Edinburgh, Scotland
EURONOISE 2009
October 26-28

Road surface noise performance over time

Jørgen Kragh
Danish Road Directorate/Road Institute
Guldalderen 12, 2640 Hedehusene, Denmark

ABSTRACT

Data from statistical Pass-By (SPB) and Close ProXimity (CPX) measurements of noise levels at surfaces of the same family but with different age were analyzed to look for characteristic noise performance time histories. Most data were from partners in the European project SILENCE, who made extracts from databases or repeated earlier measurements within the project to increase the time span of observations.

We found no indication that any model (polynomial, logarithmic or exponential) would yield better fit than a linear relation between vehicle noise level and pavement service time.

For light and heavy vehicles, the expected slope at dense asphalt pavement is in the order of 0.1 dB per year of pavement service time, both at high-speed and low-speed roads.

For porous or open graded asphalt surfaces, the expected time history slope for light vehicles is 0.4 dB per year at high-speed roads and 0.9 dB per year at city streets with low traffic speed. Heavy vehicle noise levels should be expected to increase 0.2 per year at high-speed roads with porous pavement.

1. BACKGROUND AND AIM

Noise from road traffic is the most important source of noise pollution in the industrialised world, and substantial effort is undertaken to protect populations from noise generated by road traffic. In rural and suburban areas this often takes the form of noise barriers, but in urban areas where noise sources and residential buildings are much closer together, the construction of barriers is difficult if not impossible. For this reason the interest is turning to the generation mechanisms of road traffic noise, because noise reduction at the source is very effective.

In the European project SILENCE, one task was to establish a classification of road surfacings in terms of correction factors to the noise levels occurring under standard conditions representing the initial noise reducing properties, i.e. the noise reduction encountered at newly built surfacings. The present paper summarises the results of an attempt[1] to supplement this initial noise reduction at different types of surfacings with a description of their likely development over time. This development is crucial for developing noise mitigation policies.

2. METHOD

Data from SPB and CPX noise measurements at surfacings from the same family but with different age were available from project partners who a) extracted them from their databases for the project, or b) repeated earlier measurements to increase the observed time span.

Email address. kragh@vd.dk

Data for a given family of pavement were plotted as a function of the pavement age. Later, data were normalised. The time history for each site was looked at separately and plotted with the measured noise level at the new pavement as zero dB. With such normalisation, the initial noise level becomes crucial. The project team decided to look for linear relationships between noise level and pavement age, and the final analyses were made by computing an initial noise level L_0 = 0 dB at time t_o by linear regression analysis per measurement site. For all sites with a given family of pavement, time histories of noise level change relatively to the initial noise level were plotted, see Figure 3. Finally, linear regression analyses were made of all these noise level changes on pavement age. The standard deviation s_R of the residuals has been used to characterize the quality of the fit.

3. AVAILABLE DATA

Data from the following sources were available for the final analyses:

- The database established in the SILVIA project with SPB data from many sources[2]
- French database: SPB values for passenger cars on various types of pavement[3]
- German database: SPB values for passenger cars and trucks on porous asphalt[4]
- Time series from Danish roads with single- [5] or two-layer porous pavement[6]
- Time series from a Belgian road with two-layer porous pavement[7]
- Danish CPX data from a Dutch-Danish cooperative project within the IPG programme[8]
- Californian CPX-data[9]
- CPX-data from repeated measurements at the same sites on Swedish roads[10]
- Results of measurements, the Danish Road Institute repeated for SILENCE[1].

4. SPB-MEASUREMENT RESULTS

A. Combined SPB-data from many sites

Almost 200 SPB results were available from ten types of pavement in the SILVIA-database[2]. Measurements had been carried out in seven North, East and Central European countries and they covered urban roads, highways and motorways. The pavement families are given in the caption of Figure 1. The figure shows the range and average value of passenger car SPB noise levels for each pavement family. Data labels are the number of sites within each family. The reasons for the variation within each pavement family are: wear and tear from the traffic load during surfacing lifetime, the surfacing age at the time of measurement, the maximum aggregate size, the void content, the temperature during measurement, etc.

All data were temperature normalized to 20 °C, assuming 0.05 dB lower noise level from passenger cars and 0.03 dB lower noise levels from trucks per °C higher air temperature. Groups of results comprising many sites with similar surfacing were selected and data for each group were plotted as a function of the pavement age at the time of measurement.

