Use of noise reducing pavements

- European experience

Danish Road Institute
Technical note 69
2008

Road Directorate

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Contents

Executive summary

There is increasing focus in Europe on applying noise reducing pavements on the road network as a cost-effective noise abatement measure. In the present report the newest European experiences on the practical use of noise reducing pavements are presented. The report has been produced by the Danish Road Directorate, Danish Road Institute (DRI-DK) as part of a cooperation between California Department of Transportation (Caltrans) and DRI-DK on the development of quieter pavements. The study has been structured around twelve key questions and the main conclusions follow below.

Only a few countries have an explicit policy for their use of noise reducing pavements, even though in many countries noise reducing pavements ever more often are a part of the "toolbox" – with various degree of documentation – in noise abatement. Noise reducing pavements are often used on a case-to-case basis in new road projects and in pavement maintenance.

The Netherlands apply porous asphalt on their entire main road network following an increase in 1987 of the permitted vehicle speed from 100 km/h to 120 km/h. In Denmark, a policy is still under development in the Danish Road Directorate, but noise reducing surfacings are frequently used on new roads and when significant change is made of existing roads. The municipality of Copenhagen has decided to apply noise reducing surfacings in its maintenance work on streets with an ADT exceeding 2000 vehicles. The introduction of the Danish so called SRS noise labeling system for noise reducing pavements has been a breakthrough for the use of such pavements. The reason it has been possible to introduce noise reducing pavements is more than a decade of research and development carried out in cooperation between the DRI-DK, road owners and pavement industry. This cooperation has often taken place in the framework of international projects which have enlarged the available resources and facilitated intensive knowledge sharing.

The policy in the Netherlands to use porous pavements on all main roads is very efficient from a noise abatement point of view. The Danish SRS system brings noise reducing pavement products on the market and facilitates tendering noise reducing pavement. The process of having road administrations and the pavement industry develop the SRS system in consensus with consultants gave wide acceptance and has brought the knowledge of the system to many users. The Danish Road Directorate has repeatedly published information about the system at annual Danish road conferences, in pavement magazines, workshops etc. A vital cornerstone in this achievement has been good collaboration and a team spirit between involved asphalt technologists (private and public).

Noise reducing pavement can be used in conjunction with other measures, but noise reducing pavements should always be the first choice measure because it attacks the problem at the source (tire/road noise) and it is often the most cost-effective measure of noise abatement. For example, in Denmark the widening of an express ring-road around Copenhagen combines noise reducing pavement, four meter high noise barriers and façade insulation. In the Netherlands, noise reducing pavements are frequently used in combination with noise barriers. One reason for the Dutch policy of applying noise reducing surfacing is that road administrations were required by law to reduce the noise and this could be done by increasing the height of existing noise barriers or by building new barriers, both very expensive solutions, or by using noise reducing porous pavement or thin layer surfacings which are much more cost-effective.

The noise reduction obtained by applying noise reducing pavements depends very much on what situation is used for comparison (noise reducing pavement versus new or worn surface). By choosing a reference pavement giving rise to high levels of tire/road noise the noise reducing products are seemingly better. Different types of reference pavements (with different ages) in relation to noise are used around Europe.

The reference pavement in each country is typically chosen from what would have been the most probable alternative used for high capacity roads prior to the focus on noise reducing pavements. In Denmark the reference is a worn (approx. 8 years old) surface of a dense graded asphalt concrete with 11 mm nominal maximum aggregate size. This mix type was the dominant surface course for Danish highways during 1993-1998 and has an average (structural) durability of approximately 12 years. The Netherlands use a reference pavement based on a population of surfaces all of which were probably less than two years old at the time of noise measurement. For high speed roads the reference is dense graded asphalt concrete with 16 mm maximum aggregate size, while for roads with lower speeds a combination of dense graded asphalt concrete with 11 and 16 mm maximum aggregate size is used. Sweden uses a Stone Mastic Asphalt 16 mm (or dense graded Asphalt Concrete 16 mm) at the age of one year, primarily based on CPX-measurements.

The Danish Ministry of Transport has worked out a catalogue of unit-prices for the cost of time consumption for driving, and the unit-cost to society due to air pollution and emission of CO_2, ***noise***, accidents and congestion etc. which can be used to calculate noise reducing pavement benefits. The noise costs consist of contributions from annoyance (based on house-prices in areas with different noise exposure), while the health cost is based on the risk of hospitalization and loss of life due to noise exposure. To take advantage of cost-benefit computation, reliable data are needed on the development over time of the noise level / pavement noise reducing properties. A first version of such a model was a result of the EU project SILENCE.

Some noise monitoring over time on noise reducing pavements has been done in the Netherlands, France and Germany to gain “overall experience”, but not all individual pavement works are monitored. In Denmark, several test sections have been monitored every year by SPB measurements and this is now supplemented with CPX measurement. Texture measurement by means of laser equipment will be added soon.

This has generated valuable lifetime noise reduction time histories. A continuation of this monitoring is planned, provided the necessary funding will be available.

In general the tendering of a noise reducing pavement is influenced by many practicalities. As an example, the noise measuring community has neither the standards (CPX is still a pre-standard and Round Robin Testing between equipments to assess their accuracy is lacking) nor the capability to perform noise measurements on all individual jobs for quality control. This is a topic for consideration in a future system with bonus or fines. There is a general rational coming from the European Product Specifications using initial type testing as the description of the properties of the material. When the completed pavement depends not only on the loose product but also on its application – like UTLAC (Ultra Thin Layers) and surface dressings – TAITs (Type Approval Installation Trial) are also included. With this background many countries are likely in the coming years to set up procedures for certification/declaration of a noise reducing pavement based on earlier produced trial sections.

Usually it is the road owner who pays for the noise reducing pavement, either in a project for constructing a new road or in the ongoing process of pavement renewal on existing roads. The Municipality of Copenhagen discussed to require for a developer of a new residential area to pay for a noise reducing pavement on an existing nearby road in order to be given permission to build new dwellings, but such action has not yet been decided.

Warranty periods for noise reducing pavements in Denmark are the same as for standard pavements (legally 5 years) but there is no established practice yet as to how the warranty covers the acoustical performance. When more experience is gathered with respect to the durability of the individual mix types it is assumed that durability (acoustical and structural) will be important in the competition between products /contractors like it is on standard asphalt materials.

Several countries apply correction factors in their prediction schemes to take the influence of the road surfacing into account when analyzing traffic noise impact on the environment.

Some new developments seen on the horizon are:

- The ongoing development and testing of noise reducing thin layers seem to provide low cost noise reduction. Surfacings based on the design principles for such European products could be developed with the pavement construction materials available in California
- In Germany there is a trend to replace Portland Cement Concrete (PCC) with Stone Mastic Asphalt which has a lot of application advantages in the rehabilitation and maintenance situation on a heavily congested road network. Some Portland Cement Concrete test sections have been built which show reasonable noise levels, but they are presently few and on a purely experimental stage, so no substantial information on PCC solutions is available

- Two-layer porous pavement optimized for long-term noise reduction and durability for roads with speeds above 70 km/h might be an option for testing in order to achieve high noise reduction
- Further down the road poro-elastic surfacing might be an option. There are plans for European research and development of such an idea.

Dansk sammenfatning

I Europa er der voksende fokus på støjreducerende vejbelægninger på vejnettet som et omkostningseffektivt virkemiddel til at reducere støjen. I denne rapport præsenteres de nyeste europæiske erfaringer med brug af støjreducerende vejbelægninger. Rapporten er udarbejdet af Vejdirektoratet/Vejteknisk Institut (VI) som led i et samarbejde om forskning, udvikling og demonstration på området støjreducerende vejbelægninger mellem den californiske vejmyndighed, Caltrans, og VI. Undersøgelsen har været struktureret omkring 12 hovedspørgsmål og konklusionerne præsenteres i det følgende.

Kun få lande i Europa har en eksplicit politik for brug af støjreducerende vejbelægning selvom støjreducerende belægninger i stigende omfang bliver et virkemiddel i støjbekæmpelsen. Støjreducerende vejbelægninger anvendes både i nye vejprojekter og ved vedligeholdelsesarbejder.

I Holland anvendes drænasfalt på hele motorvejsnettet. Det blev besluttet i 1987, hvor den generelle hastighedsgrænse blev hævet fra 100 til 120 km/t. Vejdirektoratet er ved at udvikle en dansk politik for brug af støjreducerende vejbelægninger samtidig med, at disse belægninger allerede ofte anvendes både på nye veje og i forbindelse med vedligeholdelsesarbejder. Københavns kommune har i 2008 besluttet at anvende støjreducerende belægninger ved vedligeholdsarbejder på alle vejstrækninger med en årsdøgntrafik på over 2000 biler.

Introduktionen af det danske SRS system for klassificering af støjreducerende belægninger har været et gennembrud for brugen af denne type vejbelægning. Baggrunden for at det har været muligt at introducere støjreducerende belægninger i Danmark er mere end ti års forskning og udvikling, gennemført i et samarbejde mellem VI, vejejere og asfaltentreprenører. Samarbejdet er undertiden gennemført inden for rammerne af internationale forskningsprojekter, hvilket har forøget de resurser, der kunne anvendes, og det har muliggjort intensiv international videndeling.

Den hollandske politik med at anvende drænasfalt på alle motorveje er meget effektiv i forhold til støjreduktion. Det danske SRS system gør det let at inkludere støj i udbud af vejbelægninger og medvirker til at fremme introduktion af støjreducerende belægninger på markedet. SRS systemet er udviklet i samarbejde og konsensus mellem involverede parter, hvilket betyder at systemet er bredt accepteret og kendt i vejsektoren i Danmark. Vejdirektoratet har løbende offentliggjort information om SRS systemet på Vejforum konferencerne, i fagtidsskrifter, ved seminarer mv. Et vigtigt aspekt ting har været det gode samarbejde og ”hold-ånd” blandt belægningsspecialister fra den offentlige og den private sektor.

Støjreducerende belægninger kan bruges i kombination med andre former for støjbeskyttelse, men en støjreducerende belægning bør være det første valg af virkemiddel fordi støjen dæmpes ved kilden (dæk-vejbane støj) og fordi det ofte er det mest omkostningseffektive virkemiddel. Ved udvidelsen af Motorringvejen omkring København anvendes en kombination af støjreducerende tyndlagsbelægning, op til 4 m høje støjskærme samt facadeisolering. I Holland anvendes støjreducerende vejbelægninger ofte i kombination med støjskærme. En af begrundelserne for at anvende støjreducerende vejbelægninger var et lovkrav om at reducere støjen, som enten kunne opfyldes ved at forøge højden af eksisterende støjskærme og bygge nye skærme, begge forholdsvis dyre løsninger, eller ved at anvende støjreducerende belægninger, hvilket var mere omkostningseffektivt.

Den støjreduktion der opnås med støjreducerende vejbelægninger afhænger af, hvilken udgangssituation der anvendes til sammenligning (fx støjreducerende belægning i forhold til en ny eller en nedslidt "standard" belægning). Hvis man vælger en referencebelægning med et højt støjniveau giver en støjreducerende belægning stor støjreduktion. Rundt omkring i Europa anvendes forskellige referencebelægninger med varierende alder. Referencebelægningen er i hvert land typisk valgt ud fra, hvad der var den mest almindelige belægning på veje med høj kapacitet, førend støj kom i fokus. I Danmark anvendes i SRS systemet og i støjberegningsmodellen en slidt tæt asfaltbeton med 11 mm maksimal kornstørrelse (AB11 t) med en alder omkring på 8 år som reference. Denne belægningstype var almindeligt anvendt på danske landeveje i perioden 1993 til 1998 og har typisk en levealder på 12 år. I Holland anvendes en reference baseret på en gruppe belægninger, der er under to år gamle. For veje med høj fart anvendes tæt asfaltbeton med 16 mm maksimal kornstørrelse (AB16 t) og for veje med lavere hastigheder anvendes en kombination af tæt asfaltbeton med 11 og 16 mm maksimal kornstørrelse. I Sverige anvendes ét år gamle SMA belægninger med 16 mm maksimal kornstørrelse som reference.

Transportministeriet i Danmark har udarbejdet et katalog over enhedspriser for omkostningen ved den tid der bruges til transport, og enhedspriser for samfundet for luftforurening, udslip af CO_2, ***støj***, trafikuheld og køkørsel, trafikpropper mv. Med disse priser kan man beregne omkostningerne ved støjreducerende vejbelægninger. Prisen på støj er fastlagt ud fra støjgener, på baggrund af undersøgelser af huspriser, og ud fra sundhedsomkostninger, på baggrund af risikoen for hospitalsindlæggelse, for tidlig død mv. som følge af langtidseksponering for trafikstøj. For at kunne beregne cost/benefit, er det nødvendigt at have pålidelige data for hvordan vejbelægningernes støjmæssige egenskaber udvikler sig over belægningernes levetid. En første model for dette er udviklet i EU projekt SILENCE.

I Holland, Frankrig og Tyskland er der foretaget langtidsmålinger ved støjreducerende belægninger for at få generel viden om støjudviklingen. Der er slet ikke overvågning af alle belægningsarbejder. I Danmark har vi løbende fulgt udvalgte forsøgsstrækninger med SPB-målinger. Disse suppleres nu med CPX-måling og vi planlægger at måle belægningernes overfladestruktur ved hjælp af laserudstyr. Det har sikret værdifulde serier af måleresultater indsamlet over lang tid.

Det er planlagt at fortsætte overvågningen i de kommende år i det omfang det er muligt at fremskaffe finansiering.

Markedets udbud af støjreducerende vejbelægning påvirkes af mange praktiske forhold. For eksempel findes der endnu ikke en international standard for måling og klassifikation (CPX metoden er stadig et forslag til en ISO målemetode, og der er ingen international procedure for regelmæssig præstationsprøvning (Round Robin Test) af det måleudstyr som anvendes). Desuden er der ikke kapacitet til at foretage støjmæssig kontrol af alle belægningsarbejder. Det må tages i betragtning ved fremtidige overvejelser om et system til støjmæssig godkendelse af udførte belægningsarbejder.

Der er en tendens til i det europæiske system for produktspecifikationer at gennemføre en initial typetestning for at karakterisere materialernes egenskaber. I de tilfælde hvor en færdig vejbelægning ikke alene er defineret ud fra de anvendte materialer men også ud fra selve udførelsen, som det for eksempel er tilfældet med tyndlags-kombinationsbelægning (TBk) og overfladebehandling (OB), foretages der også typeprøvning af det færdige produkt. Flere lande vil formentlig i de kommende år udvikle procedurer for certificering/deklarering af støjreducerende belægninger, baseret på resultater fra forsøgsstrækninger med de pågældende produkter.

Det er normalt vejejeren som betaler for en støjreducerende vejbelægning, enten i et nyt vejprojekt eller i den løbende vejvedligeholdelse. I København har det været diskuteret, om bygherren for en ny boligbebyggelse eventuelt skulle betale for udlægning af støjreducerende vejbelægning på en nærliggende vej som en betingelse for at opnå byggetilladelse. Dette dog ikke sket.

I Danmark er afhjælpningsperioden for støjreducerende vejbelægninger den samme som for andre belægninger, nemlig 5 år. Der er ikke udviklet et system for at medtage den akustiske holdbarhed. Det forventes, at når der til sin tid er indsamlet erfaring med holdbarheden af støjreducerende belægninger, vil akustisk og strukturel holdbarhed af disse belægningstyper blive en konkurrence-parameter mellem støjreducerende belægningstyper og mellem entreprenører, som tilbyder at udføre sådanne belægninger. Dette er tilfældet i dag for almindelige vejbelægninger.

I en række lande anvendes der korrektionsfaktorer i støjberegningsmodeller for at tage hensyn til virkningen af støjreducerende vejbelægninger.

Vi ser i horisonten følgende udviklingstendenser for støjreducerende vejbelægninger:

- Den igangværende udvikling af støjreducerende tyndlagsbelægning tyder på, at denne type belægning er omkostningseffektiv. Europæiske principper for design af sådanne belægninger kan blive baggrund for udvikling af tilsvarende belægninger med brug af materialer, der er tilgængelige i Californien
- I Tyskland er der af støjmæssige årsager tendens til at bruge SMA belægning i stedet for betonbelægning. Der er dog udviklet nye cementbetonbelægninger med en vis støjreduktion

- Udvikling og afprøvning af to-lags drænasfalt optimeret for lang akustisk og strukturel holdbarhed på veje med hastigheder over 70 km/t er en nærliggende mulighed
- Også videreudvikling af poro-elastisk belægning er en mulighed. Der er planer om et europæisk forsknings- og udviklingsprojekt på dette område.

1. Preface

In this report the latest European experience on the practical use of noise reducing pavements is presented. The report has been produced by the Danish Road Directorate, Danish Road Institute (DRI-DK). The work has been carried out in the framework of the Administrative Agreement on "Road Infrastructure Technologies and Quieter Pavements" between California Department of Transportation (Caltrans) and Danish Ministry of Transport and Energy, Road Directorate, Danish Road Institute signed in May 2007. The purpose of this Administrative Agreement is to define a collaborative relationship for quieter pavement research and development activities between Caltrans and DRI-DK. The objective is to facilitate and support research, development and deployment activities of mutual interest to the parties, within the framework of road infrastructure technology. It is the intention of the parties to jointly carry out Research and Development activities and exchange R&D results that may involve the exchange of funds and staff between the parties.

The present report is the result of the first project carried out in the framework of the Administrative Agreement. For practical reasons Caltrans has contracted the University of California Davis (UC Davis) to carry out the study and UC Davis has subcontracted the study to DRI-DK. A Project Steering Group with the following members has been established:

- S. David Lim, Caltrans, Division of Research and Innovation
- Linus Motumah, Caltrans, Division of Design/Pavements
- Bruce Rymer, Caltrans, Division of Environmental Analysis
- Erwin Kohler, Dynatest Consulting representing UC Davis.

The following DRI-DK Senior Researchers have performed the collection and analysis of European practice on the use of noise reducing pavements presented in this report:

- Hans Bendtsen (project leader)
- Jørgen Kragh (noise specialist)
- Erik Nielsen (pavement material specialist).

Road Directorate, Danish Road Institute
Denmark June 2008

1. Forord

I denne rapport præsenteres de nyeste europæiske erfaringer med praktisk brug af støj-reducerende vejbelægninger. Rapporten er produceret af Vejteknisk Institut/ Vejdirektoratet. Arbejdet er udført inden for rammen af en administrativ aftale fra maj 2007 om vejinfrastruktur teknologi og støjreducerende vejbelægninger mellem "California Department of Transportation – Caltrans" (Vejmyndigheden i Californien, USA) og Transportministeriet, Vejdirektoratet/Vejteknisk Institut i Danmark. Formålet med den administrative aftale er at definere en fælles ramme for forskning og udvikling af støjreducerende vejbelægninger mellem Caltrans og Vejdirektoratet/Vejteknisk Institut. Ideen er inden for den faglige ramme vejinfrastruktur teknologi at understøtte forsknings, udviklings og demonstrations aktiviteter der er til fælles interesse for de to partnere.

Intentionen er at de to partnere fælles udfører forsknings- og udviklingsaktiviteter og udveksler resultater fra forskningsprojekter. Samarbejdet kan også omfatte projektfinansiering samt udveksling af personale.

