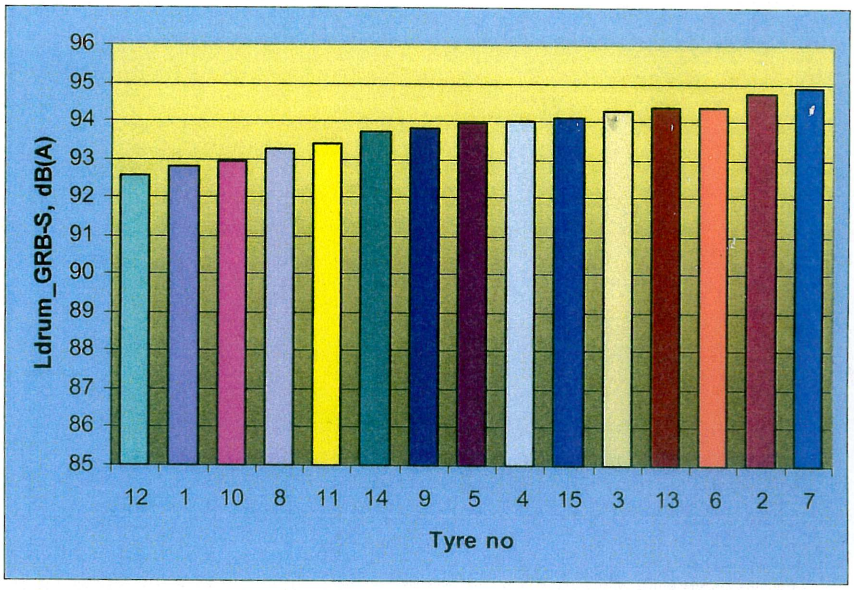
SINTEF A11729

REPORT



Noise ranking of car tyres. Results from road measurements, *SPERoN* modelling and drum measurements.

Truls Berge, Frode Haukland, Asbjørn Ustad

SINTEF ICT

Acoustics

May 2009

www.sintef.no

SINTEF

SINTEF	# SINTEF REPORT
SINTEF ICT Address: NO-7465 Trondheim, NORWAY Location: S P Andersens v 15 NO-7031 Trondheim Telephone: +47 73 59 30 00 Fax: +47 73 59 43 02 Enterprise No.: NO 948 007 029 MVA	TITLE **Noise ranking of passenger car tyres. Results from road measurements, *SPERoN* modelling and drum measurements.** AUTHOR(S) Truls Berge, Frode Haukland, Asbjørn Ustad CLIENT(S) Statens vegvesen, Vegdirektoratet, Statens forurensningstilsyn, Norges forskningsråd

REPORT NO.	CLASSIFICATION	CLIENTS REF.	
SINTEF A11729	Open	Jannicke Sjøvold, Ingunn Milford, Jan Boe Kielland	
CLASS. THIS PAGE	ISBN	PROJECT NO.	NO. OF PAGES/APPENDICES
Open	978-82-14-04441-6	90E284/90E306/90E266	66
ELECTRONIC FILE CODE		PROJECT MANAGER (NAME, SIGN.)	CHECKED BY (NAME, SIGN.)
SINTEFA11729.doc		Truls Berge	Svein Å.Storeheier
FILE CODE	DATE	APPROVED BY (NAME, POSITION, SIGN.)	
	2009-05-28	Odd Kr.Ø.Pettersen, Research Director	

ABSTRACT

The rolling noise of a selection of passenger car tyres has been investigated using 3 different approaches:

- CPX-measurements (17 tyres)
- The use of the *SPERoN* model (34 tyres)
- Laboratory drum measurements (15 tyres)

The main object was to rank tyre/road noise levels of the tyres on typical Norwegian road surfaces and compare the ranking with levels on an ISO-surface.

The main results show that the operational conditions for the three approaches are too different to make it possible to find any good correlations, based on linear regression of overall dB(A)-levels only. In addition, the spread in levels are rather small, which also could influence the correlation analysis.

CPX-measurements are used for the ranking of 17 tyres, and the results show a variation of ***2-4 dB(A)*** at 50 and 80 km/h, on a selection of dense and porous surfaces. The majority of the tyres (12 out of 17) has an average noise level, ± 0.5 dB(A), on the road surfaces included in the measurement program.

Shore hardness and rolling resistance have been measured on 15 of the tyres and correlated to noise levels.

It is recommended to include measurements on an ISO-track in future investigations, in order to be able to evaluate the effect of the new noise limits in the revised EU tyre noise directive for Norwegian conditions and the effect of noise labelling of tyres.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Acoustics	Akustikk
GROUP 2	Noise	Støy
SELECTED BY AUTHOR	Passenger car tyres	Personbildekk
	Measurements	Målinger
	Modelling	Modellering

TABLE OF CONTENTS

Foreword

This project has been jointly financed by the Norwegian Public Roads Administration, the State Pollution Agency (SFT) and the Norwegian Research Council through the research program “Environmental Noise Phase III”.

Contact persons at the Roads Administration have been Jannicke Sjøvold and Ingunn Milford. Contact person at SFT has been Jan B.Kielland.

Research Scientist Truls Berge has been the project leader. Senior engineer Asbjørn Ustad and engineer Frode Haukland have been responsible for the noise measurements.

Subcontractors to the project have been:

MüllerBBM (Germany), in collaboration with Chalmers University (Sweden): *SPERoN* modelling. Contact persons: Dr. T. Beckenbauer (MüllerBBM) and Prof. W.Kropp (Chalmers).

TUG (Poland): Drum measurements. Contact person: Dr. J. Ejsmont.

Summary

A wide range of widely used passenger car tyres have been investigated for rolling noise behaviour on 3 different operational modes:

- *SPERoN* modelling (34 tyres)
- CPX-measurements (17 tyres)
- Laboratory drum measurements (15 tyres)

Based on overall A-weighted noise levels, there seems to be no significant correlation between the CPX-measurements and *SPERoN* modelling results, or between CPX and drum measurements or drum measurements and modelling results. However, one should be aware of that this lack of correlation is based on small differences in levels, within the uncertainty of the *SPERoN* model.

Within each of the 3 modes, it is possible to rank tyres according to the rolling noise with a reasonable accuracy. However, it seems difficult to use either the modelling mode or the drum measurements to rank the tyres on real road surfaces used in Norway. ***Noise measurements,*** either by CPX or by coast-by measurements (type approval conditions) seems to be more appropriate for this purpose.

The CPX-measurements reported indicate a noise variation of between ***2-4 dB(A)*** for the most frequently used tyres. The majority of the tyres seem to have average noise levels and thus very few of the tested tyres can be categorised either as low noise tyres or noisy tyres on typical Norwegian road surfaces.

The ranking of the tyres based on CPX-results are more or less the same on all the road surfaces included in this project and being exposed to winter conditions and studded tyres.

The ranking is more or less the same at 50 and 80 km/h.

On new, quiet road surfaces, the ranking is somewhat different for some of the tyres. The spread in the levels is somewhat higher on the older surfaces (3-4 dB(A)), than on the new surfaces (approx. 2.5 dB(A).

The noise measurements on a replica of the ISO-surface on the drum facilities of TUG in Poland, show a difference in noise levels of 2-3 dB(A), which is in the same order as for CPX-measurements on smooth SMA-surfaces. The ranking of the tyres on 3 different replicas of road surfaces in the drum is very much depending on the type of surface.

The ranking of tyres based on the *SPERoN* model is quite consistent, independent of road surface. However, some tyres shift in ranking when the speed is changed from 50 to 80 km/h.
The spread in levels are much higher than for CPX and drum measurements; in the order of 8-9 dB(A) on the modelled ISO-surface (Sperenberg) at 80 km/h.

Slick tyres are not the most silent tyres, when modelled on the SMA-surface and on the ISO-surface.

Measurements of rolling resistance measured on the TUG-facilities show that the absolute values of the rolling resistance is higher on a rough surface, than on a smooth, but the variation of the values is the same within the each of the surfaces. Tyre design parameters are clearly influencing the rolling resistance. The correlation between the rolling resistance on the smooth surface and CPX-measurements on a quiet porous surface is negative.

The use of linear regression for comparison of overall dB(A)-levels has proved to be of limited use, since the tyre/road noise generation mechanisms are in general non-linear. The use of 1/3rd octave band frequency components as an alternative is recommended, when comparison between CPX and modelling results are performed.

A further investigation of the relationship between CPX and coast-by measurements is recommended, including measurements on a real ISO-surface.

1 Introduction

The importance of tyre/road noise as a major contribution to the general traffic noise levels is well established.
To reduce tyre/road noise one can both introduce quieter tyres and quieter road surfaces.
The noise of tyres is regulated by the EU-directive 2001/43/EC[1]. The directive is currently under revision and stricter noise limits are likely to be introduced from 2012.
Type approval of tyres with respect to noise is performed on an ISO-track[2]. This is in principle a dense asphalt surface with maximum chipping size of 8 mm. It was developed in the early nineties as a surface for type approval of noise from accelerating vehicles, with a low influence of the rolling noise. The ISO-surface can be considered as a relatively low noise road surface.

However, in Norway, the most common road surfaces are of SMA (stone mastic asphalt) or DAC (dense asphalt concrete) types with maximum chipping sizes in the range of 11-16 mm. In addition, the use of studded tyres during the winter season introduces a rougher texture and a higher tyre/road noise than on similar types of pavements in other European countries, where studded tyres are banned.

Since the normal used road surfaces differ quite much from the ISO-surface, it is of concern that noise labelling of tyres and a possible use of economic incentives will be less effective for Norwegian conditions to reduce road traffic noise.

The aim of this project was to investigate the noise ranking of a selection of passenger car tyres on typical Norwegian road surfaces, as well as some potential low noise road surfaces. To compare the ranking of the tyres with noise levels on ISO-surfaces with the noise on Norwegian road surfaces, three separate approaches were chosen:

1) CPX-measurements
2) Modelling of the tyre/road noise, by using the *SPERoN* model
3) Drum measurements by TUG/Gdansk in Poland

The reason to use these approaches was to see if it was possible to use a simpler and more economical way to establish the ranking on ISO-surfaces and the ranking on our surfaces, without having to do complete coast-by measurements according to the EU-directive. This directive requires measurements with 4 sets of each of the tyres mounted on one or more passenger cars (depending on the dimensions of tyre and rim). By using any of the three approaches, only one tyre of each type was necessary. In addition, CPX-measurements can be done without closing down road sections, and is also less influenced by passing vehicles (background noise).

It has not been the intention of this work to do a scientific study of the different approaches ability to describe generation mechanism of tyre/road noise in a realistic way, and thus to be able to compare all parameters influencing these mechanisms in a full frequency range; e.g. tread pattern, road texture, rolling speed, microphone positions, temperature, tyre load, etc.

2 Tyres

A total of 40 passenger cars are included in this investigation. Table 1 show an overview of the technical information of the tyres, with age (production week/year) and shore hardness for those of the tyres where this information is available.