Typical results for passenger cars are shown in Figure 2 for DAC and SMA pavement with max aggregate size 16 mm and 8 – 11 mm. The figure shows the pass-by vehicle noise level according to ISO 11819-1 as a function of the age of the pavement at the time of measurement. The figure shows linear regression lines and the standard deviation s_R of the residuals in the y-direction. Results for various combinations of reference speed, surface type, aggregate size, and results for heavy vehicles can be found in[1].

The minimum slope was 0 dB per year and the maximum slope was 0.3 dB per year. The results showed large spread, probably because different measurement teams in different countries, and different contractors building from different product batches are involved.
For the data in Figure 2, the fit of a straight line was compared with the fit of a logarithmic and a second order polynomial trend line[1]. The standard deviation s_R of the residuals in the

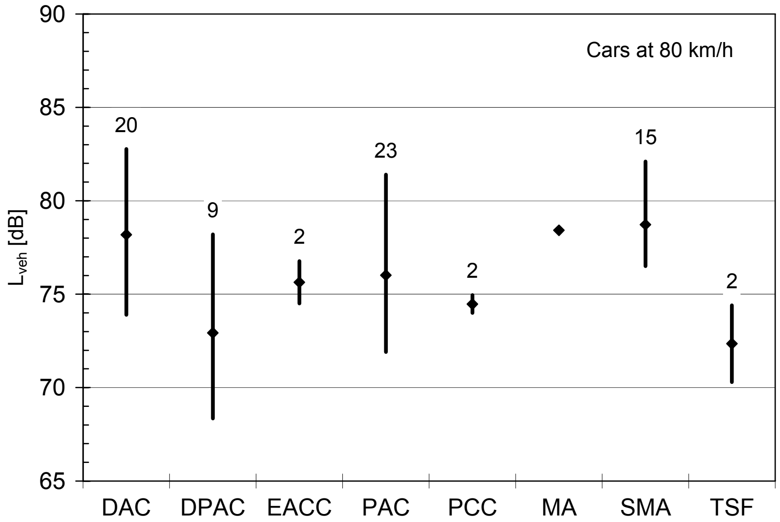

Figure 1: Average values and range of data in SILVIA database. *DAC*: dense asp-halt concrete; *DPAC*: double layer porous asphalt; *EACC*: exposed aggregate concrete; *PAC*: single layer porous asphalt; *PCC*: porous cement concrete; *MA*: mastic asphalt; *SMA*: stone mastic asphalt; *TSF*: thin layers.

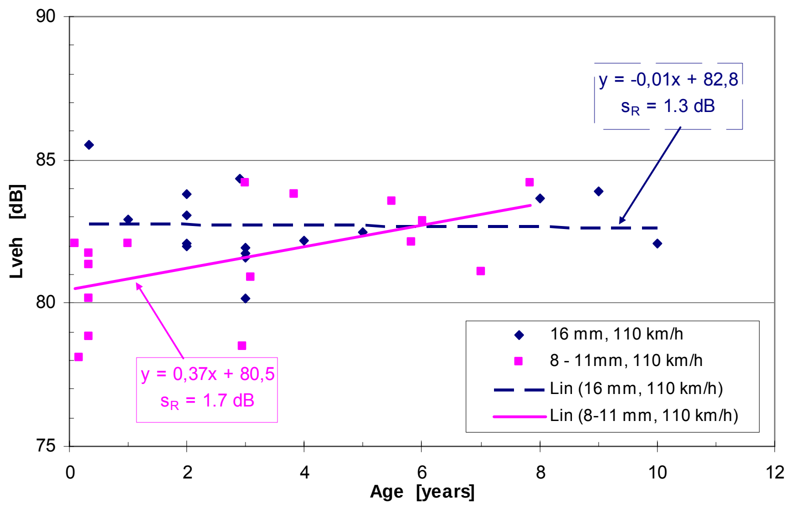

Figure 2: Pass-by noise levels from passenger cars on DAC + SMA, 110 km/h.

Y-direction was the same for all three trend lines. Judged by the explained fraction of variance (R^2), the polynomial fit was slightly less poor than the linear and logarithmic fit.

Only a limited fraction of the variation in individual measurement results is explained by pavement age. There are many possible explanations for this and chances to have the explanations identified for each data point are in reality non-existing.