Denne rapport er resultatet af det første projekt, som er udført af Vejdirektoratet/Vejteknisk Institut inden for rammerne af den administrative aftale. Af praktiske årsager har Caltrans kontraheret arbejdet til University of California Davis (UC Davis), som har subkontraheret arbejdet til Vejdirektoratet/Vejteknisk Institut. Der er oprettet en projektstyringsgruppe med følgende medlemmer:

- S. David Lim, Caltrans, Divisionen for forskning og udvikling
- Linus Motumah, Caltrans, Divisionen for belægninger og design
- Bruce Rymer, Caltrans, Miljødivisionen
- Erwin Kohler, Dynatest Consulting som repræsentant for UC Davis.

Følgende seniorforskere fra Vejdirektoratet/Vejteknisk Institut har udført indsamlingen og analyserne af den europæiske praksis om brug af støjreducerende belægninger, der er præsenteret i denne rapport:

- Hans Bendtsen (projektleder)
- Jørgen Kragh (støjspecialist)
- Erik Nielsen (asfalt materiale specialist).

Vejdirektoratet/Vejteknisk Institut
Danmark juni 2008

2. Introduction

2.1 Background

There is increasing focus in Europe on applying noise reducing pavements on the road networks as a cost effective measure of noise abatement. The driving forces for this are among others:

- An increasing demand in the population for good living conditions including an improved soundscape with less noise in residential and other urban districts. This results in public pressure on the political level and on the road administrations, especially when planning new roads or enlargement of existing infrastructure.
- The European Commission (EU) Directive on environmental noise from 2002 [1] that calls for noise mapping as well as for the development of noise action plans throughout the 27 member states.

In the case of both road infrastructure planning and noise action plans noise reducing pavements are a cost effective measure of noise abatement which can be implemented locally by the road administration.

Caltrans in California has policy, procedures and protocols for the use of noise barriers to mitigate the impact of traffic noise but does not currently have in-place policy for noise reducing pavements. Therefore Caltrans may use Danish expertise and the expertise of other European countries as a foundation for the development of a statewide Californian policy for the application of noise reducing pavements.

In Denmark, a first generation system has been developed for the specification and documentation of noise reducing pavements including a paradigm for use in contracting and preparation of tender documents, the so called "SRS-System" (see Chapter 4). In order to improve this system, the Danish Road Directorate has a need for updated information on the practical use and procurement of noise reducing pavements in Europe.

2.2 Scope of work

On that background this joint research and development project on the analyses of the use of noise reducing pavements in Europe has been initiated. The following twelve questions have been outlined to be investigated as far as possible within the given time and financial constraints of the project:

1. Which countries have a working policy for using noise reducing pavements within Europe, and for how long have the policies been in-place?

2. What factors are considered in each of the countries' policies (noise levels, traffic levels, traffic composition, population, health impact, etc.)?
3. Which policies have been found effective?
4. Are noise reducing pavements used in conjunction with other forms of noise mitigation? How is it used in combination with other noise reduction measures?
5. How do the various European countries define what is a noise reducing pavement (noise levels, surface characteristics, materials)?
6. How are the noise reducing pavement benefits or credits calculated?
7. How do the European countries monitor noise reducing pavements over time? (How do they include noise reducing pavements in their overall pavement management practices or scheme?)
8. What is the reference pavement, and how is it chosen?
9. How is it assured that noise reducing pavement attributes are achieved from construction or by contractors? (Provide any construction specifications that should be met during construction inspection?)
10. Who pays for noise reducing pavements (private developers, local governments, national government) and how about warranties?
11. New developments on the horizon to be aware of, or that would be of use to California or Denmark?
12. How are noise reducing pavement benefits incorporated into traffic noise models?

2.3 Working method

DRI-DK is the Danish knowledge centre for road traffic noise. In recent years DRI-DK has played a key role in a series of European and national research and development projects focusing on various aspects of noise abatement and especially on the development, testing and use of various types of noise reducing pavements. These projects are summarized in Table 2.1.

The present report is mainly based on the information and knowledge obtained by DRI-DK while conducting these projects. Some of this information has been supplemented and updated. This is the background for the description and analyses of the European experience with the use of noise reducing pavement presented in the present report. The time frame for the project has not made it possible to crosscheck all information, but it is the belief of the authors that minor inaccuracies do not influence the general picture given of European practice. We have tried to take the little we know of California conditions into consideration and are grateful for the support received from the project steering group.

Table 2.1. Summary of recent projects with the participation of DRI-DK.

1. The EU project SILVIA [2] where a guidance manual for the use of noise reducing pavements was developed [3] in a cooperation between fifteen European partners from eleven countries.
2. The EU project SILENCE [4] including both road and railway noise. As a representative from the organisation the Forum of European Highway Research Laboratories (FEHRL), DRI-DK was leading a large work package on a variety of aspects of road surfaces and noise reduction. The work was carried out in cooperation with five other national FEHRL institutes.
3. The EU project INQUEST where the results of the SILVIA project were disseminated to road engineering professionals at workshops in seven European countries. In the project also a workshop on noise labeling systems was organized in Slovenia. INQUEST was carried out by DRI-DK, the Belgian and the British Road Institute and FEHRL.
4. The DRI-DWW Noise Abatement Program [5] was a research cooperation between DRI-DK and the Road and Hydraulic Engineering Institute in the Netherlands (DWW and from 2007 DVS) including seven research and development projects on the long time durability of porous pavement, on the optimization of the noise reduction of thin layer pavements and on cost-benefit analysis. The DRI-DWW Noise Abatement Program was a part of the Dutch IPG research program on the development and testing of measures for reducing road traffic noise [6].
5. The development of the Danish SRS-System for noise labeling of pavements [7] together with contracting companies, regional road administrations and consultants.
6. The ERA-NET-ROAD [8] project on risk assessment of the use of noise reducing pavements [9] performed for the eleven European member countries in the ERA-NET-ROAD joint research cooperation supported by the EU. DRI-DK carried out this project together with the Belgian Road Research Institute, BRRC.
7. The report on knowledge sharing on the management and abatement of traffic noise [10] produced by the noise group of the organization Conference of European Directors of Roads (CEDR) [11]. The noise group was chaired by DRI-DK.

2.4 Report structure

The report is structured in five main chapters. Chapter 3 gives a general European outlook not focusing on technical details. In Chapter 4 the newly developed Danish noise labeling system for pavement products is presented in some detail. This is followed by a brief description in Chapter 5 of a few other type approval systems for pavements used in Europe. In order to give a more detailed and technical description of the practical use of noise reducing pavements, seven cases are presented in Chapter 6. To cover a variety of European countries Denmark, Germany, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom have been selected. Noise is an important, but not the only functional criteria for pavements. In Chapter 7, other pavement performance functionalities are discussed. Finally, conclusions are presented in Chapter 8. This chapter is structured as the 12 questions highlighted in the scope of work (Section 2.2). A list of terms and abbreviations is included as an Annex.

3. European Outlook

As an introduction, this chapter gives a brief general description of the use of noise reducing pavements in Europe.

3.1 Typical measures of noise abatement

The organization, the Conference of European Directors of Roads (CEDR), in 2006/07 performed a questionnaire survey on practice in noise abatement in the National European Road Administrations [10]. Figure 3.1 shows various means of noise abatement applied along existing national roads as well as in new road construction projects in Europe. The figure shows the percentage of countries where the different types of noise abatement are used but not the order of magnitude it is used in the countries. Along the existing roads noise reducing pavements comes in as the third most popular type after noise barriers and façade insulation. For new road projects noise reducing pavements comes as number two after noise barriers.

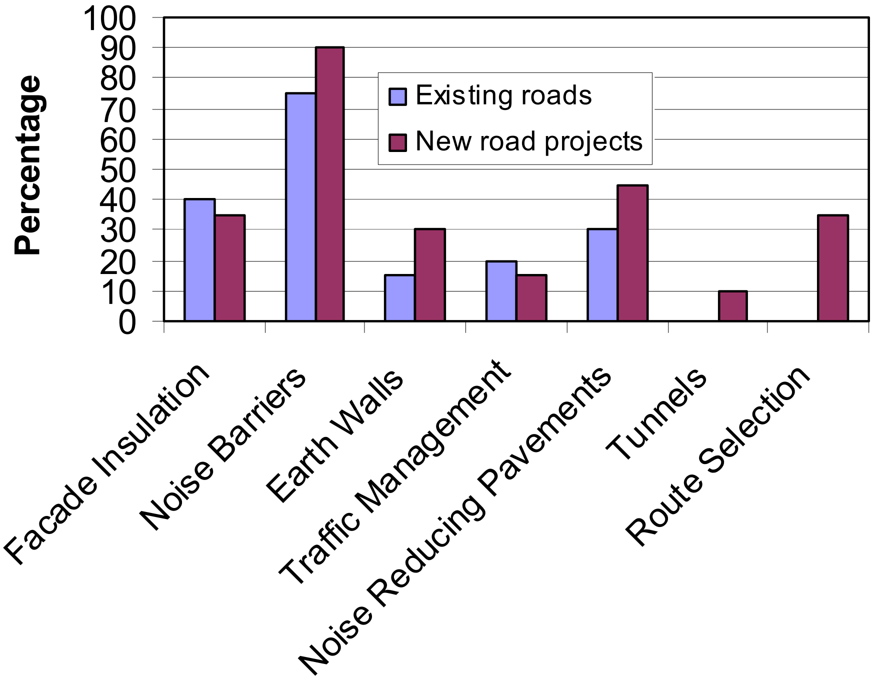

Figure 3.1. Types of noise abatement used along new and existing national roads in Europe [10]. The percentage of countries using each type of noise abatement is shown.

Different types of noise abatement are often combined in a project in order to achieve the necessary noise reduction. In the project for enlarging the ring road around Copenhagen, Denmark, from four to six lanes through a densely built up residential area (see Figure 3.2) a combination of 4 m high noise barriers, noise reducing thin layers and façade insulation is used.

Figure 3.2. The project for enlarging the ring road around Copenhagen, Denmark from four to six lanes through a densely built up residential areas combines the use of noise barriers, noise reducing thin layer surfacing and façade insulation.

3.2 Noise reducing pavements on the market

In order to talk about a noise reducing pavement it is necessary to define a reference pavement, a reference noise level and a standard method to measure the noise. There is no European standard reference pavement in relation to noise. There are different national reference pavements. These reference pavements were selected on the background of local practice and history. In Denmark the reference pavement is a Dense Asphalt Concrete (DAC) with a maximum aggregate size of 11 mm. In the other Nordic countries (Sweden, Norway and Finland) the reference is a Dense Asphalt Concrete (DAC) or a Split Mastic Asphalt (SMA) with a maximum aggregate size of 16 mm which is nearly 2 dB noisier than the Danish reference. In the Netherlands, for the speed of 50 km/h a "virtual" reference noise level is used which is a combination of DAC pavement with 11 and 16 mm maximum aggregate size and for roads with high speed the reference is a DAC with 16 mm maximum aggregate. In the United Kingdom, the reference is a Hot Rolled Asphalt which is a noisy pavement type.

The traffic noise level at a certain pavement increases due to wear and tear so it is also necessary to define the age of a reference pavement. With this in mind it can be difficult to compare noise reductions presented in different countries as the "zero-level" may vary significantly. Because of this it might be more unambiguous to mention absolute noise levels as these can be compared across borders - and this is not easily done in real life, if it is at all possible – if they are measured under exactly the same conditions.

Figure 3.3 shows the percentage of European countries where different types of noise reducing pavement are available on the market. The figure is based on information from the National Road Administrations [10] and therefore the results in the figure are related to a variety of national reference pavements. The figure gives an indication that the most common noise reducing pavement in Europe is the porous type available in 45 % of the countries followed by SMA (30 %) and thin layers (15 %). Different types of noise reducing pavement might be available in one individual country.

Porous pavement may be denoted a classical noise reducing pavement. In recent years research has been conducted in order to optimize noise reducing thin layers and some of these thin layers are based on the SMA concept. Positive results have been achieved, especially regarding the initial noise reduction [12] and on that background some road administrations now begin to use also this type of noise reducing pavement on a larger scale.

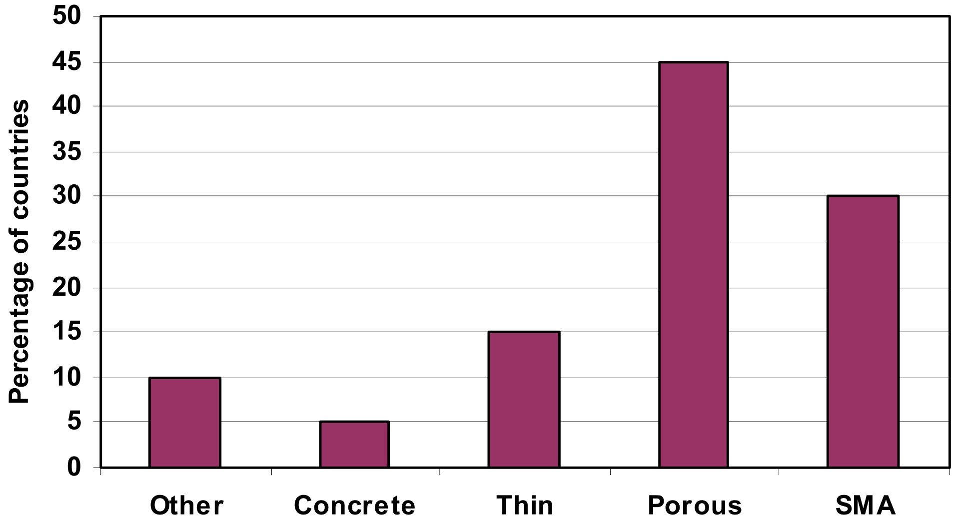

Figure 3.3. Percentage of European countries where different types of noise reducing pavement are available on the market [10].

3.3 Trends in the use of noise reducing pavements

In the Netherlands, noise reducing porous pavements have been used on the motorway network for many years. This type of pavement is currently applied on around 70 % of the network and it is a national goal to reach 100 % in 2010. The reason for using porous pavement is to reduce noise but also to improve the capacity of the roads in rainy periods. When the road surface becomes wet, splash and spray makes the drivers reduce the speed and this reduces the capacity of the motorways. Porous pavements drain away water and reduce splash and spray and increase speed and by this the capacity of the roads. In the Netherlands, special winter maintenance procedures have been developed to avoid black ice on roads with porous asphalt.

As a new trend in the Netherlands, on the background of the Dutch road noise research project (the IPG Program [6, 12]), also noise reducing thin layers are introduced on the motorway network. So far around 100 km of thin layers have been built on motorways.

Japan is another country, outside Europe, where porous pavement is used on a large scale to reduce traffic noise both in warm and in cold climate zones [13]. On around 4,300 km or 20 % of the national roads in Japan noise reducing pavement is applied [14].

In Austria, porous pavements have been used on national roads but because of problems experienced with winter maintenance and icy roads, it is not common to use porous pavements any more in Austria.

In Germany, a shift in paving policy on motorways has occurred. The more noisy cement concrete is phased out and instead SMA pavements or other treatments with higher texture are used to reduce the noise emission. There is also a current focus on optimizing single-layer porous asphalt concrete [14].

Figure 3.4. Test section with single and two layer porous asphalt on a Swedish highway north of Stockholm.

In Sweden single and double layer porous pavement is under test on highways where a high percentage of the vehicles uses studded tires in the wintertime [14].

In Denmark research on and development of single and double layer porous pavements for noise reduction has been ongoing since the beginning of the 1990s but because of a fear of problems with winter maintenance of such open structured pavement these pavements have not yet been used on a wider scale. Instead there is a trend towards using noise reducing thin layers on new national roads and in road maintenance projects. This is based on results of research and testing projects since the early 2000s [12] and is supported by the introduction of a system for noise labeling of pavements (the so called "SRS System") that makes it possible for road administrations to specify noise when tendering pavement works (see Chapter 4). This trend is seen in other countries around Europe.

In France, porous pavement is used on the main road network. On privately operated toll motorways porous pavement has been used, primarily to improve the comfort and safety of drivers paying to use these roads by reducing splash and spray under heavy rain conditions and by this also increasing the speed and capacity of the roads. This is done to attract costumers to the toll roads.

Figure 3.5. Noise reducing thin layer on the heavily trafficked ring road around Nantes in France.

France was one of the first European countries to develop noise reducing thin layers [15]. From around 1985, thin layers and ultra thin layer mixes have been developed and used in France, in order to improve visual performance under wet conditions (reduce splash and spray) and to achieve noise reduction. Thin layers with maximum aggregate size down to 6 mm were used. The typical thickness of such pavement is 20 to 30 mm even though ultra thin pavement with a thickness down to 10 - 15 mm is also used. In France a standard for thin layers was published in May 2001. Thin layers can be used for maintenance of wearing courses as well as for new surfacing. Thin layers are used for all types of traffic, low speed and high speed, low and high volumes of traffic and with high percentages of heavy vehicles. Thin layers with small maximum aggregate size have good skid resistance, often better than ordinary pavement. Various commercial products are on the market and are commonly used in France.

In some new EU member states in former Eastern Europe there is growing interest in noise reducing pavement. For example, in Slovenia and in Poland the first road sections with noise reducing pavements are under construction.

3.4 Road maintenance and noise reducing pavements

There is on-going work in all European countries as regards the maintenance of roads. This includes the repair of parts of the pavement of a road section and total renewal of the wearing course by applying new surfacing. The type of pavement used to undertake this work has an impact on the noise.

Therefore, in principle, noise abatement can be integrated into road maintenance procedures. The CEDR questionnaire on noise [10] has covered this possibility.

Generally, noise is not one of the criteria used by National Road Administrations in Europe for selecting the roads requiring a new surfacing. This selection is driven by factors like wear and tear, bearing capacity, traffic safety etc. In some countries noise is taken into consideration, although not as a main criterion and there are no general rules for the use of noise reducing pavements.

When a road has been selected to have a new surfacing, then in 65 % of the surveyed countries, noise is a parameter considered when selecting the type of pavement to be used. In some countries financial criteria can outweigh noise reducing pavements and these surfacings are avoided in situations where they can be expected to perform poorly. In some countries guidelines for the use of noise reducing pavements are currently being developed.

A way to handle noise with regard to road maintenance may be to integrate noise as an active parameter into a Pavement Management System. Only in 10 % of the surveyed countries noise is included as a parameter in the Pavement Management System. As a part of the EU project SILENCE [2] it was analyzed how noise can be integrated as an active parameter in Pavement Management Systems [16].

Figure 3.6. A way to handle noise with regard to road maintenance may be to integrate noise as an active parameter into a Pavement Management System.

The use of noise reducing pavements can be promoted by having guidelines, legislation or recommendations on how and when to use such surfacing on new roads or in the maintenance of existing roads. In 20 % of the surveyed countries, noise reducing surfacing was included in guidelines, strategies or documents with similar status. In some countries work is ongoing on the development of such guidance.

One country has an information leaflet that gives qualitative recommendations on the use of noise reducing pavements. Only in one of the surveyed countries it is the policy to use porous asphalt as a standard surfacing, especially on national roads with a maximum speed of 120 km/h.

