CEDR Transnational Road Research Programme

Call 2012: Noise: Integrating strategic noise management into the operation and maintenance of national road networks

Funded by Belgium/Flanders, Germany, Ireland, Norway, Sweden, United Kingdom

QUESTIM

Modelling of Acoustic Aging of Road Surfaces

Deliverable D2.2 8/2014

QUietness and Economics STimulate Infrastructure Management

M+P consulting engineers (coordinator) (NL)

Transport Research Laboratory (UK)

Müller-BBM GmbH (D)

Aalto University (SF)

CEDR Call2012: Noise: Integrating strategic noise management into the operation and maintenance of national road networks

QUESTIM: QUietness and Economics STimulate Infrastructure Management

Report on Acoustic Aging of Road Surfaces

Due date of deliverable: 01/02/2014
Actual submission date: 05/08/2014

Start date of project: 01.02.2013	**End date of project: 01.09.2014**
Author(s) of this deliverable	

Gijsjan van Blokland, Christiaan Tollenaar and Ronald van Loon, M+P, Netherlands

Version: 08.2014

1. Introduction

Road surfaces change their acoustic surface properties during their lifetime. Texture may increase due to stone loss or, on the other hand, may decrease due to compaction and sweating of bitumen. Open surfaces may fill with dirt leading to reduced or modified acoustic absorption and increase of flow resistivity.

Where surfaces are applied to reduce environmental noise, they specifically depend on optimal surface characteristics for that function and thus are found to be especially vulnerable to surface degradation.

The general unpredictability of the acoustic aging and the related uncertainty in planning of maintenance and resurfacing has limited the wide spread use of these surfaces as noise mitigation measures.

The CEDR organization has contracted a consortium, consisting of TRL from the UK, Müller-BBM from Germany, Aalto University in Finland and as consortium leader M+P from Netherlands, to undertake a project to develop procedures that enable the implementation of the acoustic performance of road infrastructure elements, such as road surfaces, into pavement management systems (PMS).

2. Overview of project workplan

Developing an aging model for the acoustic performance of road surfaces is a complex task. In this project we have developed the aging model with a hybrid approach that consisted of the following elements:

1. Study of the acoustic aging of road surfaces, by categorizing them into types, in climatic zones, in usage types and by types of aging processes on the basis of spectral composition and thus identifying possible usage characteristics that may be of influence.

2. Application of straight statistical analysis of the data sets to identify the relevant parameters and to define the quantitative coefficients for these parameters. The technology of Multi-variant statistics comprises several ways to address these questions. We have followed mainly the ANOVA method.

Overall we have worked according to the following plan.

1. We have gathered data on the age related acoustic performance from several areas in Europe. We have identified three interesting regions:

   a. <u>Scandinavian area</u>. This area is characterized with harsh winters and the extended use of studded tyres.
   b. <u>Mid-European area:</u> In this area studded tyres are not allowed, but still severe winters are common. On the other hand, in summer time high temperatures may occur and also frequent rain is the case.
   c. <u>Southern-European Area:</u> in this area winters are mild and frost is not often the case, summer temperatures are high and rain fall is moderate.

   The data preferably refers to repeated acoustic measurements at the same location over a series of years. As an alternative, we have used network monitoring data in which the surface type and age of all measured sections are recorded.

2. We identified time series in the measurement data and we have attributed relevant traffic data, environmental data and road construction data.

   a. With respect to road type, we mainly concentrated on regional roads and highways where traffic runs straight and minor curving occurs. Urban roads behave totally differently due to the extra wear of turning HV's.
   b. Since we expect that traffic intensity and traffic composition is of interest for the understanding of the aging, we have gathered this data for the tested locations.
   c. To be able to understand the mechanisms of acoustic aging we preferred spectral data

3. The data was studied in two ways:

   a. Identification of the mechanisms underlying the loss of performance over time through analysis of the spectral shifts in the sound recordings of traffic on these roads.
   b. Straight statistical analysis of the performance data in relation to the traffic data, in order to define the relevant parameters, explaining the aging and the coefficients.

In the analysis, a totally separate approach was used for road surface aging under Scandinavian conditions. These conditions are not only characterized by harsh and long winters with sometimes extreme low temperatures, but, even more importantly, the extended usage of studded tyres in winter time. Such tyres are allowed in Norway, Sweden and Finland but are forbidden in other areas in Europe. The impact of studded tyres requires a separate approach to the topic of aging. Firstly because the wear process of studied tyres is totally different from the wear process by general tyres and secondly because, the intensity of LV's is most relevant to the wear, in contrast to the expected result in mainland Europe where truck intensity is expected to be the dominant factor.

The topic of Scandinavian roads is therefore addressed as a separate item and is studied by Aalto University. Their results are reported in [6] .

3. Overview of available data

For the study we collected data from the indicated regions. In about 50% of the cases spectral information was available.

3.1. Netherlands

3.1.1. Overall data sets

table I Overview of NL data available for the study (source M+P).

Data set	Nr of sections	Surface type	Road type	Nr. of repetitions	Covered time	SPB/CPX	HV
Repeated	30	2-layer porous asphalt	highway	9	9 yrs	SPB	Y
Repeated	11	Porous asphalt 0/16	highway	3-8	9 yrs	SPB	Y
Repeated	11	Thin Layer 0/6	highway	3-7	8 yrs	SPB	Y
Survey	n.a.	different	Regional road	n.a.	n.a.	CPX	P/H
Repeated	15	Thin Layer 0/6	Regional road	3-6	7 yrs.	CPX	P/H

3.1.2. Data from Dutch national road authority (Rijkswaterstaat)

Within the framework of the IPG program an extensive study was performed into the reproducibility, repeatability and related aging of 2 layer porous asphalt constructions (2L-PAC). In four repeated sessions a series of 6 2L-PAC with 4/8 top layer and 2 with 2/6 top layer were laid down. Six road building companies were involved in laying surfaces with a 4/8 top layer, each laying their product at two locations. Two of the six companies also applied the sections with the 2/6 top layer. Connected to the IPG program M+P also repeatedly measured several sections of thin surface layers (TSLs) and several sections with single layer porous asphalt construction (1L-PAC). All sections are located on highways.

On a yearly basis M+P performed repeated statistical pass-by (SPB) measurements (as defined in ISO 11819-1). Note that some of the reported SPB levels are obtained at the Dutch standard height of 5,0 m. Since we are mainly interested in the development over time and not the comparison of levels on different locations, it is not regarded a problem to use these data. All data combined in time series are from the same height.

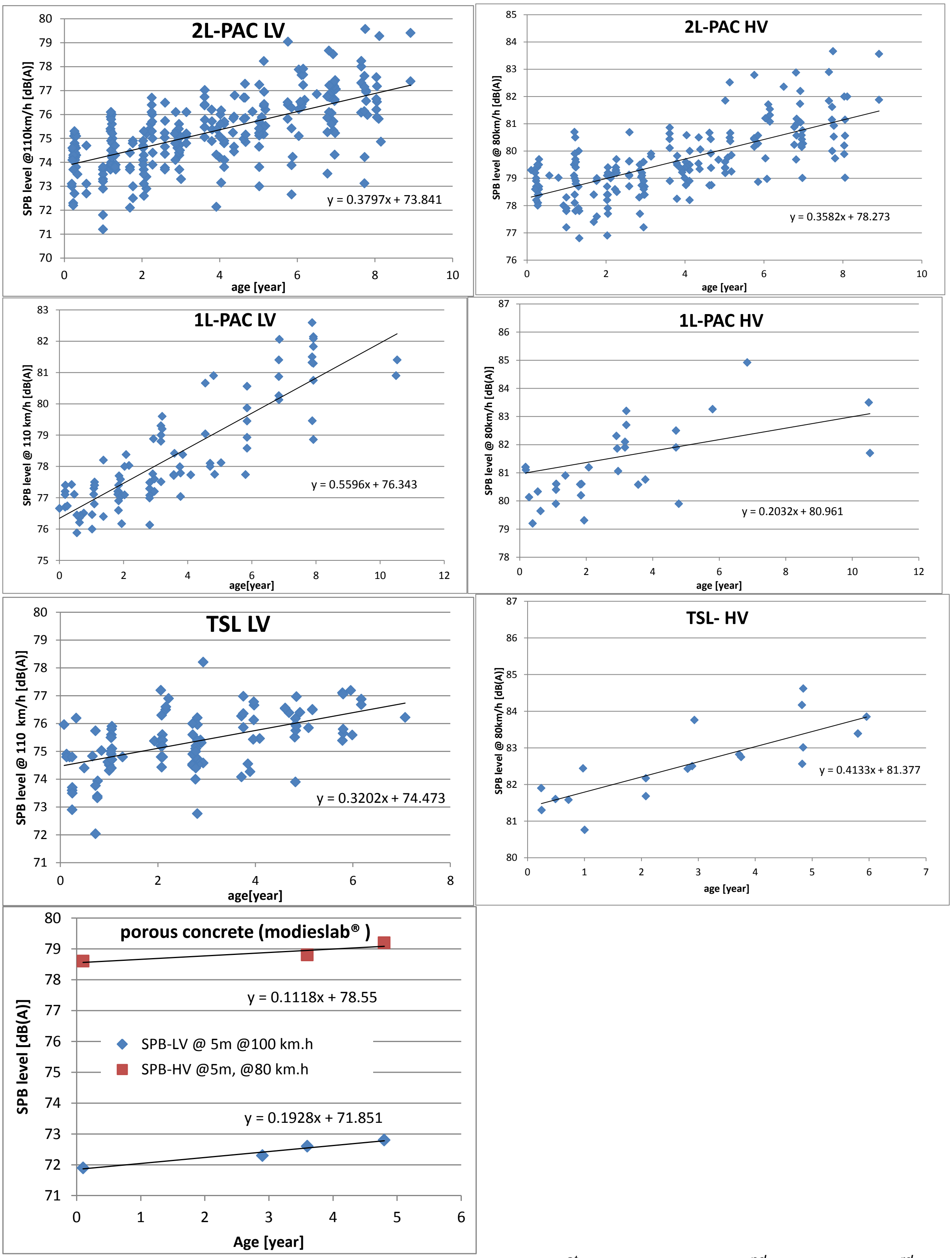


figure 1 Repeated SPB measurements on 2L-PAC (1st row), 1L-PAC (2nd row), TSL(3rd row) and 2L-PC (porous concrete) (4th row). Left: LVs at 110 km/h, right: heavy vehicles (HV's) at 80 km/h.

3.1.3. Data from province Gelderland

Within the framework of contracts for provinces M+P repeatedly measured different types of road surfaces on regional roads. These data are mainly close proximity (CPX) data (as defined in ISO/CD 11819-2). For one province the relevant noise reducing surfaces in the network were measured with a CPX system.

On regional roads that are operated by the provinces, Stone Mastic Asphalt (SMA) 0/8 and Dense Asphalt Concrete (DAC) 0/11 or 0/16 are still the regular surfaces. An valuable data set for our analysis of aging of these types of surfaces is obtained from the province of Gelderland. In the framework of a large monitoring program for low noise surfaces in that province newly laid low noise surfaces were followed with CPX measurements over a period of 2 to 4 years. Also the adjoining regular surfaces were measured for reference. In figure 2 data are given. We distinguish two situations:

1. The reference surface is laid simultaneously with the test surfaces. In this case we know the age of the reference surface. These results are presented in the left graph of figure 2.
2. The reference surface existed and was not renewed. The actual age is not known. These results are presented in the right graph of figure 2.

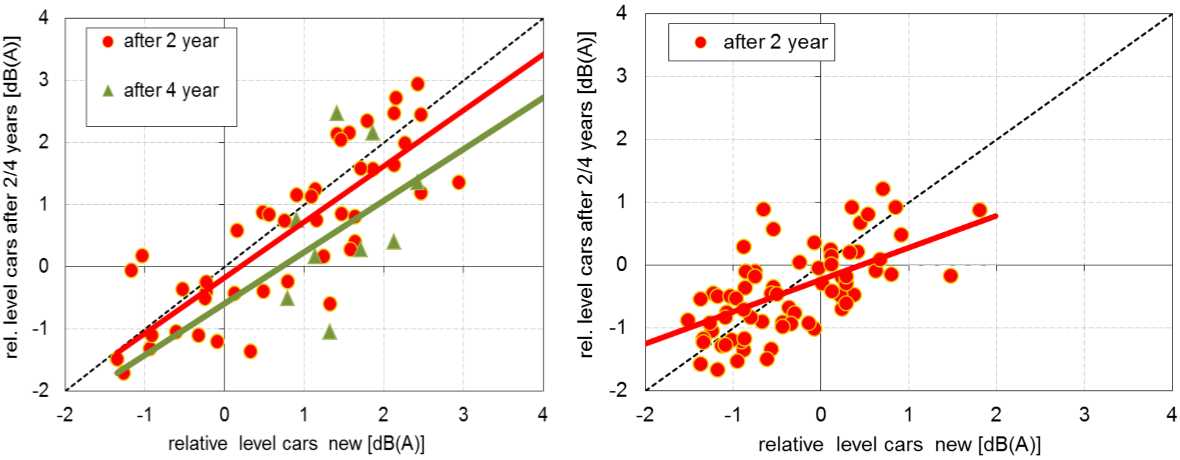


figure 2 Performance after 2 and after 4 years of a number of dense SMA and DAC surfaces. Presented is the reduction of the CPX level in initial condition (x-axis) against the reduction after 2 (red circles) and four (green triangles) years relative to a fixed reference level. The reference level is the average CPX LV's level on a series of aged DAC 0/11 surface. Left presents data when the initial condition presented a new surface. Right graph are data when the initial situation was an existing surface of unknown age.

The data presented in the left graph of figure 2 shows that the average of this series of new SMA 0/5, 0/8 and 0/11 surfaces is about 1,0 dB below the reference value. After 2 years the average value is only 0,2 dB lower and after 4 years 0,8 dB. The average loss in the first 4 years after laying is estimated to be about 0,14 dB per year. (ref. [4]).

The right graph shows a different situation where the surface was not new and the 2 and 4 years refer to actually older surfaces. Here one sees that the average level in the initial condition is already about 0,7 dB above the reference and after 2 years no additional degradation is observed. The few surfaces in the right part of this graph are obviously rather new surfaces and there the shown degradation is understandable and in line with the left graph.

3.2. Flanders/Belgium

In Flanders interest in noise reducing surfaces is raised only recently. Two programs are performed:

1. a survey of the Flanders highway system with a CPX system
2. a dedicated test on the acoustic properties of a series of surfaces on a regional road N19 at Kasterlee.

table II Overview of B (Flanders) data available for the study (source Flemish Road Authority)

Data set	Nr of sections	Surface type	Road type	Nr. of repetitions	Covered time	SPB/CPX	HV
Repeated	10	various	Regional road	3	1 yrs	SPB/CPX	Y
survey	n.a.	various	highway	n.a.	9 yrs	CPX	Y

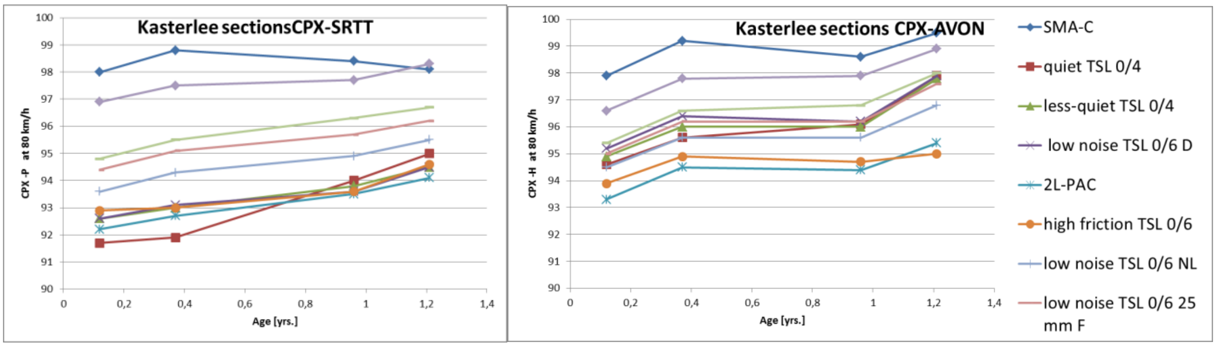


figure 3 Repeated CPX measurements on TSL and 2L-PAC test sections in Kasterlee (B). Graphs on the left with the SRTT (Standard Reference Test Tyre) tyrethat represents car tyres, graphs on the right with the AVON tyre that represents truck tyres.

3.3. Denmark

The Danish Road Directorate studies the behaviour of different low noise surfaces under highway conditions. On three highway locations test surfaces are laid and annually tested. The first test site is the M10 near Solrød where in 2004 and 2005 a total of six test surfaces of different types were laid. In 2006 12 surface types were laid on the M64 near Herning. In 2008 8 test surfaces were laid on the M68 also near Herning.

Test sections were evaluated annually with SPB measurements for light vehicles (LV's), 2-axle and multi-axle heavy vehicles (HV's). Both the total A-weighted values and the spectral composition of the Pass-by sound is available. Measurement data are available up to 2010. All results are presented in [1] .

table III Overview of DK data available for the study (Source DRD)

Data set	Nr of sections	Surface type	Road type	Nr. of repetitions	Covered time	SPB/CPX	HV
Repeated	**3 * 6**	**various**	**highway**	**7**	**2, 4 and 6yrs**	**SPB**	**Y**

In this study we focus on the M10 and M64 sections since the research data covers a longer time segment of 6 years.

Tests performed in Denmark on dense DAC and SMA reference surfaces on the M10 and M64 highways learn that the levels for LV's at around 100 km/h increase by about 0,5 to 0,7 dB/yr. For multi axle HV's increments in the order of 0,2 to 0,3 dB/yr are reported in [1] .

In the graph below (see figure 4) data over 6 years at the M10 section are presented. The linear equations refer to the best fit function through the data points.

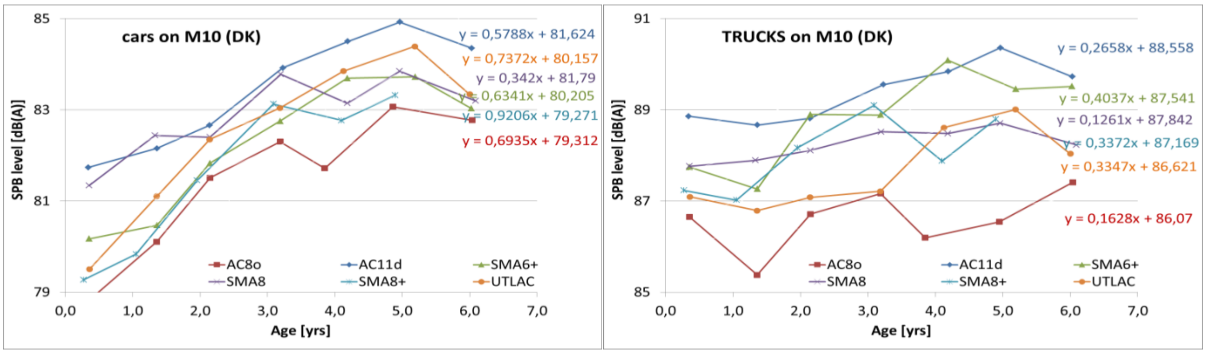


figure 4 Age related overall levels on 6 surface types on the M10 test location. The equations refer to the best fitting regression line. Colour code for surface type.

Presented below are data from Danish tests of several surfaces on M64 near Herning.

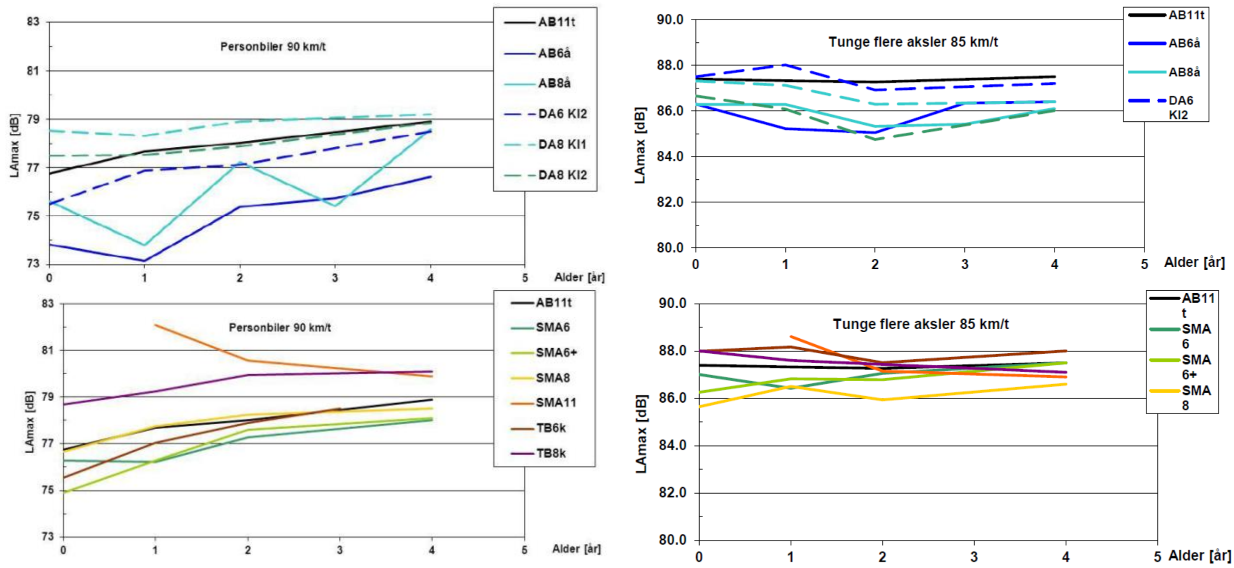


figure 5 Repeated SPB measurements on LV's (left) and HV's(right) on Danish motorway test sections: M64 near Herning.

3.4. Spain

In Spain the Spanish road authority CEDEX has performed several repeated measurements on a highway and regional road in the south of Spain near Malaga. Road surfaces were 1L-PAC, 2L-PAC and TSL. As a reference a dense asphalt concrete with 22 mm chipping size (ACSURF 22) is tested. Measurements are done with a CPX system and both the SRTT and AVON tyre were used as to represent the effect of the surface on LV's and HV's.

table IV Overview of ES data available for the study (source CEDEX)

Data set	Nr of locations	Surface type	Road type	Nr. of repetitions	Covered time	SPB/CPX	HV
Repeated CPX	A7	various	highway	3	2 yrs.	CPX	L/H
Repeated CPX	A66	11 mm TSL	highway	3	4 yrs.	CPX	L/H
Repeated CPX	N521	11 mm TSL and ACSURF 22	Regional road	2	1 yr.	CPX	L/H

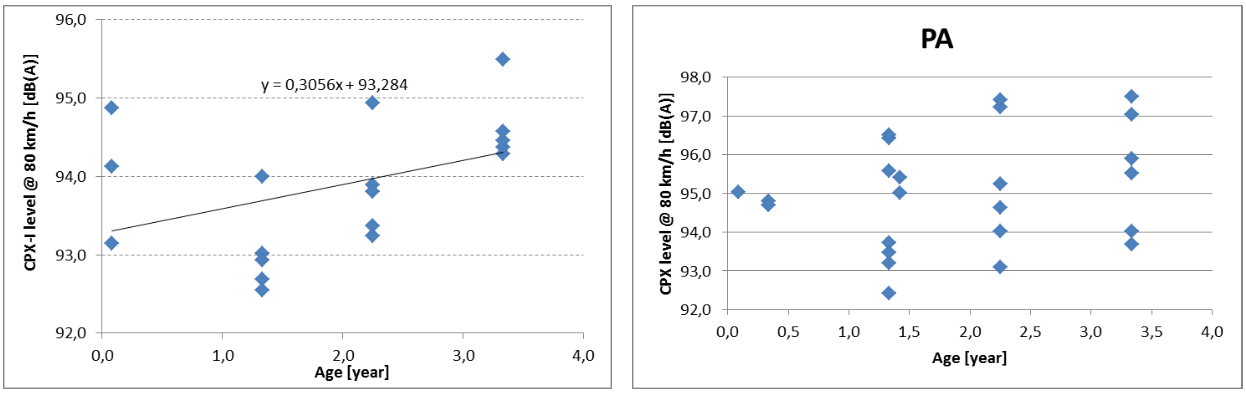


figure 6 CPX-I level @80 km/h on 1L-PAC (left) and 2L-PAC (right) in Spain. Presented are the averages of CPX SRTT and CPX AVON tyres at 80 km/h. Most data are determined at the A-7 near Malaga.

3.5. Germany

In Germany two data sets are used for the study.