The large spread in the data made the project team decide to look at time series of results of measurements repeated at the same spot. LCPC[3] and BASt[4] provided data base extracts, and DRI and BRRC provided their few time series[5-6, 7]. DRI carried out new measurements at sites measured 6 – 7 years earlier[1].

Table 1 lists the slopes and residual standard deviations from Figure 2 and other figures in[1], and gives the number of pavements in the database. Results are grouped according to vehicle speed (High: 80 - 110 km/h; Low: 50 km/h) and maximum aggregate size (Large: > 11 mm; Small: ≤ 11 mm), hypothesizing that large aggregate would be associated with smaller slopes than small aggregate. The table reveals that this is true in some but not all cases.

Table 1: Summary of results for passenger car noise levels in the SILVIA database.

Speed	Aggregate	Pavement	Slope [dB/yr]	s_R [dB]	*N* [-]
High	Large	DAC + SMA	-0.01	1.3	16
		DAC + SMA	0.21	1.9	20
		PAC 16	0.27	2.2	24
	Small	DAC + SMA	0.37	1.7	16
		DAC + SMA	0.01	1.7	12
Low	Large	DAC + SMA	0.11	1.3	8
	Small	DAC + SMA	0.27	1.8	13
		DAC + SMA	0.49	0.7	17

Data from the French database[3] were analysed in the same way as the SILVIA data. The data French are stored at the Strasbourg Regional Public Work Laboratory, mainly financed by a National Technical Department of the French Ministry for Ecology, Sustainable Development and Spatial Planning, SETRA: Technical Department for Transport, Roads and Bridges Engineering and Road Safety. Table 2 shows the pavement types in three categories R_1 – R_3.

Table 2: Pavement types and number n [-] of test sections in the French database.

Category R_1	*n*	Category R_2	*n*	Category R_3	*n*
Two-layer Porous Asphalt 4/6 10/14	4	Dense Asphalt Concrete 0/10	3	Dense Asphalt Concrete 0/14	1
Porous Asphalt 0/10	20	Very Thin Asphalt Concrete 0/10-type1	4	Very Thin Asphalt Concrete 0/14	1
Porous Asphalt 0/6	4	Ultra Thin Asphalt Concrete 0/10	2	Surface Dressing 6/10	3
Very Thin Asphalt Concrete 0/6-type 1	11	Surface dressing 4/6	1	Surface Dressing 10/14	3
Very Thin Asphalt Concrete 0/6-type 2	17	Thin Asphalt Concrete 0/10	2	Surface Dressing 6/8	2
Very Thin Asphalt Concrete 0/10-type 2	7				
Ultra Thin Asphalt Concrete 0/6	2				

The results of analyses were similar to those for the SILVIA-data: large spread and the same standard deviation s_R. For 200 SPB measurements made at different times at 65 sites with category R_1 surface, the slope was almost 0.5 dB per year, which is more than the largest slope seen in the SILVIA results. For a subset of 66 measurements from 20 sites with single-layer porous asphalt PA 0/10 the slope also was 0.5 dB per year. This is almost twice as much as for asphalt PA 16 in the SILVIA results[1]. The French data have been further analysed by looking at the time history recorded at each individual section of road, cf. Section B.

The data[4] from 13 German test sections of single layer porous asphalt PA 0/8 on rural motor-ways indicated 0.3 dB per year increase in passenger car noise levels and 0.1 dB increase per year for heavy vehicle noise. These data have also been further analysed.

B. Time series of SPB-data collected at the same spot

The upper part of Figure 3 shows the data for each individual of 20 French roads with PA 0/10. The middle part shows the same data but for each individual site, the time history has been transposed to origin at L_0 = 0 dB at the time t_0 = 0. The bottom part shows the same data, but zero dB has been defined as the value at the time t_0 = 0 of the linear regression line of noise level on pavement age, rather than as the initial measurement result. In the bottom part of Figure 3, a (black) trend line for all results has been added, and the standard deviation s_R of the residuals is given. The trend line slope is 0.4 dB per year, s_R = 1.3 dB. This slope is slightly smaller than the slope of 0.5 dB per year obtained by the more "crude" treatment described in Section A, while s_R is the same. Similar graphs for other categories of road can be found in[1]. Table 3 summarizes the outcome of the analyses of the French data.