Table 1 *Tyres and technical data*

Tyre no	Name	Dimensions	Load/ Speed index	Prod. week/ year	Shore hardness – Tread Shore A	Meas.
1	**Dayton D110**	**175/70 R14**	84 T	1207	68	Sep-08
2	**Sportiva G70**	**175/70 R14**	84 T	0307	65	Sep-08
3	**Barum Brilliantis**	**185/65 R15**	88 T	1607	67	Sep-08
4	**Toyo 330**	**185/65 R15**	88 T	4705	70	Sep-08
5	**Goodyear Excellence**	**195/65 R15**	91 H	0206	69	Sep-08
6	**Conti Premium Contact 2**	**195/65 R15**	91 V	0307	70	Sep-08
7	**Toyo Proxes T1R**	**205/55 R16**	91 W	1407	69	Sep-08
8	**Nokian Hakka H**	**205/55 R16**	94 H	3407	69	Sep-08
9	**Michelin Pilot Primacy HP**	**215/55 R16**	93 H	0206	68	Sep-08
10	**Firestone Firehawk TZ200**	**215/55 R16**	97 H	1007	66	Sep-08
11	**Conti EcoContact 3**	**195/65 R15**	91 T	0706	71	Sep-08
12	**Yokohama dB V500**	**185/65 R15**	92 H	1604	73	Sep-08
13	**Michelin Energy Saver**	**205/65 R15**	94 T	1508	66	Sep-08
14	**Hankook Ventus Prime K105**	**205/65 R15**	95 W	5207	67	Sep-08
15	**Pirelli P7**	**205/65 R15**	94 V	0707	64	Sep-08
16	**Conti CH90**	**195/65 R15**	-	-	-	-
17	**Pirelli P600**	**205/60 R15**	-	-	-	-
18	**Michelin Energy E3A**	**195/60 R15**	-	-	-	-
19	**Goodyear GT3**	**175/65 R14**	-	-	-	-
20	**Michelin Energy**	**175/65 R14**	-	-	-	-
21	**Pirelli P3000 Energy**	**175/65 R14**	-	-	-	-
22	**Conti EcoContact EP**	**175/65 R14**	-	-	-	-
23	**Vredestein Hi-Trac**	**195/65 R15**	-	-	-	-
24	**Michelin Energy**	**195/65 R15**	-	-	-	-
25	**Conti PremiumContact**	**195/65 R15**	-	-	-	-
26	**Conti slick tyre**	**175/70 R13**	-	-	-	-
27	**Uniroyal slick tyre**	**205/55 R16**	-	-	-	-
28	**Conti slick tyre**	**195/65 R15**	-	-	-	-
29	**Goodyear Ultragrip 7**	**175/65 R14**	-	-	-	-
30	**Vredestein Snowtrac**	**195/65 R15**	-	-	-	-
31	**Goodyear Wrangler MT/R**	**215/65 R16**	-	-	-	-
32	**Goodyear NCT5 EMT**	**195/55 R16**	-	-	-	-
33	**Goodyear Eagle F1 GS-D3**	**205/55 R16**	-	-	-	-
34	**Avon ZV1**	**185/65 R15**	-	-	-	-
35	**Uniroyal Tigerpaw**	**225/60 R16**	-	-	-	-
36	**Michelin MXT**	**155/70 R13**	-	-	-	-
37	**Goodyear CLUB**	**175/70 R13**	-	-	-	-
38	**Dunlop SP Winter Sport M2**	**175/65 R13**	-	-	-	-
39	**Avon ZV1**	**185/65 R15**	88 H	1903	75	Sep-08
40	**Uniroyal Tigerpaw SRTT**	**225/60 R16**	97 S	0906	67	Sep-08

Not all tyres have been measured or modelled and an overview of which of the tyres that have been measured and modelled is shown in table 2. Tyres 16-38 are from the *SPERoN*-database and are included in the investigation, as the sound levels from these tyres have been modelled on a selection of the Norwegian road surfaces.

In table 2, ***CPX-measurements*** mean that these tyres have been measured by SINTEF on different road surfaces in Norway (see chapter 4.1). ***SPERoN model*** means that these tyres have been

modelled on a selection of the Norwegian road surfaces, as well as on an ISO-surface (see chapter 5).
ISO/drum means that these tyres have been measured on 3 different replicas of road surfaces (including an ISO-surface, surface 14) on the drum facilities of TUG/Gdansk (see chapter 4.2).
The ID in table 2 is the notation used by Beckenbauer/Kropp in the *SPERoN* model (except for tyres 12-15 and 39-40, which is not included in the modelling part).

As can be seen from the table, there are two sets of the reference tyres AvonCooper ZV1 and Uniroyal Tigerpaw SRTT (CPX-method[3]). One set is the Dutch set from the IPG-project (tyres 34 and 35) and one set is the tyres used by SINTEF for general CPX-measurements (tyres 39 and 40).

Table 2 *Tyres and modelling/measurement modes*

Tyre No	Name	ID	Dimensions	CPX-meas.	*SPERoN* model	ISO/ drum
1	**Dayton D110**	SINTEF_p2_01	**175/70 R14**	X	X	X
2	**Sportiva G70**	SINTEF_p2_02	**175/70 R14**	X	X	X
3	**Barum Brilliantis**	SINTEF_p2_03	**185/65 R15**	X	X	X
4	**Toyo 330**	SINTEF_p2_04	**185/65 R15**	X	X	X
5	**Goodyear Excellence**	SINTEF_p2_05	**195/65 R15**	X	X	X
6	**Conti Premium Contact 2**	SINTEF_p2_06	**195/65 R15**	X	X	X
7	**Toyo Proxes T1R**	SINTEF_p2_07	**205/55 R16**	X	X	X
8	**Nokian Hakka H**	SINTEF_p2_08	**205/55 R16**	X	X	X
9	**Michelin Pilot Primacy HP**	SINTEF_p2_09	**215/55 R16**	X	X	X
10	**Firestone Firehawk TZ200**	SINTEF_p2_10	**215/55 R16**	X	X	X
11	**Conti EcoContact 3**	SINTEF_p1	**195/65 R15**	X	X	X
12	**Yokohama dB V500**	SINTEF	**185/65 R15**	X	-	X
13	**Michelin Energy Saver**	SINTEF	**205/65 R15**	X	-	X
14	**Hankook Ventus Prime K105**	SINTEF	**205/65 R15**	X	-	X
15	**Pirelli P7**	SINTEF	**205/65 R15**	X	-	X
16	**Conti CH90**	DB3_new	**195/65 R15**	-	X	-
17	**Pirelli P600**	DB4_new	**205/60 R15**	-	X	-
18	**Michelin Energy E3A**	Deufrako	**195/60 R15**	-	X	-
19	**Goodyear GT3**	IPG_car_01	**175/65 R14**	-	X	-
20	**Michelin Energy**	IPG_car_02	**175/65 R14**	-	X	-
21	**Pirelli P3000 Energy**	IPG_car_03A	**175/65 R14**	-	X	-
22	**Conti EcoContact EP**	IPG_car_03B	**175/65 R14**	-	X	-
23	**Vredestein Hi-Trac**	IPG_car_04	**195/65 R15**	-	X	-
24	**Michelin Energy**	IPG_car_05	**195/65 R15**	-	X	-
25	**Conti PremiumContact**	IPG_car_06	**195/65 R15**	-	X	-
26	**Conti slick tyre**	IPG_car_07	**175/70 R13**	-	X	-
27	**Uniroyal slick tyre**	IPG_car_08A	**205/55 R16**	-	X	-
28	**Conti slick tyre**	IPG_car_08B	**195/65 R15**	-	X	-
29	**Goodyear Ultragrip 7**	IPG_car_09	**175/65 R14**	-	X	-
30	**Vredestein Snowtrac**	IPG_car_10	**195/65 R15**	-	X	-
31	**Goodyear Wrangler MT/R**	IPG_car_11	**215/65 R16**	-	X	-
32	**Goodyear NCT5 EMT**	IPG_car_12	**195/55 R16**	-	X	-
33	**Goodyear Eagle F1 GS-D3**	IPG_car_13	**205/55 R16**	-	X	-
34	**AvonCooper ZV1**	IPG_car_14	**185/65 R15**	-	X	-
35	**Uniroyal Tigerpaw SRTT**	IPG_car_16	**225/60 R16**	-	X	-
36	**Michelin MXT**	VW3_new	**155/70 R13**	-	X	-
37	**Goodyear CLUB**	VW4_new	**175/70 R13**	-	X	-
38	**Dunlop SP Winter Sport M2**	VW8_new	**175/65 R13**	-	X	-
39	**AvonCooper ZV1**	SINTEF	**185/65 R15**	X	-	-
40	**Uniroyal Tigerpaw SRTT**	SINTEF	**225/60 R16**	X	-	-

3 Road surfaces

The noise measurements with the CPX-trailer have been performed on a total of 13 different road surfaces. The road surfaces are listed in table 3. Noise measurements on surface 2B (new road surface) are used for comparison of modelling results on surface 2, [Berge et al[4]], as the 3D-texture of this surface was measured when surface 2 was new.

***Table 3** Road surfaces used for CPX-measurements*

Surface No	Surface type	Road/Location	Production year	Measurement year
1	SMA 0/11	E6 Trondheim	2005	2007
2	SMA 0/11	E6 Trondheim	2006	2007
2B	SMA 0/11	E6 Trondheim	2007	2007
3	DAC 0/16	E6 Trondheim	1999	2007
4	SMA 0/11 1%	E6 Melhus	2005	2007
5	SMA 0/11 3%	E6 Melhus	2005	2007
6	DAC 0/16	Rv707 Flakk	1992	2007
7	SMA 0/11	Rv170 Bjørkelangen	2006	2008
8	DaFib8/DaFib16	Rv170 Bjørkelangen	2006	2008
9	ViaQ11/ViaQ16	Rv170 Bjørkelangen	2006	2008
10	Wa8/Da16	Rv170 Bjørkelangen	2006	2008
11	Da16	Rv170 Bjørkelangen	2006	2008
12	Da11/Da16	E6 Horg	2008	2008
13	SMA 0/11	E6 Horg	2008	2008

Road surfaces 4 and 5 are SMA 0/11-surfaces with 1 and 3% rubber granulate added to the bitumen. Not all tyres have been measured with the CPX-trailer. Table 4 shows which of the tyres measured on which road surfaces, and at which speeds (50/80 km/h).

***Table 4** Combination of road surfaces, tyre measured (CPX) and speed*

Tyre no / **Surface**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**39**	**40**
1 SMA11 2005	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	-	-	-	50/80	50/80
2 SMA11 2006	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	-	-	-	-	-
2B SMA11 2007	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	-	-	-	-	-
3 SMA16 1999	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	-	-	-	50/80	50/80
4 SMA11 2006	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	-	-	-	50/80	50/80
5 SMA11 2006	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	50/80	-	-	-	50/80	50/80
6 DAC16 1992	50	50	50	50	50	50	50	50	50	50	50	50	-	-	-	-	-
7 SMA11 2006	50/80	-	-	-	50/80	50/80	-	50/80	50/80	50/80	50/80	-	50/80	50/80	50/80	50/80	50/80
8 DaFib8/ DaFib16 2006	50/80	-	-	-	50/80	50/80	-	50/80	50/80	50/80	50/80	-	50/80	50/80	50/80	50/80	50/80
9 ViaQ11/ VIaQ16 2006	50/80	-	-	-	50/80	50/80	-	50/80	50/80	50/80	50/80	-	50/80	50/80	50/80	50/80	50/80
10 Wa8/Da16 2006	50/80	-	-	-	50/80	50/80	-	50/80	50/80	50/80	50/80	-	50/80	50/80	50/80	50/80	50/80
11 Da11 2006	50/80	-	-	-	50/80	50/80	-	50/80	50/80	50/80	50/80	-	50/80	50/80	50/80	50/80	50/80
12 Da11/ Da16 2008	50/80	-	-	-	50/80	50/80	-	50/80	50/80	50/80	50/80	-	50/80	50/80	50/80	50/80	50/80
13 SMA11 2008	50/80	-	-	-	50/80	50/80	-	50/80	50/80	50/80	50/80	-	50/80	50/80	50/80	50/80	50/80

4 Noise measurements results

4.1 CPX-measurements results

The CPX-measurements have been performed with the CPX-trailer of the Norwegian Public Roads Administration, figure 1. The trailer is fitted with two test tyres, and tyres with approximately identical dimensions were chosen for paired measurements.