1. A series of repeated SPB measurements on 1L-PAC8 (referred to in German as OPA) on several locations on German highways. In total the data set covered 11 years, but data are distributed over more locations. Not all locations covered that total period.
2. A series of repeated CPX measurements on German Highways in Bavaria. It is interesting to note that separate data is available from the left, middle and right lane of the highway.

table V Overview of D data available for the study (source BASt and M-BBM)

Data set	Nr of locations	Surface type	Road type	Nr. of repetitions	Covered time	SPB/CPX	HV
repeated	6		highway	3-4	4-6 yrs.	CPX	
Repeated	12	Porous Asphalt 0/10	highway	2-5	12 yrs.	SPB	Y

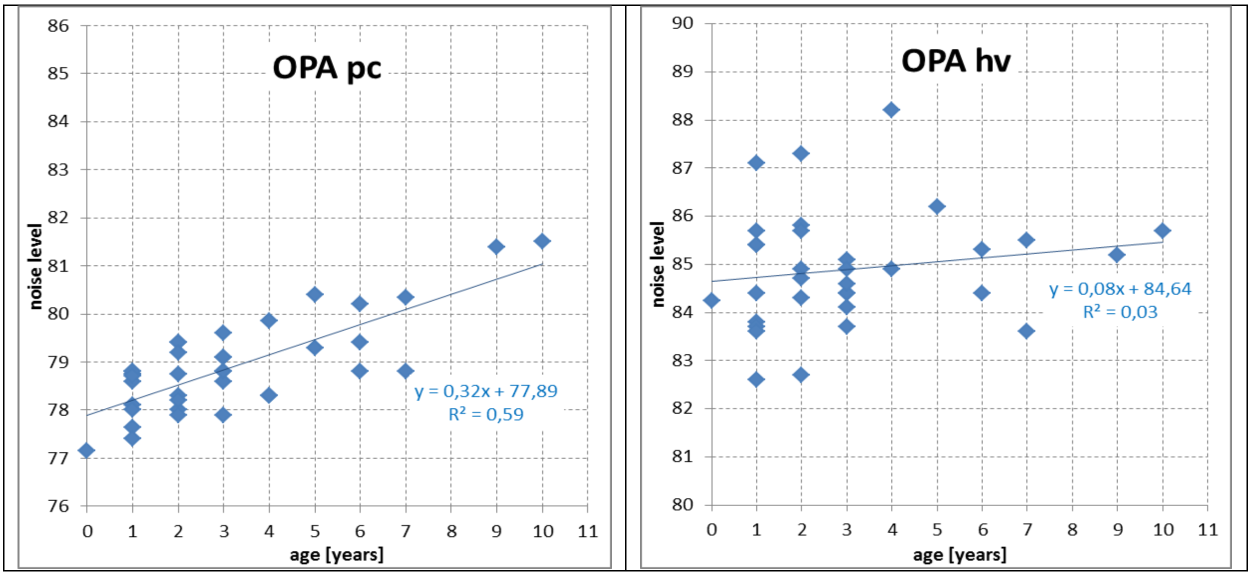


figure 7 Repeated measurements at different locations in Germany on 1L-PAC 0/8. Left LV's, right: HV's.

From the data sets in figure 7 the average development of the noise reducing capacity for LV's and HV's is calculated. The reduction is relative to the German RLS 90 standard surface. The reduction is calculated for a period of 0-7 years since beyond that period to scarce data is available.

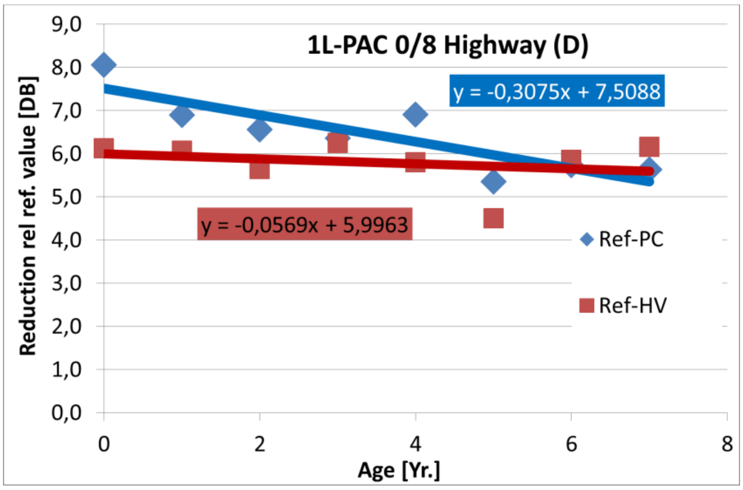


figure 8 Reduction as a function of age for passenger LV's (PC) and Heavy vehicles (HV). Source: BASt. Data are averaged per age. Source data from figure 7.

In Bavaria a series of CPX measurements with the standard SRTT tyre presenting LV's tyres (CPX-P) are performed on several locations on the autobahn. The relevance lies in the fact that data are obtained on separate lanes. The graph below shows the results of a thin hot rolled layer of 6mm (DSH-5) for the A99, which is the ring road around Munich. Two characteristics are noted:

1. the right lane is from the start noisier than the middle of left lane
2. the loss of acoustic performance is stronger on the right lane than on the left and middle lane.

The absolute values of comparable lanes on both driving directions are similar.

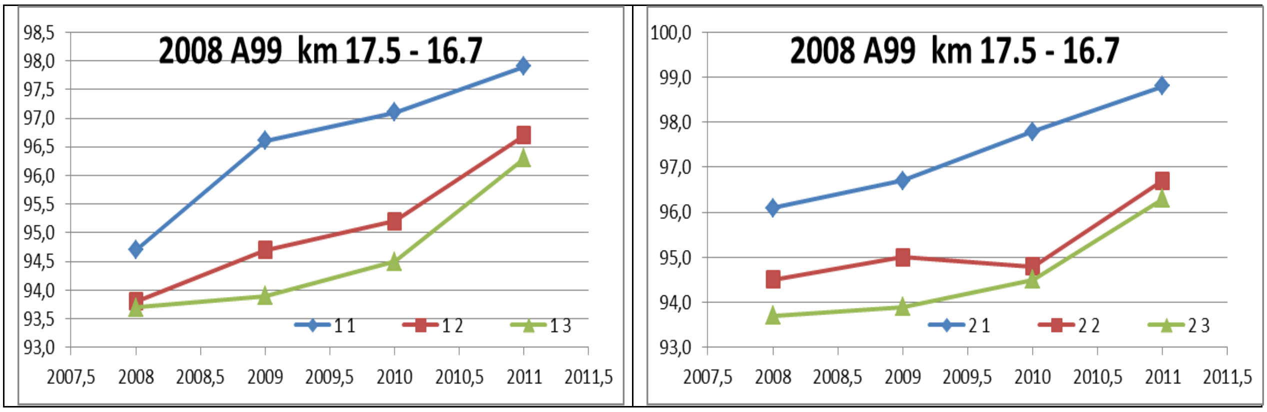


figure 9 Results from repeated CPX-P measurements on the A99 in Bavaria. Road surface type is thin hot rolled layer of 6 mm (DSH-5). In each graph the data for separate lanes are given (1, 2 and 3 for right, middle and left lane). Left and right graph indicate different directions.

In § A2.2 all available Bavarian data is presented. It can be seen that the characteristics found in the graphs above are also recognizable in the other graphs found there.

3.6. Scandinavia

Scandinavian data refers to totally different conditions with respect to wear, due to harsh winter conditions and the use of studded tyres. In Norway, Sweden and Finland several research projects are performed with the objective to find noise reducing road surfaces that maintain their properties under these harsh conditions. The available data show the strong deteriorating effects on road surface acoustics because of the Scandinavian conditions. Some examples of the quick wear of surfaces are shown below.

The development of the acoustic properties over time for the Norwegian, Swedish and Finnish situation is treated in a separate report composed by Aalto University in Finland (ref. [6]).

table VI Overview of N data available for the study (source Sintef)

Data set	Nr of locations	Surface type	Road type	Nr. of repetitions	Covered time
Repeated	**3**	**DAC**	**Regional**	**4***	**4 yrs***
Repeated	**3**	**SMA**	**Regional**	**4***	**4 yrs***
Repeated	**6**	**SMA**	**Highway**	**4***	**4 yrs***

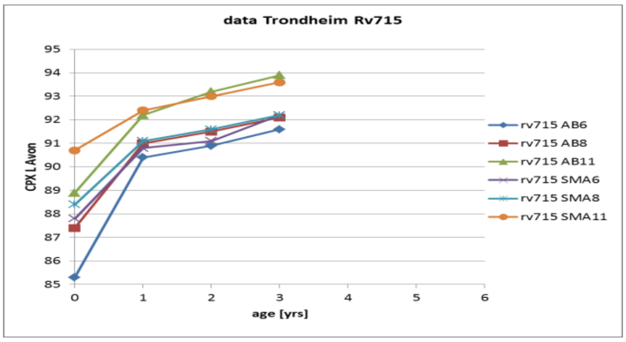
CEDR Conférence Européenne des Directeurs des Routes Conference of European Directors of Roads

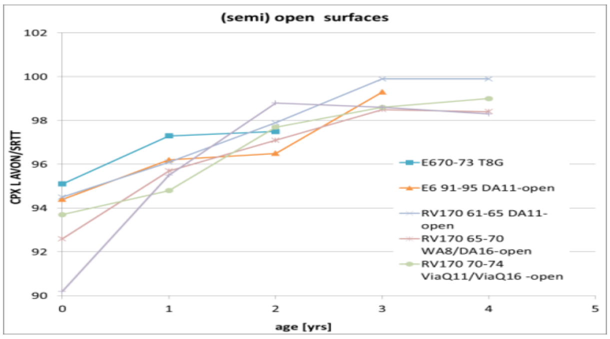
Data set	Nr of locations	Surface type	Road type	Nr. of repetitions	Covered time
Repeated	5	DAC	Highway	4*	4 yrs*
Repeated	2	Single-layer porous	Highway	4*	4 yrs*
Repeated	4	Thin layer	Regional	3*	3 yrs*
Repeated	1	Single-layer porous	Regional	3*	3 yrs*
Repeated	3	Double-layer porous	Regional	3*	3 yrs*
Repeated	4	SMA	Highway	2*	2 yrs*
Repeated	1	Thin layer	Regional	2*	2 yrs*
Repeated	3	DAC	Regional	2*	2 yrs*
Repeated	1	Double-layer porous	Highway	1*	1 yrs*
Repeated	1	Double-layer porous	Regional	1*	1 yrs*

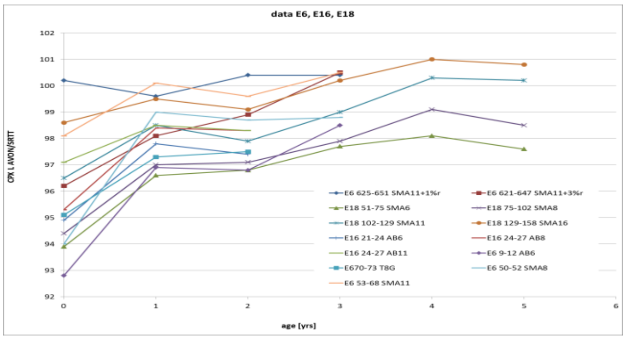
table VII Overview of SF data available for the study (source Aalto University)

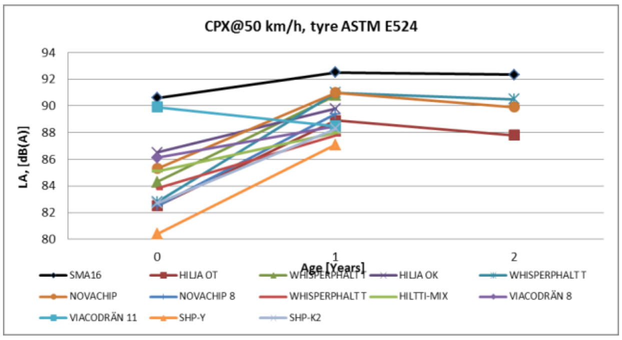
Data set	Nr of locations	Surface type	Road type	Nr. of repetitions	Covered time
Repeated	2	SMA6	Urban	3	3 yrs
Repeated	2	SMA6	Urban	2	2 yrs
Repeated	2	Double-layer porous	Urban	3	3 yrs
Repeated	4	Double-layer porous	Urban	2	2 yrs
Repeated	3	Single-layer semi-open	Urban	3	3 yrs
Repeated	9	Single-layer semi-open	Urban	2	2 yrs
Repeated	8	Single-layer semi-open	Highway	1	1 yr

From Sweden no source data was available, but only processed data in the form of graphs and tables.









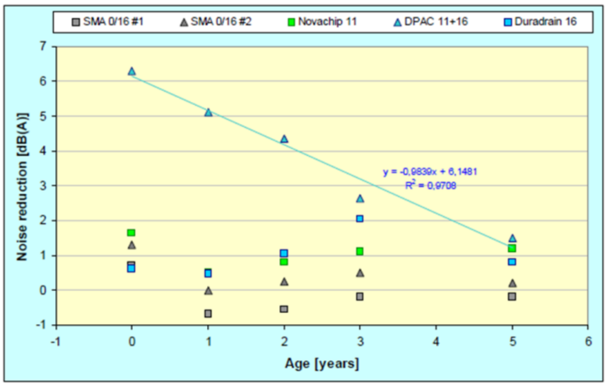


figure 10 Graphs: repeated CPX data of SRTT and AVON on test sections in Norway, Finland and Sweden.

3.7. France

In France surfaces are regularly tested with respect to their acoustic performance by the Road research organization IFFSTAR, the French Road authority SETRA and the regional road laboratory of LRPC in Strasbourg.

In total on about 70 locations repeated SPB measurements are performed on a wide variety of surface types. Separate data sets for LV's and HV's are available. An overview of the available data is given below (see figure 11). In a separate study (ref. [5]) of the research institute IDRRIM the data for 1L-PAC 10 and for semi-open TSL6 were analysed in terms of their age related acoustic performance (see figure 12).

table VIII Overview of F data available for the study (source IFFSTAR)

Data set	Nr of locations	Surface type	Road type	Nr. of repetitions	Covered time	SPB/CPX	HV
repeated	>70	various	Highway/regional roads	2-6	11yrs.	SPB	Y

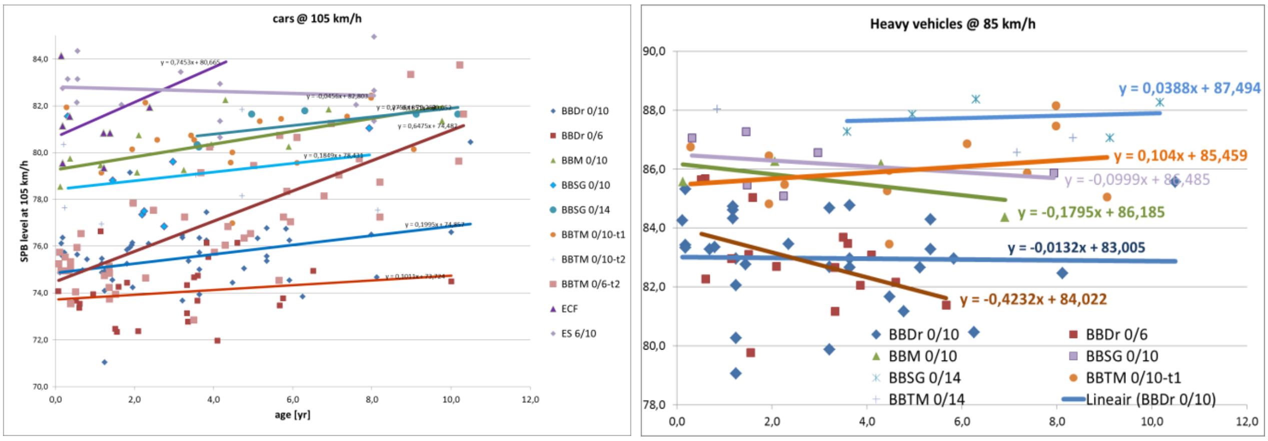


figure 11 Data base of SPB results in France. Data are categorized according to road surface type. Each type contains repeated data at several locations. Right: LV's@ 105 km/h, Left HV's @ 85 km/h.Source: SETRA and LRPC Strasbourg.

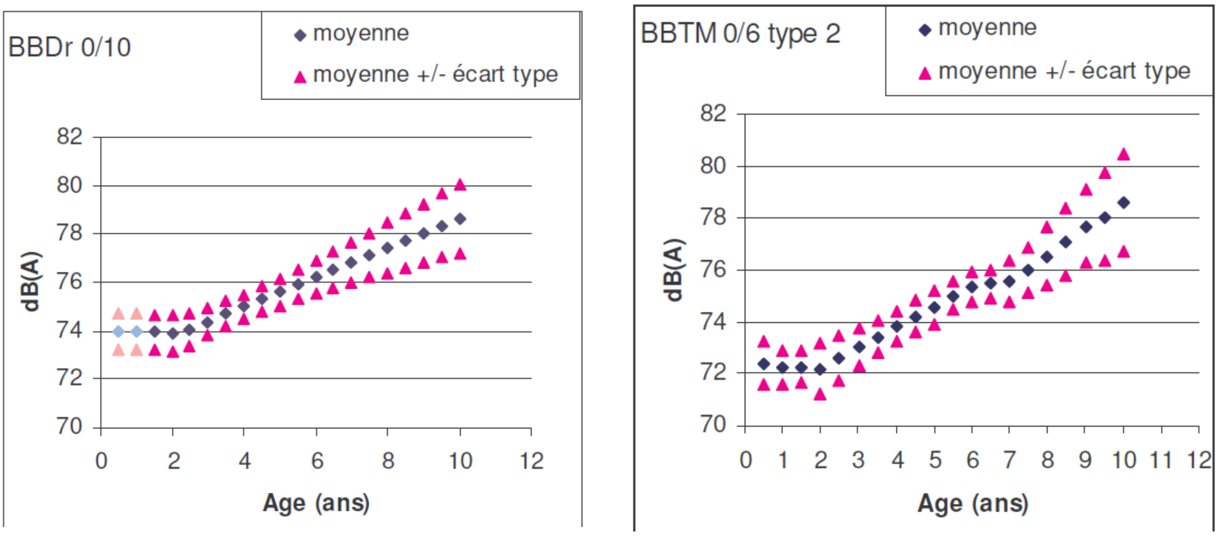


figure 12 Right: age related acoustic performance of 1L-PAC 0/10 (highways) Left: age related performance of semi-open TSL 0/6. Results for LV's @90 km/h (ref. [5]).

French data for 1L-PAC 0/10 indicate a change in acoustic performance over time of about 0,5 dB per year for LV's (see figure 11-left and figure 12-left). For heavy vehicles no change is observed in figure 11–right. In the case of a finer mixture and less porosity (TSL 0/6) the initial reduction is about 2 dB higher, but due to the stronger increase over time, the final level is about the same as 1L-PAC 0/10 (see figure 12-right).

The data displayed in figure 11 indicate an average change in acoustic performance of Dense Asphalt Concrete surfaces (BBMSG 0/10 and 0/14) of about +0,2 dB per year for LV's and nearly no change for heavy vehicles.

3.8. UK

In the UK, repeated SPB measurements were carried out within the framework of a research project on the acoustic durability of low-noise surfaces. Data is available for SMA6, -10 and 14, HRA20 (Hot rolled asphalt) and exposed aggregate concrete. The data set comprises per road surface type about 4 to 6 locations, with each location measured about 3 times over a time span ranging between 3 and 10 (SMA) and 14 (HRA and concrete) years. A graphical overview of all data is given in § A.5. In figure 13 an example is given for SPB data for LV's on SMA10.

table IX Overview of UK data available for the study (source TRL)

Data set	Nr of locations	Surface type	Road type	Nr. of repetitions	Covered time	SPB/CPX	HV
repeated	4-6	SMA6	Highway/regional roads	2-6	10yrs.	SPB	Y
repeated	4-6	SMA10	Highway/regional roads	2-6	10yrs.	SPB	Y
repeated	4-6	SMA14	Highway/regional roads	2-6	10yrs.	SPB	Y
repeated	4-6	HRA20	Highway/regional roads	2-6	14yrs.	SPB	Y
repeated	4-6	Exposed aggregate concrete	Highway/regional roads	2-6	14yrs.	SPB	Y

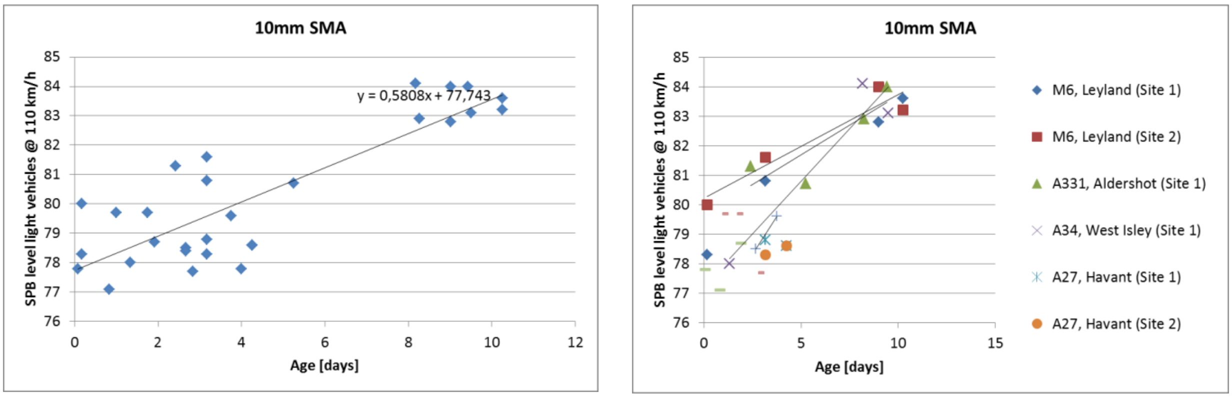


figure 13 Example of UK data for SMA10 and LV's. Left all data presented together, left: data separated for different locations.

3.9. Difference between lanes

Acoustic performance of road surfaces on highways is normally determined on the slow lane because of safety considerations and the fact that traffic on that lane dominates overall acoustic emission (highest traffic intensity and highest HV intensity). Only in a few cases is data from other lanes available. These data reveal that in many cases there exists a significant difference between the acoustic performances of the road surfaces in different lanes.

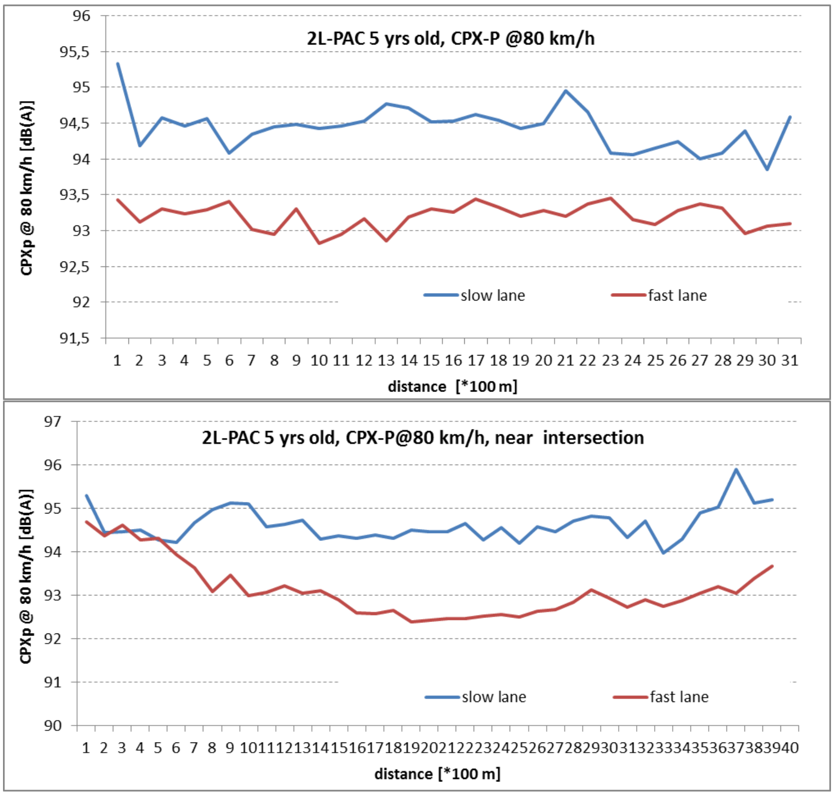


figure 14 CPX data from fast lane versus slow lane. 2L-PAC of about 5 yrs of age. Top: straight road. Bottom: just after intersection where HV's use the first 600 m of the fast lane in order to reach their designated exit lane.

The figure above (figure 14) shows CPX data from a 3 and a 4 km section on a NL highway. The graphs show a distinct difference between the two lanes. The slow lane exhibits consistently higher CPX levels than the fast lane.
German data from the Bavarian autobahn showed an almost identical picture. Consistent higher CPX levels at the slow lane compared to the other lanes. And similar relations were reported from Spainon the 2L-PAC surfaces at the A7 near Malaga.

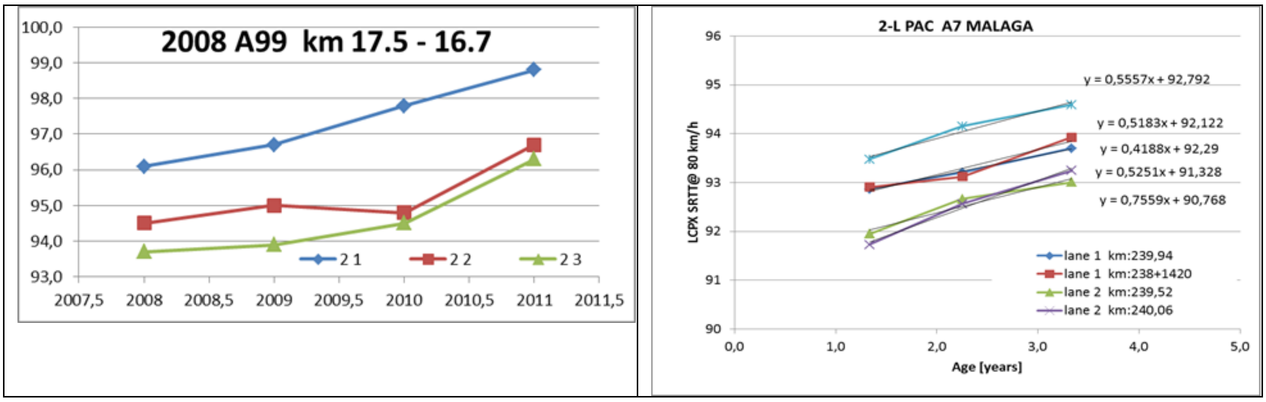


figure 15 CPX data from different lanes on highways. Left Bavarian data of DSH5 surfaces (build in 2008). Right: data from a Spanish highway with 2L-PAC.