Table 3: Summary of ageing performance derived from French data.

Pavement	v [km/h]	Slope [dB/yr]	sR [dB]	N [-]
Two-layer Porous Asphalt 4/6 10/14	90	0.19	1.2	4
Porous Asphalt 0/10		0.42	1.3	20
Porous Asphalt 0/6		0.76	1.7	4
Very Thin Asphalt Concrete 0/6-type 1		0.25	1.6	11
Very Thin Asphalt Concrete 0/6-type 2		0.78	1.9	17
Very Thin Asphalt Concrete 0/10-type 2		0.42	1.6	7
Ultra Thin Asphalt Concrete 0/6		0.58	0.6	2
Category R2		0.21	1.4	12
Category R3		(0.46)	(2.1)	(10)
Category R3, excl. Section 9		0.12	1.2	9

The top part of Figure 4 shows individual time histories of passenger car noise levels at 13 sites with single-layer porous asphalt on German rural motorways[4]. The bottom part of the figure shows the data treated like the data in Figure 3. The average increase in passenger car noise level is 0.3 dB per year, the same as reflected by the analysis mentioned in Section A. The standard deviation s_R is 1.4 dB, almost twice the value in the analysis mentioned in Section A. In this case the detailed analysis did not improve the noise vs. age fit.

The individual time histories of heavy vehicle noise levels on the 13 German sites with single-layer porous asphalt showed an average increase of less than 0.1 dB per year.

Figure 5 shows Danish time series of passenger car noise levels. The left part shows results from two dense and three single-layer porous asphalts on a rural road[5]. The life-time of the drainage asphalt was deliberately made short in this experiment. It could have been longer if the binder had been modified, see[1] for a discussion. The right part of Figure 5 gives results from three two-layer porous asphalts and one dense surface in a city street[6]. The porous asphalt was cleaned twice a year by high pressure water spraying and subsequent suction of the water. Nevertheless, the voids gradually got clogged, resulting in faster increase in noise

