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TÜV NORD
Mobilität

Investigations on Noise Emission of Motor Vehicles in Road Traffic

Research Project 200 54 135

Final Report

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16. Abstract

This report describes the results of a follow up study of similar investigations carried out in 1978, 1983, 1986 and 1992, that were related to statistical pass by measurements on different road sites in real traffic The main aim was to check, if noise limit reductions for type approval, that came into force in the meantime, led to reduction measures by the manufacturers, that also reduced the noise emission in real traffic.
Further-more should be investigated, if the still ongoing trends to wider and faster tyres for cars and higher rated power values for trucks caused higher noise emissions in real traffic. In total 31240 vehicles were measured.
The analysis of the results showed clearly that there was an effect on the in-use propulsion noise emission of the vehicles but no effect on the tyre/road noise emission. Since tyre/road noise is more important for cars than for heavy duty vehicles, the reduction effect is higher for HDV than for cars. More specific: Since tyre/road noise is dominating for cars in free flowing traffic, the reduction of the propulsion noise emission gave no benefit for this driving condition class. And even for acceleration phases at low speeds the reduction of the overall noise emission was substantially lower than the reduction of the noise limits.
The results for heavy duty vehicles showed that the reduction of noise limits in the past had the highest effect on the reduction of the in-use noise emissions compared to other vehicle categories. In the conclusions recommendations are made for improvements of the type approval noise test conditions in order to increase the effectiveness.

17. Keywords

vehicle categories, KBA-Statistics, noise measurements, noise emissions in real traffic, correlation between noise emission and technical parameters, vehicle speed or type approval level, in-use noise emission of different emission stages

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15. Zusätzliche Angaben

16. Kurzfassung

Dieser Bericht beschreibt die Ergebnisse einer Nachfolgestudie ähnlicher Untersuchungen die 1978, 1983, 1986 und 1992 durchgeführt wurden und die verwandt sind mit statistischen Vorbeifahrtmessungen an verschiedenen Straßenlagen im realen Verkehr. Das Hauptziel war festzustellen, ob die Geräuschgrenzwertsenkungen der Typprüfung, die mittlerweile Pflicht wurden und bei den Herstellern zu reduzierten Messergebnissen führte, ebenso zu reduzierten Geräuschemissionen im realen Verkehr führten. Weiterhin sollte untersucht werden, ob der immer noch anhaltende Trend zu breiteren und schnelleren Reifen für Pkw und größeren Nenndrehzahlen für Lkw höhere Geräuschemissionen im realen Verkehr bedingen. Insgesamt sind 31240 Fahrzeuge gemessen worden. Die Analyse der Ergebnisse zeigte klar, dass es einen Effekt auf das „in-use“ Antriebsgeräusch von Pkw gab, aber keinen Effekt bei der Reifen/Fahrbahngeräuschemission. Da das Reifen/Fahrbahngeräusch für Pkw wichtiger als für schwere Nutzfahrzeuge ist, ist der Minderungseffekt für sNfz größer als für Pkw. Genauer: Da das Reifen/Fahrbahngeräusch für Pkw im frei fließenden Verkehr dominiert, ergab die Minderung des Antriebsgeräusches keinen Effekt in dieser Klasse. Und selbst bei den Beschleunigungsphasen bei niedrigen Geschwindigkeiten war die Minderung der Gesamtgeräuschemission substantiell niedriger als die Reduktion der Geräuschgrenzwerte. Die Ergebnisse für sNfz zeigten, dass die Minderung der Geräuschgrenzwerte in der Vergangenheit den größten Effekt auf die Reduktion der „in-use“ Geräuschemission verglichen mit den anderen Fahrzeugkategorien hatte. In den Schlussfolgerungen wurden Vorschläge für Verbesserungen der Bedingungen für Geräuschtypprüfungen gemacht, um deren Effektivität zu verbessern.

17. Schlagworte:
Fahrzeugkategorien, KBA-Statistik, Geräuschmessungen, Geräuschemissionen im realen Verkehr, Korrelation zwischen Geräuschemission und technischen Parametern, Geschwindigkeit oder Typprüfpegel, “in-use“ Geräuschemission verschiedener Emissionsstufen

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Content

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1 Introduction and Aim

The former Forschungsinstitut Geräusche und Erschütterungen (FIGE) carried out statistical pass-by measurements in real traffic between 1976 and 1993 within the scope of several research projects by order of the German Environmental Agency (UBA) [1], [2], [3], [4]. The results enabled to derive statistically assured correlations between noise emission and vehicle speed and to quantify the influence of traffic situation and driving behaviour. Furthermore it was possible to extract differences in the noise emission of different vehicle types for cars.

In this follow up study should be checked by additional statistical pass-by measurements, if noise limit reductions for type approval, that came into force in the meantime, led to reduction measures by the manufacturers, that also reduces the noise emission in real traffic. Furthermore should be investigated, if the still ongoing trends to wider and "faster" tyres (higher speed index) for cars and higher rated power values for trucks caused higher noise emissions in real traffic.

2 Tasks and Measurement Programme

The data from the above mentioned previous research projects can be separated into the following classes with respect to driving behaviour and traffic situations:

- Starting and Acceleration conditions (up to 60 km/h),
- Free flowing traffic with
  - speed limit 30 km/h,
  - speed limit 50 km/h,
  - speed limit 70 km/h,
  - speed limit 100 km/h,
- motorway.

3 measurement sites were established in addition to these traffic situations located in the northern part of the Eifel in order to investigate the noise emission of motorcycles.

The statistical pass-by measurements were carried out in accordance to ISO 11819-1. The measurement distance was 7,5 m from the centreline of the driving lane, the height was 1,2 m above the road surface. During the pass-by of a vehicle the vehicle speed was registered by radar or light barriers in addition to the noise level. The maximum noise level (Lmax) during the pass by performs the measurement result. The air temperature was also registered several times during a measurement period. For motorcycles also the deviation from the centreline of the drive lane was measured, since these vehicles have a higher degree of freedom than cars or trucks with respect to this parameter.

In order to get information about the technical data of the measured vehicles the license plate information was recorded and then sent to the Kraftfahrtbundesamt via UBA.

In order to achieve a good comparability with results from previous projects the measurements were carried out at previous sites as much as possible. Some previous sites had to be excluded because the road design had been changed by construction measures in the meantime. The measurements were carried out between spring 2001 and autumn 2002.

3 Results

3.1 Overview of the data measured in 2001/2002

3.1.1 Overall statistics

Table 1 shows an overview of the measuring sites and their characteristics. Table 2 contains the number of measured vehicles per category. In total 29767 vehicles were measured.

no	traffic condition	posted speed in km/h	average car speed in km/h	gradient	surface
1	low speed acceleration	50	36.8	0.0%	asphalt concrete 0/11
2	low speed acceleration	50	36.9	0.0%	asphalt concrete 0/11
3	low speed acceleration	50	35.2	0.0%	asphalt concrete 0/11
4	low speed acceleration	50	38.9	0.0%	asphalt concrete 0/11
5	acceleration	50	43	4.0%	asphalt concrete 0/11
6	acceleration	130	54.2	1.0%	asphalt concrete 0/11
7	residential, 30 km/h	30	37.8	2.0%	asphalt concrete 0/11
8	acceleration	50	36.6	2.0%	asphalt concrete 0/11
9	acceleration	50	33.8	0.0%	asphalt concrete 0/11
10	residential, 30 km/h	30	31.4	4.5%	asphalt concrete 0/11
11	residential, 30 km/h	30	36.2	0.0%	asphalt concrete 0/11
12	residential, 30 km/h	30	36.7	0.0%	asphalt concrete 0/11
13	main street	50	53.5	-1.5%	asphalt concrete 0/11
14	main street	70	49.8	0.0%	asphalt concrete 0/11
15	main street	50	56.1	5.0%	asphalt concrete 0/11
16	rural	70	60	0.0%	Gussasphalt 0/11
17	rural	70	68.5	0.0%	Gussasphalt 0/11
18	rural	70	66.3	0.0%	asphalt concrete 0/11
19	rural	70	70.3	0.0%	Gussasphalt 0/11
20	rural	100	93.9	0.0%	asphalt concrete 0/11
21	rural	100	72.6	0.0%	asphalt concrete 0/11
22	motorway	130	118.6	0.0%	stone mastic asphalt 0/11
23	motorway	130	121.1	0.0%	drainage asphalt 0/11
24	motorway	130	97.4	0.0%	cement concrete longitudinal brushed
25	motorway	130	101.47	0.0%	Gussasphalt 0/11+2/5
26	motorway with gradient	130	110.9	4.2%	Gussasphalt 0/11
27	motorway with gradient	130	108.2	3.5%	Gussasphalt 0/11
28	motorcycles	100	65	0.0%	asphalt concrete 0/11
29	motorcycles	100	75.8	5.0%	asphalt concrete 0/11
30	motorcycles	100	79.1	0.0%	Gussasphalt 0/11

Table 1: Characteristics of measuring sites

site	cars	LDV	HDV up to 3 axles	trailer trucks	bus	coach	motorcycles	mopeds	sum
1	351	81	269	314	9	3	3		**1030**
2	763	70	90	44	18	1	6	6	**998**
3	831	72	107	11	30	2	15	3	**1071**
4	687	61	83	56	6	1	5		**899**
5	882	60	22	3	20		19	3	**1009**
6	912	73	49	7		1	4		**1046**
7	992	55	22		40		10	4	**1123**
8	879	61	43	5	4		15	4	**1011**
9	788	60	26		5		2		**881**
10	615	39	11		65		15	8	**753**
11	727	41	35	9	2	2	9	6	**831**
12	843	77	28	3	6		7		**964**
13	824	67	45	4	6	2	11		**959**
14	915	46	17		9		35	14	**1036**
15	882	50	28	4	14	1	8		**987**
16	895	44	25	5	6	1	9	1	**986**
17	867	35	14	15	1		6	6	**944**
18	717	64	63	54		1	28	3	**930**
19	790	77	124	48	6	2	17		**1064**
20	920	64	71	32	1		5		**1093**
21	765	71	122	85		2	16	3	**1064**
22	446	73	176	398	1	6	3		**1103**
23	453	65	187	391	1	9	2		**1108**
24	356	53	222	352	5	2	1		**991**
25	734	70	101	179	2	1	7		**1094**
26	631	68	121	267	2	3	2		**1094**
27	257	52	153	585		3	2		**1052**
28	739	55	16	2	4		150	6	**972**
29	405	4					222	1	**632**
30	863	30	42	16	1	1	86	3	**1042**
sum	**21729**	**1738**	**2312**	**2889**	**264**	**44**	**720**	**71**	**29767**

Table 2: Number of vehicles per measuring site and category

Table 3 shows the distribution of engine capacity and rated power for cars, Table 4 shows the number of cars in different subcategories with respect to engine type and engine capacity. The total number of vehicles in

Figure 1 shows the registration year distributions for cars. The majority of vehicles were Registered between 1985 and 2001. The average registration year is 1995, which mans that the average age is about 6 years. Due to the trend to Diesel engines the Diesel engine sample is younger than the petrol engine sample.

Cars registered after 1996 and equipped with a direct injection Diesel engine have a 1 dB higher limit value than cars with petrol or precombustion Diesel engines. Table 5 shows, that this “discount” is not justified any longer, because there is no difference in the average type approval level.

Table 6 shows the distribution of registration year and type approval level for cars. The average type approval level is 72,6 dB(A). Three different groups can be separated. Cars registered before 1989, cars registered between 1989 and 1995 and cars registered after 1995.

The average type approval levels of these groups decrease with increasing registration year (decreasing age) from 76,2 dB(A) to 72,6 dB(A) (see Table 6). The type approval level distributions of the three groups are shown in Figure 2.

engine capacity in cm³	rated power in kW																														
	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	330	sum
600	12	15	57	5																												89
700	1	2																														3
800	2	139	7																													148
900		111		1																												112
1000		356	681	23	1																											1061
1100		5	640		10																											655
1200		353	240	110	92																											795
1300		6	681	113	309	20																										1129
1400		1	816	106	741	101	16		1																							1782
1500			31	19	57	125	11																									243
1600		1	187	419	1004	1213	535	62	4	1	2																					3428
1700			75	102	80	104	15	27	12	2	1																					418
1800			81	21	296	899	207	803	39	49	8	23	4			10																2440
1900			4	271	134	772	383	291	138	1	3			1																		1998
2000			14	130	223	288	144	777	651	314	59	5	6	7	2			1														2621
2100					5	12	57	107	14	64																						259
2200				2	17	141	68	93	34	85	3	27	1			1																472
2300				6	16	24	13	7	158	111	9	14	38	15	1	5	6															423
2400				12	71	8	21	39	48	52	55	69	7	3																		385
2500				14	54	135	93	76	65	182	39	184	61	7	1																	911
2600										41	6	13																				60
2700						11		8	2		32	36	15	3	5	2			1								2					117
2800					4	1	8	20	17	6		48	114	32					1													251
2900						16	3	31	50	7	3	24	65	8		4																211
3000							19	6	14	24	23	42	29	24	45	23	8		1	3												261
3100							4		5						2	3																14
3200						1					6			34	75	44		1					4	2								167
3300										8	12	1				1															1	23
3400										3			1		27			1			9		1									42
3500													5	2	3	8	5	1				1										25
3600																	5		3	7			1						1	1		18
3700									2							5		3														10
3800										1	2	4		3										1								11
3900											1	1					2															4
4000											7	7	7	7	3		10	1	2	25						2						71
4100														1		2																3
4200									1		3			3		2				5	10	9		2								35
4300																			6	10												16
4400																				21				1	2							24
4600															4	2					1			1								8
4700															4																	4
4900															3	1	1	3										3				11
5000																					3	12	9									24
5200															6																	6
5300																					1											1
5400																							5		3							8
5500																				1	1											2
5700															1																	1
5800														1												3						4
5900														1																		1
6000																												2	1			3
6700																							1									1
8000																												1				1
sum	15	989	3514	1354	3114	3871	1597	2347	1255	951	274	498	353	152	182	113	37	11	14	72	25	22	21	7	5	5	2	6	2	1	1	20810
																															no information	919
																															total	21729

Table 3: Car sample, engine capacity, rated power distribution

subcategory	number of vehicles
petrol, <= 1400 cm³	5702
petrol, > 1400 cm³ <= 2000 cm³	7827
petrol, > 2000 cm³	2128
Diesel, <= 2000 cm³	1391
Diesel, > 2000 cm³	751
Diesel DI, <= 2000 cm³	2002
Diesel DI, > 2000 cm³	1007
others	2
no information	919
sum	**21729**

Table 4: Car sample, subcategories (Diesel means precombustion Diesel engines, Diesel DI means direct injection Diesel engines)

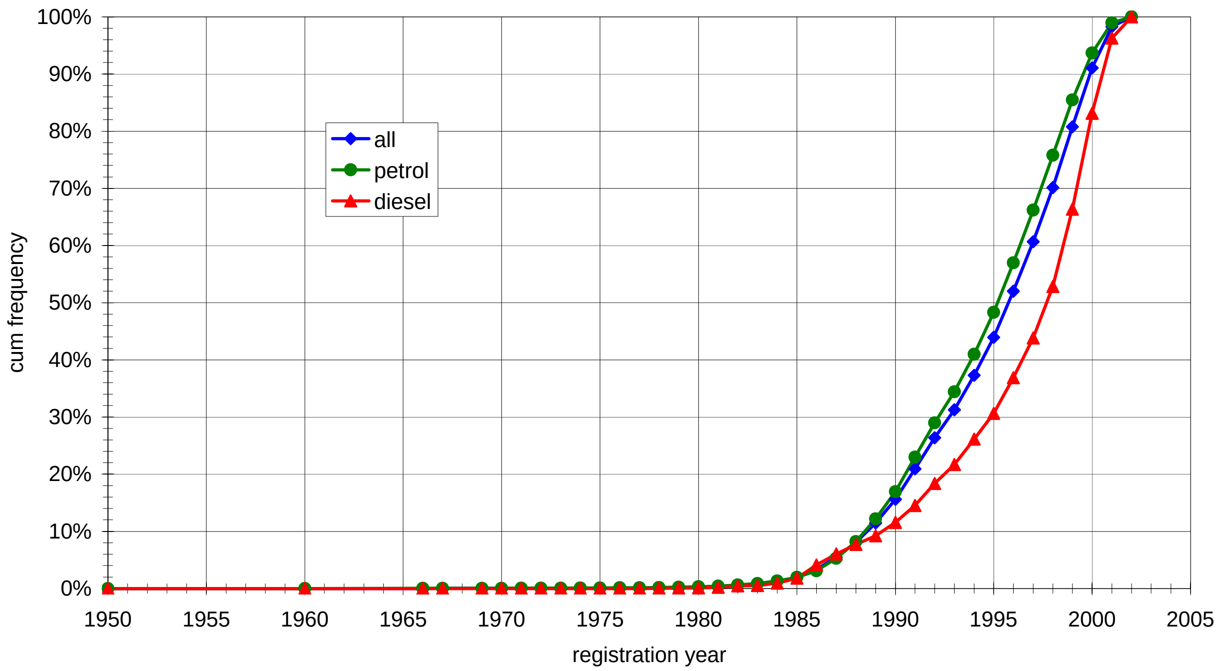

Figure 1: car sample, registration year distribution

engine type	average type approval level in dB(A)	no of vehicles
petrol	72.6	8053
Diesel	73.3	737
Diesel, DI	72.6	2850

Table 5: Average type approval level for cars, registered after 1996

	type approval value in dB(A)																	
registration year	no info	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	**sum**	
no info	906							1			1								
1950	1																	1	
1966	1																	1	
1967	1																	1	
1969	1																	1	
1970	2																	2	
1971	2																	2	
1972															1			1	
1973															2			2	
1974	2																	2	
1975										1					2	1		4	
1976									1					1			1	3	
1977											1							1	
1978	1								1		1			2	2	1		8	
1979	3								1		1	1	1	3	2	1		13	
1980	2											1	3	4	3	1		14	
1981					2	1			1	1	2	2	1	7	5	1		23	
1982	4								3	4	4	5	4	9	7			40	
1983	4				2		2	1	1	1	3	7	9	7	6			43	
1984	8					4	3	3	3	19	4	20	9	9	11			93	
1985	7				2	3	6	3	5	32	20	34	14	7	14			147	
1986	27				4	1	12	11	15	43	43	47	35	16	42			296	
1987	21				1	7	11	31	40	102	67	56	42	19	40			437	
1988	31					12	15	24	60	135	69	112	45	22	24			549	
1989	36			1		10	42	63	60	116	157	156	32	23	10		1	707	
1990	60			1		9	42	89	75	165	219	194	1	2				857	
1991	79			3	4	24	54	135	125	217	228	230	1					1100	
1992	93			6	1	24	52	163	191	287	201	113	3					1134	
1993	96	1		4		11	73	171	230	261	120	54	5					1026	
1994	125				14	26	120	263	349	231	96	36						1260	
1995	126			2	15	48	105	401	356	177	107	34	4					1375	
1996	126			6	23	176	230	512	448	99	33	8	1					1662	
1997	150	1	5	25	44	182	350	544	432	56	4							1793	
1998	132	7	5	22	60	198	441	583	456	59								1963	
1999	149	16	2	38	92	296	453	656	431	86		1						2220	
2000	178	11	14	29	73	322	503	581	359	87	2							2159	
2001	129	3	12	25	68	257	422	331	234	32	3							1516	
2002	38	1	10	14	23	39	80	80	67	12	1							365	
																			average type approval level in dB(A)
sum	**2541**	**40**	**48**	**176**	**428**	**1650**	**3016**	**4646**	**3944**	**2223**	**1387**	**1111**	**210**	**131**	**171**	**5**	**2**	**21729**	**73.6**
< 1989	118	0	0	0	11	28	49	73	131	338	215	285	163	106	161	5	1	**1684**	**76.2**
1989 to 1995	615	1	0	17	34	152	488	1285	1386	1454	1128	817	46	25	10	0	1	**7459**	**74.5**
> 1995	902	39	48	159	383	1470	2479	3287	2427	431	43	9	1	0	0	0	0	**11678**	**72.6**

Table 6: car sample, registration year and type approval values

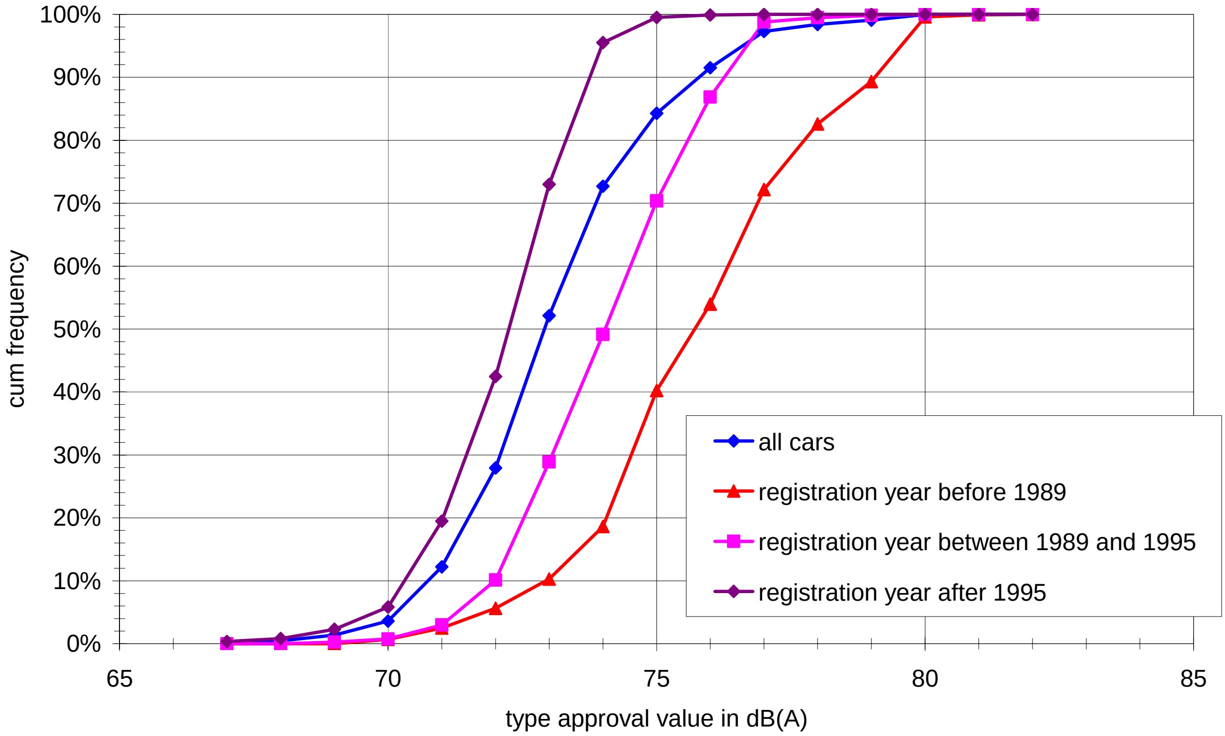

Figure 2: car sample, type approval level distributions

Similar distributions as shown before for cars are shown for light duty vehicles in Table 7 to Table 10 and Figure 3 and Figure 4. Light duty vehicles (LDV) are commercial vehicles with a gross vehicle mass (GVM) of up to 3500 kg. The age trend is the same as for cars. The youngest subsample is LDV with Diesel engines and direct injection. These vehicles get a bonus of 1 dB(A) compared to vehicles with precombustion Diesel engines or petrol engines, if they are registered after 1996. Table 9 shows the average type approval level for LDV registered after 1996 for different GVM and engine type classes. For LDV with GVM up to 2000 kg there is no significant difference in the average type approval level between the engine type classes, for LDV with GVM higher than 2000 kg the vehicles with direct injection Diesel engines have a significantly higher average type approval level than the other engine type classes.

Furthermore, since light duty vehicles with GVM up to 2000 kg and light duty vehicles with GVM > 2000 kg have different limit values (76 dB(A) and 77 dB(A)), the type approval level distributions are also split into these groups in Table 9, Table 10 and Figure 4. The difference in type approval levels is 0,5 dB for petrol and Diesel engines and 2,5 dB for direct injection Diesel engines (see Table 9).

			rated power in kW													
	cap_kl	**no info**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**sum**
engine capacity in cm³	no info	87														**87**
	1000		3	1												**4**
	1100		4	14		1										**19**
	1200			4												**4**
	1300			9	1	2										**12**
	1400			24	4	9										**37**
	1500				2	3										**5**
	1600			32	24	1	1									**58**
	1700			43	12											**55**
	1800			38	3	3	5									**49**
	1900			33	168	18	23									**242**
	2000				10	21	22	3		2						**58**
	2100			2	2	28	4	41	5	26	1					**109**
	2200				13	9	3	4	3							**32**
	2300					139	9	2			2					**152**
	2400				36	129	24	9	14							**212**
	2500				47	130	54	91	16							**338**
	2700					4	2					10	1			**17**
	2800					14	3	30	72	3						**122**
	2900						19	36	88							**143**
	3000					1										**1**
	3100							4								**4**
	3200						1									**1**
	3800					1										**1**
	4000												1			**1**
	4200													1		**1**
	4300											1				**1**
	5700									1			1		3	**5**
	5800											1				**1**
	6200									2						**2**
	sum	**87**	**7**	**200**	**322**	**513**	**170**	**220**	**198**	**34**	**3**	**12**	**3**	**1**	**3**	**1773**

Table 7: Light duty vehicle sample, engine capacity, rated power distribution

subcategory	number of vehicles
petrol, <= 2000 kg GVM	90
Diesel, <= 2000 kg GVM	163
Diesel DI, <= 2000 kg GVM	38
petrol, > 2000 kg GVM	80
Diesel, > 2000 kg GVM	724
Diesel DI, > 2000 kg GVM	677
no info	1
sum	**1773**

Table 8: Light duty vehicle sample, subcategories (GVM – gross vehicle mass)

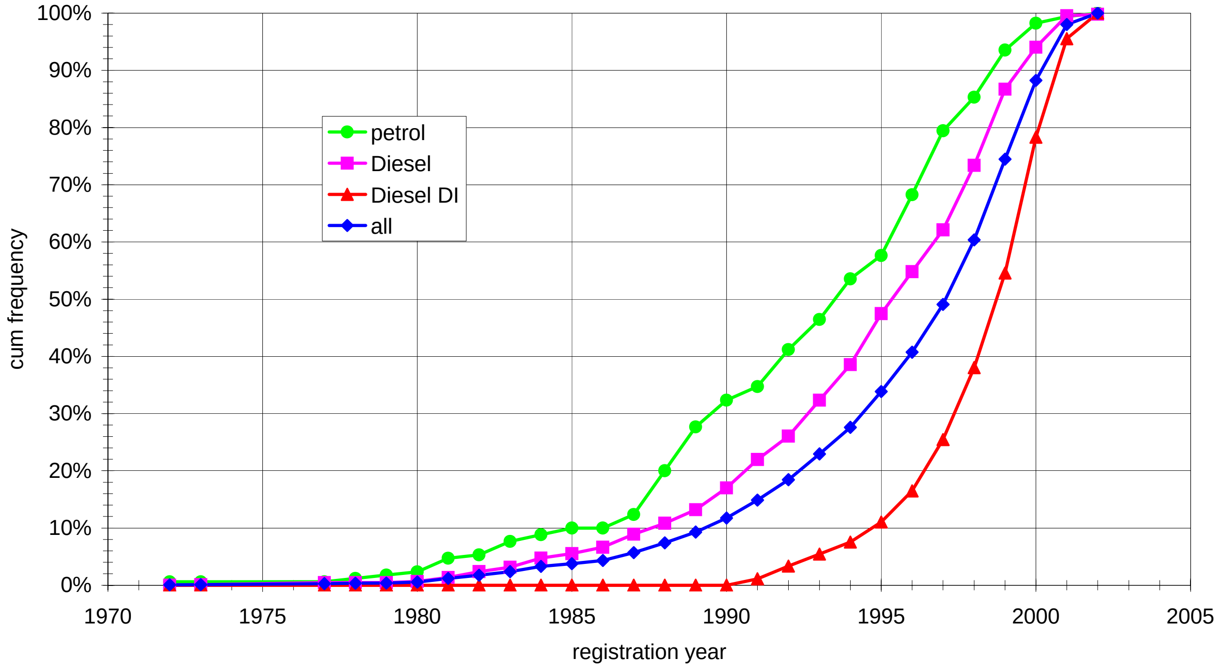

Figure 3: Light duty vehicle sample, registration year distribution

gross vehicle mass in kg	engine type	average type approval level in dB(A)	no of vehicles
<= 2000	petrol	73.4	45
<= 2000	Diesel	74.1	109
<= 2000	Diesel, DI	73.8	36
> 2000	petrol	73.9	17
> 2000	Diesel	74.7	332
> 2000	Diesel, DI	76.3	575

Table 9: Average type approval level for light duty vehicles, registered after 1996

	type approval value in dB(A)															
registration year	**no info**	**69**	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**sum**	
no info	51														**51**	
1972	1														**1**	
1973	1														**1**	
1977	3														**3**	
1978														1	**1**	
1979	3														**3**	
1980	5											5			**10**	
1981	6											3			**9**	
1982	3									1	1	3	1		**9**	
1983	6						1				2	6			**15**	
1984	6									1		2			**9**	
1985	9												1		**10**	
1986	12							1	1		1	8	1		**24**	
1987	6				1		5	2	3	3	7	3			**30**	
1988	15						4	1	4	2	4	2			**32**	
1989	24						1	1	8	1	5	1			**41**	
1990	19					6	1	13	5		4	4			**52**	
1991	14					8	8	14	4	1	3	6			**58**	
1992	22				4	10	6	16	8		1	8			**75**	
1993	25				3	3	11	11	14	5	2	1			**75**	
1994	33			2	1	12	11	22	16	9	3				**109**	
1995	19	1	1		12	29	7	17	16	15		1			**118**	
1996	14		2	1	15	38	18	12	16	25					**141**	
1997	27		3	4	11	61	18	16	18	30	2		1		**191**	
1998	30			1	6	77	18	43	11	54					**240**	
1999	38			2	13	67	17	24	17	49					**227**	
2000	18			4	18	59	32	18	12	9					**170**	
2001	7			1	4	11	7		2	1					**33**	
2002	8			1	4	12	7		2	1					**35**	
sum	**425**	**1**	**6**	**16**	**92**	**393**	**172**	**211**	**157**	**207**	**35**	**53**	**4**	**1**	**1773**	average type approval level in dB(A)
															all	**75.7**
registration year before 1989	76	0	0	0	1	0	10	4	8	7	15	32	3	1	**157**	**78.5**
registration year between 1989 and 1995	156	1	1	2	20	68	45	94	71	31	18	21	0	0	**528**	**76.0**
registration year after 1995	142	0	5	14	71	325	117	113	78	169	2	0	1	0	**1037**	**75.3**
GVM <= 2000 kg	19		6	3	60	113	41	24	14	3	8	2			**293**	**74.4**
GVM > 2000 kg	368	1		12	34	288	128	196	149	213	29	56	4	1	**1479**	**76.0**

Table 10: Light duty vehicle sample, registration year and type approval values (GVM – gross vehicle mass)

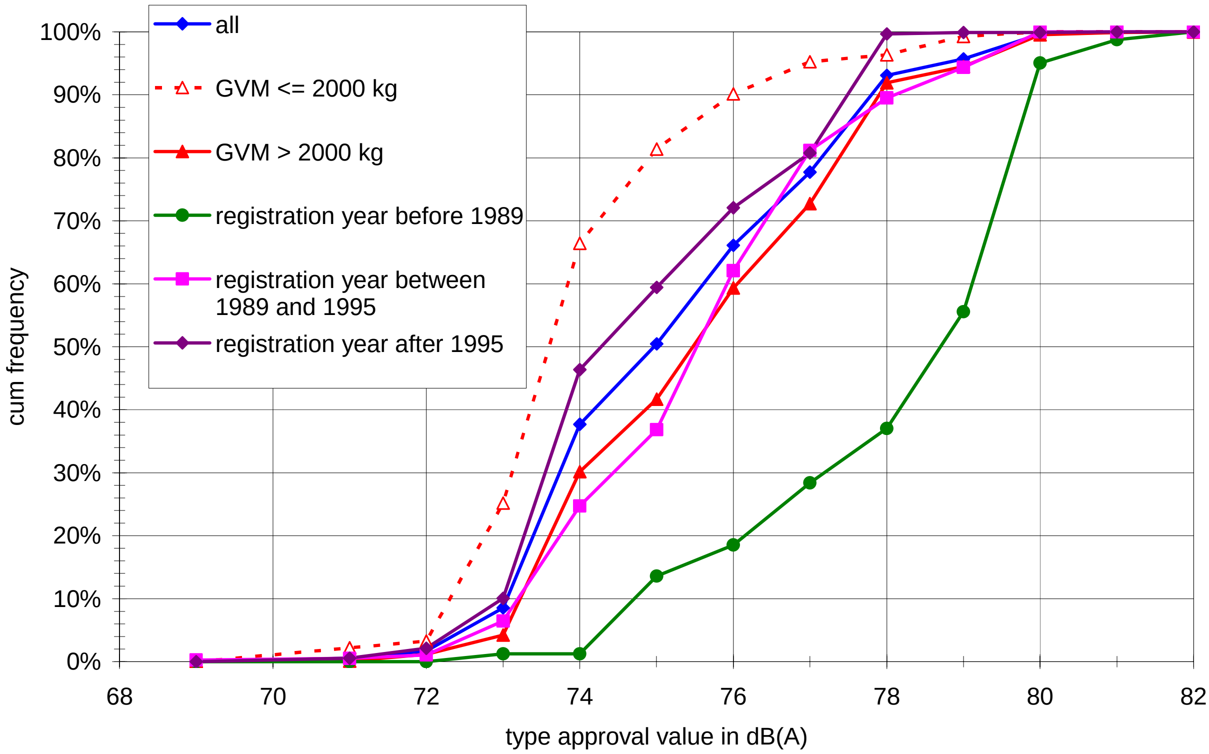

Figure 4: Light duty vehicle sample, type approval level distributions (GVM – gross vehicle mass)

Table 11 gives an overview of the distribution of engine capacity and rated power for heavy duty vehicles (HDV) with up to 3 axles. Table 12 shows the same for HDV with more than 3 axles. The age distributes for both groups are shown in Figure 5. Since the information of type approval level is missing for the major part of the HDV sample, no adequate tables or figures can be provided.

For motorcycles the information about type approval level was given, the distribution is shown in Table 13. Three different groups can be seen, motorcycles registered before 1990, between 1990 and 1996 and after 1996. The average type approval levels decrease with decreasing age from 82,8 dB(A) to 79 dB(A).

		rated power in kW																														
	cap_kl	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	340	350	370	400	sum
engine capacity in cm³	2000		2																															2
	2100				1		3																											4
	2300		10	2	1																													13
	2400	6	1	2																														9
	2500		4		6	12																												22
	2700								3																									3
	2800				2	24	2																											28
	2900			13	1	27								1																				42
	3000		1				1																											2
	3300			1		4																												5
	3400			1																														1
	3800		16	1																														17
	3900			28	4	9	59	11	4	5									1															121
	4000		9	12	16	4	33																											74
	4100		4					3																										7
	4200					6	57	115		112																								290
	4300						2			1																								3
	4600				13		3	93	6	27																								142
	4900							1																										1
	5300							1																										1
	5400						1	1																										2
	5500						1			17		1	2		2																			23
	5600						7		3	1	2																							13
	5700										1																							1
	5800						2		2																									4
	5900						58	69	1	59		31	3	12	2		1																	236
	6000					2	122		23	51			25		19																			242
	6100					2	7		2																									11
	6200					1				6		2	1	1	2																			13
	6400													79				67																146
	6500									1																								1
	6600										2			4																				6
	6800							4																										4
	6900						1	21			14		60	26	1	29	25	15																192
	7300									1		1																						2
	7700																3																	3
	7800														5		1			3			2											11
	8400												1	1																				2
	8500											1	1		2	1		2																7
	9000												4	9		4				3														20
	9200																	1																1
	9400										1																							1
	9500										5								3			6			3									17
	9600														38		9			14														61
	9800																		1			8												9
	10000																4	7			10	4												25
	10300																		1										1					2
	10600																					2			2									4
	10900											1	20																					21
	11000														31		11			15	2	11			1									71
	11300											1	34	13	1			1																50
	11600																							1										1
	11700																							1		3		1						5
	11900																	9		47	1		14	3		26			13	1				114
	12000																	6		17	1			21		14	8	1						68
	12100																			4					4			1						9
	12600																						1						2					3
	12700													1																				1
	12800																					3			6					4				13
	13700																		1															1
	13800																							4				3						7
	14500														8			5			1		1											15
	14600																1							20	10				7			1		39
	15100																4	15	2															21
	15900																														2			2
	17200																																2	2
	sum	6	47	60	44	91	359	319	44	281	25	38	151	147	111	34	59	128	9	103	15	34	18	50	26	43	8	6	23	5	2	1	2	2289

Table 11: Heavy duty vehicles up to 3 axles, distribution of engine capacity and rated power

		rated power in kW																									
		170	180	190	200	210	230	240	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390	400	410	420	430	sum
engine capacity in cm³	6400	1				4																						5
	6900	3		2	1	1																						7
	7800						1			4																		5
	8700			1																								1
	9000			2			1																					3
	9500								6			16	1															23
	9600		3		4		4																					11
	9800								1																			1
	9900																	1										1
	10000			1	2	1		10	12		1																	27
	10100										2																	2
	10300												4			22												26
	10600								4			31																35
	10900								1		1																	2
	11000				1		2	1	32		12	9	1															58
	11100											9	15	18														42
	11500						1			1																		2
	11600										5			6		4												15
	11700										14		46	1	61				7									129
	11900					2	9	1		80	3	2	335		9	311		6	5									763
	12000					2	3			2	70	2	186	229	30	2												526
	12100		1				1		6			50		1	100			19										178
	12600						1					27				91				15			1					135
	12700											2																2
	12800						1		3			41						184										229
	13800				1						6				35				19									61
	14200														2	1	3	14			4		16					40
	14500		3					1		7																		11
	14600									2	62	110				93			1	7	14		13					302
	15100				3	1																						4
	15600										1								16								4	21
	15900																		79			1	36			7		123
	16100																					1						1
	16400																								1			1
	17100														1													1
	17200																							1				1
	18300																	2			3							5
	19900															1												1
	sum	4	7	6	12	11	24	13	65	96	177	299	588	255	238	525	3	226	127	22	21	2	66	1	1	7	4	2800

Table 12: Heavy duty vehicles with more than 3 axles, distribution of engine capacity and rated power

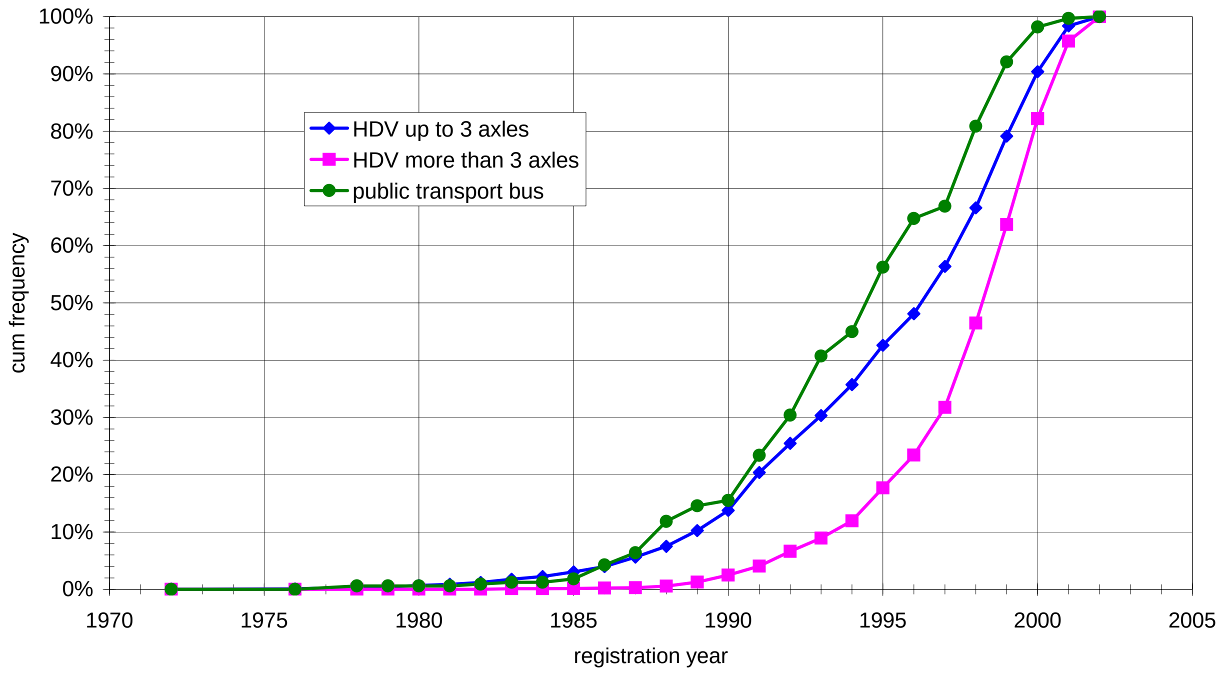

Figure 5: HDV sample, distribution of registration year

	type approval value in dB(A)														
registration year	**no info**	**74**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**sum**	
1956	1													**1**	
1958	1													**1**	
1960	1													**1**	
1966	1													**1**	
1972	1													**1**	
1975									1	1				**2**	
1977	1						1							**2**	
1978							1				1			**2**	
1980								2	1					**3**	
1981	4						1	1						**6**	
1982	3						1	2	1	1				**8**	
1983						1		1	2		1	2		**7**	
1984	3							1			2	3		**9**	
1985								1		2			1	**4**	
1986	2								12		1	1		**16**	
1987	4							2			3	2		**11**	
1988	1										2	2		**5**	
1989	1								1	1	4		1	**8**	
1990			1			1	2	3	2					**9**	
1991	4				1	2	5	6	3					**21**	
1992	6				2	1	8	10	4					**31**	
1993	4					1	6	3	3					**17**	
1994	5				2		11	9	11	1				**39**	
1995	5				1	2	10	2	5					**25**	
1996	9				4	10	17	1						**41**	
1997	4		2	2	8	13	17							**46**	
1998			2	4	6	22	10							**44**	
1999	5			2	10	30	15							**62**	
2000	3	2	1	1	5	24	16							**52**	
2001	3			2	10	30	14							**59**	
2002	2			1	5	23	15							**46**	
sum	**74**	**2**	**6**	**12**	**54**	**160**	**150**	**44**	**46**	**6**	**14**	**10**	**2**	**580**	**average type approval level in dB(A)**
registration year before 1990		0	0	0	0	1	4	10	18	5	14	10	2	**64**	**82.8**
registration year between 1990 and 1996		0	1	0	10	17	59	34	28	1	0	0	0	**150**	**80.3**
registration year after 1996		2	5	12	44	142	87	0	0	0	0	0	0	**292**	**79.0**

Table 13: Motorcycle sample, distribution of registration year and type approval values

3.1.2 Maximum pass by level versus vehicle speed, overview of vehicle categories

The road surface of the major part of the measurement sites was asphalt concrete 0/11 with a maximum chipping size of 11 mm. Therefore this surface was treated as reference. Some others were cement concrete and Gussasphalt and the road surface of one site was an open graded drainage asphalt 0/11. The results of the sites with cement concrete and Gussasphalt were "corrected" to asphalt concrete 0/11 in order to get one homogeneous sample for the reference surface. The correction was made by calculating the deviation of the average maximum pass by levels (Lmax) for a particular site from the regression curve of all sites with the reference surface. This deviation was then added to the individual Lmax results. The results for the drainage asphalt were kept unchanged. The results were then grouped in sites with free flowing traffic and sites with accelerating vehicles.

All individual Lmax values for cars on the reference surface asphalt concrete 0/11 are shown in Figure 6 in dependence of the individual vehicle speed separately for free flowing traffic and accelerating vehicles. Accelerating vehicles between 75 and 95 km/h come from the lower end of the vehicle speed range on motorway sites with normally free flowing traffic. This speed cannot be treated as normal cruising speed. The vehicles are most probably accelerating.

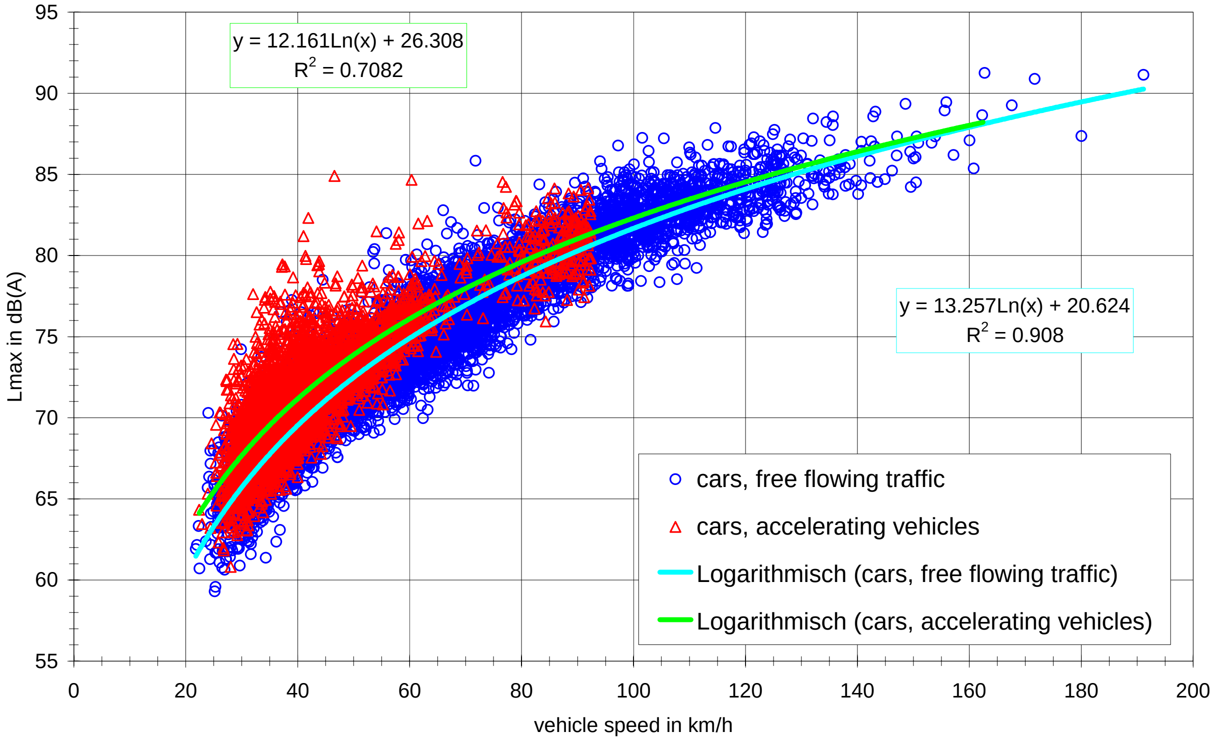

Figure 6: Lmax values for cars versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

The results can be approximated by logarithmic functions, which are also shown in Figure 6. The regression line for accelerating vehicles is higher than for free flowing traffic, the differences decrease with increasing vehicle speed. The difference is 2,4 dB(A) at 20 km/h, 1 dB(A) at 70 km/h and below 0,5 dB(A) above 115 km/h.