3.5 Road surfaces in traffic noise prediction

A report made for the European Commission [65] gives the state of the art concerning the noise classification of road surfaces for use in assessing the environmental impact of road traffic noise. Reference is given to this report concerning details. Table 3.1 - from a presentation given at a European workshop [66] - summarizes some correction terms from the report for supposedly comparable surfacings. As can be seen, for example, a Stone Mastic Asphalt in Hungary is predicted to be 3 dB noisier than a Dense Asphalt Concrete while in Austria the opposite is the case.

Table 3.1. Correction terms for supposedly comparable surfacings [66].

Country	Remarks	SMA-DAC	PA-DAC	EACC-DAC
Austria	Light vehicles / 50 km/h		-1	0
Austria	SPBI	-3.4 / -1.4	-3.3 / -1.3	-2.0 / 0.0
Austria	CPXI (LMA)	-3.7 / +0.3	-1.5 / -0.3	-2.8 / -1.0
France	0/10 mm / Light veh. / 90 km/h		-3.9	
France	0/10 mm / Light veh. / 50 km/h		-3.5	
Germany	30-50 km/h	0		
Germany	0/11 mm / > 60 km/h	0.0	-2.0	
Hungary	0/12 mm	+2.9		
Italy			-1.4	
Japan	0/13 mm / 50 km/h		-2.7	
Japan	0/13 mm / 90 km/h		-3.6	
Netherlands	Light vehicles		-2.61	-0.07 / +1.42
Slovenia	1995	-2	-3	
Slovenia	2003	-2.1	-6.9	
Spain	< 60 km/h		-1	
Spain	> 80 km/h		-3	
Switzerland		0	-4	
USA	Light vehicles		-1.55	
Nordic countries	Max. 16 mm / Light vehicles	0 / +1	-1 / 0	

4. The Danish pavement type approval system for noise

In 2006, Danish road authorities in conjunction with pavement industry and consultants worked out a system for the specification and documentation of noise reducing asphalt pavement [17], the SRS-system, SRS being the acronym for the Danish wording of Noise Reducing Surfacing. The system is based on the Close Proximity Method (CPX method [18]) for noise measurements and in order to ensure reliability and transparency it allows various independent providers of CPX measurements to offer their service as long as they participate in an annual field calibration of equipment. The system encompasses:

- A guide to the use of asphalt surfacings in traffic noise abatement
- A system for the documentation and declaration in classes of the noise reduction of the asphalt surfacing
- Three classes A, B & C, where class A surfacings exhibit the highest noise reducing effect and class B & C exhibit lower noise reducing effects as compared to regular dense graded asphalt surfacings
- Reference values of the noise emission as determined by the CPX method
- A description of the CPX method including the definition of method variables and requirements on supplementary calibration of the measuring device
- A paradigm for the contracting and preparation of tender documents.

The system is a result of a first Danish attempt to provide a system for contracting noise reducing asphalt surfacings. It has limitations and several subjects need addressing. In particular, there is a need for better knowledge on the accuracy of CPX measurement, and for the development of appropriate acceptance criteria for contracting.

4.1 The purpose and importance of classification

The intention is for the classification system to certify the noise reduction ability of road surfacings including new products as well as to improve the ability of the local road administrations – not skilled in noise considerations – to purchase proven solutions fit for use. In this connection, we shall distinguish between:

- Classification of products for contracting
- Noise characteristics for use in environmental noise prediction.

The former deals with the surfacing condition when new. The latter needs decision taken based on the (known or assumed) time history of noise reduction (initial vs. life time average noise reduction, which has been addressed in the EU project SILENCE [19]). The conclusion was that available data displayed large spread but on the average one should expect an ageing effect on the traffic noise levels as indicated in Table 4.1.The table gives the increase to be expected for the linear time history of vehicle noise levels. For both light and heavy vehicles, the expected increase at dense asphalt surfacings is in the order of 0.1 dB per year of pavement service time. This applies to high speed as well as low speed roads. For porous or open graded asphalt surfacings the expected time history increases for light vehicles is in the order of 0.4 dB per year on high speed roads and 0.9 dB per year on city streets with low traffic speed. Heavy vehicle noise levels are expected to increase with 0.2 per year on high speed roads.

Table 4.1. Overall proposed time history slopes, dB per year of pavement service time.

	Light vehicles		Heavy vehicles	
Surface family \ Traffic Speed	**High**	**Low**	**High**	**Low**
Dense asphalt	0.1	0.1	0.1	0.1
Porous / Open asphalt	0.4	0.9	0.2	-

Popular demand for traffic noise reduction made pavement contractors develop and market products, which they claimed were noise reducing. Traditionally, asphalt contractors in Denmark are responsible for the mix design within the framework of the Road Standards. Confusion among road administrations and consultants led to a widespread wish for a systematic way of expressing product noise reducing properties.

Based on recent experience, guidelines have been written for tendering noise reducing road surfacing works [20]. We expect these guidelines will ease the process of actually requesting noise reducing surfacings built as a means of noise abatement when road maintenance or new road construction work is carried out near noise sensitive areas. The Danish Road Directorate intends to use the system when tendering pavement works where noise reducing pavements are needed. We expect municipal road administrations to prescribe SRS in their traffic noise action plans. For example, the Municipality of Copenhagen in its action plan [21] has decided to apply noise reducing surfacing when maintaining surface layers in streets with an ADT of more than 2000, except at roundabouts with small radius and other places with low traffic speed or wringing traffic. By spring 2008, we expect a rapid increase in the purchase of SRS labeled pavement, especially from local administrations.

4.2 Product declaration

A contractor who wants to declare a SRS shall work out a declaration form. In this form he declares the actual noise class and presents the documentation achieved during CPX measurements on a trial section.

The declaration document shall be prepared in accordance with the paradigm of the noise declaration form. The contractor writes his name and address and the type of SRS (e.g. DA, TB k or SMA, Danish abbreviations for mix types corresponding to PA, UTLAC and SMA) including certain details of the asphalt mixture. Furthermore, he shall report details of the trial section used for the documentation.

The noise declaration will be valid for five years or until significant change in the SRS product occurs. The declaration document can on request be followed by the CPX measurement report and also by the Job Mix Formula prepared in accordance with the Danish general specification for hot mixed asphalt (AAB Varmblandet asfalt [22]).

In general, the degree of material control which the asphalt contractor shall provide is linked to the job size where two levels are defined. The border line is 1,000 tons of surface materials (in case of a Thin Layer Asphalt like an UTLAC 6 it will be approx. 28,000 m^2). Below that limit you are entitled to get information on the material type provided and the delivery tickets stating the amount (weight) of delivered materials that will make it possible to calculate for the specific job the average layer thickness in kg/m^2 which can be compared with the agreed amount in the tendering document.

Above 1,000 tons additional information will be obtained and if the general specification for the chosen mix family/type has a demand of the finished pavement (like degree of compaction) cores will be taken as documentation. There is normally no requirement on void content as it will be impossible (or difficult subjected to a lot of bias) with the available test methods to estimate the void content for the specification purposes for these Thin Layer Asphalts. For materials like UTLAC, the layer is born with an inhomogeneous void structure in the layer from top to bottom. Information on some relevant sieve sizes is provided in the declaration more for the purpose of "forensic" studies if later durability issues raise questions whether or not the right material has been delivered.

The declaration document shall be signed by the contractor.

4.3 Classification procedure

The contractor shall build a test section of at least 100 m length. The CPX-trailer shall run over the trial section at the appropriate reference speed while recording the noise levels at its two standard reference tires. The CPX index is calculated as described below and compared with the appropriate reference value, cf. Section 4.4, to determine the noise class. Finally, the contractor produces a certificate declaring his product to be classified.

Figure 4.1. DRI CPX-trailer "deciBellA" parked at calibration section on Kongelundsvej in Copenhagen.

The noise measurement result shall be reported as an index CPX_{DK}, in decibels, prescribed in a Danish addendum to ISO/CD 11819-2 [18]:

CPX_{DK} = 0.85·CPXL + 0.15·CPXH + *K*

CPXL	is the light vehicle contribution: CPXL = $L_A + 1.00$
CPXH	is the heavy vehicle contribution: CPXH = L_D
K	is a correction constant related to the actual CPX trailer (see Section 4.5)
L_A	is the CPX sound pressure level measured at reference tire A
L_D	is the CPX sound pressure level measured at reference tire D.

The first generation SRS-system does not contain restrictions as to how early after construction of the test section the contractor may perform the CPX measurements for declaration purposes.

Figure 4.2. Detail showing the microphone positions near a reference tire.

4.4 Reference values and noise classes

The system to declare the noise reducing ability enables the contractor to produce documentation of the noise reduction of a specific SRS by comparing measured values with a national reference value. The reduction in noise emission as compared to the reference is used by the contractor in his declaration of the SRS in a specific noise class.

The first generation system describes three noise classes:

A:	Very good noise reduction	(Danish: Særligt støjreducerende)
B:	Good noise reduction	(Danish: Meget støjreducerende)
C:	Noise reduction	(Danish: Støjreducerende).

Currently the contractors' SRS products are almost all declared as belonging to class B or class C. Class A was introduced as a driver of further development and enhancement.

The reference values in the first generation system refer to the CPX method and are defined as the national CPX_{DK} index. The first generation system defines such reference values at two traffic speeds, 50 km/h and 80 km/h, respectively.

The reference values were derived as pass-by noise levels [23] calculated for reference conditions using the Danish noise emission data of the Nordic prediction method for road traffic noise, Nord2000 [24]. Using data on the relation between vehicle pass-by noise levels and CPX noise levels, the Nord2000 pass-by noise levels were transformed to their corresponding CPX_{DK} values, which are used in the first generation system.

The CPX reference values are given below. The CPX values correspond to the noise emission in the Danish part of Nord2000, representing approximately 8 year old asphalt surfacings of dense graded asphalt with 11 mm nominal aggregate size (DAC 11).

CPX_{DK} reference at 80 km/h:	102.0 dB
CPX_{DK} reference at 50 km/h:	94.0 dB

No reference is defined for traffic speed 110 km/h, due to the limited amount of data obtained at this speed.

When declaring the noise reduction of an asphalt surfacing (by comparison to the reference used in Denmark), one of the following noise classes A – C should be used.

Noise class	Noise reduction in dB
A: Very good noise reduction	$x \geq 7.0$
B: Good noise reduction	$5.0 \leq x < 7.0$
C: Noise reduction	$3.0 \leq x < 5.0$

4.5 Calibration

At present two CPX trailers are used in Denmark, one is the open DRI-DK trailer named “deciBellA“, the other one is a closed Dutch trailer contracted by a Danish consultant. Trailers used in the SRS system must participate in regular field calibration to ensure comparability of their results. Currently field calibration at a speed of 50 km/h takes place on five specific sections of road on Kongelundsvej in Copenhagen, see Figure 4.1, and at a speed of 80 km/h on six specific sections of M10 at Solrød, see Figure 4.3, [17]. These sections comprise DAC 11 (AC 11d) as a reference and trial sections with various thin layer surfacings. Field calibration shall be conducted with a minimum frequency of one per year.

Figure 4.3. DRI-DK’s CPX trailer “deciBellA” on calibration section on M10.

This field calibration ensures that all sets of measurement equipment applied in the SRS-system yield the same average result for the selected sections of road. In 2006 – 2007 two trailers participated in the system. In 2006 both were assigned a correction *K* = 0.0 dB, while in 2007 one trailer had K = 0.0 dB, the other K = -0.2 dB at 50 km/h; one trailer had -0.4 dB and the other trailer had K = 0.0 dB at 80 km/h.

4.6 Available noise reducing surfacings

Figure 4.4 and Figure 4.5 show the results of CPX measurements carried out in 2007 by DRI-DK. The labels on the x-axis are generic Danish pavement names. The labels at the top of the bars give the pavement age in (decimal) years at the time of measurement. One brand new surfacing belongs to class A at 80 km/h, while all else are class B or yield higher noise levels.

Note: The designations in Figure 4.4 and Figure 4.5 are: AB t: Dense graded Asphalt Concrete; AB å: Open graded asphalt Concrete; TB: Ultra Thin Layer AC; OB: Surface Dressing; DA: Porous Asphalt (or BBTM); SMA: Stone Mastic Asphalt

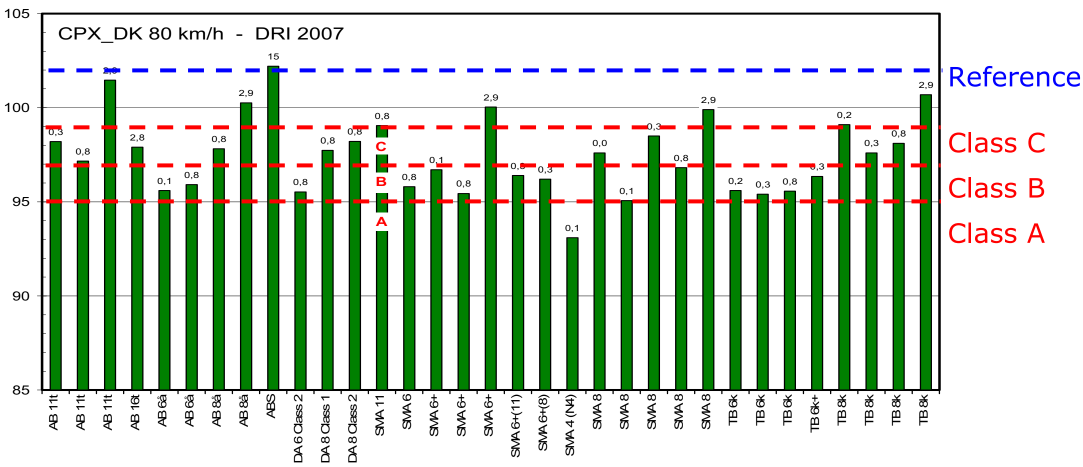

Figure 4.4. CPD_{DK} at 80 km/h measured by DRI-DK in 2007 on various surfacings. Bar labels show surfacing age in years.

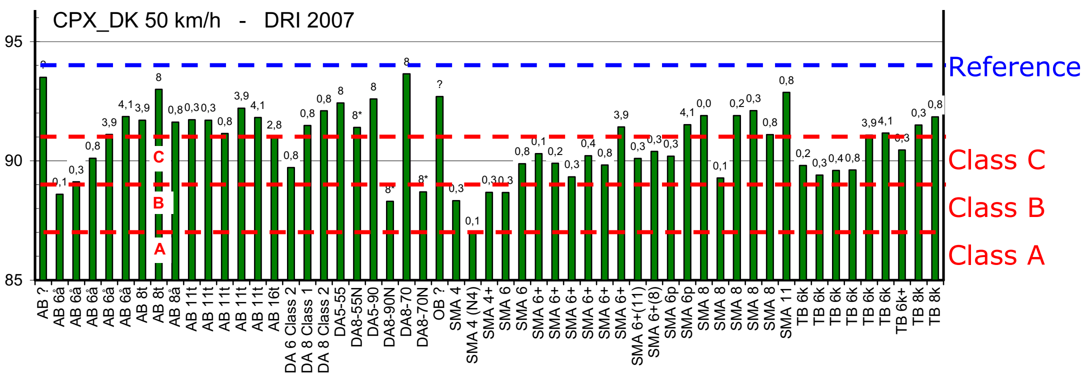

Figure 4.5. CPD_{DK} at 50 km/h measured by DRI-DK in 2007 on various surfacings. Bar labels show surfacing age in years.

4.7 Further development

4.7.1 System for testing COP

The DK SRS-system is a voluntary road standard for contracting of noise reducing pavement. In the contract for a specific job the voluntary standards become legally binding. However, at present the system is at an experimental phase with no legal actions in case of the pavement not fulfilling the noise requirements.

The Danish Road Directorate hopes – at a later state – to introduce a system for testing conformity of production (COP) based on the SRS-system. In such a system, it could for example be a possibility that contractors could receive a bonus for delivering a product tested in compliance with COP requirements. Such a bonus could be paid under the condition that the noise reduction is still there after for example two years or after five years.

If a test does not show COP after delivery, the contractor could for example be requested to do a resurfacing or to pay a fine. To reach such a practice it will take time to build sufficient confidence in the system's reliability among contractors and road administrations.

4.7.2 Variation in time

The selected calibration sections are subject to traffic and ageing effects. This means that they are changing with time. The standard reference tire properties (hardness) also change with time. This presents a challenge in obtaining fair comparisons between products tested at different points in time. The solution to this is not trivial. If we try measuring the effect of pavement ageing by measuring the traffic noise level at the side of the road at different times, we cannot be sure that vehicle and tire population is the same at different points in time. We may control parameters such as the reference tire hardness and the road surface texture level to ensure that they are within certain tolerances.

We might choose to regularly add more new calibration sections so that in ten years time or so we would have a family of sections representing all pavement ages and then use the average CPX result from such a family as a reference calibration point.

4.7.3 Same noise class at different speeds

The same type of surfacing may be seen e.g. in Figure 4.4 and Figure 4.5 as belonging to different classes at 50 and 80 km/h, respectively. Probably this is mostly a consequence of the choice of reference values. This choice was based on the relation between passenger car pass-by noise levels and CPX noise levels. In a Danish set of data there was a 1:1 relationship, while in the Dutch relation a 1 dB increase in CPX level corresponded to a 0.9 dB increase in vehicle pass-by noise level.

This latter may or may not be due to a “bias” in the mix of dense and porous surfacings in the Dutch relationship. Suppose the higher noise levels - recorded at high speed - were from porous surfacings (PA), while the lower noise levels – recorded at low speeds – were from dense surfacings (AC or SMA). At a porous surfacing, the attenuation of sound during propagation to the roadside position causes a given CPX noise level to correspond to a lower noise level than at a dense surfacing, all else like. Thus, porous surfacing at the high end of the range and dense surfacing at the low end of the range would result in a relationship with less than a one dB increase in pass-by noise level for a one dB increase in CPX-level.

The Danish SRS-group did not have the original Dutch data at its disposal, only the relationship between CPX and SPB noise levels. We may see, in a future incarnation of the SRS system, that, by dividing surfacings into families, we could obtain 1:1 relations between CPX and SPB noise levels, so that a surfacing obtains the same class certificate at different speeds – as long as propulsion noise is not too important for the SPB.

5. Systems for type approval and testing conformity of production

5.1 Overview

Beside the Danish SRS-system mentioned in Chapter 4, we have identified type approval systems in:

- The Netherlands: “C_{road}“ [25]
- The United Kingdom: “HAPAS” [26].

These systems are mentioned in sections 5.2 and 5.3.

Proposed systems are under consideration and negotiation in Europe, namely:

- The proposal developed in the EU project SILVIA [3]
- A French proposal [27].

These systems are mentioned in sections 5.4 and 5.5.

Of the European countries, only the Netherlands has implemented a system for testing conformity of production, COP. It was used on local roads but not on their main roads.

The Dutch labeling system requires SPB measurements made at five different trial sections on five different sites (individual road works) to determine the road surface correction, as the mean value obtained at these works, with certain restrictions on the variation in measurement results. The Dutch requirements on the type approval testing are more stringent than in the Danish SRS-system, based on CPX-measurement, which requests just one test section. As an intermediate in this respect, the UK system requires SPB measurements made at two trial sections. Such requirements always represent a balance between the wanted accuracy and the wish for having the system implemented in practice.