It is interesting that the difference between the lanes is almost independent from age.

The lower graph of figure 14 shows an interesting deviation from the general rule that the fast lane is less noisy than the slow lane. For the first 600 m of the tested section levels of fast and slow lane are almost identical.

Inspection of the situation there showed that at that point there was an intersection where HV's frequently use that segment of the fast lane to be able to reach their designated exit lane. A similar picture was found at other locations where HV's use fast lanes for specific reasons.

4. Overview of reported degradations

We are interested in the development of the acoustic performance of the road surface over time. We are less interested in the absolute performances of the surfaces compared to each other and compared over regions in Europe. This allows the usage of data from different sources and different types of measurements (such as CPX and SPB, both at 1,2 and 5,0 m). From each data set the yearly loss of acoustic performance (defined as a slope in dB's/yr) is derived and then slopes for comparable surfaces, for HV's and LV's and areas of Europe are combined into a series of single numbers (see table X). For some surface types different extensive data sets point to different slopes. In those cases we have presented both figures in the table.

The table represents a summary of the data sets introduced in the preceding paragraphs. From the presented data one can derive general trends. The loss in acoustic performance for HV's is generally about half of the loss observed for LV's. TSL's are most susceptible for age, and dense surfaces show on average lower degradations as can be expected.

The data sets however also lead to remarkable results. SMA surfaces, generally considered stable and robust surface types, exhibit significant slopes in UK and DK, while NL data indicate a moderate slope. Reported data indicate still some annual change in case of concrete surfaces. The fine graded 1L-PAC 0/6, at the other hand, performs remarkably stable under French conditions while the coarser 1L-PAC0/8 shows stronger degradation.

The cause and nature of these remarkable results are not known. It would be very interesting of course to learn from the positive results on how low noise surfaces can be made so that the initial performance can be maintained over a longer time span.

table X Overview of calculated slopes [dB/yr.] of different surface types, found in different countries in Europe. CPX and SPB are combined. Data represent mainly highways added with some regional roads.

Surface type	source	Slope [dB/yr]	
		LV's	HV's
1L-PAC 0/16	NL ES	0,62 0,30	0,20
1L-PAC 0/8-0/11	D	0,31	0,06
	F	0,41 / 0,19	0,00
	DK	0,65	0,09
1L-PAC 0/6	F	0,14	[0,00]
2L-PAC 0/8	NL	0,38	0,36
	ES	0,52	
TSL 0/6 semi open	NL	0,33	0,41
	F	0,60/ 0,67	-
SMA 0/14	UK	0,48	0,33
SMA 0/8 - 0/11	UK	0,58	0,35
	DK	0,35	0,10
	NL	< 0,1	
SMA 0/6	UK	0,60	0,29
	DK	0,48	0,18
HRA 0/20	UK	0,25	0,12
Exposed concrete	UK	0,22	0,09
2L-PC (porous concrete)	NL	0,16	0,12
DAC 0/8-0/11	DK	0,53	0,04
	F	0,12	0,00
DAC 0/16	NL	0,10	0,05
	F	0,11	0,04

5. Methodology, General Approach

The preceding chapter illustrated that the type and nature of the data is rather widely spread. Some contain spectral compositions, others not, both CPX and SPB methods are used, there are programmed repeated data of a series of road surfaces on the same position, but also surveys of a network. Not always is all traffic and road type data available.

We therefore composed a dedicated approach.

- We use the spectral changes over time to classify different types of aging and to indicate the mechanisms behind it.
- We use this to identify objective parameters. These are then used in a multi parameter analysis with ANOVA that is applied on some comprehensive data sets found in the Dutch IPG project. This enables us to test the hypothesis of influence of several parameters.
- We use the comprehensive but less detailed French data sets to quantify the spread in aging of surfaces within a certain road surface type against the spread found between road surface types. This indicates the achievable level of confidence in the modelling of aging behaviour.
- We use the German data sets to test the spread within a road surface type over different locations. Combined with the IPG sections, this learns also about the varying causes of aging.
- The Spanish and Danish data sets indicate the regional influence on aging. Spain with absolutely no winter conditions, Denmark at the other hand with frequent winter conditions. The same information comes from French and German data.

The Scandinavian data sets are studied separately in [6] . Since the effect of studded tyres dominates over all other sources of aging, the combining of Scandinavian data with mainland Europe data will not result in extra knowledge.

6. *Mechanisms and their spectral finger print*

From past experience we learned that causes of performance loss of low noise surfaces can be traced back to specific deterioration such as clogging of the pores, roughening of the surface by stone loss or filling up of the open porous layer. These mechanisms are reflected in the spectral composition of the pass-by sound. The graph below (figure 16) illustrates the effect of changes in the surface characteristics on the spectral composition of rolling noise of car tyres.

The numbers 1 to 4 shown in the graph (figure 16) indicate the type of change:

1. Effect of surface texture leads to variation in the low and mid frequent part of the spectrum. The frequencies above 1 250 Hz are hardly affected.
2. Effect of a closed versus an open surface (actually low and high flow resistivity) is found at frequencies above 1 000 Hz. In this case the lower frequencies are hardly affected.
3. Creating an open layer of a certain thickness introduces acoustic absorption
4. Increasing the thickness of the absorbing layer causes a shift of the absorption “dip” to lower frequencies.

Aging is actually reversing the mentioned processes.

1. Filling-up of the acoustic layer by dirt will cause a reduction of the effective absorption layer and thus shifting of the absorption “dip” to higher frequencies and eventually nearly total clogging of the porous layer leading to loss of acoustic absorption.
2. Closing of the top layer by either extensive dirt or compaction of the slightly open top layer amplifies aero-acoustic noise generation and thus increase of levels at the mid and high frequency range.
3. Degradation of the surface texture through stone-loss increases texture induced vibration of the tyre structure, that manifests itself in the lower and mid frequency range.

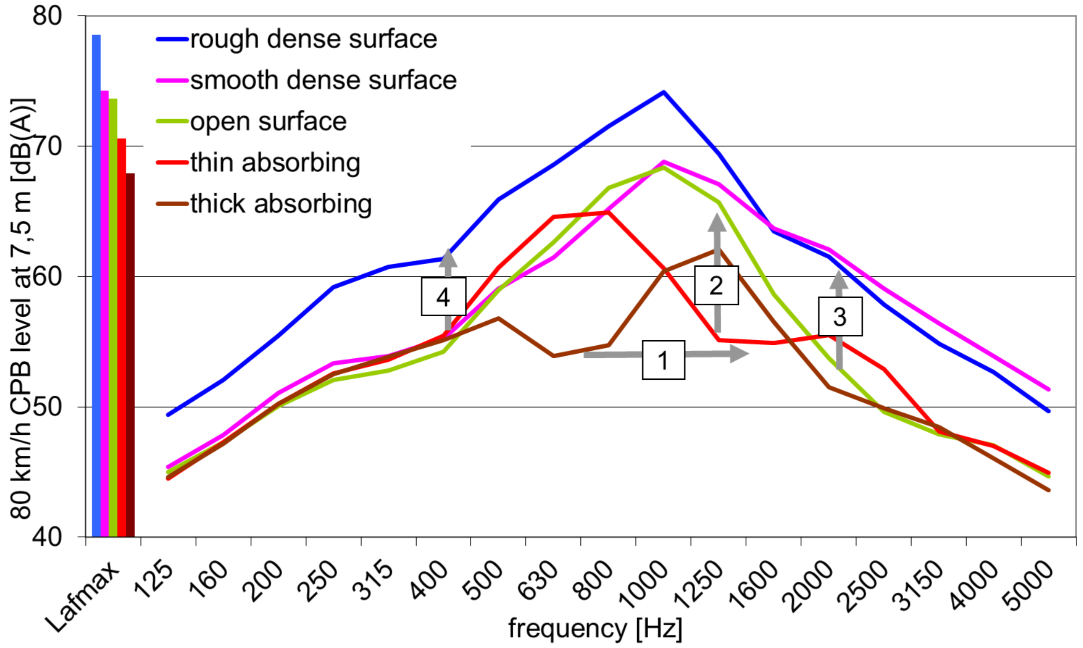


figure 16 Spectral distribution of the different aging processes: (1) filling up of the lower layer, (2) further filling, (3) clogging of top-layer and (4) stone loss. Spectra are representative for LV tyres.

The understanding of the effect of surface characteristics on the noise emission of HV's is more complicated since:

1. the pass-by noise of these vehicles consists of a larger fraction of powertrain noise than passenger LV's. Already at speeds above 50 km/h powertrain contribution can be neglected for LV's, while for HV's at 85 km/h still 30% of the sound energy originates from the powertrain.
2. HV's are equipped with a mix of different tyre types. Narrow rib tyres on the front axle, double mounted traction tyres at the drive axle and wide or double mounted rib tyres at the trailer axles. The effect of modifications in surface characteristics depends on the tyre type. An overall surface effect can be composed on the weighed contribution of all three tyre types on the total rolling sound.

The graph below presents the spectral effects of different types of surface modifications, similar to those presented for LV's in figure 16.

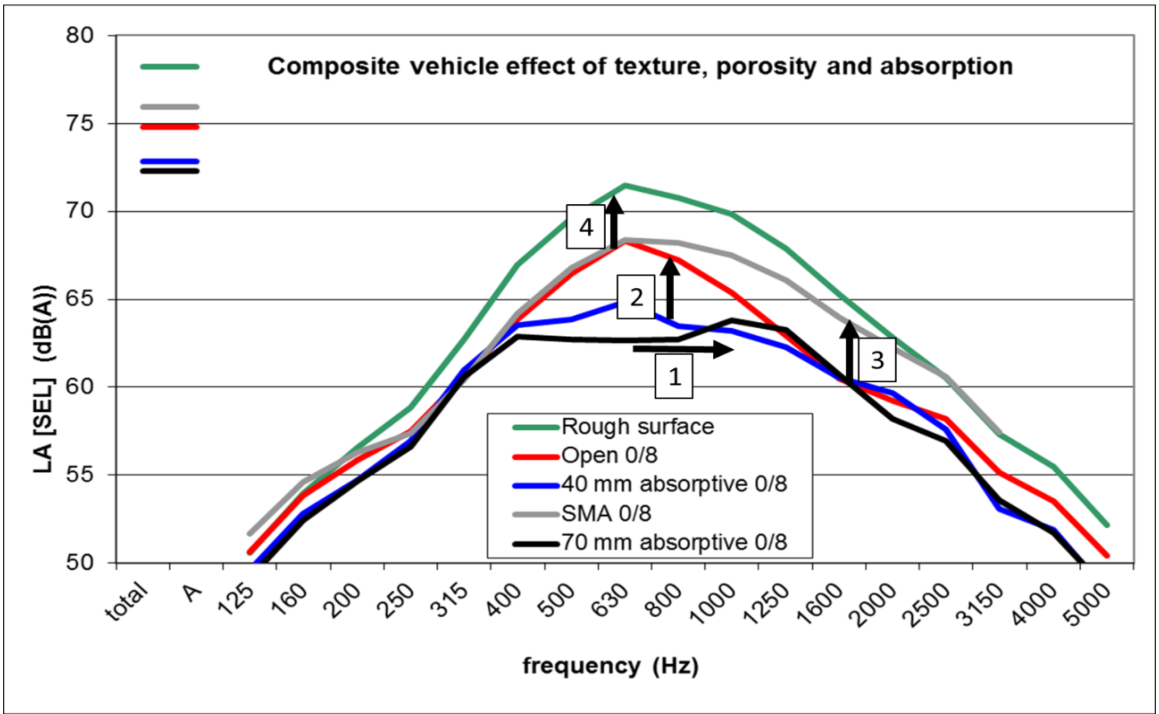


figure 17 Spectral effects of surface modifications on the rolling sound of a HV composed of two steer tyres, four drive tyres and four trailer tyres. The numbers indicate the same surface modifications as in figure 16 (1: filling of lower porous layer, 2: further filling up, 3: clogging of top layer, 4: stone loss). The measure here is SEL in order to represent a mix of steer, drive and trailer tyres.

The aging effects of surfaces on HV noise are not that different from LV's. They follow the same trend. It is found though that with smoother textures there exists hardly any dependence on texture, so it may be expected that stone loss will not decrease reduction performance. In some occasions even an improvement is found. Very smooth surfaces cause strong tonal components in the total emission and through some stone loss texture degrades and tonal components disappear.

7. Spectral analysis of aged surfaces

The preceding chapter has identified the way aging processes manifests itself in the changes in the spectral shape. In order to be able to identify such processes an extended spectral data sets are required that covers several locations and complete time lines.

The most comprehensive set of data is the Dutch IPG set. It consists of detailed and repeated SPB measurements on several locations on the Dutch highway system over a period of 8 to 9 years for both LV's and HV's. It covers three types of relevant surfaces:

1. 2L-PAC both with 4/8 and 2/6 top layer
2. 1L-PAC 0/16
3. TSL 0/6

7.1. 2L-PAC

When the developments in each spectral band in time are determined it will be possible to identify the underlying aging mechanisms. Increase at lower frequencies indicate texture degradation, increase in higher frequency ranges indicates degrading flow resistance, either through clogging of semi porous surfaces or by texture loss. Spectral increases in the mid-frequency range can point to several mechanisms.
It is the overall spectral shape variations that will learn which mechanism is most responsible for the loss in performance.

Graphs below show some examples of spectral trend analysis. The complete set is presented in § A 1.2 and § A 1.3 .

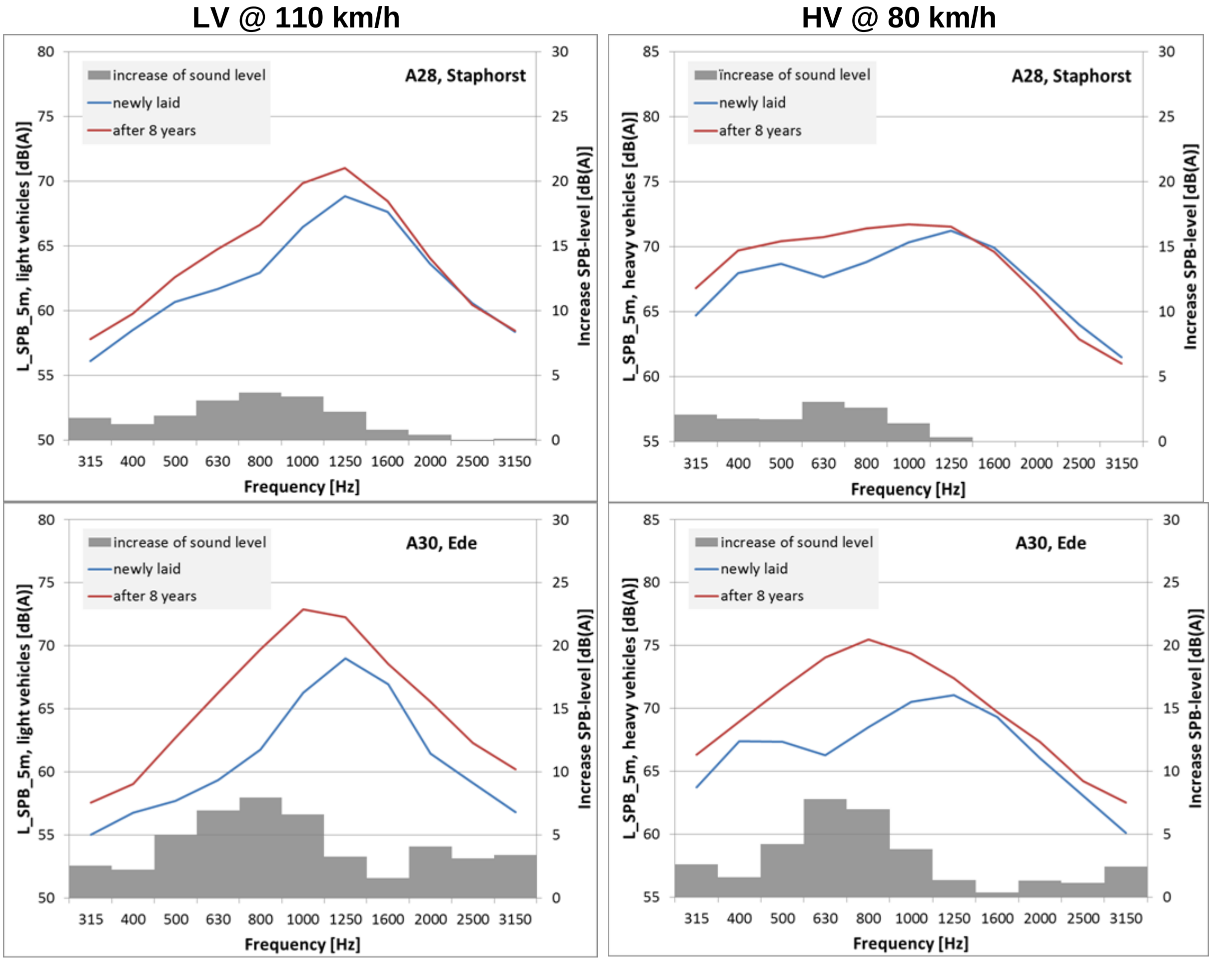


figure 18 Examples of spectral distribution of aging of 2L-PAC on two locations. Top A28 near the village of Staphorst, bottom the A30 near Ede. Each graph displays the initial spectrum and the spectrum after 8 years. The initial and final spectrum is determined from the regression line through each 3rd-octave band. The bar graph represent the increase in each frequency band after 8 years. Each graph displays the average over 6 test sections on each location. Left: LV's, right: HV's.

The graphs in figure 18 show clear differences in spectral trends between the A28 and the A30. From the spectral trends displayed in figure 16 and figure 17 one can already identify the related mechanisms. For the A28 the mechanisms are mild texture degradation with mild filling up of the porous layer, leading to a shift in the absorption maximum. For the A30 the spectral shift can be explained by clogging of the pores, leading to both, a strong degradation of the absorption characteristics and increase of flow resistivity.

At this point it is hard to understand the difference between the A28 and A30 trends:

1. The A30 ages quicker but has a lower vehicle intensity (both LV's and HV's) than the A28.
2. The A30 was built later so road engineers had more experience than when building the sections on the A28.
3. The A30 was manufactured by the same companies as on the A28.

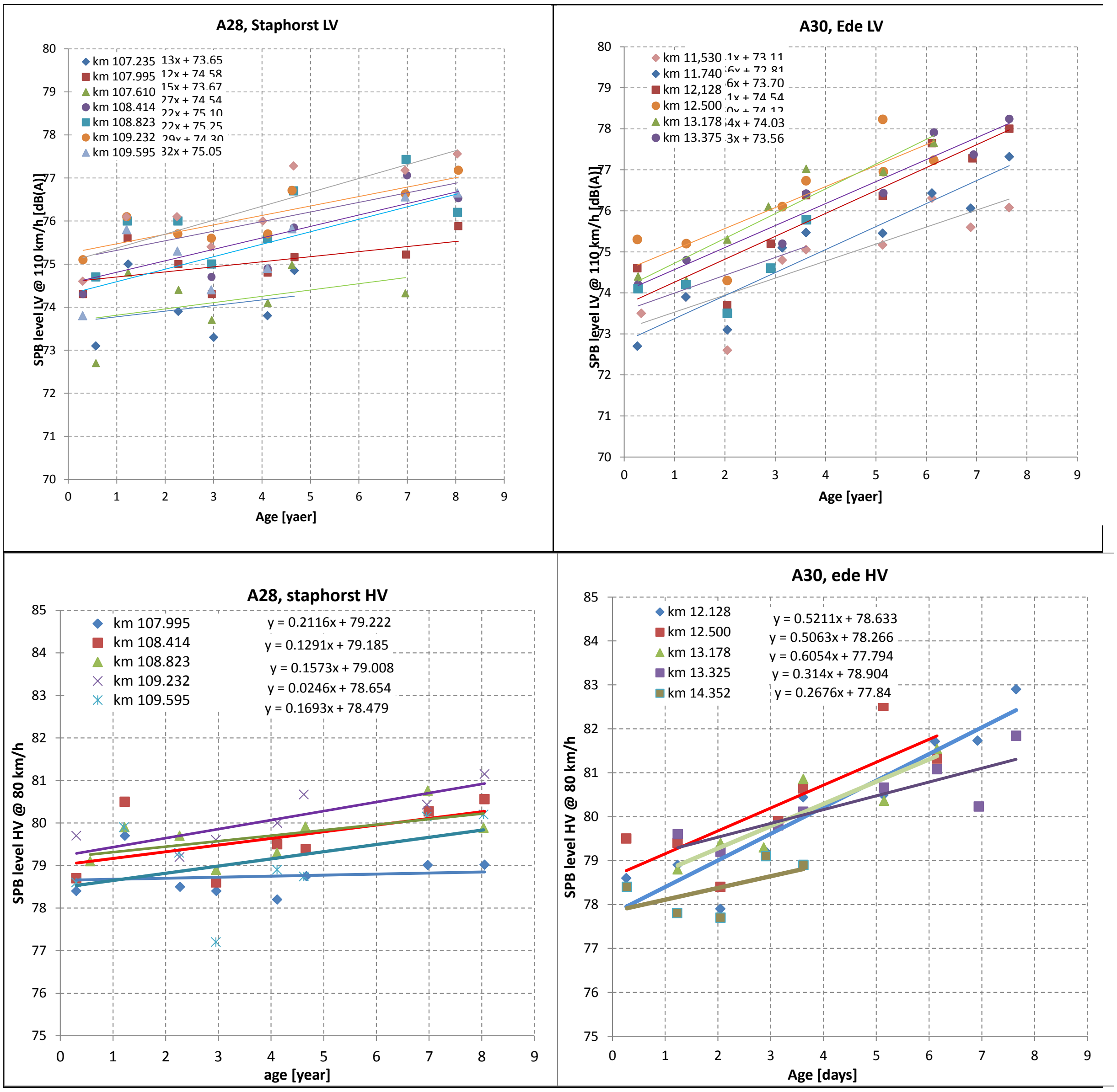


figure 19 Trend lines for each section on the A28 and A30. SPB for LV's @110 km/h and HV's @ 80 km/h.Notice that most of the trend lines per location are more or less parallel, indicating that the aging is independent from manufacturer and location defined.

Further investigation into the specific characteristicsshowed that there are a few relevant differences between the A28 and A30 that might explain the difference in behaviour. The A28 geometry exhibit excellent draining capacities for water out of the porous surface with few obstructions for water flow. The A30 shoulders were narrower and bordered by grassy areas. The material composition used for the A30might be different from that of the A28, although no proof for that is available.

The build quality however is very hard to implement in a model, since it cannot be quantified and furthermore no specific guidelines are available that can be used as reference to qualify the technical quality.

7.2. 1L-PAC 0/16

Although less extensively studied compared to 2L-PAC, the data set for 1L-PAC is still considerably large. Test sections however were not organized in repeating groups at different locations, as is the case with 2L-PAC, but are distributed over the highway network.

Study of the spectral trends over age show that the main effect for LV's is the filling up of the open surface, leading to loss of acoustic absorption. The data of Echt-Roosteren A2 and Emmeloord A6 present a clear example of how in the period up to 4 to 5 years the indent due to the acoustic absorption disappears, while the low- and high frequent area remain more or less the same (see figure 21 bottom row)

The spectral changes for heavy vehicles follow a slightly different pattern. (see figure 20 right graph for an overall spectrum and figure 22 for two specific locations). The loss of acoustic absorption is noticeable in the increase in the mid frequent area, but very surprising is thedecrease with time found at higher frequencies.

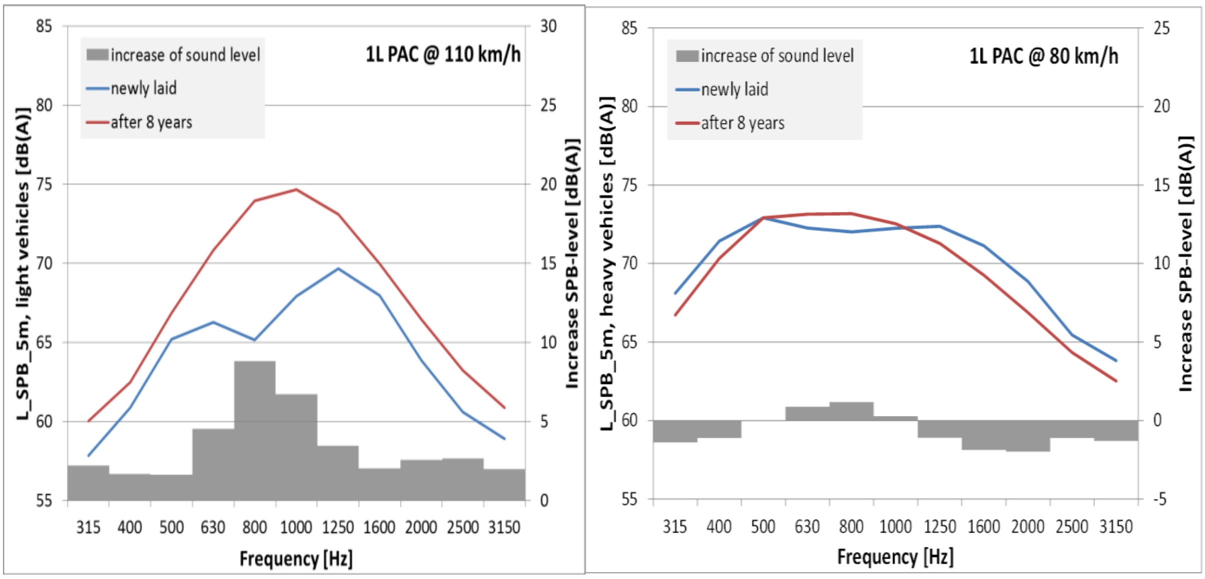


figure 20 SPB data @5m, averaged spectral trends over all 1L-PAC data available. Left: LV's@110 km/h, right: HV's @80 km//h.