The results for light duty vehicles are shown in Figure 7. Light duty vehicles are commercial vehicles with gross vehicle mass up to 3500 kg. Also their results can be approximated by logarithmic functions and the tendencies are the same as for cars. The difference between the regression curves for accelerating vehicles and free flowing traffic decrease with increasing vehicle speed and is a bit higher than for cars. At 25 km/h the average emission of accelerating vehicles is about 4 dB higher than the average emission of free flowing traffic, this difference is reduced to 2 dB at 55 km/h and 1 dB at 85 km/h.

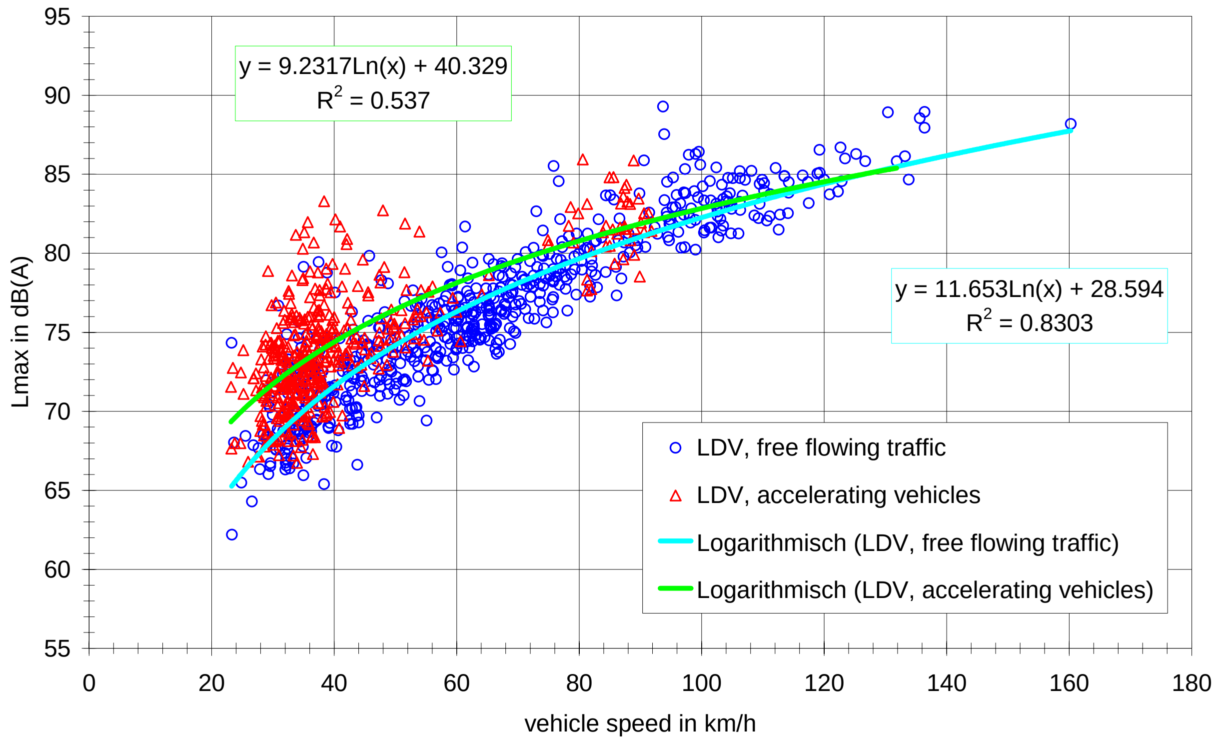

Figure 7: Lmax values for light duty vehicles versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

The results for heavy duty vehicles were separated with respect to two parameters, rated power and number of axles. Heavy duty vehicles are commercial vehicles with gross vehicle mass above 3500 kg. The current noise regulation has separate limit values for the following rated power classes: below 75 kW (77 dB(A)), between 75 and 149 kW (78 dB(A)) and 150 kW or more (80 dB(A)). The parameter “number of axles” was added because the influence of tyre/road noise is different.

The rated power class below 75 kW will no longer exist in the future because of the still on-going trend to higher rated power values. In the 2001/2002 measurement campaign only 78 vehicles with rated power below 75 kW were measured.

The results are shown in Figure 8. The results for free flowing traffic can be approximated by a linear function. For systematic reasons, this approximation was also applied for the results of accelerating vehicles, but the correlation is extremely poor due to the small speed range and the high scatter of noise values for a given speed. The differences between the average results for accelerating vehicles and free flowing traffic at the lower end of the speed range is the same as for LDV but the decrease with increasing speed is lower than for LDV.

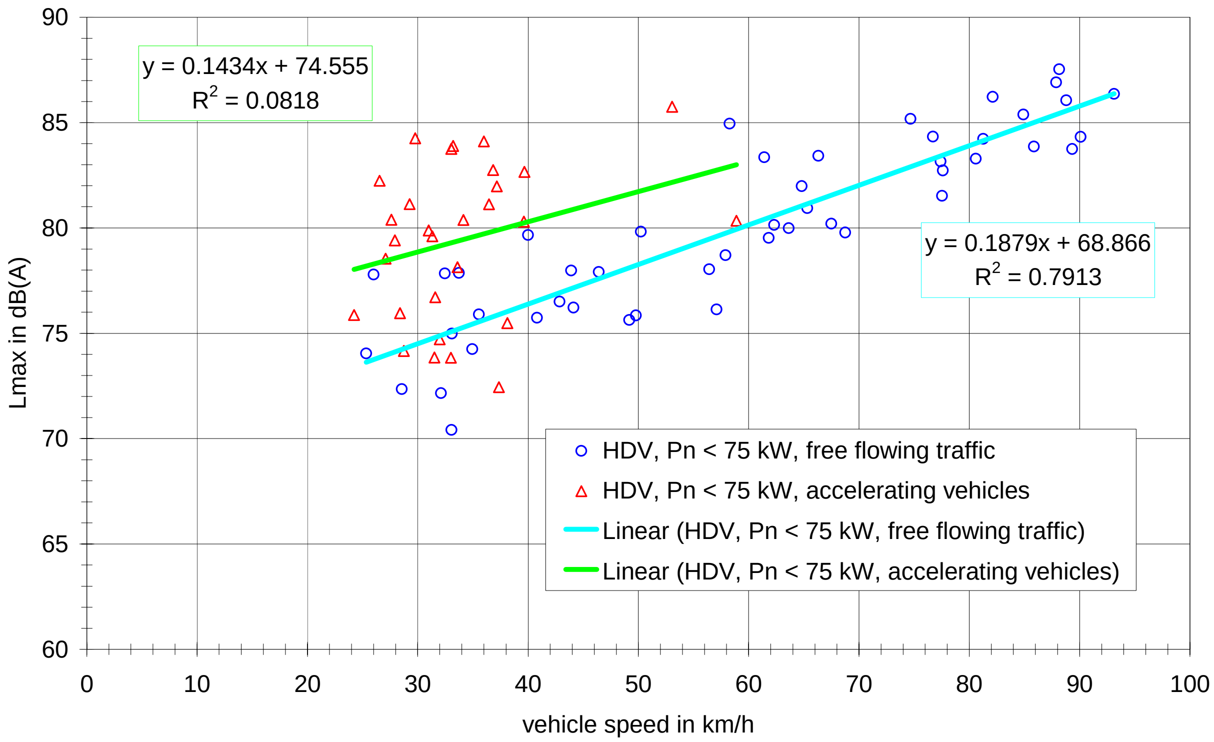

Figure 8: Lmax values for heavy duty vehicles with rated power values below 75 kW versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

Figure 9 shows similar results for HDV with rated power values of 75 kW or higher but below 150 kW. The trends are the same as for HDV below 75 kW and even the average noise values are nearly the same.

The rated power class of 150 kW or more was subdivided into two classes, rated power values of 150 kW or higher but below 250 kW and 250 kW or higher. This separation was made with respect to the proposal for new power classes that better reflect the existing situation than the power classes of the current noise regulation. Figure 10 shows the results for HDV with rated power values of 150 kW or higher but below 250 kW. Figure 11 shows similar results for HDV with rated power values of 250 kW or higher. The results for both classes show the same trends as mentioned before but the noise levels are higher.

The results for the second parameter (number of axles) are shown in Figure 12 (HDV up to 3 axles) and Figure 13 (HDV with more than 3 axles).

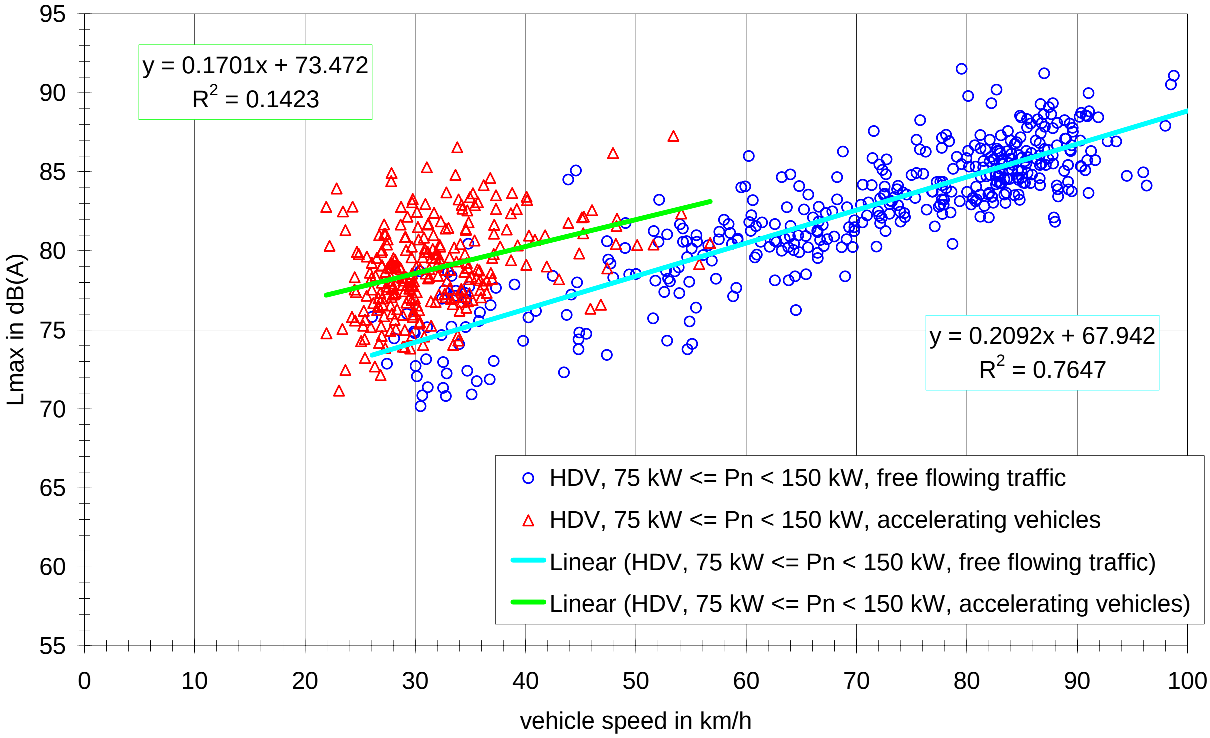

Figure 9: Lmax values for heavy duty vehicles with rated power values of 75 kW or higher but below 150 kW versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

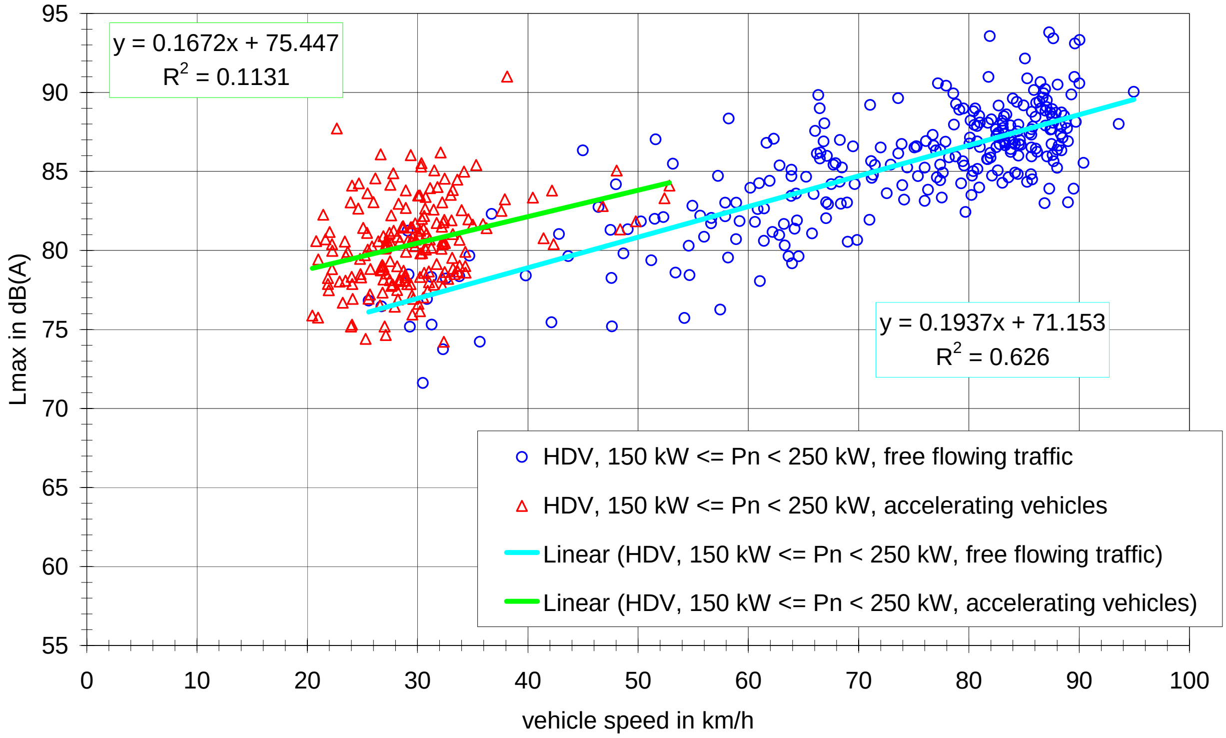

Figure 10: Lmax values for heavy duty vehicles with rated power values of 150 kW or higher but below 250 kW versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

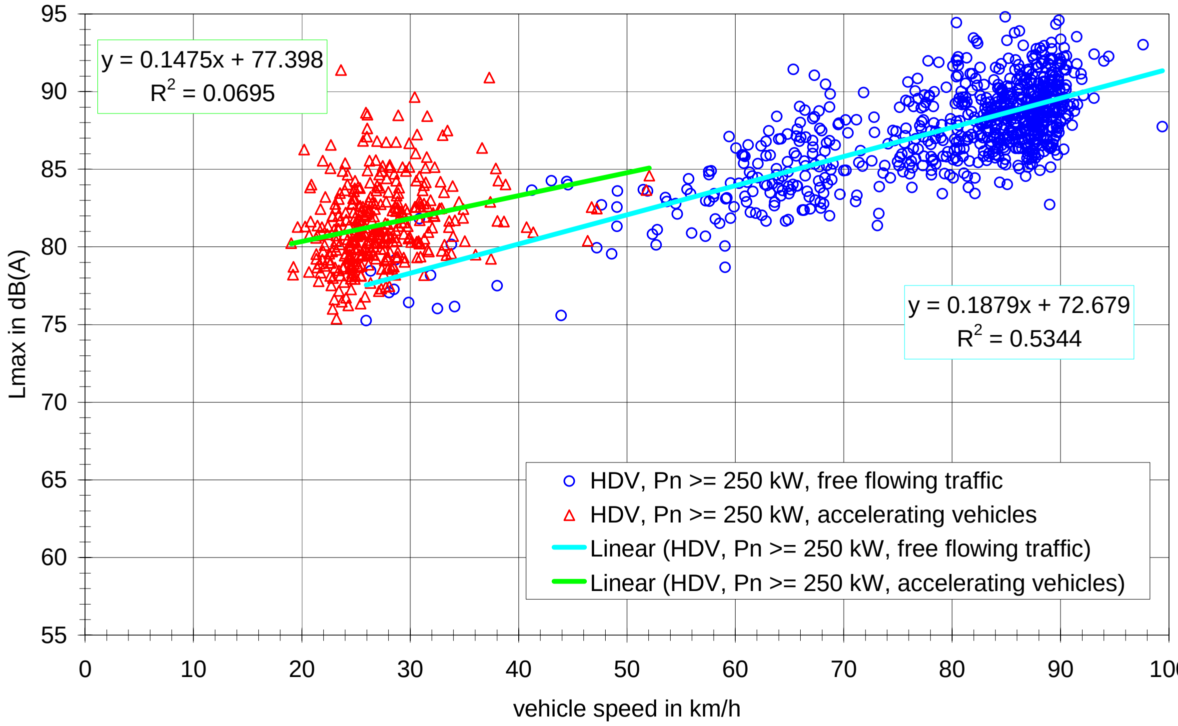

Figure 11: Lmax values for heavy duty vehicles with rated power values of 250 kW or higher versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

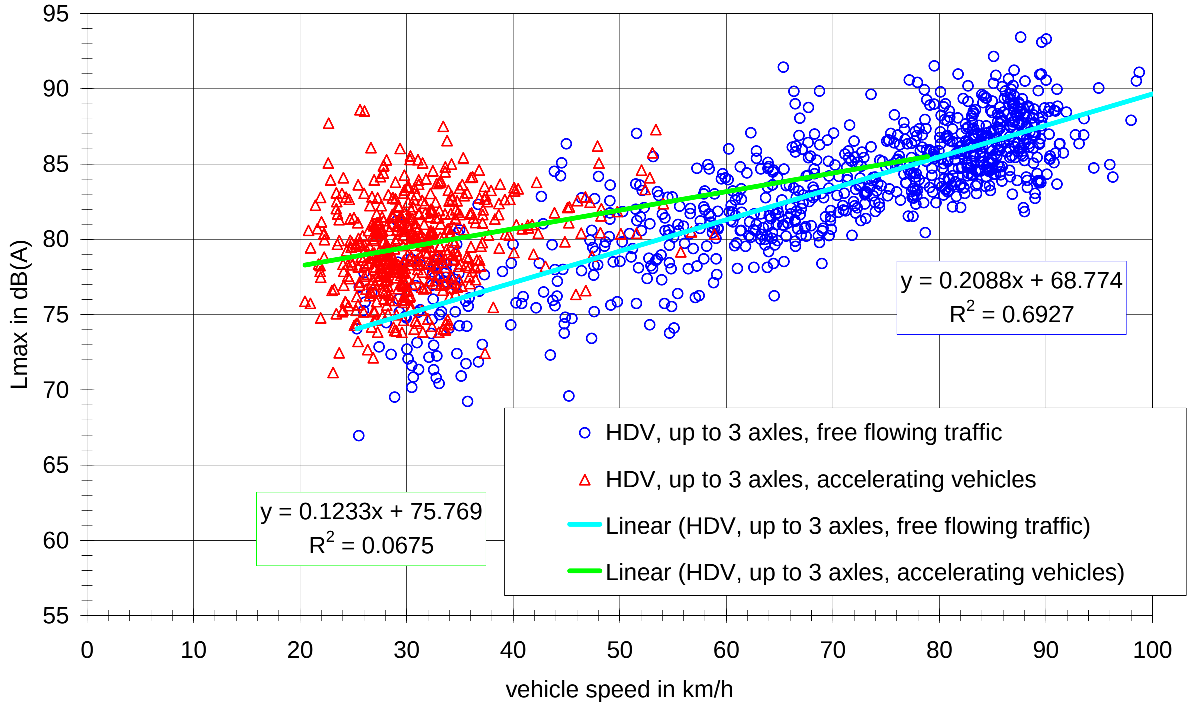

Figure 12: Lmax values for heavy duty vehicles with up to 3 axles versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

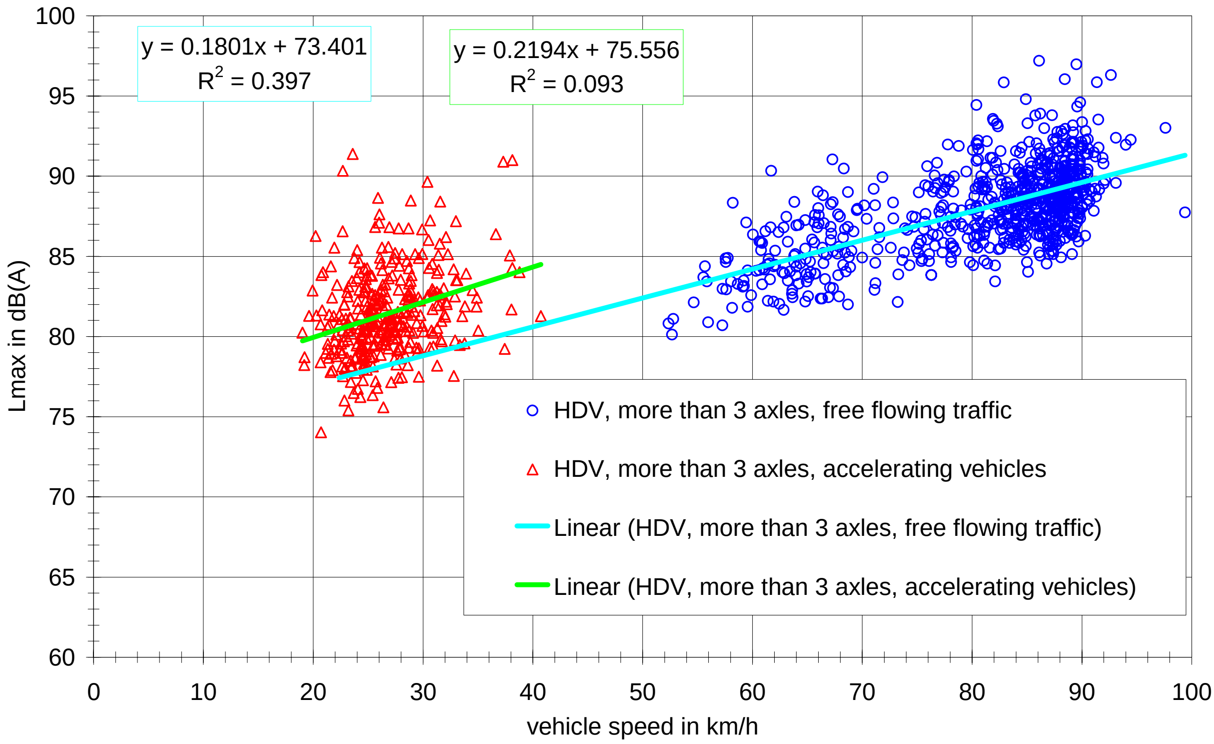

Figure 13: Lmax values for heavy duty vehicles with more than 3 axles versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

The 2001/2002 measurement campaign led only to a very small sample of public transport buses. The results are shown in Figure 14. The major part of the results is concentrated around 30 km/h. Thus the uncertainty of the speed trend is significantly higher than for the other commercial vehicles. The average difference between accelerating vehicles and free flowing traffic around 30 km/h is 2,7 dB(A).

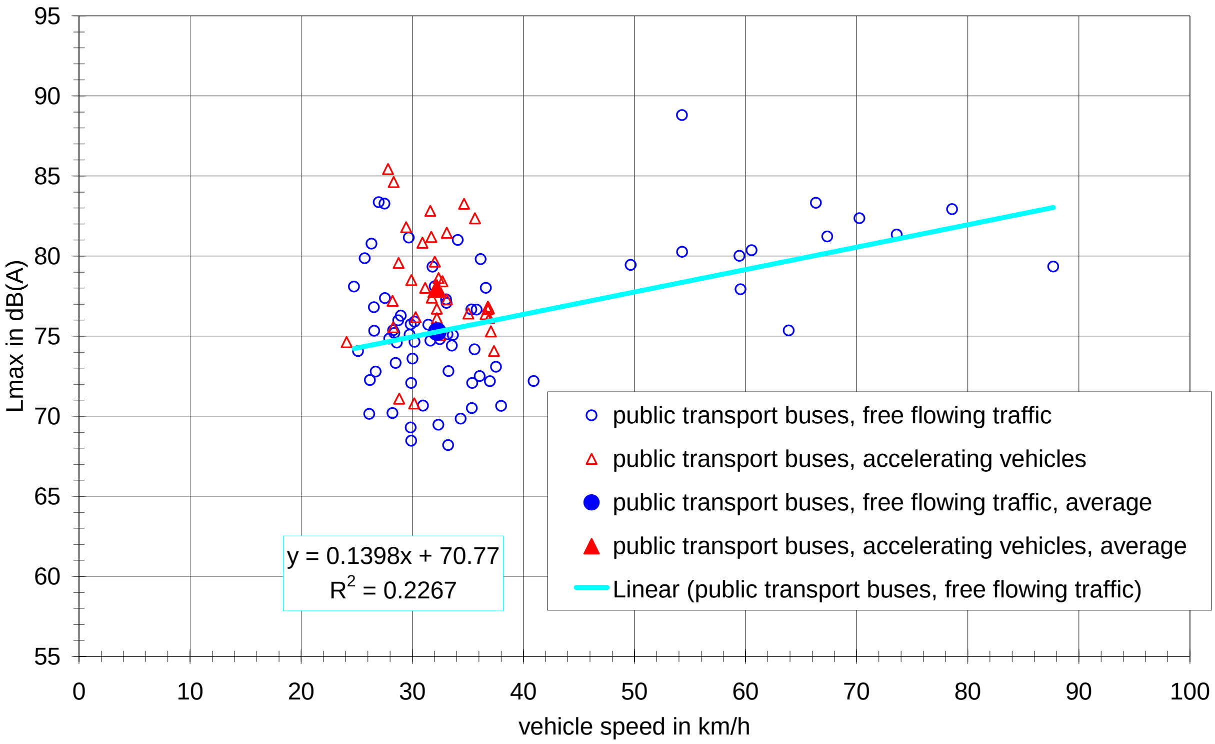

Figure 14: Lmax values for public transport buses versus vehicle speed on asphalt concrete 0/11 or stone mastic asphalt 0/11 for free flowing traffic and accelerating vehicles.

The results for motorcycles and mopeds are shown in Figure 15. They could not be separated into accelerating vehicles and free flowing traffic. The major part is most probably free flowing traffic since motorcyclists are very sensitive against speed measurements.

The regression curves for the results of the vehicle categories and free flowing traffic are shown in Figure 16, the corresponding curves for accelerating vehicles in Figure 17. Cars have the lowest noise emission levels followed by LDV. For free flowing traffic LDV have about 3 dB higher noise emission values at 20 km/h. The difference decreases with increasing speed and is zero at 130 km/h. Next in the rank order are motorcycles. Between 60 km/h and 100 km/h their average noise levels are nearly the same as for LDV. But since the regression is linear, their emission levels at lower speeds and higher speeds than the mentioned range are higher. At 30 km/h the average emission level for motorcycles is about 6 dB higher than for cars.

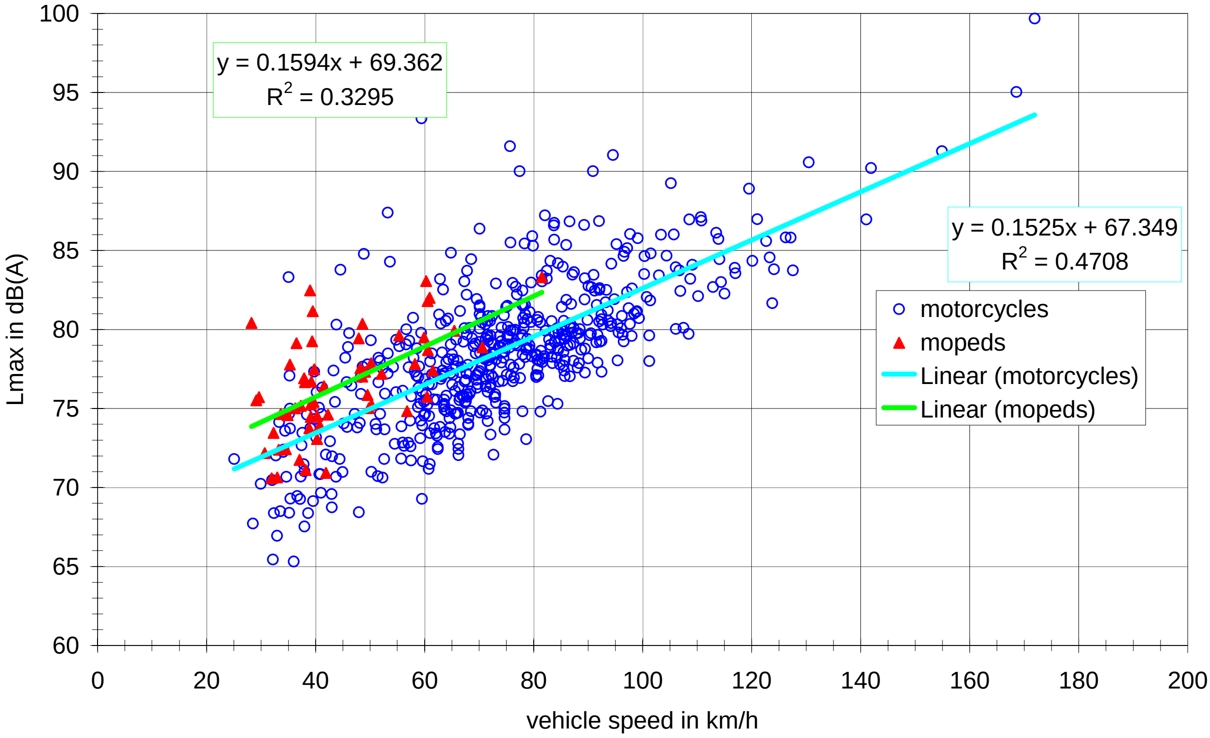

Figure 15: Lmax values for motorcycles versus vehicle speed.

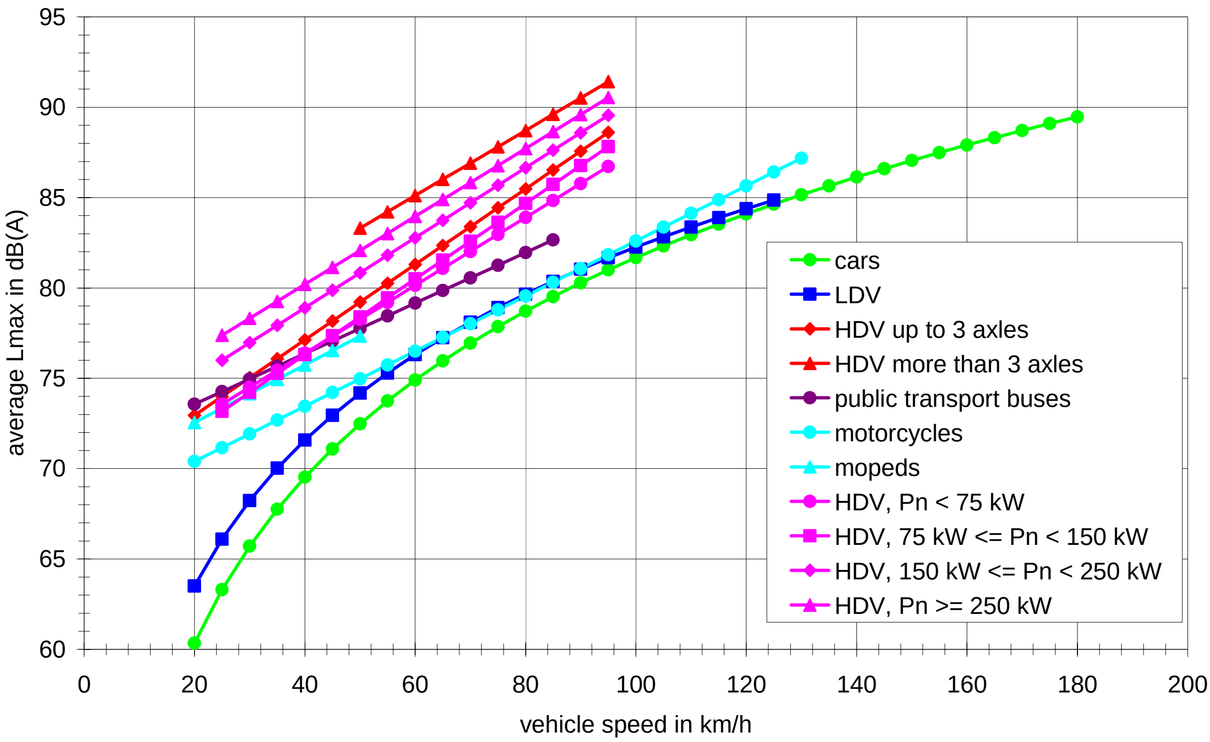

Figure 16: Average Lmax values for different vehicle categories and free flowing traffic

Mopeds have a bit more than 2 dB higher noise emission levels than motorcycles. Their emission is similar as for buses and small HDV. As already mentioned, the emission levels for HDV below 75 kW rated power and HDV with rated power values of 75 kW or more but below 150 kW is almost the same. This is also the case for accelerating vehicles (Figure 17), so that on can conclude that both classes can be merged. The emission levels of public transport buses are also nearly the same as for small HDV, although their rated power values were 150 kW or even higher.

The two highest HDV rated power classes show significantly higher noise emission levels. The difference between both is below 2 dB, but there are other reasons for the separation, that will be explained later. The comparison of the noise levels for the highest HDV rated power class and HDV with more than 3 axles leads to the conclusion that the overall noise emission is influenced by the tyres, at least for free flowing traffic and even at a vehicle speed of 50 km/h.

The average Lmax values cannot be used directly for planning and forecasts, where one needs the contributions to the Leq. These contributions are shown in Figure 18 and Figure 19 on an hourly base for one average vehicle of each category and a reference distance of 25 m. The values are calculated by the following equation:

$$\mathbf{L_m(1h) = Lmax - 10 \bullet \log\left(\frac{v}{km/h}\right) - 23{,}3 \qquad \text{in dB(A)}}$$

Where: $L_m(1h)$ hourly contribution to the Leq in 25 m distance,

L_{max} average pass by level in 7,5 m distance

v vehicle speed

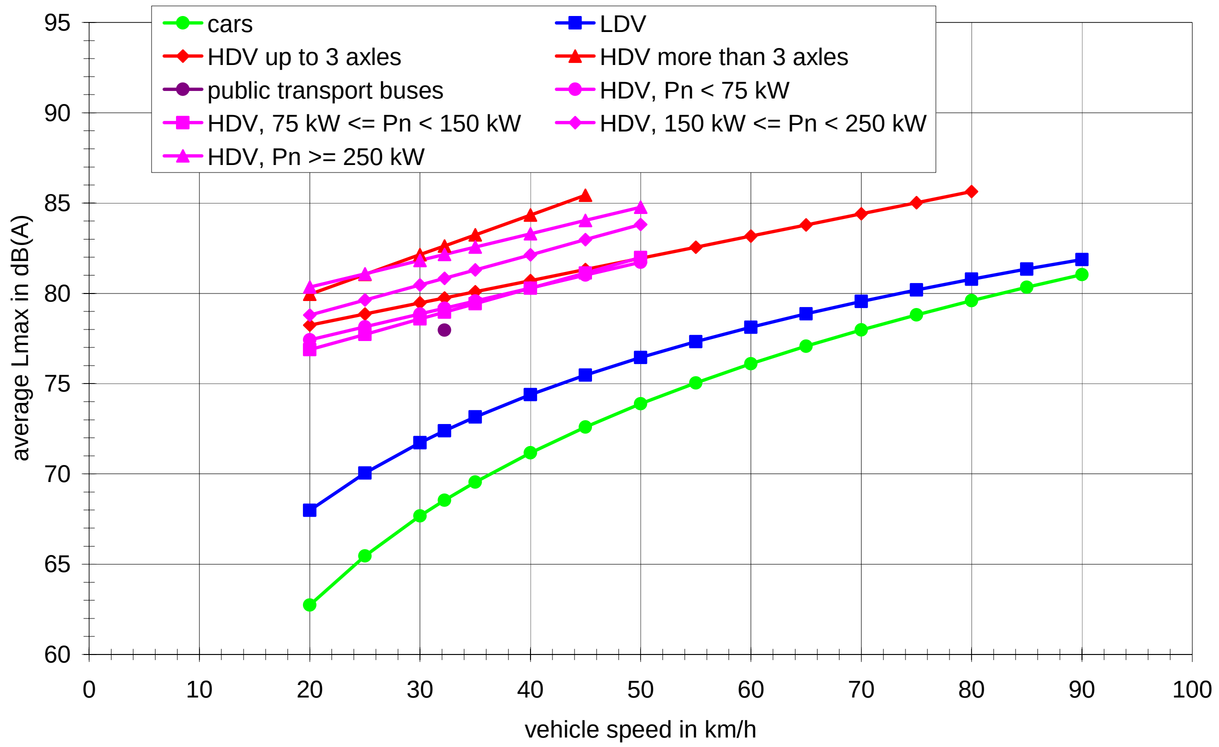

Figure 17: Average Lmax values for different vehicle categories and accelerating vehicles

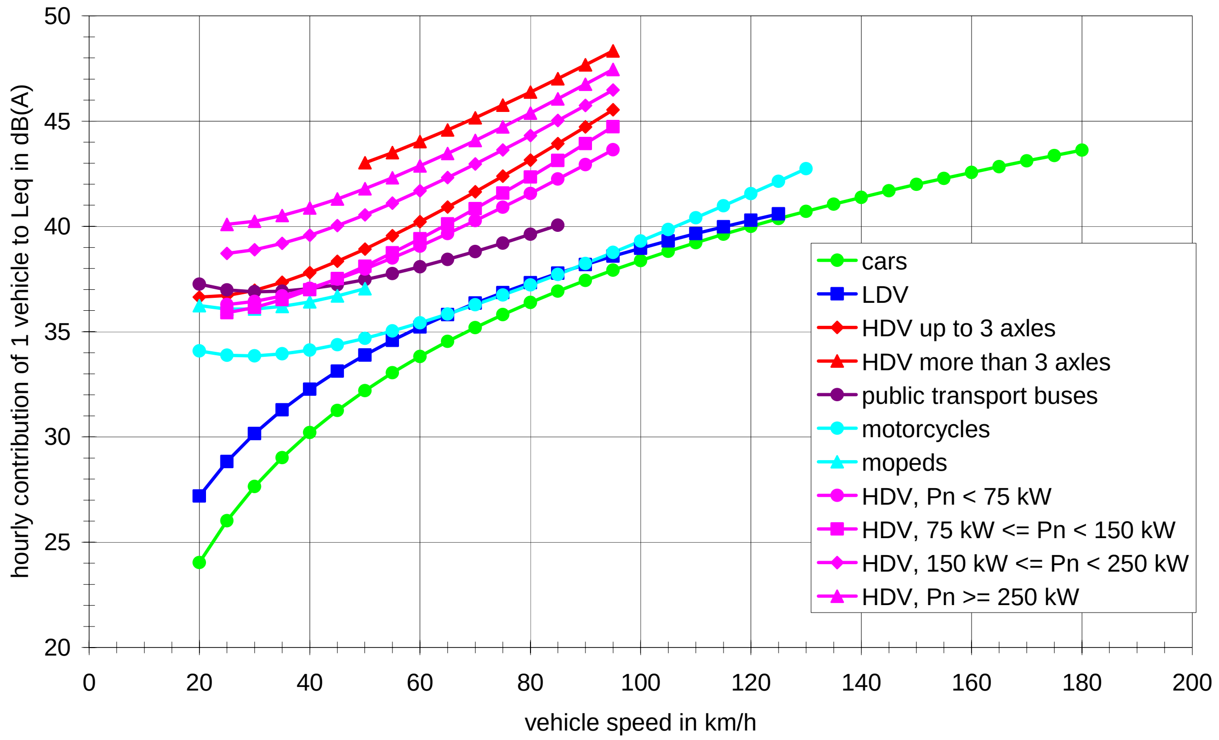

Figure 18: Average hourly contribution of 1 vehicle to the Leq for different vehicle categories and free flowing traffic

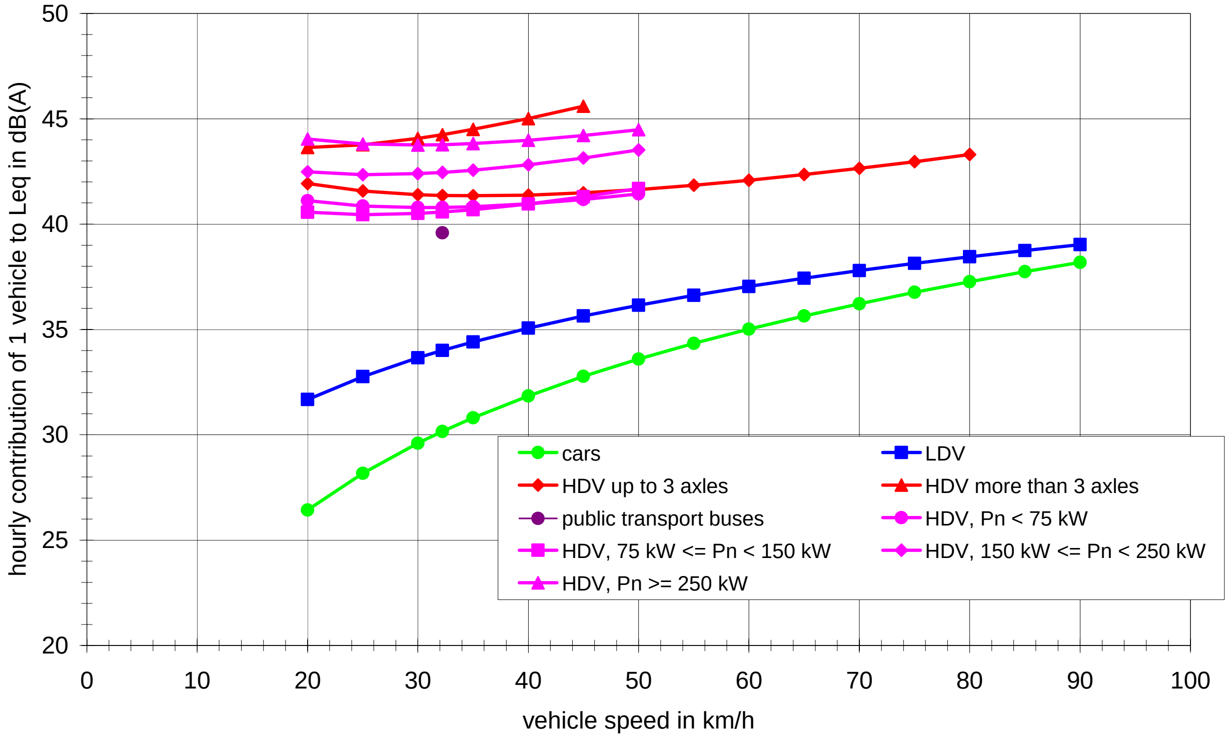

Figure 19: Average hourly contribution of 1 vehicle to the Leq for different vehicle categories and acceleration conditions

3.2 Detailed analysis for vehicle categories

The detailed analysis for vehicle categories does not include public transport buses and mopeds, because the sample size was too small.

3.2.1 Cars

3.2.1.1 Influence of technical parameters

For a further analysis the car sample was divided into

- vehicles with petrol engines,
- vehicles with precombustion Diesel engines,
- vehicles with direct injection Diesel engines.

In the following the vehicles with precombustion Diesel engines are called vehicles with Diesel engines only. The noise limit for vehicles registered after 1995 is 74 dB(A) for vehicles with petrol and Diesel engines and 75 dB(A) for vehicles with direct injection Diesel engines. For these groups the maximum pass by levels (Lmax) were plotted versus rated power, power to mass ratio and engine capacity, for acceleration phases and free flowing traffic respectively. The power to mass ratio is the ratio between rated power and kerb mass + 75 kg. Only vehicles with registration years after 1995 were considered.

The results are shown in Figure 20 to Figure 22 for accelerating vehicles with speeds between 32,5 km/h and 42,5 km/h and Figure 23 to Figure 25 for vehicles in free flowing traffic with speeds between 60 km/h and 70 km/h. These speed ranges were chosen because they contained the highest number of vehicles.

For both situations (accelerations and free flowing traffic) there is a trend of noise level increase with increasing technical parameter, but the noise level variation due to other influences (like individual traffic situation or individual driving behaviour) is by far dominating. The engine capacity shows the biggest influence of technical parameters, followed by rated power.

For acceleration phases vehicles with direct injection Diesel engines have 1 to 2 dB(A) higher noise levels than vehicles with petrol engines. But the vehicles with Diesel engines have even higher Lmax levels than the vehicles with direct injection Diesel engines. This result is astonishing for the first glance, because the 1 dB higher limit value for direct injection Diesel engines was justified with the argument, that their noise emission is higher than the noise emission of vehicles with precombustion Diesel engines. The above mentioned results for accelerating vehicles show that it is the other way round. This contradiction can be explained by the age distribution of both samples. The vehicle sample with Diesel engines is much older than the vehicle sample with direct injection Diesel engines and the vehicles with direct injection Diesel engines of current technology are less noisy than the vehicles with the first generation of direct injection Diesel engines (see Figure 31).

