

EUROPEAN COMMISSION

DG RESEARCH

SIXTH FRAMEWORK PROGRAMME

PRIORITY 6

SUSTAINABLE DEVELOPMENT, GLOBAL CHANGE & ECOSYSTEMS

INTEGRATED PROJECT – CONTRACT N. 516288



Noise classification of urban road surfaces State-of-the-art

Deliverable no.	F.D11
Dissemination level	Public
Work Package	WP F4.1 State-of-the-Art. Noise classification of road surfaces
Author(s)	G. Descornet
Co-author(s)	-
Status (F: final, D: draft)	D2_03/02/2006
File Name	SILENCE_F.D11_03/02/06_SotA.doc
Project Start Date and Duration	01 February 2005, 36 months



TABLE OF CONTENTS

<u>ACRONYMS</u>	3
<u>INTRODUCTION</u>	4
<u>1. AUSTRIA</u>	4
<u>2. BELGIUM</u>	5
<u>3. FRANCE</u>	6
<u>4. GERMANY</u>	7
<u>5. HUNGARY</u>	8
<u>6. ITALY</u>	9
<u>7. JAPAN</u>	9
<u>8. NETHERLANDS</u>	10
<u>9. POLAND</u>	10
<u>10. PORTUGAL</u>	14
<u>11. SLOVENIA</u>	14
<u>12. SPAIN</u>	15
<u>13. SWITZERLAND</u>	15
<u>14. UNITED KINGDOM</u>	16
<u>15. USA</u>	17
<u>16. NORDIC COUNTRIES</u>	17
<u>17. HARMONOISE</u>	19
<u>18. SILVIA</u>	20
<u>19. CONCLUSIONS</u>	21
<u>20. REFERENCES</u>	22

Acronyms

AADT	Annual Average Daily Traffic
COP	Conformity of Production
CPB	Controlled Pass-By (Measurement method)
CPX	Close Proximity (Measurement method)
CPXI	Close Proximity Index
DAC	Dense Asphalt Concrete
EACC	Exposed Aggregates Cement Concrete
HRA	Hot Rolled Asphalt (in UK)
PA	Porous Asphalt
PCC	Portland Cement Concrete (in USA)
SMA	Stone Mastic Asphalt
SPB	Statistical Pass-By (Measurement method)
SPBI	Statistical Pass-By Index
TD	Texture Depth

Introduction

This report aims at providing the most recent state-of-the-art of classifying road surfaces with respect to their influence on traffic noise in preparation to the development of a proposal for such a classification that would be adapted to urban conditions.

The information reported here has been obtained as the result of an enquiry sent by the author to experts in all European countries including Switzerland. The responses obtained cover nineteen countries. Among the received contributions, a state-of-the-art report from U. Sandberg [27] has been very useful in providing complementary information about some European countries as well as information about USA and Japan. In addition, two European projects recently completed are also quoted, namely HARMONOISE and SILVIA, as they include classification proposals.

1. Austria

In Austria, a model is used that is called RVS 3.02. The road surface corrections C_{surf} used in RVS is dependent on vehicle category and vehicle speed as shown in table 1 [1].

Table 1 - Road surface correction in the Austrian model RVS3.02

road surface category	Leq(50 km/h) in dB(A)				
	light vehicles	medium vehicles	low noise medium vehicles	heavy vehicles	low noise heavy vehicles
granite pavement	52	60	60	62	62
asphalt concrete and low noise cement concrete	47	54	52	59	56
cement concrete	48	55	53	60	57
drainage asphalt	46	51	49	56	53

road surface category	slope B of speed curve $Leq(v) = Leq(50 \text{ km/h}) + B \cdot \log(v/50 \text{ km/h})$				
	light vehicles	medium vehicles	low noise medium vehicles	heavy vehicles	low noise heavy vehicles
granite pavement	0	0	0	0	0
asphalt concrete and low noise cement concrete	26.2	15	24.8	15	24.8
cement concrete	30.5	18	27.8	18	27.8
drainage asphalt	23.6	10	19.8	10	19.8

Those values are based on SPB and CPB measurements converted in Leq values. Subsequently, guidelines were issued describing a measurement method using a home-made trailer [2] that was used in an investigation by ARSENAL Research [3]. The measurement campaign covered 11 road sections with different surface materials. Measurements were carried out using four methods, namely: trailer complying with RVS11.066 delivering "LMA-values", trailer complying with ISO11819-2 [38] either using all four tyres (E¹, B, C, D) delivering "CPXI4-values" or tyres E & D delivering "CPXI2-values" and SPB according to ISO11819-1 [37] delivering "SPBI-values". The results are given in table 2.

Table 2 – Summary of Austrian measurement results [3]

N°	Road surface	RVS11.066-IV	ISO/CD11819-2		ISO11819-1
	Type	LMA	CPX4	CPX2	SPBI
1	Exposed aggregate cement concrete 1	101.2	103.3	103.4	85.8
2	Exposed aggregate cement concrete 2	100.5	102.5	102.8	86.7
3	Cement concrete	103.2	104.3	104.3	86.9
4	Thin layer 1	102.1	103.5	103.4	84.6
5	Thin layer 2	101.7	-	104.6	-
6	SMA 1	99.6	102.4	102.5	84.4
7	SMA 2	102.5	-	103.9	-
8	Porous asphalt 1	103.0	-	103.7	-
9	Porous asphalt 2	101.8	103.5	103.9	84.5
10	Asphalt concrete 1	102.2	102.3	102.8	87.8
11	Asphalt concrete 2	103.3	-	103.5	85.8

From those results, the correlations between trailers appear to be excellent ($0.95 < R^2 < 0.97$) while the correlations between any trailer and SPB method are rather poor ($0.26 < R^2 < 0.30$). The ranking of surfaces happens to be much dependent of the measurement method as figure 1 shows.

2. Belgium

Although low-noise road surfaces have been used for long in Belgium, there is no systematic classification and no national calculation method. Occasionally, the French method [4] has been used by the author.

¹ An alternative for ISO tyre A.