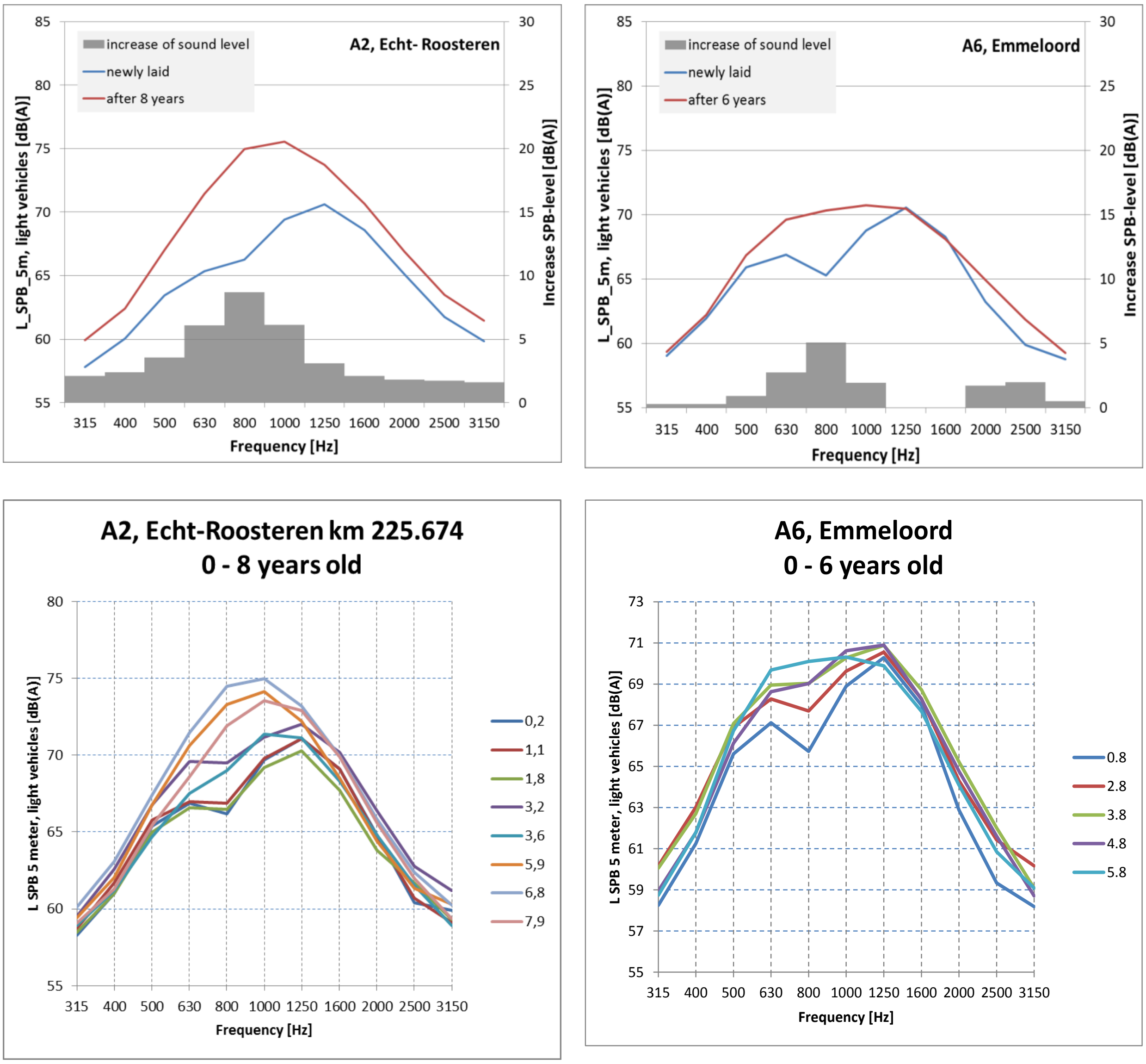


figure 21 1L-PAC 0/16. SPB data @5m for LV's @110 km/h. Top: initial and final spectra and their mutual spectral differences based on trend analysis. Bottom: repeated measurements.

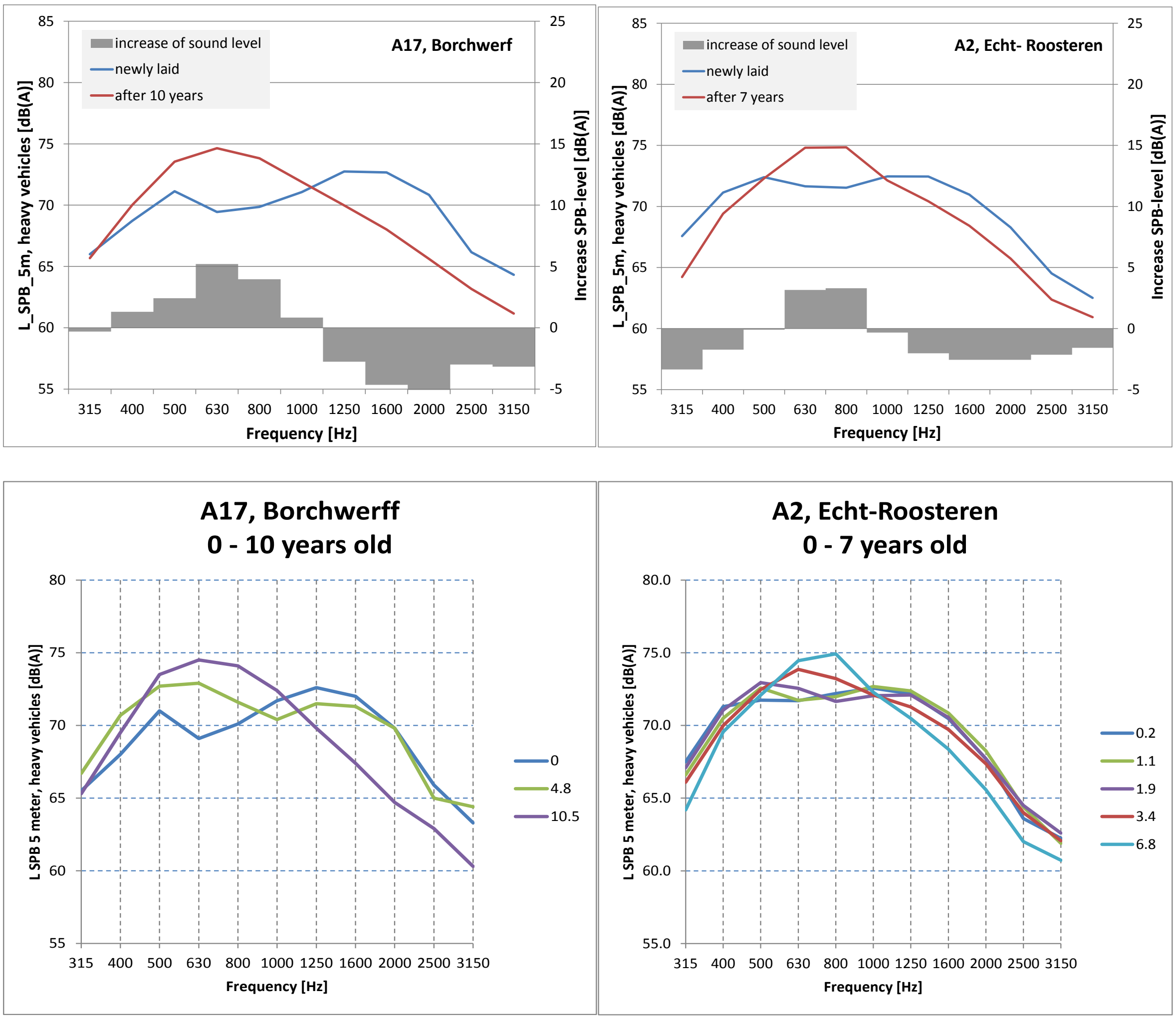


figure 22 1L-PAC. SPB data @5m for HV's @80 km/h. Top left: data from one section at A17, right: data from A2 at Echt averaged over 5 test sections. Bottom: repeated measurements. Notice the trend in both graphs at medium to high frequencies where aging leads to reduction of sound.

7.2.1. Danish data

From the Danish data we selected to two surface types to show the spectral developments over time (see § A.3). Both are based on an SMA8 type, but the SMA8+ has a slightly porous surface resulting in an additional noise reduction of about 3 dB for LV's and about 1 dB for HV's in new condition.

The SMA8+ loses its acoustic performance three times quicker than SMA8 (0,9 vs. 0,3 dB/yr. for LV's and 0,3 vs 0,1 dB/yr. for HV's)

In the spectral distribution one can notice that the largest effects are found in the mid frequency range where for SMA8+ levels are rising strongly while SMA8 levels remains about the same. The lower and higher range exhibit less shift.

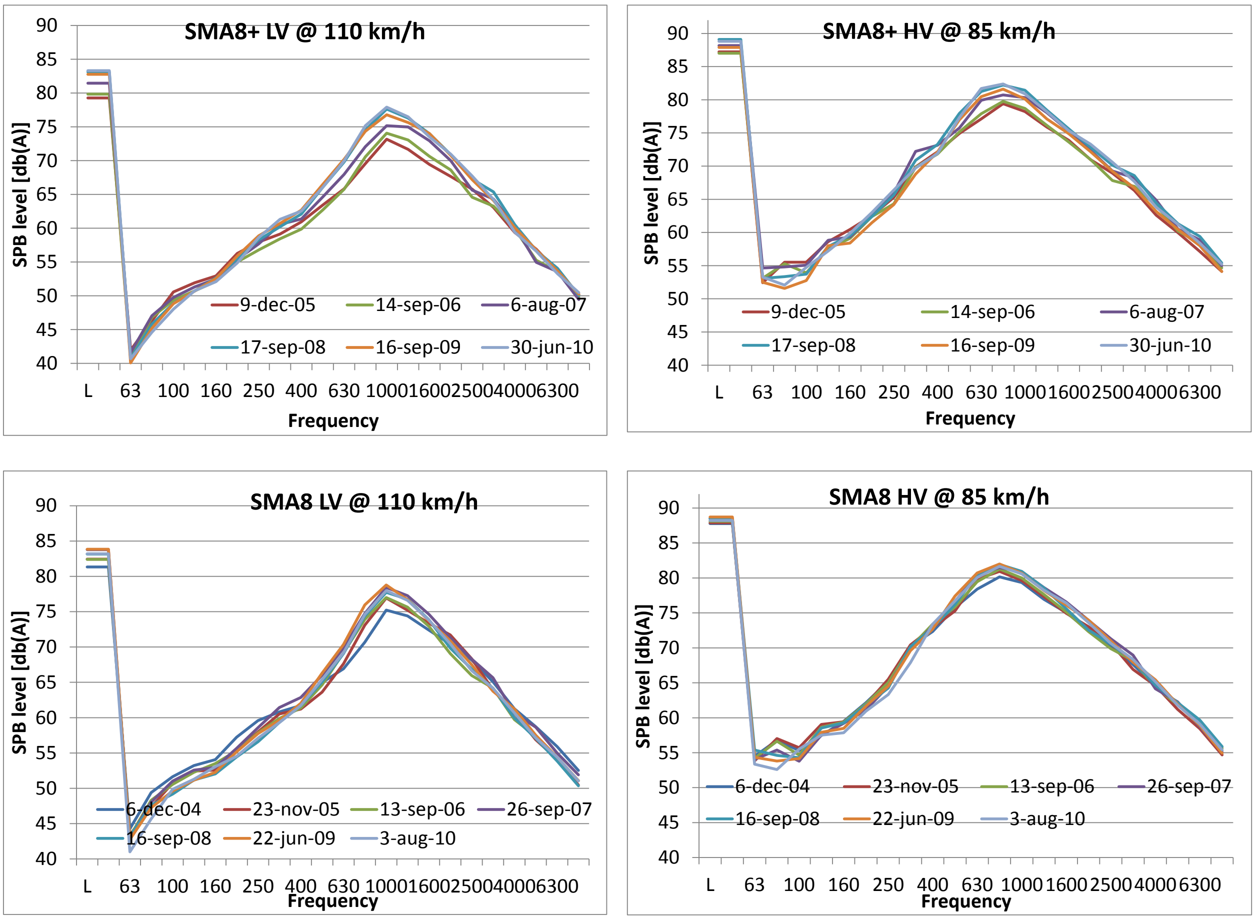


figure 23 Spectra for the Danish M10 testsections over a period of six years.Left: LV's, right: HV's. Top row: spectra for SMA8+, in the bottom row spectra for SMA8.

In figure 39 all data from the M10 sections are presented. From this the following can be noticed:

- The data for SMA6+ are similar to those of SMA8+ with the major effect around the mid frequencies.
- The data for AC11d show a more typical texture related effect, especially for LV's which manifests itself in the lower frequency range.
- Data for LV's on the TSL show after one year the characteristic spectral shift in the mid and high frequency, but after that a development similar to other road surfaces is observed. The overall level also shows a steep gradient in the first two years and after that a more moderate slope.
- Both LV's and truck data show a sudden level decrease of noise levels in the final test year. This is possibly an artefact that might be caused by insufficient correction of the levels for temperature.

8. Statistical Analysis

8.1. identification of multi parameter set

In parallel we pursued a quantitative statistical approach. Through this we developed a multi parameter model that can be used to predict the future performance of a specific road surface.

The data presented as a function of age in the graphs in chapter 3 exhibit quite a large spread. The 90% fraction of data points for a given age lie in a range of ±3dB. To be able to predict the future performance at a certain road section, a better accuracy is required. This is to be achieved by using additional parameters in the modelling of the aging effect.

From our survey of aging data and the possible causes of deterioration we have identified the following list of parameters that we will use in order to improve the quality of the final prediction model.

table XI List of parameters that is might be used to improve the prediction quality of the acoustic aging model.

1. type of surface	*SMA, 1 layer porous asphalt, 2-layer porous asphalt, TSL 6 or 8, brushed concrete, exposed aggregate, dense asphalt concrete*
2. type of road	*Highway, regional road, urban road, ..*
3. age	Years
4. initial value	The reduction value at t=0
5. traffic intensity	Number of vehicle passages (calculated as vehicle intensity times age)
6. heavy vehicle intensity	Number of heavy vehicles (calculated as heavy vehicle intensity times age)
7. location in Europe	Scandinavia (N, SE, SF), mid Europe (NL, F, UK, EIR, D, DK, PL, ..), Alpine region (CH, parts of AUT), South Europe (I, ES, P, ..)
8. manufacturer	The quality control and competences of the manufacturer influences the aging.
9. meteo conditions during building	Thin layers are vulnerable to cooling during laying, preventing compaction and there for quicker tone loss.
10. non-explained variance	There will be a residual variance, probably based on type of surface

Comment on proposed parameters:

1. Type of surface: the material and building process defines the aging behaviour. Dense surfaces where the granulate is bonded almost completely to the surrounding material exhibit stronger resistance against wear than open surfaces where the bonding is only partial. Therefor the surface type is a main parameter in the prediction of the acoustic performance over time.
2. Age: this is the main expected input parameter and an essential one in the planning of future maintenance.
3. Type of road: The relevance of the road type lies in the forces that are applied on the material, the expected dirt exposure and “vacuum clean” effect of passing vehicles. An urban road with frequent turning traffic will wear surfaces differently than a straight driven highway. A regional road may have agricultural traffic on it with dirty tyres, while traffic

speeds are too low to effectively clean the surface. Motorways exhibit high speed traffic, driving straight, with no agricultural vehicles.

4. Initial value: The graphs displayed above show that frequently the acoustic aging for the same surface type and for comparable road types are presented as parallel lines, meaning that the initial value defines the performance as a function of age.
5. Traffic intensity: As mechanical wear and clogging are assumed degradation factors, the source of this is most probably the passing of vehicles. A fair assumption is that the amount of wear is linear with the number of vehicles, indicating that cumulated traffic intensity is a relevant parameter.
6. Heavy vehicle intensity: From road engineering it is known that heavy vehicles impose large strains on the road surface. To be able to take this extra mechanical effect into account, the cumulated number of HV passages is added to the parameter list
7. Location in Europe: A clear proof of the relevance of this parameter is the distinction between Scandinavian and mid European conditions with respect to the use of studded tyres.
8. Manufacturer: As noise reducing surfaces are a sensitive product, it can be expected that the expertise of the manufacturer is of influence to the total lifetime. It is not yet clear how this parameter can be expressed in a prediction model.
9. Meteorological conditions: especially winter conditions are of great influence to the lifetime of a surface. Frequent freezing-thawing cycles cause large strain inside the material causing it to break suddenly. But also applying split and sand to keep skid resistance at level will cause effects on especially open surfaces.
10. Non-explained variation: It can be expected that even with a model that incorporates several parameters a significant fraction of the total variation cannot be explained. Aspects like compaction during laying, quality granular material and binder, specific usage of the road, exposure of the road to unexpected strain and stress will affect the aging, without the possibility to implement this in a prediction model. The existence of this is clearly demonstrated in the Dutch IPG project where 6 road building companies have, on four different locations, built a 2L-PA test section. Between locations we observed variations in aging, but also within a location and within the repeated products of the same building company.

8.2. ANOVA approach

Multi parameter regression can be done in different ways. For this project we have chosen the ANOVA approach since this approach not only selects the parameters in order of relevance but also take only the relevant parameters into account in the analysis and supplies information on the relative relevance of the selected parameters.

The predicted level is defined by a linear addition of the selected parameters P_n multiplied with a specific coefficient C_n. Added to this we include the residual error R which is actually a random figure with a standard deviation R:

$$L_{predicted} = C_0 + C_1.P_1 + C_2.P_2 + C_3.P_3 + C_4.P_4 + \cdots + Res \quad (1)$$

ANOVA supplies for each parameter the best fitting coefficient and the significance of this parameter, indicated with a p value. In the selection of relevant parameters, only parameters with a p-value < 0,05 are considered significant and therefore taken into account.

The quality of the total multi-parameter regression fit is defined by the R^2 giving the percentage of the total variance in the data set that is explained by the multi-parameter model. The quality of the prediction model is reflected in the residual variation, being the standard deviation of the actual data around the best fitting function.

Although Section 8.1 identifies a large number of parameters, only parameters that can be expressed as a quantitative unit can be used, since these parameters shall be part of a mathematical formula. Things like experience of the builder are hard to use, unless there is a way to express experience on a scale from 0 to 10. The same is true for area in Europe or for environmental condition.

A multi parameter analysis can only be applied when the data set is large enough. A too small data set will not be able to define the relevance of the secondary parameters since statistical error will deem them no- significant. Therefore we have applied the ANOVA method to the Dutch IPG data base only covering 1L-PAC0/16, 2L-PAC4/8 and 2/6 and TSL6 on highways. A relevant limitation in the project approach is that all acoustic data only refer to the right lane. All road usage data however applies to the total of all lanes. To compare only 2x2 roads is then not a problem but if 2x2 and 2x3 type of roads are mixed will this cause errors. Fortunately, the IPG data set only refers to the 2x2 situation.
We have applied this technique for a series of the Dutch Data set and have used the following parameters:

1. P_1: the initial value of that specific surface.
2. P_2: the age in years.
3. P_3: the total amount of heavy vehicle passages [$\cdot 10^6$ passages].
4. P_4: the total amount of all vehicle passages [$\cdot 10^6$ passages].

In none of the data sets was P_4 found to be relevant. So our overview of results only applied to P_1 to P_3. Results of the ANOVA analysis for three types of road surfaces and the two main vehicle categories LVs and HVs are given in the table below (table XII).

table XII : Results of multiple parameter analysis of acoustic road surface performance. The passage level for LV's at 110 km/h and for HV's at 80 km/h is given by formula (1). The coefficients including the residue are given here.

	C_0 [dB]	C_1 initial value [dB]	C_2 age [yr]	C_3 totalHVpassages(*10^6)	Res: Residue [dB]	R^2
TSL lv	26,7	0,64	0,31	0,05	0,65	0,425
TSL hv **	81,4	-	0,41	-	0,37	-
1L-PAC lv	75,5	-	0,15	0,46	0,66	0,791
1L-PAC hv **	81,0	-	0,20	-	4,1	-
2L PAC lv	-0,9	1.01	0,43	-0,03	0,58	0,724
2L PAC hv	78,8	-	0,14	0,09	1,34	0,242

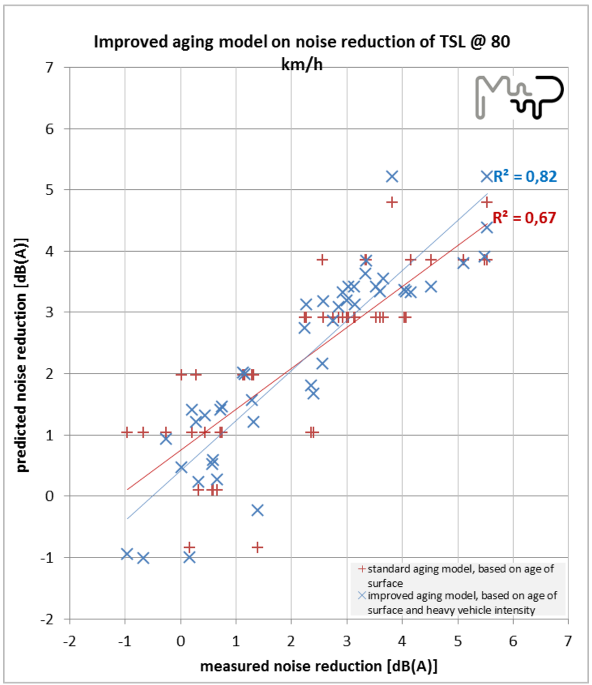


figure 24 Improvement of prediction model for TSL6 LV's when HV intensity is included.

8.3. Discussion of Multi Parameter Analysis

Multi parameter analysis is an excellent tool for trying to explain a spread in data on the basis of several parameters. It is therefore used frequently in all kind of statistical studies. The main limitation of the multi parameter analysis we are confronted with in this study is the fact that this analysis requires parameters to be independent. This is not really the case in the analysis performed here. One can argue that the fixed constant C_0 and the parameter “initial value” are strongly related. This is reflected in the fact that C_0 and C_1 seem to be connected. In a few cases C_0 is low and C_1 is high, in other cases the reverse is true. Also the parameters ”age” and “total HV passages” exhibits a strong relation as can be understood from the fact that with increasing age also the number of HV passages will increase.

The spread in acoustic performance for HV's on TSL and on 1L-PAC could not be explained by any of the parameters. The graphs in figure 1 right column, for 1L-PAC and for TSL display a trend on base of time, but this relation is too weak to be judged “significant” by statistical mores.

Still one can remark the following general properties:

1. for LV's the initial value is very relevant for the future performance of the road surface. A surface that is low noise when new maintains this property over its life time. This can be observed in figure 19 where the parallel trendlines indicate this effect.
2. for LV's the explaining power of the model is rather good. By using the designated parameters and coefficients a 90% uncertainty of ±1 dB is achieved.
3. for HV's the number of data points and the spread is such that it turned out to be very hard to conclude statistical significant trends. Only for 2-L PAC was a clear age relation found of 0,14 dB/yr but a residual variation of 1,3 dB was still left, indicating a 90% uncertainty of +/-2 dB. For 1L-PAC and TSL no significant relation with age or any

other parameter could be established. Such behaviour can also noticed from the BASt data for HV's where slopes vary between +0,2 and -0,3 dB/yr.

4. the statistical significance of the effect of HV passages is weak. The explaining power of this parameter was found to be low. This is in contrast to other findings:
    a. The survey of TSL6 on regional roads where we found that the aging was significantly influenced by HV passages
    b. The clear distinction between the acoustic performance of slow lanes versus fast lanes. The Bavarian data for DSH5 on German autobahn (see figure 9) reveals consistently such distinction. Also data found in the Netherlands and Spain corroborates these findings (see figure 14 and figure 15).

A further limitation in the interpretation of the analysis results is that in the majority of the cases the acoustic performance refers to the slow lane while the traffic data refers to the overall traffic over all lanes. If the number of HV passages is taken as the explaining parameter, then a closer relation between the traffic data on the slow lane and the reported figure 9acoustic data can be assumed.

9. Discussion

9.1. Causes of aging based on spectral shifts

Identification of the acoustic deterioration processes of road surfaces is based on the changing spectral compositions over time. Unfortunately spectral data were not available in all cases. However the Danish, Spanish and Dutch data sets comprised rather complete data sets of systematic repetitions of measurements over time. The Dutch data sets only cover a limited number of surface types, but with extensive reproducibility of the same types applied at different locations and by different manufacturers. Danish data sets covered a wider range of surface types but only on a few locations. Spanish data fell inbetween, with a few types on a few locations, but these are relevant since they are subjected to totally different climate conditions.

The overall impression is that the type of wear process is characteristic for specific surfaces. In the analysis one has to distinguish between LV's and HV's since the effect of the road surface on these two tyre types is very different. In the first approximation, car tyres are more sensitive to surface texture effects than truck tyres. The effect of acoustic absorption for LV's and truck tyres is about equal, although the effect of spectral shifts in absorption spectra does affect car tyres noise more strongly than truck tyre noise.

One must bear in mind that truck tyres are not a single type, but there exists a mix of steer and trailer tyres, with rather smooth tread patterns and traction tyres with much coarser patterns.