To the knowledge of the authors, no other type approval system exists in the EU, although several countries take the road surfacing into consideration when computing the environmental impact of traffic noise. In Germany, for example, corrections – denoted D_{StrO} – characterizing the deviation of certain types of surfacing from the reference used in the German prediction method have been determined for use in noise prediction but not for type approval or COP testing [28]. Each of these corrections are based on the results of SPB measurements at five or more different sections of road.

The SILVIA proposal and the French proposal both require a variety of measurements made on two test sections, cf. sections 5.5 and 5.6.

At a European Workshop in Ljubljana 25 April 2008, which was a part of the EU project INQUEST aiming at disseminating the SILVIA project results, the German representative indicated that Germany might apply the proposed SILVIA procedure for type approval, but only after thorough testing of its applicability [28]. On the other hand, the Swedish representative tended to support the Danish system, based on the upcoming ISO standard on CPX measurement.

5.2 Netherlands

5.2.1 Labeling - C_{road}

The reference pavement in the Dutch system for measuring and computing road traffic noise levels [29] is dense asphalt concrete, most probably DAC 16, but the aggregate size and the pavement age are not given explicitly in [29]. According to [30] the reference at high speed roads is DAC 16 and at low speed roads the reference is a mix of DAC 16 and DAC 11. The reference values at 7.5 m distance from the vehicle center line, at a height of 5 m above the road surface is given in Table 5.1.

Table 5.1. Reference values at 7.5 m distance at a height of 5 m, [29].

Vehicle Category [-]	Reference speed [km/h]	L_{AFmax} [dB]
Light	80	74,78
Medium	70	80,94
Heavy	70	83,48

The road surface correction C_{road} is the increase in noise emission as compared with that on the reference surface. One may express this increase either in terms of an overall A-weighted noise level or in terms of a correction for each octave-band with center frequencies from 63 Hz to 8 kHz. An octave-band is a range of frequencies in which the highest frequency is twice the lowest frequency.

Earlier the road surface correction was included in the publication describing the prediction method, but nowadays the Dutch organization CROW on its website publishes a list of correction factors and reports documenting the measurements behind them. As an illustration, Table 5.2 shows corrections for light vehicle noise levels downloaded from [31]. Besides corrections for twelve generic surfacings, the table contains corrections for a number of proprietary products.

For each of these products a test report can be downloaded from [31]. The first four columns of Table 5.2 identify the pavement and the documentation. Column 5 – 6 show the valid speed range. Column 7 gives the correction for use in the Dutch standard computation method I (SRMI) while column 8 gives the correction in each of the octave-bands for use in the Dutch standard computation method II (SRMII). Columns 7 – 8 give the correction *a* at the reference speed v_0 = 80 km/h. Column 9 gives a value, *b*. The resulting correction at the speed *v* is

$$C_{road,v} = a + b \cdot \log_{10}(v/v_0) \qquad \textit{Eq.(1)}$$

Figure 5.1. Urban road in the Netherlands with noise reducing thin layer pavement

Table 5.2. Road surface corrections, light vehicles [31] download 2 June 2008.

Lichte motorvoertuigen		Wegdeksoort	laatste update			Snelheidsbereik		Snelheidsbereik		SRMI	SRMII								SRMI/SRMII
Nr	Wegdektype/-product		op Stillerverkee	publicatie	datum	Vmin1	Vmax1	Vmin2	Vmax2	Delta L	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	b
0	referentiewegdek	asfalt	14-05-04	CROW publicatie 200	apr-04	40	130			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1	1L ZOAB	asfalt	14-05-04	CROW publicatie 200	apr-04	50	130			-2,61	1,30	-3,70	-4,00	0,06	-2,27	-4,33	-3,32	0,17	-8,02
2	2L ZOAB	asfalt	14-05-04	CROW publicatie 200	apr-04	50	130			-5,05	-0,67	-4,53	-5,23	-3,53	-4,93	-5,88	-5,24	-3,51	-5,41
3	2L ZOAB fijn	asfalt	14-05-04	CROW publicatie 200	apr-04	50	120			-6,39	-2,51	-5,77	-6,96	-5,66	-5,88	-7,69	-6,28	-4,66	-5,38
4	SMA 0/6	asfalt	14-05-04	CROW publicatie 200	apr-04	40	80			-1,91	-3,55	-4,95	-4,42	-0,01	-1,90	-2,47	-1,41	0,13	-3,94
5	uitgeborsteld beton	beton	14-05-04	CROW publicatie 200	apr-04	50	130			1,42	0,57	-4,43	-3,43	0,82	2,23	0,80	0,35	1,41	-0,21
6	geoptim. uitgeborsteld beton	beton	14-05-04	CROW publicatie 200	apr-04	70	80			-0,07	-0,70	-4,82	-4,13	-0,30	0,92	-1,29	-1,32	-0,22	-1,63
7	fijngebezemd beton	beton	14-05-04	CROW publicatie 200	apr-04	70	120			1,63	0,43	-4,57	-2,06	0,64	1,41	2,58	1,80	1,02	5,09
8	oppervlakbewerking	asfalt / beton	14-05-04	CROW publicatie 200	apr-04	70	130			2,29	1,84	-3,16	-2,18	2,53	3,61	0,18	-0,35	0,64	-2,81
9	gewone elementenverharding	elementen	14-05-04	CROW publicatie 200	apr-04	40	60			4,00	6,85	3,33	3,00	5,28	5,07	1,36	1,22	1,03	0,00
10	stille elementenverharding	elementen	14-05-04	CROW publicatie 200	apr-04	40	60			-2,18	4,42	-1,59	-1,14	0,88	-1,89	-4,78	-3,77	-1,46	-5,72
11	dunne deklagen 1	asfalt	14-05-04	CROW publicatie 200	apr-04	40	80			-4,21	-1,11	-5,88	-5,59	-1,08	-3,80	-6,67	-5,10	-3,86	-7,24
12	dunne deklagen 2	asfalt	14-05-04	CROW publicatie 200	apr-04	40	80			-5,71	2,26	-4,47	-4,65	-0,97	-6,42	-8,85	-5,56	-3,13	-6,59
13	ZSA-O	asfalt	1-07-2004	M+P.KWS.02.7.4	13-11-2003	40	50			-6,64	0,71	-5,84	-5,57	-2,07	-7,37	-9,18	-5,62	-3,65	-10,62
14	ZSA-SD	asfalt	1-07-2004	M+P.KWS.02.7.2	4-11-2003	40	60			-6,08	0,34	-6,10	-5,81	-1,13	-6,26	-9,76	-7,20	-5,67	-7,10
15	Dubofalt	asfalt	25-06-2007	VKA.06bm11.07r033	22-06-2007	40	70			-4,93	-3,17	-5,64	-5,92	-2,59	-4,47	-6,69	-5,70	-5,36	-2,52
16	Nobelpave	asfalt	1-07-2004	M+P.VERM.01.2.1	16-06-2004	40	50			-6,29	-0,32	-6,46	-5,58	-0,84	-6,93	-9,90	-6,76	-5,80	-8,52
17	ZSM	asfalt	1-07-2004	VKA.04te10.04r64	26-06-2004	40	50			-5,76	2,24	-6,04	-5,65	-1,96	-6,15	-7,35	-6,05	-4,92	-8,83
18	Micropave	asfalt	1-07-2004	VKA.04ve10.04r62	25-06-2004	50	80			-4,78	-0,29	-6,29	-5,87	0,23	-5,12	-7,64	-5,88	-4,43	-4,89
19	SilenTONE	elementen	1-07-2004	M+P.HAMER.01.1.1	3-07-2004	40	50			-1,43	4,71	-0,59	-0,20	2,51	-1,17	-4,92	-3,14	-1,06	-3,04
20	Viagrip	asfalt	9-01-2007	VKA.06jj17.06r116	22-12-2006	40	50			-6,99	-6,78	-8,64	-8,83	-5,81	-6,15	-8,67	-8,74	-6,91	-14,86
21	Geosilent	elementen	1-07-2004	VKA.w.03.mb.10.04r20	29-06-2004	40	50			-2,93	4,46	-2,55	-2,43	-0,99	-3,09	-3,64	-2,92	-1,56	-8,48
22	Micro-Top 0/6	asfalt	1-07-2004	VKA.04ba10.04r53	11-06-2004	50	60			-5,53	-0,93	-6,95	-6,65	-0,37	-6,09	-8,17	-6,27	-4,69	-5,97
23	Micro-Top 0/8	asfalt	1-07-2004	VKA.04ba10.04r52	11-06-2004	50	70			-2,66	2,64	-5,17	-3,99	0,46	-2,39	-4,78	-2,73	-1,53	-3,36
24	Stilstone	elementen	1-07-2004	VKA.03.mw.10.04r22	21-06-2004	40	50			-2,61	4,15	-1,68	-0,85	0,65	-2,16	-5,86	-5,2	-2,41	-5,87
26	Redufalt	asfalt	5-07-2004	DGMR.V.2004.1140.00.001	28-06-2004	50	60			-4,67	2,54	-5,04	-5,18	-0,15	-4,96	-7,01	-5,81	-5,70	-6,43
27	Accoduit	asfalt	5-07-2004	DGMR.V.2004.1140.00	3-06-2004	50	80			-1,28	2,35	-4,98	-3,90	1,89	-0,38	-4,50	-4,66	-5,60	-4,67
28	Novachip	asfalt	5-07-2004	VKA.04nc11.04r55	28-06-2004	60	80			-1,41	-1,52	-6,08	-5,35	-0,71	-0,59	-2,63	-2,68	-0,28	-2,63
29	Tapisville	asfalt	5-07-2004	DGMR.V.2004.1140.00	3-06-2004	40	50			-5,24	4,34	-3,84	-4,28	0,23	-5,74	-9,47	-6,98	-7,09	-9,06
30	Fluisterfalt	asfalt	14-05-2007	VKA.06bm14.07r034	10-05-2007	50	120			-5,34	1,59	-3,26	-3,37	-3,94	-5,13	-6,33	-6,72	-6,05	-4,36
31	Microville	asfalt	18-03-2005	VKA.05bi10.05r022	1-03-2005	40	50			-6,11	-2,69	-7,84	-7,83	-3,86	-5,31	-8,36	-8,73	-7,00	-11,58
32	Microflex 0/6	asfalt	5-05-2006	M+P.WHE.05.3.9	20-04-2006	40	80			-5,07	-0,65	-6,64	-6,49	-1,22	-5,09	-7,17	-5,28	-4,10	-3,78
33	Decipave	asfalt	8-07-2004	M+P.RASEN.02.1.2	6-07-2004	40	60			-5,73	-0,42	-6,96	-5,71	-0,65	-6,34	-8,35	-6,41	-5,29	-6,96
34	Twinlay-m (*)	asfalt	27-08-2004	M+P.WHE.03.13.3	21-07-2004	40	50	110	110	-6,60	-1,91	-5,36	-6,16	-5,35	-6,20	-8,27	-5,88	-4,17	-5,78
35	Stil Mastiek	asfalt	30-11-2004	VKA.04re10.04rA4	19-11-2004	50	60			-5,85	0,78	-6,90	-6,12	-0,29	-6,11	-10,05	-8,76	-7,51	-7,12
36	Bruitville	asfalt	18-01-2005	VKA.04bl10.04.rC2	14-01-2005	40	60			-4,63	1,75	-4,82	-4,53	0,36	-4,95	-7,88	-5,72	-4,78	-4,89
37	Duolay	asfalt	8-02-2005	M+P.KWS.05.2.1	18-01-2005	110	120			-6,65	-3,62	-5,96	-7,28	-5,97	-5,81	-8,74	-6,66	-5,19	-4,27
38	Minifalt	asfalt	1-04-2008	M+P.LEE.07.01.2	25-01-2008	70	90			-5,46	-3,12	-7,74	-7,20	-1,07	-5,11	-9,04	-7,17	-6,61	-2,74
39	Konwé Stil	asfalt	12-05-2006	M+P.KWS.05.1.18	24-11-2005	50	50			-4,02	-2,89	-6,56	-6,21	-2,33	-3,58	-5,09	-4,89	-3,81	-3,53
40	DuraSilent	elementen	23-01-2007	VKA.06bb10.06r098	22-01-2007	40	50			-1,87	2,88	-2,80	-1,61	0,98	-1,42	-4,06	-3,99	-3,55	-4,73
41	GRAB	asfalt	1-08-2007	VKA.04sz10.07r047	27-06-2007	40	60			-5,35	2,41	-5,91	-5,14	0,23	-6,23	-8,33	-6,59	-5,59	-3,05
42	Nobelpave HS	asfalt	29-11-2007	VKA.06ve11.07r070	26-11-2007	80	80			-5,46	-4,43	-6,03	-6,63	-4,11	-4,81	-6,93	-6,67	-4,89	-7,08
43	straatbakstenen in keperverband	elementen	10-01-2008	M+P.SPS.07.01.1	23-11-2007	30	40			2,04	5,22	0,90	1,38	3,40	2,96	-0,18	-0,06	0,89	-0,71
44	Deciville	asfalt	18-01-2008	VKA.06bil l.07r077	15-01-2008	50	60			-3,49	-0,06	-6,53	-7,61	-6,06	-2,63	-4,01	-3,43	-4,08	-0,08
45	SilentWay	elementen	13-05-2008	M+P.STRUY.08.02.1	8-05-2008	40	40			-3,50	0,99	-3,30	-1,30	0,31	-3,58	-6,17	-4,24	-2,92	-6,17
46	Topfalt	asfalt	16-05-2008	VKA.08ge10.08r042	13-05-2008	50	70			-4,45	0,04	-6,02	-6,18	-0,51	-4,27	-7,04	-5,27	-4,84	-6,00

5.2.2 Dutch COP testing system

For the Dutch main road network there is no system for testing COP of delivered surfacings.

For the local road network, a special detailed procedure - mainly based on CPX measurement - was in existence during the years 2001-2004. This special law, the "Regulation for the Stimulation of the use of Low Noise Pavements", was a temporary initiative of the Dutch Ministry of Housing, Spatial Planning and Environment (VROM). The technical background of the law is given in the background document [32]. The local authority could tender and select a contractor according to its normal procedures [32] but recommended that the contract should put the responsibility for complying with the acoustic requirement on the contractor. The reason for the strict COP procedures was that local road administrations could get a refund from the Ministry for applying noise reducing surfacing and that the Ministry wanted to be certain its money was well spent.

The COP procedure is illustrated in Figure 5.2. The idea is to measure CPX along the delivered roadwork. From this, the average SPB level is estimated, based on a CPX-SPB relation measured on the site or a relation known beforehand. Finally, the SPB level is compared with the COP requirement.

5.3 UK – The HAPAS System

The following applies to the UK Highways Agency (HA) which is responsible for 4 % of the UK road network (highways and trunk roads) carrying 30-40 % of the road traffic. For information on "non-trunk roads" one would have to contact the County Surveyor Society or many (i.e. thousands of) local road administrations.

For a contractor to build pavement on the national highway network he needs a noise label certificate from the Highway Agency Product Approval Scheme (HAPAS).

The UK HA defines a noise reducing surfacing as one with a Road Surface Influence RSI ≤ -2.5 dB. RSI is defined in the HAPAS guidelines [33], see also Table 5.3 and Eq.(2) – Eq.(3). Noise testing must be made at two road sections with the same pavement type. The noise level used to determine the RSI is a combined SPB noise level from light, dual-axle heavy and multi-axle heavy vehicles. Such surfacing is denoted "Thin surface course system (for highways)", and it can be any surfacing as long as RSI ≤ -2.5 dB. The producer must certify his product has an RSI ≤ -2.5 dB. There are at present 28 surface products with a HAPAS thin surface certificate [33]; more than 50 % of these also have chosen the option to include a certification of noise [75]. A HAPAS certificate generally has a 5 years lifetime.

The reference for comparison in the UK is a "new" (i.e. at least 12 months old) hot rolled asphalt (HRA) with 20 mm nominal aggregate size and with an aimed mean texture depth MTD = 1.5 mm (sand patch). The reference values were established in the 1970-1980s based on average pass-by measurement results at many sites. Compared to the dense asphalt concrete reference pavements used in other European countries, the British reference is a rather noisy reference pavement.

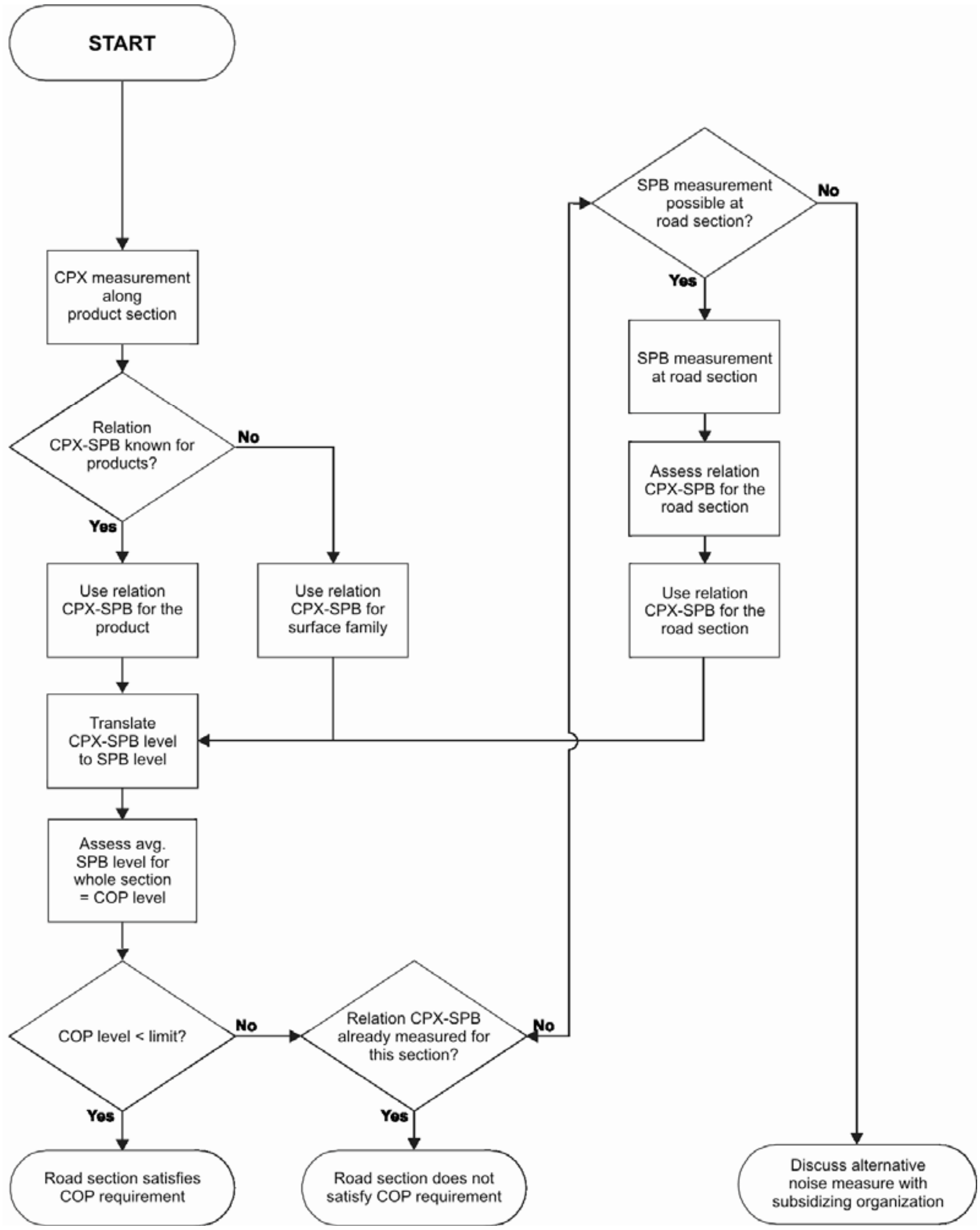

Figure 5.2. Flow diagram illustrating temporary Dutch COP testing system [32].