Figure 1 The Norwegian CPX-trailer

Tyres 1-11 was measured on road surfaces 1-6 in 2007 and all these results have been previously reported in [Berge et al.[4,5]]. Only the measurements on surfaces 7-13 are reported here in details.

Tyres 1, 5, 6, 8, 9, 10, 11, 13, 14 and 15 where chosen to be included in the CPX-measurements of road surfaces 7-13. In addition, tyres 39 and 40 had also been measured on these surfaces as part of another project [Berge et. al.[6]] and the results could therefore be included in this project.

Tables 5-18 and figures 2-15 show the results from the CPX-measurements.
In the tables, the average sound level over the measured distance (approx. 300 m) is shown, with the standard deviation and the 95 % confidence interval. The tyres are ranked according to the measured sound level. The age of the surface is of importance, as it indicates if the surface layer has been exposed to winter conditions (surfaces 7-11) or not (surfaces 12-13).

Road surface 7: SMA11 2006. 2 years old

Table 5 *Speed 50 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**90.5**	0.59	0.41
15	**92.0**	0.29	0.15
11	**92.3**	0.26	0.19
8	**92.4**	0.19	0.11
10	**92.5**	0.27	0.13
6	**92.7**	0.40	0.28
9	**92.7**	0.34	0.17
14	**92.9**	0.23	0.12
5	**93.1**	0.28	0.21
40	**93.3**	0.24	0.12
39	**93.8**	0.20	0.10
13	**94.4**	0.40	0.24
Average	**92.7**		
Max. diff.	**3.9**		

Table 6 *Speed 80 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**97.9**	0.37	0.16
15	**99.0**	0.41	0.24
11	**99.4**	0.32	0.14
10	**99.6**	0.17	0.10
8	**99.7**	0.28	0.16
5	**99.9**	0.33	0.14
14	**100.0**	0.17	0.10
9	**100.0**	0.34	0.20
6	**100.2**	0.34	0.15
40	**100.3**	0.23	0.12
39	**100.8**	0.29	0.13
13	**101.3**	0.41	0.23
Average	**99.8**		
Max. diff.	**3.4**		

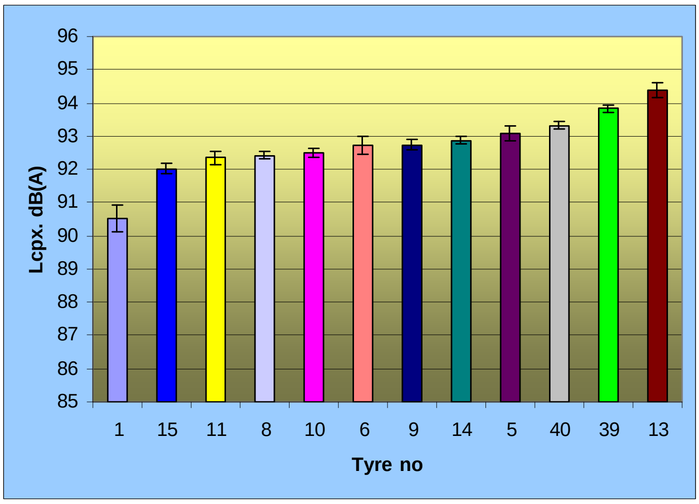


Figure 2 *SMA11 2006, 50 km/h*

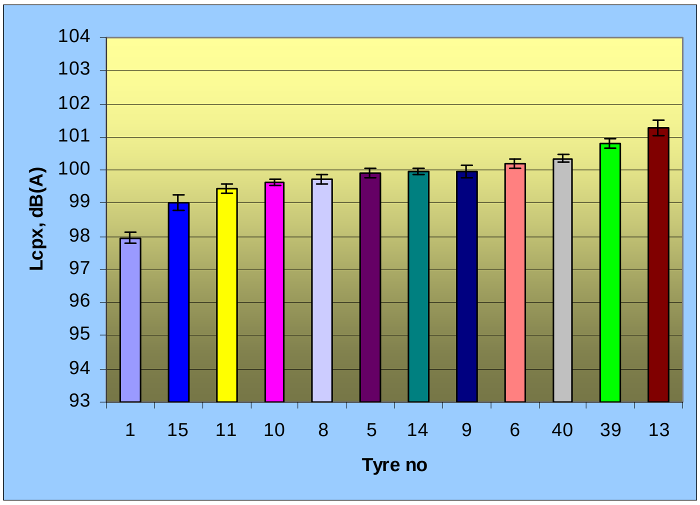


Figure 3 *SMA11 2006, 80 km/h*

Road surface 8: DaFib8/DaFib16 (2 layer porous) 2006. 2 years old

Table 7 *Speed 50 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**89.6**	0.36	0.14
15	**90.5**	0.39	0.15
8	**90.9**	0.19	0.07
11	**90.9**	0.21	0.08
9	**90.9**	0.42	0.16
10	**91.1**	0.29	0.11
5	**91.5**	0.40	0.15
40	**91.6**	0.42	0.16
14	**91.6**	0.23	0.09
39	**91.7**	0.35	0.14
6	**91.7**	0.19	0.07
13	**93.4**	0.43	0.16
Average	**91.3**		
Max. diff.	**3.8**		

Table 8 *Speed 80 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**97.4**	0.41	0.16
15	**98.1**	0.29	0.11
11	**98.3**	0.23	0.09
10	**98.4**	0.21	0.08
8	**98.4**	0.16	0.06
9	**98.4**	0.50	0.19
14	**98.7**	0.24	0.09
5	**98.8**	0.38	0.14
40	**98.8**	0.50	0.21
6	**99.2**	0.22	0.08
39	**99.3**	0.30	0.12
13	**100.6**	0.39	0.15
Average	**98.7**		
Max. diff.	**3.2**		

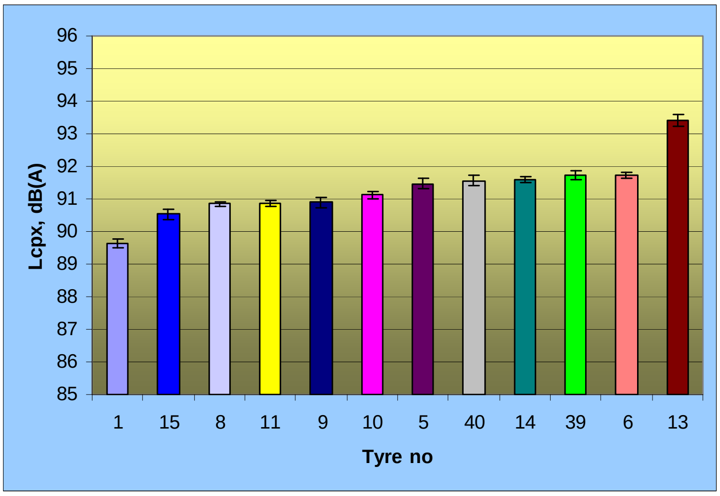


Figure 4 *DaFib8/DaFib6, 50 km/h*

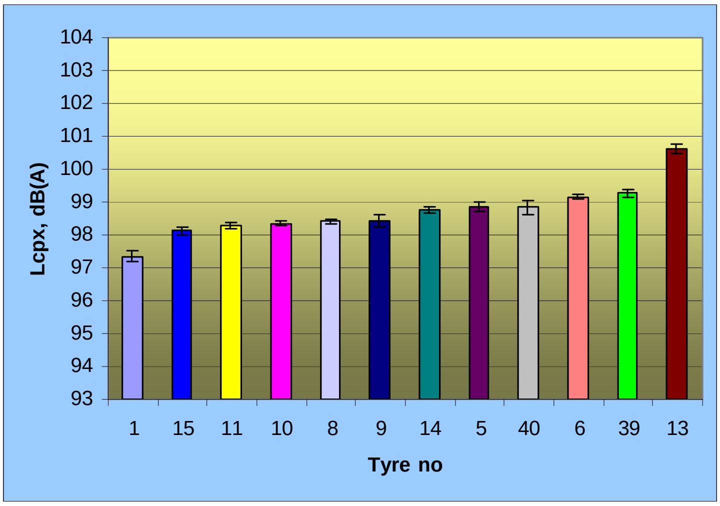


Figure 5 *DaFib8/DaFib6, 80 km/h*

Road surface 9: ViaQ11/ViaQ16 (2 layer porous) 2006. 2 years old

Table 9 *Speed 50 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**89.0**	0.44	0.18
15	**89.5**	0.54	0.21
9	**89.8**	0.58	0.23
40	**90.0**	0.39	0.16
5	**90.3**	0.59	0.23
39	**90.7**	0.55	0.23
8	**90.7**	0.34	0.14
11	**90.8**	0.26	0.10
10	**90.9**	0.34	0.14
14	**91.4**	0.25	0.10
6	**91.7**	0.30	0.12
13	**92.3**	0.57	0.23
Average	**90.6**		
Max. diff.	**3.3**		

Table 10 *Speed 80 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**96.7**	0.43	0.17
15	**96.8**	0.47	0.19
40	**97.2**	0.35	0.15
9	**97.2**	0.43	0.18
5	**97.5**	0.54	0.22
39	**97.8**	0.58	0.25
10	**98.0**	0.34	0.14
11	**98.1**	0.34	0.14
8	**98.1**	0.39	0.16
14	**98.6**	0.29	0.12
6	**99.1**	0.34	0.14
13	**99.6**	0.51	0.21
Average	**97.9**		
Max. diff.	**2.9**		