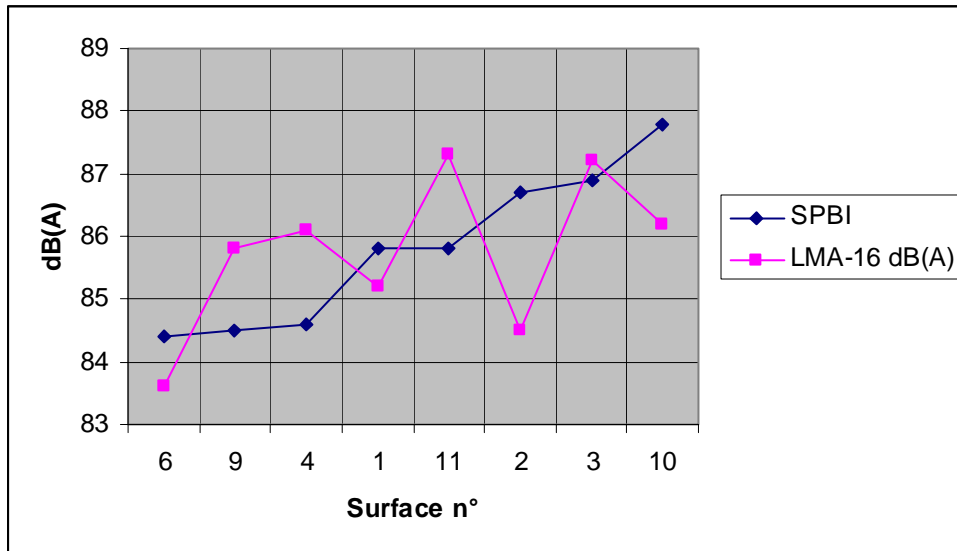


Figure 1 – Ranking of surfaces versus the measurement method in the Austrian noise measurement campaign [3]. SPBI is the SPB Index according to ISO 11819-1 [37]. LMA is the Austrian CPX trailer with 16 dB(A) subtracted to the CPX level.

3. France

In France, the calculation method developed in the seventies [4] does not consider the influence of the road surface. Presently, work is in progress with a view to updating the procedure, namely by including that influence and also taking into account the evolution of vehicle technology [5, 6]. So far, formulas predicting the level of the rolling noise component have been established for different categories of surfaces versus vehicle category and speed as in table 3.

Table 3 – Rolling noise level (L_{Amax} at 7.5 m) versus speed, surface category and vehicle category. The speed range is 5 to 130 km/h for light vehicles and 5 to 100 km/h for heavy vehicles

Surface category	Light vehicles	Heavy vehicles
R1	$73.8 + 30.2 \log(V/90)$	$83.8 + 26.0 \log(V)$
R2	$77.7 + 31.5 \log(V/90)$	$87.2 + 31.0 \log(V)$
R3	$80.2 + 32.2 \log(V/90)$	$88.3 + 32.6 \log(V)$

The surface categories include the following (table 4):

Table 4 – Road surface categories in the French updated calculation method

R1	R2	R3
Very thin asphalt layer 0/6 (types 1 & 2) Ultra thin asphalt layer 0/6 Porous asphalt 0/10 Very thin asphalt layer 0/10 (type 2)	Very thin asphalt layer 0/10 (type 1) Dense asphalt concrete 0/10 Cold mix Ultra thin asphalt layer 0/10	Cement concrete Very thin asphalt layer 0/14 Dense asphalt concrete 0/14 Surface dressing 6/10 & 10/14

It is to be noted that there is no reference surface. The formulas are not corrections: they give the contribution of tyre/road noise in terms of noise levels.

4. Germany

The German guidelines “Richtlinien für den Lärmschutz an Strassen, 1990” (RLS90) include the surface corrections n° 1-4 presented in table 5a in their prediction model [7].

Table 5a - Road surface correction according to the German prediction model

Road surface		DStrO in dB(A) at posted speed limit of		
		30 km/h	40 km/h	50 km/h
1	Non-grooved Gussasphalt Asphalt concrete Stone mastic asphalt	0	0	0
2	Cement concrete Grooved Gussasphalt	+1,0	+1,5	+2,0
3	Paving stones with even surface	+2,0	+2,5	+3,0
4	Miscellaneous paving stones	+3,0	+4,5	+6,0

There are additional surface corrections included in “Allgemeines Rundschreiben Straßenbau Nr. 14/1991” [34] presented in table 5b.

Table 5b – Road surface correction according to the German prediction model

Road surface		DStrO in dB(A) for rural roads with speeds > 60 km/h
1	Cement concrete after “ZTV Beton 78” with steel brush with longitudinal smoothing	+1,0
2	Cement concrete after “ZTV Beton 78” without steel brush with longitudinal smoothing, textured with burlap	-2,0
3	Asphalt concrete ≤ 0/11 and stone mastic asphalt 0/8 and 0/11 without loose chippings	-2,0
4	Open porous asphalt with a void content ≥ 15 % after construction with grain size 0/11	-4,0
	Open porous asphalt with a void content ≥ 15 % after construction with grain size 0/8	-5,0

The corrections can be determined using either the SPB or the CPB method according to GEstro-92 ("Geräuschemission von Strassenoberflächen, 1992") [8].

5. Hungary

Guidelines have been recently issued by the Hungarian Ministry of Environment and Water [9]. They specify the investigation and calculation methods for establishing strategic noise maps. They include corrections to be applied on the traffic noise level as in table 6.

The indicator is L_{Aeq} at 7.5 m. The correction applies equally to daytime, evening and night traffic noise levels.

Although it is not explicitly quoted as such, the reference surface can be considered here as a Dense Asphalt Concrete similar to many other reference surfaces.

Table 6 – Road surface corrections in the guidelines of the Hungarian Ministry of Environment and Water

Road surfaces		Correction (dBA)
Category	Types	
A	Dense asphalt concrete (0/8) Dense asphalt concrete (0/12) Stone mastic asphalt (0/8) Mastic asphalt (0/8) Mastic asphalt (0/12) Modified thin asphalts layers	0
B	Dense asphalt concrete with polymer-modified binder Mastic asphalt with polymer-modified binder Thin asphalts layers older than 4 years Stone mastic asphalt (0/12) Modified stone mastic asphalt (0/12) Surface-dressed asphalt concrete (0/12)	+2.9
C	Dense asphalt concrete with polymer-modified binder older than 4 years Mastic asphalt with polymer-modified binder older than 4 years Single and double surface dressing (5/8, 2/5) Dense asphalt concrete (0/16) Surface-dressed asphalt concrete (0/16) Dense asphalt concrete (0/20)	+4.9
D	Cement concrete Cracked asphalt concrete Dense asphalt concrete (0/16) older than 4 years Surface-dressed asphalt concrete (0/16) older than 4 years Dense asphalt concrete (0/20) older than 4 years	+6.7
E	Fretted or plucked cement concrete Small sett paving Ornamental paving blocks Ceramic blocks Chipped sand asphalt (0/16) Chipped sand asphalt (0/20)	+7.8

6. Italy

In Italy, there are software models for noise prediction by the name Citymap and Disiapyr [10]. These include a road surface correction table, which appears in table 7. This table is unique in that it includes corrections in octave bands, not just a flat correction for the A-weighted overall level. It also includes, as the two last lines, a correction for longitudinal road gradient, one for driving 5 % uphill and another for driving 5 % downhill.

