlled is very helpful in these cases. And the fact that the contractor knows that he will meet this control regime on every place in the country, is also a contribution to good communication between the road owner and the executioner of the work. [7]

Training courses, education

Recruitment into the road and paving area is a big challenge nowadays, and at the same time a whole generation of experienced personnel is about to retire. NPRA has, in the recent years, put a lot of effort in work to improve (or at least maintain) the competence within road planning, construction, maintenance and operation. One initiative has been to establish a set of adapted educational/training courses. The idea is that people in different positions, from skilled workers to officers, may find courses suitable for his/her profession.

Based on the work carried out in the "Durable roads" project, including introduction of the new practical guidelines listed above, one such action has been a two-day seminar for NPRA's laboratory technicians and asphalt inspectors. Here new/young professionals from NPRA's five regions can meet with more experienced ones to get good advice. The different guidelines are presented and discussed. As pointed out, a common understanding of the current specifications and contract regulations, and how these shall be followed up, is very important.

The seminar also allows for comparison and calibration of equipment/control instruments that are to be used in the coming season, both in the field and in the laboratory, as shown in figure 16.

Figure 16: Asphalt inspector gathering; here comparison of asphalt density gauges.

Competence/skill requirement in contracts

NPRA has incorporated quite strict competence requirements in their winter maintenance and operation contracts. This is motivated from both safety and work quality reasons. All personnel who shall do winter work operations on the Norwegian roads (snow removal, salt application, grit spreading etc.) must now have a certificate showing that they have undergone a four day course in winter maintenance, and passed the accompanying exam. Every year, some 2000 persons go through this course.

A similar system has been discussed regarding asphalt pavement operations, for the same reasons. As a first step, some general formulations will be included in the 2016 contracts/tender documents. All "key personnel" should document experience from asphalt works on trafficked areas. An at least one person on each paving team should have a formal certificate of apprenticeship. This is to encourage the contractors to focus on skills and competence training within their organisations.

4. POTENTIAL FOR COST SAVING

4.1 Method for calculating benefits from R&D project "Durable roads"

There are not that many reports in the literature on calculation of economic outputs from pavement research and development programs. Transportation Research Board has gathered information from some projects on their web-site [8]. And there are some more to be found, among others in UK and France. It seems that there are no generic methodology for R&D benefit calculations; since all projects are different and it might be difficult to find one good indicator. And often there is not enough information regarding before- and after-situations. Other limitations may be difficulties in isolating the R&D effects from other activities and uncertainties regarding implementation.

Nevertheless, "Durable roads" is among the few Norwegian R&D projects that has been investigated in detail in order to come up with an objective estimate on possible future payback. The results are to be found in a separate "Durable roads" report. [9]

The following procedure has been chosen for the calculations:
1. Identify and describe the project results
2. Determine and describe benefits from the results
3. Determine influence area for the results (activities, volumes, actors etc.)
4. Calculation of potential benefits and cost savings (provided full implementation)
5. Implementation evaluation; to what extent can potential benefits be realized

The benefits are split into two categories; quantifiable and non-quantifiable. Quantifiable benefits are calculated as annual pavement costs. This indicator is chosen because it is a well-known figure that can be related to yearly budgets and expenditures, and also it says something about the time span for benefit realisation.
The savings are calculated as the difference in predicted annual pavement costs before and after implementing the project results and actions. The savings are summarised over a period of 20 years. This period is chosen because it will take some time to gain full effects of different results from the program, and also this is the normal life expectancy/design period in Norwegian pavement design.

4.2 Results – pavement cost saving potential

Longer lasting pavements on the main road network
The project has described a set of actions that will contribute to improve Norwegian asphalt pavements in the future, some of them are briefly discussed in the previous sections in this paper. Some measures of technical nature can be quite easily quantifiable, while other activities dealing with competence building, motivation etc. are more difficult to quantify. All together implementation of the results will contribute to a substantial increase in pavement service life and eliminate (or at least reduce) the number of sections with early distresses.