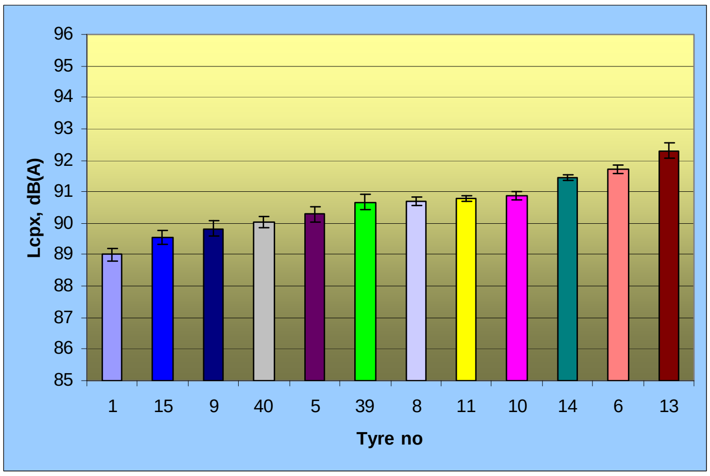


Figure 6 *ViaQ11/ViaQ16, 50 km/h*

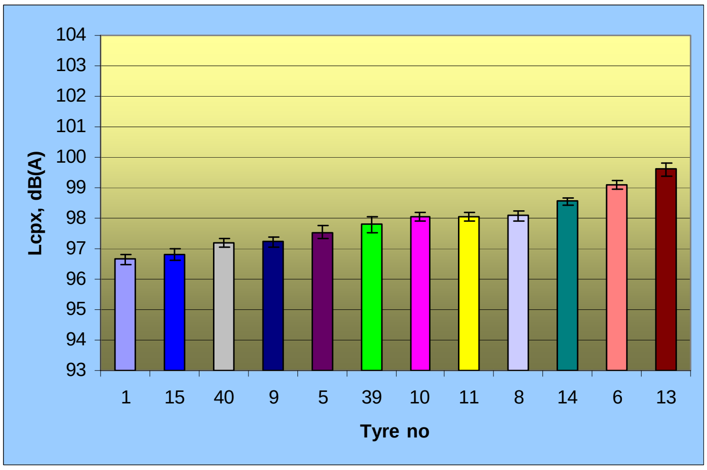


Figure 7 *ViaQ11/ViaQ16, 80 km/h*

Road surface 10: Wa8/Da16 (2 layer porous) 2006. 2 years old

Table 11 *Speed 50 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**89.1**	0.32	0.13
9	**89.9**	0.40	0.16
15	**89.9**	0.40	0.16
40	**90.0**	0.46	0.19
8	**90.2**	0.35	0.14
10	**90.3**	0.35	0.14
11	**90.3**	0.27	0.11
5	**90.8**	0.26	0.11
14	**91.0**	0.30	0.12
39	**91.2**	0.27	0.11
6	**91.4**	0.30	0.12
13	**92.4**	0.31	0.12
Average	**90.5**		
Max. diff.	**3.3**		

Table 12 *Speed 80 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
40	**96.3**	0.67	0.28
1	**96.8**	0.22	0.09
15	**97.5**	0.38	0.16
9	**97.6**	0.37	0.15
10	**97.7**	0.31	0.13
8	**97.8**	0.29	0.12
11	**97.9**	0.28	0.12
5	**98.2**	0.34	0.14
14	**98.3**	0.30	0.12
39	**98.6**	0.31	0.13
6	**98.7**	0.34	0.14
13	**99.9**	0.39	0.16
Average	**97.9**		
Max. diff.	**3.6**		

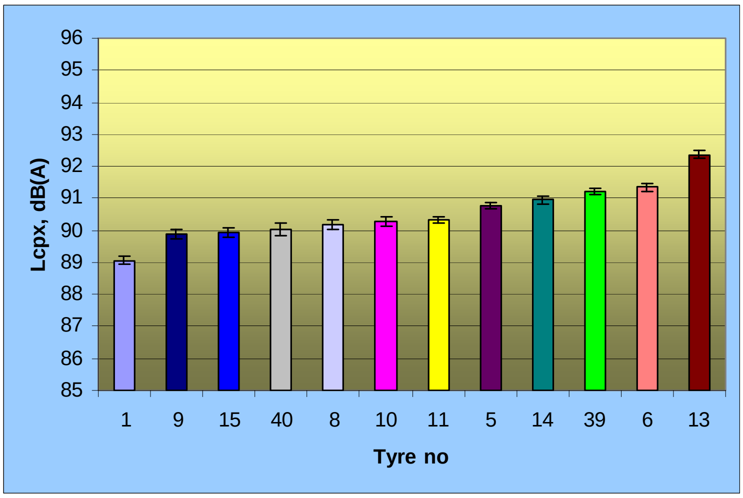


Figure 8 *Wa8/Da16, 50 km/h*

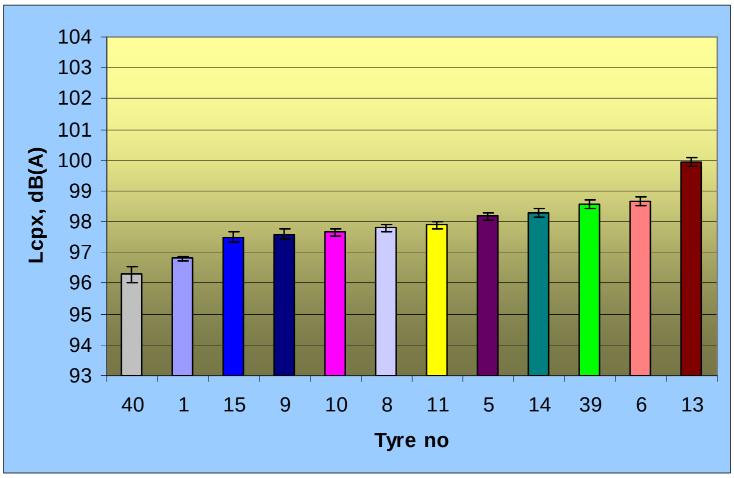


Figure 9 *Wa8/Da16, 80 km/h*

Road surface 11: Da11 (1 layer porous) 2006. 2 years old

***Table 13** Speed 50 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**90.3**	0.25	0.10
40	**91.1**	0.46	0.18
15	**91.1**	0.31	0.12
9	**91.3**	0.27	0.11
8	**91.4**	0.33	0.13
10	**91.6**	0.35	0.14
11	**91.7**	0.17	0.07
5	**92.0**	0.26	0.10
14	**92.3**	0.19	0.08
6	**92.7**	0.18	0.07
39	**92.9**	0.54	0.23
13	**93.7**	0.33	0.13
Average	**91.8**		
Max. diff.	**3.4**		

***Table 14** Speed 80 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**97.4**	0.24	0.10
15	**98.1**	0.34	0.14
40	**98.5**	0.46	0.18
9	**98.8**	0.47	0.19
5	**98.8**	0.36	0.14
10	**98.8**	0.32	0.13
8	**99.0**	0.26	0.10
11	**99.1**	0.23	0.09
14	**99.2**	0.32	0.13
6	**99.2**	0.34	0.14
39	**99.2**	0.46	0.19
13	**101.0**	0.36	0.15
Average	**98.9**		
Max. diff.	**3.6**		

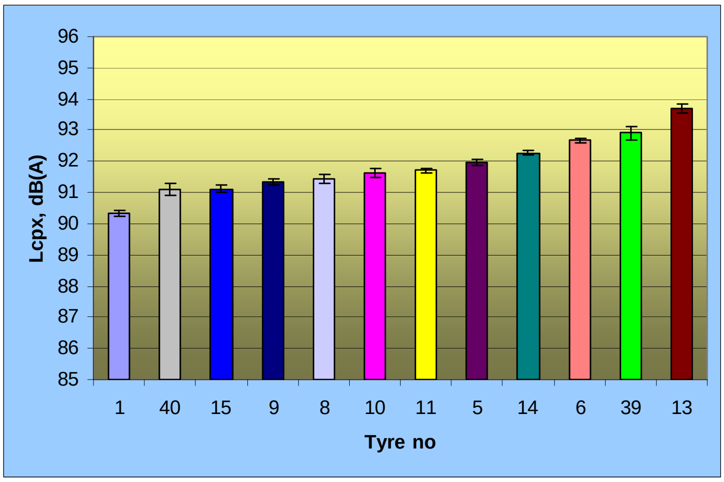


***Figure 10** Da11, 50 km/h*

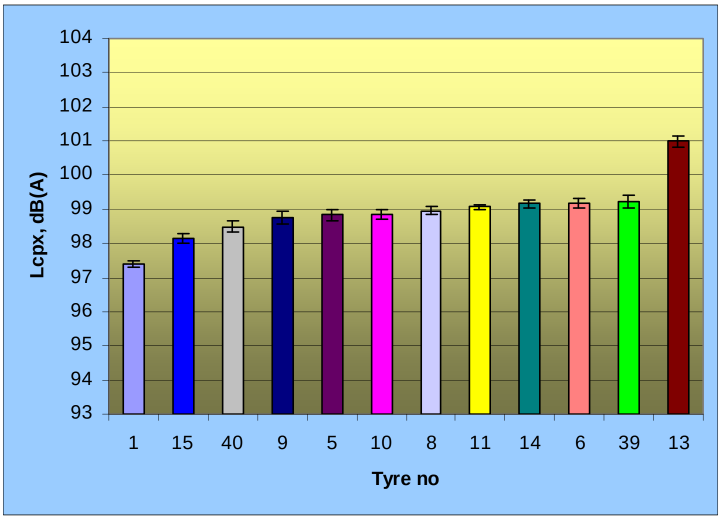


***Figure 11** Da11, 80 km/h*

Road surface 12: Da11/Da16 (2 layer porous) 2008. New

Table 15 *Speed 50 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
9	**87.2**	0.49	0.15
40	**87.4**	0.60	0.18
10	**87.6**	0.53	0.16
1	**87.7**	0.44	0.14
8	**87.9**	0.49	0.15
15	**88.6**	0.52	0.16
39	**88.6**	0.60	0.18
11	**88.8**	0.46	0.14
5	**89.0**	0.52	0.16
6	**89.3**	0.48	0.15
13	**89.7**	0.58	0.18
14	**89.8**	0.57	0.18
Average	**88.5**		
Max. diff.	**2.6**		

Table 16 *Speed 80 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
40	**94.0**	0.55	0.17
9	**94.0**	0.59	0.18
1	**94.5**	0.44	0.14
10	**94.6**	0.61	0.19
8	**94.6**	0.56	0.17
15	**94.6**	0.49	0.15
39	**94.9**	0.62	0.19
5	**95.2**	0.49	0.15
11	**95.5**	0.49	0.15
6	**95.7**	0.52	0.16
14	**96.2**	0.57	0.17
13	**96.2**	0.49	0.15
Average	**95.0**		
Max. diff.	**2.3**		