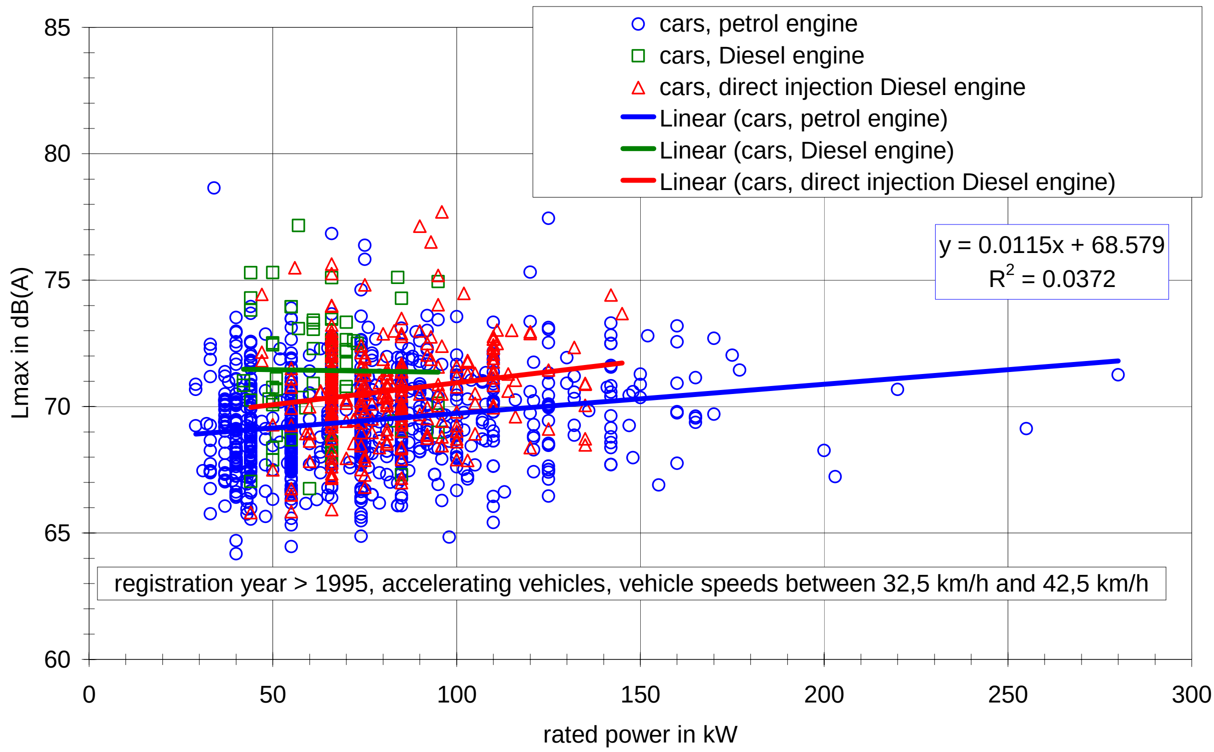

Figure 20: Pass by level of accelerating cars versus rated power

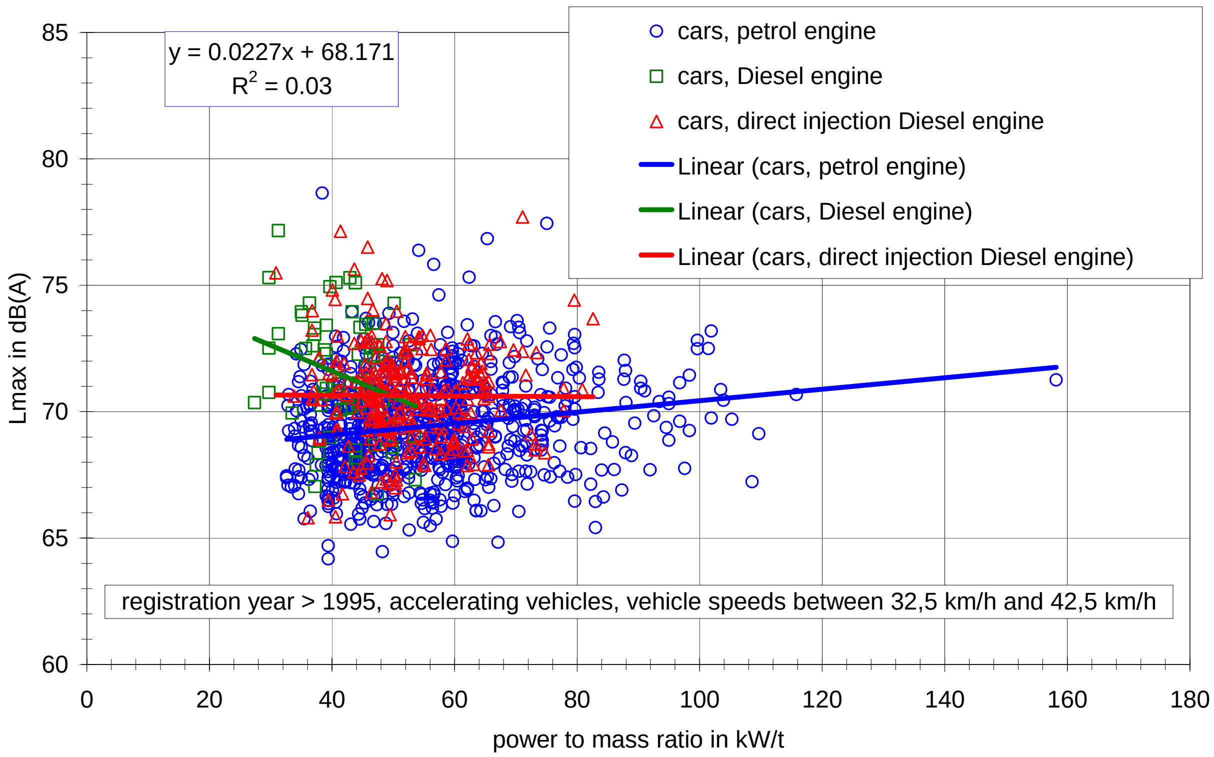

Figure 21: Pass by level of accelerating cars versus power to mass ratio

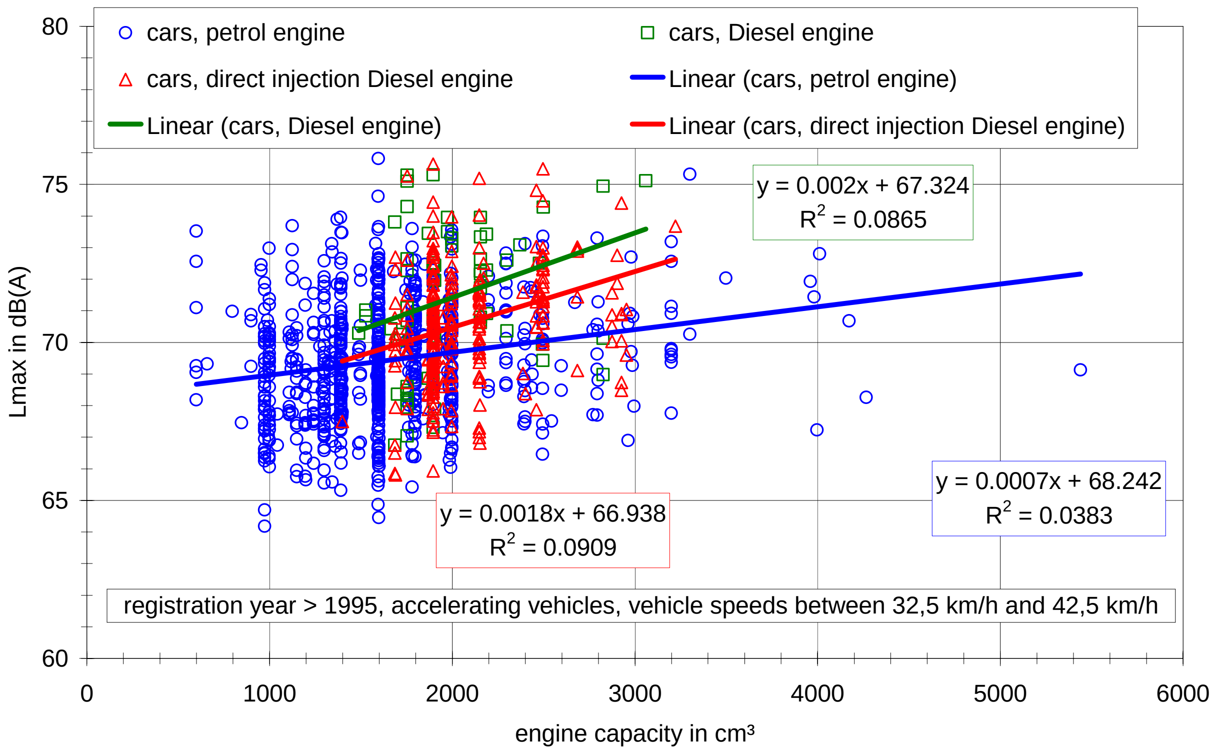

Figure 22: Pass by level of accelerating cars versus engine capacity

For free flowing traffic there is no significant difference in the noise emission of the different engine categories. This can be explained by the fact that tyre/road noise is dominating in this driving mode.

Figure 26 and Figure 27 show the Lmax levels for the different engine categories versus vehicle speed for acceleration phases and for free flowing traffic. These figures confirm the above mentioned statements.

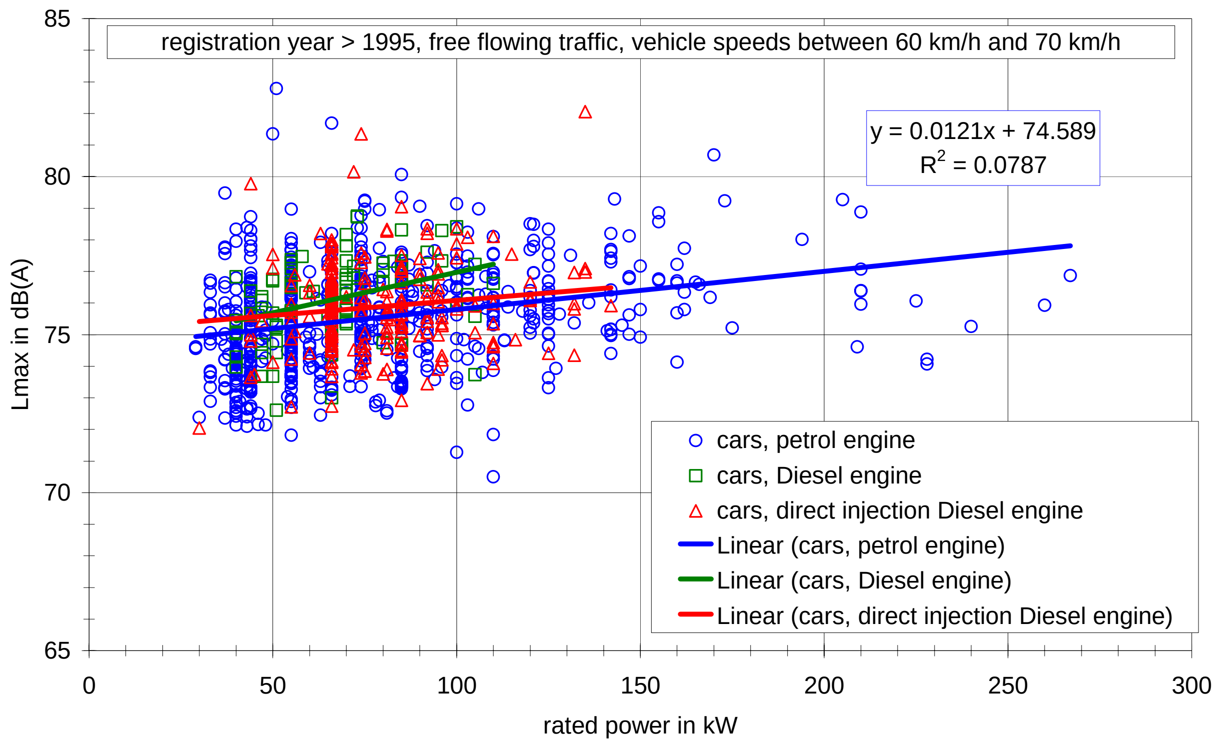

Figure 23: Pass by level of cars in free flowing traffic versus rated power

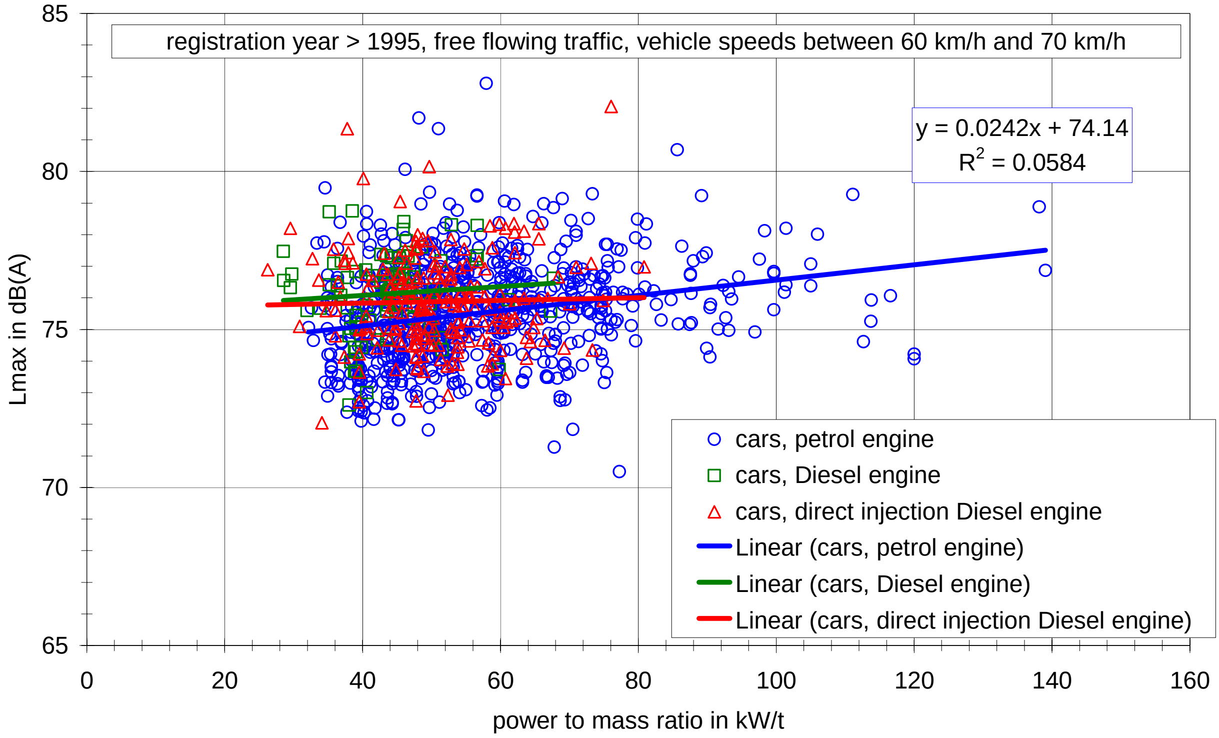

Figure 24: Pass by level of cars in free flowing traffic versus power to mass ratio

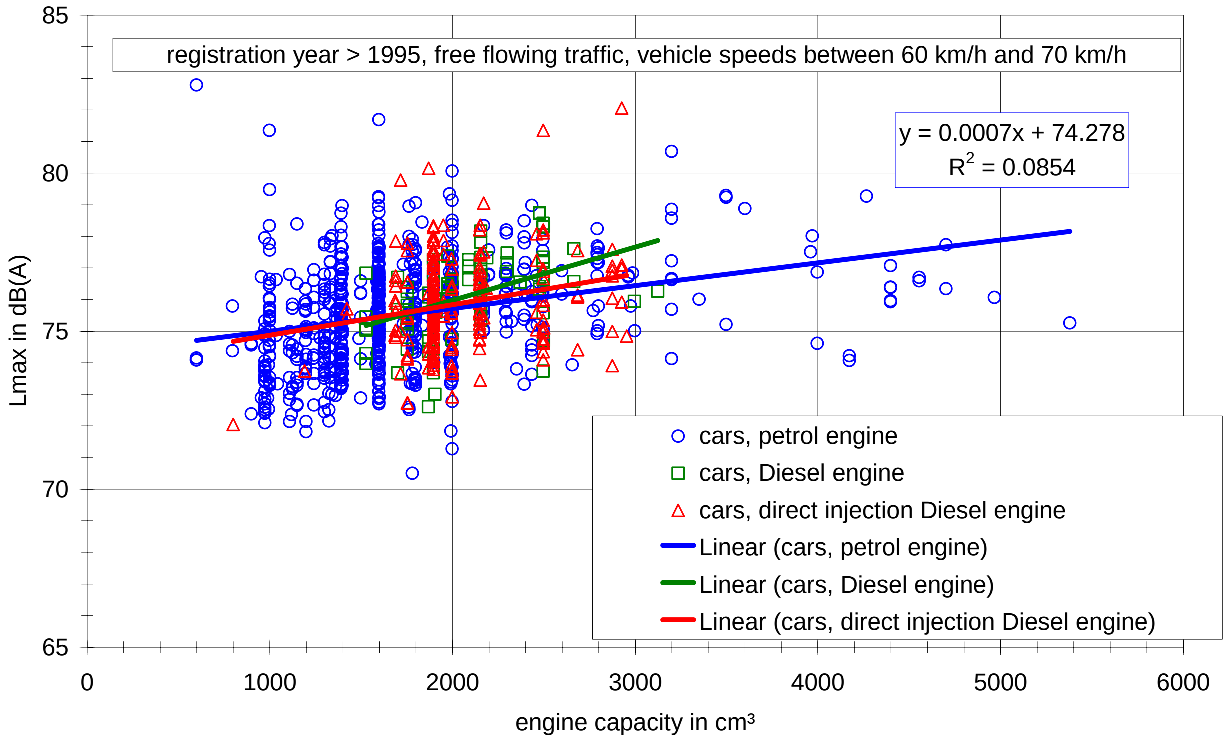

Figure 25: Pass by level of cars in free flowing traffic versus engine capacity.

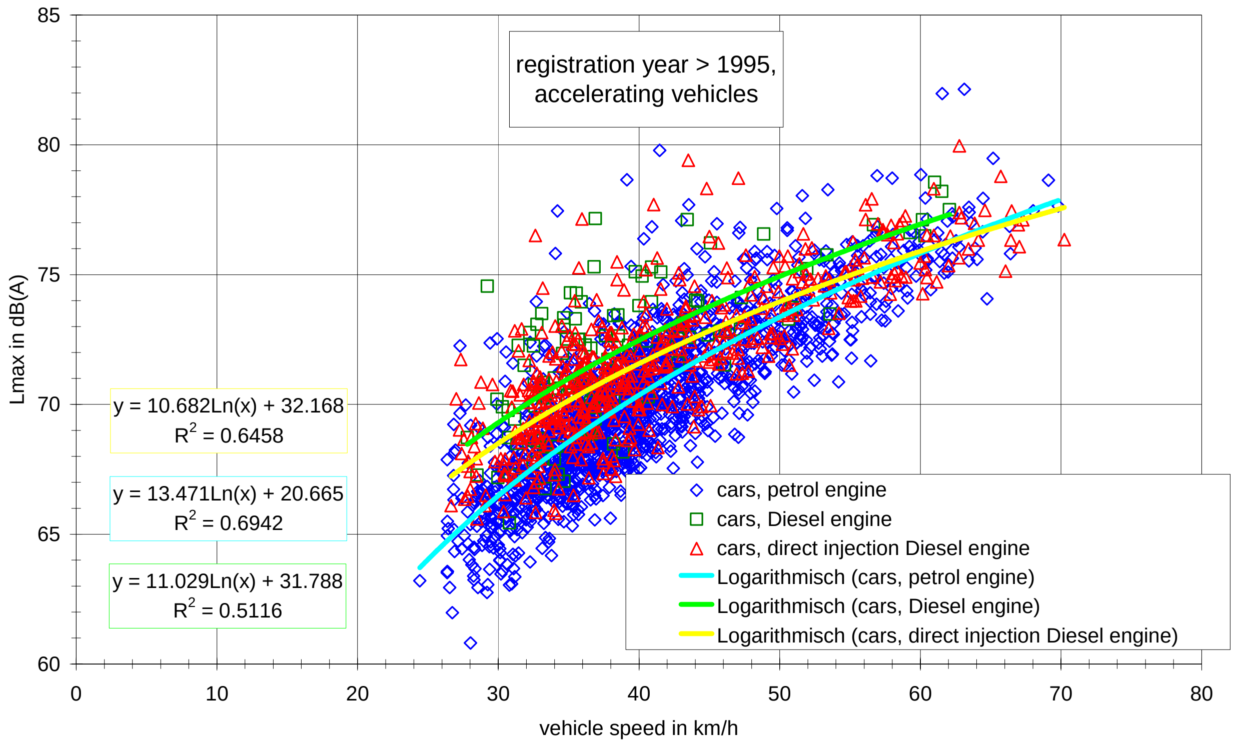

Figure 26: Pass by level of accelerating cars versus vehicle speed

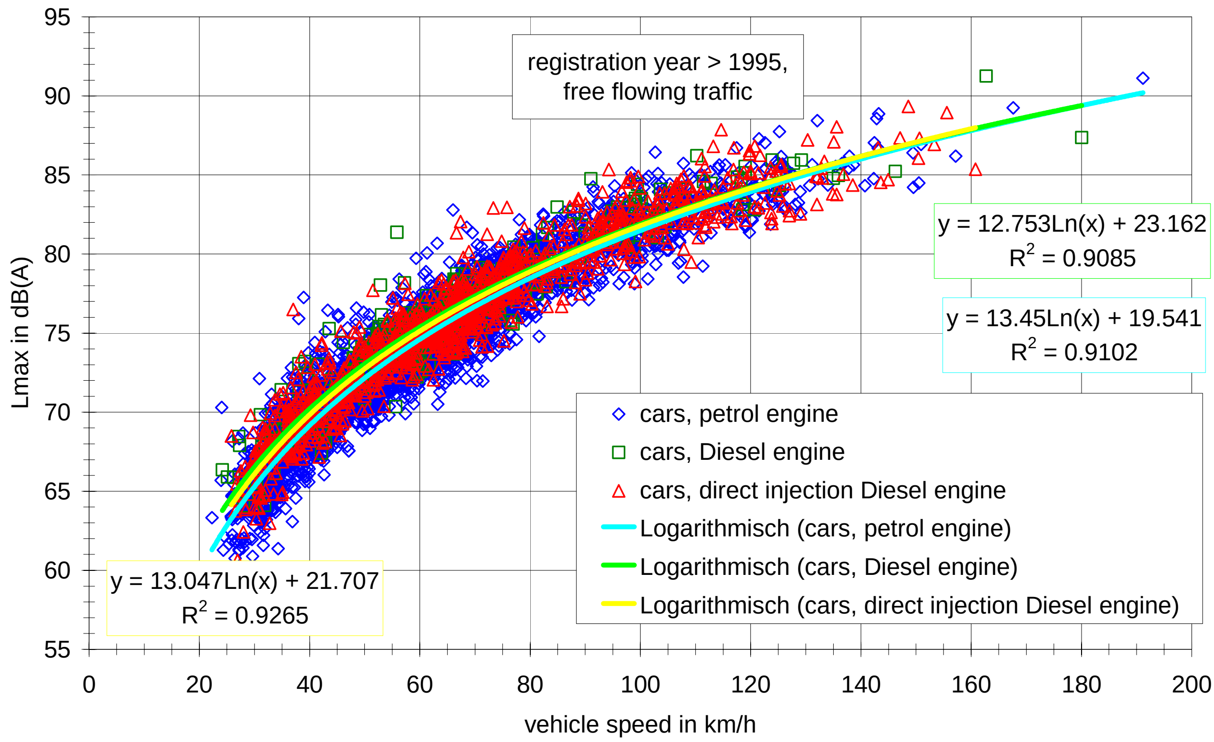

Figure 27: Pass by level of cars in free flowing traffic versus vehicle speed

In an additional step the car sample with Diesel engines was separated into the following subgroups:

- cars with precombustion Diesel engines,
- cars with direct injection Diesel engines,
- light duty vehicles with car homologation.

The latter were derived from the car sample by separating vehicles with gross vehicle mass of more than 2500 kg and rated power values of up to 73 kW. This subgroup could also include off road vehicles but is dominated by light duty vehicles. The Lmax levels versus vehicle speed are shown in Figure 28 for accelerating vehicles and in Figure 29 for free flowing traffic. For accelerating vehicles the regression curve for LDV with car homologation is significantly higher than the regression curves for the other subgroups. The average emission level curve of LDV with car homologation is almost the same as for LDV with gross vehicle mass above 2000 kg (see Table 16). For free flowing traffic the regression curve for LDV with car homologation is only slightly higher than the regression curves of the two other subgroups.

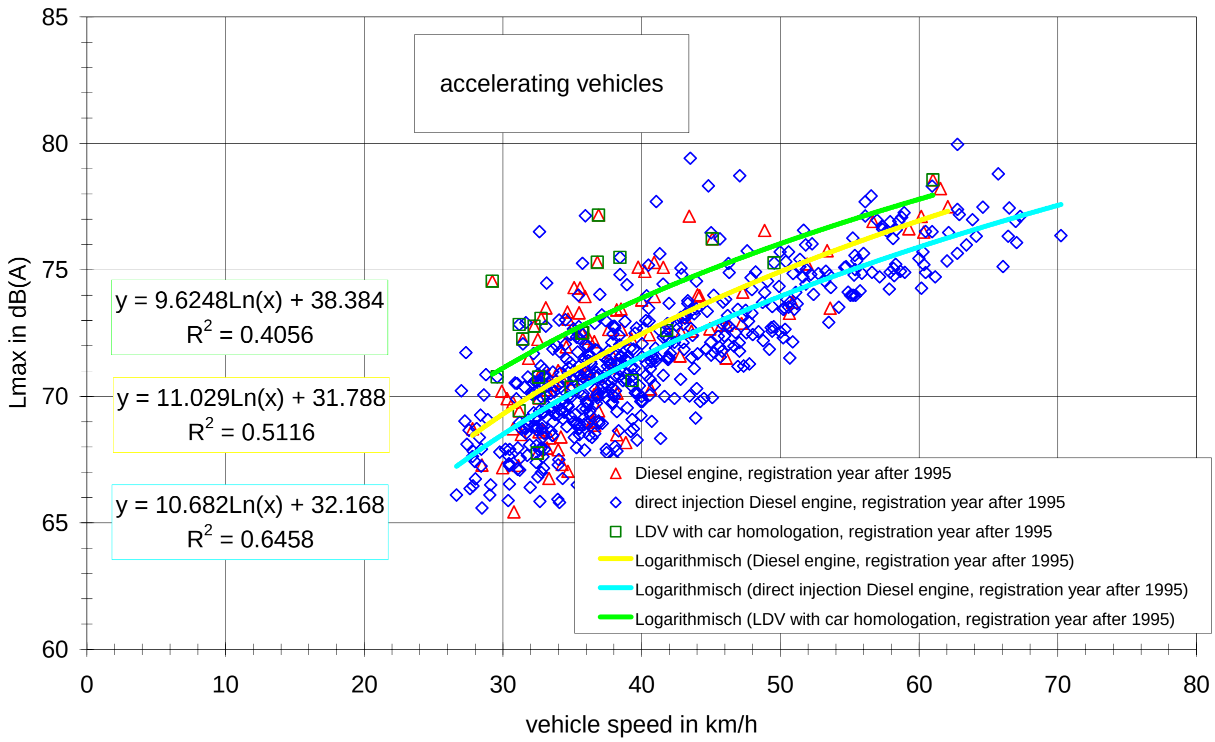

Figure 28: Pass by levels of accelerating LDV with car homologation with Diesel engines

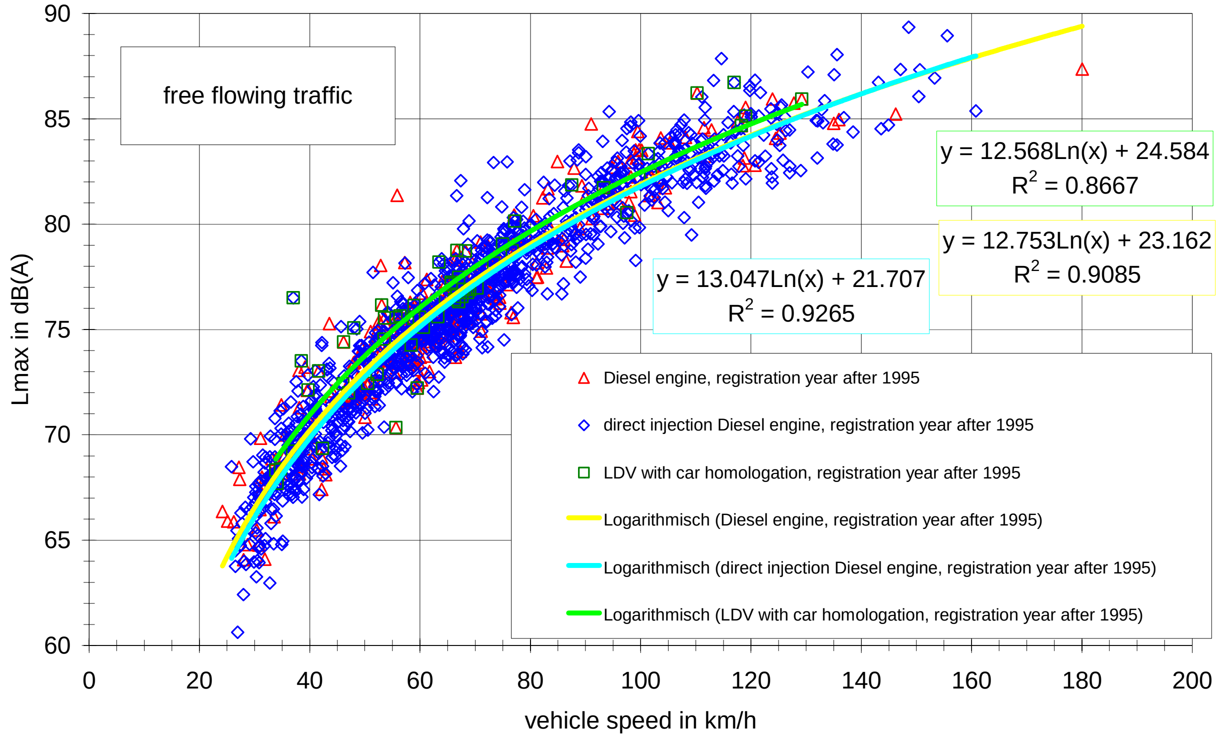

Figure 29: Pass by levels of LDV with car homologation in free flowing traffic with Diesel engines

Influence of different emission stages

In another step the car sample was separated into different registration year classes. The borderlines were drawn in relation to limit value changes. As a consequence the following classes were built:

- petrol, registration year before 1982, limit value 82 dB(A),
- petrol, registration year between 1982 and 1988, limit value 80 dB(A),
- petrol, registration year between 1989 and 1995, limit value 77 dB(A),
- petrol, registration year after 1995, limit value 74 dB(A),
- Diesel, registration year before 1982, limit value 82 dB(A),
- Diesel, registration year between 1982 and 1989, limit value 80 dB(A),
- Diesel, registration year between 1990 and 1995, limit value 77 dB(A),
- Diesel, registration year after 1995, limit value 74 dB(A),

Only a few vehicles were measured with registration years before 1982; so this class is not considered. The results of the other registration year subgroups are shown in Figure 30 for accelerating vehicles with petrol engines. The regression curves of these groups follow the trend of the limit values, at least at the lower end of the engine speed range. At 30 km/h an average pass by level reduction of 2 dB(A) can be found for a noise limit reduction of 6 dB(A). This poor effect on the real world noise emissions can partly be explained by compensatory effects of changes in the type approval measurement method and partly by the fact that the tyre/road noise contribution is not sufficiently considered in the current type approval method.

The results for today's vehicles with direct injection Diesel engines are also shown for comparison. Their average noise emission at 30 km/h is 2 dB higher than the average noise emission of today's cars with petrol engines and thus the same as for cars with petrol engines and registration years between 1982 and 1988. But the difference between the noise emission of today's vehicles with petrol and direct injection Diesel engines goes down to zero with increasing vehicle speed.

Figure 31 shows the results for accelerating vehicles of different registration year classes and different Diesel engine types. No regression curve is drawn for vehicles with precombustion Diesel engines and registration years after 1995, because this technology vanished in the meantime from the market and thus the sample is too small. In comparison to vehicles with precombustion Diesel engines and registration years between 1982 and 1989 the noise levels of today's vehicles with direct injection Diesel engines are 2 dB lower at 30 km/h. The comparison of the regression curves for vehicles with direct injection Diesel engines registered between 1990 and 1995 and registered after 1995 at 30 km/h show clearly that the propulsion noise emission for vehicles with engines of this technology was reduced in the meantime.

Corresponding results for free flowing traffic are shown in Figure 32 and Figure 33. There are no significant differences between the regression curves of the different registration year classes for vehicles with petrol engines and there is only a vague tendency of lower noise emission for vehicles with Diesel engines with decreasing age at low speeds.

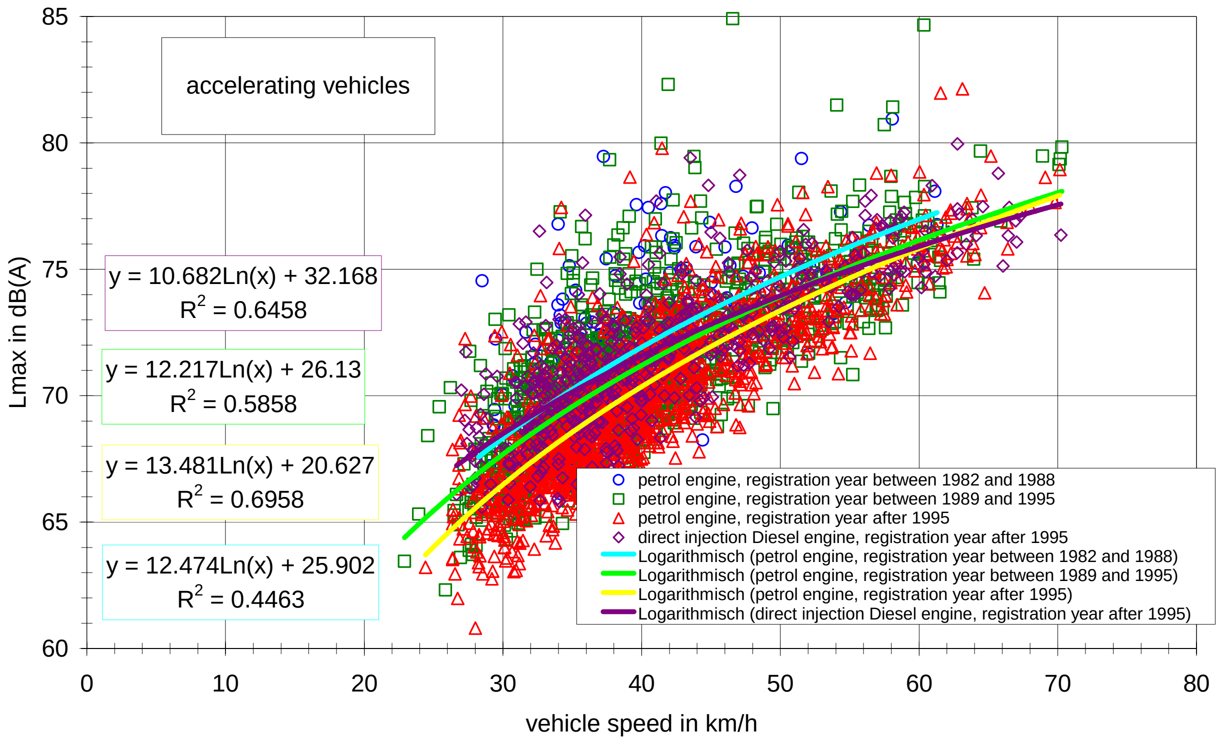

Figure 30: Pass by levels of accelerating cars with petrol engines and different registration year classes

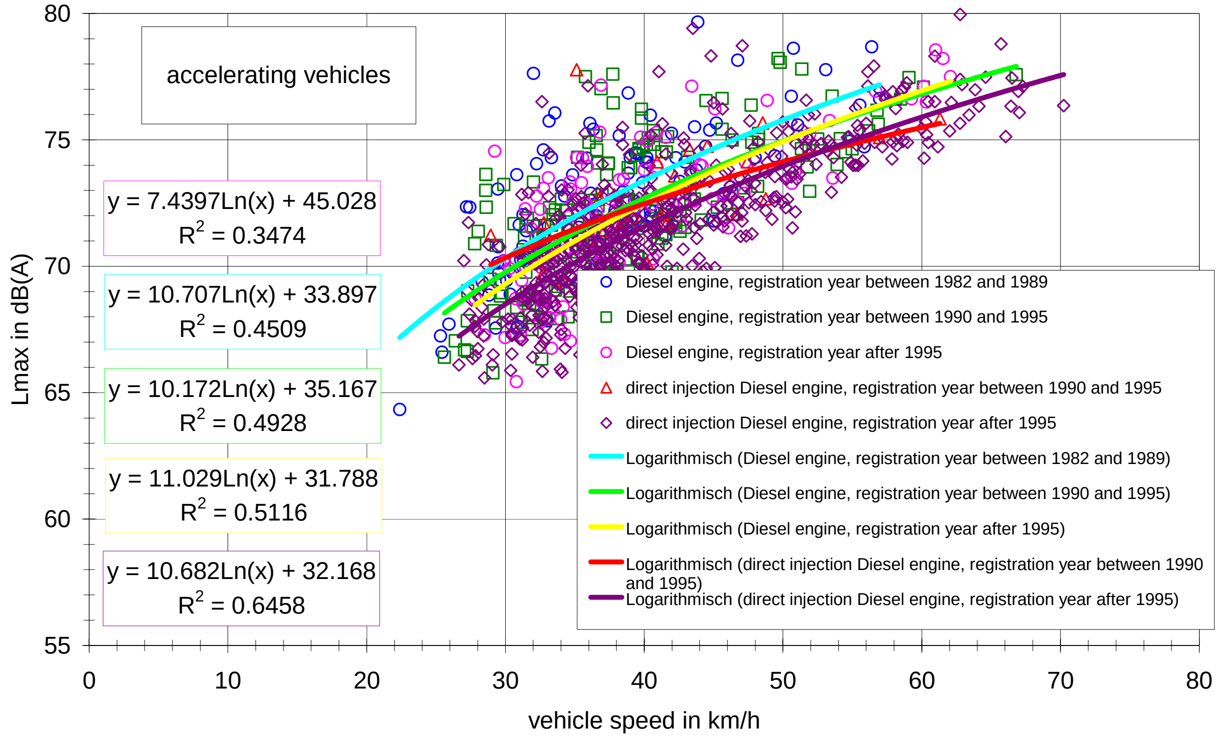

Figure 31: Pass by levels of accelerating cars with Diesel engines and different registration year classes

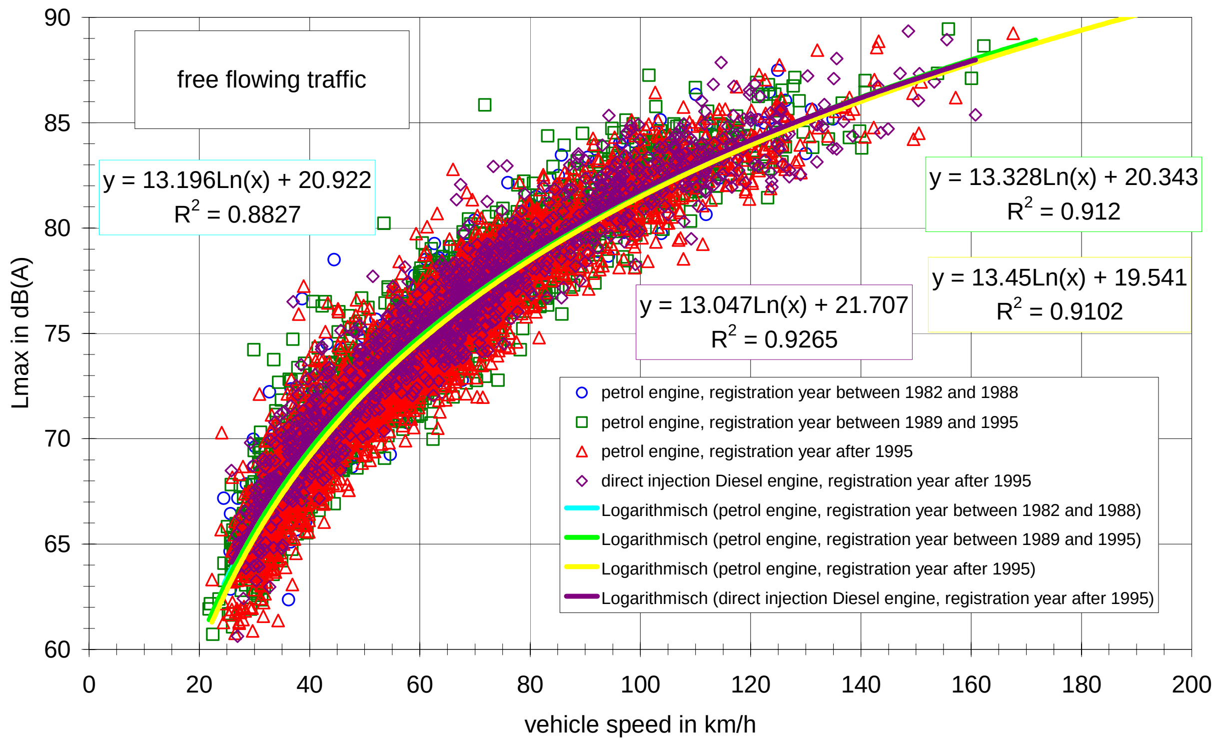

Figure 32: Pass by levels of cars in free flowing traffic with petrol engines and different registration year classes

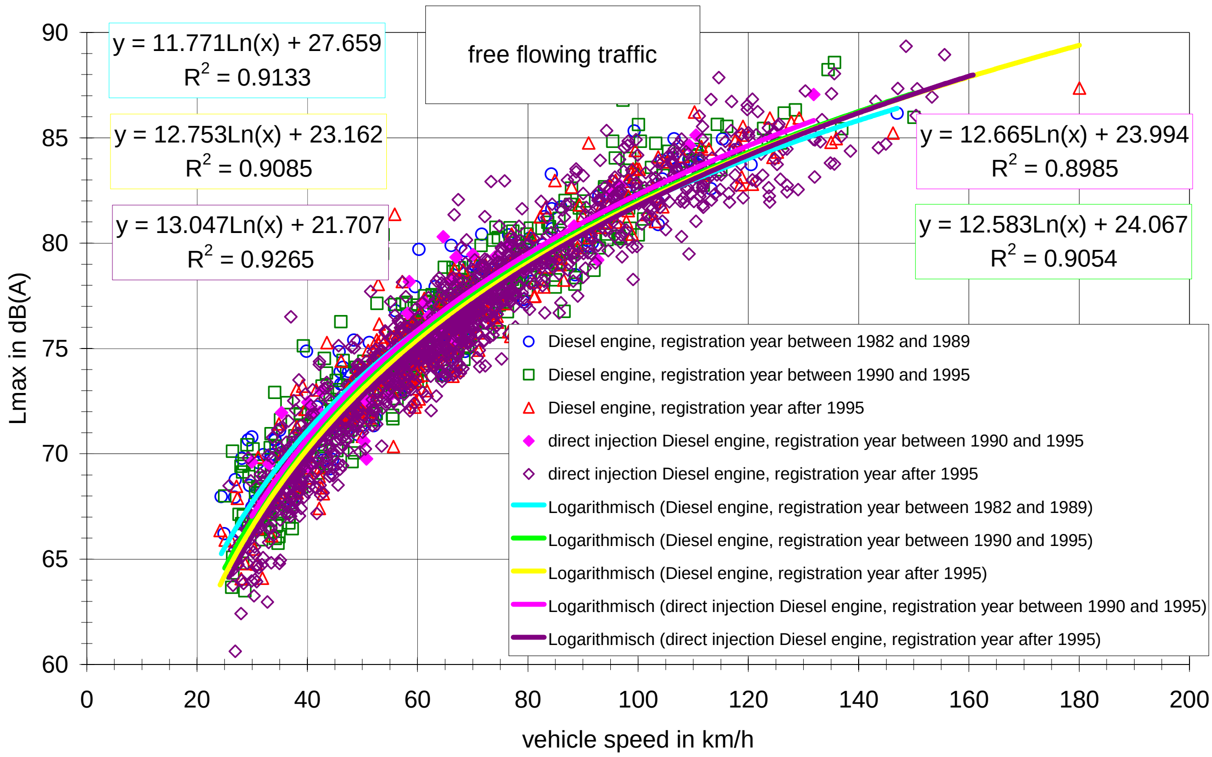

Figure 33: Pass by levels of cars in free flowing traffic with Diesel engines and different registration year classes

Within the context of the registration year analysis it was also checked whether there is a correlation between the noise emission in real traffic and the type approval levels of the vehicles. For that reason the average Lmax levels for cars with petrol, precombustion and direct injection Diesel engines were calculated for accelerating vehicles in the speed range between 27,5 km/h and 37,5 km/h (around 35 km/h) and for free flowing traffic in the speed range between 60 km/h and 70 km/h (around 65 km/h) and plotted versus the type approval levels. The speed ranges were chosen in order to maximise the vehicle number of each vehicle group.

The results for the accelerating vehicles can be seen in Figure 34 and show a clear tendency: The noise levels in real traffic for acceleration phases at low speeds decrease with decreasing type approval level and the slope is a bit higher for vehicles with Diesel engines of both combustion types than for vehicles with petrol engines. This can be explained by the fact, that for a given type approval level the in-use noise levels for Diesel vehicles are about 1,5 to 2 dB higher than the in-use noise levels for vehicles with petrol engines. These higher levels indicate a higher propulsion noise influence on the in-use noise emission of the Diesel vehicles compared to the petrol vehicles.

For free flowing traffic at higher speeds (65 km/h) there is no correlation between type approval levels and in-use noise emission levels for vehicles with Diesel engines of both combustion types and only a vague tendency of decreasing in-use levels with decreasing type approval levels for vehicles with petrol engines in the type approval level range between 69 dB(A) and 75 dB(A) (Figure 35). In order to be able to show this tendency, the petrol vehicles are shown twice in the legend of Figure 35.