The Road Surface Influence for high (H) and medium (M) speed roads are:

$$RSI_H = 10\log_{10}(7.8\times 10^{\frac{L_{veh,L}}{10}} + 0.578\times 10^{\frac{L_{veh,H1}}{10}} + 10^{\frac{L_{veh,H2}}{10}}) - 95.9 \qquad Eq.\ (2)$$

$$RSI_M = 10\log_{10}(11.8\times 10^{\frac{L_{veh,L}}{10}} + 0.629\times 10^{\frac{L_{veh,H1}}{10}} + 0.157\times 10^{\frac{L_{veh,H2}}{10}}) - 92.3 \qquad Eq.\ (3)$$

Table 5.3. Reference values for various categories of vehicles and roads [34].

Speed [km/h] / L_{veh} [dB]	$L_{veh,light}$	$L_{veh,dual-ax}$ ($L_{veh,H1}$)	$L_{veh,multiax}$ ($L_{veh,H2}$)
High Speed	110 / 84.7 dB	90 / 86.6 dB	90 / 89.1 dB
Medium Speed	80 / 81.1 dB	70 / 83.8 dB	70 / 86.6 dB

In principle, the full HAPAS certificate cannot be issued until it has been proved that 24 months after construction, the surface in fact still retains MTD ≥ 1.2 mm. In practice, the noise level is certified shortly after 12 months.

The vehicle noise level L_{veh}, used as a reference is 1 – 2 dB higher than the reference noise level used e.g. in Denmark for classifying road surface noise reduction.

Concerning lifetime average noise performance, calls for tenders are based on the expectation that HAPAS procedures will assure an average noise reduction as given by RSI (measured at the at least 12 months old surface) multiplied by 0.7 [35], limited to a maximum of 3.5 dB. With the UK prediction method [36] one can use this correction in noise computations.

5.4 The SILVIA proposal

5.4.1 Labeling

The SILVIA classification system [3] proposes two optional labeling procedures:

1. LABEL1, which is preferred, based on SPB and CPX measurements
2. LABEL2, based on SPB measurements and on texture, sound absorption, etc.

Both noise labels require SPB measurement. The result of such a measurement is - in principle - just valid for a short section of road near the microphone. Therefore, the proposal requires additional measurements to assess the acoustic performance over the full length of the trial section. The SILVIA proposal requires two trial sections.

Table 5.4 summarizes the proposed labeling system. To obtain a LABEL1, the SPB measurement shall be supplemented by CPX measurement carried out over the entire length of the trial surface. A LABEL2 allows for indirect assessment based on surface properties such as texture.

For an open graded surfacing, also its sound absorption shall be measured, and for a (poro-)elastic surfacing, its mechanical impedance shall be measured. These parameters are important to the generation and propagation of noise.

Table 5.4. SILVIA system for labeling the acoustic performance of road surfaces [3].

Label Identification	Method of assessment for different road surfaces		
	Dense Graded	Open Graded	
	Rigid[1]	Rigid	Elastic
LABEL1 (Preferred)	SPB CPX	SPB CPX	SPB CPX
LABEL2	SPB Texture	SPB Texture Absorption	SPB Texture Absorption Mechanical Impedance

[1] Rigid surfaces are defined as normal asphalt (dense and open graded) and concrete;

5.4.2 Test of COP

According to the SILVIA proposal, conformity of production (COP) of surfaces with a noise LABEL1 certification shall be tested with CPX measurement, while surfaces with a LABEL2 certification shall be assessed by measuring the properties of the surface used in deriving the noise label. Table 5.5 summarizes the recommended method for testing COP.

Table 5.5. SILVIA system proposed for testing COP of road surfaces [3].

Label Identification	Method of assessment for different road surfaces		
	Dense Graded	Open Graded	
	Rigid[1]	Rigid	Elastic
LABEL1 (Preferred)	CPX	CPX	CPX
LABEL2	Texture	Texture Absorption	Texture Absorption Mechanical Impedance

[1] Rigid surfaces are defined as normal asphalt (dense and open graded) and concrete;

5.5 The French proposal

The description below of the French proposal is based on a presentation at a European workshop in Brussels [27] and on supplementary information obtained by personal communication [37].

5.5.1 Labeling

The French proposal prescribes SPB and CPX measurements on a minimum of two test sections. The test sections shall be built in different regions of France. The labeling result is the average obtained from these measurements.

The average passenger car pass-by noise level allows comparison of the acoustic performance of the surfacing with other surfacings listed in a national database, LRPC of Strasbourg [38].

Figure 5.3 illustrates the proposed procedure.

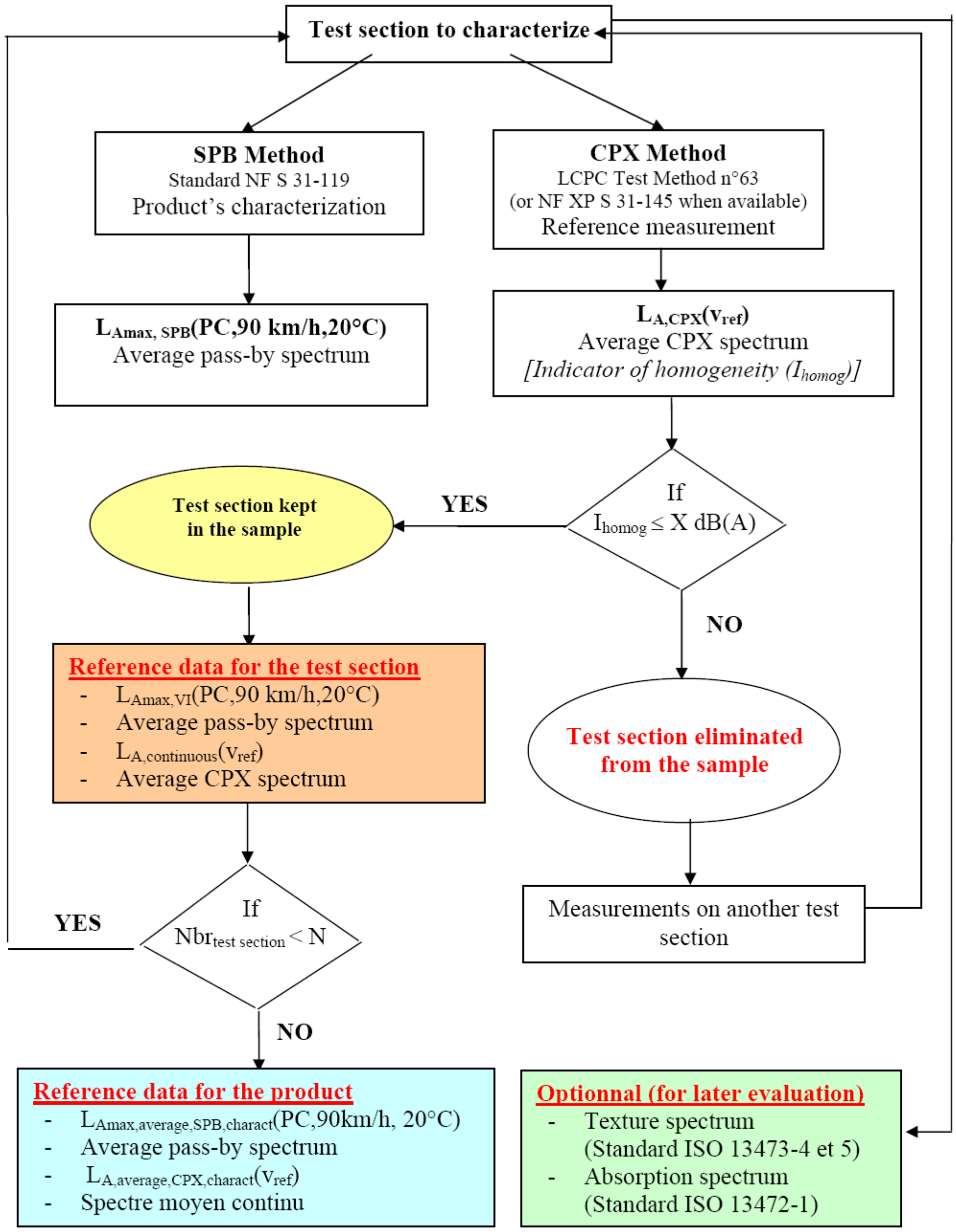

Figure 5.3. Structure of French labeling proposal [27].

SPB measurements shall be made according to ISO 11819-1 [23] or to a corresponding French standard for passenger car pass-by measurement [39]. For each test section the results are:

- L_{AFmax} for passenger cars at 90 Km/h, 20 °C
- One-third octave-band passenger car pass-by noise frequency spectrum at 90 km/h.

For the sample of test sections, the arithmetical average of each of these results is calculated.

CPX measurements shall be performed on each test section according to a French method [40] or [41] at reference speed(s), v_{ref}, depending on the intended future use of the product. Rather than prescribing specific test tires, these measurements are based on a "common" tire from the market, and the system (tire, vehicle and measuring equipment) is calibrated on a specific test track (with dense asphalt concrete DAC 10). An initial reference value was established in 2005 and calibrations are based on this reference on this track by introducing a "system correction coefficient" in all the measurements.

The French method [40] describes procedures for:

- Product characterization, where the "speed law" is determined (several runs at different speeds
- Check of conformity of production (several runs at one speed).
- Network monitoring (to be published) with one run using longer segments for noise measurements.

Figure 5.4. Microphones mounted according to the French standard for CPX measurement.

For each test section, the results are the:

- Sound level characterizing the test section at each reference speed $L_{A,CPX}(v_{ref})$
- Third octave-band spectrum of this sound level for the reference speed v_{ref}
- Indicator of spatial homogeneity of the test section I_{homog} [yet to be defined].

If the indicator of spatial homogeneity of the test section is higher than *X* dB [*X* to be defined], then the SPB measurement cannot be representative of the whole test section and this test section must be excluded from the sample.

For the sample of test sections, the following values are calculated:

- The arithmetic average of the mean sound level characterizing each trial section at each reference speed $L_{A,average,CPX,charact}(v_{ref})$
- The average spectrum, obtained from the arithmetic average of the spectra related to each test section.

The French proposal recommends supplementary measurements on each test section of:

- The texture spectrum according to ISO 13473 - parts 4 and 5, [42] – [43]
- If the product appears porous, the absorption spectrum according to ISO 13472-1 [44].

5.5.2 Test of COP

The proposed French procedure for checking a product after building the surfacing consists of a CPX measurement. Figure 5.5 illustrates the structure. The result of this measurement is compared to the reference level at the same speed obtained during the labeling phase.

The result is considered compliant if it is lower than or equal to the reference level defined during the labeling procedure to which a tolerance is added. The tolerances are still to be defined: *Y* dB on the making and laying of the product and *Z* dB for the reproducibility.

In case of non-compliance, measurements of the texture spectrum (ISO 13473-4 and ISO 13473-5, [42] – [43]) and absorption spectrum (ISO 13472-1 in case of porous surfacing [44]) are recommended as an aid in interpreting the results.

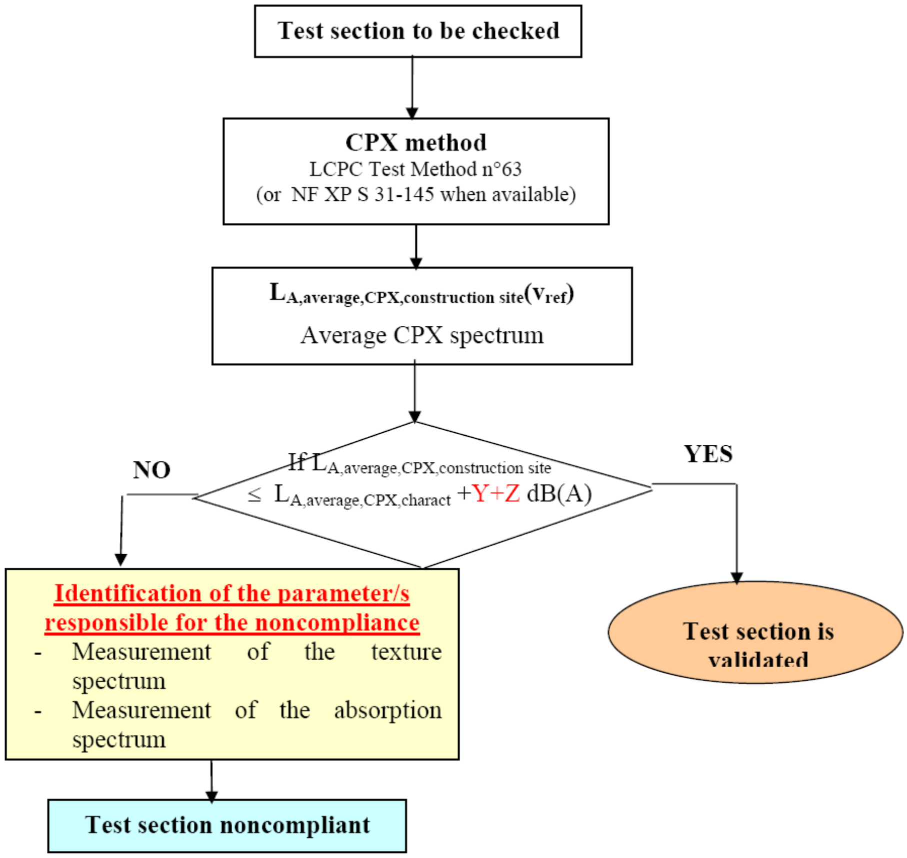

Figure 5.5. Structure of French proposal for testing COP [27].

6. Selected cases from European countries

6.1 Background

This chapter gives a synthesis of the situation of noise reduction policy and related issues in a number of European countries. The seven selected countries are different with respect to traffic loads, urbanization, climate and level/history of application of noise reducing pavement. For this reason they can - to a large extent - be taken as representative for a larger number of European countries by analogy, as they display various approaches to policy and promotion of noise reducing pavement.

This is perhaps not obvious but assessing the situation in Europe can in general be a little confusing from a non-European perspective. The development in countries that you from a bird's perspective would think would be analogous actually show up quite different due to subtle deviations in historical and technical evolution of the respective road sectors with respect to factors like road administration organization, division of responsibility and know-how between public and private players in the sector.

The selected countries are: Denmark (DK), Germany (D), The Netherlands (NL), Norway (N), Sweden (S), Switzerland (CH) and the United Kingdom (UK), see Figure 6.1. The last five of these countries were studied recently in an ERA-NET project [9] with reference to Performance Management of Low Noise Pavement / noise reducing pavement.

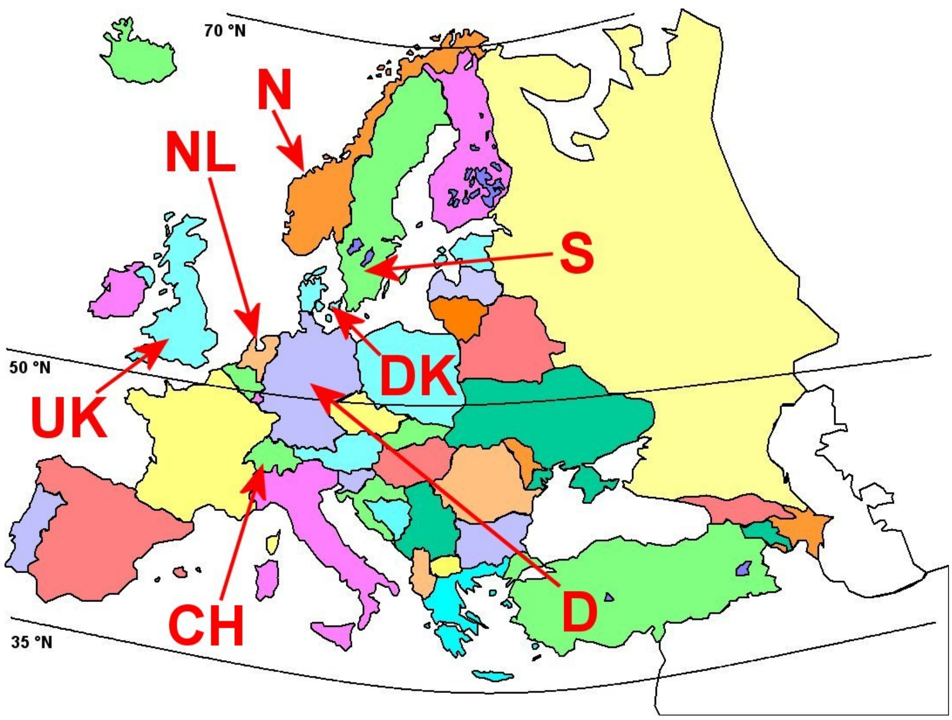

Figure 6.1. Selected countries indicated by their national abbreviation.

For the sake of understanding some of the background from the individual countries, a few subjective characteristics can be offered.

Denmark:

- Temperate, costal climate, low altitude.
- Mild winter condition, freeze-thaw cycling.
- High population density and high rate of urbanization.
- Low – middle traffic congestion.
- Numerous test sections with noise reducing pavements and installation trials since 1990.
- Application of low noise pavements is getting momentum and large interest in public.

Germany:

- Temperate continental climate, predominantly non-mountainous.
- Mild winter conditions in the North to more heavy winter conditions in the South.
- High population density and high level of traffic congestion.
- Two large cross industry pavement noise research programs with trials since 2001.

The Netherlands:

- Temperate, costal climate, low altitude.
- Mild winter condition, freeze-thaw cycling.
- High population density and high rate of urbanization.
- Heavy traffic congestion.
- Advanced state of application of low noise pavements.
- > 70 % of primary road network covered by Porous Asphalt.

Norway:

- Cold climate, mountainous landscape.
- Harsh winter condition, deep frost, heavy snowfall.
- Low population density and low rate of urbanization.
- Low traffic intensity.
- State of application of low noise pavements : experimental.
- Extensive use of studded tires in wintertime.

Sweden (South of Stockholm):	• Cold climate, mainly low altitude. • Harsh winter conditions, deep frost, heavy snow fall. • Low population density and low rate of urbanization. • Low - middle traffic congestion. • State of application of low noise pavements: experimental. • Extensive use of studded tires in wintertime.
Switzerland:	• Continental climate, mountainous landscape. • Strong winter condition, heavy snow fall. • High population density and high rate of urbanization. • Heavy traffic congestion. • State of application of low noise pavements: experimental but some use of Porous Asphalt on motorways. • Studded tires are not allowed.
United Kingdom: (primarily England)	• Temperate, costal climate, mainly low altitude. • Mild winter condition. • High population density and high rate of urbanization. • Heavy traffic congestion. • State of application of low noise pavements: experimental stage.