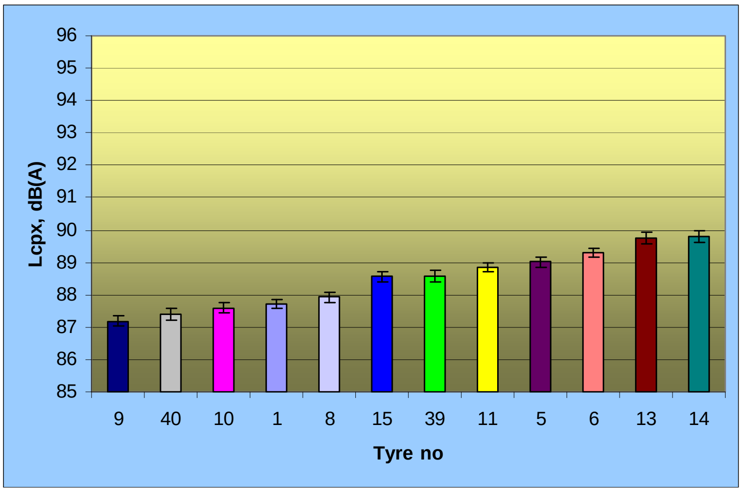


Figure 12 *Da11/Da16, 50 km/h*

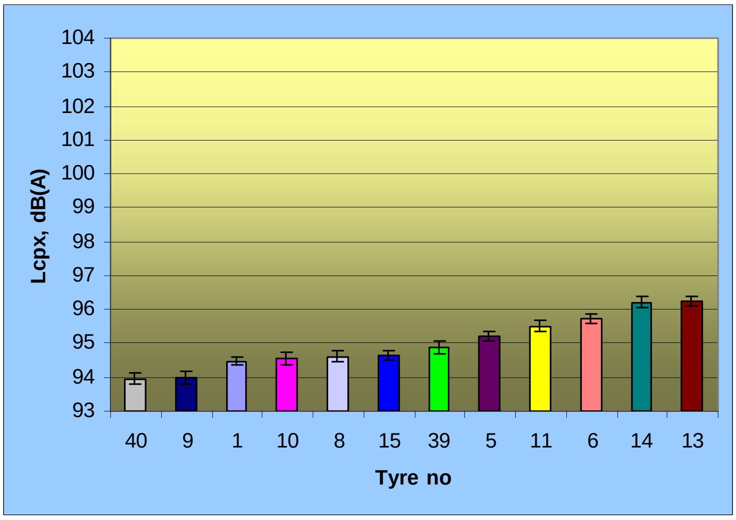


Figure 13*Da11/Da16, 80 km/h*

Road surface 13: SMA11 2008. New

Table 17 *Speed 50 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**90.4**	0.26	0.08
10	**91.1**	0.30	0.09
8	**91.2**	0.27	0.08
9	**91.2**	0.22	0.07
15	**91.5**	0.23	0.07
11	**91.6**	0.26	0.08
40	**91.7**	0.22	0.07
39	**92.2**	0.20	0.06
6	**92.3**	0.34	0.10
14	**92.3**	0.32	0.10
5	**92.6**	0.23	0.07
13	**93.1**	0.24	0.07
Average	**91.8**		
Max. diff.	**2.7**		

Table 18 *Speed 80 km/h*

Tyre no	Lcpx, dB(A)	St.dev	95% Conf
1	**97.6**	0.27	0.08
15	**98.2**	0.25	0.08
40	**98.3**	0.26	0.08
10	**98.5**	0.32	0.10
8	**98.5**	0.27	0.08
9	**98.6**	0.31	0.09
11	**98.7**	0.31	0.10
39	**99.1**	0.24	0.07
5	**99.2**	0.29	0.09
6	**99.2**	0.37	0.11
14	**99.2**	0.35	0.11
13	**100.0**	0.24	0.07
Average	**98.8**		
Max. diff.	**2.4**		

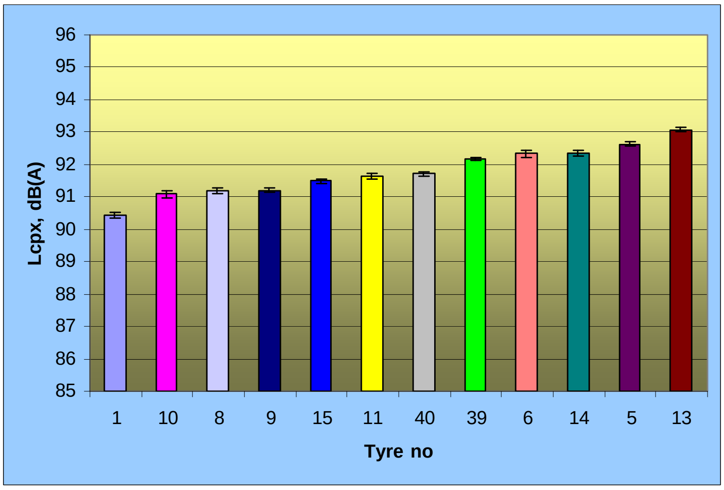


Figure 14 *SMA11 2008, 50 km/h*

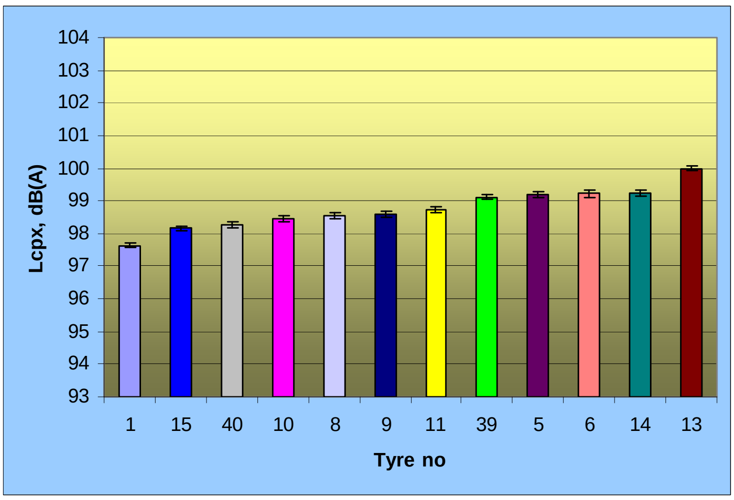


Figure 15 *SMA11 2008, 80 km/h*

The following conclusions can be made from these results:

- The ranking of the tyres are more or less the same on all the measured surfaces that have been exposed to winter conditions (surfaces 7-11).
- On a new, quiet porous surface, the ranking is somewhat different for some of the tyres.
- Tyre 13 (Michelin Energy Saver) is, with one exception (see figure12), the most noisy tyre on all measured surfaces.
- The spread in levels is somewhat higher on the older surfaces (2.9-3.9 dB(A)), than on the new surfaces (2.3-2.7 dB(A)).
- It is difficult from these results to confirm the assumption that “old” and rough SMA-surfaces differentiate less between the noise levels of tyres, than a new, quiet porous road surface (on a smooth surface, differences in tread pattern is more important for the noise generation).

In figures 16, the correlation between the CPX-measurements on surface 7 (SMA11 2006-2 year old) and on surface 13 (SMA11 2008-new) is shown. The correlation between the levels on these two surfaces is quite good (r^2 = 0.87). In figure 17, a similar correlation between levels on surface 7 and surface 12 (Da11/Da16-new) is shown. Here, the correlation is significantly less (r^2 = 0.33).

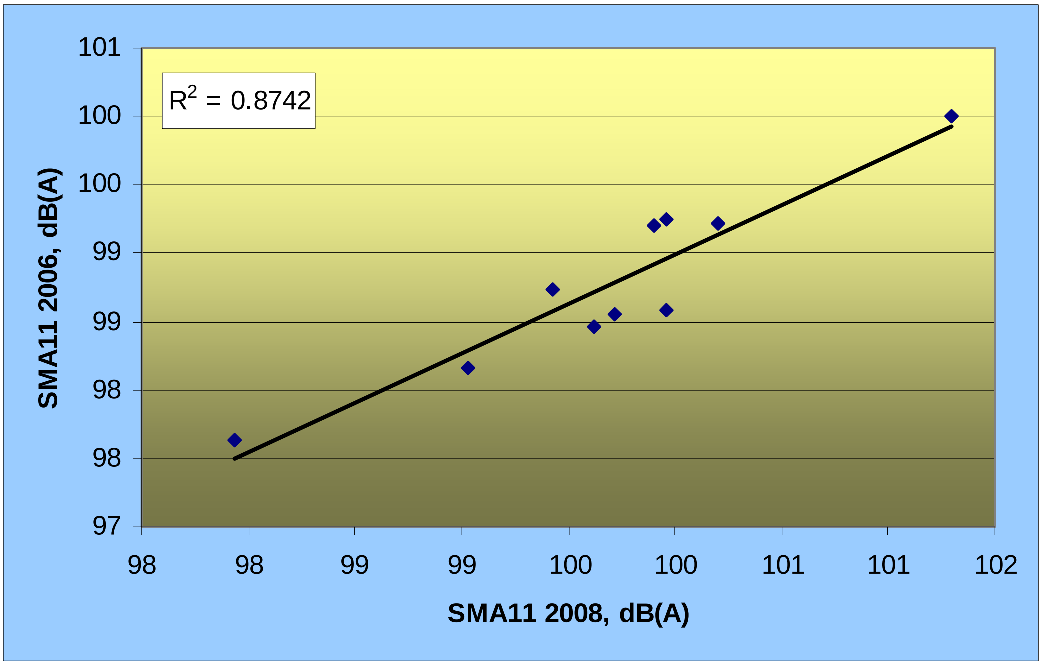


Figure 16 *Correlation between CPX-measurements on SMA11 2006 and SMA11 2008, 80 km/h*

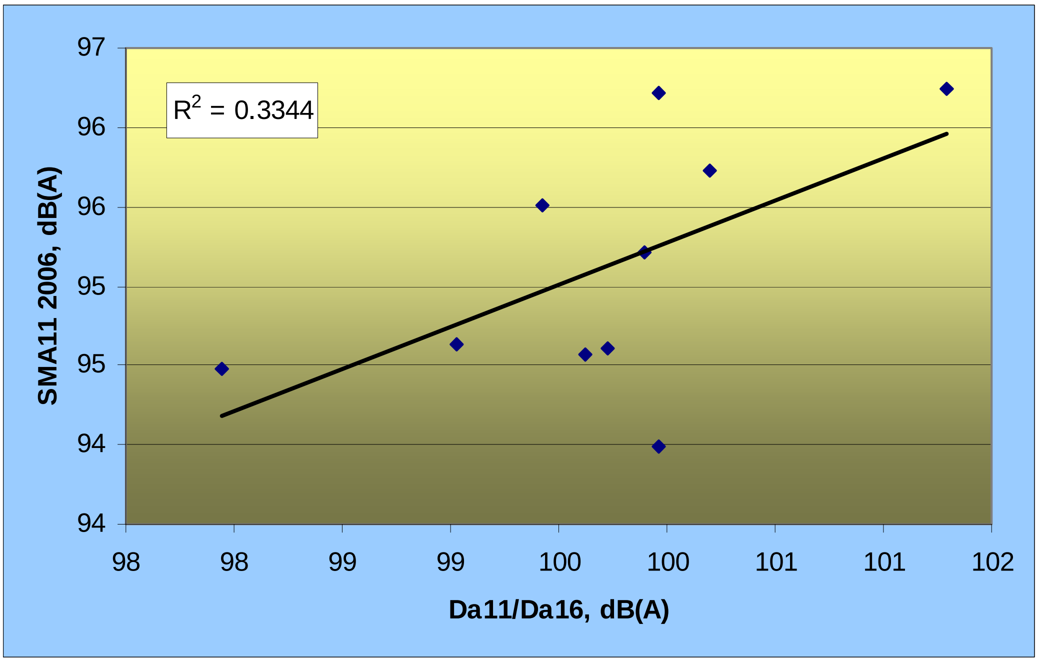


Figure 17 *Correlation between CPX-measurements on SMA11 2006 and Da11/Da16 2008, 80 km/h*

4.2 Drum measurements results

Tyres 1-15 have been measured at the drum facilities of TUG/Gdansk in Poland.
Three replicas of surfaces were used; ISO, GRB-S (dense asphalt concrete) and APS-4 (rough textured surface).
The tyres were measured at speeds from 30 to 130 km/h. Only the results for 50 and 80 km/h are reported here, to be able to compare results with the CPX-measurements, see tables 19, 20 and 21. In figures 18 to 23, the tyres are ranked according to the measured noise levels on the drum.