1. For LV's:
   a. Porous surfaces are found to lose their acoustic absorption over time, possibly due to filling up of the open pores from below. This is reflected in the gradual decrease of the "absorption dip" in the pass-by spectra. At low and high frequency where respectively texture degradation and increase of flow resistivity are observed, lesser shifts were found in the data sets. This process is clearly present for 1L-PAC surfaces and lesser for 2L-PAC.
   b. For 2L-PAC one can observe an effect of increasing texture, probably due to stone loss.
   c. Semi-porous surfaces such as TSL are found to mainly lose their pressure release performance by increasing flow resistance. This is reflected spectrally in the increase at high frequencies (see figure 35 left). Although in some cases a process is observed that reflects texture worsening and possibly some absorption loss. (see figure 35 right).
   d. Dense texture optimized surfaces lose their performance mainly in the middle and lower spectral range where texture related effects are expected. Also the fine graded 2L-PAC surfaces with 2/6 top layer distinctly lose their performance both in the texture related spectral range and in the flow resistance related range (see figure 31).
2. For HV's the effect of wear can be very different.
   a. For porous surfaces the loss of acoustic absorption can also be noticed in the HV spectra. For 2L-PAC the spectral differences due to this effect are clearer than for LV's (compare figure 29 top row withfigure 30 top row).
   b. For 1L-PAC an interesting spectral shift is noticed. Over time the levels in the mid frequency range increase as might be expected by the filling up process. At high

frequency though, a significant decrease in levels is observed over time. This effect is found at several test locations (see figure 20, right and figure 22).

c. Dutch TSL6 data display behaviour over time similar to that of LV's is found. For the A6-Emmeloord surfaces a process like that for the 1L-PAC is seen, namely a decrease of sound level at high frequencies over time. No explanation can be given to this.

d. Data for Danish test surfaces of the dense and semi dense type do not show such explicit spectral aging characteristics. Effects are distributed over the mid frequency range from about 400 to 2 000 Hz. No specific mechanism can be attributed to it. It will most probably be a combination of loss of porosity and slightly worsened texture.

3. For the study of the aging processes of dense surfaces only limited spectral data is available. Since the surface is dense and not permeable, only texture effects and, to a limited extent, flow resistivity effects may occur. The Danish DAC11 and SMA8 data do not clearly indicate such processes, but seem to present a mixture and also even some effects due to shifts in texture spectra.

4. Concrete surfaces present a special case. Their surfaces properties are hardly changing over time and end of service life is caused by failure of the foundation and cracking of the surface. The data sets from France and UK corroborate this estimation, with yearly losses of about 0,1 dB/yr for brushed concrete and exposed aggregate.

9.2. Magnitude of aging effects.

The data concerning the overall loss of acoustic performance of road surfaces differ widely. For LV's slopes between about 0 dB/yr up to 5 dB/yr were reported for individual surfaces. The worst aging effects are found in Scandinavia where the service life of some noise reducing surfaces is only one year before it has to be removed because of serious damage.

If we exclude the north European data (i.e. N, SE and SF) from the middle and southern European data variation decreases, but still maxima of 1 dB/yr are reported for LV's. For HV's aging is in first approximation, about one half of that of LV's, but again with much variation in individual cases.

Ranking of road surface types on the basis of the speed of aging leads to the following listing (see table XIII). Assumed are highway conditions or straight regional roads without agricultural traffic.

table XIII ranking of road surface types with respect to amount of yearly loss of acoustic performance. Rank #1 is lowest performance loss; values of yearly loss are estimated on base of mid and south-European data. Assumed are Highway conditions.

rank	Road surface type	loss of acoustic performance dB/yr. LV's	HV's
1	Brushed and exposed aggregate concrete surfaces	0,1	0,1
2	SMA 11 and SMA16 surfaces	0,15	0,1
3	ACSURF11 and ACSURF16	0,2	0,1
4	ACSURF8, SMA8 and SMA6	0,2	0,1
5	2L-PAC8	0,4	0,3
6	1L-PAC8 to 1L-PAC16	0,5	0,3
7	TSL6	0,7	0,5

9.3. *Influence of usage and environmental parameters.*

The data presented in this study show that even for the same surface aging effects vary strongly. As an example of the observed variation, the following values are presented:

- Graphs of 2L-PAC8 under Dutch highway conditions show slopes varying between 0,2 and 0,6 dB/yr for LV's
- German data for 1L-PAC8 vary between 0,1 and 0,5 dB/yr for LV'sand for HV's: between 0,2 and -0,3 dB/yr.
- UK data for SMA10 vary between 0,4 and 0,6 dB for LV's and 0,3 to 0,4 dB/yr for HV's.

We have tried to identify external factors that may explain such variation on the basis of the usage of the road, the type of road and climatic conditions. As already noticed, the Scandinavian conditions have a strong effect on the wear and explains why Scandinavian data deviate from middle and southern European data. But after excluding Scandinavian data significant variation still remains.

We identified influencing parameters and applied multi parameter analysis on the data set in order to improve the prediction of aging. As already discussed in §8.3 age and initial value were identified as significant explaining parameters to predict age related acoustic performance. Surprisingly, for HV's age was a lesser important parameter. Only for HV's on 2L-PAC significance could be demonstrated of the parameter "age".

The following relations between performance and parameters are estimated.

table XIV   ranking of parameters influencing the acoustic aging of road surfaces

Influencing parameter	Vehicle type	
	LV's	**HV's**
Type of surface	strong	strong
Age	strong	weak to medium
Climatic zone	medium	weak
Type of road	medium	medium
Initial value	strong	medium
Traffic intensity	weak	weak
HV intensity	strong?	weak?

Below the parameters will be discussed.

9.3.1. *Surface type*

Clearly surface type is a relevant parameter for describing the aging of acoustic performance for both LV's and HV's. First the durability of the acoustic performance varies strongly over surface types. Some types show almost no change over time, while others degrade more quickly (see table XIII). In addition the adverse effect of high HV intensities on the velocity of aging differs between surface types. 2L-PAC is less affected by HV's passages than 1L-PAC (see table XII).

However, even within a certain surface type large variations in acoustic deterioration over time is observed, between countries, between locations in the same country and even betweensections on the same location.

9.3.2. Age

The influence of age on the acoustic performance of road surfaces was found to be not so straightforward. For most surface types there is a clear relationship between the acoustic performance for LV's and the age of the surface. For coarser surfaces such as 1L-PAC and SMA11 and for surfaces that already exhibit low aging effects such as concrete, the relation with age becomes much weaker.

For heavy vehicles relationships with age were very hard to observe in general. Danish data show only minor age relationships in the acoustic performance for almost all surfaces, German 1L-PAC exhibit on average nearly no age relationship (0,06 with a spread of 0,2 dB/yr). The French data base also show minor average trends with large individual spreads for nearly all surface types. English data for nearly all surfaces is inconclusive. A trendline can be calculated by the uncertainty in the slope is as large as the slope itself. The multi parameter testing of Dutch data only leads to significance of the parameter "age" in the case of 2L-PAC8.

9.3.3. Climatic zone

The effect of harsh winter conditions as occur in Scandinavia (N, SE,SF) is undisputed, although the effect is mainly indirect. The effect of the conditions itself is not clear since the main cause of the much quicker aging of surfaces in Scandinavia compared to mainland Europe comes from the extensive use of studded tyres in wintertime.

We observed that deterioration of acoustic quality of surfaces in Denmark is on average slightly larger than that of similar surfaces in NL, F or ES (see table X and chapter 3). Although the cause of this cannot be linked to certain aging processes in the road surface, it may lead to the conclusion that the more frequent freezing/thawing cycles in DK may cause quicker aging than the more moderate conditions in F and ES.

9.3.4. Type of road

The road type, urban, regional or highway, is closely related to vehicle intensity and HV intensity and thus part of the road type effect will be addressed by those parameters. In addition the road type will affect the driving behaviour and vehicle types. Urban roads are known for their frequent turning vehicles. In particular, turning HV's will apply tangential forces to the road that are known to destroy especially porous and semi porous surfaces.

Regional roads are open to agricultural vehicles that will bring loose material from the land to the road. Again it is the porous and semi-porous surfaces that will lose their acoustic performance due to clogging.

The effect of road type cannot however be modelled since no quantitative data on turning operations and the occurrence of agricultural vehicles is known.

9.3.5. Traffic intensity

Traffic intensity was not observed to be of any relevance. We found no indications that when HV intensity is taken into account, overall intensity is to be considered a significant factor.

9.3.6. Heavy vehicle intensity

The effect of heavy vehicles on the aging of road surfaces is found only to be statistically significant in the case of 2L-PAC8 when applying multi parameter analysis on the data sets. For other surfaces coefficients could be calculated but proof of statistical significance failed.

One notices however several other clues indicating that HV intensity have to be taken into account when understanding acoustic aging.

- Results from a survey of TSL6 surfaces on regional roads displays a clear relation between HV intensity and loss of noise reducing capabilities (see figure 25)
- The observation that middle and fast lanes of highways consistently perform better than slow lanes (see §3.9 and data in Annex A). Even in the case when such behaviour is absent (figure 14 bottom) it can be explained by the routing of HV's.
- HV intensity was found to be a significant parameter in the ANOVA analysis of 2L-PAC data and of TSL6 data (see figure 24) .

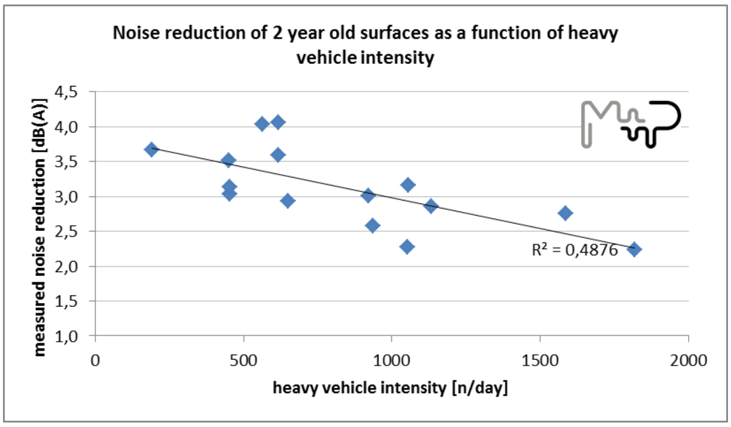


figure 25 Result of a survey of TSL6 surfaces on regional roads. Presented is the amount of noise reduction (relative to ACSURF11) as function of the HV intensity of that road. One observes a clear negative effect due to higher HV intensity.

9.3.7. Initial value

In the case of LV's on TSL6 and 2L-PAC8 the analysis revealed that the initial value is a main factor to explain the variation. In case of 2L-PAC8 the coefficient on 1,0 indicate that the initial value has to be taken into account for 100% meaning that a 2 dB lower initial value leads to a 2 dB lower value over its entire life time. For TSL6 the factor is still 0,64.

Such large coefficients indicate that the performance of different surfaces over time can be described as nearly parallel functions when plotting age related performances of different surfaces (see figure 27). The 2L-PAC data from Spain (figure 40) and the German 1L-PAC8 data in figure 37 show a similar behaviour.

For HV's the significance of the initial value is found to be lower (compare for instance data right and left in figure 37). This is reflected in the ANOVA results in table XII that do not present any significance of initial values in the case of HV's and in the case of 1L-PAC16.

9.3.8. Manufacturers' expertise

Loss of acoustic performance of low noise surfaces can be traced back to the deterioration of surface materials. The amount of deterioration depends of course on the vulnerability of the material and the external forces and influences on this material. However some materials can withstand such negative influences better than other materials. Such variation can be explained by the experience of the manufacturer. The mechanical properties of a specific road material are the sum of the properties of the ingredients and the properties of the building process. The building company can influence both in order to produce the optimal product. The graphs below illustrate the difference between two manufacturers.

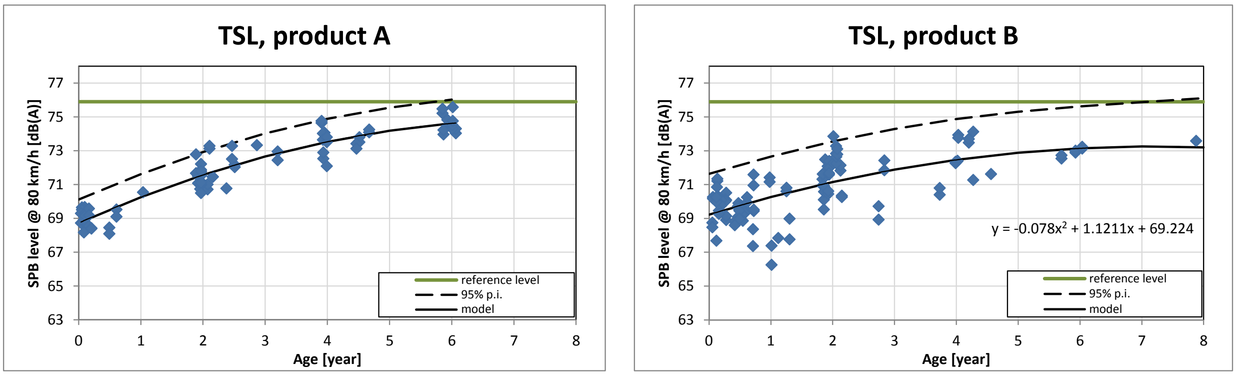


figure 26 Results of age related noise reduction of two TSL6 products. Product B performs significantly better than A although both have the same initial value.

However, from the Dutch 2L-PAC8 data from repeated tests of the same surface at different locations no manufacturers influence could be detected but this is possibly shielded by the location effect.

9.3.9. Unknown influencing parameters

The multi parameter analysis was able to identify some parameters to explain the observed variation, but was unable to explain all variations. In fact for HV's on 1L-PAC and TSL6 almost no improvement could be obtained from adding parameters.

A factor found to be relevant is the road design. The excellent performance of 2L-PAC8 on A28 Staphorst relative to the performance of the same surface types on the A30 near Ede seem to be in contradiction with the traffic situation. The A28 is a busy freight route to the North, while the A30 is a less busy connecting route. Observation on the spot revealed that the drainage of water from the surface was better facilitated on the A28 than on the A30.

Most certainly, such design properties also attribute to the variation found at other locations.

9.4. Overall discussion

In this study a very large data set is used to understand the processes behind the changes in acoustic performance caused by aging of the surface. The observed variations in the actual changes in performance were large and attempts to explain the variation based on objective criteria and parameters were partly successful. In several cases, especially for HV performance, still a significant fraction remained unexplained.

We identified local circumstances and manufacturers expertise as possible causes for this still unexplained variation, although we have difficulty in understanding the reason why the remaining variability is larger for HV's than for LV's.

A complicating factor when comparing data over a long period, is that the measurement instrument is not stable. In case of CPX measurements, the changing quality of the tyre over time will affect aging results. Even when the tyre is renewed regularly such effects may occur since tyre technology gradually shifts.

When using SPB data the comparison over time does assume a constant noise emission of the vehicle fleet over time. Several studies revealed that small but gradual shifts in vehicle sound emission characteristics occur. For instance, between 1997 and 2010 the Dutch vehicle fleet of LV's became about 1 dB louder around 100 km/h. A perfectly stable surface would be regarded as having lost 1 dB of performance because of this effect.

However the observed effects are, in general, much larger then this sift of less then 0,1 dB/yr, so it is neglected.

10. Model and conclusions

10.1. Model

The majority of the data studied in this Work Package showed that in first approximation the aging of the acoustic performance (defined in terms of a reduction relative to a reference noise level) of a road surface can be described by a linear function of the form:

$$\Delta L_{reduction} = C_0 + C_1.P_1 + C_2.P_2 + C_3.P_3 \quad (2)$$

with:
C_0: average initial noise reduction level
C_1: coefficient 1(average age effect [dB/yr]
P_1: age [yr]
C_2: coefficient 2 (effect of specific initial level)
P_2: specific initial noise level-average initial noise level [dB]
C_3: coefficient 3 (effect of heavy vehicle passages)
P_3:total number of heavy vehicle passages[$*10^6$]

The coefficients are derived on base of the Dutch IPG data for 1L-PAC16, 2L-PAC8 and TSL6 and refer to highway usage (LV@110 km/h, HV@90 km/h). Coefficients are defined separately for LV's and for HV's. Reference level is an age averaged ACSURF16.

table XV Coefficients for equation (2) for three types of surfaces. Noise reduction is defined relative to ACSURF16 and negative value indicates lower pass-by level than on reference surface. Values refer to LV@110 km/h and HV@90 km/h.

coefficient	**1L-PAC16**		**2L-PAC8**		**TSL6**	
	LV	**HV**	**LV**	**HV**	**LV**	**HV**
C_0	-3,9	-4,5	-6,7	-6,5	-5,8	-3,0
C_1	0,15	0,20	0,43	0,14	0,31	0,41
C_2	-	-	1,0	-	0,6	-
C_3	0,46	-	-0,03	0,09	0,05	-

The linear model is a fair approximation of the age relation for *middle and southern European road surfaces*. One can argue that in the case for TSL's a power law is better, but that is only the situation where clogging of the pores is the main process. Once texture degradation occurs an asymptotic behaviour is less realistic and more or less gradual increase of noise will probably be observed.

For Scandinavian conditions almost all data indicate a power law with a quick loss of reducing capabilities in the beginning and gradual loss at later ages.

10.2. Conclusions

1. This study has collected repeated noise measurements from several areas in Europe and from a wide range of surfaces.
2. This study has observed a wide variation of age effects between different surface types, ranging from almost no effect up to 5 dB/yr.

3. A large part of the variation can be explained by climatic conditions. The separation between the data sets of Scandinavia (N, SE, SF) and the set based on mainland Europe data resulted in a significant lower variability within a set.
4. Further explanation was found in the type of surface. Concrete surfaces showing the smallest age effect, TSL's presenting the stronger effects.
5. Next vehicle type was found to be relevant. Aging due to HV's was in general about half of the aging due to LV's.
6. Within a surface type age related loss of acoustic performance may vary with about a factor 2.
7. Attempts to explain this inter-type variability were only partially successful. We found an effect of the number of HV passages, but the observed correction was minor. This was found to be inconsistent with the results of dedicated measurements on separate lanes on a highway, where much larger effects, of the order of 1 to 2 dB, were observed. It is our opinion that these differences are caused mainly by the lower HV intensity on middle and fast lanes.
8. The initial value was found to be a relevant factor. The quieter the surface is initially, the better its performance over the lifetime.
9. The processes underlying the loss of acoustic performance were identified by means of the spectral shifts that were recorded during service life. For TSL, clogging of the pores is the main cause. For porous surfaces the performance loss can be explained by assuming filling up of the porous layer while still remaining open on top. For the fine graded top layer with 2/6 grading additional texture deterioration was indicated from the spectral shifts. This could most probably caused by stone loss.
10. Apart from the large differences between aging under Scandinavian and mid and southern Europe conditions, we observed slightly larger aging effects in DK and UK data compared to those of the same surfaces in NL, B, D, F and ES data. For DK data the harsher winter conditions might explain that, but for the UK data no cause could be found.
11. The model developed is able to explain a part of the observed variation, but we acknowledge that a significant part is still unexplained. Effects like the expertise of the road builder, the climatic conditions, the design of the road, etc… are of major influence to the actual acoustic performance of the road.
12. For a reliable prediction of the expected service life of a road surface, additional measurement information is found to be essential. Both the initial value and the value after 3-5 years is required. Not having these data decreases the accuracy of the end-of-service life prediction significantly.

11. Acknowledgements

The authors gratefully acknowledge the valuable contribution from several institutes to supply the data for this study. Sintef (Mr. T.Berge) and the Norwegian Road directorate in Norway, VTI (Mr. U.Sandberg) in Sweden, Finish road directorate, the IFFSTAR (Mrs. F.Anfossoo) and SETRA from France, the Spanish road directorate CEDEX (Mrs. L.Parra), the Danish Road Directorate (Mr. J.Kragh), The German BASt (Mr. W.Bartolomaeus) and the UK Highway agency.

This study is performed under the Cross-border funded Transnational Research Programme CEDR call 2012: “Noise: Integrating strategic noise management into the operation and maintenance of national road networks”. The program is funded by Belgium/Flanders, Germany, Ireland, Norway, Sweden and United Kingdom. The authors gratefully acknowledge their financial contribution and the valuable technical and scientific support.

12. References

[1] “STØJDÆMPNING OVER LANG TID”, Danish Road Directorate, Status report 2010, Hbe/8-2-2013
[2] “Studie van de akoestische kwaliteit van stille deklagen en dubbel-laags zeer open asfalt”,T. Vercauteren, Master Thesis, University of Antwerp, Faculty of Applied Engineering Sciences, 2013-2014
[3] “ACOUSTIC AGING OF PAVEMENT DVS-DRD Joint research Program – Super Silent Traffic”, J.Kragh et al., December 14, 2012. DRD-09/16007-8
[4] “Study of long term monitoring of Gelderland road surfaces”, F.Reinink et al, report M+P.PWG.(in progress),
[5] Groupe Bruit du GNCDS, “Diffusion de la base de données « bruit de roulement »,Institut Des Routes, des Rues et des Infrastructures pour la Mobilité” N°5 dated: May, 2011.
[6] A.Kuosmanen, “WP.2.1: Performance, maintenance and materials of low noise surfaces under winter conditions”, QUESTIM. March 2014

ANNEX: OVERVIEW OF AVAILABLE DATA FOR THE STUDY

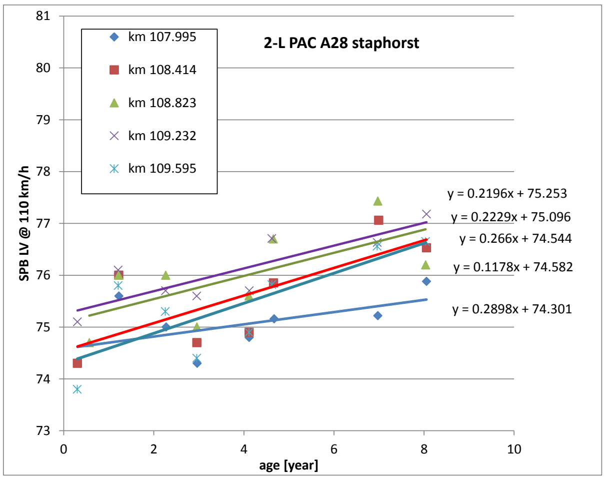
A1. Dutch Highway Data

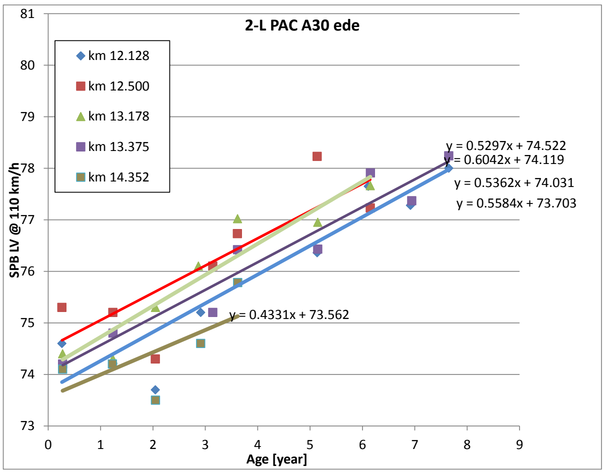
Within the framework of the Dutch IPG project 2L-PAC was studied with the objective to determine the feasibility to use it on a wider scale on Dutch highways. In addition, the alternatives 1L PAC 0/16 and TSL 0/6 were also studied.

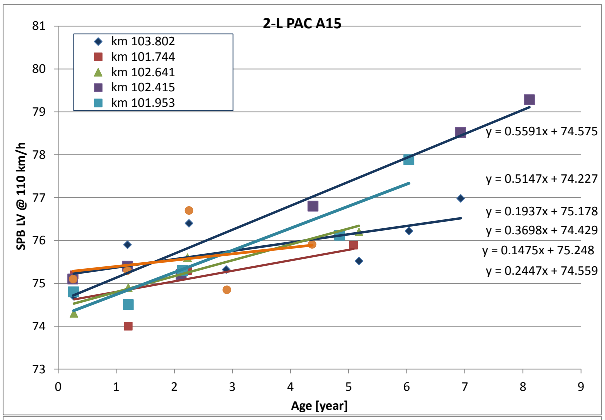
These data sets generated extensive information for the QUESTIM study, so we have analysed this data into great detail.