6.2 Denmark

Denmark had an introduction to Porous Asphalt in the late 1960s for the sake of safer driving conditions when wet, but due to low durability and winter maintenance problems, the mix type was abandoned for a number of years. In the early 1980s open graded asphalt concrete was introduced as a mix type for primary and secondary road network with the emphasis on providing better driving conditions when wet. Again it was the "anti-splash and spray" effect of the open texture surface that was in focus with its possible positive effect on traffic safety especially when overtaking lorries on multiple lane highways.

Noise reduction as the top priority subject for pavement materials in Denmark came in 1990 with a test site at Viskinge. Since then numerous test sections have been produced and followed in the course of various research projects [50, 51, 52, 53, 54].

The development started out slow but the challenge was picked up by the innovative environment among asphalt contractors and asphalt technologists in the public road administration (nationally and in the municipality of Copenhagen and other cities). The development gained momentum through the many trials and well monitored test sections partly sponsored by European projects.

Industry involvement and competition led to cost-effective solutions, and a long Danish tradition for developing road standards in consensus among the various parties of the road sector gave rise to the tentative Type Approval/Declaration system (SRS) based on functional characteristics measured on produced pavements, see Chapter 4. This system has been engineered to facilitate the purchase of noise reducing pavements on a technically sound base, also among public administrations in smaller communities with limited in-depth knowledge of asphalt technology. The reference material is chosen as a worn (approx. 8 years old) surface of a dense graded asphalt concrete with 11 mm as nominal maximum aggregate size, DAC 11. This mix type was the dominant surface course for Danish highways in the period 1993-1998 and is expected to have an average (structural) durability of approx. 12 years.

The Danish Road Directorate (national public road administration) will continuously evaluate the experience gained with the SRS-system in order to improve it and in parallel the Danish Road Directorate is in the process of developing a noise policy (see Chapter 4). Other public administrations are engaged in similar considerations. The municipality of Copenhagen has decided that every urban street having an ADT (annual daily traffic) of more than 2000 vehicles shall be paved with noise reducing materials. The only limitation is areas where the speed is very low and no additional noise reducing effects is expected (like roundabouts with small diameter and residential areas with low speed limits).

Figure 6.2. A closed Polish CPX trailer performing noise measurements on a Danish test section with noise reducing thin layers.

The availability of cost-effective solutions with respect to the reduction of traffic noise levels in congested urban areas is now increasingly driven by a public demand on the politicians. Reduction of traffic noise levels by the selection of tailor made road surfaces is now one of the recognized options in overall optimization of pavement strategy.

The noise reducing effect of a pavement material is seen as just another functionality of the road surface so apart from the selection of the pavement type it is normal contractual relations that apply for the works. This means that the client (the public or private road owner) pays for the road/functionality offered and that a standard warranty period (which applies for all construction work in Denmark) of 5 years is enforced but where the client has expectations for much longer structural durability. It must be mentioned that noise is not a functionality covered by the warranty period. For example, expected average life time (structural durability) of a DAC 11 is 11-12 years and for SMA approx. 15 years. Due to good track records at the public administrations and the asphalt industry being dominated by stationary asphalt plants the expected average life time (structural durability) is an important part of the competition among the asphalt contractors.

Figure 6.3. SPB noise measurements at a Danish test section with a noise reducing thin layer.

Presently, average acoustic lifetime has not yet been established for the different types of noise reducing pavements, but a client would expect structural durability of an offered pavement in the same range as a traditional offered mix of the same type. With reference to the SRS system the effect has to be ≥ 3dB in order to be considered a noise reducing pavement.

When a client wants to purchase a noise reducing pavement he has to decide how he wants to use the SRS system:

- If he wants to specify the mix type (like SMA) he can chose between offered mix formulation having "SRS" attached to the name and a layer thickness (typically by mass/m^2).
- If he wants to specify a noise reduction according to a specific class (like Class B meaning a noise reduction between 5 and 7 dB) he can choose between possibilities of that class but then he cannot specify the mix type.

6.3 Germany

Germany has not directly, but indirectly, a policy for the application of noise reducing pavements. The law says that when building a new road or widening or grossly changing an existing road certain noise levels may not be exceeded. There is a standard procedure to calculate that noise level [45] on the basis of traffic volume, geometry etc. In these calculations there is a contribution for the road surface. This means that if Stone Mastic Asphalt is applied, 2 dB may be subtracted from the calculated value and in the case of Porous Asphalt 5 to 6 dB may be deducted. This regulation is a federal law and applies all over Germany.

During the legal process of planning a road it is very often stated in the terms of reference for the project, that a "minus 2" pavement or a "minus 5" surface layer must be applied. These values are based on the German reference pavement which is a "non-corrugated Mastic Asphalt" (a Mastic Asphalt without additional chippings for friction as known from the English Hot Rolled Asphalt) [58].

The documentation for the "minus 2" and "minus 5" originates from huge federal research effort aimed at "Quiet Transport" where a part called "Leiser Strassenverkehr" (Quiet Road Traffic) [59] from 2001 to 2003 played an important role. It was continued in "Leiser Strassenverkehr 2" [60] from 2005 to - . The project involves 15 partners covering tire and car manufacturers and road building industry and research, and the first program contained 22 projects which had the objective to:

- Develop, build and test within three years components in the overall system of tire-car-road surface that will accomplish a 3 dB noise reduction
- Achieve through a calculation model within a five years period components (car, tire and road surface) for a 5 dB noise reduction.

With respect to the part of noise reducing pavements the first objective resulted in nine test sections of optimized road surfaces which were presented in October 2003 [57]. In comparison to the reference surface "non-corrugated Mastic Asphalt", the optimized road surfaces showed some clear noise reductions. The sound level of trucks at 80 km/h was reduced by approximately 4 dB on improved porous asphalt, measured on the Federal motorway A1. On the B56, a federal highway with road surfaces of porous concrete, concrete with exposed aggregate and noise-reducing Mastic Asphalt, the statistical pass-by level at 100 km/h was reduced by up to 6 dB.

The continuation of the research since 2005 has three focus areas: "Quiet tires", "Quiet roads" and "Monitoring/Control". For the "Quiet roads" the project will centre in on porous pavements and improving their durability. Utilization of polymers and nanotechnology is intended to make the pore system better to resist clogging and ease its ability to transport water and clean it.

The EU directive on environmental noise is becoming a strong driving force in the promotion of road industry for the application of noise reducing pavements but people and politicians are also increasingly seeing the benefits of noise reducing asphalt materials. It is reported that a newly constructed brick road in a city after a few weeks under traffic was transformed into noise reducing asphalt because of complaints from the public about the noise emission.

6.4 The Netherlands

Since the late 1970s, the Netherlands has had a working policy on a national and local level formed from a Law on Noise Nuisance (LNN) which includes traffic noise.

The LNN differentiates between the following cases:

- New top layer on existing road (maintenance).
- Modification/widening of the road (sanitation situation).
- Modification/ widening of the road (no sanitation situation).
- A totally new route.

In the last three cases, a limit value is stated, which has to be respected by taking measures. Application of two-layer porous asphalt is possible after a cost benefit analysis showing that it is a cost effective measure of noise abatement. If it isn't, then other measures are considered also after the analysis and/or a higher limit value is established. The first case of the new top layer is by far the most frequent.

The driving factor for the wide utilization of Porous Asphalt was indirectly a governmental decision taken in the late 1980s to increase the allowed traffic speed on Dutch highways from 100 km/h to 120 km/h. In order to compensate for the increased noise emission the Ministry of Housing, Spatial Planning and the Environment and the Ministry of Transport, Public Works and Water Management agreed to gradually apply single layer Porous Asphalt on the main road network. This meant basically all highways and the main secondary roads. Presently more than 70 % is covered by Porous Asphalt and the goal is to reach total coverage in 2010.

When a low noise pavement is called for the asphalt contractor can either deliver a Porous Asphalt according to some "standard specification" or provide a proprietary solution of his own design.

In the latter case a (preliminary) test procedure including laboratory tests and/or test sections is described by the road authorities for documentation of the quality of the offered design, see Section 5.2. The requirement for special designs is that at least the same level as single layer Porous Asphalt is achieved.

If the road authorities decide to apply Porous Asphalt the tendering is quite simple. The call for tenders indicates the location and that Porous Asphalt shall be applied. The Asphalt contractors has to live up to a warranty period of seven years on some structural requirements (like skid resistance) but the acoustic performance is taken as "expected". The tenders are then evaluated and the chosen contractor is found by the lowest price.

The noise reference in the Netherlands is a virtual reference originating from a population of weighted measurements as described previously in Section 3.2.

The performance of each individual job is not monitored to decide bonus or fine for that particular job, but a general annual inventory (survey) is done on network level in order to provide data for maintenance planning etc. The survey includes:

- Longitudinal and transversal profiles
- Skid resistance
- Rutting
- Raveling and
- Cracks detection (tearing).

The Porous Asphalt pavements are applied on high speed roads so they are expected to be "self cleaning" which means that special cleaning operations are not foreseen. In case of roads with emergency lanes which are also paved with Porous Asphalt cleaning operations are performed in the emergency lanes as they tend to clog due to the lack of traffic.

Winter maintenance is adapted to the special conditions asked for by Porous Asphalt (awareness of weather conditions and additional salt applied).

The Netherlands do not expect any substantial improvement of the noise reducing properties of Porous Asphalt, but perhaps that better durability (both acoustical and structural) is achieved. In the last few years increased interest in the Thin Layer Asphalt concept has been signaled. This is especially for utilization in urban areas because of the more pronounced self cleaning ability, better expected durability and the reduced need for adjusting other road elements (curbs etc.). These pavements are also used now on the national road network.

Figure 6.4. Noise barriers and noise reducing porous pavements are combined on some sections of the Dutch highway network.

6.5 Norway

Norway performed in the period from the late 1980s to 1994 an intensive research effort with respect to "Low noise pavements" in the project series "Støysvake vegdekker". During this program a substantial amount of information was gathered both on the impact to society and on the influence of various parameters on the acoustical performance of asphalt materials. The conclusion of these findings was that the main problems to be solved were:

- To obtain a durable noise reducing capability of the low noise pavements.
- To develop new binders with non-plastic properties that can ensure the possible cleaning of the porous pavements in spite of the continued use of studded tires.

Recently noise has been put in focus again in Norway and in 2004 the next major attempt on the subject was initiated with the project "Miljøvennlige vegdekker" (Environmentally friendly pavements) which has a duration from 2004 to 2008. The objective is to:

- Reduce the number of people influenced by noise near the Norwegian roads and streets.
- Ensure air quality in heavy populated areas (dust/particle pollution partly due to the wear and tear from the studded tires).

The project is a response to a decision from Stortinget (the Norwegian parliament) to set the objective to reduce the noise nuisance by 25 % before 2010 and to follow up on recent European activities in the field of noise reducing pavements (like the SILVIA-project) under Norwegian conditions.

Figure 6.5. Studded tires are used in Norway in the wintertime.

This means that Norway is still in a "*research and development*" phase and that daily contracting for noise reducing pavements is not at hand. However, Norway has a tradition for using functional contracts in their tendering highlighted in the Specific Pavement Wear for surface layers in order to obtain optimum quality of surface layer. Based on this tradition tendering for research and development work in the form of laboratory research, test sections etc. followed by a negotiation often results in very good research projects with an open collaboration between the asphalt contractor and the road administration.

As it is evident from the objectives of the on-going research project, the impact of wear from studded tires in the winter season is of utmost importance to the introduction of low noise pavements in Norway. As it will be described later for Sweden it is difficult to strike the balance between low noise pavement for the reduction of traffic noise and durable, wear resistant pavement towards the deterioration by studded tires. The need for studded tires in winter time is connected to traffic safety and is often seen as a necessary evil. Huge benefit to society can be gained through reduced cost to health, pavement maintenance and renewal and cleaning operation in cities, if the use of studded tires could be reduced or even abandoned.

Even though there is a public demand for traffic noise reduction there has also been a recent trend for increased mobility; that is increased speed limit on high volume roads. This puts extra pressure on the wear resistance of the low noise pavements as the wear increases with the power of 2 with an increase in speed. It is foreseen that outside the major cities in Norway and on the westside of the country the use of studded tires will not go below 20-25 % during winter so it will be a challenge for the years to come.

6.6 Sweden

The national Swedish Road Administration is planning to develop a policy for the use of noise reducing pavements, but they do not have one today. Sometimes it is decided to include noise reduction measures when environmental impact of road projects is assessed. In a manual for planning new roads, a general recommendation states that low noise pavements shall be considered when people are exposed to road traffic noise, but at the end of the day it can be overruled by the project manager.

A standard low noise pavement is not defined, but both single and two layer Porous Asphalt have been applied together with a few mix types of Thin Layer Asphalt concept. A low noise pavement is normally considered to have a 2-3 dB noise reduction compared with a reference pavement which in Sweden is a Stone Mastic Asphalt 16 mm (or dense graded Asphalt Concrete 16 mm) at the age of one year primarily based on CPX-measurements. This rather noisy reference is due to the fact that wear from studded tires is the major deteriorating effect on highly trafficked national roads. A typical durability of the reference pavement is 6 years, a consequence of the heavy use of studded tires in the winter season.

In some situations tendering documents are set-up as functional contracts where a noise reduction of ≥ 3 dB shall be reached with reference to the old pavement on the site.

The situation in Sweden with respect to noise reducing pavements is unavoidably linked to the use of studded tires. A reduction in pavement wear from studded tires (either through reduced usage or use of tires with a reduced number of light weight spikes) will have a great positive impact on the potential noise reduction. The evident problem is that with respect to pavement wear the larger the aggregate size the better durability where the opposite is valid for noise reduction (the smaller aggregate size the better). The Thin Layer Asphalt concept with 5 to 8 mm maximum aggregate size has little or no resistance against wear and Porous Asphalt gets clogged by mineral particles worn from the pavement itself.

Sweden has its highest population density in the coastal areas of the south third of the country (Stockholm and South of Stockholm) where also the winter condition is the mildest. New development in (unspiked) winter tires has a huge potential in Sweden as they can bring several positive effects (low wear, more durable pavement, potential for cost-effective traffic noise reduction and less pollution from mineral particles). Politically, it will be a balance between traffic safety and other positive effects. Because of the potential Sweden has been promoting a number of test sections of low noise pavement in relation to the SILVIA project and other projects trying to optimize aggregate quality and wear with noise reduction; some of the recent ones are based on functional contracts where large reductions in noise are demanded.

Figure 6.6. DRI-DK performing SPB noise measurements at a test section in southern Sweden with noise reducing thin layer pavement developed for roads with vehicles with studded tires.

In October 2007, a document was issued by the Swedish National Road Administration on the selection of pavement. It will influence approx. 4 % of the rehabilitation of the national road network in 2008 and will include 3 projects in the Stockholm area. The new policy focuses on noise, particles (aggregate dust) and rolling resistance with reference to SMA 16. The aim is to apply SMA 8 or SMA 11. Porous Asphalt and Thin Layer Asphalt are not considered presently in the new policy [46].

6.7 Switzerland

In Switzerland the regional administrations (the cantons) are obliged to take measures in accordance with legislation on environment and noise. This includes noise mapping and making plans where certain noise exposures are exceeded, differentiated into areas of various sensitivity. The limit noise levels in $L_{r[dBA]}$ together with the definition of the term can be found in [55] and corresponding annexes. The limits are given in Table 6.1 below.

Table 6.1. Limit noise levels in dB in Switzerland according to legislation [55].

Sensitivity	Planning		Immission limit		Alarm level	
	Day	Night	Day	Night	Day	Night
I	50	40	55	45	65	60
II	55	45	60	50	70	65
III	60	50	65	55	70	65
IV	65	55	70	60	75	70

Based on a calculated Index of Economical Sustainability (called WTI), the effect and decision concerning noise barriers, façade insulation, low noise pavements or combinations is determined for further action.

$$WTI = \frac{Effectiveness * Efficiency}{25}$$

where:

Effectiveness	=	degree of protection achieved in percent of the legal requirement
Efficiency	=	Utility/Cost
Utility	=	Value of noise reduction achieved * Number of people benefiting.

For a project to be acceptable, the estimated WTI shall be ≥ 1.0.

With respect to the contribution of the road surface in noise reduction a fixed, specific reference pavement is not defined but the reference is taken as the global average of all earlier performed noise measurements of all kinds of road surface. From this level a definition for a low noise pavement exists. It shall provide an initial reduction of noise of at least 3 dB and a reduction of 1 dB over a time span (in the case of Porous Asphalt for 10 years and 15 years for non-porous pavements).

Four different mixes are standardized that are expected to fulfill the mentioned noise reduction and reference is given to the specific mix type in the tendering document where noise is not mentioned explicitly. The standardized mixes [56] are with Swiss designation and maximum aggregate size:

- PA8 & PA11 (Porous Asphalt 8 and 11 mm)
- SPA8 (Stone Mastic Asphalt 8 mm) and
- ACMR8 (gap graded Asphalt Concrete 8 mm)

Monitoring of the production of low noise pavement is limited to the classical materials data determined on cores and evaluated from the surface characteristics. Even though acoustic follow-up is performed (also at time zero) the results have no legal binding obligation for the contractor. This must be ascribed to the fact that Switzerland is still in an "*information gathering*" phase, not in a "*business as usual*" phase with respect to noise reducing pavement.

Switzerland has collected various pieces of experience linked to local conditions (climate, traffic etc.) which highlight some of the pros and cons of noise reducing pavements:

- Porous Asphalt on motorways is expected to stay un-clogged due to the "self-cleaning" action of the passing vehicles.

- Clogging of Porous Asphalt in city streets is a problem. Test with cleaning operation has so far been unsuccessful. Thin Layer Asphalt concept is seen as a possible solution but may not provide sufficient noise reduction.
- Porous Asphalt is avoided in the mountainous part of Switzerland and where the slope of the road is above 3 %.
- Studded tires are in Switzerland not allowed on motorways and used little elsewhere. In mountainous part chained tires are used instead. (For the combination of Porous Asphalt and chained tires see [61]).
- Winter maintenance of Porous Asphalt needs to be performed at the right time. Too late salting of Porous Asphalt can lead to road closure due to in-depth ice build-up.

6.8 United Kingdom

The national road administration in the United Kingdom, Highway Agency, in their design manual for roads and bridges in 2006 decided that in all but exceptional cases a Thin Layer Asphalt concept shall be applied. In the interest of sustainability the use of "very quiet" surfacing materials is recommended only in very noise sensitive areas.

In UK a Road Surface Index (RSI) based on SPB-measurement is used. The limit value for a "very quiet" surfacing material is RSI < -3.5 dB. The definition of a low noise pavement is in UK actually any pavement that has a noise reduction in terms of RSI of ≤ -2.5 dB. As the traditional surface layer in UK for many years has been Hot Rolled Asphalt the noise level is starting off at a higher point than in many countries in continental Europe. The Danish reference, dense graded Asphalt Concrete 11 mm, has approx. 1 to 2 dB lower values than the UK reference, so a noise reduction is more easily achievable in UK than in many European countries.

There is a third party certification scheme being used extensively in UK called HAPAS which specifies the conditions for issuing declaration/certification documents in the road sector. This organization monitors Type Approval Installation Trials (TAITs) which can be the part of achieving documentation for process influenced products (like slurry surfacings and surface dressings) or other parameters over time. In the case of issuing documentation for low noise pavement materials the HAPAS scheme monitors the noise level after 12 months or more and the remaining surface texture after 24 months or more, see Section 5.3.