Table 19 *Drum measurements on ISO-surface*

Tyre no	Name	50 km/h dB(A)	80 km/h dB(A)
1	**Dayton D110**	89.5	96.9
2	**Sportiva G70**	90.4	98.2
3	**Barum Brilliantis**	91.2	97.6
4	**Toyo 330**	90.1	97.2
5	**Goodyear Excellence**	89.4	95.9
6	**Conti Premium Contact 2**	90.6	97.9
7	**Toyo Proxes T1R**	90.2	97.7
8	**Nokian Hakka H**	89.2	97.0
9	**Michelin Pilot Primacy HP**	89.1	96.9
10	**Firestone Firehawk TZ200**	88.5	96.1
11	**Conti EcoContact 3**	89.9	97.3
12	**Yokohama dB V500**	88.8	95.7
13	**Michelin Energy Saver**	90.3	98.1
14	**Hankook Ventus Prime K105**	89.1	96.8
15	**Pirelli P7**	89.8	98.1

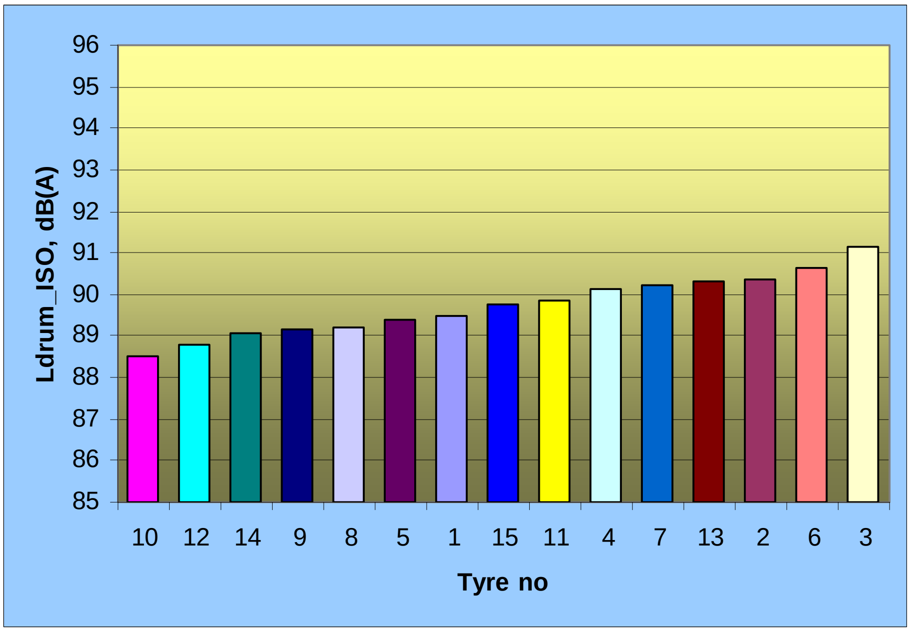


Figure 18 *TUG-drum measurements, ISO-surface, 50 km/h*

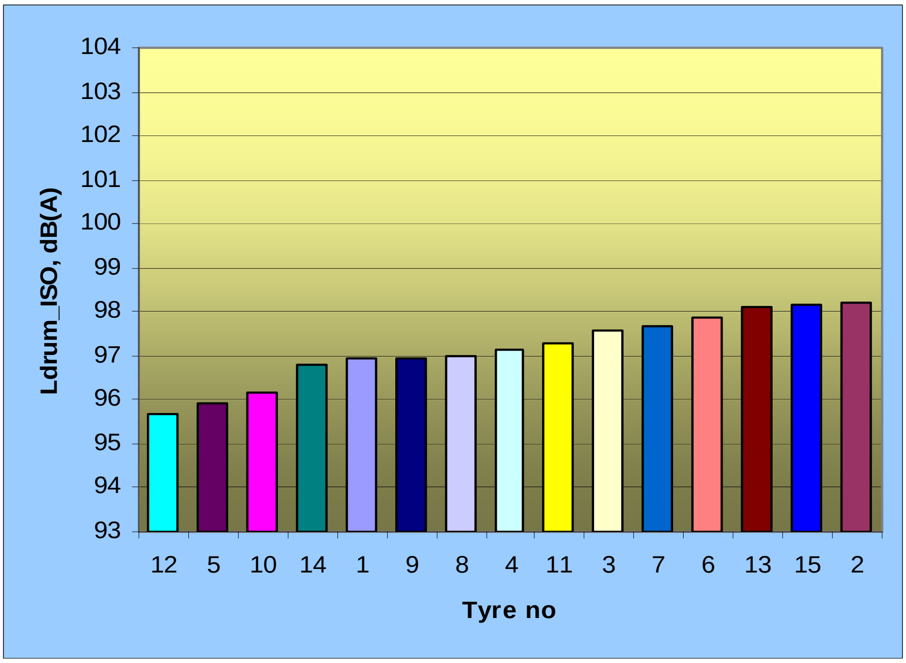


Figure 19 *TUG-drum measurements, ISO-surface, 80 km/h*

Table 20 *Drum measurements on GRB-S*

Tyre no	Name	50 km/h dB(A)	80 km/h dB(A)
1	**Dayton D110**	92.8	101.2
2	**Sportiva G70**	94.8	102.4
3	**Barum Brilliantis**	94.3	101.7
4	**Toyo 330**	94.0	101.6
5	**Goodyear Excellence**	94.0	101.7
6	**Conti Premium Contact 2**	94.4	101.9
7	**Toyo Proxes T1R**	94.9	102.6
8	**Nokian Hakka H**	93.3	101.1
9	**Michelin Pilot Primacy HP**	93.8	102.0
10	**Firestone Firehawk TZ200**	93.0	100.2
11	**Conti EcoContact 3**	93.4	101.7
12	**Yokohama dB V500**	92.6	100.5
13	**Michelin Energy Saver**	94.4	101.7
14	**Hankook Ventus Prime K105**	93.7	101.4
15	**Pirelli P7**	94.1	101.4

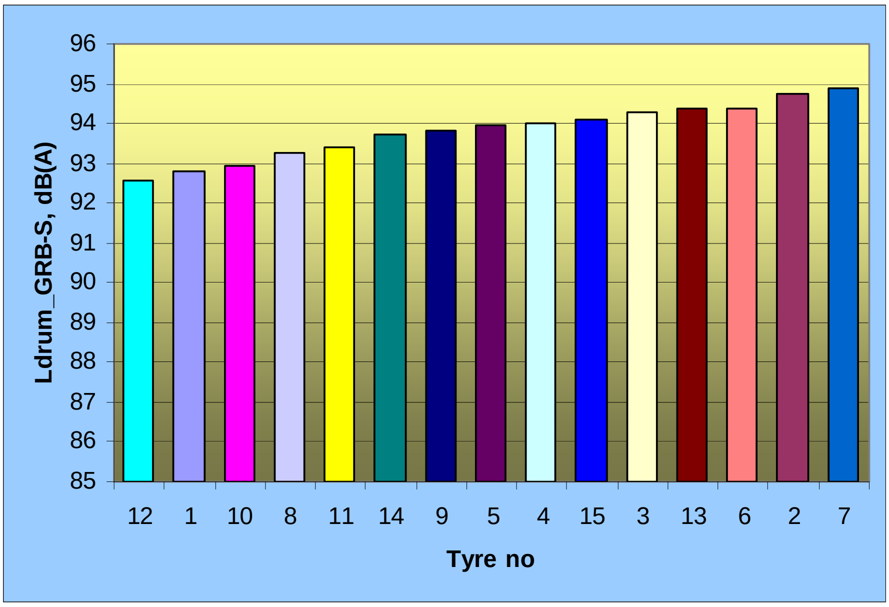


Figure 20 *TUG-drum measurements, GRB-S, 50 km/h*

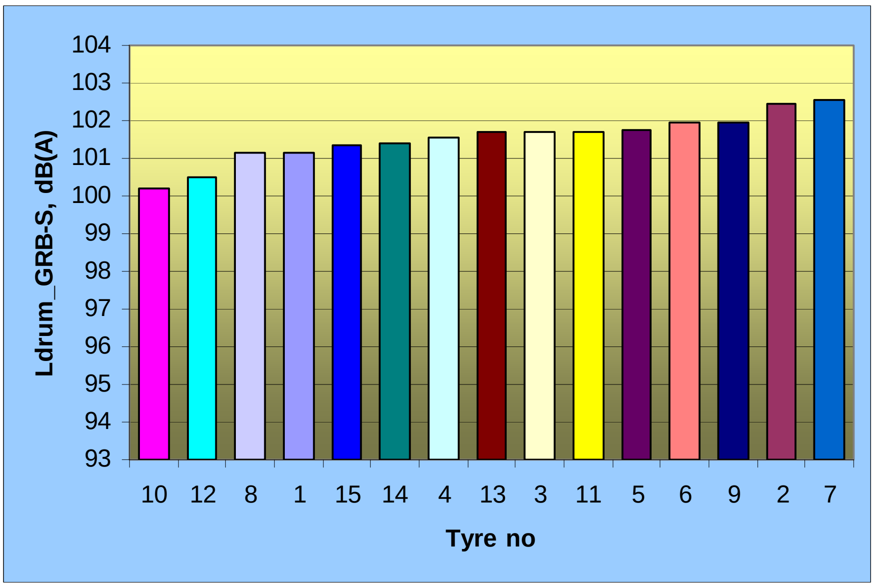


Figure 21 *TUG-drum measurements, GRB-S, 80 km/h*

Table 21 *Drum measurements on APS-4*

Tyre no	Name	50 km/h dB(A)	80 km/h dB(A)
1	**Dayton D110**	92.1	100.4
2	**Sportiva G70**	92.9	101.2
3	**Barum Brilliantis**	92.1	100.1
4	**Toyo 330**	93.5	100.9
5	**Goodyear Excellence**	92.5	100.7
6	**Conti Premium Contact 2**	93.3	100.8
7	**Toyo Proxes T1R**	92.0	100.6
8	**Nokian Hakka H**	91.6	100.5
9	**Michelin Pilot Primacy HP**	91.7	100.4
10	**Firestone Firehawk TZ200**	91.2	99.8
11	**Conti EcoContact 3**	92.2	100.5
12	**Yokohama dB V500**	92.4	100.0
13	**Michelin Energy Saver**	94.8	102.9
14	**Hankook Ventus Prime K105**	92.7	100.9
15	**Pirelli P7**	92.1	99.3