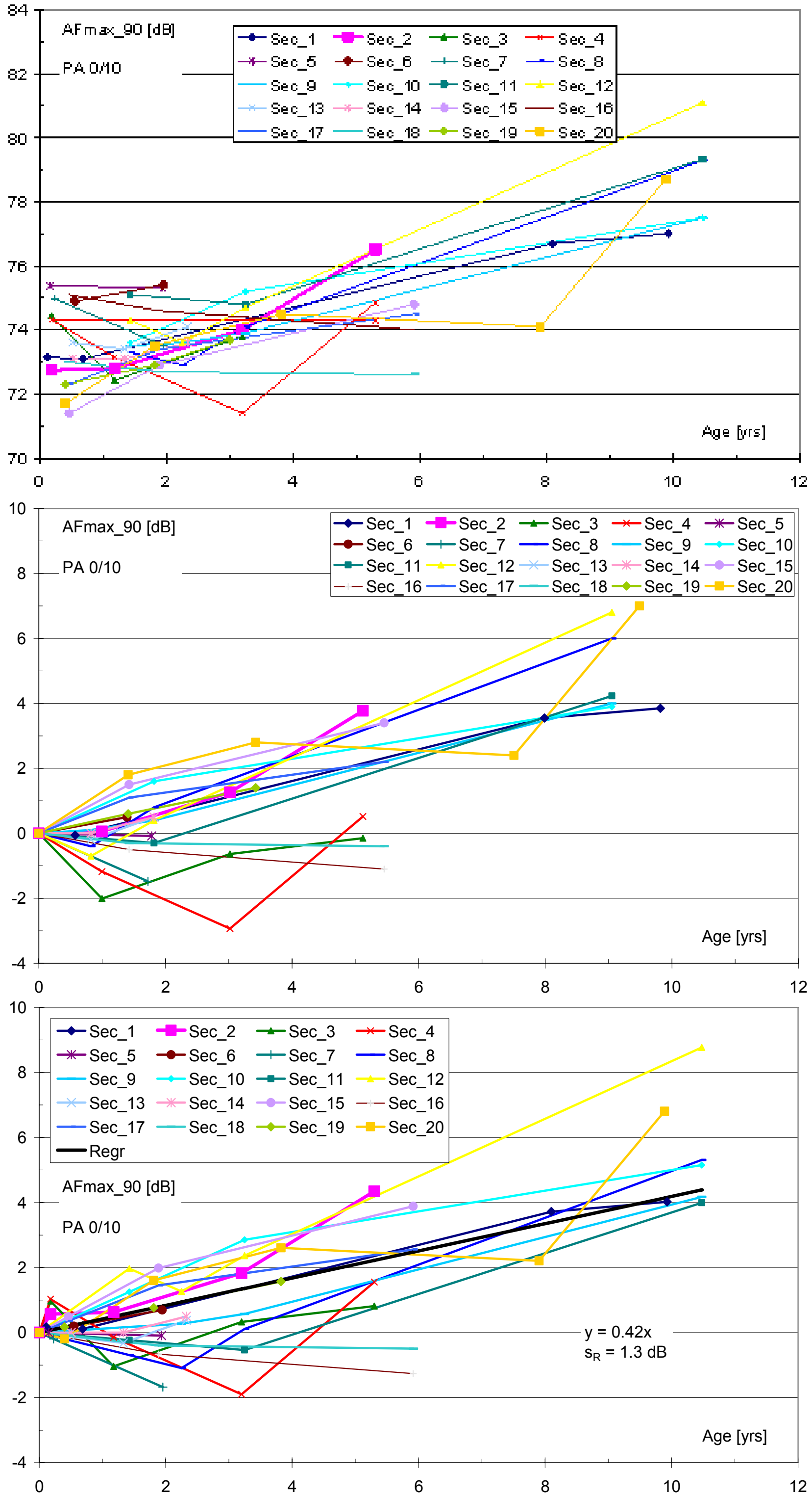

Figure 3: Pass-by noise levels from passenger cars on French PA 0/10, 90 km/h.

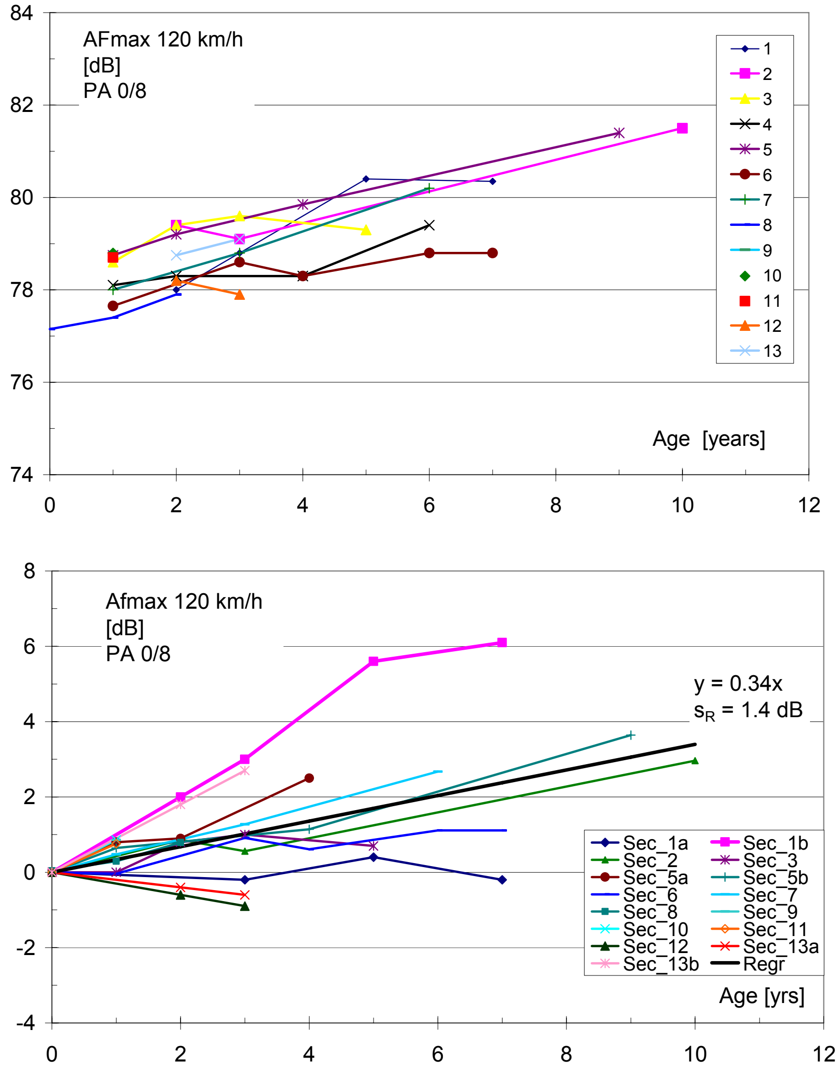

Figure 4: Pass-by noise levels from passenger cars on German PA 0/8, 120 km/h.

levels than at the reference surface. The average increase in noise level was appr. 1 dB per year. The newest data were collected after the top layer had been replaced[7].