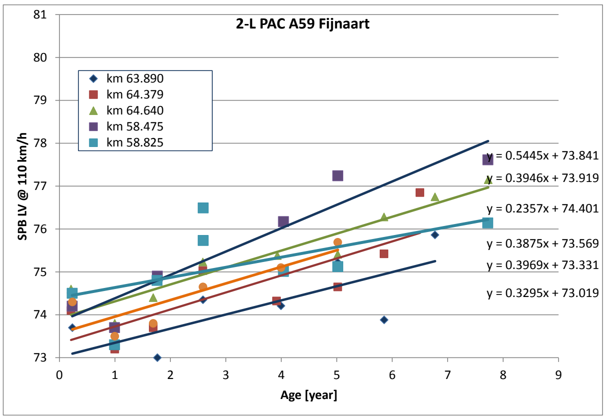
A1.1 Overview of 2L-PAC8data sets for LV's and HV's

LV's









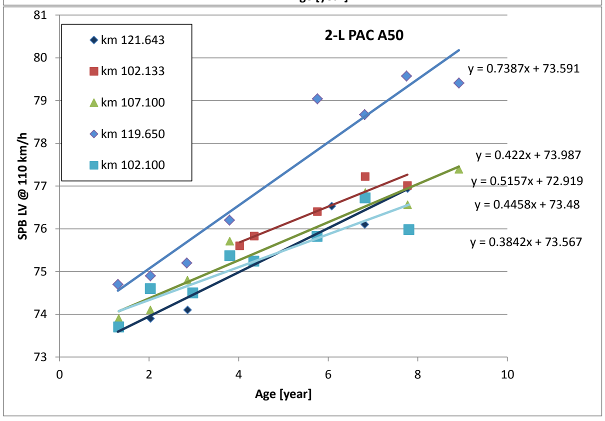
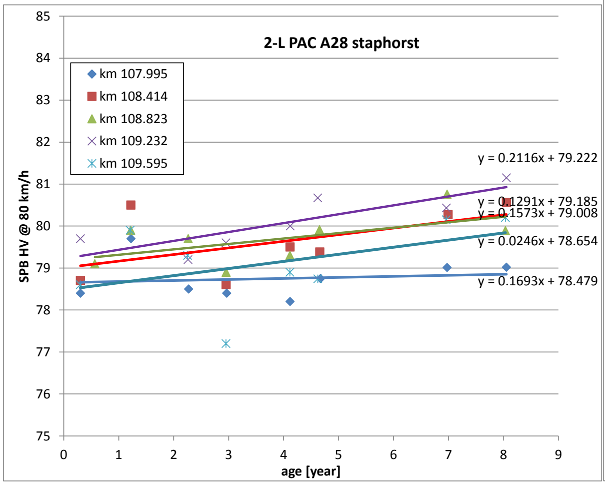
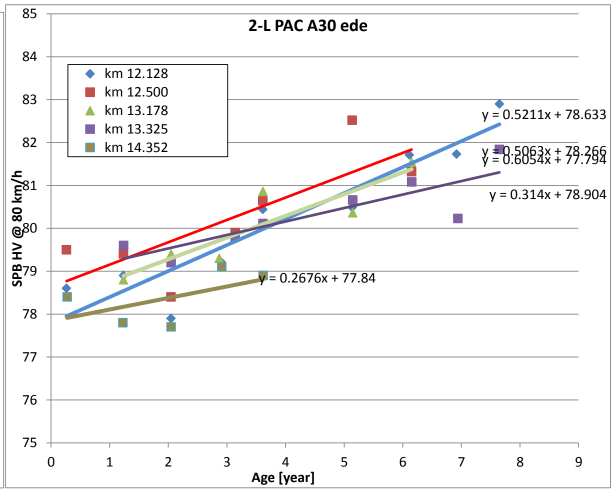


figure 27 *Measurement data (SPB @ 5 m, LV @110 km/h). for several test locations of 2L-PAC in the Netherlands. Each location comprised up to 6 4/8-11/16 sections and 2 2/6-11/16 sections.*

HV's





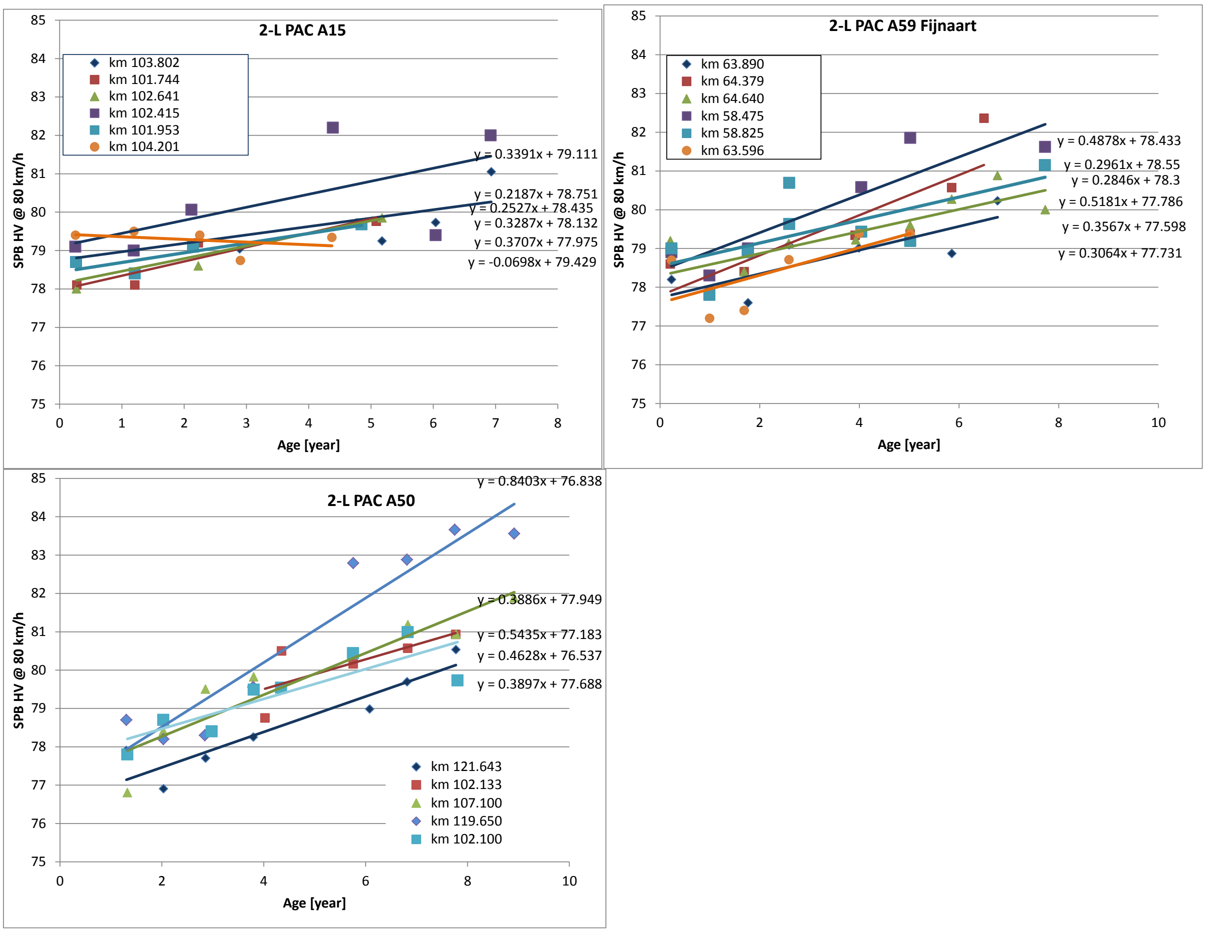


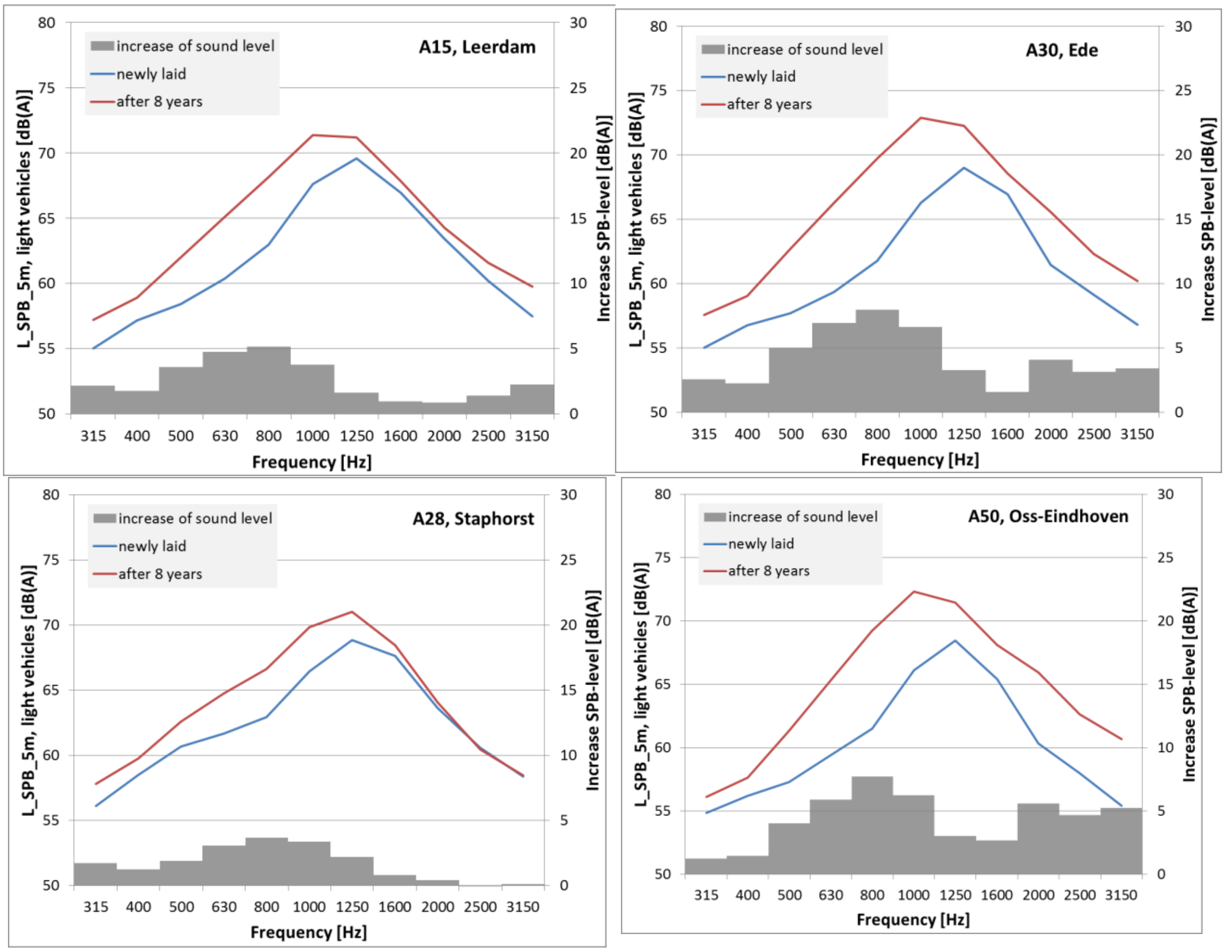
figure 28 Measurement data (SPB @ 5 m, HV @80 km/h). for several test locations of 2L-PAC in the Netherlands. Each location comprised up to 6 4/8-11/16 sections and 2 2/6-11/16 sections.

A1.2 Spectral data for 2L-PAC8LV's and HV's

LV's

The presented spectra are a result of a linear regression analysis of the SPB-results as a function of time. On each test section SPB-measurements are performed annually (from 0 – 8 years after laying).

An average spectrum shortly after laying and a spectrum after eight years is presented. The increase of the SPB-levels for each third-octave band is presented on the y-axis on the right.



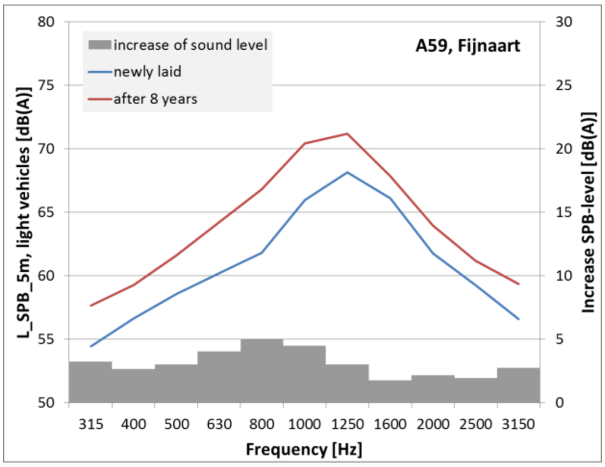
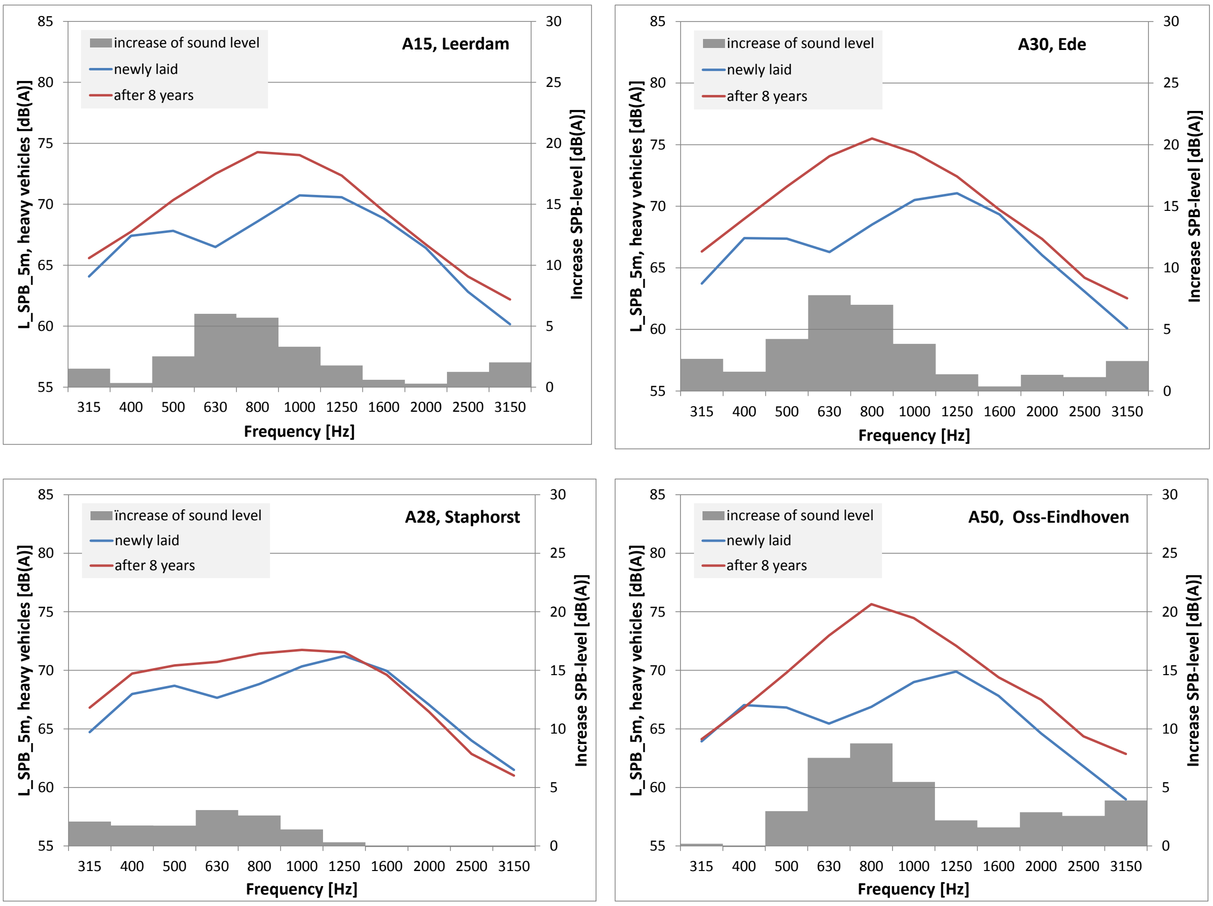


figure 29 SPB data @5m for LV's @110 km/h. Spectral trends averaged over test sections on a specific test location.

HV's

The presented spectra are a result of a linear regression analysis of the SPB-results as a function of time. On each test section SPB-measurements are performed annually (from 0 – 8 years after laying).

An average spectrum shortly after laying and a spectrum after eight years is presented. The increase of the SPB-levels for each third-octave band is presented on the y-axis on the right.



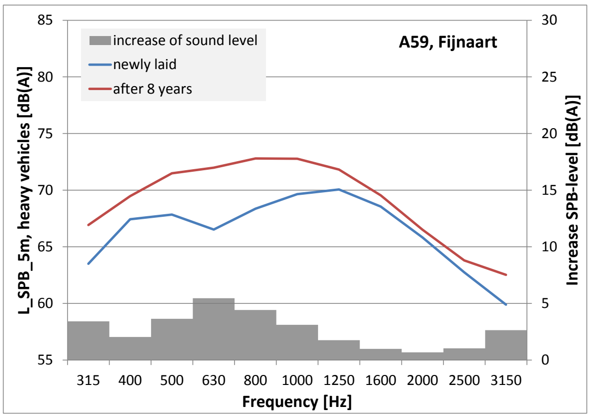


figure 30 SPB data @5m for HV's @80 km/h. Spectral trends averaged over test sections on a specific test location.

A1.3 Spectral data for 2L-PAC6,LV's and HV's

LV's

The presented spectra are a result of a linear regression analysis of the SPB-results as a function of time. On each test section SPB-measurements are performed annually (from 0 – 8 years after laying)

An average spectrum shortly after laying and a spectrum after eight years is presented. The increase of the SPB-levels for each third-octave band is presented on the y-axis on the right. The test sections on the location Staphorst (A28) are replaced six years after laying.

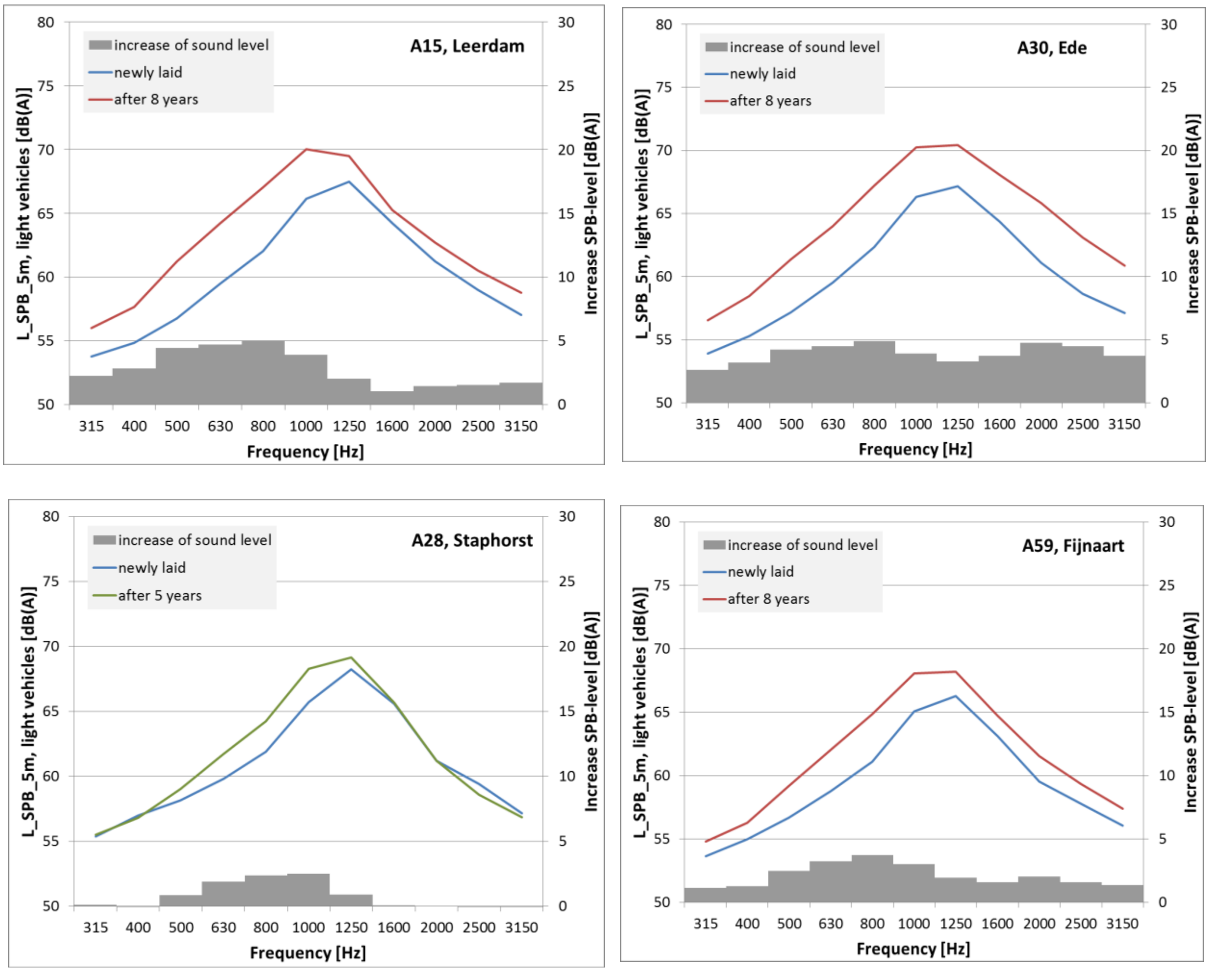


figure 31 SPB data @5m for LV's @110 km/h. Spectral trends averaged over test sections on a specific test location. Test surface 2L-PAC with 2/6 top layer. Note: A28 sections measured until 5 years.

HV's

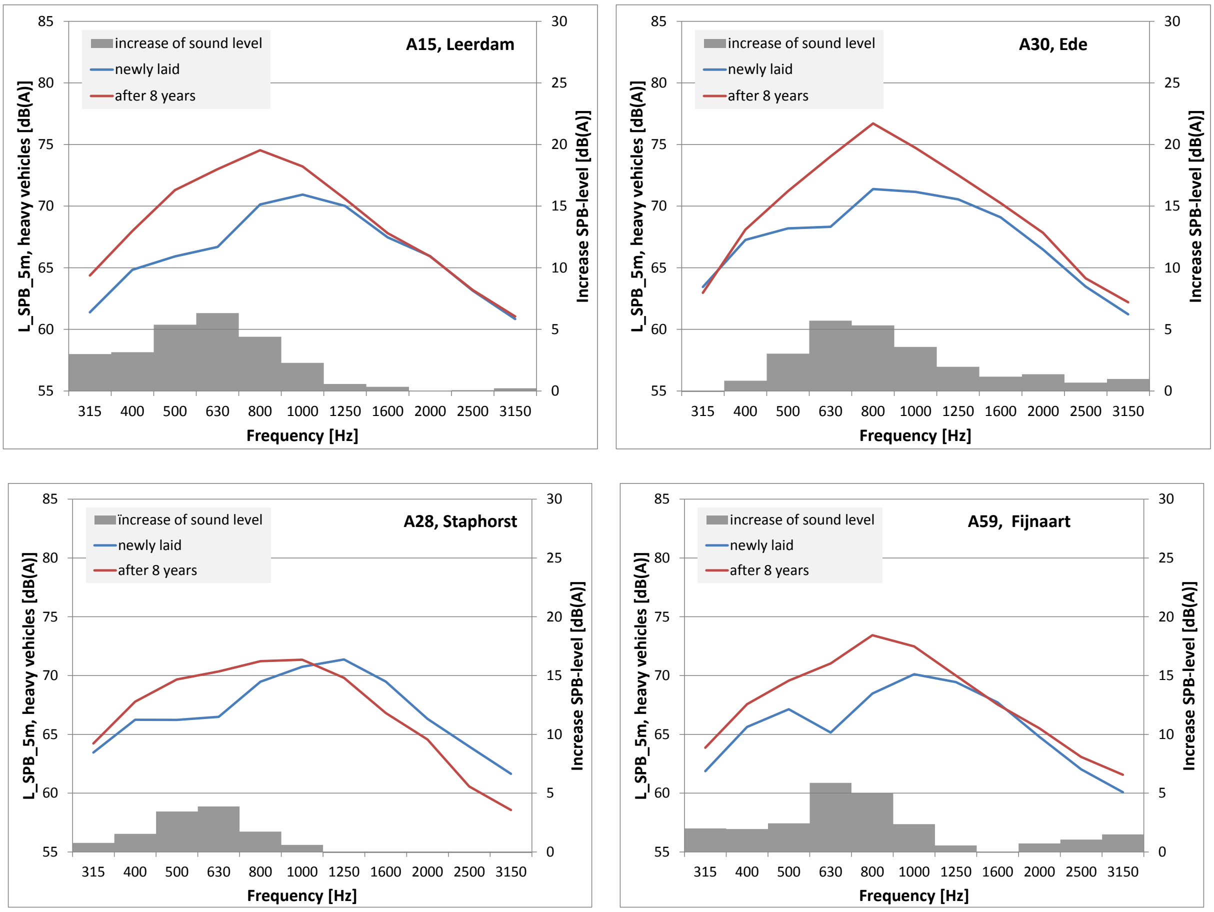
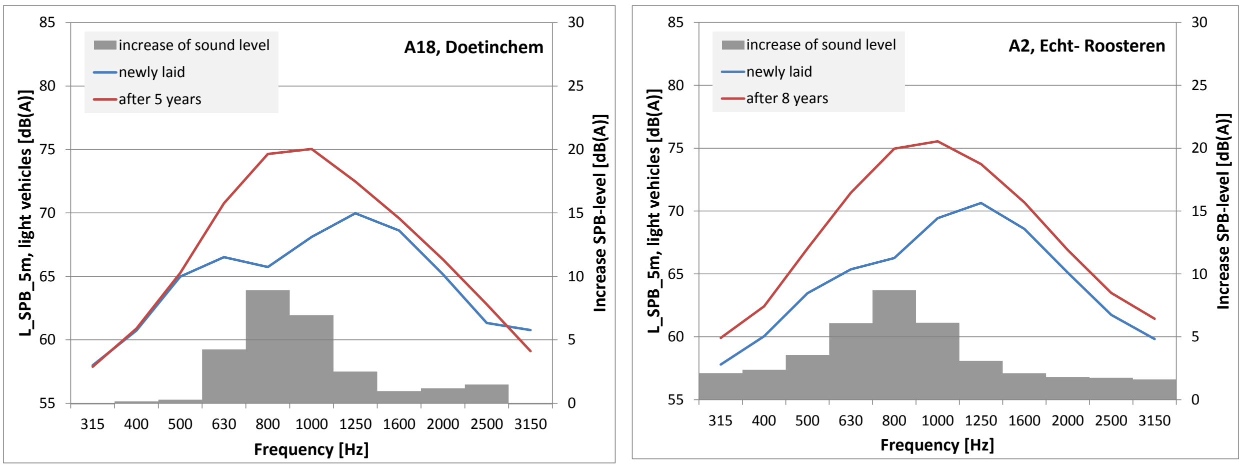
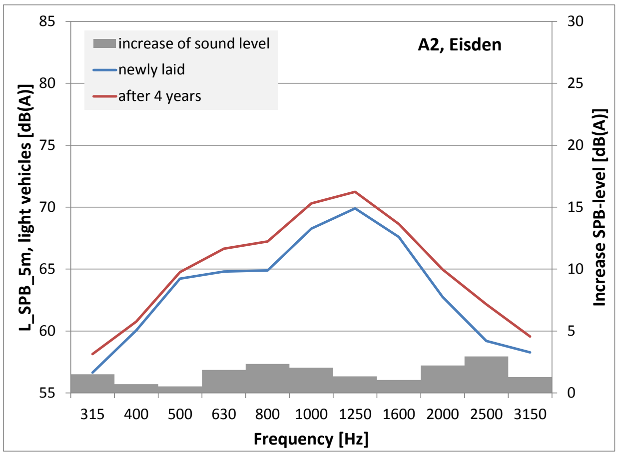


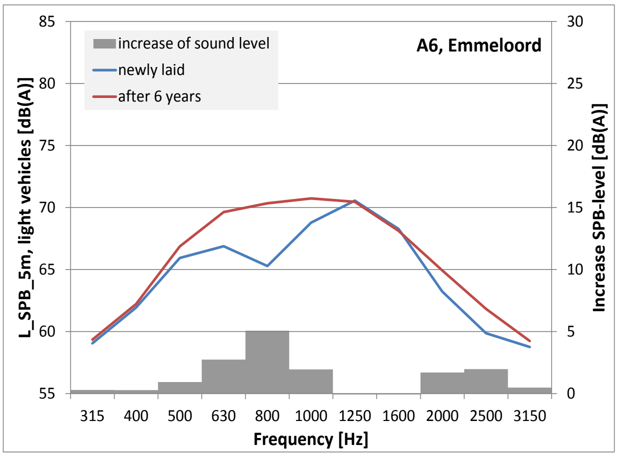
figure 32 SPB data @5m for HV's @80 km/h. Spectral trends averaged over test sections on a specific test location. Test surface 2L-PAC with 2/6 top layer. Note: A28 sections measured until 5 years.