Table 1: Pavement maintenance of state and county roads in Norway 2010 – 2015

Year	Mill EUR	Km	1000 metric tons	Repaving frequency (years) [1]
2015	297	3 683	2 284	14,9
2014	297	3 507	2 261	15,7
2013	252	3 230	1 966	17,0
2012	224	3 246	2 160	16,9
2011	248	3 759	2 207	14,6
2010	209	3 484	1 952	15,8

[1] *The repaving frequency cannot completely be set equal to pavement service life; yearly available budgets also play a role*

Ideally, pavement service life should be the basis for the calculations. However, this information is hard to get on a detailed level, even from the National road data bank. Repaving frequency is easier to control, and should be a good substitute. Table 1 shows that the overall repaving frequency is about 15 years on the Norwegian main road network.
It is expected that implementation of the project results will increase the overall service life with 1-3 years. The benefits can then be summarised as shown in table 2, given a pavement cost of 0,09 mill EUR per km. Over a period of 20 years, this gives an accumulated benefit (cost saving) in the range of 250-700 mill EUR, as shown in figure 17.

Table 2: Change in repaving frequency and costs by improved asphalt pavement quality

	Repaving frequency (years)	Annual pavement costs (EUR/km/year)
Before	15	5900
After (low estimate)	16	5560
After (high estimate)	18	4940

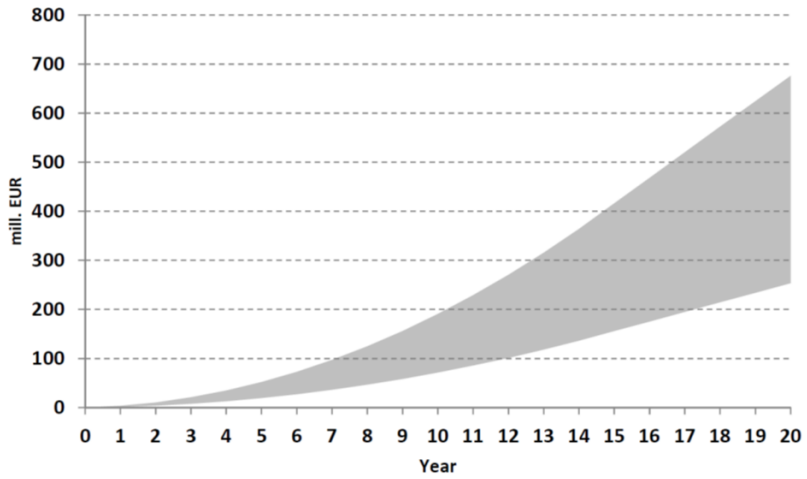

Figure 17: Potential cost savings due to improved pavement maintenance, accumulated over 20 years

Reduced patching and local repair costs

Implementing the results from «Durable roads» is expected also to give a considerable reduction in need of patching and local pavement repairs. There are no detailed statistics regarding patching in Norway, but the current cost models used for budgeting and forecasting use numbers as shown in table 3.

Table 3: Patching costs on the Norwegian main road network

	Annual costs (mill EUR)
State roads	0,5
County roads	9,5
Sum state and county roads	10,0

The need for patching can hardly be 100 % eliminated, many distresses are caused by weaknesses in the layers underneath the asphalt. Most of the Norwegian roads have developed over time, often on top of the old track/path network. That is, the old history (weak materials) are still present in the road constructions.

Nevertheless, patching costs should be reduced over time as an effect of better execution of works, improved control procedures, higher competence levels etc. If we assume that 50 % of current patching works are caused by insufficient asphalt executions, and that the effects of improving these works will be fully seen in 15-20 years, a potential benefit from reduced patching over a 20 years period will be in the range of 100-170 mill EUR, as shown on figure 18.