Table 7 - Road surface correction in the Italian model Citymap [10]. The last two lines are corrections for longitudinal road gradient

Road surface	63 Hz	125Hz	250Hz	500Hz	1 kHz	2 kHz	4 kHz	8 kHz	dB(A)
Conventional asphalt pavement (ref)	81.7	87.4	81.4	76.2	75.1	73.8	70.6	71.1	81.3
Paving stones	+1.1	+1.2	+2.1	+2.3	+1.5	+1.6	+1.8	+1.3	+1.9
Drainage asphalt pavement	-0.1	-0.3	-1.1	-1.8	-2.4	-2.1	-1.2	-1.3	-1.4
Conv. asphalt, gradient + 5 % ↗	+2.2	+2.4	+3.1	+2.1	+2.0	+1.3	+1.6	+1.4	+2.2
Conv. asphalt, gradient - 5 % ↘	-1.2	-1.3	-0.8	-1.1	+1.0	-0.2	+0.7	+0.8	+0.1

7. Japan

The model used in Japan is called the ASJ Model. The latest version is from 1998 [11]. This model contains a surface correction, but only for porous asphalt pavements (PA 0/13, usually having about 20 % voids in new condition) in relation to "normal" dense asphalt pavements (DAC 0/13), the former being the most used for noise reduction. The correction is valid over the speed range 40-140 km/h for light vehicles and 40-120 km/h for heavy vehicles, and it is as follows [12]:

$$Correction = -3.5 \log(V) + 3.2 \quad (1)$$

Where V is the vehicle speed in [km/h].

The Japanese are going to revise this model. One of the improvements considered is to take the age of the surface into account.

Tyre/road noise levels are measured by means of special vans ("Road Acoustic Checker") equipped with a special tyre as a fifth wheel. The method resembles the CPX method. The tyre is a normal Bridgestone tyre for which the normal tread has been buffed-off and a new tread has been fitted with a very special tread pattern. The tread pattern consists of large "suction cups" on one side of the tyre and large "crossbar lugs" on the other side. In this way, both the vibrational impact mechanism and the air-pumping mechanism are excited in a maximum way. The classification of surfaces with this tyre does not correlate so well with the SPB method, since on smooth surfaces both mechanisms are excited to a very high degree. However, within the porous asphalt surface group, the main subject of the system, tested relations show a reasonable correlation CPX-SPB [32].

8. Netherlands

The Dutch official specifications for noise calculation and measurement [13] provides for a correction term for the road surface influence called “ C_{road} ”. It is as a function of vehicle category and speed if one uses the simplified procedure. It is also given by octave-bands if one uses the full procedure. It is defined as follows:

$$\text{Simplified procedure: } C_{road,m} = \Delta L_m + b_m \log\left(\frac{V_m}{V_{0,m}}\right) \quad (2)$$

$$\text{Full procedure: } C_{road,m,i} = \Delta L_{m,i} + b_m \log\left(\frac{V_m}{V_{0,m}}\right) \quad (3)$$

where m and i are respectively the subscripts for vehicle category and frequency band (octaves). That correction is to be applied with respect to a reference surface, which is a smooth, dense asphalt concrete. That surface is specified by means of its reference values given in tables 8 & 9 [14].

Table 8 – Reference values of the parameters in the equation of the noise level vs. speed of the reference surface: $L = a + b \log(V/V_0)$

	a (dBA)	b (dBA)	V₀ (km/h)
Light vehicles	74.8	33.0	80
Medium heavy vehicles	80.9	20.9	70
Heavy vehicles	83.5	22.5	70

Table 9 – Reference spectrum in octave-bands

	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Light vehicles	-28.6	-19.6	-14.4	-10.2	-3.1	-5.1	-13.1	-22.6
Medium & heavy veh.	-25.4	-18.2	-11.2	-5.8	-3.9	-7.5	-14.1	-21.4

The measurement method specified to determine C_{road} is the SPB with a microphone height of 5 m.

Tables 10 & 11 list C_{road} values for light and medium/heavy vehicles respectively [15].

9. Poland

There is no such classification in Poland for the moment. An investigation is underway on the road surface influence on road traffic [16].

Table 10 – Corrections for the road surface to be used in the Dutch noise calculation procedure for light vehicles

N°	Product type		Vmin	Vmax	L	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	b
0	Reference surface	asphalt	40	130	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1	Single layer porous asphalt	asphalt	50	130	-2,61	1,30	-3,70	-4,00	0,06	-2,27	-4,33	-3,32	0,17	-8,02
2	Double layer porous asphalt	asphalt	50	130	-5,05	-0,67	-4,53	-5,23	-3,53	-4,93	-5,88	-5,24	-3,51	-5,41
3	Double layer porous asphalt (fine)	asphalt	50	120	-6,39	-2,51	-5,77	-6,96	-5,66	-5,88	-7,69	-6,28	-4,66	-5,38
4	SMA 0/6	asphalt	40	80	-1,91	-3,55	-4,95	-4,42	-0,01	-1,90	-2,47	-1,41	0,13	-3,94
5	Exposed aggregates cement concrete	cement	50	130	1,42	0,57	-4,43	-3,43	0,82	2,23	0,80	0,35	1,41	-0,21
6	Exposed aggregates cement concrete (optimized)	cement	70	80	-0,07	-0,70	-4,82	-4,13	-0,30	0,92	-1,29	-1,32	-0,22	-1,63
7	Finely brushed cement	cement	70	120	1,63	0,43	-4,57	-2,06	0,64	1,41	2,58	1,80	1,02	5,09
8	Surface treatment	asphalt / cement	70	130	2,29	1,84	-3,16	-2,18	2,53	3,61	0,18	-0,35	0,64	-2,81
9	common pavement blocks	blocks	40	60	4,00	6,85	3,33	3,00	5,28	5,07	1,36	1,22	1,03	0,00
10	Silent pavement blocks	blocks	40	60	-2,18	4,42	-1,59	-1,14	0,88	-1,89	-4,78	-3,77	-1,46	-5,72
11	Thin layers 1	asphalt	40	80	-4,21	-1,11	-5,88	-5,59	-1,08	-3,80	-6,67	-5,10	-3,86	-7,24
12	Thin layers 2	asphalt	40	80	-5,71	2,26	-4,47	-4,65	-0,97	-6,42	-8,85	-5,56	-3,13	-6,59
13	ZSA ² - open	asphalt	40	50	-6,64	0,71	-5,84	-5,57	-2,07	-7,37	-9,18	-5,62	-3,65	-10,62
14	ZSA- semi dense	asphalt	40	60	-6,08	0,34	-6,10	-5,81	-1,13	-6,26	-9,76	-7,20	-5,67	-7,10
15	Dubofalt	asphalt	50	60	-6,01	-0,47	-6,22	-5,22	-0,91	-6,98	-8,15	-6,51	-5,09	-3,60
16	Nobelpave	asphalt	40	50	-6,29	-0,32	-6,46	-5,58	-0,84	-6,93	-9,90	-6,76	-5,80	-8,52
17	ZSM ³	asphalt	40	50	-5,76	2,24	-6,04	-5,65	-1,96	-6,15	-7,35	-6,05	-4,92	-8,83
18	Micropave	asphalt	50	80	-4,78	-0,29	-6,29	-5,87	0,23	-5,12	-7,64	-5,88	-4,43	-4,89
19	SilentSTONE	blocks	40	50	-1,43	4,71	-0,59	-0,20	2,51	-1,17	-4,92	-3,14	-1,06	-3,04
20	Viagrip	asphalt	40	50	-6,36	-2,24	-9,01	-8,23	-2,69	-5,91	-9,28	-7,36	-6,32	-13,48