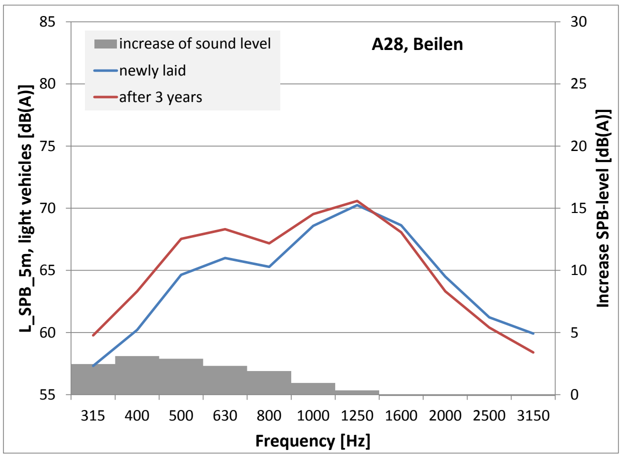
A1.4 Spectral data for 1L-PAC16,LV's and HV's

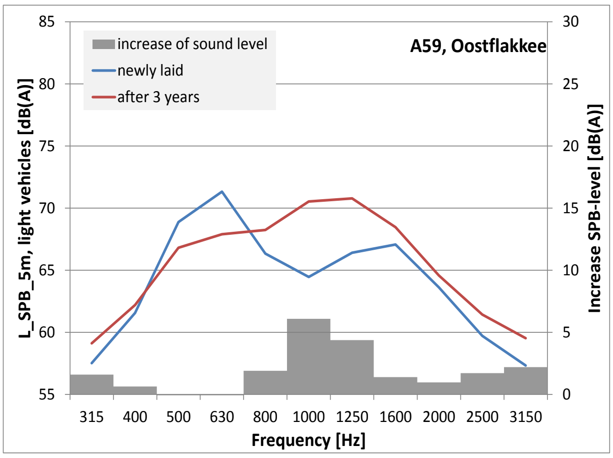
LV's











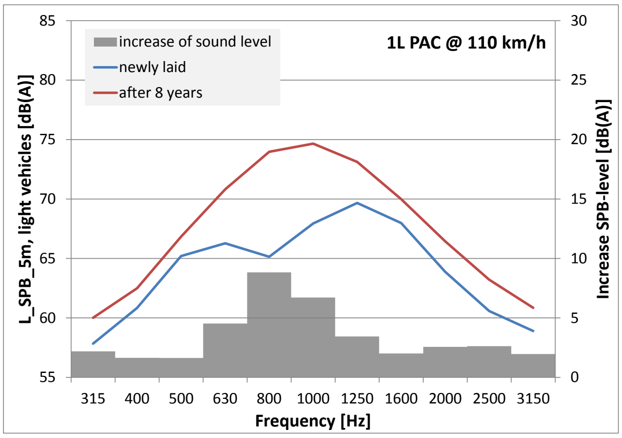
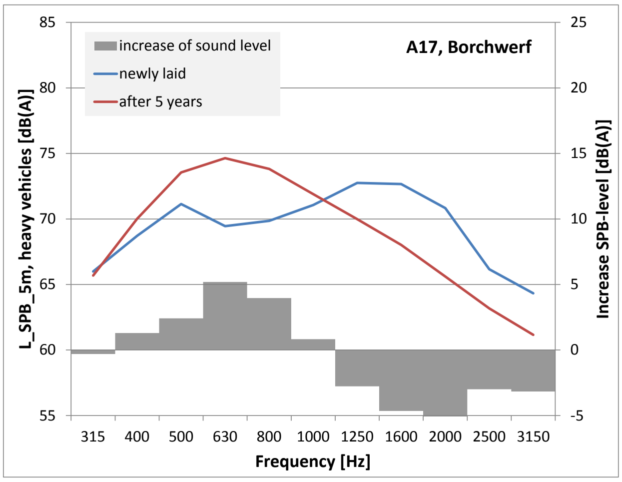
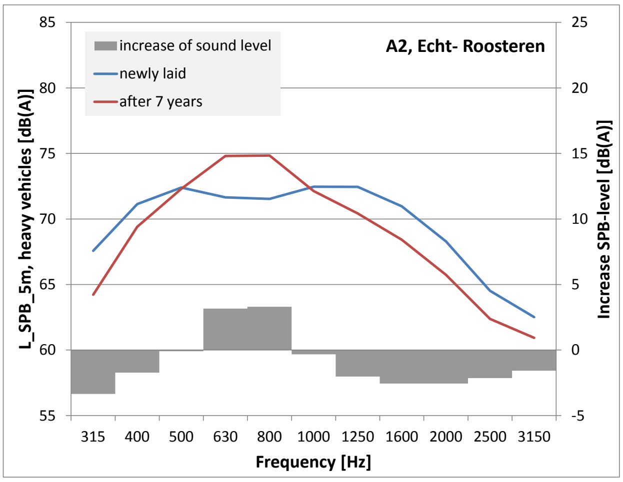


figure 33 SPB data @5m for LV's @ 110 km/h. Left: Spectral trends averaged over all test sections.

HV's





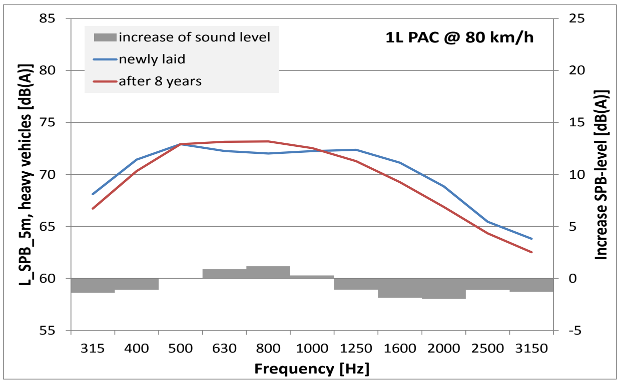


figure 34 SPB data @5m for HV's @ 80 km/h. Spectral trends averaged over test sections on a specific test location. Left: averaged over all sections. Notice the surprising behaviour at high frequencies where aging leads to lower sound levels.

A1.4 Spectral data for TSL,LV's and HV's

LV's

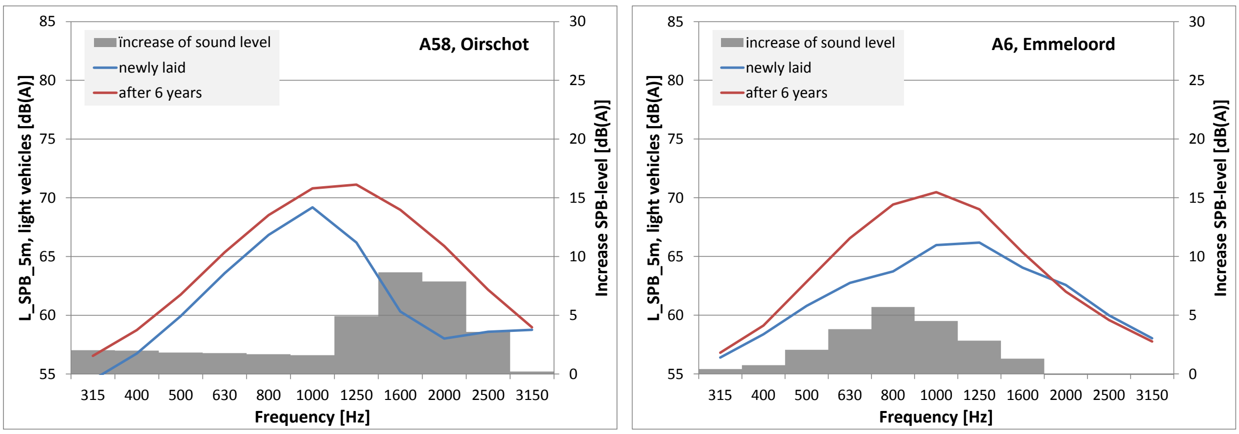


figure 35 SPB data @5m for LV's @ 110 km/h at two locations with TSL in Netherlands. Right: data averaged over 5 sections.

HV's

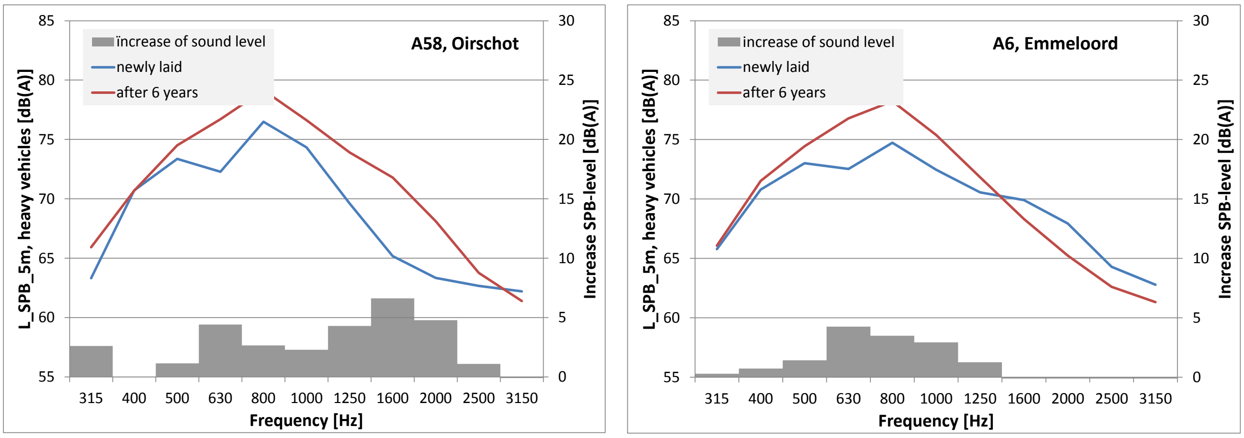
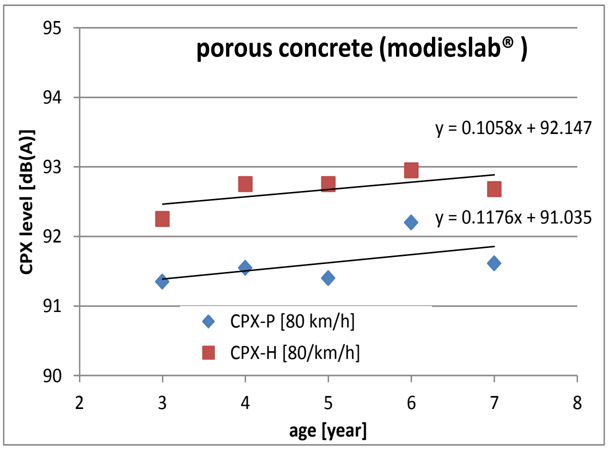


figure 36 SPB data @5m for HV's @ 80 km/h at two locations with TSL in Netherlands. Right: A6 data averaged over 5 sections.

A1.5 Spectral data for porous concrete,LV's and HV's



A2 German Highway Data

A2.1 BASt SPB data

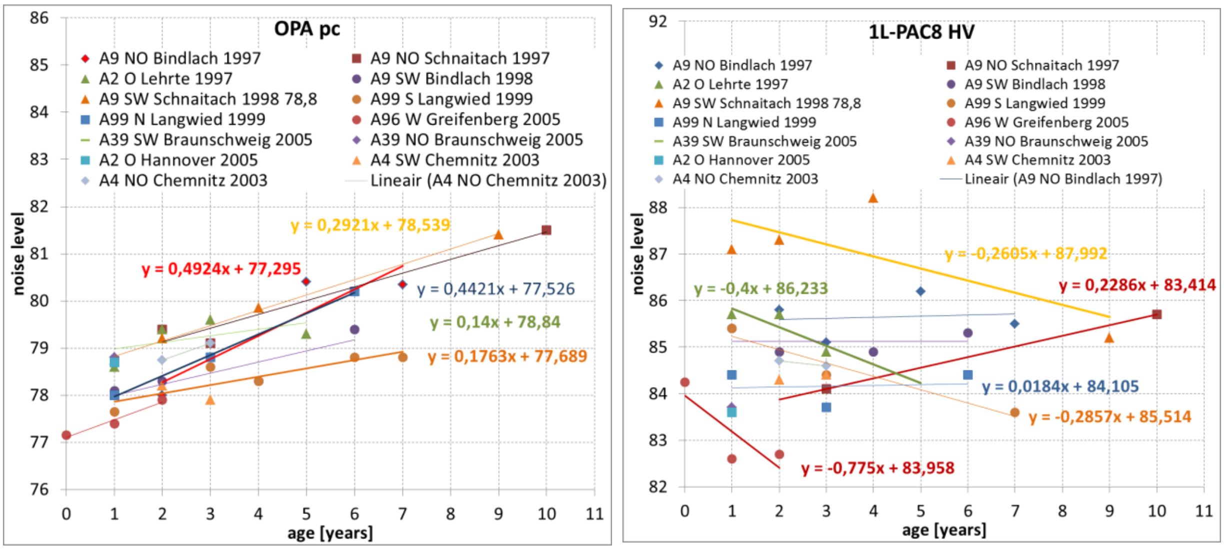
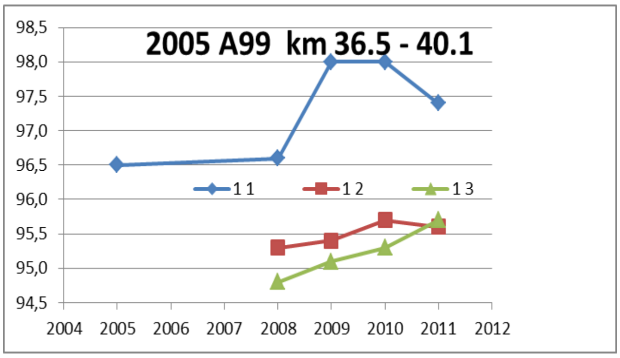
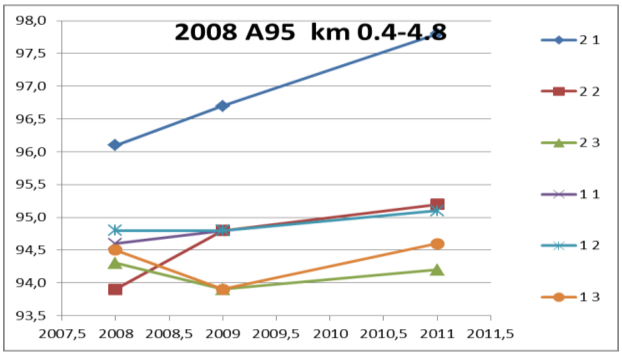


figure 37 SPB data from German measurements on 1L-PAC8 on highways. Left: LV's, right: HV's. Measurements are made at different location in Germany.

A2.2 Bavaria CPX data

In Bavaria repeated CPX measurements are performed on the Autobahn network. These measurements are performed on each lane. We selected from the data set the data with at least 4 repetitions. Data are given in the graphs below. The graphs are coded with the lane and driving direction as n,m. with n=1, 2 for driving direction and m=1,2,3,.. Lane number with 1 is right most lane.





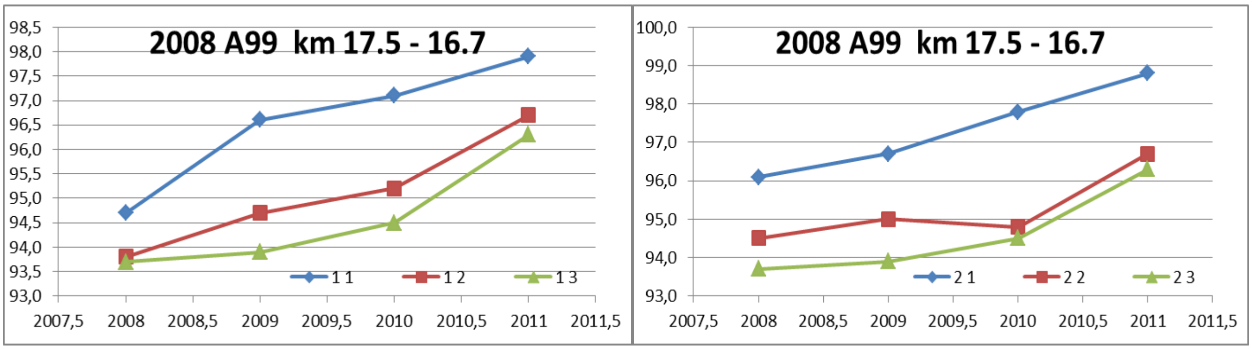
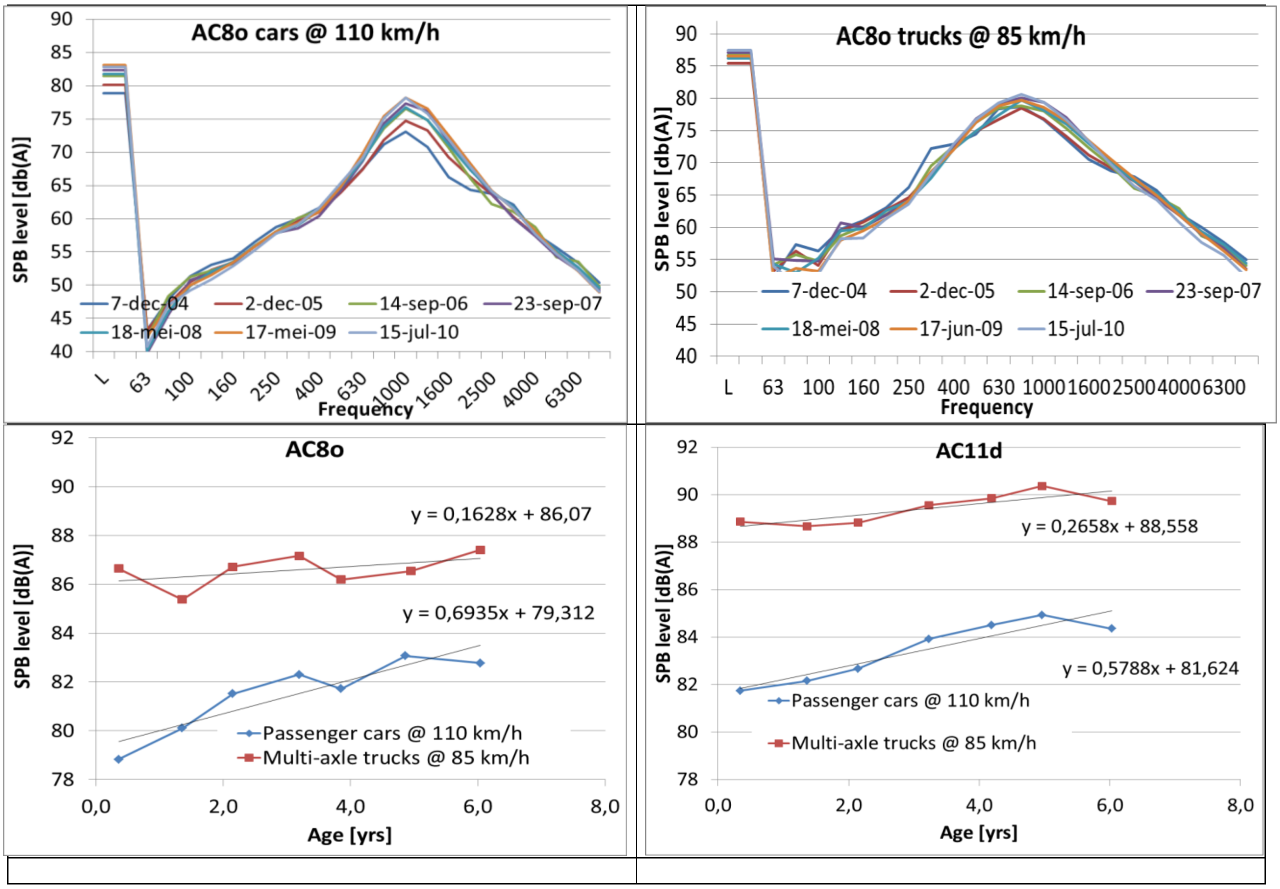
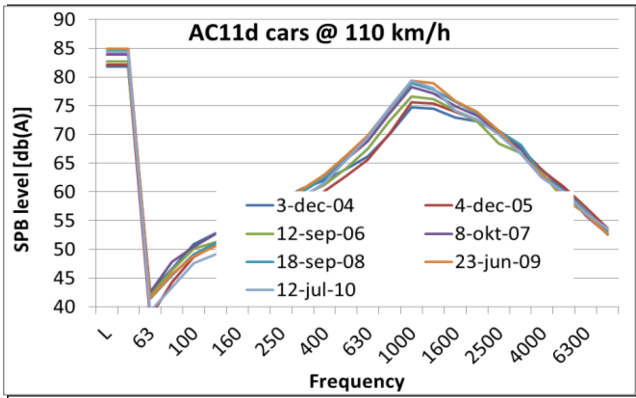


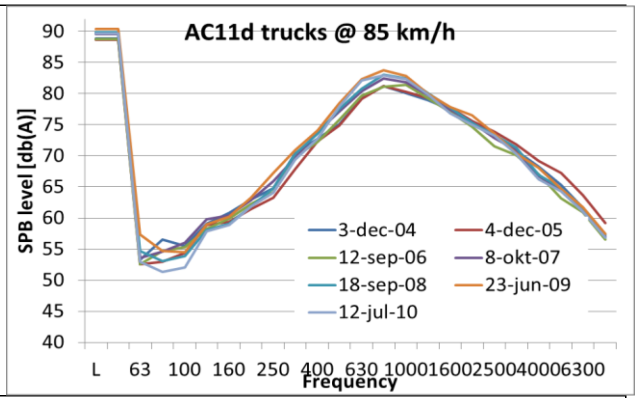
figure 38 CPX-P data from Bavarian highways. Distinguished are slow lanes and fast lanes.

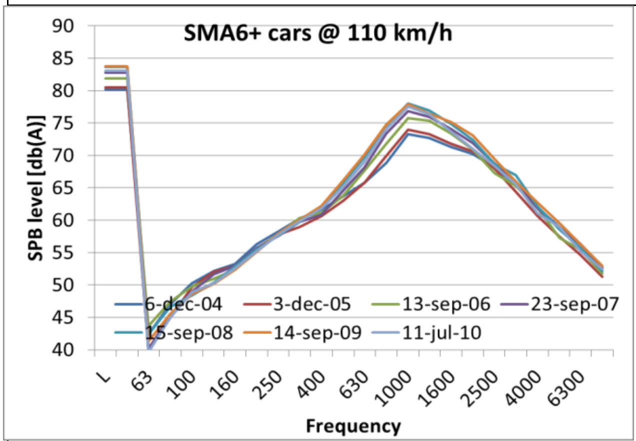
A3 Danish data on M10

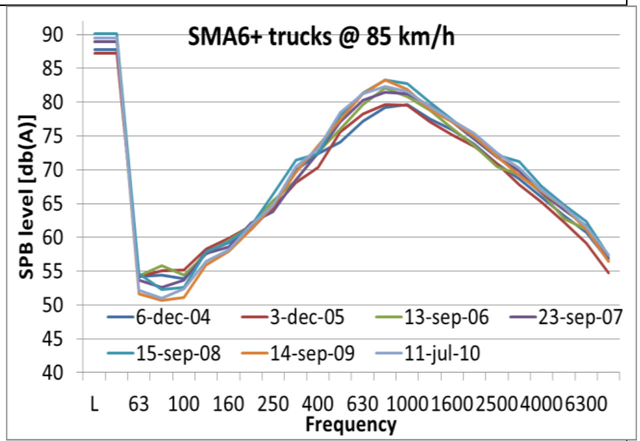
In Denmark, thee studies are performed on different test sections on highways. The one covering the largest time period is the study done on the M10 near Solrød. The graphs below present the overall changes over time and the spectral changes over time for both cars and trucks.