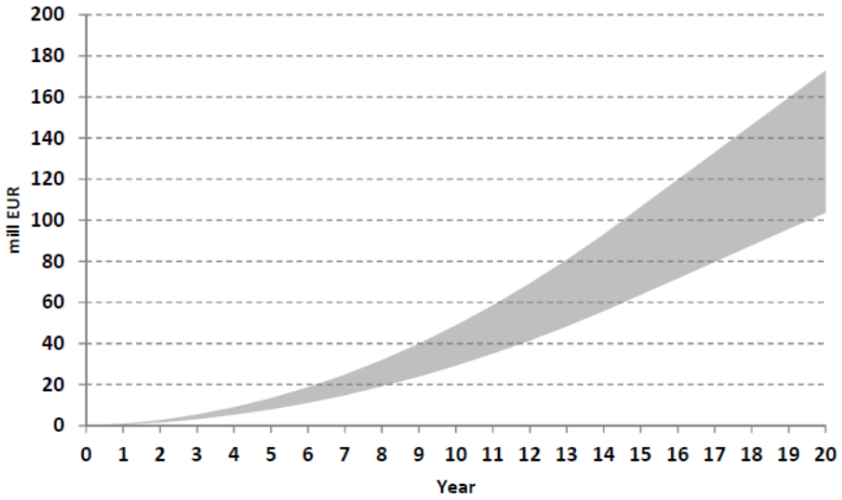

Figure 18: Potential cost savings due to less patching of asphalt pavements, accumulated over 20 years

Effects on municipal and private roads

One should expect that an overall increase/improvement in quality on NPRA's contracts also would have positive effects on the quality and service life of other paving works. The total asphalt production in Norway is about 7 000 000 metric tons per year. NPRA is the main customer, but deliveries to municipalities, airports, private customers, terminals and others also represent as much as 3 000 000 tons.

Probably the results from «Durable roads» can be partly utilised also among customers in the municipal and private sector, but the implementation there will likely be less targeted and determined. All these areas may not be relevant to include. A reasonable estimate on savings could be about 1/3 compared to pavement maintenance costs on state and county roads. The benefit report [10] has calculated a possible cost saving potential of about 90-230 mill EUR for municipal and private asphalt works, as shown in figure 19.

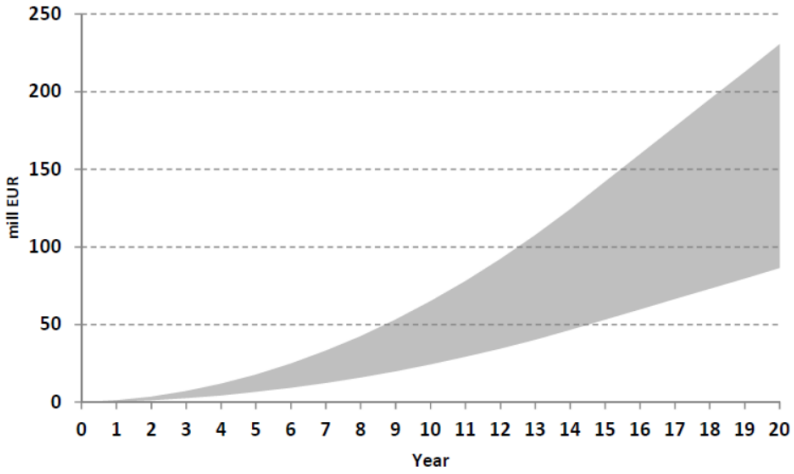

Figure 19: Potential cost savings on municipal and private asphalt pavements, accumulated over 20 years

5. CONCLUSION

There is a strong need in Norway for improved expertise in the area of road technology and road maintenance. Premature failures /distresses occur too often, also on new roads. Focus on costs and completion time often leads to low quality work, improper use of materials is often seen, and there is a growing lack of professionals. One part of the research program "Durable roads" 2011-2015 has been to look into how to improve asphalt pavement quality and thereby achieve longer service life, from a practical point of view. The measures that have been taken can be divided in two main categories;

- technical improvements, including clearer and more precise requirements
- competence improvements, involving both road owners and contractors

This paper presents and discusses briefly the main improvements that now are being implemented by the Norwegian Public Roads Administration (NPRA).

As one of few NPRA R&D projects, "Durable roads" has been thoroughly evaluated regarding future cost saving potential. The different areas of activity have been studied separately, where quantifiable and non-quantifiable parameters have been identified. The quantifiable parameters have been priced, allowing for calculation of potential benefits. The work shows that huge savings are possible, if the research results are implemented.

This paper presents the figures when improvement of the asphalt layers is considered. Only within this field, the calculated potential savings are in the range of 440-1100 mill EUR, over a period of 20 years.

It is possible to obtain a very good payback for emphasising quality and competence within the asphalt area.

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