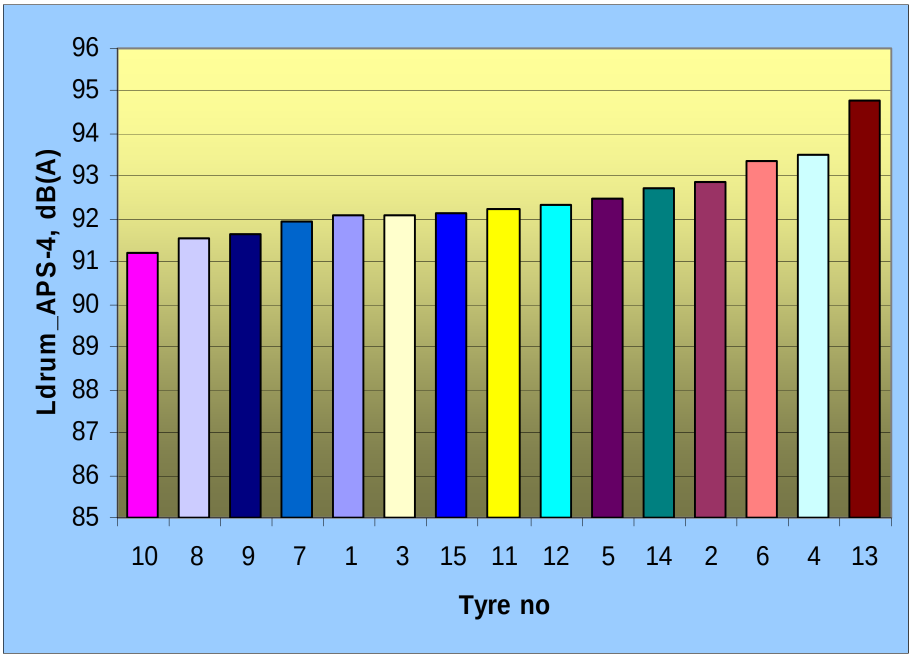


Figure 22 *TUG-drum measurements, APS-4, 50 km/h*

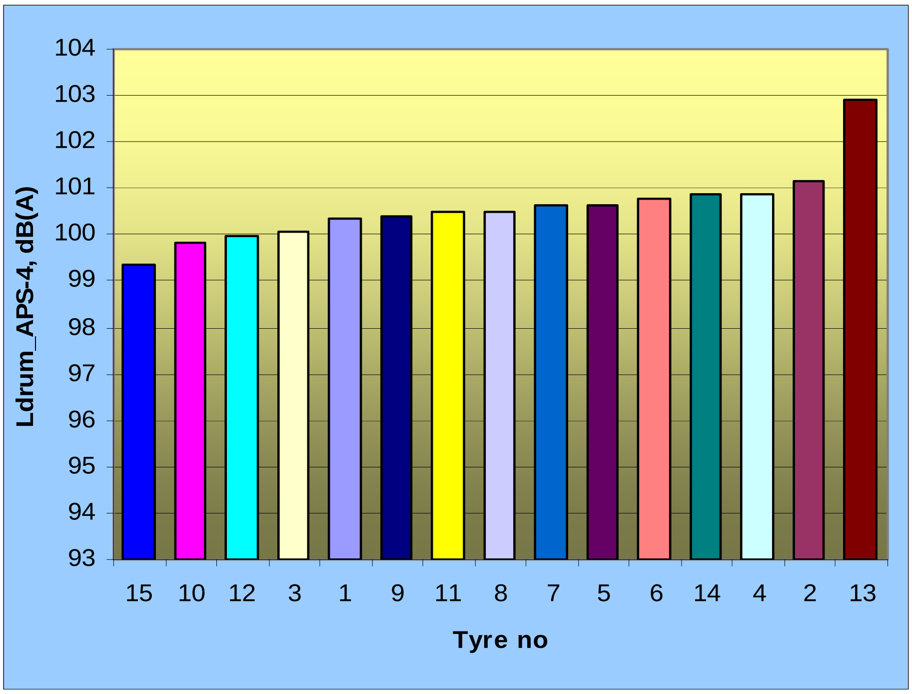


Figure 23 *TUG-drum measurements, APS-4, 80 km/h*

In figure 24, the correlation between the measured levels on the ISO-surface and the GRB-S is shown. In figure 25, the correlation between the ISO-levels and the levels on the APS-4 are shown, and in figure 26, between the GRB-S and APS-4. All results are at 80 km/h.

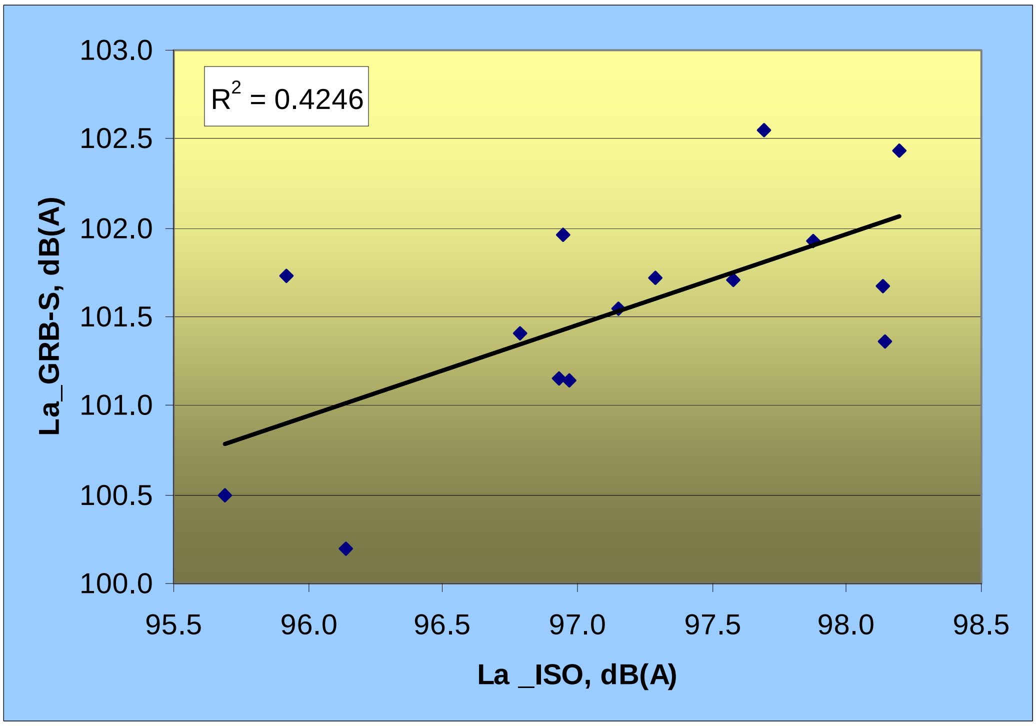


Figure 24 *Correlation between ISO-surface and GRB-S. Drum measurements at 80 km/h*

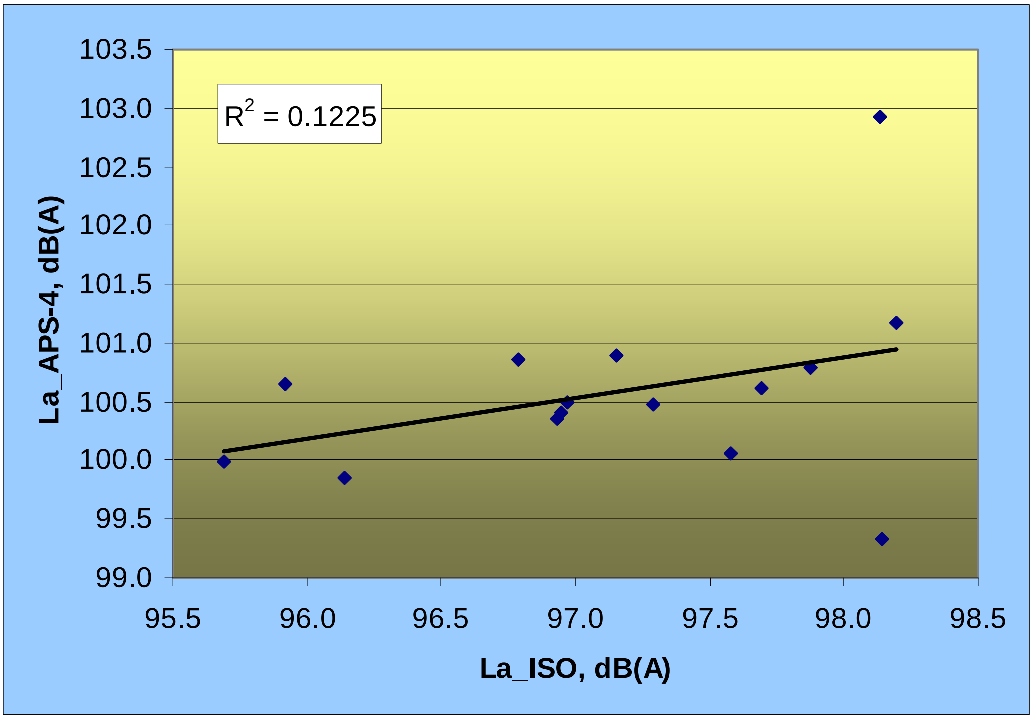


Figure 25 *Correlation between ISO-surface and APS-4. Drum measurements at 80 km/h*

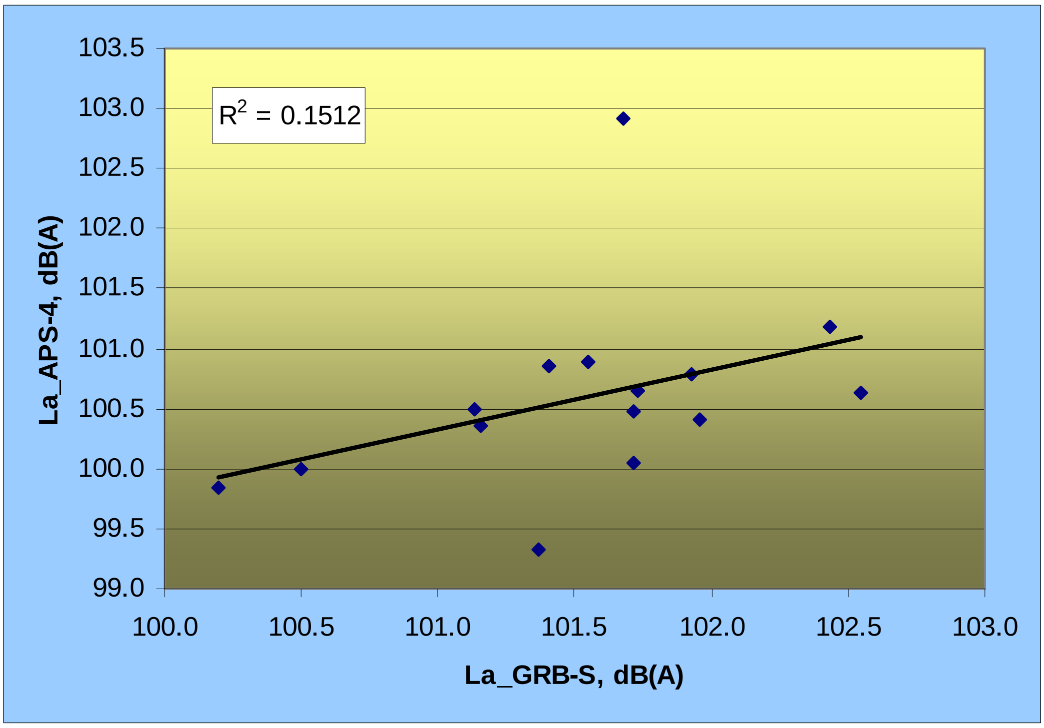


Figure 26 *Correlation between GRB-S and APS-4. Drum measurements at 80 km/h*

Between the ISO-surface and the GRB-S surface the correlation is low, but even less between the others. This can probably be explained by differences in the texture spectra of the surfaces.