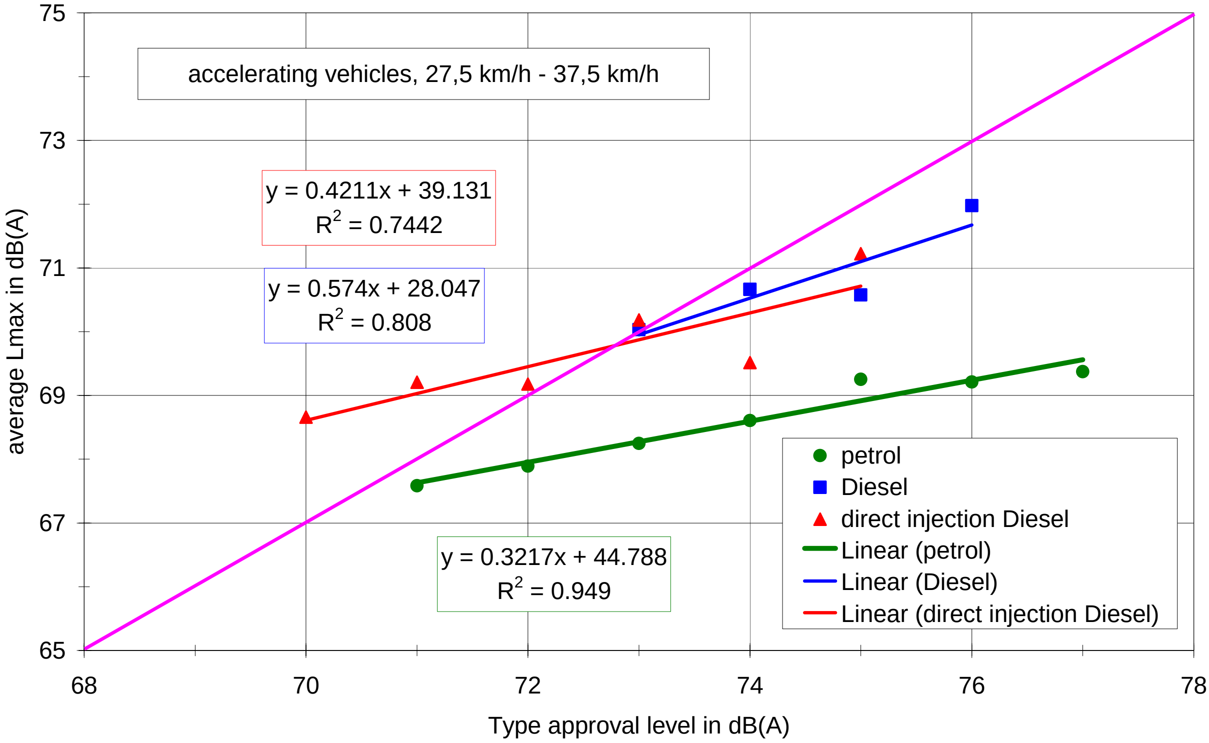

Figure 34: average pass by level of accelerating cars versus type approval levels

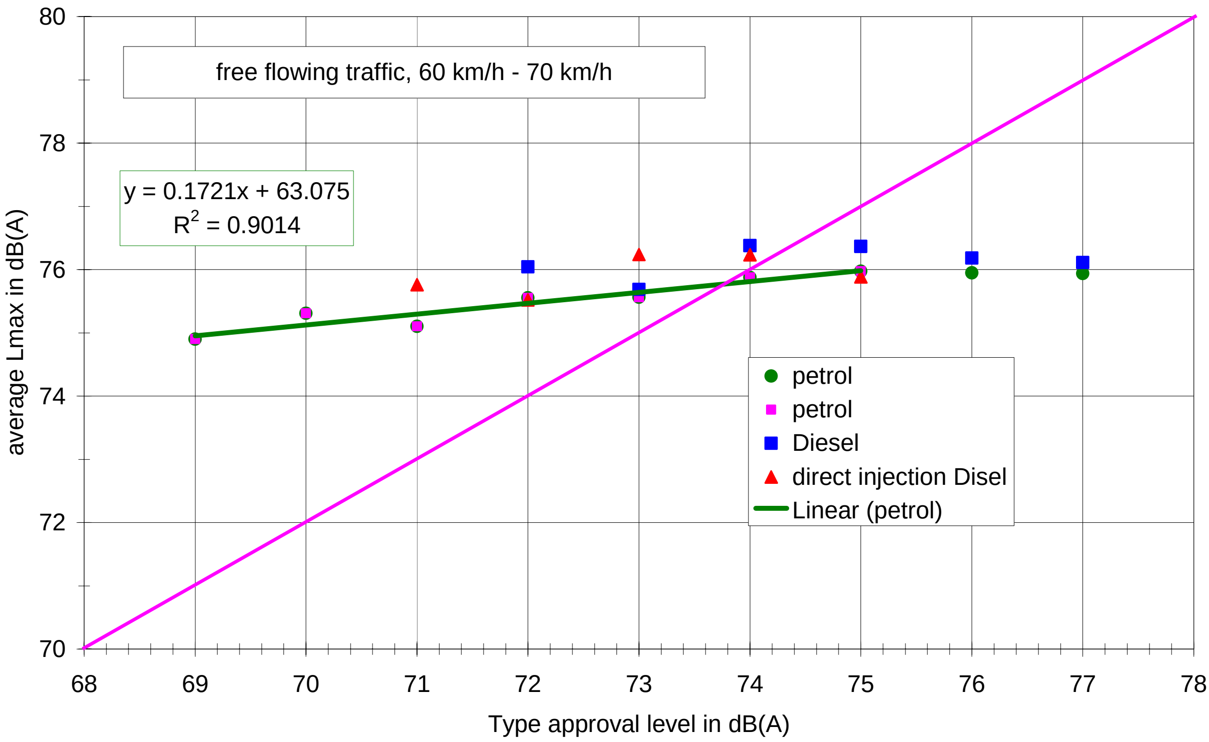

Figure 35: average pass by level of cars in free flowing traffic versus type approval levels

3.2.1.2 Vehicle Types

Another analysis step was related to vehicle types. But despite of the huge number of cars measured, it was difficult to extract vehicle types from the database, because the number of variants per type has increased meanwhile, so that the registration number of a type could not be used as separation criterion. As an alternative vehicles equipped with the same engine – with respect to engine capacity and rated power – were defined as vehicle types. For both driving condition modes (acceleration phases and free flowing traffic) a regression analysis of Lmax versus vehicle speed was carried out using logarithmic functions (see Figure 36).

The noise levels calculated from the regression curves for different speeds are shown in Table 14 for acceleration phases for all types with a sample size of 40 vehicles or more. These vehicle types dominate the fleet composition on the roads. Table 15 shows the corresponding results for free flowing traffic. The averages for different emission stages (limit value stages) are added in these tables.

7 types could be extracted for acceleration phases. The difference between the loudest and the quietest type decreases from 3,2 dB at 20 km/h to 2,2 dB at 50 km/h. A substantial part of the differences can be explained by the different emission stages. The remaining range within an emission stage is below 2 dB(A) for speeds below 50 km/h, which means that there is no significant difference between those vehicle types that dominate the fleet composition in real traffic.

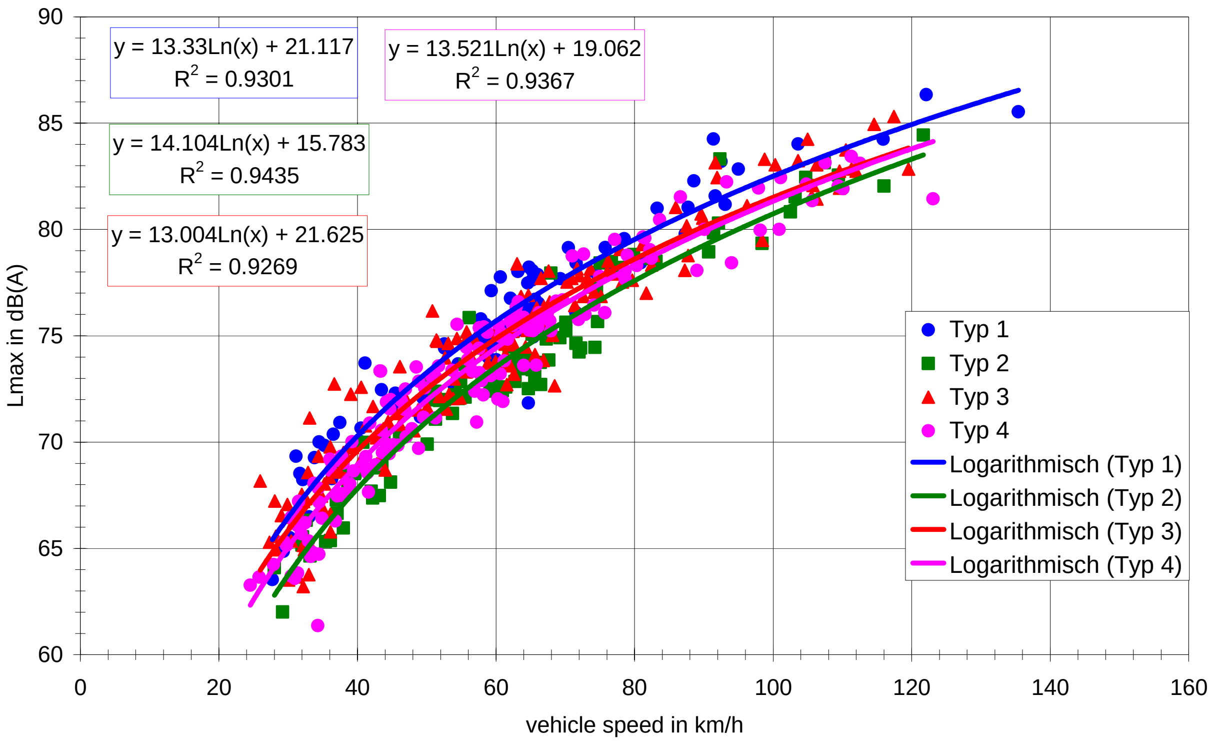

Figure 36: Pass by levels of vehicle types (free flowing traffic)

				vehicle speed in km/h		
engine capacity in cm³	**number of vehicles**	**Limit value in dB(A)**	**vehicle type**	**20**	**30**	**50**
973	42	74	type 1, petrol, 40 kW	59.8	65.3	72.3
1595	40	74	type 2, petrol, 74 kW	60.8	66.2	73.1
1299	47	74	type 3, petrol, 44 kW	61.3	66.6	73.3
1896	44	75	type 4, direct injection Diesel, 66 kW	61.5	67.2	74.5
1598	65	77	type 5, petrol, 55 kW	61.7	67.3	74.3
1389	68	77	type 6, petrol, 44 kW	63.0	67.5	73.2
1781	59	77	type 7, petrol, 66 kW	63.0	67.9	74.0
	Limit value in dB(A)	**number of types**	**range**	**3.2**	**2.6**	**2.2**
	74/75	4	min	59.8	65.3	72.3
			ave	**60.8**	**66.3**	**73.3**
			max	61.5	67.2	74.5
			range	**1.8**	**1.9**	**2.2**
	77	3	min	61.7	67.3	73.2
			ave	**62.6**	**67.6**	**73.9**
			max	63.0	67.9	74.3
			range	**1.2**	**0.5**	**1.1**

Table 14: Results of the regression analysis for vehicle types (accelerating vehicles)

A lot more vehicle types (34) could be extracted for free flowing traffic, including also 2 types with limit values of 80 dB(A). The difference between the loudest and the quietest type decreases from 3,9 dB at 30 km/h to 2,2 dB at 70 and 90 km/h. The differences between the different emission stages are below 1 dB , but with a tendency to lower in-use levels for lower limit values. Figure 37 and Figure 38 show that the differences between the vehicle types can be related to the engine capacity influence. Beside this also for free flowing traffic no significant difference in the in-use noise emission could be found.

The engine capacity influence needs to be commended further in order to avoid misleading conclusions. The noise emission for free flowing traffic conditions is tyre/road noise dominated. Higher engine capacity means higher rated power and higher maximum speed values and as a consequence wider tyres with a higher speed index. So most probably, the engine capacity is an indirect technical parameter for the noise emission of vehicles in free flowing traffic.

				vehicle speed in km/h			
engine capacity in cm³	number of vehicles	Limit value in dB(A)	vehicle type	30	50	70	90
973	90	74	type 1, petrol, 40 kW	63.8	71.0	75.7	79.3
1390	58	74	type 2, petrol, 55 kW	64.8	71.9	76.6	80.1
1595	86	74	type 3, petrol, 74 kW	65.5	72.4	76.9	80.2
1598	52	74	type 4, petrol, 55 kW	65.3	72.3	76.9	80.4
1998	52	74	type 5, petrol, 100 kW	65.4	72.7	77.4	81.0
1896	103	75	type 6, direct injection Diesel, 66 kW	65.7	72.5	77.1	80.4
1896	49	75	type 7, direct injection Diesel, 85 kW	66.1	72.8	77.2	80.5
1043	44	77	type 8, petrol, 33 kW	65.1	71.7	76.1	79.3
1119	40	77	type 9, petrol, 37 kW	65.4	71.9	76.2	79.4
1124	43	77	type 10, petrol, 44 kW	65.1	71.7	76.0	79.3
1195	83	77	type 11, petrol, 33 kW	64.7	71.5	76.0	79.3
1195	70	77	type 12, petrol, 33 kW	64.6	71.5	76.1	79.5
1299	87	77	type 13, petrol, 44 kW	65.3	72.2	76.7	80.0
1389	146	77	type 14, petrol, 44 kW	65.1	72.0	76.5	79.9
1390	68	77	type 15, petrol, 44 kW	65.9	72.3	76.6	79.8
1595	44	77	type 16, petrol, 74 kW	65.4	72.4	77.1	80.5
1596	59	77	type 17, petrol, 75 kW	65.6	73.0	77.8	81.4
1597	46	77	type 18, petrol, 66 kW	66.1	72.7	77.1	80.4
1598	63	77	type 19, petrol, 52 kW	65.3	72.2	76.8	80.2
1598	160	77	type 20, petrol, 55 kW	65.9	72.5	76.9	80.1
1598	82	77	type 21, petrol, 55 kW	65.6	72.5	77.0	80.4
1598	48	77	type 22, petrol, 74 kW	65.4	72.4	77.0	80.4
1781	98	77	type 23, petrol, 55 kW	64.8	72.1	77.0	80.6
1781	132	77	type 24, petrol, 66 kW	65.3	72.5	77.3	80.8
1796	41	77	type 25, petrol, 66 kW	65.7	72.0	76.2	79.3
1799	78	77	type 26, petrol, 90 kW	66.5	73.4	77.9	81.3
1991	78	77	type 27, petrol, 110 kW	66.5	73.3	77.8	81.1
1998	51	77	type 28, petrol, 85 kW	66.0	72.9	77.4	80.8
1896	50	77	type 29, Diesel, 55 kW	67.4	73.5	77.5	80.4
1997	57	77	type 30, Diesel, 55 kW	67.0	73.5	77.8	81.1
1896	49	77	type 31, direct injection Diesel, 66 kW	66.2	73.0	77.5	80.9
1896	43	77	type 32, direct injection Diesel, 66 kW	66.4	72.9	77.2	80.4
1263	45	80	type 33, petrol, 40 kW	64.0	71.4	76.2	79.9
1983	42	80	type 34, Diesel, 53 kW	67.7	73.8	77.8	80.8
	Limit value in dB(A)	**number of types**	**range**	**3.9**	**2.8**	**2.2**	**2.2**
	74/75	7	min	63.8	71.0	75.7	79.3
			ave	**65.2**	**72.2**	**76.8**	**80.3**
			max	66.1	72.8	77.4	81.0
			range	**2.3**	**1.8**	**1.7**	**1.7**
	77	25	min	64.6	71.5	76.0	79.3
			ave	**65.7**	**72.5**	**76.9**	**80.3**
			max	67.4	73.5	77.9	81.4
			range	**2.8**	**2.1**	**2.0**	**2.2**
	80	2	min	64.0	71.4	76.2	79.9
			ave	**65.8**	**72.6**	**77.0**	**80.3**
			max	67.7	73.8	77.8	80.8
			range	**3.6**	**2.4**	**1.6**	**0.9**

Table 15: Results of the regression analysis for vehicle types (free flowing traffic)

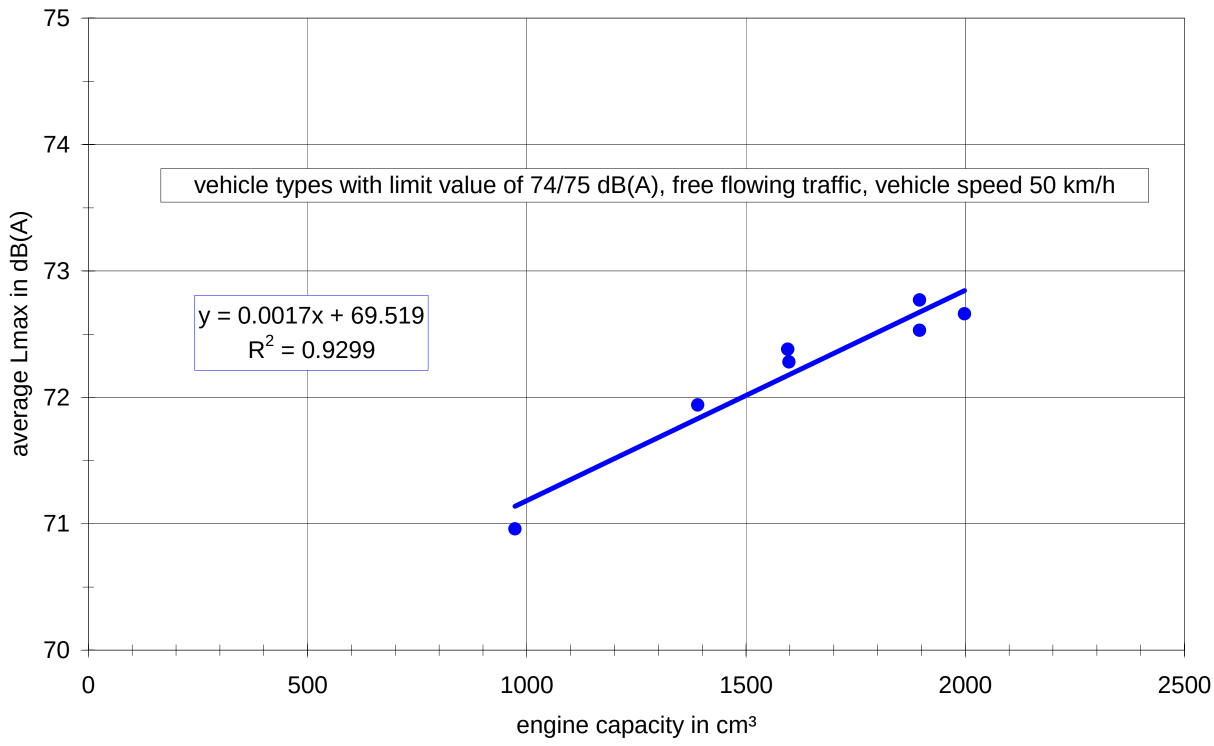

Figure 37: Average pass by levels of car types with 74/75 dB(A) limit value versus engine capacity.

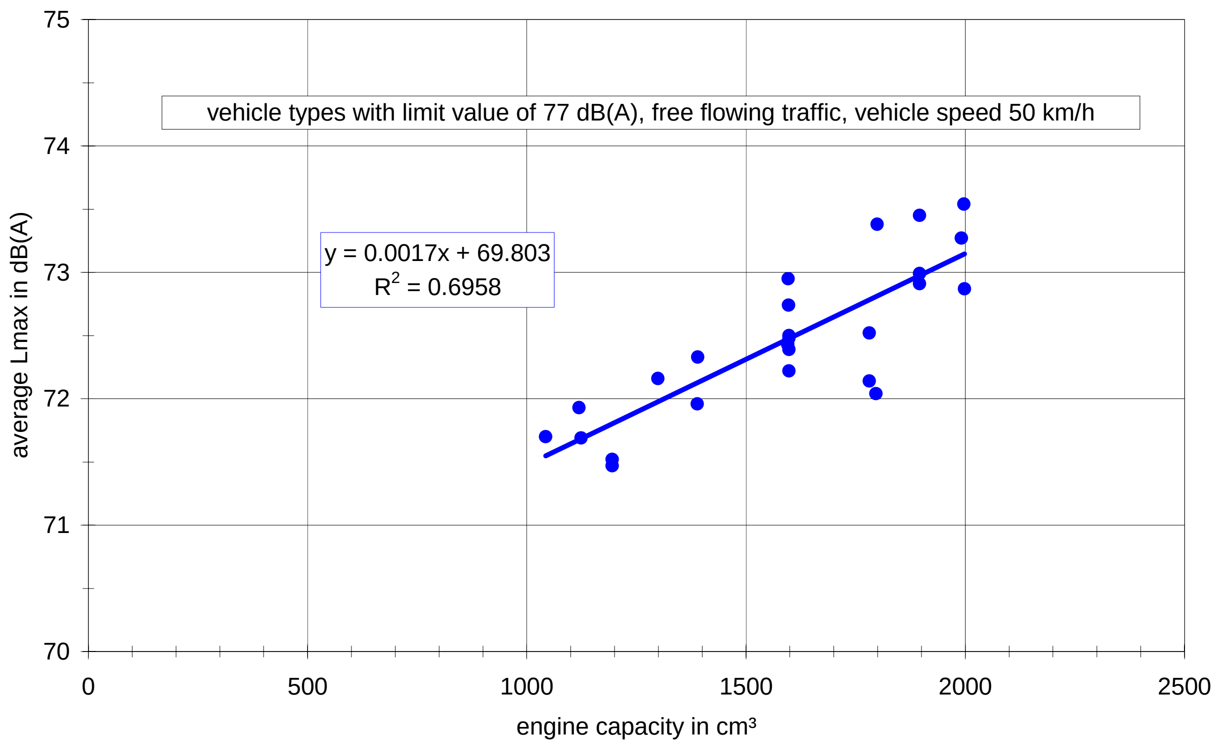

Figure 38: Average pass by levels of car types with 77 dB(A) limit value versus engine capacity.

3.2.2 Light duty vehicles

Since light duty vehicles with gross vehicle mass up to 2000 kg and above 2000 kg have different noise limits (76/77 dB(A)), the first analysis step was made with respect to these classes and to different engine types. Only 19% of the whole light duty vehicle sample belongs to the gross vehicle mass (GVM) class of up to 2000 kg. In this class 28,5% of the vehicles were equipped with a petrol engine, 58,2% with a precombustion Diesel engine and 13,3% with a direct injection Diesel engine. The percentage of petrol engine vehicles in the GVM class above 2000 kg is only 4,7%, so that this subclass was excluded from the further analysis. The rest is equipped with Diesel engines, half of it with direct injection Diesel engines.

Figure 39 shows the Lmax levels of the above described LDV subclasses versus vehicle speed for vehicles registered after 1995 and free flowing traffic. For this driving condition mode as well as for acceleration phases a regression analysis of Lmax versus vehicle speed was carried out using logarithmic functions. The noise levels calculated from the regression curves for different speeds are shown in Table 16 for acceleration phases. Table 17 shows the corresponding results for free flowing traffic.

For acceleration phases the sample of vehicles with petrol engines was too small, so that no results are shown in Table 16 for this subgroup.

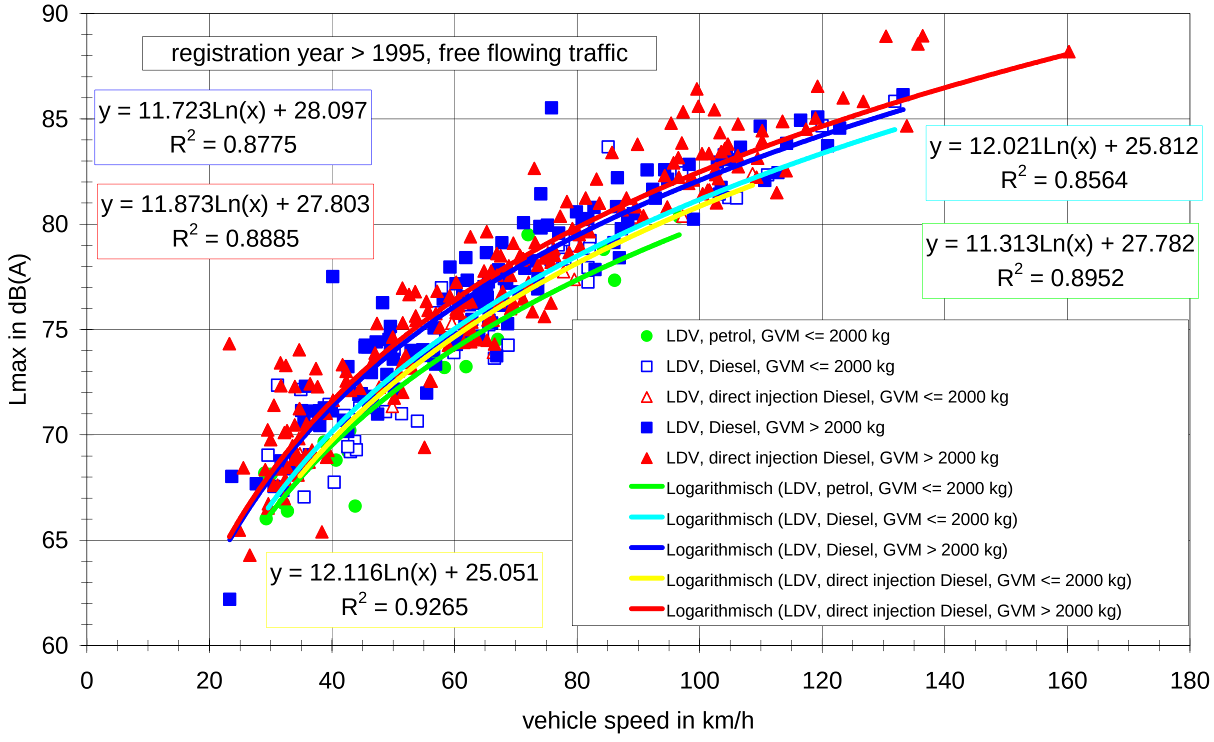

Figure 39: Pass by levels of light duty vehicles with different engine types and different gross vehicle mass classes

As for cars one can expect that LDV with precombustion Diesel engines will vanish from the fleet, so the classes with direct injection Diesel engines are most important. The difference in the average Lmax levels for acceleration phases between LDV with direct injection Diesel engines and GVM up to 2000 kg and GVM above 2000 kg varies between 1,4 and 2,2 dB(A), decreasing with increasing vehicle speed. The differences can be explained by differences in the engine capacity. In the GVM class above 2000 kg there is no difference between vehicles with precombustion and direct injection Diesel engines, in the GVM class up to 2000 kg the vehicles with precombustion Diesel engines are quieter than those with direct injection Diesel engines. But this result should not be overestimated because the sample sizes are substantially lower than for the GVM class above 2000 kg and no difference was found for free flowing traffic.

For free flowing traffic there is also no difference between the Diesel engine type classes with precombustion and with direct injection in both GVM classes, but the differences between both classes are 1,3 to 1,5 dB(A), which once again can be explained by differences in engine capacity. LDV with GVM up to 2000 kg and petrol engines are about 1 dB(A) quieter than those with Diesel engines.

subcategory	average engine capacity in cm³	vehicle speed in km/h		
		20	30	50
LDV, Diesel, GVM <= 2000 kg	1846	63.8	68.5	74.4
LDV, direct injection Diesel, GVM <= 2000 kg	1880	66.3	70.1	74.9
LDV, Diesel, GVM > 2000 kg	2253	67.7	71.6	76.6
LDV, direct injection Diesel, GVM > 2000 kg	2539	68.5	71.9	76.2

Table 16: average Lmax levels for different LDV subcategories, accelerating vehicles

subcategory	average engine capacity in cm³	vehicle speed in km/h		
		50	70	90
LDV, petrol, GVM <= 2000 kg	1304	72.0	75.9	78.7
LDV, Diesel, GVM <= 2000 kg	1783	72.8	76.9	79.9
LDV, direct injection Diesel, GVM <= 2000 kg	1899	72.5	76.5	79.6
LDV, Diesel, GVM > 2000 kg	2226	74.0	77.9	80.9
LDV, direct injection Diesel, GVM > 2000 kg	2492	74.3	78.3	81.2

Table 17: average Lmax levels for different LDV subcategories, free flowing traffic

Since this GVM class has the highest sample number a further analysis related to registration year classes was based on this subclass. The results are shown in Figure 40 for accelerating vehicles. There is a tendency of lower pass by levels with decreasing vehicle age over the whole speed range. But the difference between vehicles with registration years between 1990 and 1995 and vehicles with registration years after 1995 is only about 1 dB(A). Compared to vehicles registered before 1990 the differences seem to be higher, but this sample is too small to draw reliable conclusions.

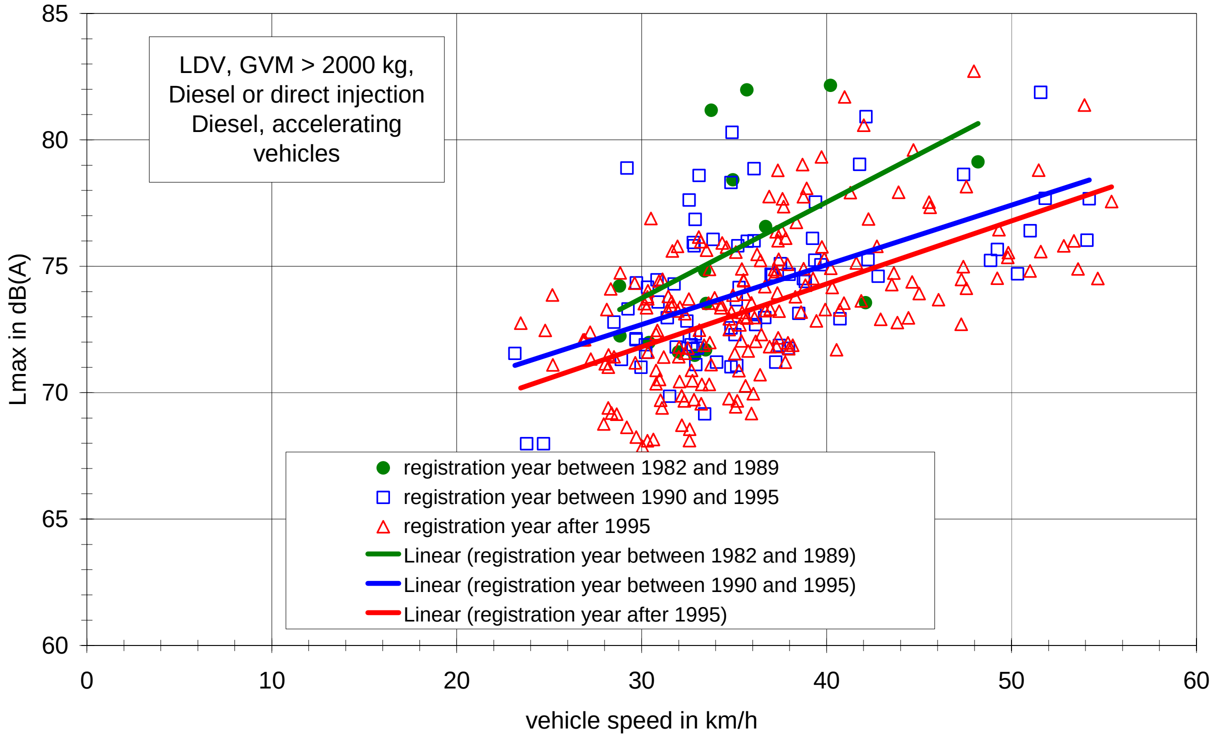

Figure 40: Pass by levels of LDV of different registration year classes, accelerating vehicles

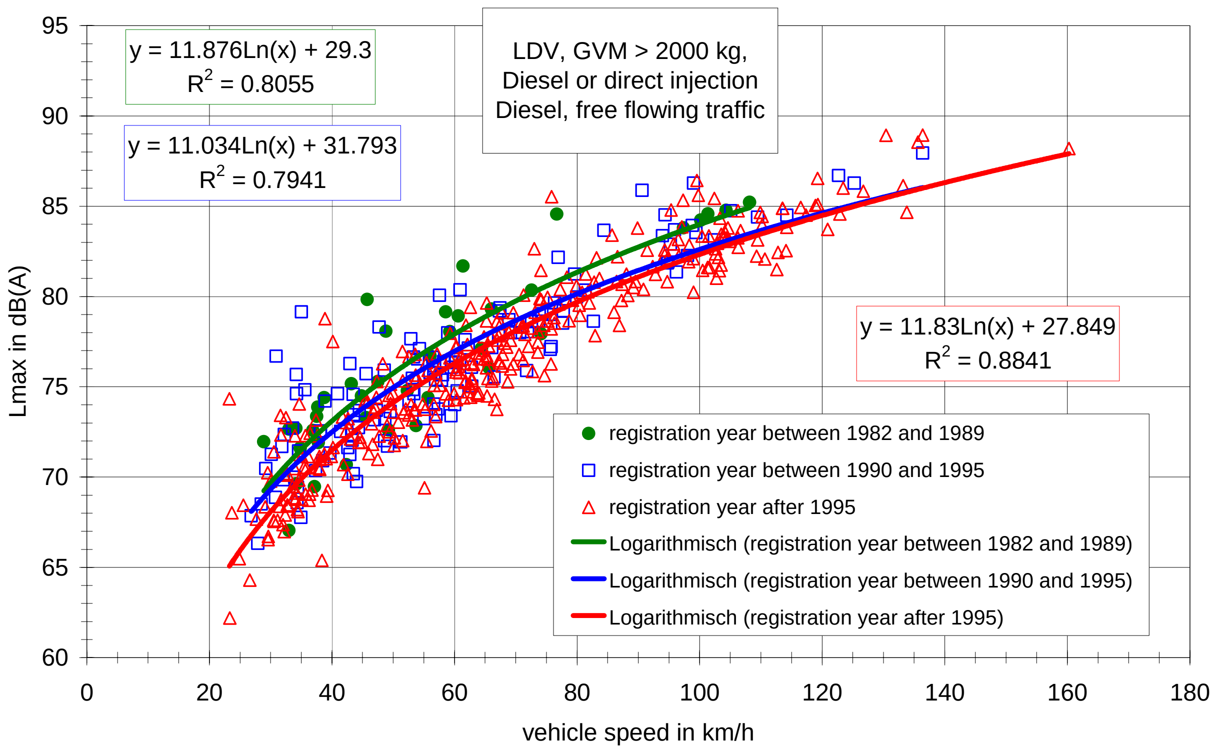

Figure 41: Pass by levels of LDV of different registration year classes, accelerating vehicles

3.2.3 Heavy duty vehicles

With respect to the noise limits heavy duty vehicles (HDV) are separated into the following three rated power (Pn) classes:

- Pn < 75 kW,
- 75 kW <= Pn < 150 kW,
- Pn >= 150 kW

Consequently the first analysis was executed in accordance with these classes but separately for HDV with up to 3 axles and HDV with more than 3 axles.

As can be seen in Table 18 there are only a few vehicles in the 2001 sample with rated power values below 75 kW. A further analysis of the registration year showed that this power class will vanish in the future, since only 2 vehicles are in the database, that were registered after 1996. The major part of the sample with up to 3 axles has rated power values between 100 and 125 kW and 150 and 200 kW. 43% of this sample belongs already to the highest rated power class of the current type approval noise regulation.

Concerning HDV with more than 3 axles the rated power structure is as shown in Table 19. Nearly 90% of the sample has rated power values between 250 and 350 kW.

HDV <= 3 axles	number of vehicles	percentage	percentage
Pn < 75 kW	83	5.5%	5.5%
75 kW <= Pn < 100 kW	145	9.6%	51.6%
100 kW <= Pn < 125 kW	442	29.3%	
125 kW <= Pn < 150 kW	191	12.7%	
150 kW <= Pn < 200 kW	323	21.4%	42.9%
200 kW <= Pn < 250 kW	187	12.4%	
250 kW <= Pn < 300 kW	106	7.0%	
Pn >= 300 kW	30	2.0%	
sum	**1507**	**100.0%**	**100.0%**

Table 18: Rated power structure of the HDV sample with up to 3 axles

HDV > 3 axles	number of vehicles	percentage
150 kW <= Pn < 200 kW	15	1.0%
200 kW <= Pn < 250 kW	33	2.2%
250 kW <= Pn < 300 kW	688	45.0%
300 kW <= Pn < 350 kW	675	44.2%
Pn >= 350 kW	117	7.7%
sum	**1528**	**100.0%**

Table 19: Rated power structure of the HDV sample with more than 3 axles

3.2.3.1 Results for vehicles registered after 1995 (current emission stage)

In a first step it should be checked whether there is a correlation between the in-use noise emission levels and the technical parameters rated power and engine capacity. Both technical parameters were classified and the averages of the Lmax levels were calculated for accelerating vehicles in the speed range between 20 km/h and 40 km/h for each power and capacity class. Since the tyre/road noise contribution is depending on the number of axles this analysis step was carried out separately for vehicles with up to 3 and more than 3 axles.

The results for the rated power classes are shown in Figure 42 for rated power and in Figure 43 for engine capacity. Only classes with at least 10 vehicles were considered. For HDV with up to 3 axles the in-use noise levels clearly increase with increasing rated power or increasing engine capacity respectively. But astonishingly for HDV with more than 3 axles the in-use noise emission levels decrease slightly with increasing power or engine capacity. The rated power ranges of both axle classes are clearly separated. There is no power class above 250 kW with 10 vehicles for HDV up to 3 axles and no power class below 250 kW for HDV with more than 3 axles.

For engine capacity there is a small region between 11000 and 12000 cm³, where both axle classes overlap. In this region no significant difference between the 2 axle classes can be seen, so that one can conclude that acceleration phases in this speed range are not much influenced by tyre/road noise.

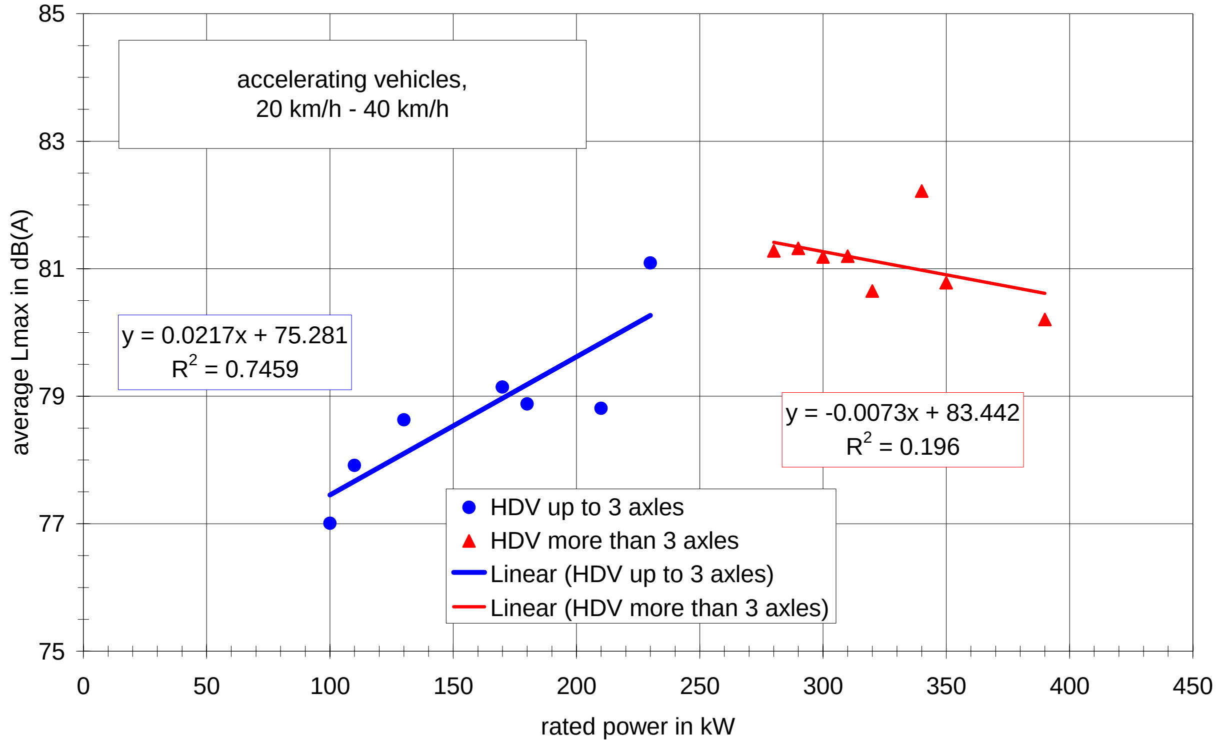

Figure 42: Average pass by levels of accelerating HDV versus rated power for the two axle number classes (registration year > 1995)

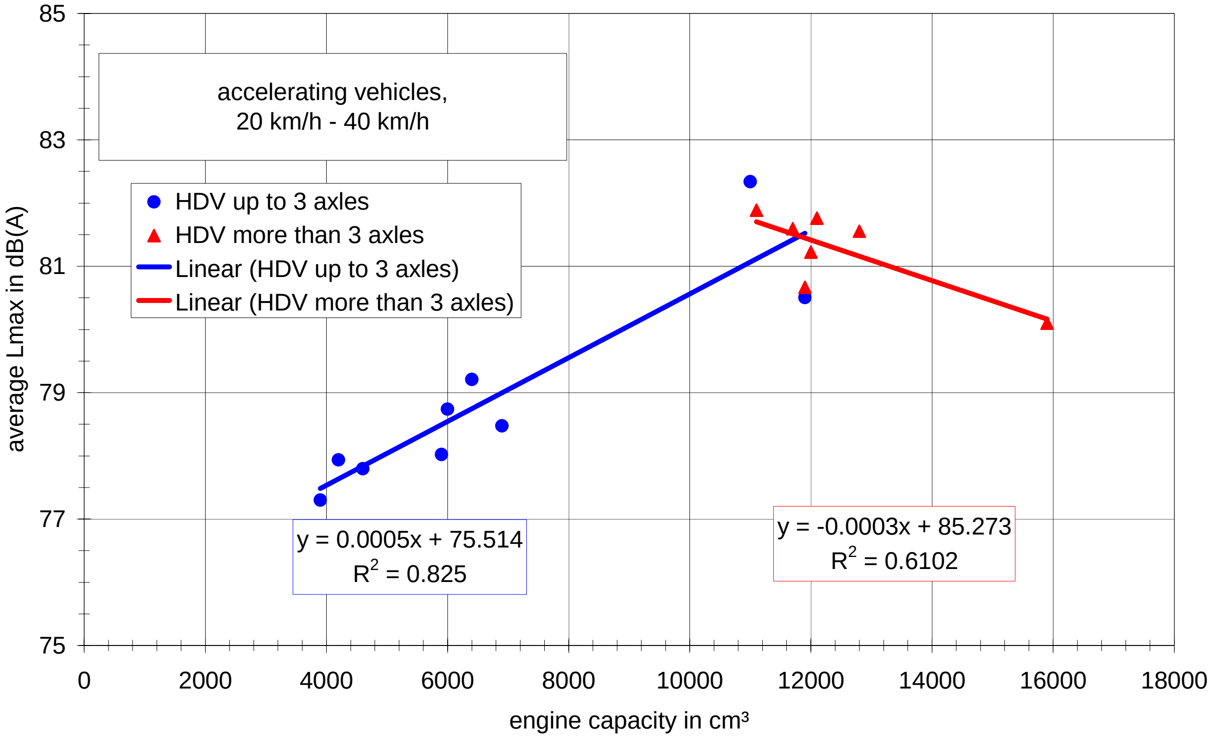

Figure 43: Average pass by levels of accelerating HDV versus engine capacity for the two axle number classes (registration year > 1995)

In order not to mix up the possible rated power effects by age effects and in order to get a better insight into the power effect the further analysis was restricted to vehicles registered after 1995 and the following rated power classification for both axle number classes was used:

- Pn <= 100 kW,
- 100 kW < Pn <= 150 kW,
- 150 kW < Pn <= 250 kW,
- Pn > 250 kW

The borderlines at 150 kW and 250 kW are defined slightly different than for the analysis for categories, but this had no consequence for the results and conclusions. These classes are proposed to be used for an amendment of the EU and ECE noise regulations for heavy duty vehicles. Figure 44 shows the individual Lmax levels of each power class versus vehicle speed for accelerating vehicles. For HDV with more than 3 axles only the highest power class was considered, because there are only a few vehicles with power values below 250 kW in the database.

Since the speed range is small, the noise level variances at given speeds are high and the speed influence on the results is of minor importance, the noise level distribution curves were calculated for each power and axle class in order to get a clearer picture. The resulting distributions are shown in Figure 45. The distributions for HDV up to 3 axles are clearly separated with respect to the power classes and for noise levels up to 82 dB(A). Above that level the distributions of the power classes above 100 kW coincide. This coincidence is most probably caused by vehicles with abnormal noise emissions due to maintenance problems.