² ZSA is a product name of the company KWS. ZSA stands for "Zeer Stil Asfalt", which means "Very Silent Asphalt"

³ ZSM is a product name of the company Temmink Infra B.V. ZSM stands for "Zeer Stil Mastiek", which means "Very silent mastic"

21	Geosilent	blocks	40	50	-2,93	4,46	-2,55	-2,43	-0,99	-3,09	-3,64	-2,92	-1,56	-8,48
22	Micro-Top 0/6	asphalt	50	60	-5,53	-0,93	-6,95	-6,65	-0,37	-6,09	-8,17	-6,27	-4,69	-5,97
23	Micro-Top 0/8	asphalt	50	70	-2,66	2,64	-5,17	-3,99	0,46	-2,39	-4,78	-2,73	-1,53	-3,36
24	Stilstone	blocks	40	50	-2,61	4,15	-1,68	-0,85	0,65	-2,16	-5,86	-5,2	-2,41	-5,87
26	Redufalt	asphalt	50	60	-4,67	2,54	-5,04	-5,18	-0,15	-4,96	-7,01	-5,81	-5,70	-6,43
27	Accoduit	asphalt	50	80	-1,28	2,35	-4,98	-3,90	1,89	-0,38	-4,50	-4,66	-5,60	-4,67
28	Novachip	asphalt	60	80	-1,41	-1,52	-6,08	-5,35	-0,71	-0,59	-2,63	-2,68	-0,28	-2,63
29	Tapisville	asphalt	40	50	-5,24	4,34	-3,84	-4,28	0,23	-5,74	-9,47	-6,98	-7,09	-9,06
30	Fluisterfalt	asphalt	50	90	-5,36	4,51	-2,6	-2,98	-3,66	-5,44	-6,51	-6,55	-4,93	-6,29
31	Microville	asphalt	40	50	-6,11	-2,69	-7,84	-7,83	-3,86	-5,31	-8,36	-8,73	-7,00	-11,58
32	Microflex 0/6	asphalt	50	80	-4,81	-0,62	-6,42	-6,28	-0,96	-4,69	-7,33	-4,97	-3,80	-3,86
33	Decipave	asphalt	40	60	-5,73	-0,42	-6,96	-5,71	-0,65	-6,34	-8,35	-6,41	-5,29	-6,96
34	Twinlay-m (*)	asphalt	40	50	-6,60	-1,91	-5,36	-6,16	-5,35	-6,20	-8,27	-5,88	-4,17	-5,78
35	Silent Mastic	asphalt	50	60	-5,85	0,78	-6,90	-6,12	-0,29	-6,11	-10,05	-8,76	-7,51	-7,12
36	Bruitville	asphalt	40	60	-4,63	1,75	-4,82	-4,53	0,36	-4,95	-7,88	-5,72	-4,78	-4,89
37	Duolay	asphalt	110	120	-6,65	-3,62	-5,96	-7,28	-5,97	-5,81	-8,74	-6,66	-5,19	-4,27

(*) Also valid for 110 km/h.

Table 11 – Corrections for the road surface to be used in the Dutch noise calculation procedure for medium and heavy vehicles

N°	Product type		Vmin	Vmax	L	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	b
0	Reference surface	asphalt	40	90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1	Single layer porous asphalt	asphalt	70	100	-3,90	-1,60	-6,60	-4,26	-3,09	-4,65	-3,23	-3,39	-2,08	-6,05
2	Double layer porous asphalt	asphalt	70	100	-6,28	-5,54	-6,99	-6,82	-6,23	-6,27	-5,90	-5,98	-6,03	1,02
3	Double layer porous asphalt (fine)	asphalt	50	90	-5,66	-4,31	-6,46	-6,99	-6,08	-5,03	-5,89	-5,26	-5,87	-6,08
4	SMA 0/6	asphalt	50	70	-0,92	-0,79	-5,79	-3,93	-0,98	-0,76	-0,09	0,03	1,13	-3,33
5	Exposed aggregates cement concrete	cement	70	100	-0,64	-1,10	-6,10	-5,18	-0,80	0,27	-0,72	-1,49	-1,61	7,01
6	Exposed aggregates cement concrete (optimized)	cement	70	80	-1,97	-4,74	-6,20	-7,30	-1,78	-1,18	-2,40	-2,04	-2,29	-4,01
7	Finely brushed cement	cement	70	90	1,44	1,11	-3,89	-3,14	1,37	2,45	1,19	-0,29	-0,61	6,26
8	Surface treatment	asphalt / cement	70	100	-0,70	-0,13	-5,13	-3,76	0,46	-0,27	-2,05	-2,29	-2,31	4,27
9	Common pavement blocks	blocks	40	60	4,00	6,85	3,33	3,00	5,28	5,07	1,36	1,22	1,03	0,00
10	ilent pavement blocks	blocks	40	60	-0,01	5,71	-0,30	0,15	2,17	-0,60	-3,50	-2,48	-0,18	0,00
11	Thin layers 1	asphalt	40	80	-1,73	0,64	-4,14	-3,84	0,66	-2,05	-4,92	-3,35	-2,11	0,00
12	Thin layers 2	asphalt	40	80	-3,36	3,17	-3,55	-3,74	-0,06	-5,51	-7,94	-4,65	-2,22	0,00
14	ZSA ⁴ -semi dense	asphalt	50	60	-4,25	-3,06	-5,04	-4,02	-2,71	-4,93	-5,51	-4,16	-4,59	0,18
34	Twinlay-m	asphalt	80	80	-5,98	-5,89	-6,47	-7,12	-6,74	-5,44	-5,71	-5,20	-5,84	-1,73

⁴ See note ².