Figure 6 shows results of measurements at six sites, which DRI made for SILENCE[1], six or seven years after the original measurements[11]. The pavement was dense asphalt concrete with 11 mm maximum aggregate size. The error bars show the standard uncertainty of the regression line value. In three cases the noise levels were higher seven years later, and in three other cases the noise levels were lower seven years later. The differences are rather small and could perhaps be attributed to measurement uncertainty, see[1] for a discussion. Figure 6 show lines sloping 0.2 dB per year placed at an arbitrarily chosen level, and the data – in spite of the apparently contradictory trends – support the general picture that the traffic noise level at dense asphalt concrete increases by 0 - 0.2 dB per year.

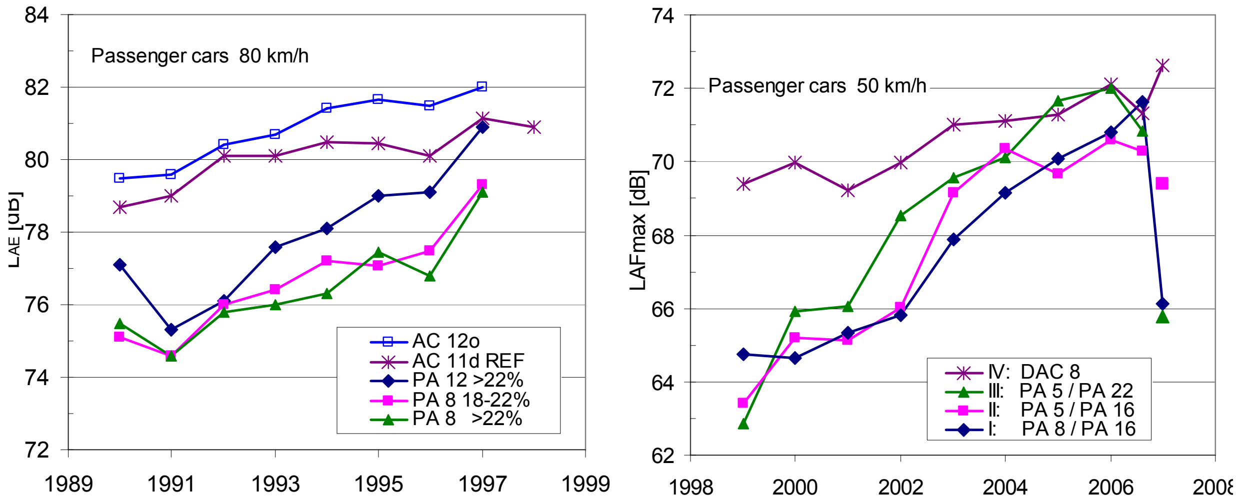

Figure 5: Pass-by noise levels at a Danish rural road (left) and a Danish city street (right).