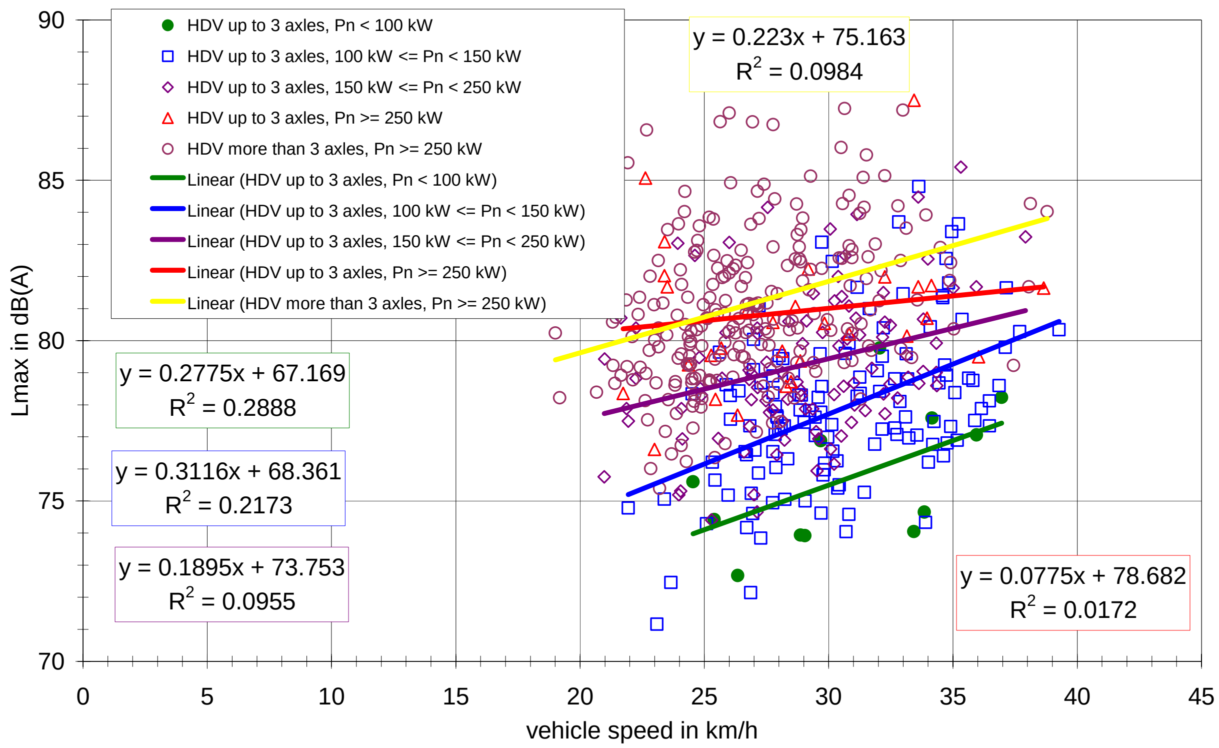

Figure 44: Pass by levels of accelerating HDV versus vehicle speed for different subcategories (registration year > 1995)

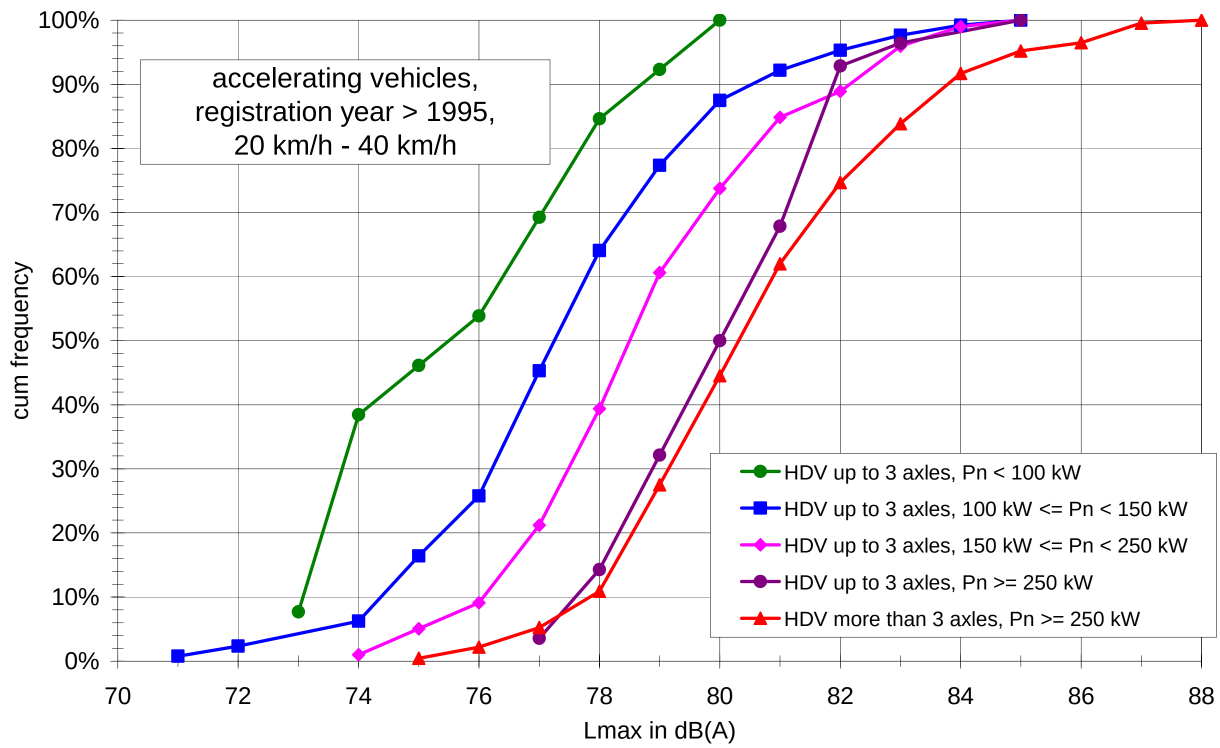

Figure 45: Pass by level distributions of accelerating HDV for different subcategories (registration year > 1995)

The noise level distributions for the 2 HDV axle classes with rated power values above 250 kW are close together up to 81 dB(A), but diverge increasingly with increasing noise level, which could be explained by the differences in vehicle load.

The average noise levels for the different HDV subclasses are summarised in Table 20. It is interesting but not surprising, that the average speed values decrease with increasing power class. The lowest value was found for the HDV class with more than 3 axles. In order to compensate the speed influence, speed corrected levels for 30 km/h were calculated and included in the table using 2 dB level increase per 10 km/h speed increase. The differences of these corrected Lmax levels compared to the lowest power class are also shown in Table 20. For 3 axle vehicles the difference from one power class to the other is 1,7 to 2 dB(A), resulting in a 5,4 dB(A) difference between the highest and the lowest power class. The difference between the 2 axle classes for HDV in the highest power class is below 1 dB(A).

A higher difference was found for both classes for free flowing traffic conditions (see Figure 46, Table 21 and Table 22. Figure 46 shows the individual Lmax levels versus vehicle speed wit regression curves, Table 21 shows the average Lmax levels together with speed corrected levels for 75 km/h using the same speed correction as for accelerating vehicles. Table 22 contains the speed corrected levels of both driving conditions for comparison reasons.

For 3 axle vehicles the difference from one power class to the other is 0,7 to 1,1 dB(A), resulting in a 3,9 dB(A) difference between the highest and the lowest power class. These differences are lower than the differences for accelerating vehicles, which leads to the conclusion that the in-use noise levels at 75 km/h are already influenced by tyre/road noise. The difference between the 2 axle classes for HDV in the highest power class at 75 km/h free flowing traffic is 1,1 dB(A), which is also an indication for the tyre/road noise influence.

HDV subcategory	number of vehicles	average speed in km/h	average Lmax in dB(A)	speed corrected Lmax in dB(A) for 30 km/h	Delta L in dB(A)
HDV up to 3 axles, Pn < 100 kW	13	31.1	76.0	75.8	0.0
HDV up to 3 axles, 100 kW <= Pn < 150 kW	128	30.6	77.9	77.8	2.0
HDV up to 3 axles, 150 kW <= Pn < 250 kW	99	28.9	79.2	79.5	3.7
HDV up to 3 axles, Pn >= 250 kW	30	28.4	80.9	81.2	5.4
HDV more than 3 axles, Pn >= 250 kW	235	26.9	81.2	81.8	6.0

Table 20: Average Lmax levels of accelerating HDV for different subcategories (registration year > 1995)

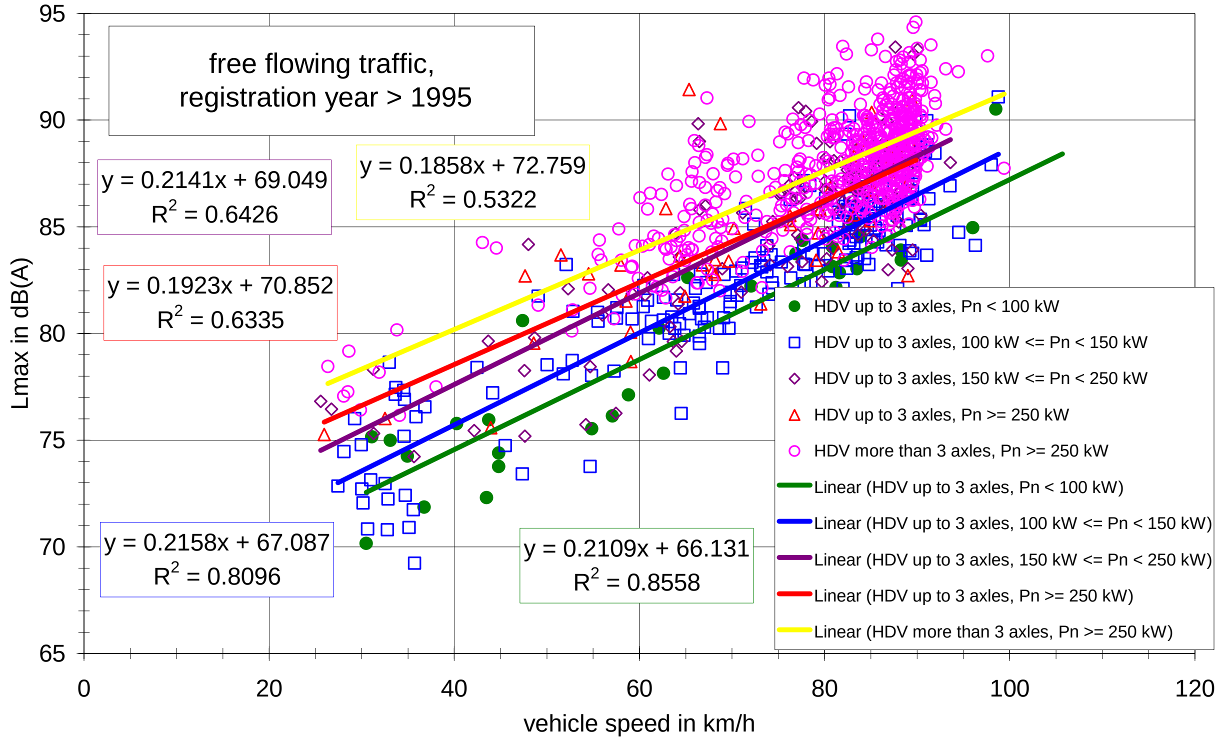

Figure 46: Pass by levels of HDV in free flowing traffic for different subcategories (Registration year > 1995)

HDV subcategory	number of vehicles	average speed in km/h	Lmax in dB(A)	speed corrected Lmax in dB(A) for 75 km/h	Delta L in dB(A)
HDV up to 3 axles, Pn < 100 kW	33	65.4	80.0	81.9	0.0
HDV up to 3 axles, 100 kW <= Pn < 150 kW	197	71.3	82.5	83.2	1.1
HDV up to 3 axles, 150 kW <= Pn < 250 kW	130	75.4	85.2	85.1	3.2
HDV up to 3 axles, Pn >= 250 kW	52	72.9	84.9	85.3	3.9
HDV more than 3 axles, Pn >= 250 kW	575	81.0	87.8	86.6	5.0

Table 21: Average Lmax levels of HDV in free flowing traffic for different subcategories (registration year > 1995)

HDV subcategory	Lmax at 30 km/h in dB(A), accelerating vehicles	Delta L in dB(A)	Lmax at 75 km/h in dB(A), free flowing traffic	Delta L in dB(A)
HDV up to 3 axles, Pn < 100 kW	75.8	0.0	81.9	0.0
HDV up to 3 axles, 100 kW <= Pn < 150 kW	77.8	2.0	83.2	1.1
HDV up to 3 axles, 150 kW <= Pn < 250 kW	79.5	3.7	85.1	3.2
HDV up to 3 axles, Pn >= 250 kW	81.2	5.4	85.3	3.9
HDV more than 3 axles, Pn >= 250 kW	81.8	6.0	86.6	5.0

Table 22: Average Lmax levels of HDV accelerating and in free flowing traffic for different subcategories (registration year > 1995)

3.2.3.2 Results for different emission stages

In addition an analysis was carried out in each of the new proposed rated power and axle classes for vehicles with registration years before 1990, between 1990 and 1995 and after 1995. These time periods are related to different limit value periods. The results for acceleration conditions are shown in Figure 47 to Figure 49 and summarised in Table 23. The delta L values are related to consecutive registration year classes. For the highest power class no vehicles were found in the database with registration years before 1990. The speed corrections in Table 23 were made in the same way as described in the previous chapter.

For the power classes below 250 kW and HDV with 3 axles a comparison can be made between today's vehicles and vehicles registered before 1990, whose type approval noise limits differ by 8 dB(A). The average pass by levels for accelerations between 20 and 40 km/h for today's vehicles are 3,3 to 4,2 dB(A) lower than for vehicles registered before 1990. The differences decrease with increasing power class. That means that the noise reduction in real traffic for these vehicles is higher than for cars or LDV and that the type approval noise limit reduction was more effective. This is not the case for HDV with rated power values above 250 kW. For these vehicles the last limit reduction step was 4 dB(A), resulting in a reduction of the in-use emissions for accelerations at low speeds of only 0,9 to 1,4 dB(A).

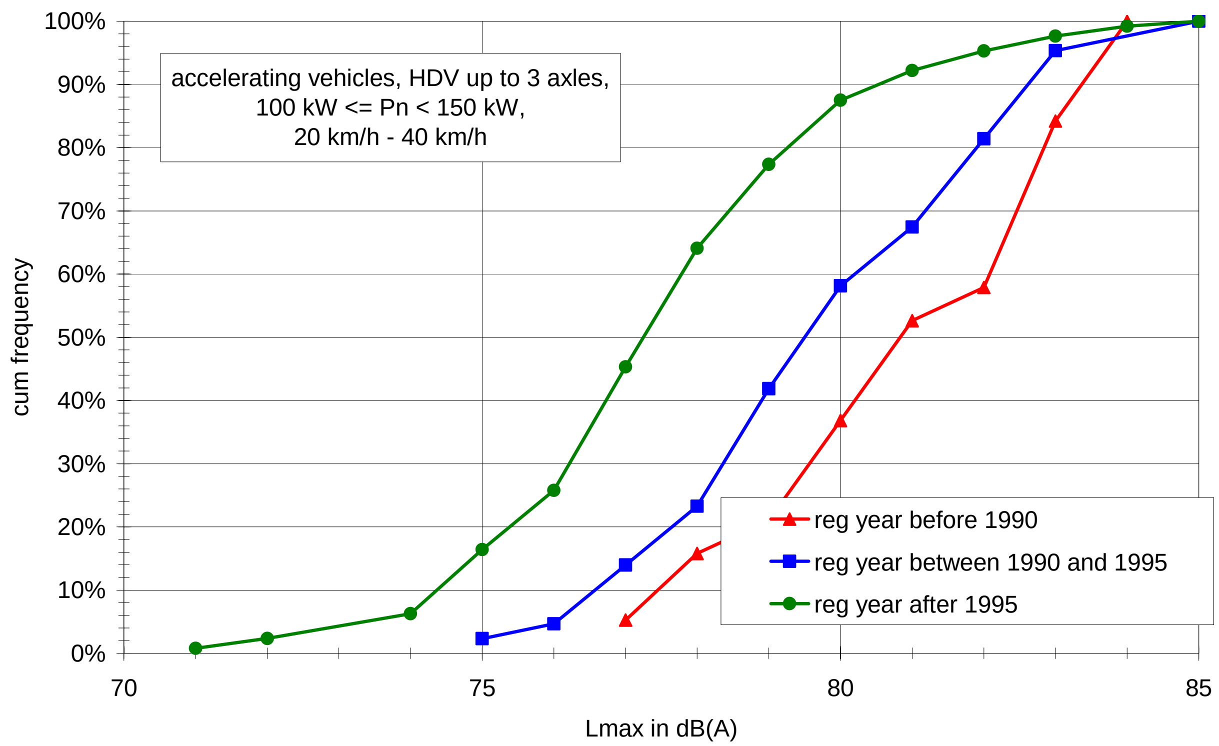

Figure 47: Pass by level distributions of HDV up to 3 axles, 100 kW <= rated power < 150 kW for different registration year periods

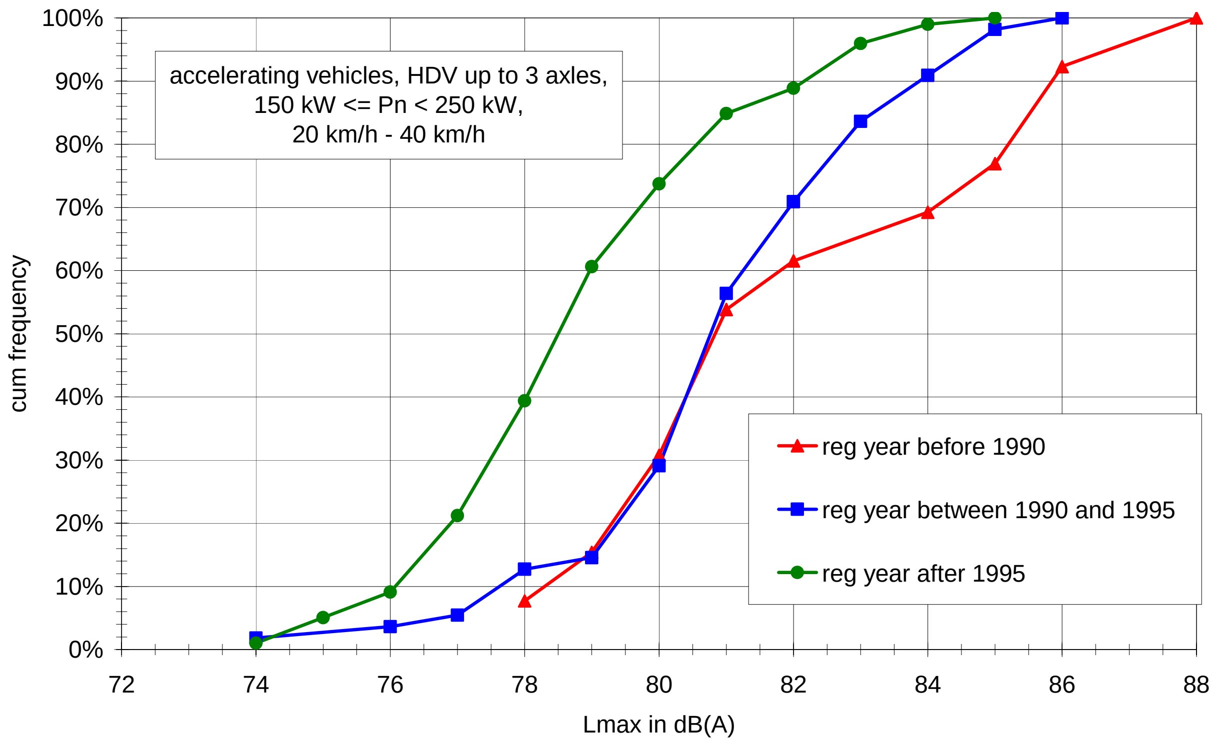

Figure 48: Pass by level distributions of HDV up to 3 axles, 150 kW <= rated power < 250 kW for different registration year periods

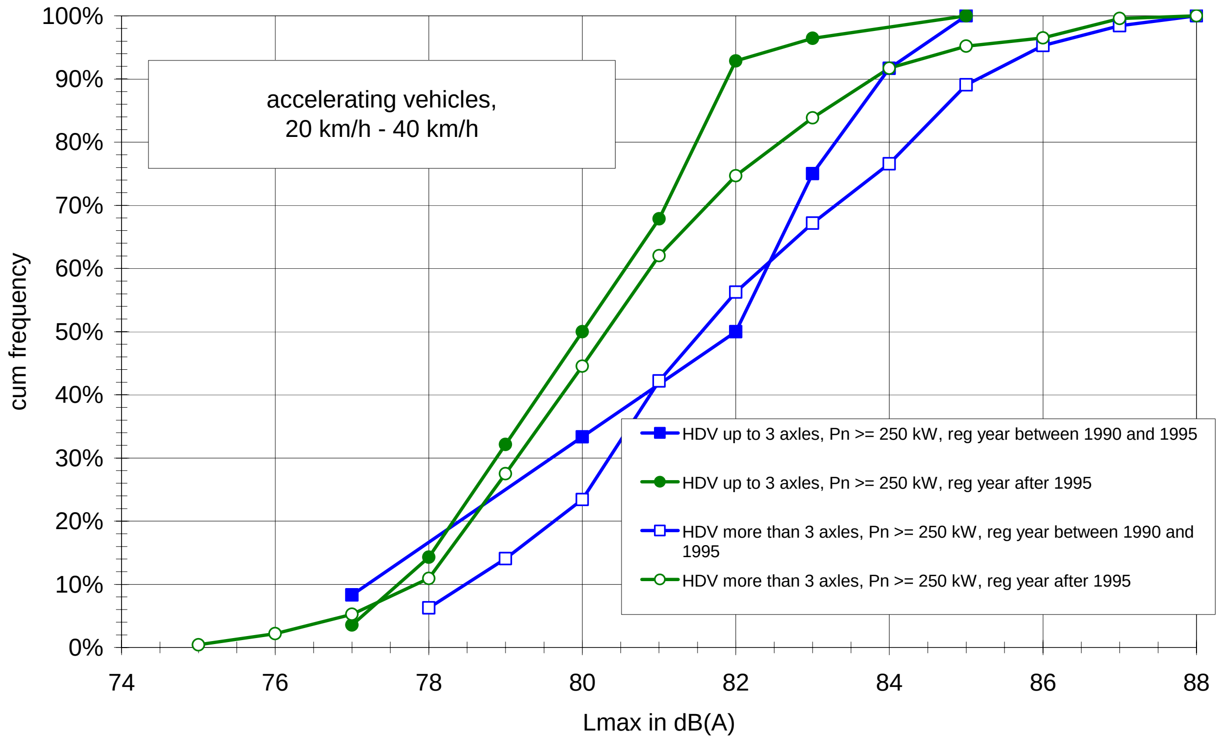

Figure 49: Pass by level distributions of HDV with rated power >= 250 kW for different registration year periods

HDV subcategory	registration year	number of vehicles	average rated power in kW	average engine capacity in cm³	average speed in km/h	average Lmax in dB(A)	speed corrected Lmax in dB(A) for 30 km/h	Delta L in dB(A)	Noise limit in dB(A)
HDV up to 3 axles, Pn < 100 kW	before 1990	17	67.7	3877	30.2	80.3	80.3		86
	between 1990 and 1995	47	83.4	4678	31.3	78.9	78.7	-1.6	83
	after 1995	14	82.4	3588	31.1	76.3	76.1	-2.6	78
HDV up to 3 axles, 100 kW <= Pn < 150 kW	before 1990	19	115.6	6027	29.2	81.2	81.4		86
	between 1990 and 1995	43	115.4	5772	30.3	80.1	80.1	-1.3	83
	after 1995	128	112.6	4490	30.6	77.9	77.8	-2.3	78
HDV up to 3 axles, 150 kW <= Pn < 250 kW	before 1990	13	182.5	11033	27.5	82.3	82.8		88
	between 1990 and 1995	55	188.6	9450	29.0	81.3	81.5	-1.3	84
	after 1995	99	191.6	7554	28.9	79.2	79.5	-2.1	80
HDV up to 3 axles, Pn >= 250 kW	before 1990								88
	between 1990 and 1995	12	273.4	13512	29.2	81.9	82.1		84
	after 1995	30	297.3	12676	28.4	80.9	81.2	-0.9	80
HDV more than 3 axles, Pn >= 250 kW	before 1990								88
	between 1990 and 1995	65	287.6	12962	26.2	82.4	83.2		84
	after 1995	232	308.2	12440	27.0	81.2	81.8	-1.4	80

Table 23: Average Lmax levels of accelerating HDV different subcategories and registration year periods

Corresponding results as discussed before are shown in Figure 50 and Table 24 for free flowing traffic. The figure just gives an example for HDV up to 3 axles and rated power values between 150 and 250 kW. The averaged and speed corrected levels for 70 km/h are shown in the table. The speed corrections were made in the same way as described before (2 dB per 10 km/h). For the 3 power classes

As for acceleration phases the power classes below 250 kW and HDV with 3 axles contain also results for vehicles registered before 1990. The in-use noise level reduction between today's vehicles and those before 1990 are less than half of the reduction achieved for acceleration phases. This significant deterioration of the effectiveness of the limit reduction is most probably caused by the increased influence of the tyre/road noise for these driving conditions. For vehicles with rated power values above 250 kW the difference to today's vehicles and the emission stage before is in the same order as for accelerating vehicles, which means it is rather low.

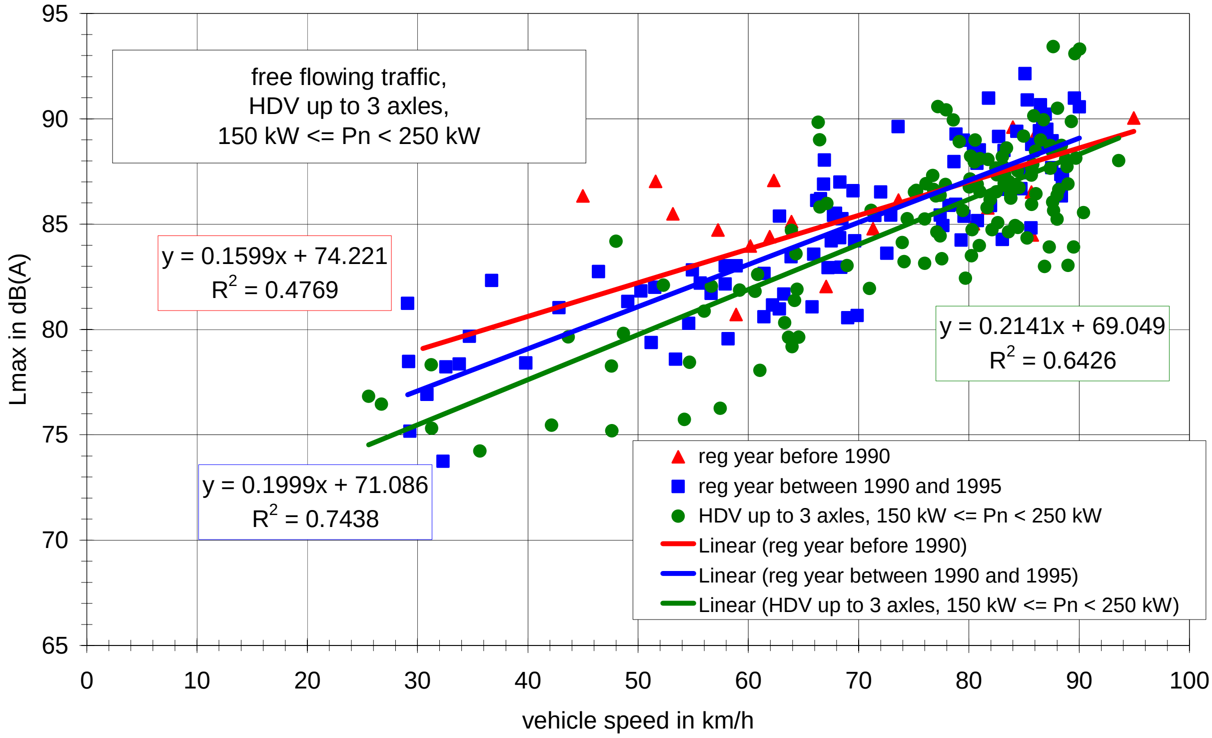

Figure 50: Pass by levels of HDV up to 3 axles, 150 kW <= rated power < 250 kW for different registration year periods

HDV subcategory	registration year	number of vehicles	average rated power in kW	average engine capacity in cm³	average speed in km/h	average Lmax in dB(A)	speed corrected Lmax in dB(A) for 70 km/h	Delta L in dB(A)	Noise limit in dB(A)
HDV up to 3 axles, Pn < 100 kW	before 1990	32	69.8	4142	57.9	80.4	82.8		86
	between 1990 and 1995	59	82.2	4576	68.7	82.7	83.0	0.1	83
	after 1995	33	84.0	3019	65.4	80.0	80.9	-2.0	78
HDV up to 3 axles, 100 kW <= Pn < 150 kW	before 1990	36	109.2	6262	62.3	81.5	83.0		86
	between 1990 and 1995	100	114.1	5663	70.1	83.1	83.1	0.0	83
	after 1995	197	114.3	4595	71.3	82.5	82.2	-0.8	78
HDV up to 3 axles, 150 kW <= Pn < 250 kW	before 1990	23	175.8	11082	70.0	85.4	85.4		88
	between 1990 and 1995	95	186.2	9715	68.4	84.8	85.1	-0.3	84
	after 1995	130	187.3	7770	75.4	85.2	84.1	-1.0	80
HDV up to 3 axles, Pn >= 250 kW	before 1990								88
	between 1990 and 1995	19	266.7	12418	65.8	84.1	85.0		84
	after 1995	52	281.2	11832	72.9	84.9	84.3	-0.7	80
HDV more than 3 axles, Pn >= 250 kW	before 1990								88
	between 1990 and 1995	100	288.2	13273	76.6	88.4	87.1		84
	after 1995	575	304.1	12352	81.0	87.8	85.6	-1.5	80

Table 24: Average Lmax levels of HDV in free flowing traffic for different subcategories and registration year periods

3.2.3.3 Vehicle Types

Concerning vehicle types the same approach was used as for cars and LDV. That means within an axle class a type is defined by the same engine capacity and rated power. For accelerating vehicles the Lmax levels as well as the speed levels between 20 and 40 km/h were averaged and speed corrected levels for 30 km/h were calculated. The results are shown in Table 25 and Table 26 for types with at least 10 vehicles. The difference between the loudest and the quietest type is 4,4 dB(A) for HDV up to 3 axles and 1,8 dB(A) for HDV with more than 3 axles. The 4,4 dB(A) difference can be explained by differences in rated power or engine capacity (see Figure 51 and Figure 52). The unexplained rest of variance is about 2 dB(A). This rest cannot be reduced for in-use noise measurements and such small vehicle samples.

number of axles	vehicle type number	rated power in kW	engine capacity in cm³	number of vehicles	average vehicle sped in km/h	average Lmax in dB(A)	up to 3 axles, speed corrected Lmax in dB(A) for 30 km/h
up to 3	1	100	3908	14	31.5	76.9	76.6
	2	100	4249	12	34.3	77.6	76.8
	3	105	5861	13	31.5	77.7	77.4
	4	112	4249	25	31.3	78.5	78.2
	5	114	4580	14	30.5	77.9	77.8
	6	170	6374	19	30.2	79.8	79.7
	7	205	6374	24	28.8	78.9	79.2
	8	230	11946	10	27.6	80.5	80.9

Table 25: Average Lmax levels of accelerating HDV with up to 3 axles for different vehicle types, registration year > 1995

number of axles	vehicle type number	rated power in kW	engine capacity in cm³	number of vehicles	average vehicle sped in km/h	average Lmax in dB(A)	more than 3 axles, speed corrected Lmax in dB(A) for 30 km/h
more than 3	1	290	11946	26	28.7	81.0	81.3
	2	294	11967	30	26.4	81.3	82.0
	3	301	11967	40	26.2	81.0	81.8
	4	309	11705	13	26.5	81.1	81.8
	5	315	11946	20	26.1	79.8	80.6
	6	338	12816	12	27.8	81.7	82.1
	7	350	15928	12	27.2	80.5	81.1
	8	390	15928	10	26.2	79.6	80.3

Table 26: Average Lmax levels of accelerating HDV with more than 3 axles for different vehicle types, registration year > 1995

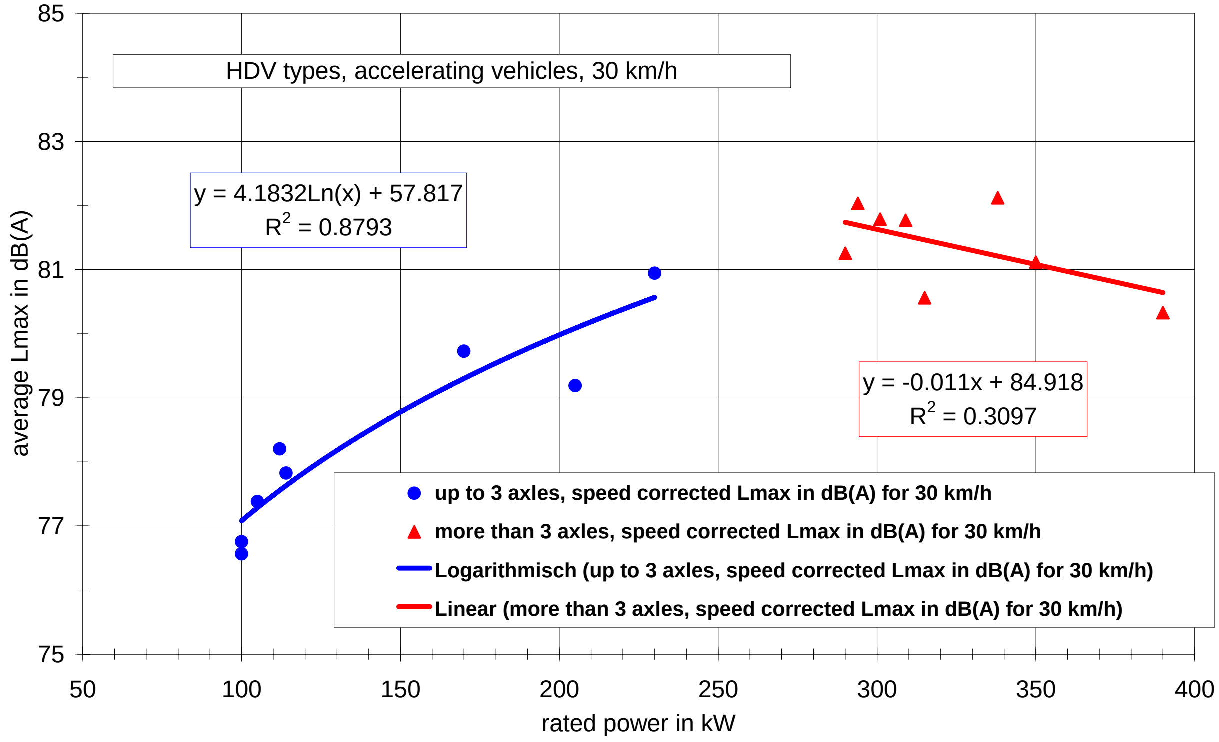

Figure 51: Average Lmax levels of accelerating HDV with up to 3 axles for different vehicle types versus rated power values, registration year > 1995

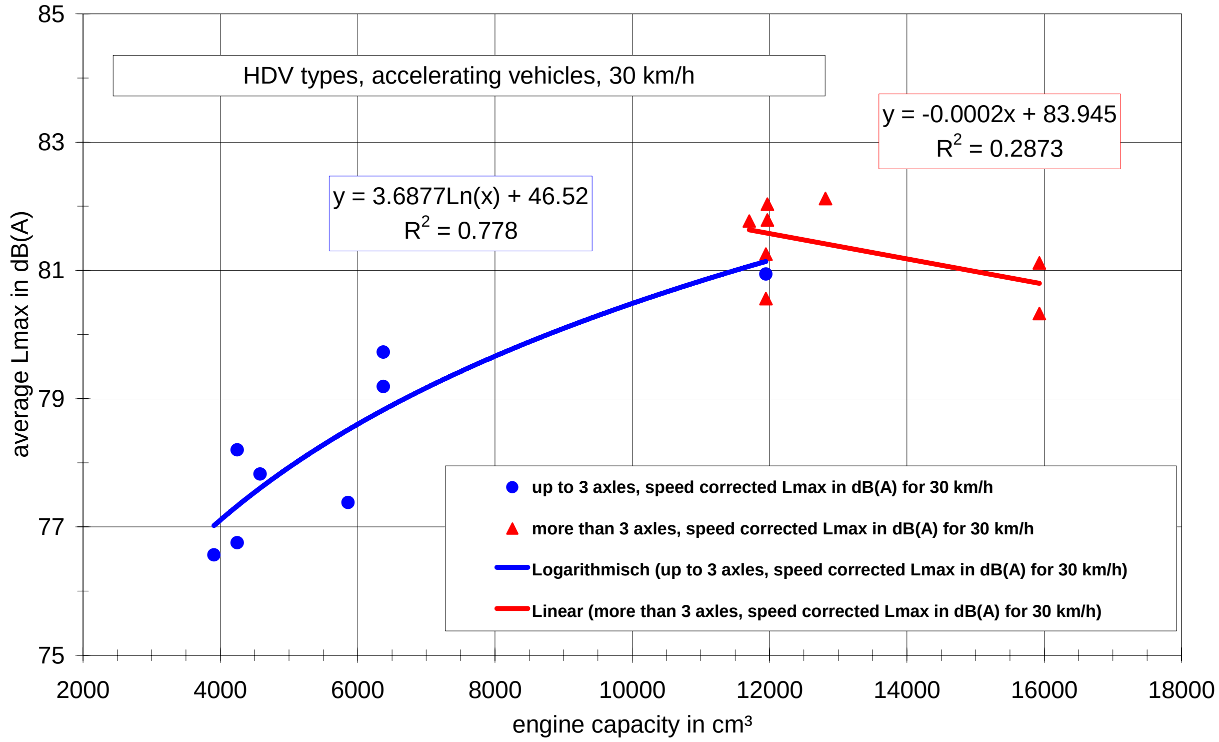

Figure 52: Average Lmax levels of accelerating HDV with up to 3 axles for different vehicle types versus engine capacity values, registration year > 1995

Corresponding results for free flowing traffic are shown in Table 27 and Table 28. The influences of rated power and engine capacity are shown in Figure 53 and Figure 54. The difference between the loudest and the quietest type is 3,5 dB(A) for HDV up to 3 axles and 2,3 dB(A) for HDV with more than 3 axles and can also partly be explained by rated power or engine capacity differences.

The conclusion is the same as for cars and LDV: There are no type specific differences in the in-use noise emission.

number of axles	vehicle type number	rated power in kW	engine capacity in cm³	number of vehicles	average vehicle sped in km/h	average Lmax in dB(A)	up to 3 axles, speed corrected Lmax in dB(A) for 70 km/h
up to 3	1	90	2874	10	64.8	79.8	80.8
	2	100	3908	13	63.7	80.2	81.5
	3	100	4249	11	78.4	83.8	82.2
	4	105	5861	12	69.3	82.3	82.4
	5	112	4249	31	73.6	82.8	82.1
	6	114	4580	31	69.0	81.6	81.8
	7	125	4249	18	73.3	83.7	83.1
	8	125	4249	14	69.6	82.8	82.9
	9	162	6871	14	79.1	85.4	83.6
	10	170	6374	23	70.2	84.0	84.0
	11	205	6374	13	79.0	85.4	83.6
	12	230	11946	11	75.6	85.5	84.4

Table 27: Average Lmax levels of HDV with up to 3 axles in free flowing traffic for different vehicle types, registration year > 1995

number of axles	vehicle type number	rated power in kW	engine capacity in cm³	number of vehicles	average vehicle sped in km/h	average Lmax in dB(A)	more than 3 axles, speed corrected Lmax in dB(A) for 80 km/h
more than 3	1	260	11946	23	78.6	87.3	87.6
	2	279	12130	12	80.8	86.2	86.1
	3	280	14618	30	76.9	87.7	88.3
	4	290	11946	99	80.6	87.3	87.2
	5	294	11967	29	83.9	87.8	87.1
	6	294	11705	15	82.8	88.4	87.8
	7	301	11967	42	77.1	87.0	87.6
	8	309	12130	16	83.5	88.6	88.0
	9	309	11705	10	84.9	88.8	87.9
	10	315	11946	80	80.3	87.6	87.6
	11	315	12580	27	86.6	89.1	87.8
	12	316	10308	13	81.6	87.5	87.2
	13	338	12816	38	80.3	87.8	87.7
	14	350	15928	15	81.5	88.5	88.2

Table 28: Average Lmax levels of HDV with more than 3 axles in free flowing traffic for different vehicle types, registration year > 1995

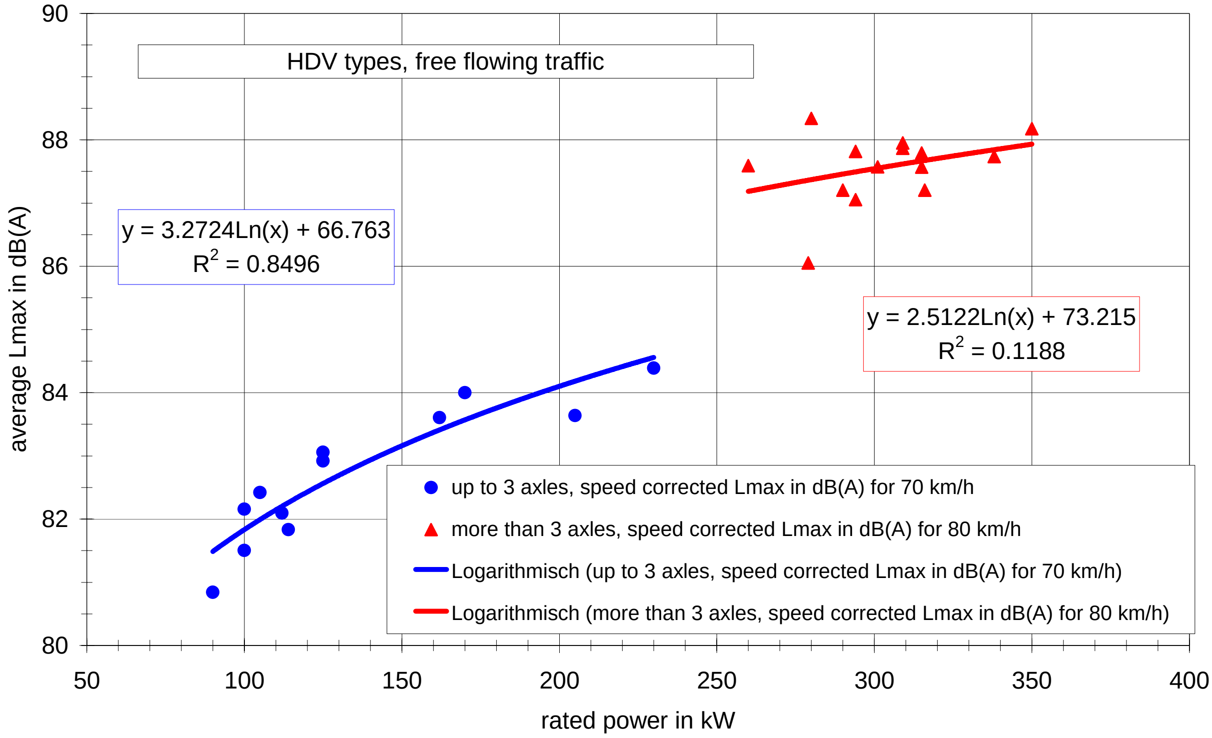

Figure 53: Average Lmax levels of HDV with up to 3 axles in free flowing traffic for different vehicle types versus rated power values, registration year > 1995

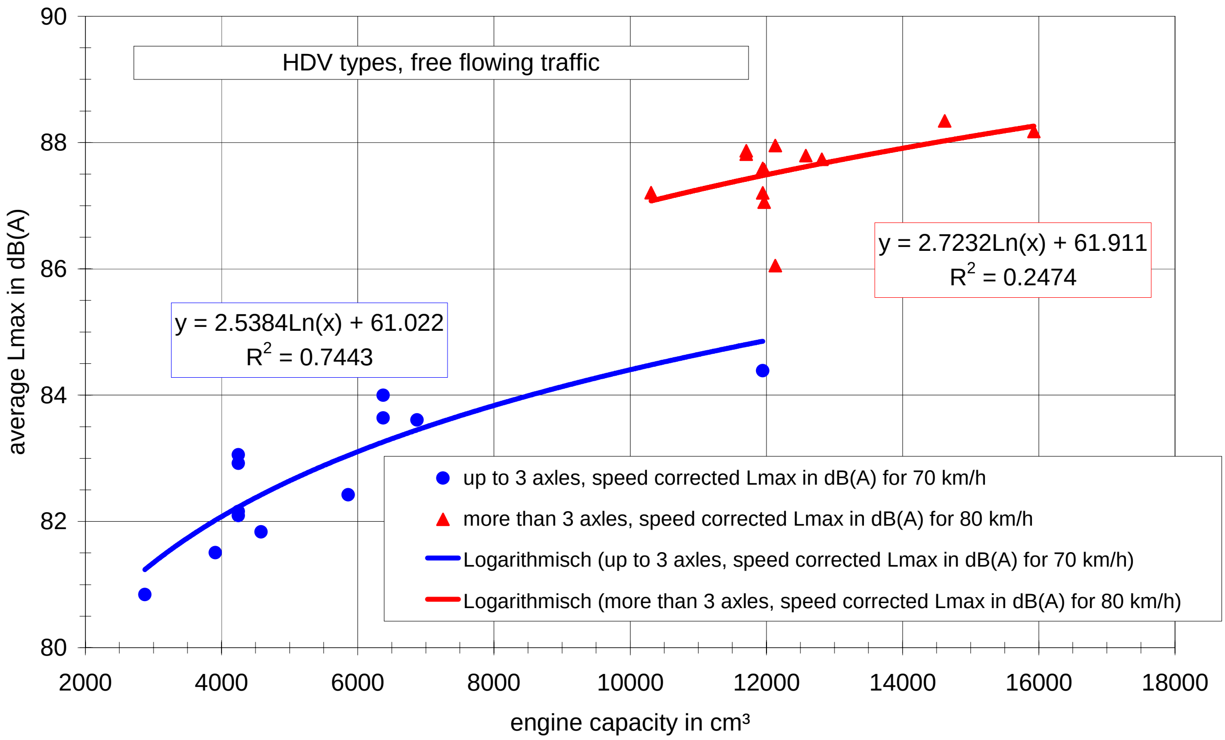

Figure 54: Average Lmax levels of HDV with more than 3 axles in free flowing traffic for different vehicle types versus engine capacity values, registration year > 1995

3.2.3.4 In-use noise levels on motorways with and without gradients

In order to get in-use noise level results for HDV on motorways with gradients two measure-ment sites were established on motorways with uphill gradients of about 4%. The results are compared in Figure 55 and Figure 56 with the results of 3 other, flat motorway sites for the two HDV axle classes as individual Lmax levels versus vehicle speed. As one could expect the results on the uphill sites show a lower slope for the speed dependency than the flat sites. That means that the differences increase with decreasing speed. The difference was about 3 dB(A) at 50 km/h for the HDV sample with up to 3 axles and below 3 dB(A) for HDV with more than 3 axles. The reason is that the vehicles going uphill try to run with the highest possible speed and thus use more power and produce more noise than in flat condition. But differently to former measurement campaigns a substantially part of the vehicle sample nowadays has enough power to run uphill gradients of 4% with maximum vehicle speed.