10. Portugal

There is no such classification in Portugal for the moment. Wherever needed and whenever possible, for noise limitation purposes, they use porous asphalt, rubber modified mixes or conventional asphalt mixes with minimal texture and roughness [17].

11. Slovenia

For taking the influence of road surfaces on traffic noise emission, they use the regulation that defines the method of evaluation of traffic noise impact on the environment [18]. The method is entirely based on German guidelines RLS – 90, according to which the corrections listed in table 12 have been determined.

Table 12 – Road surface corrections specified in the Slovenian method for evaluating traffic noise impact on the environment [18, 19]

Surface types	Correction (dBA)
Porous asphalt	-3
Stone mastic asphalt	-2
New asphalt concrete	0
Asphalt concrete with bigger chipping sizes	+2
Old cement concrete	+3
Flat paving stones	+3
Damaged stone paving	+6

From a subsequent measurement campaign covering Surface dressings, SMA's, Porous asphalts and Dense asphalts [20], it appears that the correction is fairly well confirmed for SMA but not for PA, the noise-reducing performance of which is significantly underestimated by the guidelines (table 13).

Table 13 – Comparison between subsequent measurement results and guidelines

Speed (km/h)	AC	SD	SD-AC	SMA	SMA-AC	PA	PA-AC
50	71,7	70,4	-1,3	69,1	-2,6	65,7	-6,0
70	77,4	75,8	-1,6	75,2	-2,1	70,5	-6,8
90	80,7	79,0	-1,7	78,7	-2,0	73,5	-7,2
110	83,0	81,2	-1,8	81,3	-1,7	75,5	-7,5
Nr. of sections	12	1		16		2	
Average			-1,6		-2,1		-6,9
Guideline			N.A.		-2,0		-3,0

12. Spain

There is no specific regulation about road surface influence on traffic noise. However, there are some mentions in two standards, namely:

- The standard about rehabilitation of pavements for the Road State Network [21] includes a paragraph in the section about resurfacing. It says that, in case the rolling noise should be reduced, it is possible to use porous asphalt or some SMA, always taking into account the other surface characteristics of these mixes.
- The standard for designing pavements in the Andalusia Region Road Network [22] says that, although in general it's not advisable to use porous asphalt (because of climatic constraints), they can be used in urban areas with AADT>2000 vehicles/day if noise reduction is needed.

Correction terms for road surface "noisiness" in calculations (noise mapping) have been proposed [23] (table 14).

Table 14 – Proposed noise corrections for road surfaces in Spain

Surface types	Correction (dBA)		
	0-60 km/h	61-80 km/h	81-130 km/h
Porous asphalt	-1	-2	-3
Smooth asphalt concrete	0	0	0
Cement concrete	2	2	2
Rough asphalt concrete	3	3	3
Bald paving blocks	3	3	3
Harsh paving blocks	6	6	6

Now, measurements of rolling noise using the CPX method are underway. In the future, they are planning to start a research about the absorption measurement of different kind of pavements using MLS⁵ techniques.

13. Switzerland

The Swiss noise calculation model "SonRoad" includes corrections for the road surface as in table 15 [24].

⁵ "Maximum Length Sequences" according to ISO 13472-1 [36].

Table 15 – Corrections for the road surface in the Swiss “SonRoad” calculation model

Surface type	Correction (dBA)
Porous asphalt (0/8, 0/11)	-4
« Macro-rough » asphalt ⁶ (0/8, 0/11)	-1
Asphalt concrete (0/8, 0/11, 0/16) Mastic asphalt (0/8, 0/11, 0/16) Surface dressing (3/6) Stone mastic asphalt (0/8, 0/11) Grainy asphalt mix ⁷ Asphalt mix added with tar ⁸ (0/10)	0
Surface dressing (6/11) Asphalt mix added with tar (0/16)	+1
Sett paving	+6

Table 15 is said to be valid for pavements between 3 and 20 year old. It is warned that the correction for the sett paving applies to tyre/road noise only while the other corrections are for the global vehicle noise. In our opinion, tyre/road noise anyway determines the global noise level in this case.

14. United Kingdom

In the method used in the U.K., termed CRTN, the correction is expressed as follows [25]:

For roads which are impervious to surface water and where the traffic speed (V) is >75 km/h the following correction to the basic noise level is required:

for concrete surfaces: $Correction = 10 \log (90 TD + 30) - 20 \text{ dB(A)}$ (4)

for bituminous surfaces: $Correction = 10 \log (20 TD + 60) - 20 \text{ dB(A)}$ (5)

where TD is the texture depth measured by the sand-patch test. It means that the CRTN needs access to a measured or predicted texture depth.

For road surfaces and traffic conditions which do not conform to these requirements a separate correction to the basic noise level is required. For impervious bituminous and concrete road surfaces, 1 dB(A) should be subtracted from the basic noise level when the traffic speed (V) is <75 km/h. Roads surfaced with pervious macadams have different acoustic properties from the surfaces described above. For roads surfaced with these materials, 3.5 dB(A) should be subtracted from the basic noise level for all traffic speeds.

⁶ “Asphalt macro-rugueux”

⁷ “Enrobé bitumineux grenu”

⁸ “Enrobé avec adjonction de goudron”

Later on, “the introduction of new proprietary and the failure of previous empirical relationship to accurately predict noise levels from measurements of road surface characteristics has led to the consideration of direct measurement of noise” [26]. This has been implemented in the HAPAS⁹ type approval system, according to which the influence of the road surface on traffic noise is determined using the SPB method. The result is expressed in terms of Road Surface Influence as follows:

$$RSI_H = 10\log_{10}\left(7.8 \times 10^{\frac{L_{veh,L}}{10}} + 0.578 \times 10^{\frac{L_{veh,H1}}{10}} + 10^{\frac{L_{veh,H2}}{10}}\right) - 95.9 \quad (6)$$

for high speeds, and

$$RSI_M = 10\log_{10}\left(11.8 \times 10^{\frac{L_{veh,L}}{10}} + 0.629 \times 10^{\frac{L_{veh,H1}}{10}} + 0.157 \times 10^{\frac{L_{veh,H2}}{10}}\right) - 92.3 \quad (7)$$

for medium speeds.