The HAPAS scheme including its control procedures is presupposed to ensure the conformity of production of the finished pavement surface, so no field testing is done to monitor the specific paved site.

The low noise pavements are still a rather new commodity so the durability has not been determined yet, but is presumed to be in the range from 8 to 12 years with an expected average of 10 which shall be seen as opposed to the expected lifetime of 20 years for Hot Rolled Asphalt.

This deviation in lifetime between the "old" preferred surface layer (HRA) and the new solution (Thin Layer Asphalt concept) is perhaps getting narrower in the coming years for two reasons: the durability of Thin Layer Asphalts will probably be improved further and there is a rumor out that the expected lifetime for the remaining HRA is declining due to a change in lorries as more continental European trucks with wide base tires (Super single) are driving on the UK network.

6.9 General comments

In order to fully assess the set-up in Europe on noise reducing pavements some remarks are needed with respect to standardization and the impact it has on the development and dissemination of knowledge on materials characteristics (constituents, composition, properties etc.).

In 2006, the European standardization organization, CEN, approved several product standards on bituminous hot mixes in the European Norm series EN 13108. After a transition period, all EU members and associated countries (like Norway) should follow these product standards and place a CE-mark on the products in order to verify that the products are safe and technically sound products to be put on the European market under the Construction Product Directive (European legislation) [47]. The EN 13108 series [48] consists of several parts

EN 13108-1	Asphalt Concrete
EN 13108-2	Asphalt concrete for very thin layers
EN 13108-3	Soft Asphalt
EN 13108-4	Hot rolled Asphalt
EN 13108-5	Stone Mastic Asphalt
EN 13108-6	Mastic Asphalt
EN 13108-7	Porous Asphalt
	Ultra Thin Layer Asphalt Concrete (in preparation in CEN)

This range of standards is the first set of common European product standards. They are described as "first generation standards" and are primarily a framework of "mix composition" type of specifications for asphalt materials as "*loose mix on the lorry leaving the asphalt plant*". So they are by no means "blind" specifications (e.g. linked to functional requirements of the finished pavement and not to mix composition). Some part of Type Testing is performed on laboratory produced specimens, but no characteristics of the real pavement are part of the present generation of standards.

As these first generation standards are the first attempt of a common framework of product specifications on the European market there are examples that the specifications are a compromise and at certain points the lowest common denominator.

Noise reducing pavements are for many countries still something for the future and as noise reduction is linked to the surface texture and pore structure obtained at the real compacted pavement, functional specifications for noise reduction are not part of the framework.

There is another route for achieving a CE-mark on a product and that is through a European Technical Approval (ETA) where the contractor gets an approval of a product when checked or tested against all six essential requirements for the Construction Product Directive [47].

This is an expensive but possible route for marketing proprietary products with a CE-mark. If a family of products (like Ultra Thin Layer Asphalt Concrete) is expected to achieve an ETA, an ETAG (European Technical Approval Guideline) is normally developed to "streamline" the content and appearance of the corresponding ETA´s [62].

Another important piece of European legislation called the Public Procurement Directive [49] has a huge impact on the scene. The intention/essence of the directive is that public entities (like public road administrations) are allowed to purchase only CE-marked products if such CE-marked products are on the market. In a strict interpretation this means public road administrations (on national, regional and local level) are bound to purchase products according to EN 13108-x or having an ETA.

The reason for the confusion in standardizing the UTLAC materials on the European scene is on the one hand the decision from CEN to make product specifications for "*the loose mix on the lorry leaving the asphalt plant*" and on the other hand the argument that UTLAC is not a *material* but a *system* combining a gap-graded asphalt concrete paved in a thick unbroken polymer modified bituminous emulsion. The ETAG for UTLAC is expected to be issued late 2008, but the EU Commission's Standing Committee responsible for the Construction Product Directive has decided that CEN shall develop a product standard for the asphalt material being used in UTLAC. How this will be done in detail is still a matter of discussion like whether or not it will be used. (Denmark intends to use the product standard for asphalt concrete EN 13108-1 which in its framework gives specification options for open graded mixes.)

As long as noise reduction is not incorporated into the EN 13108-x series and no company has obtained an ETA for a noise reducing pavement material, the public administrations are allowed to "ask for/purchase" materials based on a functional requirement of noise reduction.

The Catch 22 in this situation is that even though some noise reducing pavement material may be specified within the EN 13108-x series, a lot of mix design development is taking place that cannot be defined within the common standards. This situation and competition between different asphalt contractors drives a trend towards proprietary products specified primarily according to a functional requirement for noise reduction and where nearly all other information is "secret" know-how information of the individual companies which is well protected in order to keep the competitive edge.

The bottom line is that it is difficult to obtain a scientific gathering of information for the purpose of disseminating know-how on and introducing noise reducing pavements in society.

7. Noise versus other pavement functionalities

Noise reducing pavements are often divided into two sub-groups:

- Thick (relatively) lifts of Porous Asphalt (PA) containing an integrated pore structure
- Thin lifts of primarily very thin/ultra thin layer asphalt concrete (VTAC/UTLAC) having an open textured surface.

These two groups have some general features in common which are linked to the noise reducing effect, but also exhibit individual characteristics that highlight the different approaches of these materials.

Without being too technical, this chapter will elaborate on some functionalities of noise reducing pavements that can influence the acceptance or the opposite with respect to policy issues. The point is that noise reducing effects cannot be offered without introducing pros and cons that link into other functional requirements or established policies.

7.1 Structural durability

Structural durability is here defined as a term embracing general durability issues of the material or the pavement structure itself apart from the durability of its noise reducing effect. Structural durability has many facets and some of the main points linked to noise reducing pavements are mentioned in the following sections.

7.1.1 Ravelling and fretting

Noise reducing pavement materials consist – in a broad description – of an aggregate skeleton with a void structure covered (PA) or partly filled (TLA) with a rich bituminous mortar which often is modified/stabilized by addition of polymers, waxes and cellulose fibers.

Due to the open textured surface, fretting (loss of mortar) is normally not an issue, but the large exposed area of the materials towards oxygen (hardening of the binder) and moisture (stripping) place raveling (loss of aggregate) high on the list of deteriorating mechanisms.

Dense graded asphalt materials will gradually deteriorate at the pavement surface over some years starting with fretting in poorly compacted areas and then into widespread fretting and eventually raveling sets in. This will give the road administration some years of forewarning to plan their maintenance and rehabilitation effort. Noise reducing pavement with thick lifts of Porous Asphalt will not by a general visual inspection give the same forewarning and can deteriorate dramatically within a short period of time.

7.1.2 Shearing (and braking) forces

Noise reducing pavement materials are sensitive to the action of shearing forces, especially at high temperatures. Sharp turning curves (street corners in urban area) and parking/turning situations (cars using servo-steering) shall be handled with extra consideration when materials are selected.

7.1.3 Permanent deformation or rutting

As noise reducing pavements are based on an aggregate skeleton and the bituminous binder often is modified the resistance of permanent deformation of these materials are normally – if well compacted – excellent.

7.2 Structural issues

Noise reducing pavements also have an impact on pavement design.

7.2.1 Bearing capacity and elastic modulus

Thin layer asphalt concrete will, due to the low thickness, only give a small contribution to the bearing capacity of the pavement, but as the aggregate skeleton is partly filled with bituminous mortar the material will give a contribution.

For Porous Asphalt and especially two layer Porous Asphalt, it is necessary to take the reduced elastic modulus of the materials into account as void volumes easily can exceed 24 % and the material in some cases is applied in thick lifts of perhaps 80 mm or more.

7.2.2 Perpetual Pavement concept

Noise reducing pavements of the thin layer type can be good choices for surface layer if the Perpetual Pavement concept is applied. The noise reducing pavements provide the optimum ride quality to the drivers at a minimum of thickness and in the case of UTLAC provides an excellent moisture protection of the bituminous base and binder course.

7.3 Traffic safety

There are a few points to be mentioned with respect to traffic safety.

7.3.1 "Anti splash" and aquaplaning

All the noise reducing pavements materials exhibit excellent surface texture and in the case of Porous Asphalt even a pore structure for water transport. This means that the drivers in case of heavy rainfall will experience an improved visibility as the splash and spray from other vehicles will be reduced. This improves also safety in overtaking lorries and trucks.

The surface texture has also a positive effect towards avoiding aquaplaning.

7.3.2 Skid resistance or friction

Compared with the standard reference pavement to be used on a given jobsite, the noise reducing pavement will normally have a reduced maximum aggregate size. Initially when asphalt technologists suggested 8 or even 5 mm maximum aggregate sizes on high speed roads, anxiety for reduced friction was flagged. Measurements after placement have revealed that the coefficient of friction or the skid resistance on these surfaces can be excellent and even improved [63]. Low skid resistance in the first period just after paving has been observed until the very durable bituminous mortar (stabilized in different ways for the long term durability) has been worn off.

Figure 7.1. The DRI-DK friction measurement equipment.

7.3.3 Winter situations issues

Porous asphalt due to the high void volume has a reduced heat capacity compared with especially dense graded asphalt materials. If Porous Asphalt is applied in various small stretches in a road network an undesired safety situation can occur. When frost at night occurs there can be a difference in time when a Porous Asphalt and a normal dense graded asphalt concrete surface gets slippery due to the difference in heat capacity.

Porous Asphalt will also demand extra awareness in winter strategy and possibly a change in salt spreading operations strategy as the pore system removes the brine solution that should have protected against slippery conditions in case additional snow falls occur.

In mountainous areas where chained wheel or snow ploughs are necessary, the durability of Porous Asphalt can be reduced through crushing and scarring of the surface.

7.4 Climate, energy and environmental issues

There are also some minor points to be made with respects to climate, energy and environmental issues.

7.4.1 Climate

If the climate generates an increasing occurrence of extremely heavy rain in the form of quick showers or they already occur locally, Porous Asphalt can with its integrated pore system provide the capability to remove water from the road to the shoulder or a sewage system and for prolonged periods in these situations provide a safer surface to drive on.

7.4.2 Life Cycle Assessment

Life Cycle Assessment (LCA) can be used on specific projects for the comparison of noise reducing and non-noise reducing pavements. As noise reducing pavements are skeleton-based mix types for surface layers exposed to moisture, the aggregate needs to be of optimum quality with respect to strength, polishing resistance and with good adhesion properties. A combination of aggregate fractions from different mineral sources is often needed to create the right pore structure or surface texture of the mix. The availability of these aggregates can have huge influence the result of a LCA calculation.

7.4.3 Rolling resistance and energy and CO_2

Energy considerations for the vehicles driving on noise reducing pavements are mainly linked to evenness and rolling resistance of the surface. With respect to evenness the thin layer asphalt materials are of course very much dependent on the transversal and longitudinal profile of the surface upon which it will be paved but that is not more important for noise reducing materials than for "normal" asphalt materials. Paving operations for noise reducing pavements show no additional risk for production of an uneven surface. As noise reducing pavements tend to use smaller maximum aggregate sizes compared to the standard solution, the rolling resistance is expected to be the same (or perhaps even less) for these surfaces (without loss of friction) [64].

The CO_2 issue is not a subject for this report as that will need an extensive study in itself because only few elements of information in that regard are known presently and setting the limits for such a study can influence the overall results grossly. However by analogy it can be foreseen that compared to other known asphalt materials there are no indications that noise reducing pavements will have negative contributors to such a study.

7.4.4 Tire noise labeling

Road traffic noise is a major source of environmental noise exposure, and European directives and amendments [70, 71] have been enforced to cover vehicle noise while tire noise is regulated by another directive [72].

In order for a vehicle tire to be sold on the European market it shall be labeled that it complies with the Directive on tire noise [67].

The label signals that the tire/road noise emission is below the noise limit specified in the Directive. The noise limit depends on the tire category and the tire width. The tire label does not tell how much less noise it emits and thus the label is not as useful as it could be for vehicle owners wanting to purchase a set of comparatively quiet tires.

[73] quotes a report from FEHRL on Road/Tire Noise [74] which recommends a two phase step for tighter limit values which are equivalent to an effective noise reduction - taking into account different tire classes and dimensions - of:

- Passenger car tires: 2.5-5.5 dB
- Commercial vehicle tires: 5.5-6.5 dB.

The FEHRL report demonstrates that:

- Quieter tires do not compromise safety (wet grip, aquaplaning) or fuel economy (rolling resistance)
- The proposed limit values for car and truck tires would lead to an estimated overall roadside traffic noise reduction of up to 3 dB, which is equivalent to halving the number of vehicles on the roads
- Enforcing these standards will not incur huge costs. The technologies and products have already been developed, and the industry is prepared
- Benefits will be further magnified when quieter tires are used on silent road surfaces.

7.5 Additional issues

7.5.1 Utility works and "noise print"

Noise reducing pavements function through large areas of well designed surface texture/pore structure. This gives them a potential drawback which is especially evident in urban areas with a high risk of frequent utility works. Patch repair of noise reducing pavements is difficult with disturbing the surface texture and leaving a "noise print" behind even if the company is knowledgeable about that they are repairing a low noise pavement. For Porous Asphalt tack coating of the patch material in the trench can easily block the pore system within the pavement leaving pockets of water reservoirs by hindrance of the water flow.

7.5.2 Noise reducing pavements on bridge decks

Strictly from a noise reduction point of view, there is no difference whether a noise reducing road surface is produced on a normal road or a bridge deck. The noise reduction will be produced that the texture and/or pore system will provide, but there are other considerations that could have preference instead of noise reduction.

A bridge or flyover is a huge investment compared to the same length of normal road. For this reason, safety factor considerations with respect to protecting the bridge deck from the deteriorating effects of penetrating water and chlorides can reject some mix types with pore structures if not total confidence exists in the membrane system below. This is valid for both steel and cement concrete bridge decks.

The surface layer has also to be considered as an integrated part in the bridge design phase as the mass per square meter of the total pavement and protection system has a huge influence of the structural capability needed in the bridge design.

Bridges "offer" also some advantages though due to the relatively high investment cost of the bridge. Using premium and very expensive binders for noise reducing mix types will be more cost effective on bridge decks compared with normal roads, as the necessity for water resistance and protection is more self evident.

Apart from the pavement, other structural elements for bridges and flyovers in urban areas can present themselves. Screens to shield the traffic from the influence of high winds or the surroundings from reflecting lights from the cars can be combined with noise barriers and for instance in Japan flyovers constructed as tubes can be an elegant solution to several problems.

Further aspects of noise issues combined with the design of bridges and expansion joints will apart from these few general comments be beyond the scope of this report.

8. Conclusions

The conclusions of this study of European experience with the use of noise reducing pavements are structured around the twelve questions asked in Chapter 2. Where feasible, a table summarizes the findings.

1. **Which countries have a working policy for using noise reducing pavements within Europe, and for how long have the policies been in-place?**

Answer:

Only a few countries have an explicit policy for their use of noise reducing pavement, even though in many countries noise reducing pavements are increasingly becoming a part of the "toolbox" – with various degree of documentation – for consideration in noise abatement. Noise reducing pavements are often used on a case-to-case basis in new road projects and in pavement maintenance.

Country	Policy status
Denmark	National roads: Under development Copenhagen: Policy in place
Germany	No defined policy
The Netherlands	Policy in place
Norway	No defined policy
Sweden	No defined policy
Switzerland	No defined policy
United Kingdom	Policy in place

a. The Netherlands apply porous asphalt on their entire main road network following an increase in 1987 of the permitted vehicle speed from 100 km/h to 120 km/h. For the local roads, the law puts an obligation on administrations to propose measures when the 24-hour average road traffic noise level exceeds 60 dB. The Minister of Housing, Spatial Planning and the Environment in 2001 issued a regulation for three years to fund the application of noise reducing pavement by local authorities, cf. Chapter 5.

b. The British Highway Agency in its design manual published in 2006 prescribes that in all but exceptional cases so-called “Thin Surface Course System (for highways)” shall be applied in new roadwork and when maintaining their main roads, cf. Chapter 5.

c. The situation in Denmark is mentioned under Question 2.

2. What factors are considered in each of the countries' policies (noise levels, traffic levels, traffic composition, population, health impact, etc.)?

Answer:

a. As mentioned above, the Netherlands apply porous asphalt on all main roads.

b. In Denmark, a policy is under development in the Road Directorate, while noise reducing surfacings are already frequently used on new roads and when significant change is made of existing roads. The municipality of Copenhagen has decided to apply noise reducing surfacings in its maintenance of streets with an ADT exceeding 2000 vehicles. The introduction of the Danish SRS system mentioned in Chapter 4 has kick-started the process. The reason that it is possible to introduce noise reducing pavements is more than a decade of research and development carried out in cooperation between the Danish Road Institute, road owners and the pavement industry. This cooperation has often taken place in the framework of international projects which have enlarged the available resources and facilitated intensive know-ledge sharing.

c. The permitted pavement surfacing material for new and maintenance construction in England is Thin Surface Course Systems, i.e. DAC or SMA, and only by special permission porous asphalt or other pavement surfacings may be applied.

3. Which policies have been found effective?

Answer:

a. The policy in the Netherlands to use porous pavement on all main roads is very efficient from a noise abatement point of view. To assess the feasibility of a total coverage with Porous Asphalt one would have to take local conditions into account.

b. The Danish SRS system brings noise reducing pavement products on the market and facilitates tendering noise reducing pavement. The process of having road administrations and the pavement industry develop the system in consensus with consultants gave wide acceptance and has brought the knowledge of the system to many users. The Danish Road Directorate has repeatedly published information about the system at an annual Danish road conference, in pavement magazines, workshops etc. A vital cornerstone in this achievement has been good collaboration and a kind of team spirit between all involved asphalt technologists (private and public).

c. The English design manual prescribing DAC or SMA as pavement surfacings ensures moderate noise reduction compared with the former widely used HRA with larger maximum aggregates.

4. **Are noise reducing pavements used in conjunction with other forms of noise mitigation? How is it used in combination with other noise reduction measures?**

Answer:

Noise reducing pavement can indeed be used in conjunction with other measures, but noise reducing pavements should always be the first choice measure for the following reasons:

a. A noise reducing pavement attacks the problem at the source (tire-road-noise) or close to it (engine noise), so to speak before the noise is emitted.
b. Comparison with other or additional measures in several studies have shown that noise reducing pavements are the most cost-effective with respect to the noise reduction achieved relatively to the investment [68].

In Denmark, the widening of an express ring-road around Copenhagen combines noise reducing pavement, four meter high noise screens and façade insulation.

In the Netherlands, noise reducing pavements combined with noise barriers/screens are used frequently. One reason for the Dutch policy of applying noise reducing surfacing is that there is a legal demand on road administrations to reduce the increasing noise and this can be done by increasing the height of existing noise barriers or by building new barriers, both very expensive, or by using noise reducing porous pavement or thin layer surfacings which are much more cost-effective.

5. **How do the various European countries define what is a noise reducing pavement (noise levels, surface characteristics, materials)?**

Answer:

The noise reduction obtained by applying noise reducing pavements depends very much on the reference or what situation is used for comparison (noise reducing pavement versus new or worn surface). By choosing a reference pavement giving rise to high levels of tire/road noise the noise reducing products are seemingly better.