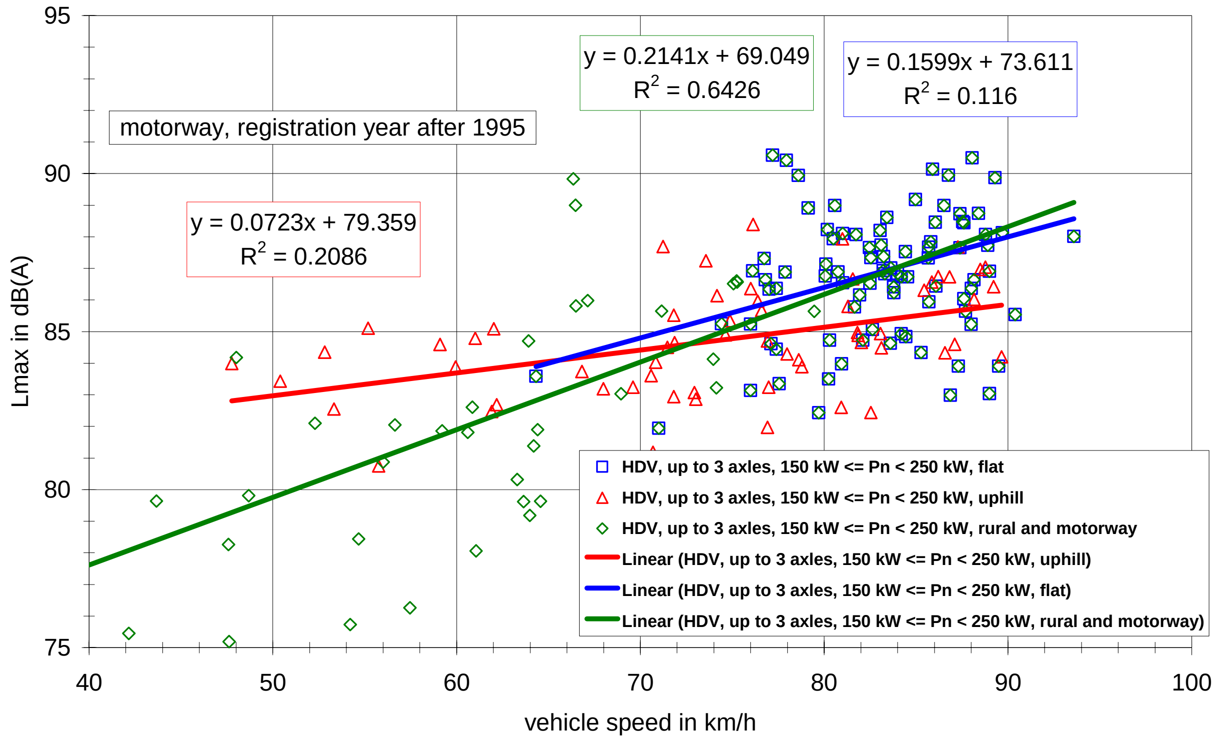

Figure 55: Comparison of Lmax levels of HDV up to 3 axles on motorway sites with and without gradients

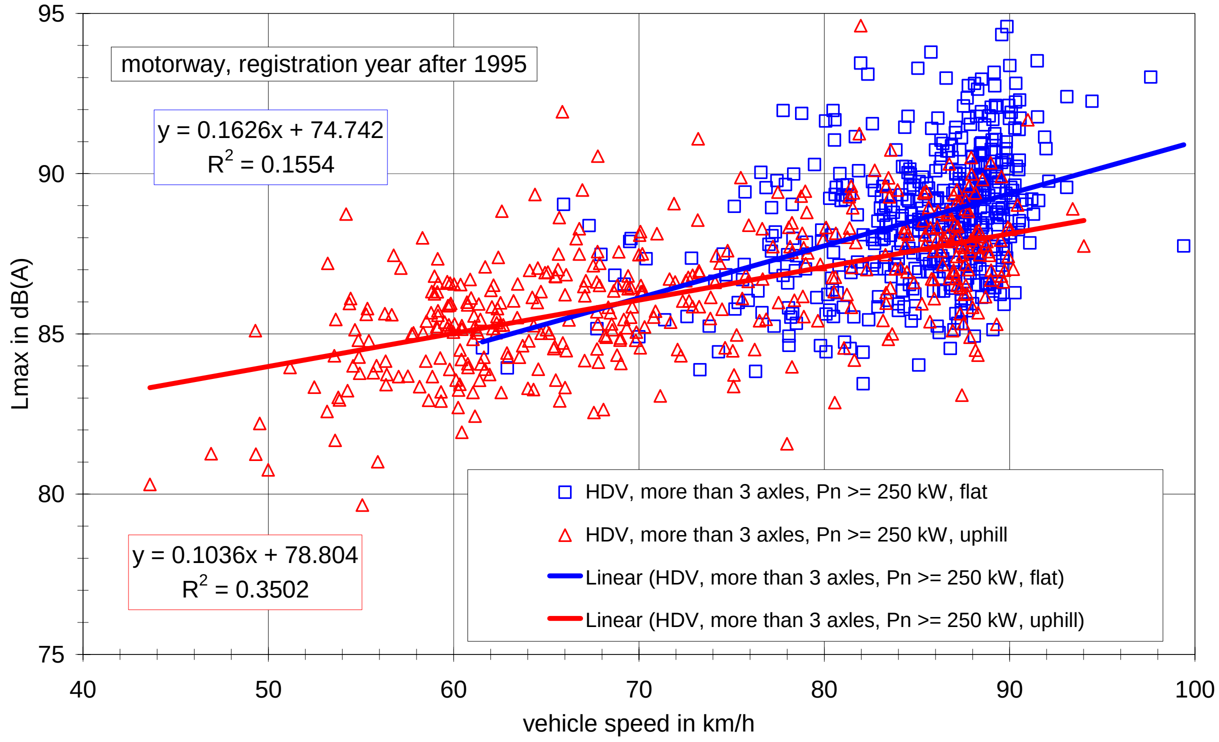

Figure 56: Comparison of Lmax levels of HDV more than 3 axles on motorway sites with and without gradients

3.2.4 Motorcycles

The motorcycle sample, for which technical data were available, contained 392 vehicles. An analysis was carried out with respect to rated power, engine capacity and registration year. With respect to rated power the following classes were defined:

1. Pn <= 25 kW,
2. 25 kW < Pn <= 50 kW,
3. 50 kW <Pn <= 75 kW,
4. Pn > 75 kW

Figure 57 shows the results for four different rated power classes. The differences in the regression curves are not significant. The high variances of the individual results are partly caused by different driving behaviour and partly by the use of noise increasing exhaust and/or intake silencers.

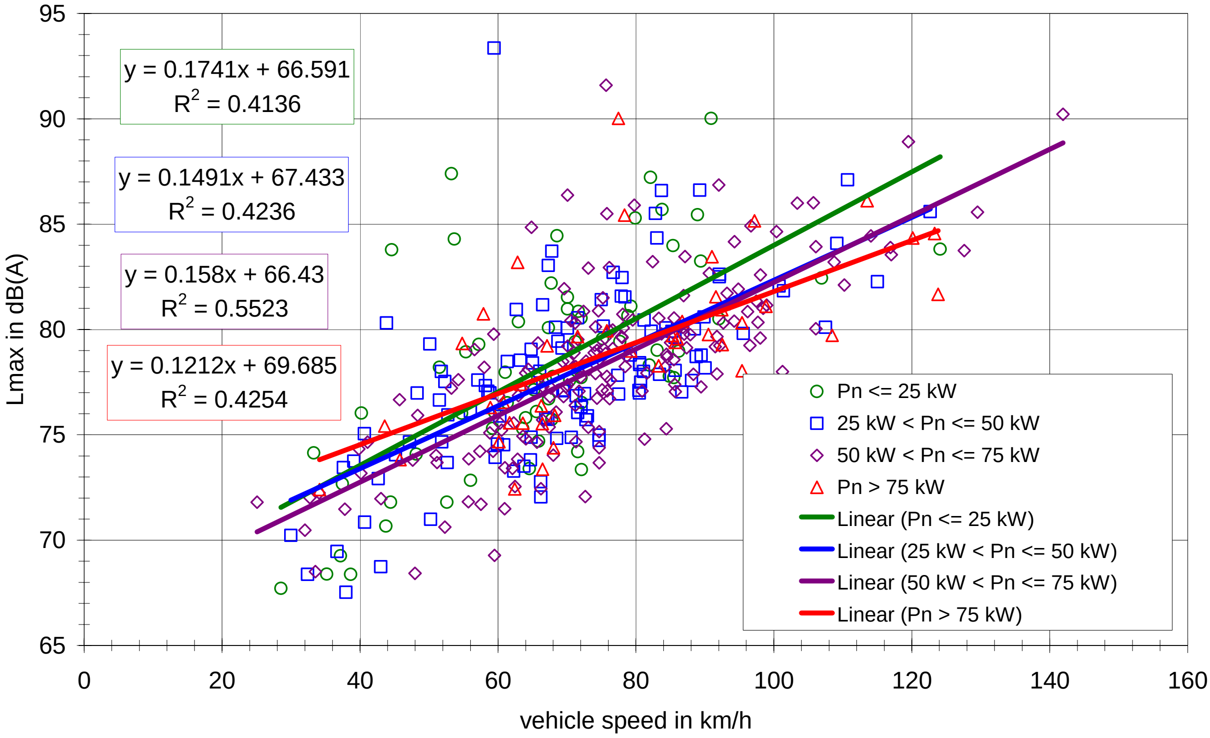

Figure 57: Pass by levels of motorcycles for different rated power classes

Concerning engine capacity the following classes were defined:

1. <= 125 cm³,
2. 125 cm³ < eng cap < 400 cm³,
3. 400 cm³ <= eng cap < 750 cm³,
4. 750 cm³ <= eng cap < 1000 cm³,
5. >= 1000 cm³

Although we are aware that motorcycles up to 175 cm³ and motorcycles above 175 cm³ have different limit values, this border was ignored in the analysis, because only 7 vehicles with engine capacity up to 175 cm³ were measured.

Figure 58 shows the results for these five different engine capacity classes. The regression curves for the engine capacity classes 1, 3, 4 and 5 have nearly the same slope, those for 3 and 4 are identical. Class 1 vehicles have slightly higher levels class 5 vehicles have slightly lower levels than the classes 3 and 4. The differences between the regression curves are not higher than 2 dB(A) for these classes. The class 2 vehicles show a different speed dependency but the sample is so small that the difference cannot be considered as reliable.

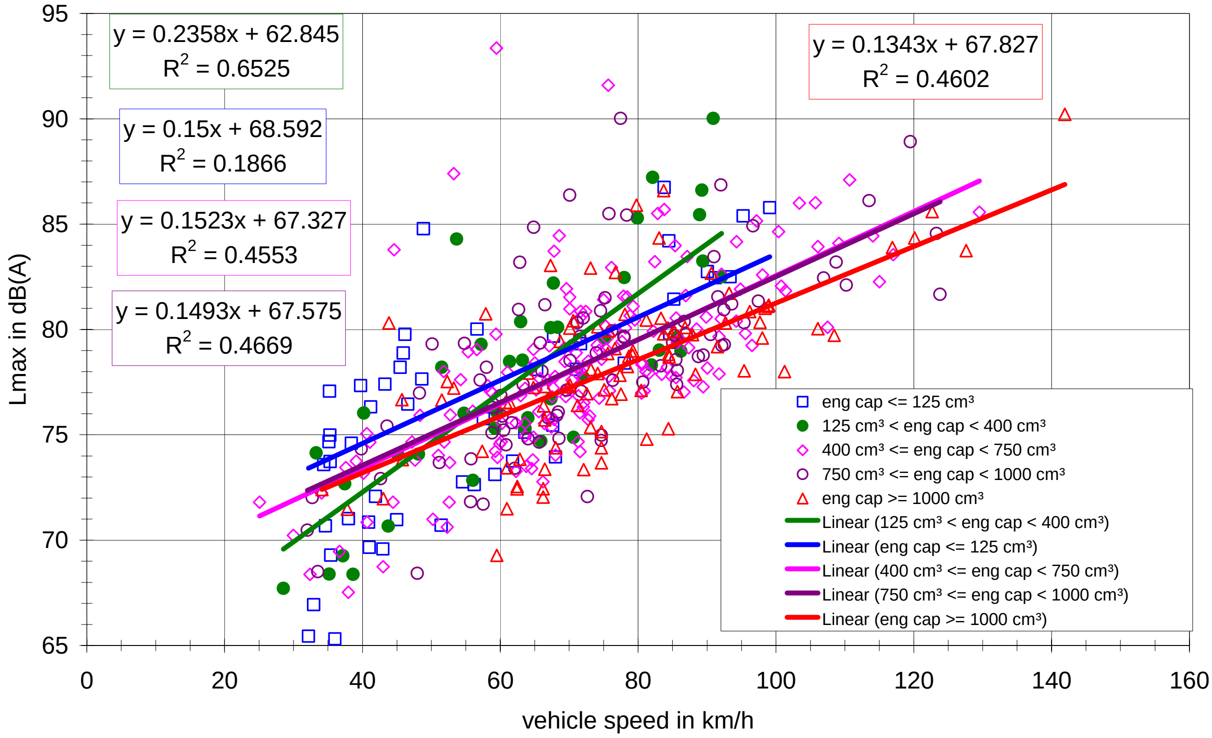

Figure 58: Pass by levels of motorcycles for different engine capacity classes

Concerning the registration year the following three different classes were analysed:

- < 1990,
- 1990 to 1995,
- > 1995

Figure 59 shows the results. Although the uncertainty range due to the low sample numbers does not allow interpreting the differences in the regression curves as significant, at least a trend to lower pass by levels for the today's vehicles could be stated for vehicle speeds below 60 km/h.

A vehicle type analysis could not be carried out because of the small sample size.

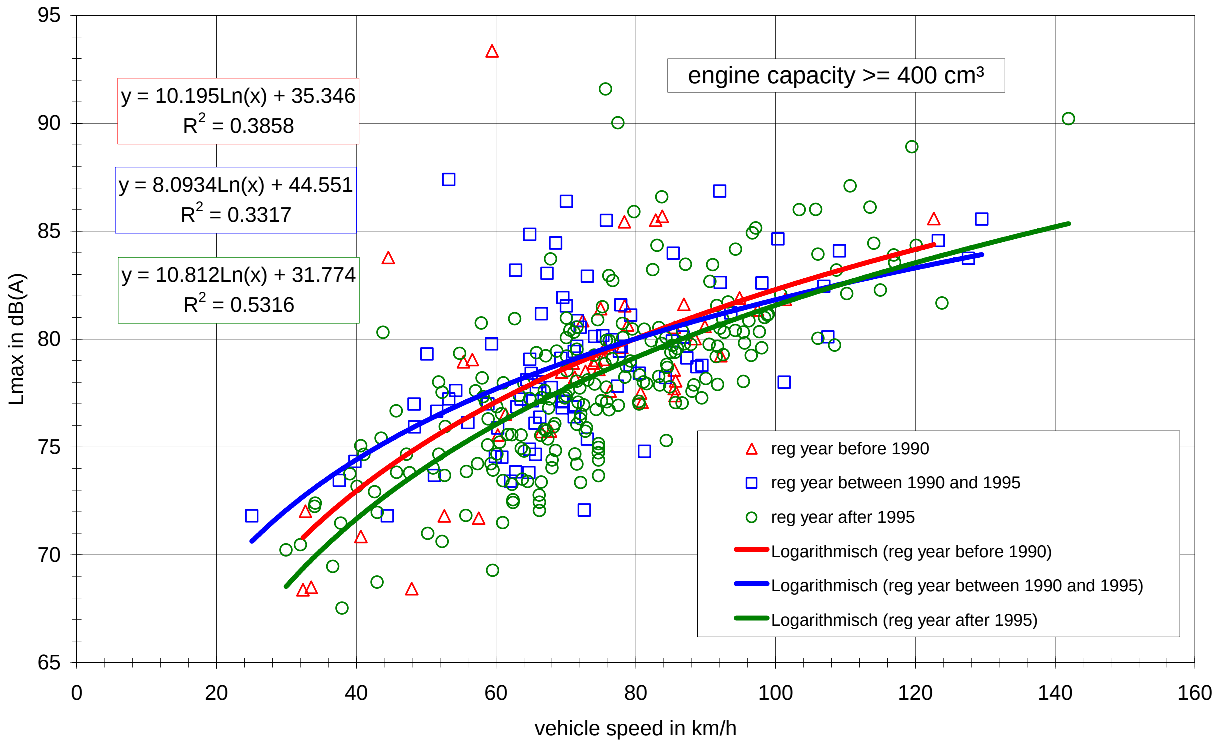

Figure 59: Pass by levels of motorcycles for different registration year periods

3.3 Noise reduction effect of drainage asphalt compared to stone mastic asphalt

There is one measurement site that was excluded from the analysis so far, a motorway site with a drainage asphalt surface (max. chipping size 11 mm, DA 0/11). The reduction effect of this surface shall be demonstrated by comparing the results for cars, HDV with up to 3 axles and HDV with more than 3 axles on this site with another motorway site with a stone mastic asphalt surface (max. chipping size 11 mm, SMA 0/11). The average speeds were nearly the same for each vehicle category on both sites.

The results for cars are shown in Figure 60. The regression curve for DA 0/11 is about 8,5 dB(A) lower than the regression curve for SMA 0/11. The results for HDV with up to 3 axles and more than 3 axles are shown in Figure 61. The regression curves for DA 0/11 is about 6,5 dB(A) lower than the regression curves for SMA 0/11 for both axle classes.

Comparisons of average 3rd octave band spectra for cars at 125 km/h and HDV at 85 km/h are shown in Figure 62 to Figure 64. The spectra are based on an average of between 34 and 107 vehicles, depending on the vehicle category and the surface. The reduction effect starts for cars at 800 Hz, for HDV at 630 Hz. The higher reduction achieved for cars is due to the fact that the peak at 1000 Hz on SMA 0/11 is more pronounced for cars than for HDV and that this peak is cut off completely by the DA 0/11 surface.

For cars the variation of results at the same speed is nearly the same on both surfaces. For HDV the variation on DA 0/11 is significantly higher than for SMA 0/11. The reason for this becomes clear when one studies the whole bandwidth of the spectra for single vehicles on each surface and each vehicle category. The corresponding results are shown in Figure 65 to Figure 73. For cars the reduction effect works over the whole variation range, for HDV this is not the case. The most probable explanation is that the reduction works mainly for rolling noise and rarely for propulsion noise and that for some HDV in the sample propulsion noise was dominating even at 85 km/h.

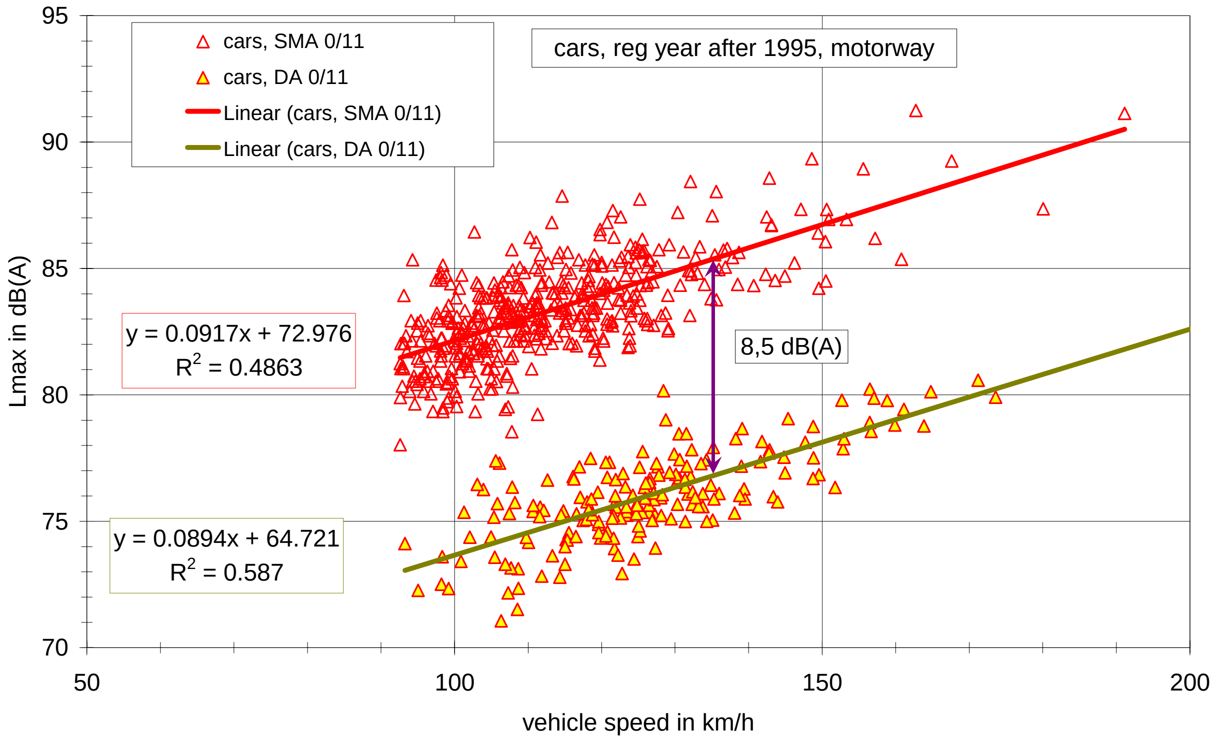

Figure 60: Pass by levels of cars on motorway sites with drainage asphalt and stone mastic asphalt surface (both with 11 mm max. chipping size, registration year after 1995)

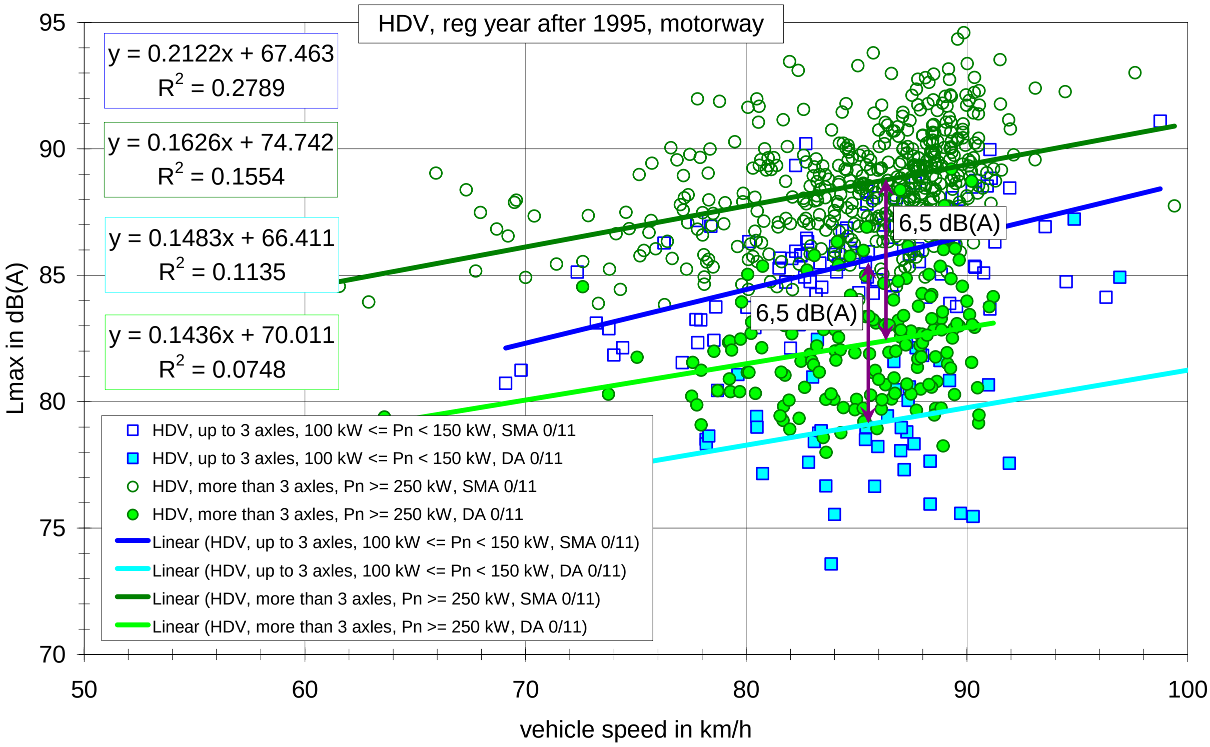

Figure 61: Pass by levels of HDV on motorway sites with drainage asphalt and stone mastic asphalt surface (both with 11 mm max. chipping size, registration year after 1995)

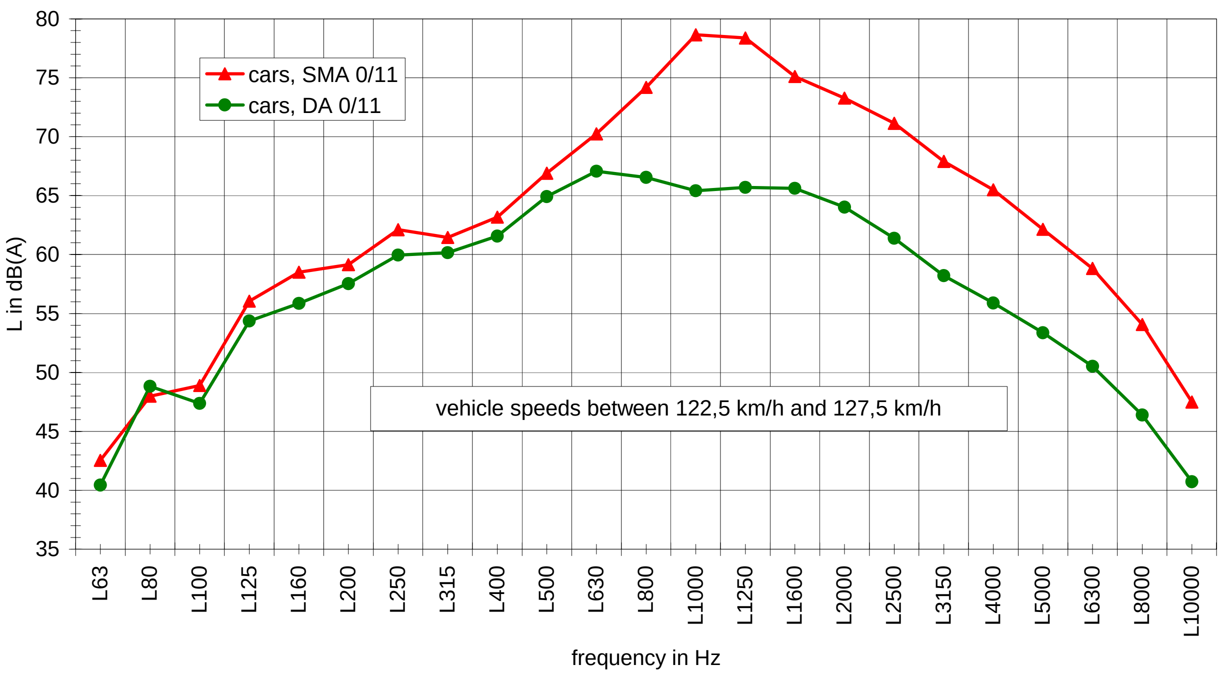

Figure 62: Average frequency spectra of cars on motorway sites with drainage asphalt and stone mastic asphalt surface (both with 11 mm max. chipping size)

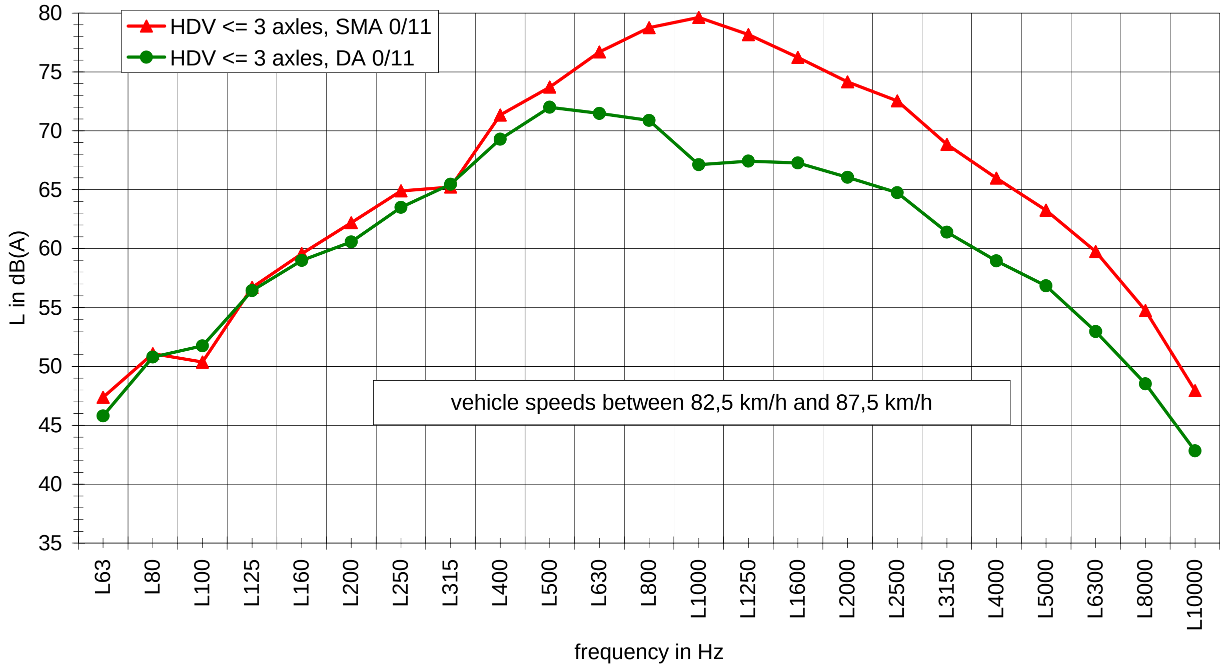

Figure 63: Average frequency spectra of HDV with up to 3 axles on motorway sites with drainage asphalt and stone mastic asphalt surface (both with 11 mm max. chipping size)

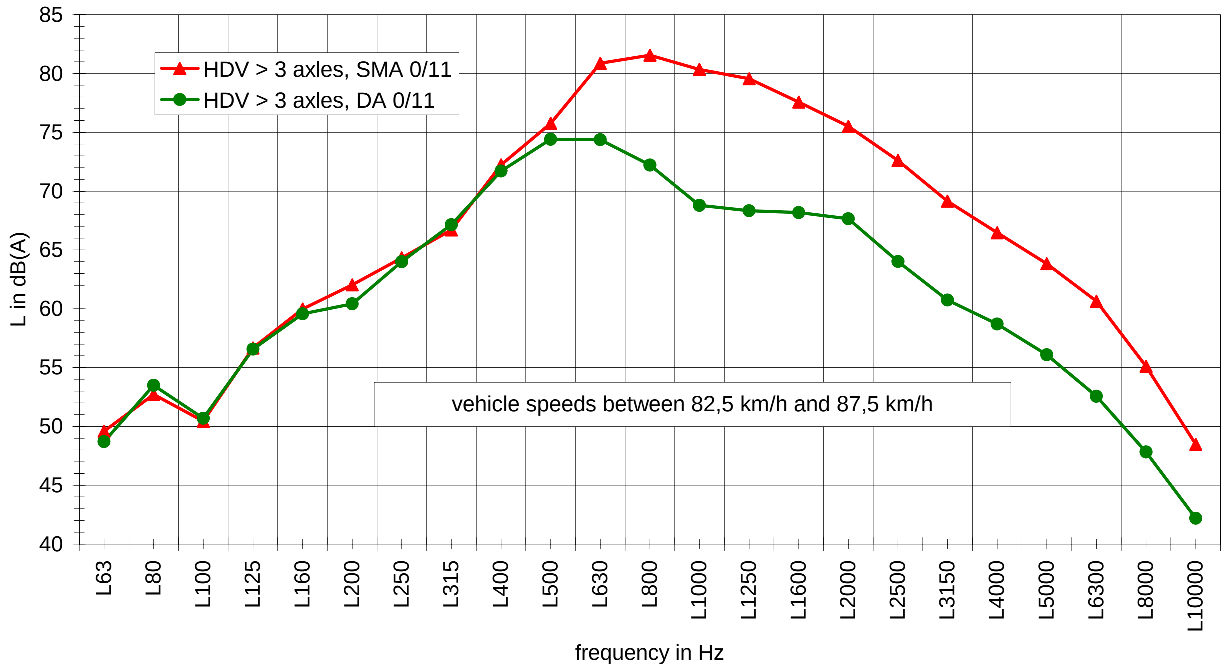

Figure 64: Average frequency spectra of HDV with more than 3 axles on motorway sites with drainage asphalt and stone mastic asphalt surface (both with 11 mm max. chipping size)

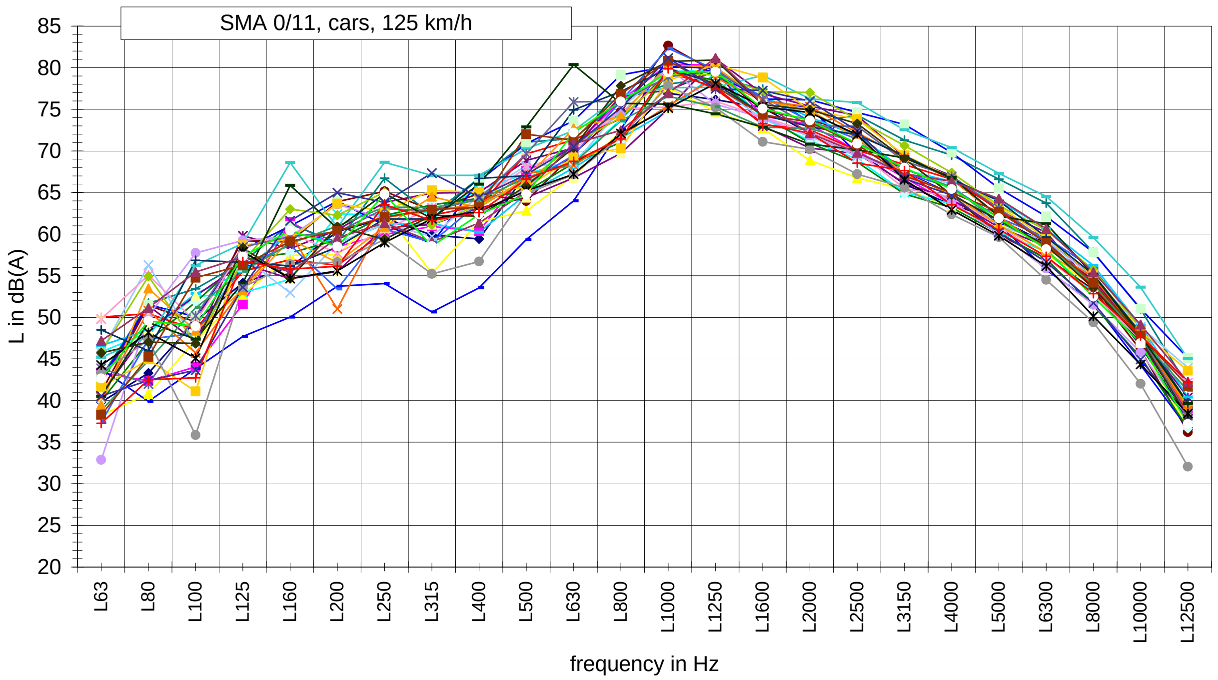

Figure 65: Frequency spectra of cars on a motorway site with stone mastic asphalt surface (11 mm max. chipping size)

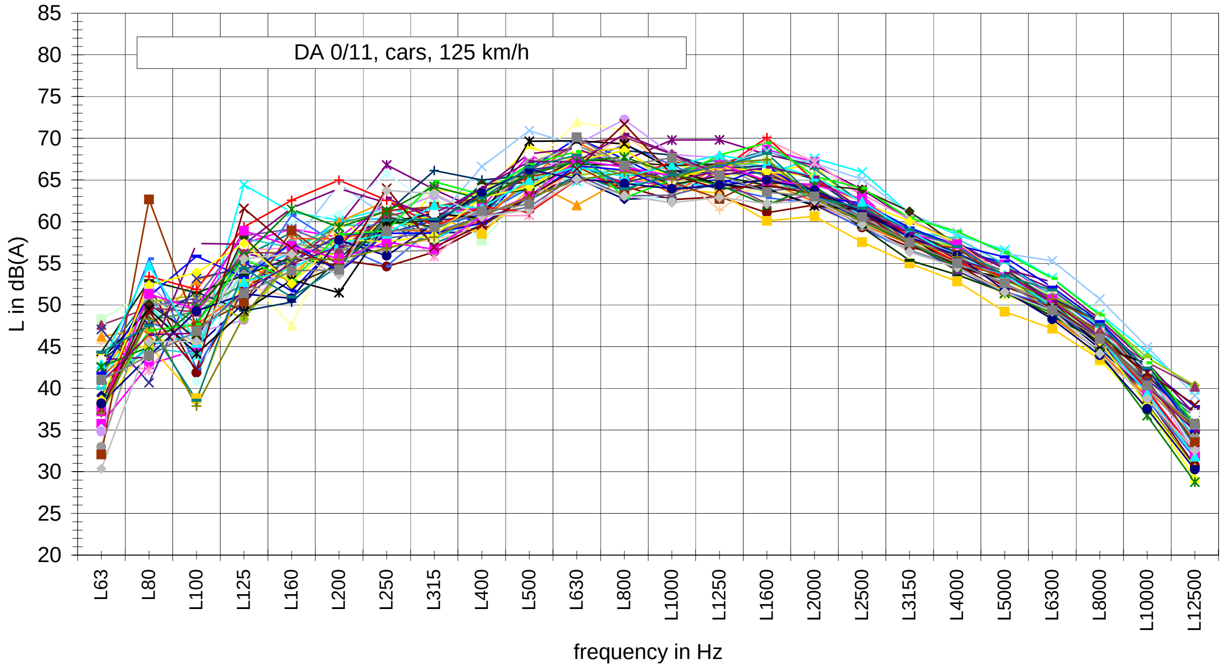

Figure 66: Frequency spectra of cars on a motorway site with drainage asphalt surface (11 mm max. chipping size)

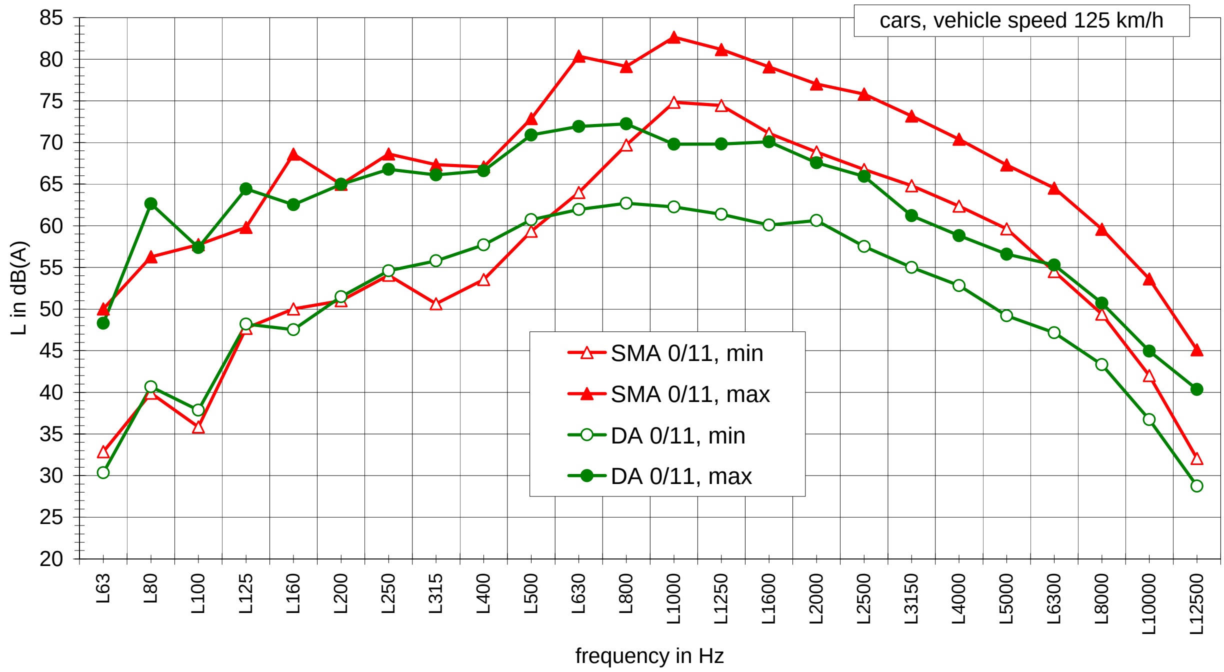

Figure 67: Lower and upper envelopes of the frequency spectra of cars on motorway sites with stone mastic asphalt and drainage asphalt surface (both 11 mm max. chipping size)

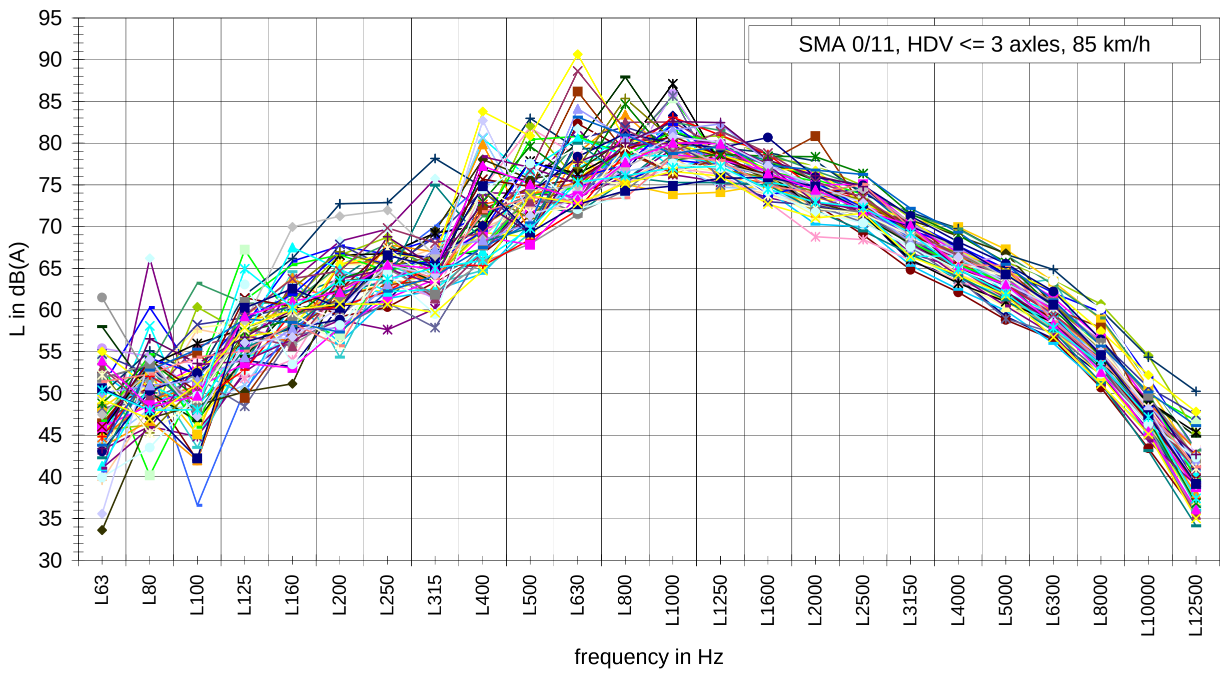

Figure 68: Frequency spectra of HDV with up to 3 axles on a motorway site with stone mastic asphalt surface (11 mm max. chipping size)

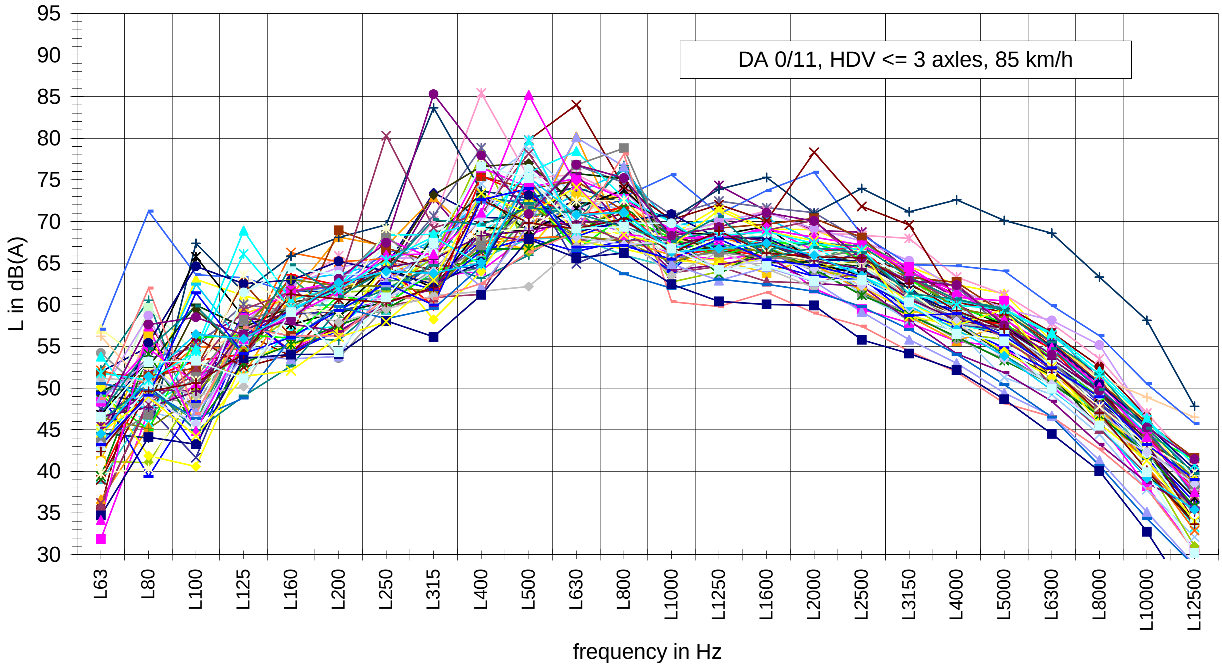

Figure 69: Frequency spectra of HDV with up to 3 axles on a motorway site with drainage asphalt surface (11 mm max. chipping size)

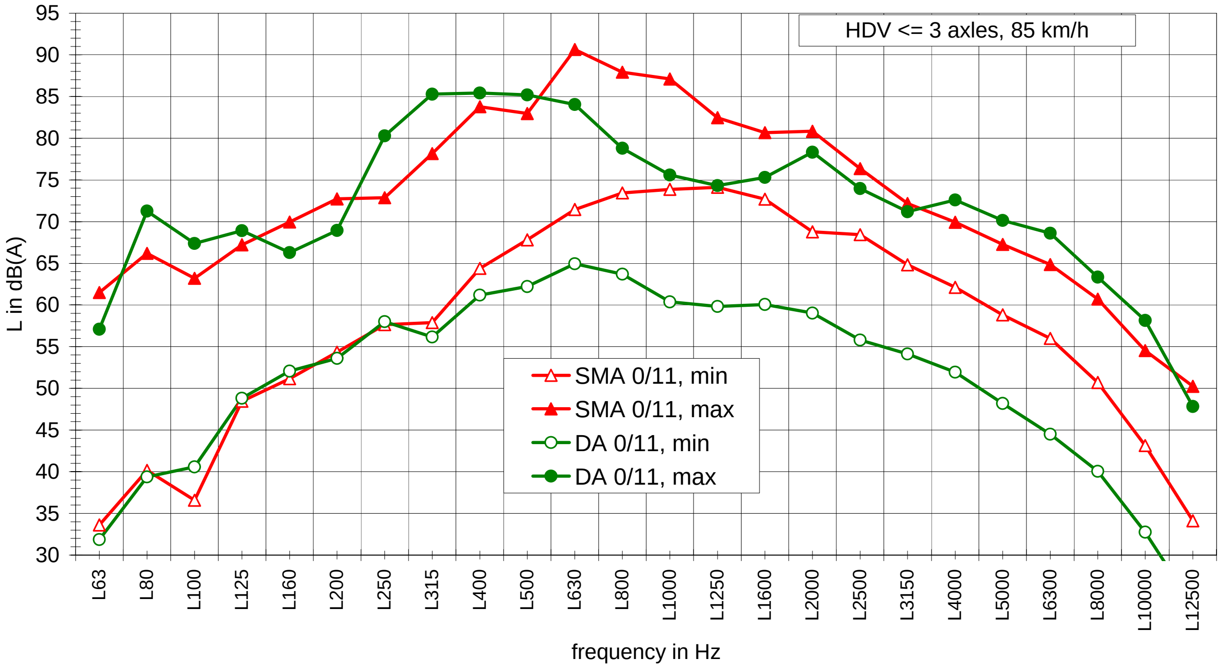

Figure 70: Lower and upper envelopes of the frequency spectra of HDV with up to 3 axles on motorway sites with stone mastic asphalt and drainage asphalt surface (both 11 mm max. chipping size)