15. USA

In the Traffic Noise Model (TNM) used in the USA, the road surface correction is presented in table 16 [27]. A mix of DAC and PCC constitutes the reference surface. The same correction applies for all speeds.

Table 16 - Correction in the US TNM model in dB(A) compared to the reference case

	Automobiles	Medium trucks & busses	Heavy trucks	Motorcycles
Reference: A mix of DAC and PCC surfaces	0	0	0	0
Dense asphalt concrete	-0.65	-0.64	-0.59	0
Portland Cement Concrete	+2.36	+1.47	+0.72	0
Open-graded asphalt	-2.20	-1.15	-1.66	0

16. Nordic countries

Since first introduced in the 1970's, the five Nordic countries (Sweden, Denmark, Norway, Finland and Iceland) have had a common prediction model. The latest one is from 1996 [28] and has an optional road surface correction according to table 17. This correction comes from [29] where its background is also described (see also [35]).

A new model called Nord2000 is presently being developed. It is scheduled to be completed by 31 March 2006. The newest version of the source model [Source modelling report 060102, only for distribution between project partners] is very brief concerning road surface characterisation. The road categories will be as in table 18 [30]. This means that the very detailed list in the 1996 version will be replaced with a less detailed one.

⁹ Highway Authorities Product Approval Scheme.

Table 17 - Road surface correction table in the Nordic model, version 1996

Road surface			Correction term in dB(A) for a certain % of heavy vehicles							
N°	Type (max. chipping size also indicated here)	Age [year]	0-60 km/h			61-80 km/h			81-130 km/h	
			0-5 %	6-19 %	20-100 %	0-5 %	6-19 %	20-100 %	0-5 %	6-100 %
1.a	Asph. concr., dense, smooth (### 12-16 mm)	1-20	ref	ref	ref	ref	ref	ref	ref	ref
1.b	Do. newly laid	<1	0	0	-1	-2	-1	-1	-2	-2
2.a	Asph. concr., dense, smooth (### 8-10 mm)	1-20	0	0	0	-1	0	0	-1	-1
2.b	Do. newly laid	<1	-1	-1	-1	-2	-1	-1	-2	-2
3.a	Mastic asphalt (max 12-16 mm)	1-20	0	0	0	+1	0	0	+1	0
3.b	Do. newly laid	<1	0	0	0	+1	0	0	+1	0
4.a	Mastic asphalt (max 8-10 mm)	1-20	-1	-1	0	-1	-1	-1	-1	-1
4.b	Do. newly laid	<1	-2	-1	0	-2	-2	-1	-2	-2
5.	Chipped asphalt (BCS) ("hot rolled asph.")	0-20	+1	0	0	+2	+1	0	+2	+1
6.a	Chip seal, single (Y1), max 16-20 mm	1-20	+1	0	0	+2	+1	0	+2	+1
6.b	Do. newly laid	<1	+2	+1	0	+3	+1	-1	+2	+1
7.a	Chip seal, single (Y1), max 10-12 mm	1-20	0	0	0	0	0	0	0	0
7.b	Do. newly laid	<1	0	0	0	0	0	-1	0	0
8.a	Chip seal, single (Y1), max 6-9 mm	1-20	0	0	0	-1	0	0	-1	0
8.b	Do. newly laid	<1	-1	0	0	-1	-1	-1	-1	-1
9.a	Chip seal, double (Y2), max 16-20 mm	1-20	0	0	0	+1	0	-1	0	0
9.b	Do. newly laid	<1	+1	0	0	+1	0	-2	0	0
10.a	Chip seal, double (Y2), max 10-12 mm	1-20	0	0	0	0	0	-1	0	-1
10.b	Do. newly laid	<1	0	0	0	0	-1	-2	0	-1
11.a	Porous asph., max 14-16mm (###20%voids)	3-7	0	0	0	-1	-1	-1	-1	-1
11.b	Do. "medium aged"	1-2	-1	-1	0	-1	-1	-1	-1	-2
11.c	Do. newly laid	<1	-2	-2	-2	-2	-2	-3	-2	-3
12.a	Porous asph., max 8-12 mm (###20% voids)	3-7	0	0	0	-1	-1	-1	-2	-2
12.b	Do. "medium aged"	1-2	-1	-1	-1	-2	-2	-2	-3	-3
12.c	Do. newly laid	<1	-3	-3	-3	-4	-4	-5	-5	-5
13.	Cem. concr., dense, smooth ### 20-80 mm	0-40	+2	+1	+1	+2	+2	+2	+2	+2
14.	Cem. concr., dense, smooth, ### 12-18 mm	0-40	+1	+1	+1	+2	+2	+2	+2	+2
15.	Cem. concr., ground (grinding not worn)	0-5	-1	-1	-1	-2	-2	-2	-1	-1
16.	Paving stones, cobble stones (older type)	0-90	+3	+3	+2	+5	+4	+3	+5	+4
17.	Cement block pavement (interlocking)	0-20	0	0	0	0	0	0	0	0

Table 18 - Road categories in the Nord2000 model

Main category	Sub category	Name
1	1a	Asph. concr., dense, smooth ($\leq 12-16$ mm)
	1b	Asph. concr., dense, smooth ($\leq 8-10$ mm)
2	2a	Mastic asphalt (SMA) (max 12-16 mm)
	2b	Mastic asphalt (SMA) (max 8-10 mm)
3	3a	Chipped asphalt (BCS) ("hot rolled asph.")
	3b	Chip seal, single (Y1), max 16-20 mm
	3c	Chip seal, single (Y1), max 10-12 mm
	3d	Chip seal, single (Y1), max 6-9 mm
4	4a	Chip seal, double (Y2), max 16-20 mm
	4b	Chip seal, double (Y2), max 10-12 mm
5	5a	Porous asph., max 14-16 mm (≥ 20 % voids)
	5b	Porous asph., max 8-12 mm (≥ 20 % voids)
6	6a	Cem. concr., dense, smooth max 20-80 mm
	6b	Cem. concr., dense, smooth, max 12-18 mm
	6c	Cem. concr., ground (grinding not worn)
7		Paving stones, cobble stones (older type)
8		Cement block pavement (interlocking)

17. HARMONOISE

Since the reference surface type must be one that is reasonably common in each member state, and states have different preferences and policies, it is impossible to define one and only one reference surface. Instead, it is proposed to define a "cluster" of reference surfaces having fairly similar noise characteristics. These are consistent with ISO 11819-1 [37] and are as follows:

DAC 0/11, DAC 0/12, DAC 0/13, DAC 0/14, DAC 0/16
SMA 0/11, SMA 0/12, SMA 0/13, SMA 0/14, SMA 0/16

A "Golden reference" is defined within this reference cluster, which is the ideal reference surface on which the basic values of HARMONOISE are based. It is (basically) close to a DAC 0/13 or an SMA 0/13. Then, depending on the actual reference surface used in a particular country and in a particular situation, one may make small corrections that normalize the actually chosen reference surface to the "Golden reference". See further another technical report within HARMONOISE, dealing specifically with this issue [31]. The HARMONOISE engineering method for predicting road traffic noise [39] gives the noise emission from vehicles on the standard reference at standard temperature while road surface corrections are given in appendix for the following surfaces:

- PA 6/16
- 2 layer PA
- transversely brushed concrete
- exposed aggregate concrete
- SMA 0/6
- surface dressing 1/3
- paving stones
- HRA 20
- block paving.