Country	**Definition of noise reducing pavement**
Denmark	≥ 3 dB reduction (reference ~8 years old DAC 11)
Germany	≥ 2 dB SMA (reference non-corrugated mastic asphalt)
The Netherlands	Porous Asphalt (by definition)
Norway	No definition (reference probably DAC 16 / SMA 16)
Sweden	2-3 dB reduction (reference DAC 16 / SMA 16)
Switzerland	4 defined mixes in specification (reference general level)
United Kingdom	Any surface ≥ 2.5 dB reduction (reference Hot Rolled Asphalt)

a. In Denmark, the term noise reducing is applied when a new pavement surfacing yields a rolling noise level that is 3 dB or more lower than a dense asphalt concrete with 11 mm nominal grain size, after it has been in service for 8 years. The present Danish system has no requirements concerning the noise reduction at later stages.

b. The Germans seem to consider Stone Mastic Asphalt (-2 dB) and Porous Asphalt (-5 dB) as noise reducing alternatives to non-corrugated mastic asphalt (no further details are available at the moment).

c. The Netherlands consider Porous Asphalt by default to be a noise reducing pavement.

d. In Sweden, to be considered a low noise pavement it must yield 2-3 dB noise reduction compared with a reference pavement which in Sweden is a Stone Mastic Asphalt 16 mm (or a dense graded Asphalt Concrete 16 mm) at an age of one year, primarily based on CPX-measurement.

e. Switzerland considers the following four mix types noise reducing pavement (by default) when produced according to specification:

i - ii.	PA 8 and PA 11	(Porous Asphalt 8 and 11 mm)
iii.	SMA 8	(Stone Mastic Asphalt 8 mm) and
iiii.	ACMR 8	(gap graded Asphalt Concrete 8 mm)

f. In the United Kingdom, a noise reducing pavement is any surfacing yielding a noise reduction of 2.5 dB or more relatively to a 12 months old Hot Rolled Asphalt.

6. How do you calculate noise reducing pavement benefits or credits?

Answer:

The Danish Ministry for Transport has worked out a catalogue of unit-prices for:

a. the cost of time consumption in passenger and goods traffic (in money units per passenger-hour, vehicle-hour or goods-ton-hour).

b. fixed and variable cost of driving passenger cars, vans and trucks.

c. cost for operators of public transport.

d. society unit-cost due to air pollution and emission of CO_2, ***noise***, accidents and congestion.

These unit-prices are the basis for comparison of various planned road works.
The noise costs consist of contributions from annoyance (based on house-prices in areas with different noise exposure), while the health cost is based on the risk of hospitalization and loss of life due to noise exposure.

To take advantage of costs/benefit computation we need reliable data on the development over time of the noise level / pavement noise reducing properties. A first version of such a model was a result of the SILENCE project mentioned in Section 4.1.

7. How do the European countries monitor noise reducing pavements over time? (How do they include noise reducing pavements in their overall pavement management practices or scheme)?

Answer:

a. Some monitoring is done in the Netherlands, France and Germany to gain "overall experience"; but not all individual pavement works are monitored.

b. The pavements built with government funding on Dutch local roads, see Chapter 5, have their noise reduction measured by a CPX measurement. If the noise reduction requirement is fulfilled, funding is approved, or else it is refused. Noise measurements shall be made after 2, 5, 8 and 11 years. There are no financial consequences connected to these results, but they shall be sent to a central office for information.

c. In Denmark, several test sections have been monitored every year by SPB measurements and now this is supplemented with CPX measurement. Texture measurement by means of laser equipment will be added soon. This has generated valuable lifetime noise reduction time histories. A continuation of this monitoring is planned, provided the necessary funding will be available.

A European study identified an average noise level increase of 0.1 dB per year at dense asphalt surfacings, cf. Section 4.1. For porous or open graded asphalt, the time history increase for light vehicle noise is in the order of 0.4 dB per year at high speed roads and 0.9 dB per year at city streets with low traffic speed. Heavy vehicle noise levels increase with an average 0.2 per year at high speed roads.

8. What is your reference pavement, and how do you choose that? (Based primarily on Danish experience and include other countries)?

Answer:

a. The reference pavement(s) in the different countries are typically chosen from what would have been the most probable alternative used for high capacity roads prior to the focus on noise reducing pavements.

b. In Denmark, the reference is a worn (approx. 8 years old) surface of a dense graded asphalt concrete with 11 mm as nominal maximum aggregate size. This mix type was the dominant surface course for Danish highways during the period 1993-1998 and is expected to have an average (structural) durability of approximately 12 years.

c. The Netherlands use a reference pavement based on a population of measured surfaces all of which were probably less than two years old at the time of noise measurement. For high speed roads the reference is dense graded asphalt concrete with 16 mm as maximum aggregate size, while for roads with lower speeds a combination of dense graded asphalt concrete with 11 and 16 mm maximum aggregate size is used.

d. Norway has not yet defined a reference, but is expected to include considerations similar to those of Sweden.

e. Sweden uses a Stone Mastic Asphalt 16 mm (or dense graded Asphalt Concrete 16 mm) at the age of one year primarily based on CPX-measurements. The low age of the reference was chosen because of the use of studded tires. On high capacity, high speed roads 30-40 mm of surface layer can be worn off in approximately 4 years.

f. In Switzerland, with respect to the contribution of the road surface in noise reduction a fixed, specific reference pavement is not defined but a reference was taken as the global average of all earlier performed noise measurements on all kinds of road surface.

9. How do you assure noise reducing pavement attributes are achieved from construction or by contractors? (Provide any construction specifications that should be met during construction inspection)?

Answer:

In general, the tendering of a noise reducing pavement is influenced by many practicalities. As an example, the noise measuring community has neither the standards (CPX is still a pre-standard and round robin testing between equipments to assess precision is lacking) nor the capability to perform noise measurements on individual jobs for quality control. This could be a topic for consideration in a future system with bonus or fines.

a. There is a general rational coming from the European Product Specifications using initial type testing as the description of the properties of the material. If the completed pavement depends not only on the loose product but is also on its application – like UTLAC (Ultra Thin Layers) and surface dressings – TAITs (Type Approval Installation Trial) are also included. With this background many countries are likely to set up a procedure for certification/declaration of a noise reducing pavement based on earlier produced trial sections.

b. Denmark uses in the SRS-system a "control" based on the certified declarations and the rudimentary material specification of these declarations as an alternative (indirect) specification of the noise reducing effect. This is a point where we hope to gain more experience on the run.

c. The Netherlands had a system for COP, but now relies on the default assumption of the noise reducing effect of proven products.

d. Switzerland assumes the noise reducing effect by default if the specification for noise reducing mix type is followed.

10. Who pays for noise reducing pavements (private developers, local governments, national government) and how about warranties?

Answer:

a. Usually it is the road owner who pays either in a project for constructing a new road or in the ongoing process of pavement renewal on existing roads.
b. In Denmark it is the road authorities (either on a National or a Municipality level) who pay for the noise reducing pavement. Different approaches can be used in the initial phase if an asphalt contractor wants to promote a (new) noise reducing pavement. A typical example can be the following scenario: Normally noise reducing porous pavements are significantly more expensive than the standard solution while the price of a noise reducing thin layer surfacing does not necessarily deviate much from the price of the standard solution. In his tender an asphalt contactor may offer alternatively to deliver a part or the whole job as a noise reducing pavement at normal or reduced price in order to achieve a Type Approval Installation Trial (TAIT) under realistic traffic conditions. So some form of division of responsibility is worked out between the contractor and the road administration where the latter can flag to the public that initiatives are taken.
c. In Denmark, it has been discussed at the Municipality of Copenhagen that a developer of a new residential area should pay for a noise reducing pavement on a nearby road in order to be given permission to build the new dwellings. But for various reasons this has not become reality.
d. Warranty periods for noise reducing pavements in Denmark are the same as for standard pavements (legally 5 years) but there is no established practice yet as to how the warranty covers the acoustical performance. When more experience is gathered with respect to the durability of the individual mix types it is assumed that durability (acoustical as well as structural) will be important in the competition between products / contractors like it is on standard asphalt materials.

11. Do you see any new developments on the horizon that we should be aware of, or that would be of use to California or Denmark?

Answer:

a. The ongoing development and testing of noise reducing thin layers seems to provide low cost noise reduction. Surfacings based on the design principles for such European products could be developed with the pavement construction materials available in California.
b. In Germany there is a trend to replace Portland Cement Concrete (PCC) with Stone Mastic Asphalt which has a lot of application advantages in the rehabilitation and maintenance situation on a heavily congested road network. Some Portland Cement Concrete test sections have been built which show reasonable noise levels, but they are presently few and on a purely experimental stage so no substantial information on PCC solutions is available.

c. Two-layer porous pavement optimized for long-term noise reduction and durability for roads with speeds above 70 km/h might be an option for testing in order to achieve high noise reduction.
d. Further down the road poro-elastic surfacing might be an option. There are plans for European research and development of such an idea.

12. How are noise reducing pavement benefits incorporated into traffic noise models?

Answer:

Several countries apply correction factors in their prediction schemes to take the influence of the road surfacing into account when analyzing traffic noise impact on the environment: Spain, Slovenia, Switzerland, Germany, Austria, France, Italy, Hungary, the Nordic countries (Denmark, Finland, Iceland Norway, Sweden), the Netherlands and Great Britain. Tables of corrections are given in [65] and some have been summarized in Section 3.5 of the present report.

a. The Netherlands use a correction denoted C_{road} , see Chapter 5. This implies that the life-time noise reduction is equal to the initial noise reduction at a new surfacing, i.e. 2 months old.
b. The Nordic model for noise assessment, Nord 2000, has a table of corrections for road surfacings deviating from the default surface. Denmark has no established practice to take the individual road surfacing into account, but this will probably be the case when more noise level time history data become available.
c. UK applies a correction of 0.7 times the initially certified noise reduction measured at the new surfacing, limited to a maximum of 3.5 dB.

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Appendix A
List of terms and abbreviations

This appendix contains a list of terms and abbreviations used in the present report. European nomenclature is used, and in some cases additional explanatory notes are offered to give a better understanding of the literature references.

AC	Asphalt Concrete, Definition: Asphalt in which the aggregate particles are continuously graded (dense graded) or gap-graded (open graded) to form an interlocking structure. Mix of aggregates and bituminous binders, surface layer and/or bituminous base (AC ≠ Asphalt Cement) AC xd = Dense graded Asphalt Concrete with x mm as nominal maximum aggregate size (*some times DAC is as abbreviation for Dense graded asphalt concrete*) AC xo = Open graded (gap-graded) Asphalt Concrete with x mm as nominal maximum aggregate size European product standard : EN 13808-1:2006
ADT	Annual daily traffic, number of vehicles
AOC	Attestation of Conformity, term used in European product standards linked to the level of quality control defined in the European Construction Product Directive. The term is linked to Factory Production Control, FPC.
Asphalt	European nomenclature is used because of reference to literature etc. : Definition : Mixture of aggregates and bituminous binder (Asphalt (Eng.) ≠ Asphalt Cement (US)) see bitumen
Bitumen	Asphalt (US) or Asphalt Cement (US)
Bituminous	Describing term for binder which predominantly consists of bitumen but may also contain additives (like polymers and/or waxes)
BBTM	Asphalt Concrete for very thin layers (surface layer, thickness approx. 20-30 mm) The European (Eng.) abbreviation originates from French : Béton bitumineux très mince European product standard : EN 13808-3:2006

CBA	Cost-benefit analysis
CEDR	Conférence européenne des directeurs des routes (European conference of road directors)
COP	Conformity of production. Lose term for national description of conformity procedure which may vary among the European countries. (as opposed to Attestation of Conformity (AoC) and Factory Production Control (FPC)).
CPX	Close proximity method, (Acoustic measurement of the influence of road surfaces on tire/road noise, continuous measurement on the run using trailer mounted microphones) ISO draft standard : ISO/CD 11819-2
CPX_{DK}	CPX index used in Danish SRS classification system
CPXL	CPX sound pressure level representing light vehicle noise
CPXH	CPX sound pressure level representing heavy vehicle noise
C_{road}	Noise correction for the road influence (NL)
CROW	The national Dutch information and technology platform for infrastructure, traffic, transport and public space)
DAC	Dense (graded) Asphalt Concrete. Example DAC 16 dense graded Asphalt Concrete with 16 mm nominal maximum aggregate sixe. See also AC
EACC	Exposed Aggregates Cement Concrete
EU	European Union
FPC	Factory production control, European specification for production control at the asphalt plant under third party inspection. European standard : EN 13808-21:2006
HA	Highways Agency (UK)
HAPAS	Highway Authorities Product Approval Scheme (UK)
HRA	Hot rolled asphalt, Definition: Dense gap-graded bituminous mixture in which mortar of fine aggregate, filler and high viscosity binder are major contributors to the performance of the laid material. Coated chippings are always rolled into and form part of a Hot Rolled Asphalt surface layer. European product standard : EN 13808-4:2006

ITT	Initial type testing; Initial performance determination of mix design (Type Testing) European standard : EN 13808-20:2006
K	Calibration correction based on field calibration of trailers in Danish SRS-system
L_A	CPX sound pressure level at standardized reference tyre A
L_{Aeq}	A-weighted equivalent noise level
L_D	CPX sound pressure level at standardized reference tyre D
L_{den}	Indicator of the overall noise level during the day, evening and night
LNN	Law on noise nuisance (NL)
LNP	Low-noise pavement
MTD	Mean Texture Depth; measure of surface texture
OGFC	Open Graded Friction Course, corresponds to the European asphalt family of Porous Asphalt, PA (may in European literature be confused with gap-graded asphalt concrete and asphalt concrete for very thin layers (BBTM))
PA	Porous Asphalt , understood either as the asphalt material generally or as single pavement layer of Porous Asphalt (as opposed to TLPA = Two Layer Porous Asphalt) Definition : bituminous materials with bitumen as binder prepared so as to have a very high content of interconnected voids which allows passage of water and air in order to provide the compacted mixture with drain and noise reducing characteristics. European product standard : EN 13808-7:2006
PmB	Polymer-modified Bitumen
PMS	Pavement Management System
PSV	Polished Stone Value
RA	Road administration
RSI	Road surface influence (UK)

SBS	Styrene-Butadiene-Styrene co-block polymer, elastomeric additive to bituminous binder
SILVIA	Silenda Via (EU project, 6th Framework Program, GROWTH)
SMA	Stone Mastic Asphalt Definition: gap-graded asphalt mixture with bitumen as a binder, composed of a course crushed aggregate skeleton bound with a mastic mortar. European product specification : EN 13808-5:2006
SPB	Statistical pass-by method, (Acoustic measurement of the influence of road surfaces on traffic noise, spot measurement using a microphone at the roadside) ISO standard : ISO 11819-1:2001
SRS	Noise reducing surfacings (Danish abbreviation)
TAIT	Type approval installation trial
TAT	Type approval test
TB *x*k	Thin layer surfacing with nominal aggregate size *x* mm (Danish abbreviation for UTLAC)
TINO	Tire Noise (EU-project, Brite Euram, BRPR 950121)
TLA	Thin Layer Asphalt concept, used in this report as a common term for thin lifts of noise reducing pavements (typically thicknesses below 40 mm) with a rough surface texture and perhaps semi-open pores to the surface but no interconnected void structure inside the pavement layer.
TLPA	Two-layer porous asphalt (the upper fine graded porous asphalt acts as a kind of filter layer for the lower porous asphalt which has a course void structure) see PA
UTLAC	Ultra thin layer asphalt concrete (surface layer, thickness approx. 10-20 mm) Definition: Open graded hot mix asphalt concrete laid with a special paver in a thick layer of unbroken polymer-modified bituminous emulsion. The "boiling" of the water from bituminous emulsion creates an extremely good bound between the old surface and the new asphalt material European product standard : material standard now in preparation under CEN; a "system" guideline (combination of material and application "standard") under the responsibility of European Organization of Technical Approvals, EOTA, is expected issued late 2008 [62])

Eksternt notat / Technical notes		
Nr. No.	Titel/Title/Shortcut	Forfatter/Author
38/06	Acoustical characteristics of Danish road surfaces	Jørgen Kragh
39/06	Noise reducing SMA pavements – Mix design for Silence – F2	Erik Nielsen Jørn Raaberg Hans Bendtsen
40/06	Ravelling of porous asphalt - Seletion of road sections	Carsten Bredahl Nielsen
41/06	Durability of porous asphalt - International experience	Carsten Bredahl Nielsen
42/06	Porous pavements with PMB – Selection of road sections	Carsten Bredahl Nielsen
43/06	Notes from INTER-NOISE 2006	Hans Bendtsen
44/06	Acoustic performance - low noise road pavements	Bent Andersen Jørgen Kragh Hans Bendtsen
45/06	Noise reducing pavements – Evaluation workshop	Carsten B. Nielsen Hans Bendtsen
46/06	Traffic noise at two-layer porous asphalt – Øster Søgade, Year No. 7	Jørgen Kragh
47/07	Microstructure of porous pavements – experimental procedures	Carsten B. Nielsen
48/07	Ravelling of porous pavements – assessments of test sections	Carsten B. Nielsen
49/07	Railway crossings - Road traffic noise measurements	Sigurd N. Thomsen Jørgen Kragh Hans Bendtsen
50/07	Roads with paving Stones - Noise measurements	Sigurd N. Thomsen Jørgen Kragh Hans Bendtsen
51/07	Trafikstøj ved rumleriller – et pilotforsøg	Jørgen Kragh Bent Andersen
52/07	Traffic Safety and Noise Reduction - Thin Layers	Hans Bendtsen Jørn Raaberg
53/07	Modified bitumen in porous pavements – Assessment of test sections	Carsten B. Nielsen
54/07	Clogging of Porous Pavements - Assessment of test sections	Carsten B. Nielsen
55/07	Clogging of Porous Pavements - International Experiences	Hans Bendtsen Jørn Raaberg
56/07	Ageing of Porous Pavements – Acoustical effects	Jørgen Kragh
57/07	Acoustical characteristics of Danish road surfaces - Part 2	Bent Andersen
58/07	Replacement of Porous Top Layer - Process and noise effect	Jørgen Kragh Sigurd N. Thomsen
59/07	Faglig strategi for støjtemaet	Hans Bendtsen
60/07	Clogging of porous pavements – The cleaning experiment	Carsten B. Nielsen
61/07	Noise Classification – Asphalt pavement	Jørgen Kragh
62/07	Inter·Noise konferencen 2007 i Istanbul - Rejserapport	Hans Bendtsen
63/07	HSD Measurements at the BASt Test Track - COST 354: Short Term Scientific Mission, 2006	Susanne Baltzer Gregers Hildebrand
65/07	Fremtidens Vej – Tre skridt til fremtiden	Carsten B. Nielsen Erik Nielsen Finn Thøgersen Knud A. Pihl
66/08	Optimized thin layers – urban roads – the Kastrupvej experiment	Sigurd N. Thomsen Hans Bendtsen Bent Andersen
67/08	Traffic noise measurements in Malmö – Results from 1st and 2nd year	Bent Andersen Hans Bendtsen Sigurd N. Thomsen
68/08	Surface dressings – Noise measurements	Hans Bendtsen Sigurd N. Thomsen
69/08	Use of noise reducing pavements - European experience	Hans Bendtsen Jørgen Kragh Erik Nielsen

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