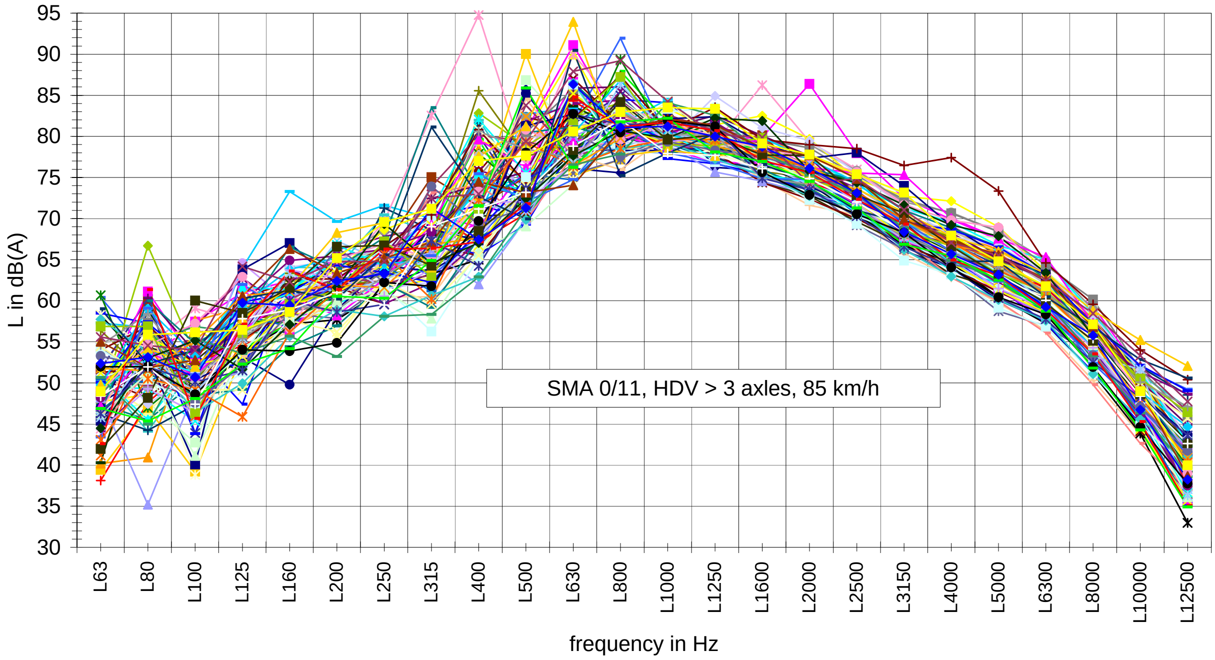

Figure 71: Frequency spectra of HDV with more than 3 axles on a motorway site with stone mastic asphalt surface (11 mm max. chipping size)

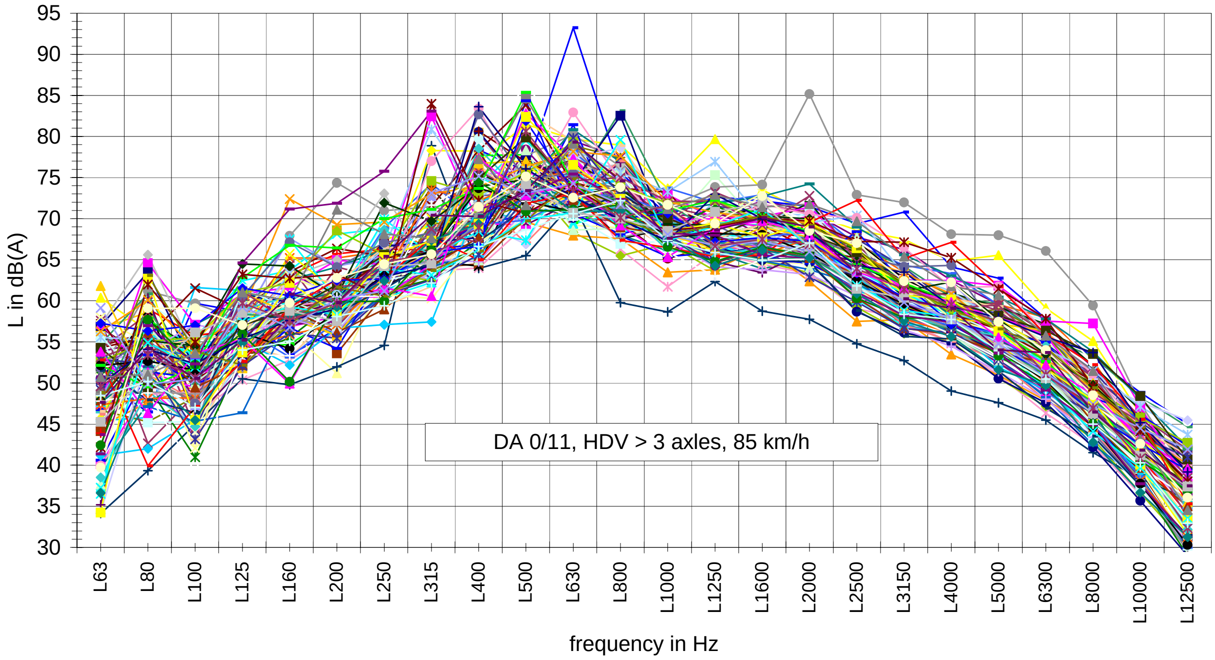

Figure 72: Frequency spectra of HDV with more than 3 axles on a motorway site with drainage asphalt surface (11 mm max. chipping size)

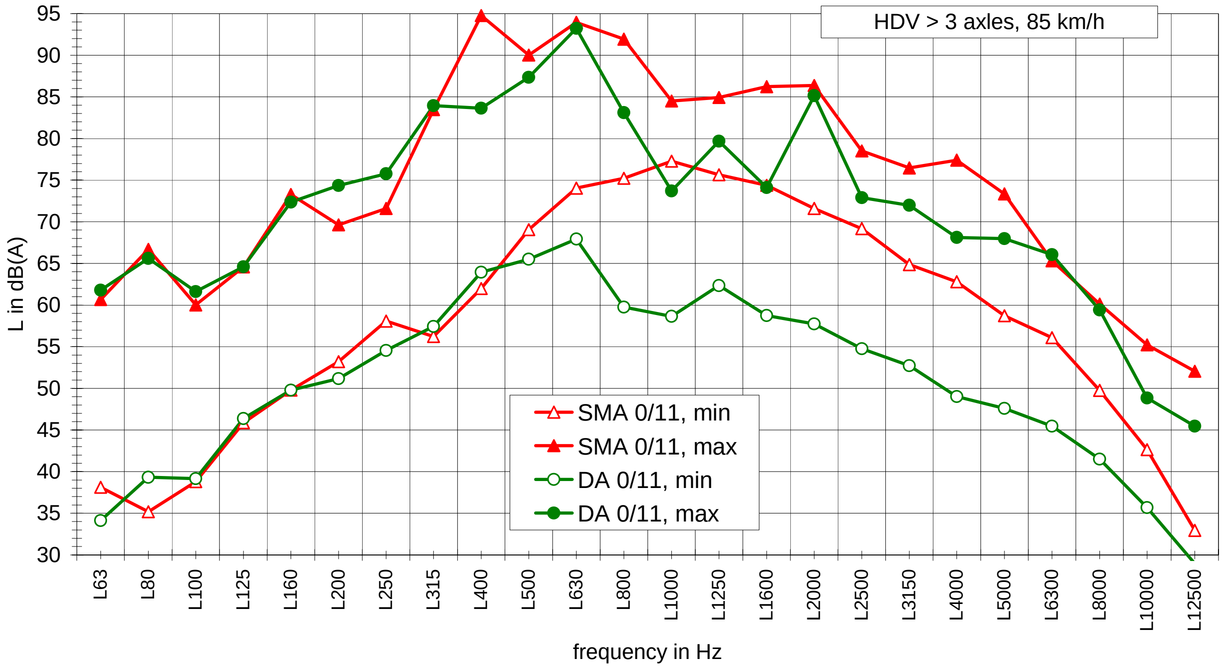

Figure 73: Lower and upper envelopes of the frequency spectra of HDV with more than 3 axles on motorway sites with stone mastic asphalt and drainage asphalt surface (both 11 mm max. chipping size)

3.4 Comparison with the results of previous investigations

In order to compare the results of this investigations with the results of previous investigations the data of the previous investigations were corrected for road surface influences in the same way as described in chapter 3.1.2. Four previous investigations were considered for the comparison of vehicles in free flowing traffic, from 1978 [1], 1983 [2], 1986 [3] and 1992 [4]. For accelerating vehicles the 1986 period was disregarded because it contained no special measurement sites for this driving condition.

Figure 74 shows the pass by levels for accelerating cars from the 1978, 1983, 1992 and 2001 investigation periods. At low speeds (20 to 40 km/h) a clear trend to lower emission values for higher reference years can be seen. The average Lmax levels for 1992 are significantly lower than the corresponding levels for 1978 and 1983 and the levels for 2001 are even lower than those for 1992. At high speeds (above 60 km/h) the regression curves coincide more or less or seem to show a contrary tendency. But this must not be overestimated because of the low number of vehicles, especially above 70 km/h. What can also be seen is the fact that the scattering of the results is highest for 1978 and lowest for 2001.

Figure 75 shows corresponding results for free flowing traffic. Here no significant differences between the regression curves for different investigation periods can be found. But as for accelerating vehicles the scattering of the results decreases with increasing reference year.

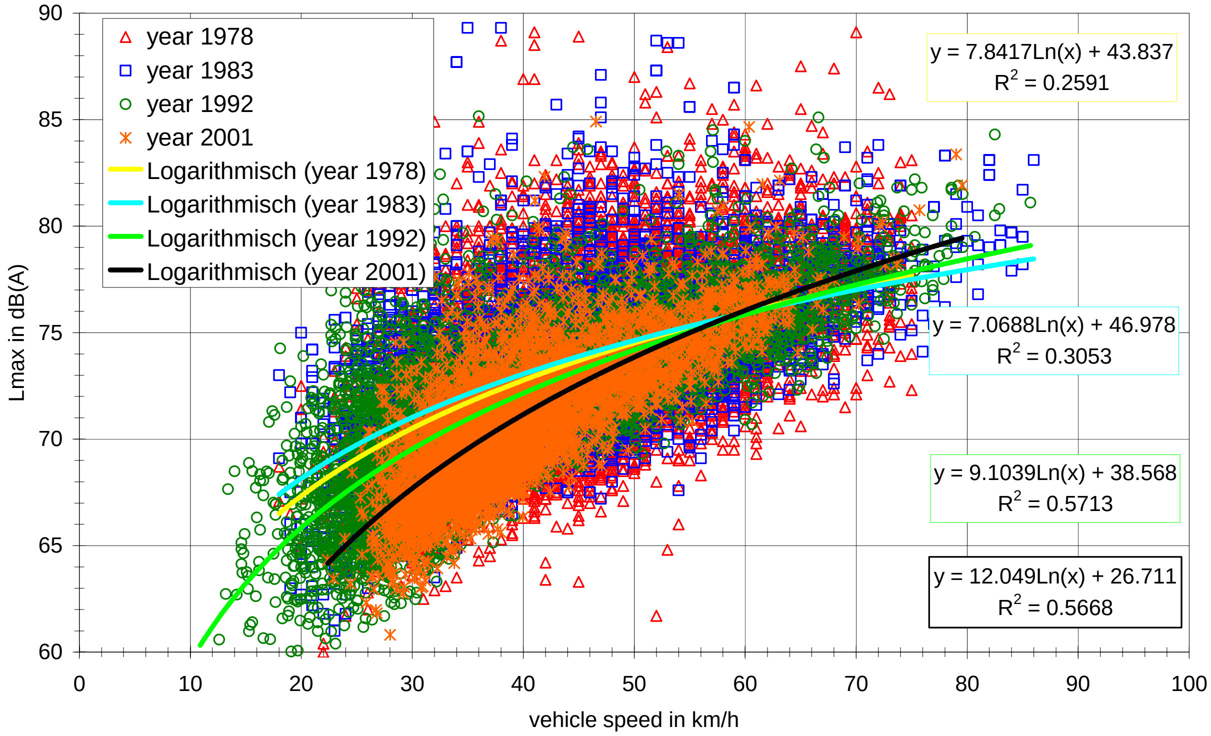

Figure 74: Pass by levels of accelerating cars for different investigation periods

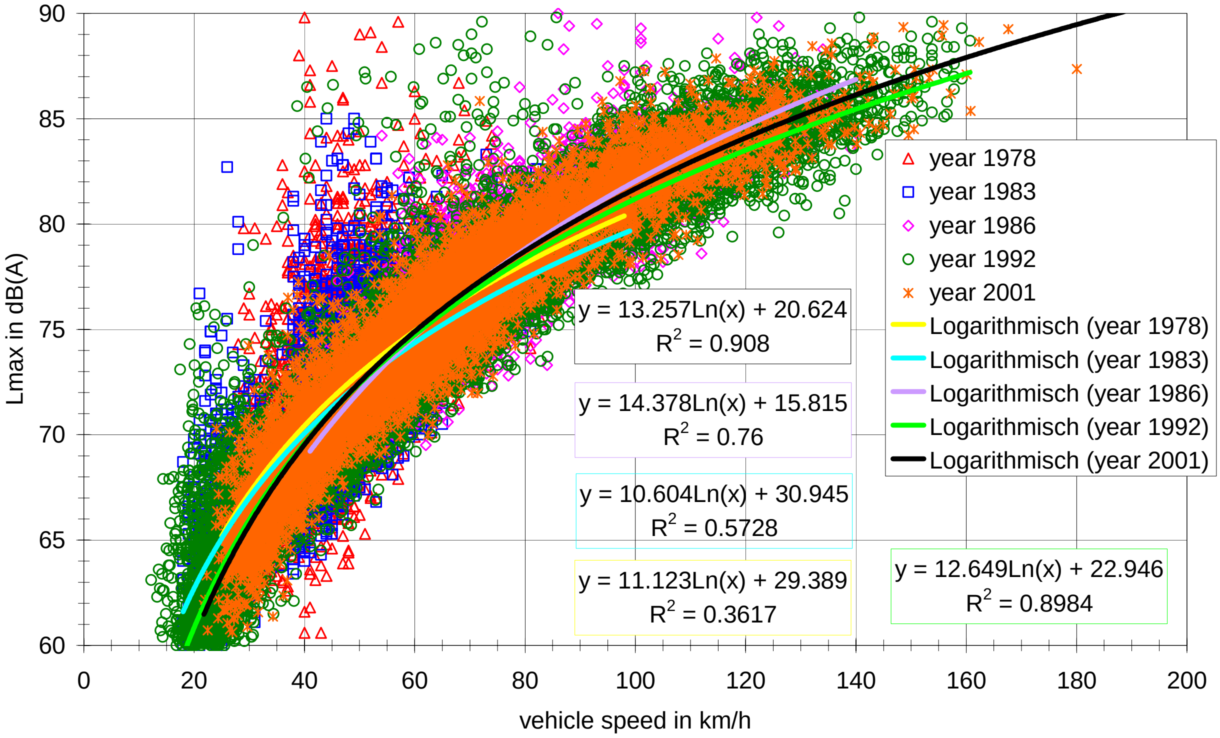

Figure 75: Pass by levels of cars in free flowing traffic for different investigation periods

The logarithmic trend lines shown in Figure 75 and Figure 76 are determined by the (core) speed ranges with the highest vehicle numbers, which is 30 to 45 km/h for accelerating vehicles and 40 to 80 km/h for free flowing traffic. In speed regions outside the core regions the regression curves are of higher uncertainty. In order to reduce this influence average Lmax levels were calculated for speed classes of 5 km/h bandwidth that contain at least 30 vehicles. The results are shown in Figure 76 and confirm the statements made before.

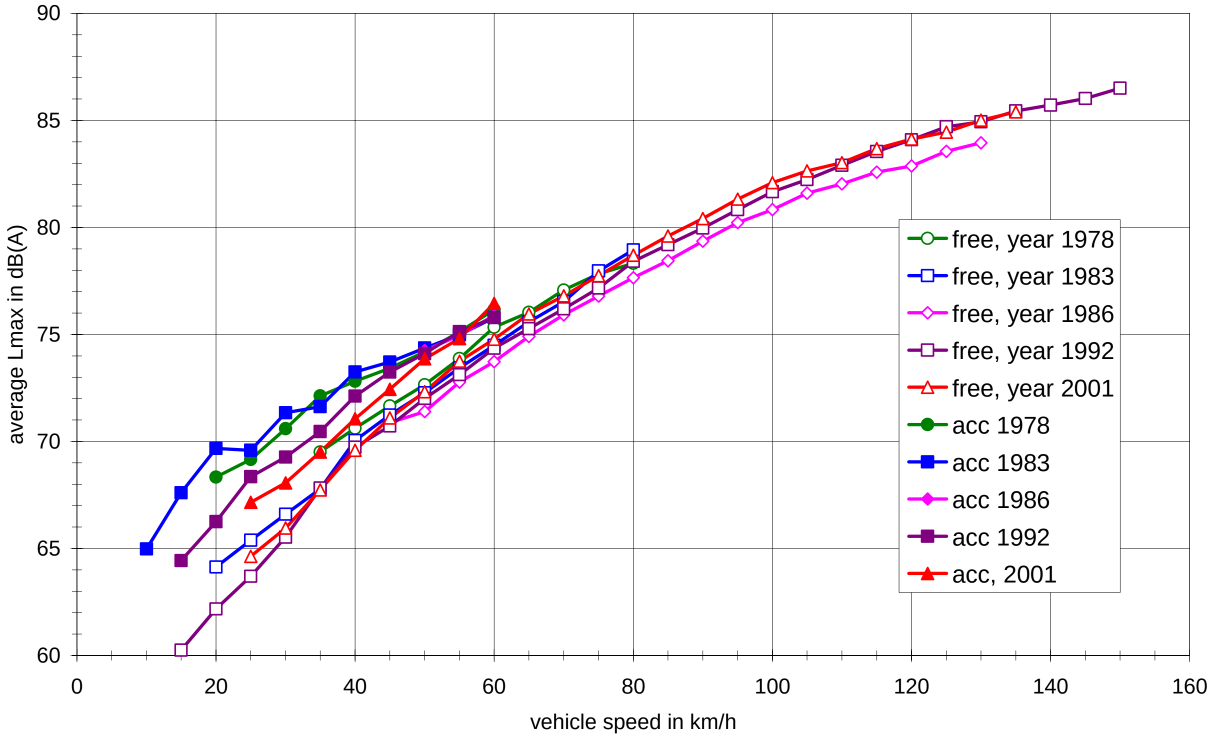

Figure 76: Average pass by levels of cars for different driving conditions and investigation periods

Since the sample number for other categories than cars are significantly lower another approach was chosen for further comparisons. The average Lmax levels and the 95-percentiles of the Lmax levels were calculated within the speed range of 20 to 40 km/h for accelerating vehicles and 45 to 55 km/h (cars and LDV) or 40 to 60 km/h (HDV) for each investigation period. Averages were calculated for sample sizes of at least 10 vehicles, L_95 levels for at least 60 vehicles, so that this level is exceeded by at least 3 vehicles.

The results of accelerating cars are shown in Figure 77 for different engine types. Vehicles with petrol engines from 1992 had about 2 dB(A) lower average Lmax levels (-1,9 dB(A) for the average and -2,3 dB(A) for the L_95) than vehicles from 1978 or 1983. Because no significant difference could be found between the 1978 and 1983 periods the mentioned differences are related to the averages of 1978 and 1983. The reduction for the 2001 period compared to 1978/1983 is 3,7 dB(A) for the average and 5 dB(A) for the L_95.

For cars with precombustion engines the reductions are about 3 dB(A) for the 2001 period, but this result is not meaningful any more because this engine type will vanished from the fleet in the near future. For cars with direct injection Diesel engines no such trends can be shown because they did not exist in the samples before 1992 and there are even too few in the 1992 sample. For the 2001 period the L_95 level for cars with direct injection Diesel engines is less than 1 dB(A) higher than the L_95 for cars with petrol engines. The difference for the average is about 1 dB(A).

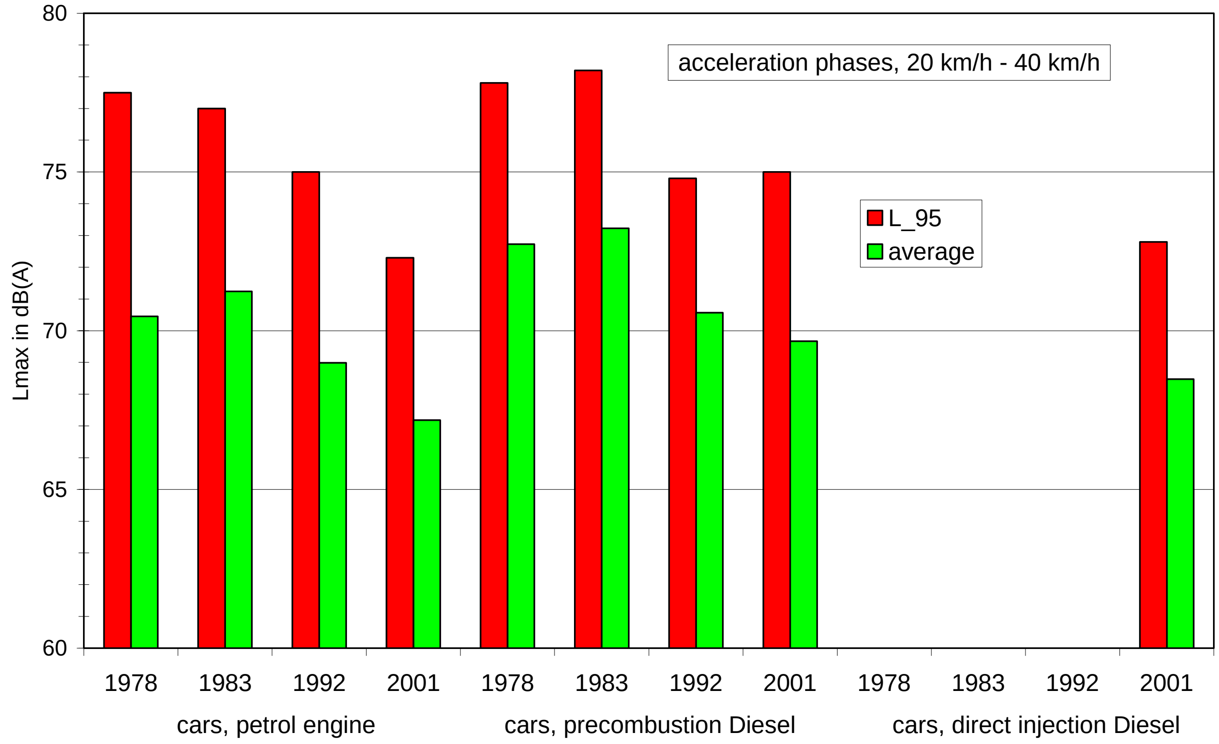

Figure 77: Average and peak values of pass by levels for accelerating cars from different investigation periods

Figure 78 shows corresponding results for light duty vehicles separated into GVM up to 2000 kg and GVM above 2000 kg. For LDV with GVM up to 2000 kg no L_95 level could be calculated because of the small sample sizes. The average level for 2001 is 3,5 dB(A) lower than the average levels for 1978/1983. For LDV with GVM above 2000 kg the improvement is a bit lower. Average and peak level for 2001 are a bit more than 2 dB(A) lower than for 1978/1983.

Figure 79 shows the results for heavy duty vehicles with rated power values up to 100 kW and between 101 and 150 kW. For the latter peak values are missing in the 1992 period. The reduction between 1978/1983 and 2001 is about 2,5 dB(A) for HDV up to 100 kW and 5,5 dB(A) (average) to 6,5 dB(A) (L_95) for HDV with rated power between 101 and 150 kW. Since the reduction for HDV up to 100 kW is only half of the reduction for HDV with rated power between 101 and 150 kW, the difference between both groups decreased with increasing reference year. For the investigation periods 1978/1983 the difference is about 3,5 dB(A), for 2001 there is no significant difference any more.

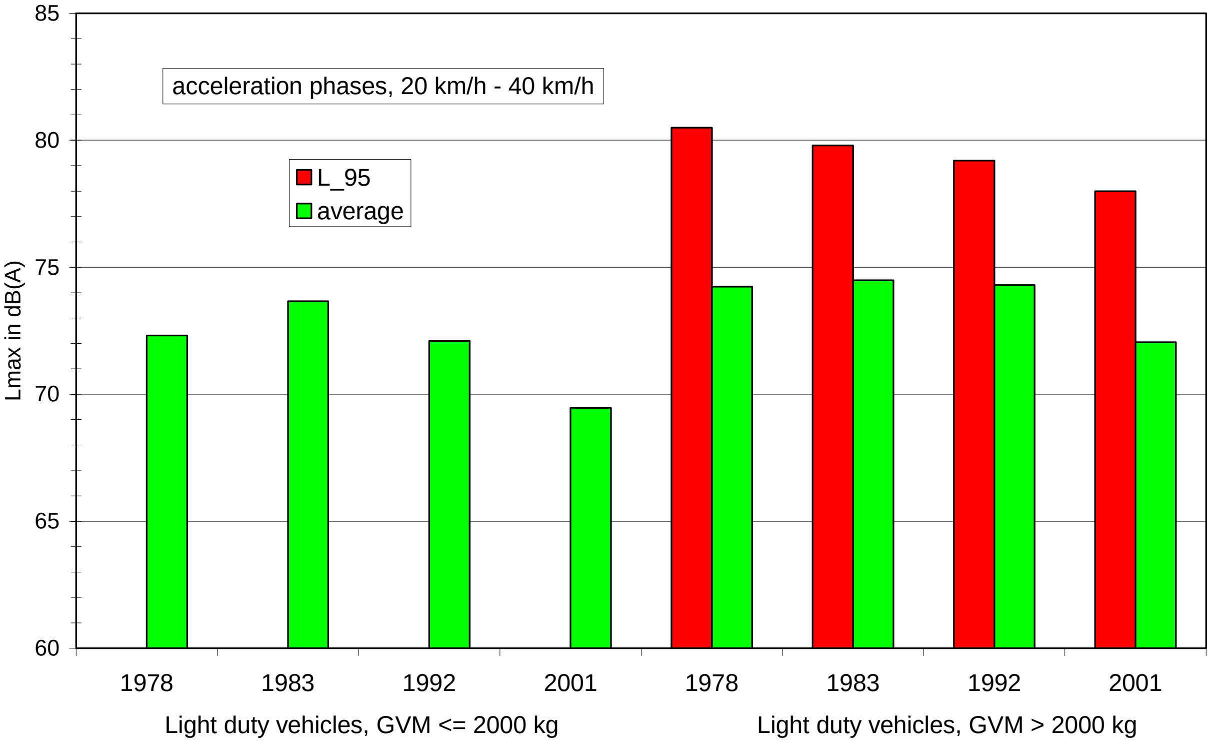

Figure 78: Average and peak values of pass by levels for accelerating light duty vehicles from different investigation periods

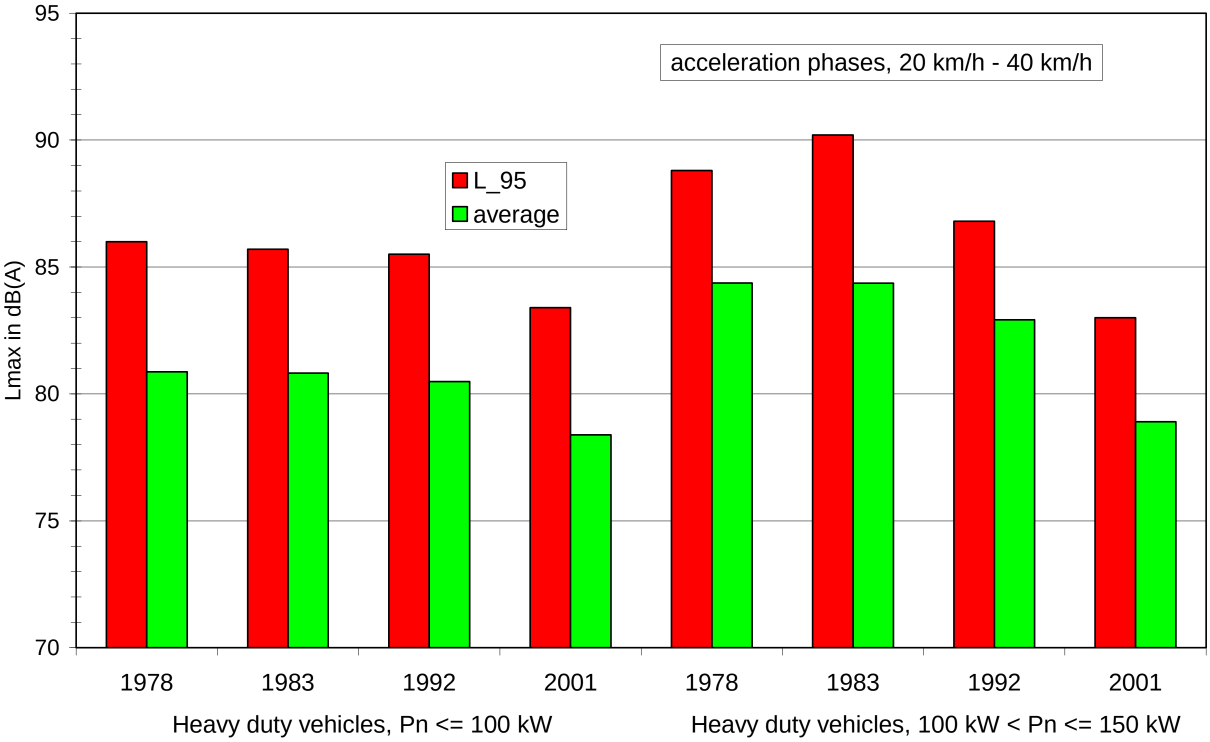

Figure 79: Average and peak values of pass by levels for accelerating heavy duty vehicles from different investigation periods

Figure 80 shows the results for the two highest HDV rated power classes. The reduction of the Lmax levels of HDV with power values between 151 and 250 kW between 1978/1983 and 2001 is 7,5 dB(A) for the average and 6,4 dB(A) for L_95. This is the highest reduction of all HDV classes.

HDV with rated power values above 250 kW did not exist in the investigation periods of 1978 and 1983 and even the sample of 1992 is not big enough to calculate the L_95 level. The averages from 1992 and 2001 follow the same trend as for the power class below.

The results for cars in free flowing traffic with vehicle speeds around 50 km/h are shown in Figure 81. For free flowing traffic also the investigation period from 1986 could be included. With respect to cars with direct injection Diesel engines the same problem occurs than for accelerating vehicles. No vehicles for the periods before 1992 and not enough for 1992 to calculate L_95. Between 1978 and 2001 Cars with petrol engines and precombustion Diesel engines show the same trends: A reduction of L_95 of about 2 dB(A) but no significant changes for the average levels.

Figure 82 shows the results for LDV with GVM above 2000 kg and HDV with rated power up to 100 kW. LDV with GVM up to 2000 kg could not be considered because of the low number of vehicles. No significant reduction is found between the periods 1978 and 2001 for LDV. The reduction for HDV up to 100 kW is 2,4 dB(A) for the average and 5 dB(A) for L_95. The latter is even higher than for accelerating vehicles, but based on a small number of vehicles so that no general conclusions could be drawn..

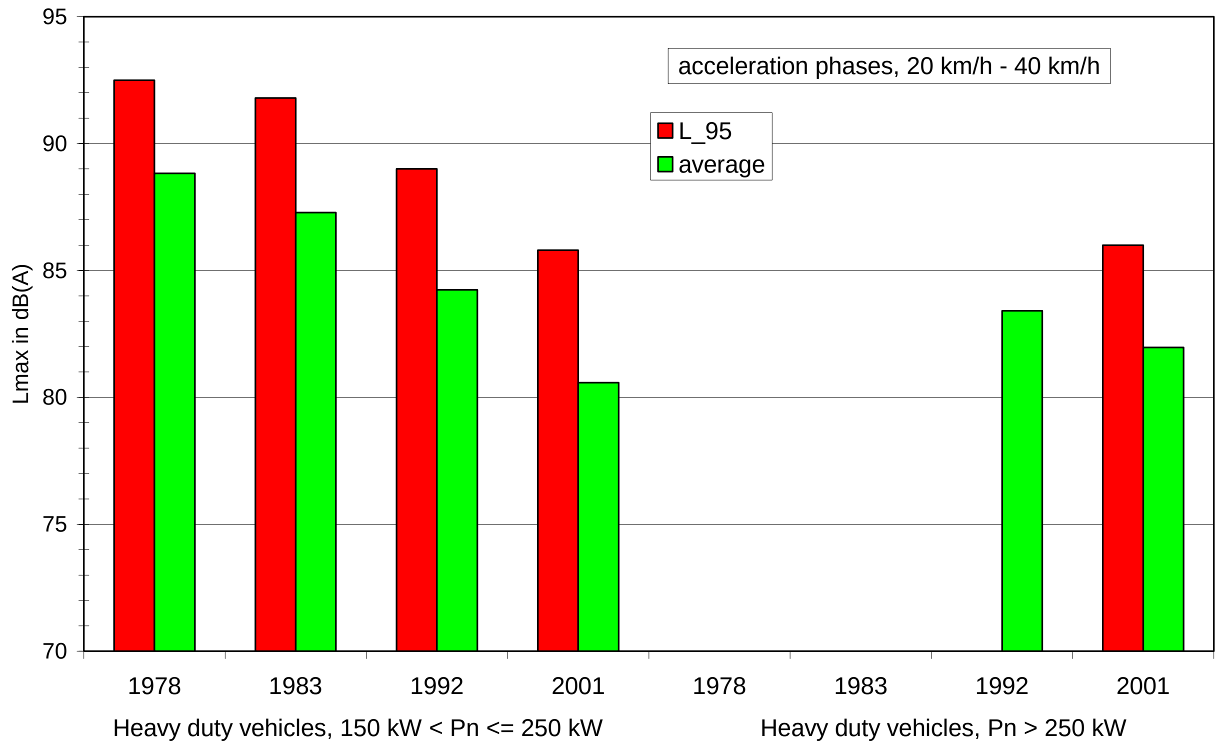

Figure 80: Average and peak values of pass by levels for accelerating heavy duty vehicles from different investigation periods

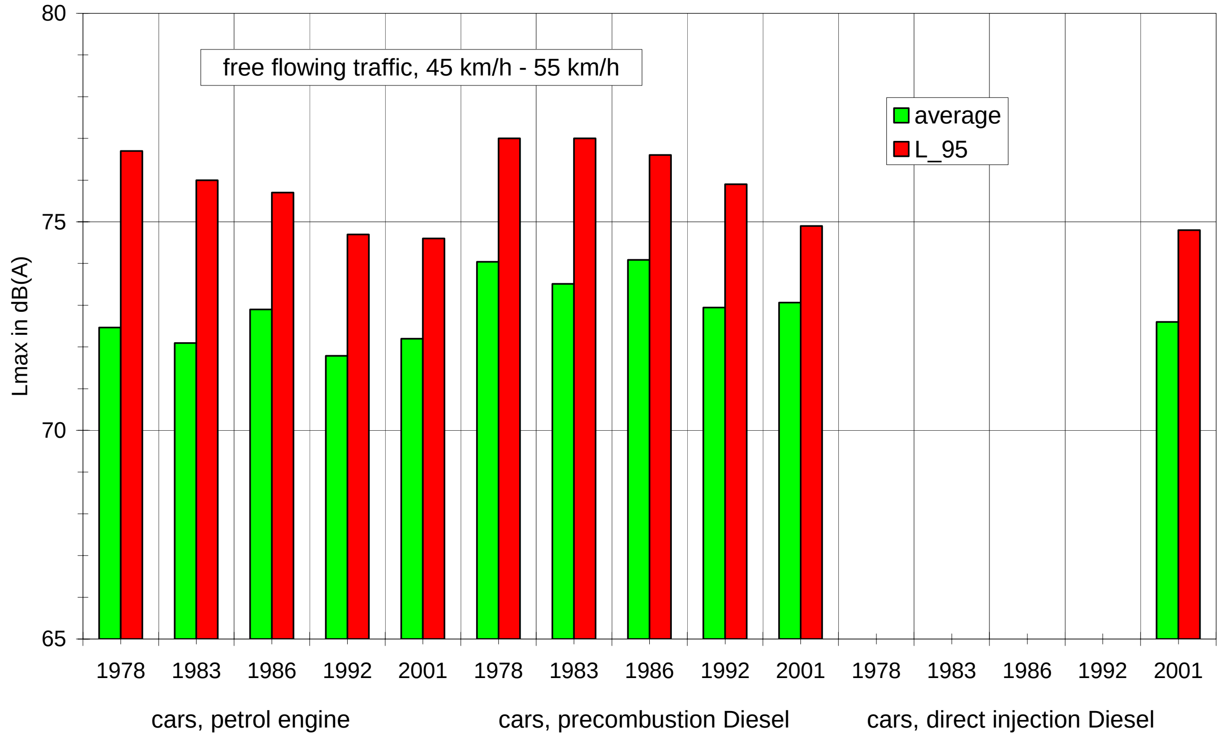

Figure 81: Average and peak values of pass by levels for cars in free flowing traffic from different investigation periods

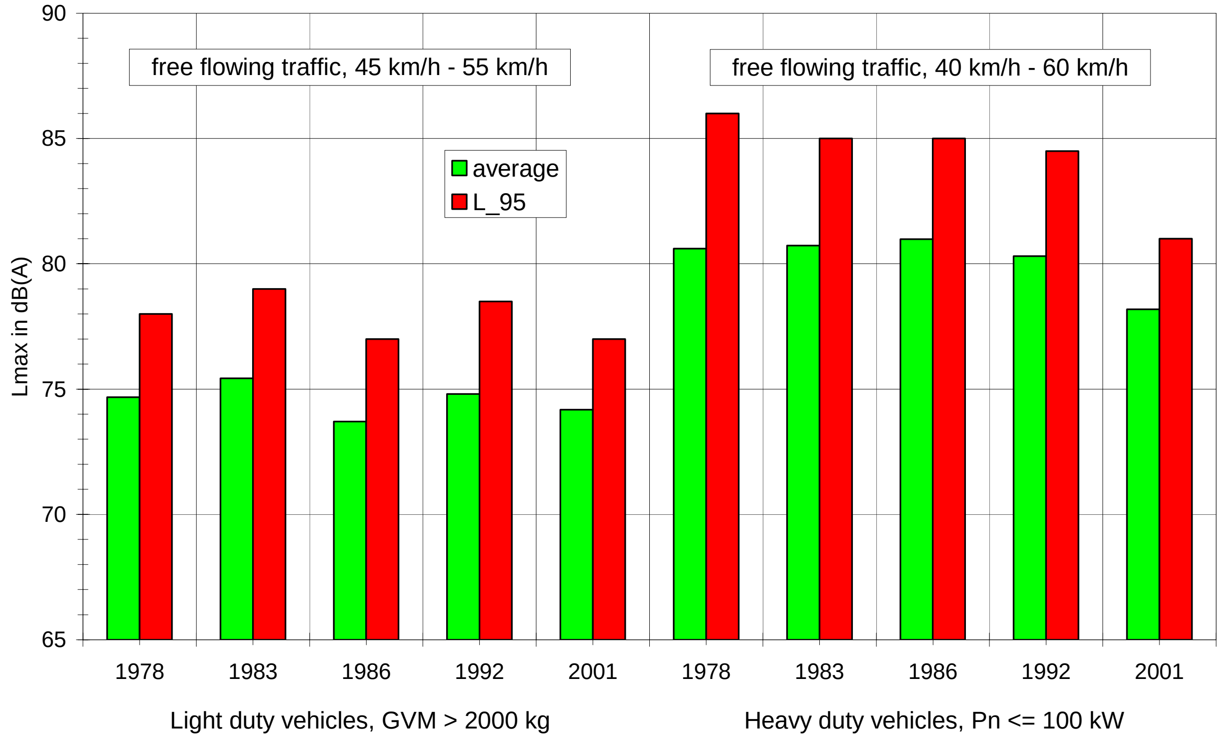

Figure 82: Average and peak values of pass by levels for light and heavy duty vehicles in free flowing traffic from different investigation periods

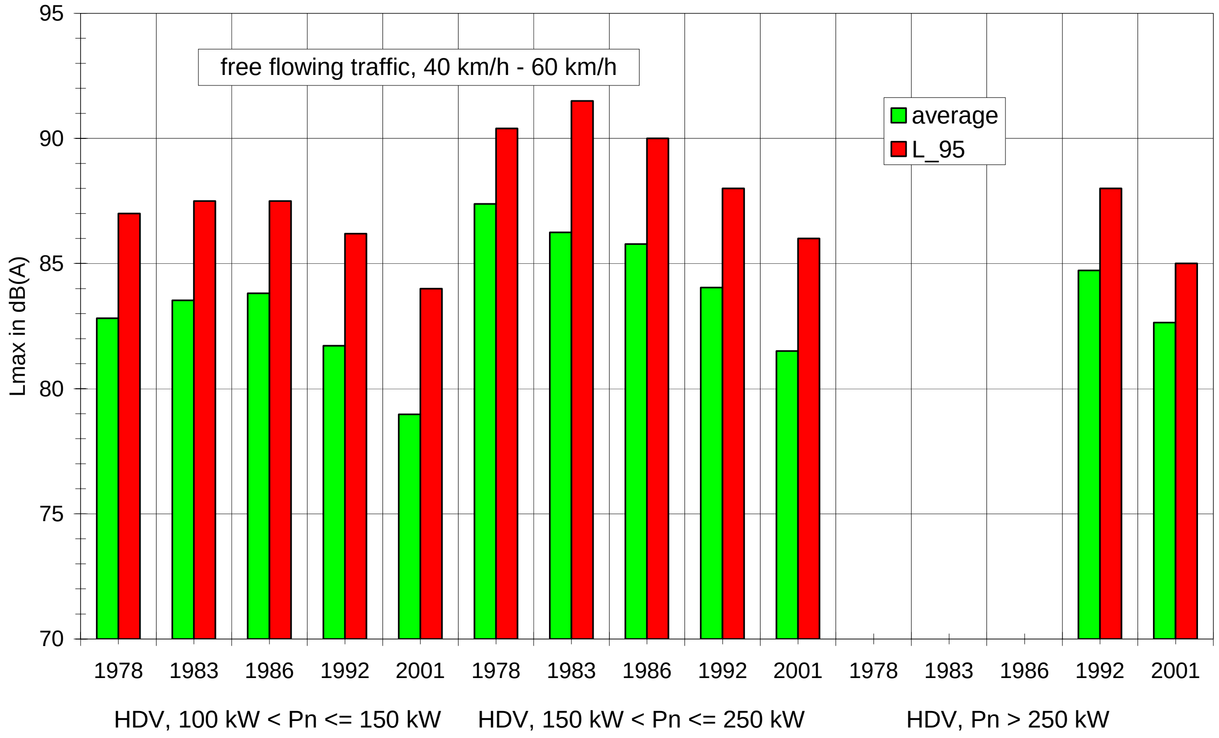

Figure 83: Average and peak values of pass by levels for heavy duty vehicles in free flowing traffic from different investigation periods

In Figure 83 the results for HDV with rated power between 101 and 150 kW, between 151 and 250 kW and above 250 kW are plotted. For the latter class only the time periods 1992 and 2001 could be considered. The average levels as well as the peak levels (L_95) of the 2 other classes show a common trend: no significant changes between 1978 and 1986, but significant reductions for 1992 and 2001. The differences between 1986 and 2001 are in the order of 3,5 to 5 dB(A). The same trend occurs for HDV with rated power above 250 kW. The reduction between the periods 2001 and 1992 is 2 dB(A) for the average and 3 dB(A) for L_95.

Finally corresponding results for free flowing traffic were calculated for rural driving between 70 and 90 km/h. For HDV besides rural sites also measurement sites on motorways were included in order to increase the sample sizes. The investigation periods 1986, 1992 and 2001 could be considered for this analysis.

The results for cars are shown in Figure 84, for LDV and HDV in Figure 85. For cars no significant differences between the periods could be found, one could only state a tendency for slightly higher levels with increasing reference year, especially for cars with precombustion Diesel engines. For LDV and HDV up to 250 kW there is a trend to lower levels with increasing reference year. The reduction from 1986 to 2001 ranges from 1 to 2,5 dB(A). For HDV above 250 kW results are only available from 1992 and 2001, but there are nearly no differences between both samples.