18. SILVIA

In SILVIA, the proposed classification system [33] identifies specific measurement procedures necessary for labelling the acoustic performance of a road surface. There are two possible labelling procedures:

LABEL1 (preferred): Assessment based on SPB and CPX measurements;

LABEL2: Assessment based on SPB measurements and measurements of intrinsic properties of the road surface, e.g. texture and sound absorption (plus mechanical impedance if relevant).

Both noise labels are based on SPB measurements. However, due to the limitations of the SPB method in assessing only a small section of a road section, additional measurements to assess the acoustic performance over the full length of the trial section is required. LABEL1 includes a direct assessment of noise over the entire length of the trial surface using the CPX method and is the preferred method. LABEL2 allows for an indirect assessment based on measurements of the intrinsic properties of the surface which can be related to the generation and propagation of noise e.g. texture and sound absorption.

For the purposes of assessing conformity-of-production (COP), surfaces with a noise LABEL1 certification are to be assessed using the CPX method, whereas surfaces with a noise LABEL2 certification are assessed according to the relevant measurement of the intrinsic properties of the surface used in deriving the noise label.

Table 19 summarises the recommended method of assessment for noise labelling and Table 20 summarises the recommended method for assessing COP.

Table 19 - Recommended labelling system for assessing the acoustic performance of different types of road surfaces - Determining the noise label

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

Table 20 - Recommended labelling system for assessing the acoustic performance of different types of road surfaces - Assessing COP

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

“Rigid” surfaces are defined as normal asphalt and concrete, i.e. being much stiffer than tyres.

19. Conclusions

Across countries, the names of the different surfacing materials and techniques are not always comparable or translatable. In the Dutch and Swiss tables (Tables 10, 11, 15), the surfacing types have been translated by us. In all other tables, the categories are as given in English in the source documents. The comparison is still more difficult when proprietary names are used.

When the comparison seems possible, like between popular materials and technologies like DAC, PA, SMA, EACC for instance, the rankings are in general poorly consistent as table 21 shows.

Table 21 – Comparison between rankings of “popular” surfacing types.

Country	Reference	SMA-DAC	PA-DAC	EACC-DAC	Remarks
AT	Table 1		-1	0	Light veh. 50 km/h
AT	Table 2	-3.4 / -1.4	-3.3 / -1.3	-2.0 / 0.0	SPBI
AT	Table 2	-3.7 / +0.3	-1.5 / -0.3	-2.8 / -1.0	LMA
FR	Tables 3&4		-3.9		All 0/10 mm. Light veh. 90 km/h
FR	Tables 3&4		-3.5		All 0/10 mm. Light veh. 50 km/h
DE	Table 5a	0			30-50 km/h
DE	Table 5b	0.0	-2.0		All 0/11 mm. > 60 km/h
HU	Table 6	+2.9			All 0/12 mm
IT	Table 7		-1.4		
JP	Formula 1		-2.7		All 0/13 mm. 50 km/h
JP	Formula 1		-3.6		All 0/13 mm. 90 km/h
NL	Table 10		-2.61	-0.07 / +1.42	Light veh.
SI	Table 12	-2	-3		
SI	Table 13	-2.1	-6.9		
ES	Table 14		-1		< 60 km/h
ES	Table 14		-3		> 80 km/h
CH	Table 15	0	-4		
US	Table 16		-1.55		Light veh.
NO	Table 17	0 / +1	-1 / 0		All max. 16 mm. Light veh.

However, when there is a reference surface, it is consistently a dense asphalt concrete or a combination of DAC and some other common surface like in USA and in the HARMONOISE proposal.

There is also a lack of comparability between different classifications due to the use of different measurement and evaluation methods. In that respect it is to be highlighted that CPX and SPB are not equivalent as the Austrian data show in table 2. See also [33].

Although, in some cases, the ranking is given for different speeds including low speeds, in general, it is not clear whether it also applies to urban conditions where not only low speeds but also low gear settings are used. In addition, when a ranking is given in terms of an index including a certain proportion of heavy vehicles like with SPBI or L_{eq} , the ranking could obviously not be adapted to urban conditions.

Among the factors that influence the precision of the classification, we can quote the variability of road surfacing materials mainly regarding texture depending on the characteristics of ingredients, laying circumstances, characteristics of traffic and climatic effects on ageing, etc. With those remarks in view, it seems questionable whether the two decimals given in the Dutch and American tables (Tables 10, 11, 16) have any significance. Even the first decimal is probably not significant either, unless it is rounded to the closest half unit. Actually, nowhere is the precision stated except in the procedures proposed by SILVIA where tolerances are indicated on the Labelling and COP results (not reported here; see [33]).

This review was intended to collect information on how to classify road surfaces with respect to noise, with particular focus on urban conditions. From that standpoint, considering the remarks made here above, we can conclude that until the procedures proposed by SILVIA are applied routinely, the figures reported here could be used as default values for comparable surfacing types. However, the classifications reported here are generally based on data collected several years ago. In the meantime, other technologies like thin layers have become popular, often under proprietary names as in the Dutch classification (Tables 10&11), which can moreover be different across borders. So, there is a need for supplementing the tables in that respect. In addition, since urban conditions are probably not well represented by the available classifications, there is a need for extending the data base to urban conditions including low speeds and low gear settings. This will require adapting also the measurement method.

20. References

[1] "Adaptation and revision of the interim noise computation methods for the purpose of strategic noise mapping". Two reports within the main title are of interest here, namely "Final draft report" and "Road Traffic Noise – Noise emission: databases". Contract B4-3040/2001/329750/MAR/C1, European Commission, DG Environment, Brussels.