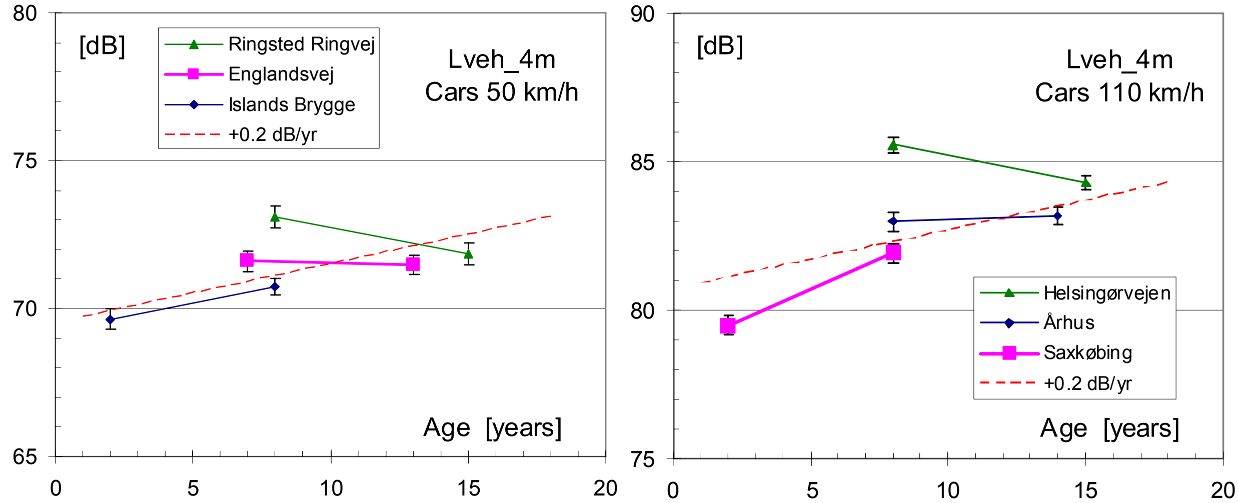

Figure 6: Pass-by noise levels from passenger cars on Danish roads with DAC 11.

6. CPX-MEASUREMENT RESULTS

In a Dutch-Danish project, CPX-measurements were carried out on Danish roads[8] and noise data were available for various types of pavement of different age, see[1].

CPX-data from the US – measured by University of California - became available[9]. Figure 8 gives a view of their dependence on pavement age. The general trend is +0.2 dB per year. By pavement type: rubberized, gap graded asphalt concrete and open graded asphalt concrete: +0.3 dB per year; for dense asphalt concrete: +0.03 dB per year.

7. SUMMARY OF REGRESSION LINE SLOPES

Table 4 summarizes the regression line slopes. It distinguishes between SPB and CPX data,

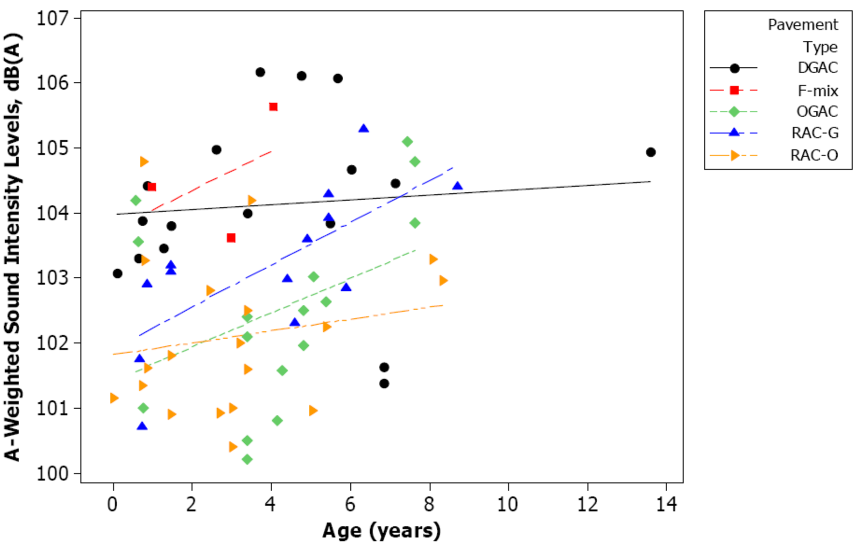

Figure 7: CPX-sound intensity levels measured on: *DGAC*: Dense graded AC; *OGAC*: Open graded AC; *RAC-G*: Rubberized, Gap graded; *RAC-O*: Rubberized, Open graded; *F-mix*: special mix[9].

and groups results into pavement families: dense surfaces, thin layer surfaces with an open structure, open graded asphalt concrete (OGAC), and porous asphalt. The results have been grouped into passenger car noise levels and heavy vehicle noise levels, respectively, at high (110 – 120 km/h), medium (70 – 90 km/h) and low speed (50 km/h).

Inspection of the table will reveal large variation in results. The slope varies between zero and almost 0.5 dB per year at dense surfaces such as DAC and SMA. This applies to both passenger car noise levels and heavy vehicle noise levels, although the slope of 0.39 dB per

Table 4: Summary of regression line slopes, dB per year.