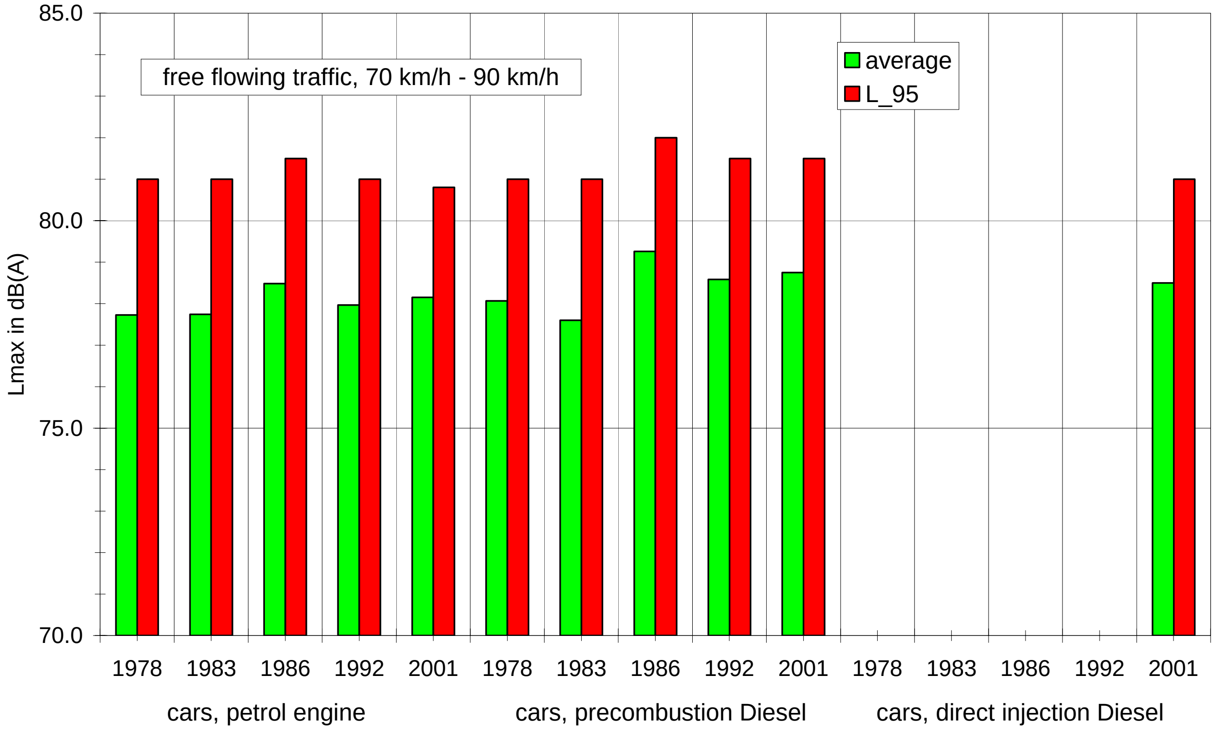

Figure 84: Average and peak values of pass by levels for cars in free flowing traffic from different investigation periods

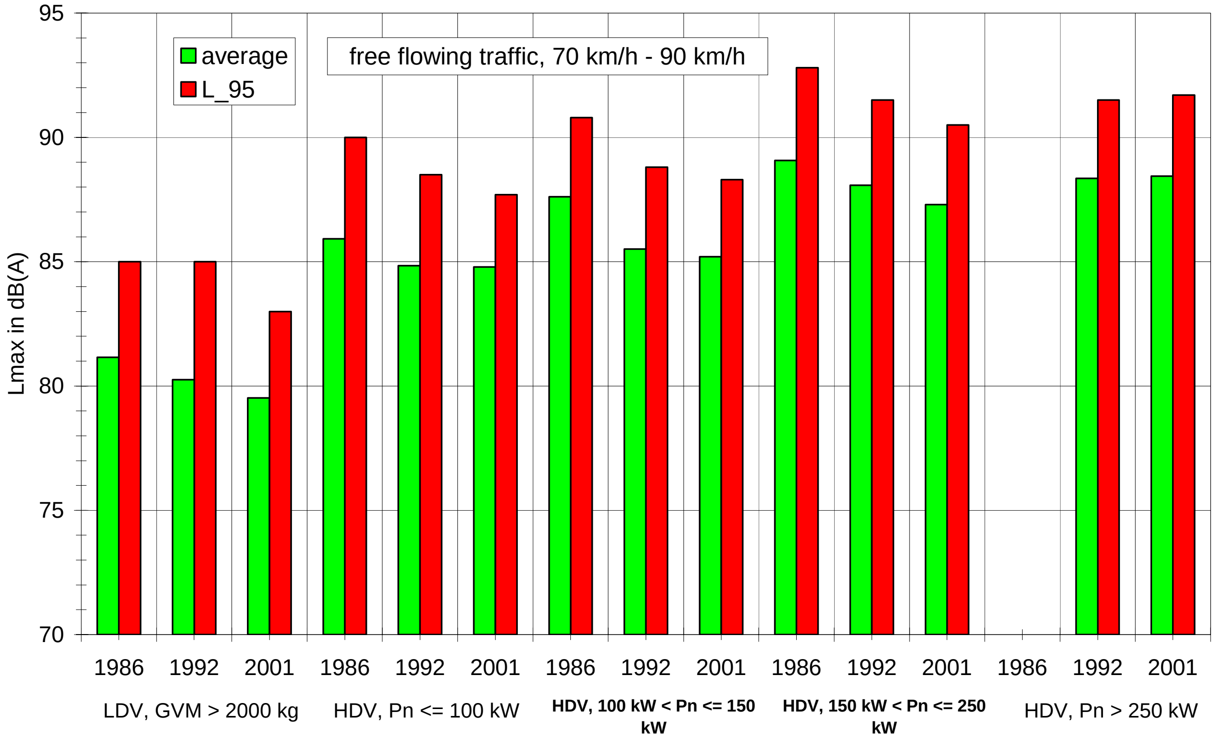

Figure 85: Average and peak values of pass by levels for light and heavy duty vehicles in free flowing traffic from different investigation periods

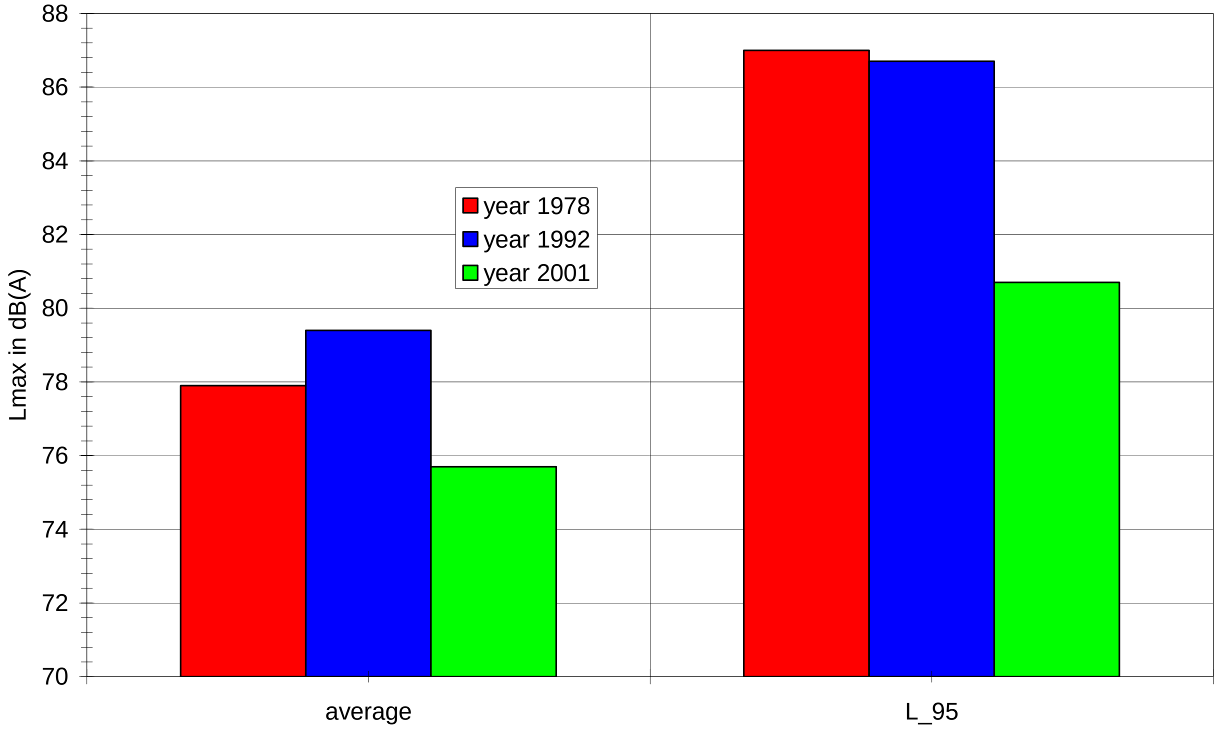

Figure 86: Average and peak values of pass by levels for motorcycles between 40 and 60 km/h from different investigation periods

Also for motorcycles a trend towards lower noise emission levels over time was found (see Figure 86, about 2,5 dB(A) for the average and 5 dB(A) for L_95). But since the results are highly influenced by vehicles with illegal silencers and since no information about the percentages of these vehicles in the sample is available, a general interpretation is difficult. The higher reduction for the L_95 compared to the reduction for the average could for example be explained by a lower percentage of manipulated vehicles in 2001 than for the previous periods. But there is no possibility to verify this.

4 Consequences for further noise reduction measures

4.1 Priorities for further noise reduction measures

The results of this investigation confirm the conclusions already drawn in [5] with respect to priorities for further reduction measures.

The rank order for urban streets is:

1. Tyre/road noise reduction measures for cars and light duty vehicles,
2. Propulsion noise reduction measures for light and heavy duty vehicles.

For rural roads and motorway operation a 3rd topic has to be added:

3. Tyre/road noise reduction measures for heavy duty vehicles.

Since the reduction potential for the tyres seems to be limited (see [5]), road surface related measures have to be worked out with high priority. The drainage asphalt shows the possible reduction potential although it is a solution with limited application possibilities. On a long term scale dense surfaces with a comparable reduction potential need to be developed.

4.2 Vehicle noise emission and type approval measurement method

4.2.1 Cars and light duty vehicles

The implementation of propulsion noise reduction measures requires further lowering of the limit values within the type approval procedure and an improved efficiency with respect to in-use noise emissions. For possible propulsion noise reduction measures see [5]. With respect to the type approval measurement method the following conclusions can be drawn:

The results of this project showed that the noise emission of cars with Diesel engines during acceleration phases at low speeds is 1 to 2 dB(A) higher than the noise emission for cars with petrol engines. This difference is partly caused by differences in average engine capacity between both groups, because it was also found that the in-use noise emission for accelerating cars at low speeds increase with increasing engine capacity. The remaining part is engine type related. But the noise emission of cars with today's direct injection Diesel engines in acceleration phases is lower than the corresponding noise emission of cars with precombustion Diesel engines, which do no longer exist on the market. Taking into account that there is no difference in the average type approval levels any more between cars with direct injection Diesel engines and cars with petrol engines, **the 1 dB(A) "discount" for cars with direct injection Diesel engines is no longer justified.**

The results of this project showed that there is a correlation between the noise emission in real traffic and the type approval levels of the vehicles. The results for the accelerating vehicles show a clear tendency: The noise levels in real traffic for acceleration phases at low speeds decrease with decreasing type approval level. For free flowing traffic at higher speeds (65 km/h) no correlation between type approval levels and in-use noise emission levels was found.

But an in-use noise level reduction of 2 dB(A) (for acceleration phases) is related to a type approval noise limit reduction of 6 dB(A). This poor effect on the real world noise emissions can partly be explained by compensatory effects of changes in the type approval measurement method and partly by the fact that the tyre/road noise contribution is not appropriate considered in the current type approval method.

The propulsion noise contribution is too high compared to in-use emissions, even for acceleration phases. A further limit value reduction would lead to measures that are too much focussed on the propulsion noise contribution and thus would be only effective for acceleration phases at low speeds (below 30 km/h). This was already proven in [5]. Furthermore there are other good reasons for an improvement of the current type approval noise emission measurement method.

The method is sensitive for cycle bypass measures since no acceleration is required for the wide open throttle test. This is for example the reason that vehicles with automatic transmission often get a better test result than comparable vehicles with manual transmission. Another example is the borderline between high performance cars and others (> 140 kW rated power and > 75 kW/t max. power to max. vehicle mass ratio). This borderline needs to be updated because of the still ongoing trend to higher rated power values for cars. **A power to mass ratio of 100 kW/t related to gross vehicle mass or 120 kW/t related to kerb mass plus drivers mass would be appropriate for the today's car fleet.**

A more balanced method with a higher tyre/road noise contribution would be more in line with in-use conditions and would require also noise reduction measures for tyres and thus increase the effectiveness with respect to in-use emissions. **But the effectiveness for the in-use emissions will still be limited, if the reduction measures are only applied to OEM tyres and do not include aftermarket tyres.**

With respect to light duty vehicles significant differences were found in the in-use noise emission of accelerating vehicles for LDV with gross vehicle mass up to 2000 kg and GVM above 2000 kg. The noise emission of the first mentioned subclass is nearly the same as for cars of the same engine type, the noise emission of the second class is significantly higher (2 to 3 dB(A). Consequently one can conclude that LDV with GVM above 2000 kg form an own vehicle class with respect to limit values. Interestingly no difference was found in the noise emission of LDV with GVM above 2000 kg and corresponding vehicles with car homologation. That means that the manufacturers obviously do not use less effective noise reduction measures for these vehicles, if they are type approved as LDV's and thus do not ladle out the margin given by the higher limit value of LDV with GVM above 2000 kg compared to the car limit value.

The existing type approval measurement method was more effective for HDV than for cars, because propulsion noise is still dominating in urban streets.

The in-use noise emissions of heavy duty vehicles showed an influence of engine capacity or rated power respectively, especially for accelerating vehicles. Heavy duty vehicles are commercial vehicles with GVM above 3500 kg. The influences of both parameters are more or less equivalent. The noise emission increases with increasing power or engine capacity. **So, the principle of different limit values for different rated power classes in the existing noise regulations is justified. But due to the trend to higher rated power values the existing classification needs to be updated.** For example the power class below 75 kW will vanish from the market in future. Based on the analyses carried out during this project the following classification is proposed for amendments of the EU and ECE noise regulations:

1. Pn <= 100 kW,
2. 100 kW < Pn <= 150 kW,
3. 150 kW < Pn <= 250 kW,
4. Pn > 250 kW

The results for today's HDV (registered after 1995) showed that the differences in the noise emission of accelerating vehicles between the classes 1 and 2 on one hand and 3 and 4 on the other hand are small, the 4 class approach is proposed in order to allow different reduction steps for limit values in the future and thus improve the effectiveness of the type approval noise emission limitation. This classification can bed applied for buses as well as for trucks.

The results showed further that the reduction of noise limits in the past had the highest effect on the reduction of the in-use noise emissions compared to other vehicle categories. But the in-use noise reduction for accelerating vehicles is only about half of the noise limit reduction. This is due to the fact that the noise emission during the type approval test is related to rated engine speed, while the in-use noise emissions are related to the speed range between idling speed and a percentage of rated speed varying from 60% to 85% depending on the vehicle size and rated power.

A corresponding amendment of the ECE R 51, considering the above mentioned recommendations for cars, LDV and HDV, is already on the way. Its introduction can be expected for 2008. But as already said, this regulation covers only OEM tyres. **Significant improvements of the effectiveness of limit reductions with respect to in-use noise emissions require stricter noise limits for the tyre/road noise regulation (ECE R 117). The limit values for both regulations need to be coordinated in that way that the requirements for the tyres are equivalent in both regulations.**

The today’s situation is characterised by the fact that the currently discussed limit values for Regulation 51 would require quieter tyres than Regulation 117.

5 Summary and conclusions

5.1 General

The former Forschungsinstitut Geräusche und Erschütterungen (FIGE) carried out statistical pass-by measurements in real traffic between 1976 and 1993 within the scope of several research projects by order of the German Environmental Agency (UBA) [1], [2], [3], [4]. The results enabled to derive statistically assured correlations between noise emission and vehicle speed and to quantify the influence of traffic situation and driving behaviour. Furthermore it was possible to extract differences in the noise emission of different vehicle types for cars.

In this follow up study should be checked by additional statistical pass-by measurements, if noise limit reductions for type approval, that came into force in the meantime, led to reduction measures by the manufacturers, that also reduced the noise emission in real traffic. Furthermore should be investigated, if the still ongoing trends to wider and faster tyres (higher speed index) for cars and higher rated power values for trucks caused higher noise emissions in real traffic.

The data from the above mentioned previous research projects can be separated into sites with accelerating vehicles (mainly in the speed range between 20 and 40 km/h) and sites with free flowing traffic (urban, rural and motorway with different speed limits). In addition 1 site was established on a motorway with drainage asphalt surface, 2 sites on motorways with 4 % uphill gradient (for heavy duty vehicles) and 3 sites located in the northern part of the Eifel in order to investigate the noise emission of motorcycles.

The statistical pass-by measurements were carried out in accordance to ISO 11819-1. The measurement distance was 7,5 m from the centreline of the driving lane, the height was 1,2 m above the road surface. During the pass-by of a vehicle the vehicle speed was registered by radar or light barriers in addition to the noise level. The maximum noise level (Lmax) during the pass by together with the vehicle speed perform the measurement result. In order to get information about the technical data of the measured vehicles the license plate information was recorded and then sent to the Kraftfahrtbundesamt via UBA.

In order to achieve a good comparability with results from previous projects the measurements were carried out at previous sites as much as possible. Some previous sites had to be excluded because the road design had been changed by construction measures in the meantime. The measurements were carried out between spring 2001 and autumn 2002. In total 29767 vehicles were measured. The majority of vehicles were registered between 1985 and 2001. The average registration year for cars is 1995, which mans that the average age is about 6 years. Cars registered after 1996 and equipped with a direct injection Diesel engine have a 1 dB higher limit value than cars with petrol or precombustion Diesel engines. This "discount" is not justified any longer, because no difference was found in the average type approval level of both groups.

5.2 Maximum pass by level versus vehicle speed, overview of vehicle categories

The road surface of the major part of the measurement sites was asphalt concrete 0/11 with a maximum chipping size of 11 mm. Therefore this surface was treated as reference. Some others were cement concrete and Gussasphalt and the road surface of one site was an open graded drainage asphalt 0/11. The results of the sites with cement concrete and Gussasphalt were "corrected" to the reference surface in order to get one homogeneous sample for the reference surface. The results for the drainage asphalt were kept unchanged. The results were then grouped in sites with free flowing traffic and sites with accelerating vehicles.

In a first step a regression analysis was carried out for the relationship between maximum noise level and vehicle speed separately for accelerating vehicles and free flowing traffic and for different vehicle categories. The following vehicle categories were considered: cars, light duty vehicles (LDV), heavy duty vehicles (HDV) in 4 different rated power classes and 2 number of axle classes, buses, motorcycles and mopeds.

Light duty vehicles are commercial vehicles with gross vehicle mass up to 3500 kg. Heavy duty vehicles (HDV) are commercial vehicles with gross vehicle mass above 3500 kg. The current noise regulation has separate limit values for the following rated power classes: below 75 kW (77 dB(A)), between 75 and 149 kW (78 dB(A)) and 150 kW or more (80 dB(A)). The parameter "number of axles" was added because the influence of tyre/road noise is different. The rated power class below 75 kW will no longer exist in the future because of the still ongoing trend to higher rated power values. In the 2001/2002 measurement campaign only 78 vehicles with rated power below 75 kW were measured. The rated power class of 150 kW or more was subdivided into two classes, rated power values of 150 kW or higher but below 250 kW and 250 kW or higher. This separation was made with respect to the proposal for new power classes that better reflect the existing situation than the power classes of the current noise regulation.

The results for cars and light duty vehicles could be approximated by logarithmic functions, the results for other categories by linear functions. Concerning the difference between accelerating vehicles and free flowing traffic at the same speed the following can be stated:

The regression lines for accelerating vehicles are higher than for free flowing traffic, the differences decrease with increasing vehicle speed.

The results for motorcycles and mopeds could not be separated into accelerating vehicles and free flowing traffic. The major part is most probably free flowing traffic since motorcyclists are very sensitive against speed measurements.

The differences in the regression curves between the different categories can be summarised as follows: Cars have the lowest noise emission levels followed by LDV. For free flowing traffic LDV have about 3 dB higher noise emission values at 20 km/h. The difference decreases with increasing speed and is zero at 130 km/h. Next in the rank order are motorcycles. Between 60 km/h and 100 km/h their average noise levels are nearly the same as for LDV. But since the regression is linear, their emission levels at lower speeds and higher speeds than the mentioned range are higher. At 30 km/h the average emission level for motorcycles is about 6 dB higher than for cars.

Mopeds have a bit more than 2 dB higher noise emission levels than motorcycles. Their emission is similar as for buses and small HDV. As already mentioned, the emission levels for HDV below 75 kW rated power and HDV with rated power values of 75 kW or more but below 150 kW is almost the same. This is also the case for accelerating vehicles, so that on can conclude that both classes can be merged. The emission levels of public transport buses are also nearly the same as for small HDV, although their rated power values were 150 kW or even higher.

The two highest HDV rated power classes show significantly higher noise emission levels. The difference between both is below 2 dB. The comparison of the noise levels for the highest HDV rated power class and HDV with more than 3 axles leads to the conclusion that the overall noise emission is influenced by the tyres, at least for free flowing traffic and even at a vehicle speed of 50 km/h.

5.3 Detailed analysis for vehicle categories

The detailed analysis for vehicle categories did not include public transport buses and mopeds, because the sample size was too small.

5.3.1 Cars

Combustion type

For a further analysis the car sample was divided into vehicles with petrol engines, vehicles with precombustion Diesel engines, vehicles with direct injection Diesel engines.

The noise limit for vehicles registered after 1995 is 74 dB(A) for vehicles with petrol and Diesel engines and 75 dB(A) for vehicles with direct injection Diesel engines. For these groups the maximum pass by levels (Lmax) were plotted versus rated power, power to mass ratio and engine capacity, for acceleration phases and free flowing traffic respectively. The power to mass ratio is the ratio between rated power and kerb mass + 75 kg. Only vehicles with registration years after 1995 were considered for this analysis.

For both situations (accelerations and free flowing traffic) there is a trend of noise level increase with increasing technical parameter, but the noise level variation due to other influences (like individual traffic situation or individual driving behaviour) is by far dominating. The engine capacity shows the biggest influence of technical parameters, followed by rated power.

For acceleration phases vehicles with direct injection Diesel engines have 1 to 2 dB(A) higher noise levels than vehicles with petrol engines. But the vehicles with precombustion Diesel engines have even higher Lmax levels than the vehicles with direct injection Diesel engines. This result is astonishing for the first glance, because the 1 dB higher limit value for direct injection Diesel engines was justified with the argument, that their noise emission is higher than the noise emission of vehicles with precombustion Diesel engines.

For free flowing traffic significant difference in the noise emission of the different engine categories was found. This can be explained by the fact that tyre/road noise is dominating in this driving mode.

In an additional step the car sample with Diesel engines was separated into the following subgroups: cars with precombustion Diesel engines, cars with direct injection Diesel engines, light duty vehicles with car homologation.

The latter were derived from the car sample by separating vehicles with gross vehicle mass of more than 2500 kg and rated power values of up to 73 kW. This subgroup could also include off road vehicles but is dominated by light duty vehicles. For accelerating vehicles the regression curve for LDV with car homologation is significantly higher than the regression curves for the other subgroups. The average emission level curve of LDV with car homologation is almost the same as for LDV with gross vehicle mass above 2000 kg. For free flowing traffic the regression curve for LDV with car homologation is only slightly higher than the regression curves of the two other subgroups.

Emission stages

In another step the car sample was separated into different registration year classes. The borderlines were drawn in relation to limit value changes. The regression curves of these groups follow the trend of the limit values, at least at the lower end of the vehicle speed range. At 30 km/h an average pass by level reduction of 2 dB(A) was found for a noise limit reduction of 6 dB(A). This poor effect on the real world noise emissions can partly be explained by compensatory effects of changes in the type approval measurement method and partly by the fact that the tyre/road noise contribution is not sufficiently considered in the current type approval method.

The average noise emission (for accelerating vehicles) of today's vehicles with direct injection Diesel engines at 30 km/h is 2 dB higher than the average noise emission of today's cars with petrol engines and thus the same as for cars with petrol engines and registration years between 1982 and 1988 but are 2 dB lower than the average noise emission of vehicles with precombustion Diesel engines and registration years between 1982 and 1989. The difference between the noise emission of today's vehicles with petrol and direct injection Diesel engines goes down to zero with increasing vehicle speed.

The comparison of the regression curves for vehicles with direct injection Diesel engines registered between 1990 and 1995 and registered after 1995 at 30 km/h show clearly that the propulsion noise emission for vehicles with engines of this technology was reduced in the meantime. At 30 km/h an average pass by level reduction of 2 dB(A) can be found for a noise limit reduction of 6 dB(A).

Corresponding results for free flowing traffic showed no significant differences between the regression curves of the different registration year classes for vehicles with petrol engines and there was only a vague tendency of lower noise emission for vehicles with Diesel engines with decreasing age at low speeds.

Correlation between in-use noise emissions and type approval levels

Within the context of the registration year analysis it was also checked whether there is a correlation between the noise emission in real traffic and the type approval levels of the vehicles. For that reason the average Lmax levels for cars with petrol, precombustion and direct injection Diesel engines were calculated for accelerating vehicles in the speed range between 27,5 km/h and 37,5 km/h (around 35 km/h) and for free flowing traffic in the speed range between 60 km/h and 70 km/h (around 65 km/h) and plotted versus the type approval levels. The speed ranges were chosen in order to maximise the vehicle number of each vehicle group.

The results for the accelerating vehicles show a clear tendency: The noise levels in real traffic for acceleration phases at low speeds decrease with decreasing type approval level. For free flowing traffic at higher speeds (65 km/h) there is no correlation between type approval levels and in-use noise emission levels.

Vehicle types

Another analysis step was related to vehicle types and resulted in the fact that substantially parts of the differences could be explained by the different emission stages or the engine capacity influence. That means those vehicle types that dominate the fleet composition in real traffic do not differ significantly in their noise emission.

5.3.2 Light duty vehicles

Since light duty vehicles with gross vehicle mass up to 2000 kg and above 2000 kg have different noise limits (76/77 dB(A)), the first analysis step was made with respect to these classes and to different engine types. Only 19% of the whole light duty vehicle sample belongs to the gross vehicle mass (GVM) class of up to 2000 kg. In this class 28,5% of the vehicles were equipped with a petrol engine, 58,2% with a precombustion Diesel engine and 13,3% with a direct injection Diesel engine. The percentage of petrol engine vehicles in the GVM class above 2000 kg is only 4,7%, so that this subclass was excluded from the further analysis. The rest is equipped with Diesel engines, half of it with direct injection Diesel engines.

As for cars one can expect that LDV with precombustion Diesel engines will vanish from the fleet, so the classes with direct injection Diesel engines are most important. The difference in the average Lmax levels for acceleration phases between LDV with direct injection Diesel engines and GVM up to 2000 kg and GVM above 2000 kg varies between 1,4 and 2,2 dB(A), decreasing with increasing vehicle speed. The differences can be explained by differences in the engine capacity. In the GVM class above 2000 kg there is no difference between vehicles with precombustion and direct injection Diesel engines.

For free flowing traffic there is no difference between the Diesel engine type classes with precombustion and with direct injection in both GVM classes, but the differences between both classes are 1,3 to 1,5 dB(A), which once again can be explained by differences in engine capacity. LDV with GVM up to 2000 kg and petrol engines are about 1 dB(A) quieter than those with Diesel engines.

Emission stages

Since this GVM class has the highest sample number a further analysis related to registration year classes was based on this subclass. There is a tendency of lower pass by levels with decreasing vehicle age over the whole speed range. But the difference between vehicles with registration years between 1990 and 1995 and vehicles with registration years after 1995 is only about 1 dB(A). Compared to vehicles registered before 1990 the differences seem to be higher, but this sample is too small to draw reliable conclusions.

5.3.3 Heavy duty vehicles

With respect to the noise limits heavy duty vehicles (HDV) are separated into the following three rated power (Pn) classes: Pn < 75 kW, 75 kW <= Pn < 150 kW, Pn >= 150 kW. Consequently the first analysis was executed in accordance with these classes but separately for HDV with up to 3 axles and HDV with more than 3 axles.

There were only a few vehicles in the 2001 sample with rated power values below 75 kW. A further analysis of the registration year showed that this power class will vanish in the future. The major part of the sample with up to 3 axles has rated power values between 100 and 125 kW and 150 and 200 kW. 43% of this sample belongs already to the highest rated power class of the current type approval noise regulation. Nearly 90% of the sample of HDV with more than 3 axles has rated power values between 250 and 350 kW.

Influence of rated power and engine capacity

In a first step should be checked whether there is a correlation between the in-use noise emission levels and the technical parameters rated power and engine capacity. This step was related to vehicles registered after 1995. Both technical parameters were classified and the averages of the Lmax levels were calculated for accelerating vehicles in the speed range between 20 km/h and 40 km/h for each power and capacity class. Since the tyre/road noise contribution is depending on the number of axles this analysis step was carried out separately for vehicles with up to 3 and more than 3 axles. Only classes with at least 10 vehicles were considered. For HDV with up to 3 axles the in-use noise levels clearly increase with increasing rated power or increasing engine capacity respectively. But astonishingly for HDV with more than 3 axles the in-use noise emission levels decrease slightly with increasing power or engine capacity. The rated power ranges of both axle classes are clearly separated. There is no power class above 250 kW for HDV up to 3 axles and no power class below 250 kW for HDV with more than 3 axles.

For engine capacity there is a small region between 11000 and 12000 cm^3, where both axle classes overlap. In this region no significant difference between the 2 axle classes can be seen, so that one can conclude that acceleration phases in this speed range are not much influenced by tyre/road noise.

In order not to mix up the possible rated power effects by age effects and in order to get a better insight into the power effect the further analysis was restricted to vehicles registered after 1995 and the following rated power classification for both axle number classes was used: Pn <= 100 kW, 100 kW < Pn <= 150 kW, 150 kW < Pn <= 250 kW, Pn > 250 kW

The borderlines at 150 kW and 250 kW are defined slightly different from those used for the analysis for categories and from the classes defined in the current EU directive or ECE regulation, but this had no consequence for the results and conclusions. These classes are proposed to be used for an amendment of the EU and ECE noise regulations for heavy duty vehicles.

Average noise levels for the different HDV subclasses were calculated for a reference speed of 30 km/h. For 3 axle vehicles in acceleration phases the difference from one power class to the other is 1,7 to 2 dB(A), resulting in a 5,4 dB(A) difference between the highest and the lowest power class. The difference between the 2 axle classes for HDV in the highest power class is below 1 dB(A).

For 3 axle vehicles in free flowing traffic the difference from one power class to the other is 0,7 to 1,1 dB(A), resulting in a 3,9 dB(A) difference between the highest and the lowest power class. These differences are lower than the differences for accelerating vehicles, which leads to the conclusion that the in-use noise levels at 75 km/h are already influenced by tyre/road noise. The difference between the 2 axle classes for HDV in the highest power class at 75 km/h free flowing traffic is 1,1 dB(A), which is also an indication for the tyre/road noise influence.

Emission stages

In addition an analysis was carried out in each of the new proposed rated power and axle classes for vehicles with registration years before 1990, between 1990 and 1995 and after 1995. These time periods are related to different limit value periods. For the highest power class no vehicles were found in the database with registration years before 1990.

For the power classes below 250 kW and HDV with 3 axles a comparison can be made between today's vehicles and vehicles registered before 1990, whose type approval noise limits differ by 8 dB(A). The average pass by levels for accelerations between 20 and 40 km/h for today's vehicles are 3,3 to 4,2 dB(A) lower than for vehicles registered before 1990. The differences decrease with increasing power class. That means that the noise reduction in real traffic for these vehicles is higher than for cars or LDV and that the type approval noise limit reduction was more effective. This is not the case for HDV with rated power values above 250 kW. For these vehicles the last limit reduction step was 4 dB(A), resulting in a reduction of the in-use emissions for accelerations at low speeds of only 0,9 to 1,4 dB(A).

As for acceleration phases the power classes below 250 kW and HDV with 3 axles contain also results for vehicles registered before 1990 for free flowing traffic. The in-use noise level reduction between today's vehicles and those before 1990 are less than half of the reduction achieved for acceleration phases. This significant deterioration of the effectiveness of the limit reduction is most probably caused by the increased influence of the tyre/road noise for these driving conditions.

Vehicle types

Concerning vehicle types the same approach was used as for cars and LDV. The analysis led to similar results: A substantially part of the differences in the noise emission between the types can be explained by differences in rated power or engine capacity. The unexplained rest of variance is about 2 dB(A). This rest cannot be reduced for in-use noise measurements and such small vehicle samples. The conclusion is the same as for cars and LDV: There are no type specific differences in the in-use noise emission.

In order to get in-use noise level results for HDV on motorways with gradients two measurement sites were established on motorways with uphill gradients of about 4%. The results were compared with the results of 3 other, flat motorway sites for the two HDV axle classes as individual Lmax levels versus vehicle speed. As one could expect the results on the uphill sites show a lower slope for the speed dependency than the flat sites. That means that the differences increase with decreasing speed. The difference was about 3 dB(A) at 50 km/h for the HDV sample with up to 3 axles and below 3 dB(A) for HDV with more than 3 axles. The reason is that the vehicles going uphill try to run with the highest possible speed and thus use more power and produce more noise than in flat condition. But differently to former measurement campaigns a substantially part of the vehicle sample nowadays has enough power to run uphill gradients of 4% with maximum vehicle speed.

5.3.4 Motorcycles

The motorcycle sample, for which technical data were available, contained 392 vehicles. An analysis was carried out with respect to rated power, engine capacity and registration year. With respect to rated power the following classes were defined: Pn <= 25 kW, 25 kW < Pn <= 50 kW, 50 kW <Pn <= 75 kW, Pn > 75 kW

The differences in the regression curves are not significant. The high variances of the individual results are partly caused by different driving behaviour and partly by the use of noise increasing exhaust and/or intake silencers.

Concerning engine capacity the following classes were defined: <= 125 cm^3, 125 cm^3 < eng cap < 400 cm^3, 400 cm^3 <= eng cap < 750 cm^3, 750 cm^3 <= eng cap < 1000 cm^3, >= 1000 cm^3. Although we are aware that motorcycles up to 175 cm^3 and motorcycles above 175 cm^3 have different limit values, this border was ignored in the analysis, because only 7 vehicles with engine capacity up to 175 cm^3 were measured.

The regression curves for the engine capacity classes 1, 3, 4 and 5 have nearly the same slope, those for 3 and 4 are identical. Class 1 vehicles have slightly higher levels class 5 vehicles have slightly lower levels than the classes 3 and 4. The differences between the regression curves are not higher than 2 dB(A) for these classes. The class 2 vehicles showed a different speed dependency but the sample was so small that the difference cannot be considered as reliable.

Concerning the registration year the following three different classes were analysed: < 1990, 1990 to 1995, > 1995. Although the uncertainty range due to the low sample numbers does not allow to interpret the differences in the regression curves as significant, at least a trend to lower pass by levels for the today's vehicles could be stated for vehicle speeds below 60 km/h.

5.4 Noise reduction effect of drainage asphalt compared to stone mastic asphalt

There is one measurement site that was excluded from the analysis so far, a motorway site with a drainage asphalt surface (max. chipping size 11 mm, DA 0/11). The reduction effect of this surface was demonstrated by comparing the results for cars, HDV with up to 3 axles and HDV with more than 3 axles on this site with another motorway site with a stone mastic asphalt surface (max. chipping size 11 mm, SMA 0/11). The average speeds were nearly the same for each vehicle category on both sites.

For cars the regression curve for DA 0/11 is about 8,5 dB(A) lower than the regression curve for SMA 0/11. For HDV with up to 3 axles and more than 3 axles the regression curves for DA 0/11 is about 6,5 dB(A) lower than the regression curves for SMA 0/11 for both axle classes.

5.5 Comparison with the results of previous investigations

In order to compare the results of this investigations with the results of previous investigations the data of the previous investigations were corrected for road surface influences in the same way as described in chapter 3.1.2. Four previous investigations were considered for the comparison of vehicles in free flowing traffic, from 1978 [1], 1983 [2], 1986 [3] and 1992 [4]. For accelerating vehicles the 1986 period was disregarded because it contained no special measurement sites for this driving condition.

At low speeds and for accelerating cars (20 to 40 km/h) a clear trend to lower emission values for higher reference years was found. The average Lmax levels for 1992 are significantly lower than the corresponding levels for 1978 and 1983 and the levels for 2001 are even lower than those for 1992. At high speeds (above 60 km/h) the regression curves coincide. What can also be seen is the fact that the scattering of the results is highest for 1978 and lowest for 2001.

For free flowing traffic no significant differences between the regression curves for different investigation periods were found. But as for accelerating vehicles the scattering of the results decreases with increasing reference year.

Since the sample number for other categories than cars are significantly lower another approach was chosen for further comparisons. The average Lmax levels and the 95-percentiles of the Lmax levels were calculated within the speed range of 20 to 40 km/h for accelerating vehicles and 45 to 55 km/h (cars and LDV) or 40 to 60 km/h (HDV) for each investigation period. Averages were calculated for sample sizes of at least 10 vehicles, L_95 levels for at least 60 vehicles, so that this level is exceeded by at least 3 vehicles.

Cars with petrol engines from 1992 had about 2 dB(A) lower Lmax levels (-1,9 dB(A) for the average and -2,3 dB(A) for the L_95) than vehicles from 1978 or 1983. Because no significant difference could be found between the 1978 and 1983 periods the mentioned differences are related to the averages of 1978 and 1983. The reduction for the 2001 period compared to 1978/1983 is 3,7 dB(A) for the average and 5 dB(A) for the L_95.

For cars with precombustion engines the reductions are about 3 dB(A) for the 2001 period, but this result is not meaningful any more because this engine type will vanished from the fleet in the near future. For cars with direct injection Diesel engines no such trends can be shown because they did not exist in the samples before 1992 and there are even too few in the 1992 sample. For the 2001 period the L_95 level for cars with direct injection Diesel engines is less than 1 dB(A) higher than the L_95 for cars with petrol engines. The difference for the average is about 1 dB(A).

For LDV with GVM up to 2000 kg no L_95 level could be calculated because of the small sample sizes. The average level for 2001 is 3,5 dB(A) lower than the average levels for 1978/1983. For LDV with GVM above 2000 kg the improvement is a bit lower. Average and peak level for 2001 are a bit more than 2 dB(A) lower than for 1978/1983.

The reduction between 1978/1983 and 2001 is about 2,5 dB(A) for HDV up to 100 kW and 5,5 dB(A) (average) to 6,5 dB(A) (L_95) for HDV with rated power between 101 and 150 kW. Since the reduction for HDV up to 100 kW is only half of the reduction for HDV with rated power between 101 and 150 kW, the difference between both groups decreased with increasing reference year. For the investigation periods 1978/1983 the difference is about 3,5 dB(A), for 2001 there is no significant difference any more.

The reduction of the Lmax levels of HDV with power values between 151 and 250 kW between 1978/1983 and 2001 is 7,5 dB(A) for the average and 6,4 dB(A) for L_95. This is the highest reduction of all HDV classes. HDV with rated power values above 250 kW did not exist in the investigation periods of 1978 and 1983 and even the sample of 1992 is not big enough to calculate the L_95 level. The averages from 1992 and 2001 follow the same trend as for the power class below.

For free flowing traffic also the investigation period from 1986 could be included. With respect to cars with direct injection Diesel engines the same problem occurs than for accelerating vehicles. No vehicles for the periods before 1992 and not enough for 1992 to calculate L_95. Between 1978 and 2001 Cars with petrol engines and precombustion Diesel engines show the same trends: A reduction of L_95 of about 2 dB(A) but no significant changes for the average levels.

No significant reduction was found for LDV in free flowing traffic between the periods 1978 and 2001. The reduction for HDV up to 100 kW is 2,4 dB(A) for the average and 5 dB(A) for L_95. The latter is even higher than for accelerating vehicles, but based on a small number of vehicles so that no general conclusions could be drawn..

In Figure 83 the results for and are plotted. For HDV above 250 kW only the time periods 1992 and 2001 could be considered. The average levels as well as the peak levels (L_95) of HDV with rated power between 101 and 150 kW and HDV between 151 and 250 kW show a common trend: no significant changes between 1978 and 1986, but significant reductions for 1992 and 2001. The differences between 1986 and 2001 are in the order of 3,5 to 5 dB(A). The same trend occurs for HDV with rated power above 250 kW. The reduction between the periods 2001 and 1992 is 2 dB(A) for the average and 3 dB(A) for L_95.

Finally corresponding results for free flowing traffic were calculated for rural driving between 70 and 90 km/h. For HDV besides rural sites also measurement sites on motorways were included in order to increase the sample sizes. The investigation periods 1986, 1992 and 2001 could be considered for this analysis.

For cars no significant differences between the periods could be found, one could only state a tendency for slightly higher levels with increasing reference year, especially for cars with precombustion Diesel engines. For LDV and HDV up to 250 kW there is a trend to lower levels with increasing reference year. The reduction from 1986 to 2001 ranges from 1 to 2,5 dB(A). For HDV above 250 kW results are only available from 1992 and 2001, but there are nearly no differences between both samples.

Also for motorcycles a trend towards lower noise emission levels over time was found (about 2,5 dB(A) for the average and 5 dB(A) for L_95). But since the results are highly influenced by vehicles with illegal silencers and since no information about the percentages of these vehicles in the sample is available, a general interpretation is difficult. The higher reduction for the L_95 compared to the reduction for the average could for example be explained by a lower percentage of manipulated vehicles in 2001 than for the previous periods. But there is no possibility to verify this.

5.6 Conclusions

The main aim of this investigation was to get an answer to the question, if noise limit reductions for type approval, that came into force in the meantime, led to reduction measures by the manufacturers, that also reduces the noise emission in real traffic. The analysis of the results showed clearly that there was an effect on the in-use propulsion noise emission of the vehicles but no effect on the tyre/road noise emission. Since tyre/road noise is more important for cars than for heavy duty vehicles, the reduction effect is higher for HDV than for cars.

More specific: Since tyre/road noise is dominating for cars in free flowing traffic, the reduction of the propulsion noise emission gave no benefit for this driving condition class. And even for acceleration phases at low speeds the reduction of the overall noise emission was found to be substantially lower than the reduction of the noise limits, which is partly caused by the tyre/road noise influence and partly by changes in the measurement method. On the other hand can be stated that the still ongoing trends to wider and faster tyres for cars did not lead to a significant increase of the overall noise emission for free flowing traffic. Since this trend would have led to an increase in the tyre/road noise emission without any reduction measures (and the results for cars in free flowing traffic support this hypothesis, one can state that the tyre manufacturers were able to apply noise reduction measures but only to that extend that these measures compensated the increase being expected.

The results showed also that the noise emission of cars with Diesel engines during acceleration phases at low speeds is 1 to 2 dB(A) higher than the noise emission for cars with petrol engines. This difference is partly caused by differences in average engine capacity between both groups, because it was also found that the in-use noise emission for accelerating cars at low speeds increase with increasing engine capacity. The remaining part is engine type related. But the noise emission of cars with today's direct injection Diesel engines in acceleration phases is lower than the corresponding noise emission of cars with precombustion Diesel engines, which do no longer exist on the market. Taking into account that there is no difference in the average type approval levels any more between cars with direct injection Diesel engines and cars with petrol engines, the 1 dB(A) "discount" for cars with direct injection Diesel engines is no longer justified.

With respect to light duty vehicles significant differences were found in the in-use noise emission of accelerating vehicles for LDV with gross vehicle mass up to 2000 kg and GVM above 2000 kg. The noise emission of the first mentioned subclass is nearly the same as for cars of the same engine type, the noise emission of the second class is significantly higher (2 to 3 dB(A). Consequently one can conclude that LDV with GVM above 2000 kg form an own vehicle class with respect to limit values. Interestingly no difference was found in the noise emission of LDV with GVM above 2000 kg and corresponding vehicles with car homologation. That means that the manufacturers obviously do not use less effective noise reduction measures for these vehicles, if they are type approved as LDV's and thus do not ladle out the margin given by the higher limit value of LDV with GVM above 2000 kg compared to the car limit value.

The in-use noise emissions of heavy duty vehicles showed an influence of engine capacity or rated power respectively, especially for accelerating vehicles. Heavy duty vehicles are commercial vehicles with GVM above 3500 kg. The influences of both parameters are more or less equivalent. The noise emission increases with increasing power or engine capacity. So, the principle of different limit values for different rated power classes in the existing noise regulations is justified. But due to the trend to higher rated power values the existing classification needs to be updated. For example the power class below 75 kW will vanish from the market in future. Based on the analyses carried out during this project the following classification is proposed for amendments of the EU and ECE noise regulations:

5. Pn <= 100 kW,
6. 100 kW < Pn <= 150 kW,
7. 150 kW < Pn <= 250 kW,
8. Pn > 250 kW

The results for today's HDV (registered after 1995) showed that the differences in the noise emission of accelerating vehicles between the classes 1 and 2 on one hand and 3 and 4 on the other hand are small, the 4 class approach is proposed in order to allow different reduction steps for limit values in the future and thus improve the effectiveness of the type approval noise emission limitation. This classification can bed applied for buses as well as for trucks.

The results showed further that the reduction of noise limits in the past had the highest effect on the reduction of the in-use noise emissions compared to other vehicle categories. But the in-use noise reduction for accelerating vehicles is only about half of the noise limit reduction. This is due to the fact that the noise emission during the type approval test is related to rated engine speed, while the in-use noise emissions are related to the speed range between idling speed and a percentage of rated speed varying from 60% to 85% depending on the vehicle size and rated power.

The results for HDV showed also that the influence of tyre/road noise on the overall noise emission of accelerating vehicles is of no importance until now, but that this influence is significant for the overall noise emission of free flowing traffic above 50 km/h.

For motorcycles no substantial conclusions can be drawn because of the small sample size and the lack of information about possible noise increasing modifications.

With respect to the type approval measurement method the following conclusions can be drawn:

For cars a in-use noise level reduction of 2 dB(A) for accelerating vehicles was found related to a type approval noise limit reduction of 6 dB(A). This poor effect on the real world noise emissions can partly be explained by compensatory effects of changes in the type approval measurement method and partly by the fact that the tyre/road noise contribution is not appropriate considered in the current type approval method.

The propulsion noise contribution is too high compared to in-use emissions, even for acceleration phases. A further limit value reduction would lead to measures that are too much focussed on the propulsion noise contribution and thus would be only effective for acceleration phases at low speeds (below 30 km/h). This was already proven in [5]. Furthermore there are other good reasons for an improvement of the current type approval noise measurement method.

The method is sensitive for cycle bypass measures since no acceleration is required for the wide open throttle test. This is for example the reason that vehicles with automatic transmission often get a better test result than comparable vehicles with manual transmission. The borderline between high performance cars and others (> 140 kW rated power and > 75 kW/t max. power to max. vehicle mass ratio) needs to be updated because of the still ongoing trend to higher rated power values for cars.

A more balanced method with a higher tyre/road noise contribution would be more in line with in-use conditions and would require also noise reduction measures for tyres and thus increase the effectiveness with respect to in-use emissions. But the effectiveness for the in-use emissions will still be limited, if the reduction measures are only applied to OEM tyres and do not include aftermarket tyres.

The existing method for HDV should be modified in that way that it takes into account the most frequently used engine speeds rather than rated speed.

A corresponding amendment of the ECE R 51, considering the above mentioned recommendations for cars, LDV and HDV, is already on the way. Its introduction can be expected for 2008. But as already said, this regulation covers only OEM tyres. Significant improvements of the effectiveness of limit reductions with respect to in-use noise emissions require stricter noise limits for the tyre/road noise regulation (ECE R 117). The limit values for both regulations need to be coordinated in that way that the requirements for the tyres are equivalent in both regulations.

The today's situation is characterised by the fact that the currently discussed limit values for Regulation 51 would require quieter tyres than Regulation 117.

6 Literature

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