[2] "Baudurchführung – Grundlagen – Prüfverfahren – Feldprüfungen – Rollgeräuschmessung", RVS 11.066, Bauministerium für Wirtschaftliche Angelegenheiten, Wien, April 1997.

- [3] HAIDER M., "Rollgeräuschmessung – Optimierung von erfahrung und Grenzwerten", Strassenforschung 3.277, Endbericht, Arsenal Research, Wien, 2004.
- [4] "Guide du Bruit des Transports Terrestres – Prévision des niveaux sonores". Ministère de l'Environnement et du Cadre de Vie/Ministère des Transports/CETUR, Novembre 1980.
- [5] BESNARD F. et al., "The procedure for updating the vehicle noise emission values of the French « Guide du Bruit »", EURONOISE, Naples, 2003.
- [6] BESNARD F. et al., "The procedure for updating the vehicle noise emission values of the French « Guide du Bruit des Transports Terrestres»", Ministère de l'Équipement, des Transports, du Logement, du Tourisme et de la Mer, Note Technique, Paris, Novembre 2002.
- [7] "Richtlinien für den Lärmschutz an Strassen (RLS-90)". Ausgabe 1990, Bundesministerium für Verkehr, Postfach 210360, 5000 Köln 21, Germany.
- [8] "Verfahren zur Messung der Geräuschemission von Strassenoberflächen (GESTrO-92)", Anlage zum ARS 16/1992, Der Bundesminister für Verkehr, 1992.
- [9] "Decree on the content- and form-related requirements for strategic noise maps serving for the assessment and management of environmental noise as well as the calculation and investigation methods implemented for the preparation of strategic noise maps", Hungarian Ministry of Environment and Water, Guidelines 25/2004 (XII.20).
- [10] <http://pcangelo.eng.unipr.it>.
- [11] TACHIBANA, H., "Road traffic noise prediction model 'ASJ Model 1998' proposed by the Acoustical Society of Japan - Part 1: Its structure and the flow of calculation". Proc. of INTER-NOISE 2000, Nice, France.
- [12] OSHINO, Y.; KONO, S.; OHNISHI, H.; SONE, T.; TACHIBANA, H., "Road traffic noise prediction model 'ASJ Model 1998' proposed by the Acoustical Society of Japan - Part 2: Calculation model of sound power levels of road vehicles". Proc. of INTER-NOISE 2000, Nice, France.
- [13] "Reken- en Meetvoorschrift Verkeerslawaaï", Regeling als bedoelt in artikel 102, 1ste en 2de lid, van de Wet geluidhinder, Den Haag, Sdu, 1981.
- [14] EIJBENSEN et al.: « De methode Cwegdek 2002 voor wegverkeersgeluid », Publicatie 200, CROW, Ede (NL), April 2004.
- [15] <http://www.stillerverkeer.nl>.
- [16] JEZIERSKA D., Private communication, 2005.
- [17] « Clasificacion acustica de pavimentos », Ministerio das obras publicas, transportes e comunicaçoes, Gabinete de ambiente, Nota tecnica, Almada, Portugal, 2005.
- [18] Slovenian Official Gazette n°45:1995.

- [19] Slovenian Technical Specification TS 06.640:2003.
- [20] RAMSAK M., KOKOT D., TUŠAR M.: "Comparative study of traffic noise emission for characteristic types of asphalt mixtures in Slovenia", SIIV 2004, "New technologies and model tools for roads", Firenze, 27-29 October 2004.
- [21] "Rehabilitación de Firmes", Norma 6.3 IC, Ministerio de Fomento, Dirección General de Carreteras, Madrid (Spain), December 2003.
- [22] « Instrucción para el Diseño de Firmes de la Red de Carreteras de Andalucía », Junta de Andalucía, Consejería de Obras Públicas y Transportes, Dirección General de Carreteras, Andalucía (Spain), 1999.
- [23] ALFÈREZ J.R., ECHAZARETTA F. S., MATEOS M.D.J. : « Elaboracion de mapas estrategicos de ruido de carreteras », RUTAS, Nov.-Dec. 2004.
- [24] HEUTSCHI K., « SonRoad – Modèle de calcul du trafic routier », Cahier de l'Environnement n°366, OFEFP, Berne, 2004.
- [25] "Calculation of Road Traffic Noise", Dept. of Transport, Welsh Office, HMSO, London, U.K., 1988.
- [26] PHILLIPS S., KOLLAMTHODI S., MORGAN P.A., "Classification of low noise road surfacings", INTERNOISE 2001, The Hague, Netherlands, 27-30 August 2001.
- [27] SANDBERG U., "Road Surface Categorization and Correction in HARMONOISE – Basic Considerations", Final Technical Report, HAR11TR-030116-VTI05, 2003.
- [28] "Road Traffic Noise - Nordic Prediction Method (TemaNord) ". Report 1996:525, Nordic Council of Ministers, Copenhagen, Denmark, 1996.
- [29] SANDBERG U., "Korrigerering i den nordiska trafikbullermodellen för inverkan av vägyta". VTI Meddelande 706, Swedish National Road and Transport Research Institute (VTI), Linköping, 1993.
- [30] JONASSON, H.G.; STOREHEIER, S.Å., "Nord 2000. New Nordic Prediction Method for Road Traffic Noise". SP Report 2001:10, Swedish National Testing and Research Institute (SP), Borås, Sweden, 2001.
- [31] SANDBERG U., "Considerations with regard to reference surface in HARMONOISE", Technical Report, HAR11TR-030715-VTI01, 2003.
- [32] SANDBERG U., "Low-noise road surface classification and procurement system in Japan", Private communication, 30/06/2005.
- [33] SILVIA, "Guidance manual for the implementation of low-noise road surfaces", BRRC, Brussels (in preparation).
- [34] "Allgemeines Rundschreiben Straßenbau, ARS Nr. 14/1991", Der Bundesminister für Verkehr, 1991.

[35] Sandberg U., Ejsmont J., "Tyre/Road Noise Reference Book", INFORMEX, Harg, SE-59040, Kisa, Sweden (2002).

[36] "Acoustics -- Measurement of sound absorption properties of road surfaces in situ -- Part 1: Extended surface method", ISO 13472-1:2002.

[37] "Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 1: Statistical Pass-By method", ISO 11819-1:1997.

[38] "Acoustics -- Measurement of the influence of road surfaces on traffic noise -- Part 2: Close-proximity method", ISO/CD 11819-2: 2001.

[39] "Engineering method for road traffic and railway noise after validation and fine-tuning", Technical Report HAR32TR-040922-DGMR20 (Deliverable D18), 20 January 2005 (<http://www.imagine-project.org>).