	Source	Speed	Passenger cars High	Passenger cars Medium	Passenger cars Low	Heavy vehicles Medium	Heavy vehicles Low
Dense	SPB	SILVIA	0.00 / 0.37	0.01/0.21	0.11/0.49	0.04 / (0.39)	-
		LCPC (R2)	-	0.21	-	-	-
		BASt	< 0.05	-	-	< 0.05	-
		DRI	-	0.40	0.33	0.15	-
	CPX	DRI	-	0.11 / 0.16	0.13	-	-
		UCPRC	0.03	-	-	-	-
Thin layer	SPB	LCPC BBTM-1	-	0.25	-	-	-
		BBTM-2		0.42 / 0.78	-	-	-
OGAC	SPB	DRI	-	0.37	-	0.32	-
	CPX	UCPRC	0.30	-	-	-	-
Porous	SPB	SILVIA	0.27	-	-	0.04	0.14
		LCPC	-	0.42	-	-	-
		BASt	0.34	-	-	0.08	-
		DRI	-	0.69 / 0.78	0.98 / 1.09	0.09 / 0.35	-
		DWW	0.41	-	-	0.18	-
		BRRC	-	0.28	-	-	-

year for heavy vehicles is associated with large uncertainty[1].

There is a trend for steeper regression line slopes for porous and open graded surfacings than for dense surfaces, and the few data for porous pavement in city streets indicate steeper slopes for porous pavement with slow traffic than for porous pavements on roads with high speed traffic. In Table 5 an overall summary has been attempted.

8. CONCLUSIONS

No indication could be found that any model (polynomial/logarithmic/exponential) would yield better fit to the data than a simple linear relation between vehicle noise level and pavement service time. This may be due to the large scatter in measurement results. It may be speculated that a clearer pattern might have appeared if each surface had also been characterized by the total traffic load it had carried rather than only by its number of years in service.

Table 5 summarizes the slopes to be expected for a linear time history of vehicle noise levels. For both light and heavy vehicles, the slope to be expected at *dense* asphalt surfacings is +0.1 dB per year of pavement service time. This applies to high speed and to low speed roads. For *porous* or *open graded* asphalt the expected slope for light vehicles is 0.4 dB per year at high speed roads, and 0.9 dB per year at city streets with low traffic speed. Heavy vehicle noise can be expected to increase by 0.2 per year at high speed porous roads.

Table 5: Overall proposed time history slopes, dB per year of pavement service time.

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

REFERENCES

1. J. Kragh, “Road surfacings – Noise reduction time history”, *Danish Road Institute Report 161* (2008) vejdirektoratet.dk/publikationer/VIrap161/index.htm
2. B. Andersen, J. Kragh, H. Bendtsen, “Acoustic performance of low noise road pavements”, *Danish Road Institute note 44* (2006) vejdirektoratet.dk/publikationer/VInot044/index.htm
3. Extract of database, M. Berengier *personal communication to J. Kragh*, June 2007
4. Extract of database, W. Bartolomaeus *personal communication to J. Kragh*, Sep – Oct 2007
5. J. Kragh, "Long-term performance of drainage asphalt road surfaces", *Proceedings Internoise 98*, Paper #332, Christchurch (1998)
6. J. Kragh, H. Bendtsen, “Replacement of Porous Top Layer - Process and noise effect”, *Danish Road Institute note 58* (2007) vejdirektoratet.dk/publikationer/VInot058/index.htm
7. L. Goubert, *personal communication to J. Kragh*, 2006
8. J. Kragh, B. Andersen, H. Bendtsen, “Acoustical characteristics of Danish road surfaces”, *Danish Road Institute note 38* (2006) vejdirektoratet.dk/publikationer/VInot038/index.htm
9. E. Kohler, “Findings from the Tire/Pavement Noise Study at the UC Pavement Research Center (UCPRC), Part of Caltrans Quiet Pavement Research (QPR) program. *Presentation at TRB Summer Meeting*, 2007 adc40.org/summer2007/2007presentations.html
10. U. Sandberg, *personal communication to J. Kragh*, December 2007
11. J. Kragh, B. B. Jessen, “Noise emission data for vehicles at constant speed in road traffic measured 1999 – 2000 by DELTA” (in Danish); *DELTA Report AV 1018/01*, Kgs. Lyngby 2001