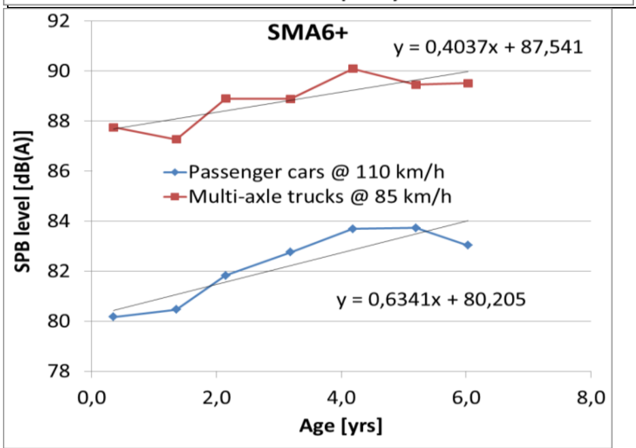


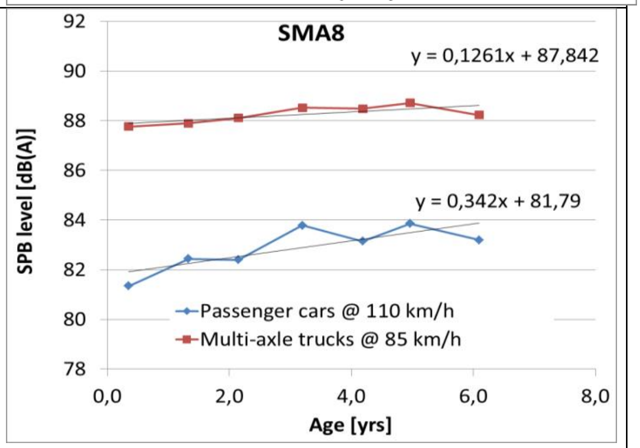

AC11d cars @ 110 km/h
SPB level [db(A)]
Frequency
3-dec-04
4-dec-05
12-sep-06
8-okt-07
18-sep-08
23-jun-09
12-jul-10

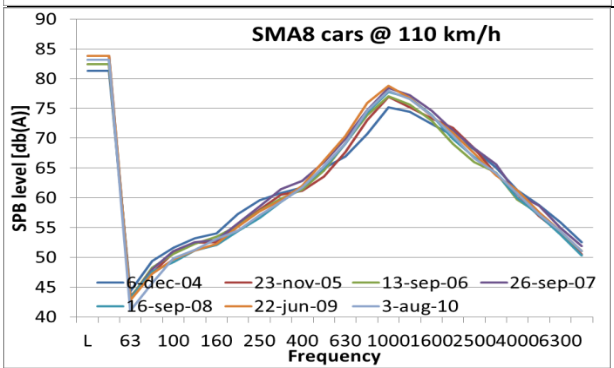

AC11d trucks @ 85 km/h
SPB level [db(A)]
Frequency
3-dec-04
4-dec-05
12-sep-06
8-okt-07
18-sep-08
23-jun-09
12-jul-10

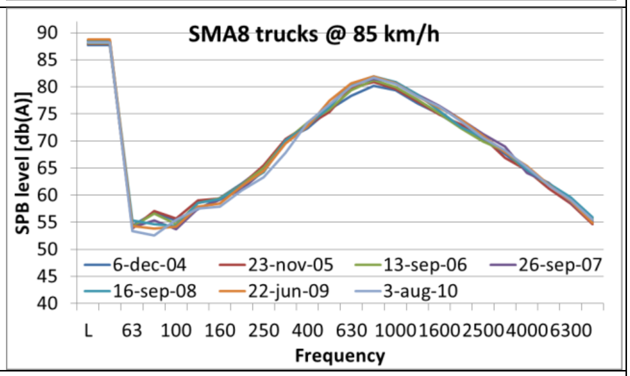

SMA6+ cars @ 110 km/h
SPB level [db(A)]
Frequency
6-dec-04
3-dec-05
13-sep-06
23-sep-07
15-sep-08
14-sep-09
11-jul-10


SMA6+ trucks @ 85 km/h
SPB level [db(A)]
Frequency
6-dec-04
3-dec-05
13-sep-06
23-sep-07
15-sep-08
14-sep-09
11-jul-10


SMA6+
y = 0,4037x + 87,541
Passenger cars @ 110 km/h
Multi-axle trucks @ 85 km/h
y = 0,6341x + 80,205
SPB level [dB(A)]
Age [yrs]


SMA8
y = 0,1261x + 87,842
y = 0,342x + 81,79
Passenger cars @ 110 km/h
Multi-axle trucks @ 85 km/h
SPB level [dB(A)]
Age [yrs]


SMA8 cars @ 110 km/h
SPB level [db(A)]
Frequency
6-dec-04
23-nov-05
13-sep-06
26-sep-07
16-sep-08
22-jun-09
3-aug-10


SMA8 trucks @ 85 km/h
SPB level [db(A)]
Frequency
6-dec-04
23-nov-05
13-sep-06
26-sep-07
16-sep-08
22-jun-09
3-aug-10

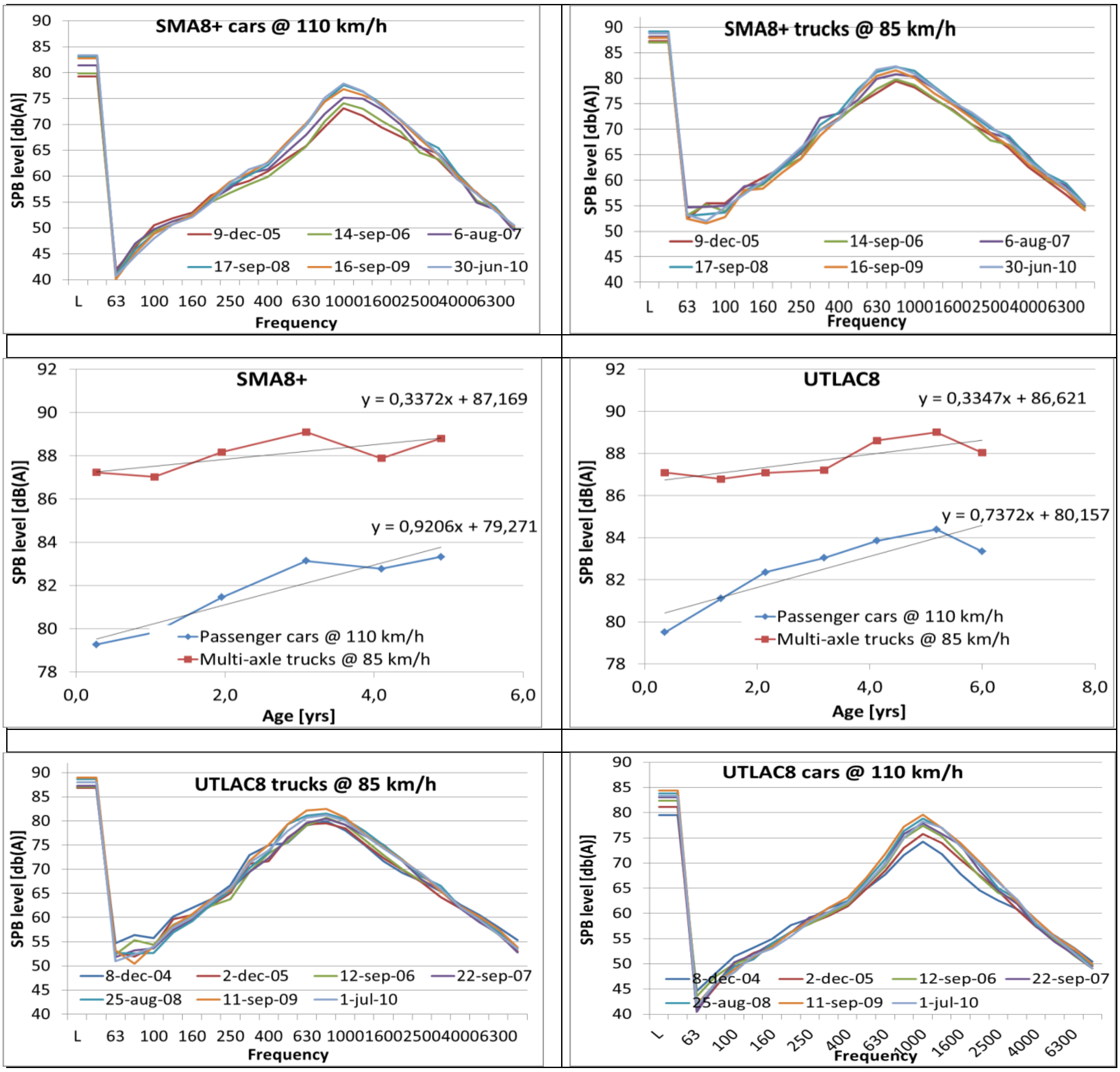
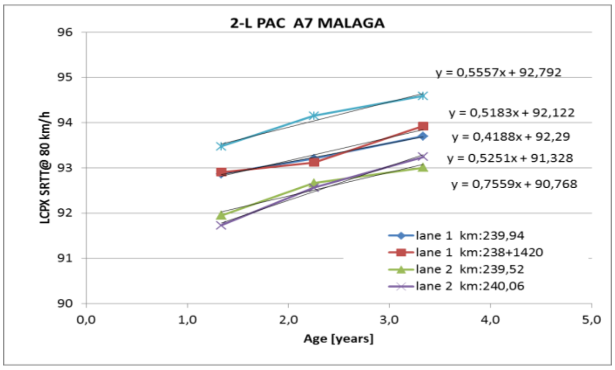


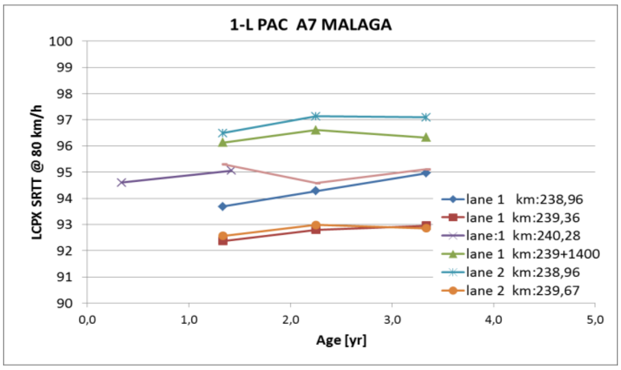
figure 39 Results from repeated SPB measurements on the highway M10 test location . AC8o=1L-PAC8, AC11=DAC11mm, UTLAC=TSL8mm, SMA6+ and 8+ are slightly open SMA surfaces. SMA8+ is built in September 2005, the other pavements on August 2004.

A4 Data from Spain

Overall CPX data

In Spain extensive measurements are carried out with the CPX method in the framework of the EU-END. In a few locations repeated measurements are carried out to follow the development of the acoustic characteristics of the surface. This is done at the A7 in Malaga where 5 sections with 2L-PAC and 5 sections with 1L-PAC were followed over a period of about 4 years. Measurements were done with a SRTT tyre, assumed to represent LV's, and an AVION tyre that represents HV's. The overall performance is defined with the average of SRTT and AVON results.





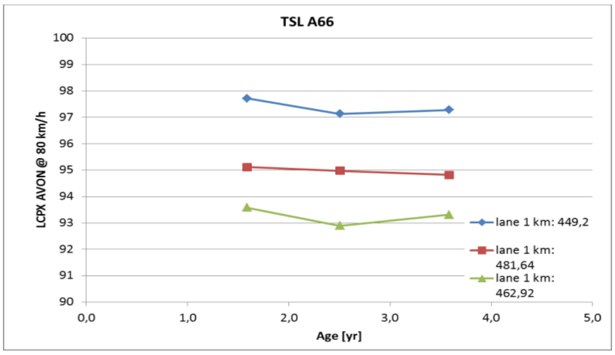
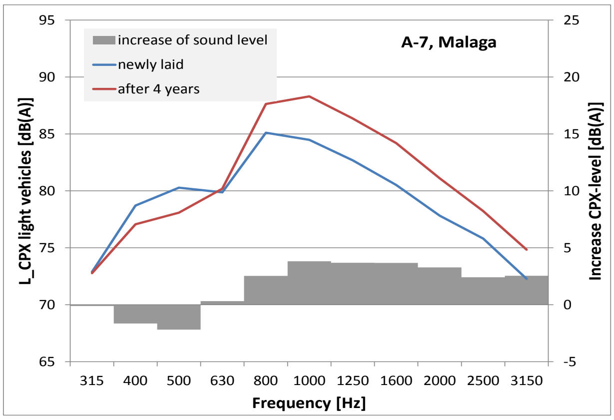
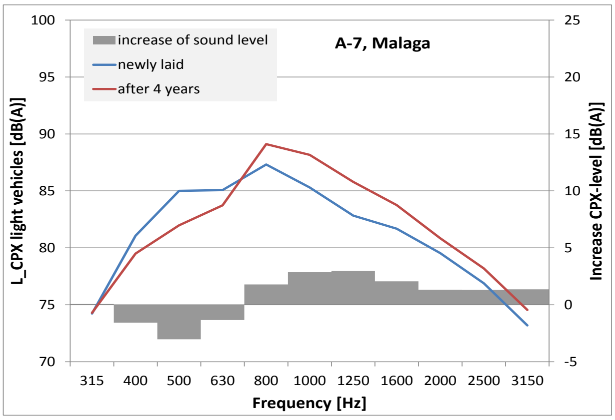


figure 40 The overall CPX data (SRTT+AVON) at 5 locations with 2L-PAC (left) and 6 locations with 1L-PAC (right).

Spectral data

LV's





CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

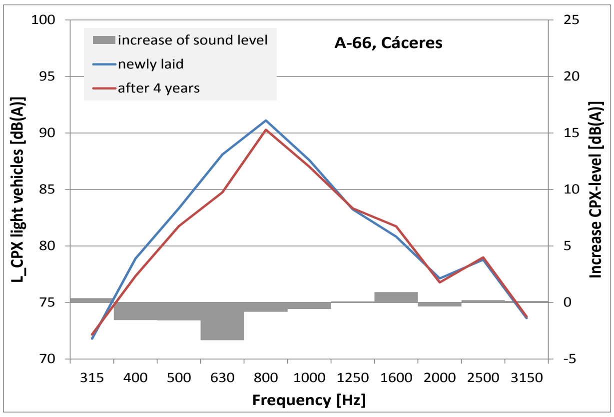
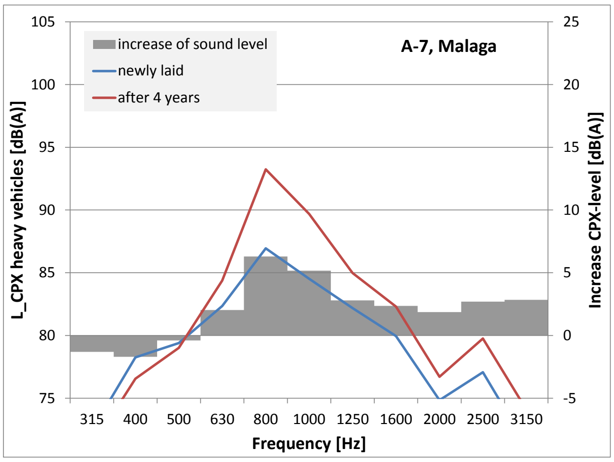
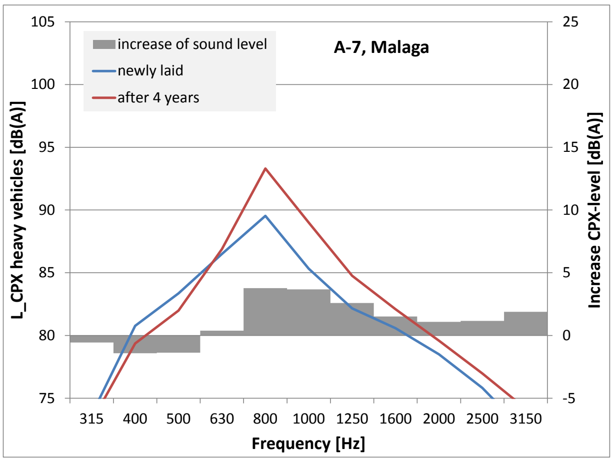


figure 41 CPX data for tyre SRTT (LV's) at three locations in Spain. Top-left: 4 2L-PAC sections at A-7 Malaga. Top-right: 3 sections with 1-L PAC at A-7 malaga. Left: TSL sections at A-66 Caceres.

HV's





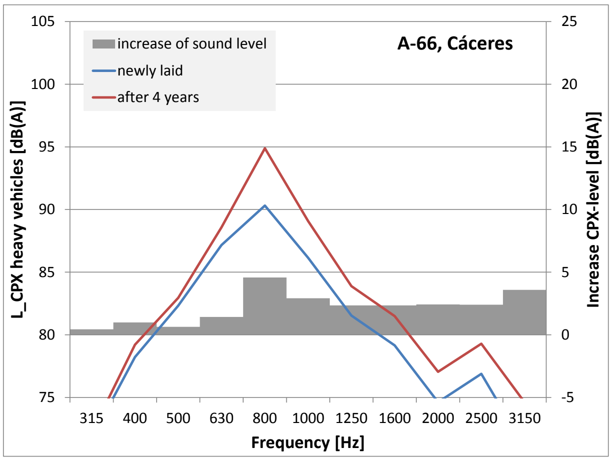
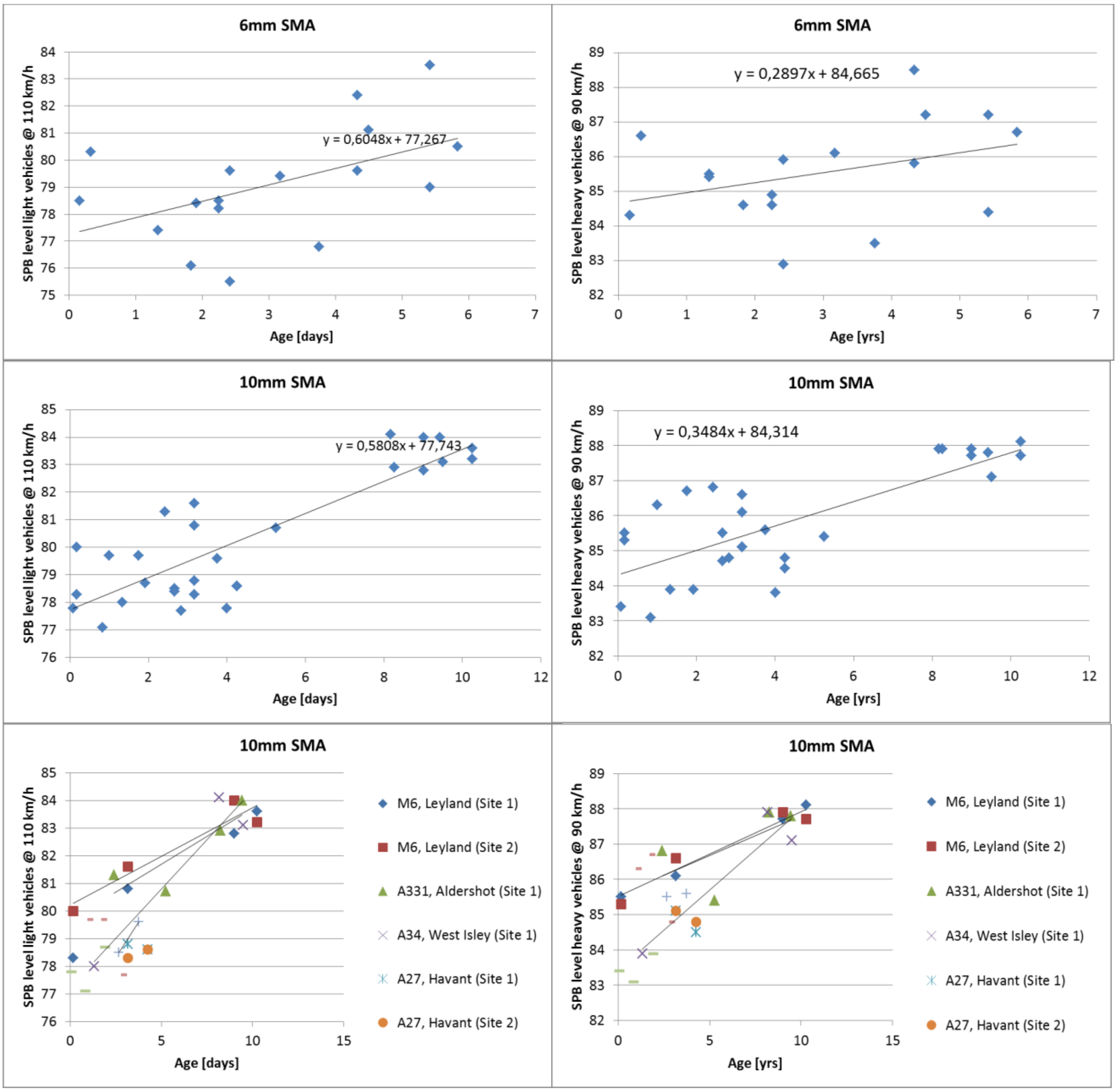


figure 42 CPX data for tyre AVON (HV's) at three locations in Spain. Top-left: sections with 2L-PACat A-7 Malaga. Top-right: sections with 1L-PAC at A-7 Malaga. Left: TSL sections at A-66 Caceres.

A5 Data from UK

In the UK, repeated SPB measurements were carried out within the framework of a research project on the acoustic durability of low-noise surfaces. The data set comprises per road surface type about 4 to 6 location, with each location measured about 3 times over a time span ranging between 3 and 10n years. The graphs below present the data. Through the data points a linear function is fitted with regression analysis.

LV's **HV's**



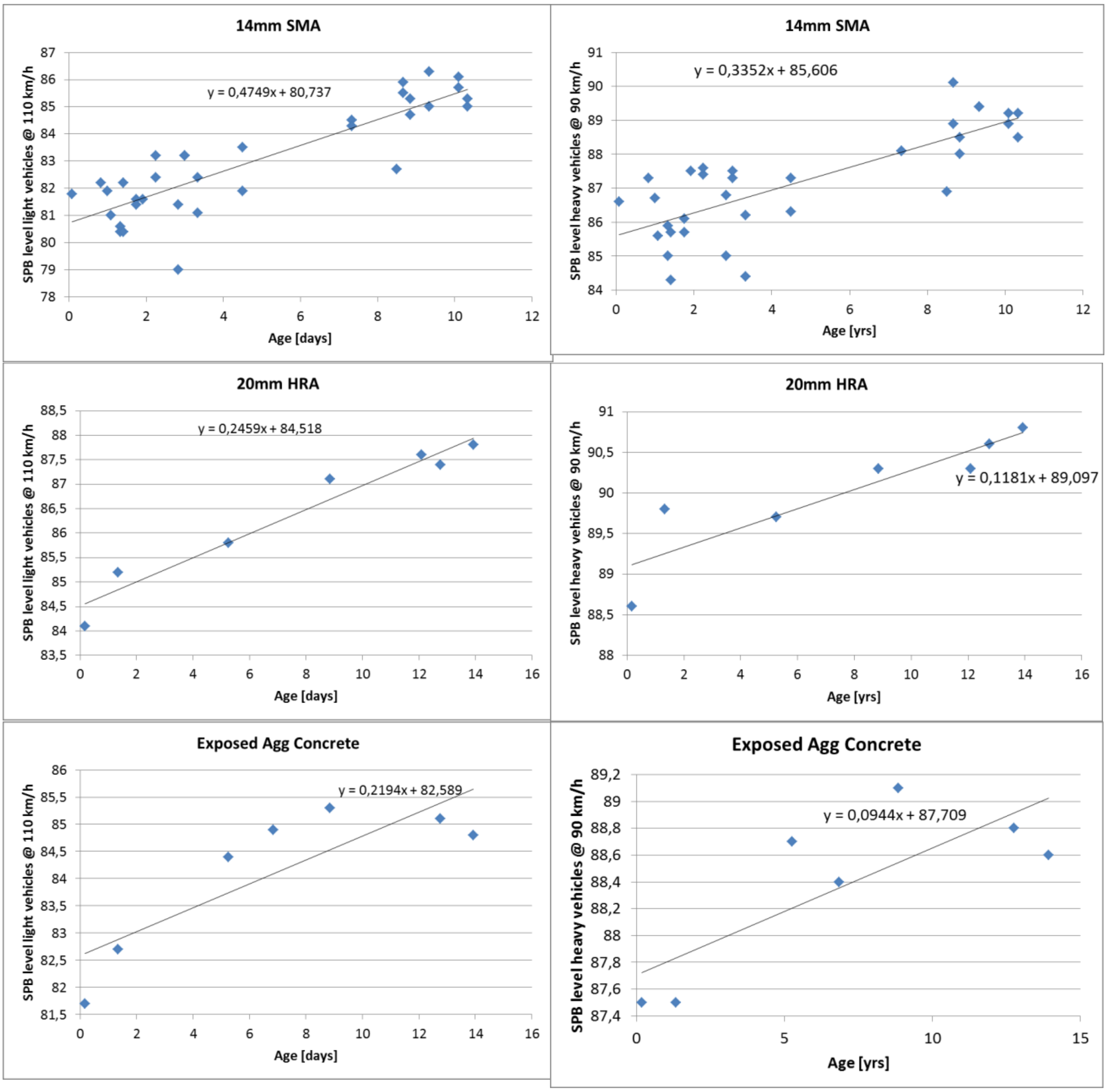


figure 43 Data from UK on different road surface types. All graphs are composed of repeated measurements on several locations. The 3rd row presents for the case of SMA 0/10, data points from individual locations.