The main conclusions from the drum measurements are:

- The differences in noise levels on the ISO-surface are between 2-3 dB(A), which is in the same order as for the CPX-results on the smooth surfaces 12 and 13 (see tables 15-18).
- On the rough APS-4 surface, the spread in the levels are higher, about 3.5 dB(A).
- The ranking of the tyres on the GRB-S surface compared to the results for the APS-4 is quite different, especially for tyre 13, which clearly is the noisiest on the APS-4. This tyre has also the highest levels when measured with the CPX-trailer.
- Tyre 15 is ranked as a tyre with a high level on the ISO-surfaces, while being the tyre with the lowest level on the APS-4 surface at 80 km/h.

5 *SPERoN* modelling results

As shown in table 2, the rolling noise levels of the tyres 1-11 have previously been modelled by using the *SPERoN* model, as well as being measured with the CPX-trailer and on the TUG-drum facilities. The modelling results, including frequency spectra, are documented in [Beckenbauer, Kropp[7,8]]. Only the main results are presented in this report. Tyres 16-38 (from the *SPERoN*-database) are modelled on the same road surfaces as the tyres 1-11, including the ISO-surface at Sperenberg (surface 14), but not measured with the CPX-trailer.

In table 22 and 23 the modelling results are given for the tyres 1-11 and 16-38 for the two speeds, 50 and 80 km/h.

***Table 22** SPERoN modelling results, 50 km/h*

Tyre no	Surface 1 SMA11	Surface 2 SMA11	Surface 3 SMA16	Surface 4 SMA11 1%	Surface 5 SMA11 3%	Surface 6 DAC16	Surface 14 ISO
1	69.3	68.3	70.5	69.9	69.2	68.7	65.7
2	69.3	68.4	70.6	70.1	69.3	69.0	65.7
3	69.3	68.5	71.2	70.0	69.4	68.8	65.5
4	70.4	68.9	72.5	70.7	70.0	69.2	65.8
5	69.6	68.5	71.1	70.4	69.5	69.2	65.5
6	70.1	68.9	72.3	70.6	70.2	69.3	66.2
7	70.1	69.1	71.5	71.2	70.2	69.6	66.1
8	71.2	69.6	72.5	71.9	70.8	70.1	66.4
9	70.8	69.9	72.8	71.6	71.0	70.3	66.5
10	70.7	70.2	72.4	71.6	71.5	70.1	67.0
11	70.0	69.0	71.6	70.3	69.9	69.5	65.9
16	69.1	68.9	70.3	69.8	69.4	69.5	66.4
17	69.3	69.0	70.5	70.2	69.6	69.6	66.4
18	69.8	69.0	71.0	70.2	69.6	69.3	65.8
19	68.7	68.1	70.0	69.6	69.0	68.7	65.6
20	69.0	68.4	70.1	69.9	69.4	68.9	65.8
21	70.0	69.4	70.7	70.1	69.7	69.5	66.9
22	68.4	68.0	69.7	69.3	68.8	69.0	65.8
23	69.7	69.0	71.3	70.3	69.7	69.1	65.9
24	70.3	69.1	72.1	70.9	70.2	69.8	66.1
25	69.8	69.1	72.2	70.4	69.7	69.3	66.3
26	70.4	69.5	70.9	70.5	69.9	69.5	66.6
27	70.7	69.8	72.1	71.9	71.0	71.2	67.2
28	70.7	69.3	70.5	71.4	70.2	70.7	66.1
29	70.0	68.8	71.2	70.2	69.8	68.8	66.5
30	69.3	68.6	71.4	69.8	69.3	68.9	65.8
31	73.9	71.5	74.1	73.7	73.3	70.4	69.0
32	70.0	68.8	71.7	70.5	69.7	69.2	65.9
33	69.9	68.8	72.0	70.1	69.6	69.6	65.6
34	68.8	68.3	71.1	69.5	69.0	68.3	65.6
35	72.0	71.7	74.1	73.2	72.3	71.4	68.4
36	67.8	67.1	68.7	68.4	67.7	68.1	65.0
37	71.5	70.5	71.6	70.9	70.8	70.1	68.0
38	68.9	68.4	69.4	68.7	68.5	68.6	66.1

Table 23 *SPERoN modelling results, 80 km/h*

Tyre no	Surface 1 SMA11	Surface 2 SMA11	Surface 3 SMA16	Surface 4 SMA11 1%	Surface 5 SMA11 3%	Surface 6 DAC16	Surface 14 ISO
1	78.3	77.5	79.5	78.2	78.1	77.8	73.6
2	76.5	76.0	78.3	77.1	77.0	76.5	71.8
3	76.6	75.1	78.2	76.8	76.9	75.7	70.7
4	77.5	77.0	79.3	78.1	77.4	77.0	71.9
5	80.7	79.7	81.6	80.8	80.4	79.2	75.9
6	77.7	76.5	79.2	77.7	77.8	76.5	71.6
7	77.3	76.2	79.2	77.9	77.6	77.2	71.7
8	79.1	76.5	80.1	78.9	77.9	77.2	72.3
9	79.5	79.2	80.7	80.8	80.3	79.1	74.6
10	80.4	79.3	80.9	80.3	79.6	78.9	75.0
11	78.2	76.7	79.6	77.7	77.7	77.4	72.1
16	76.8	76.8	77.8	77.0	77.2	76.7	71.7
17	78.6	78.1	79.3	78.7	78.6	77.9	73.4
18	77.7	76.8	79.2	77.3	77.5	77.0	72.3
19	75.9	75.0	77.8	76.0	76.0	75.5	70.8
20	76.2	75.6	77.7	77.2	77.0	75.8	71.1
21	82.0	80.9	82.6	81.3	81.2	79.9	77.2
22	74.9	74.9	76.8	75.6	76.3	75.3	70.2
23	77.9	76.2	79.1	77.7	77.3	76.6	71.3
24	77.4	76.0	79.4	78.0	77.5	77.0	71.9
25	77.2	76.3	78.6	77.6	77.1	76.3	70.7
26	77.2	76.8	78.3	77.4	78.6	76.8	71.6
27	78.4	77.6	79.9	78.7	78.9	78.4	72.0
28	78.7	76.2	78.6	78.9	77.9	77.5	71.4
29	78.7	77.1	79.8	78.4	78.3	76.4	73.4
30	78.7	78.3	79.7	78.9	79.0	77.9	73.8
31	83.3	79.9	82.6	82.7	81.8	78.6	76.3
32	77.1	75.8	79.1	77.4	76.9	76.2	71.0
33	78.3	75.9	79.7	78.2	77.4	77.0	71.6
34	78.7	76.4	78.7	78.4	77.7	76.4	72.8
35	78.9	79.2	80.0	79.7	80.0	79.0	73.9
36	74.8	73.9	76.2	75.2	74.6	74.3	69.6
37	84.1	82.5	83.6	83.3	82.9	81.5	79.2
38	76.4	76.0	76.9	76.3	75.8	75.9	71.3

In figures 27-40, the tyres are ranked according to the modelled rolling noise levels at 50 and 80 km/h on each of the 7 road surfaces.

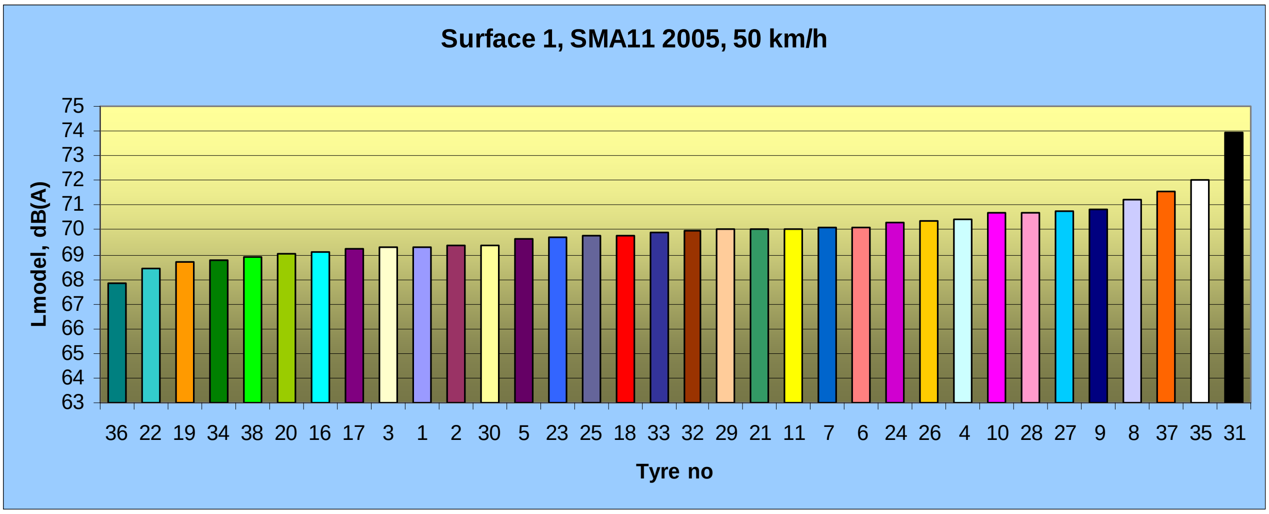


Figure 27 *SPERoN modelling results on surface 1, 50 km/h*

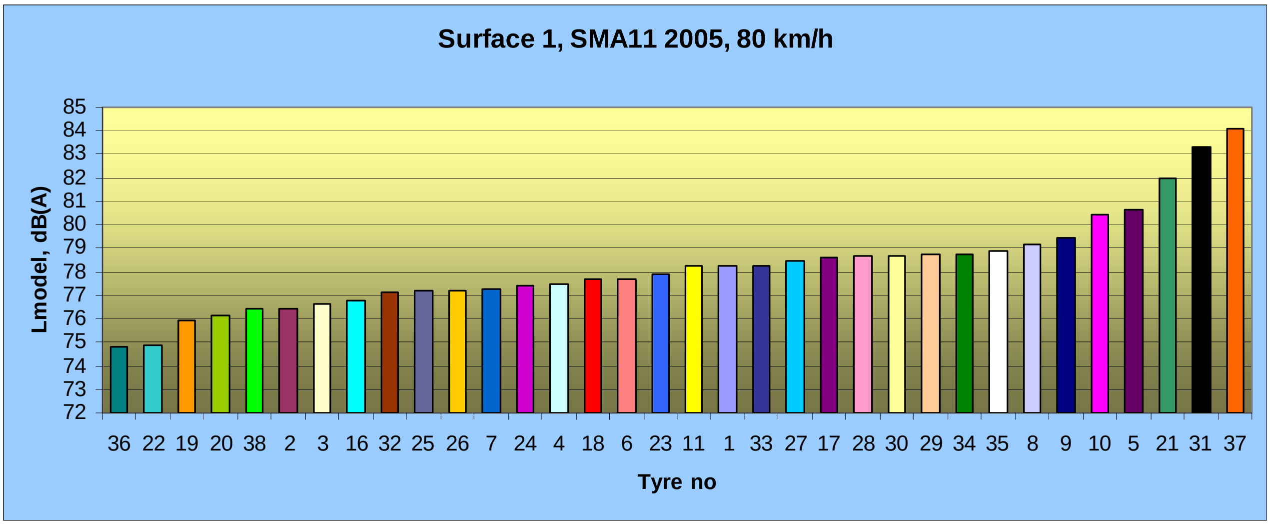


Figure 28 *SPERoN modelling results on surface 1, 80 km/h*

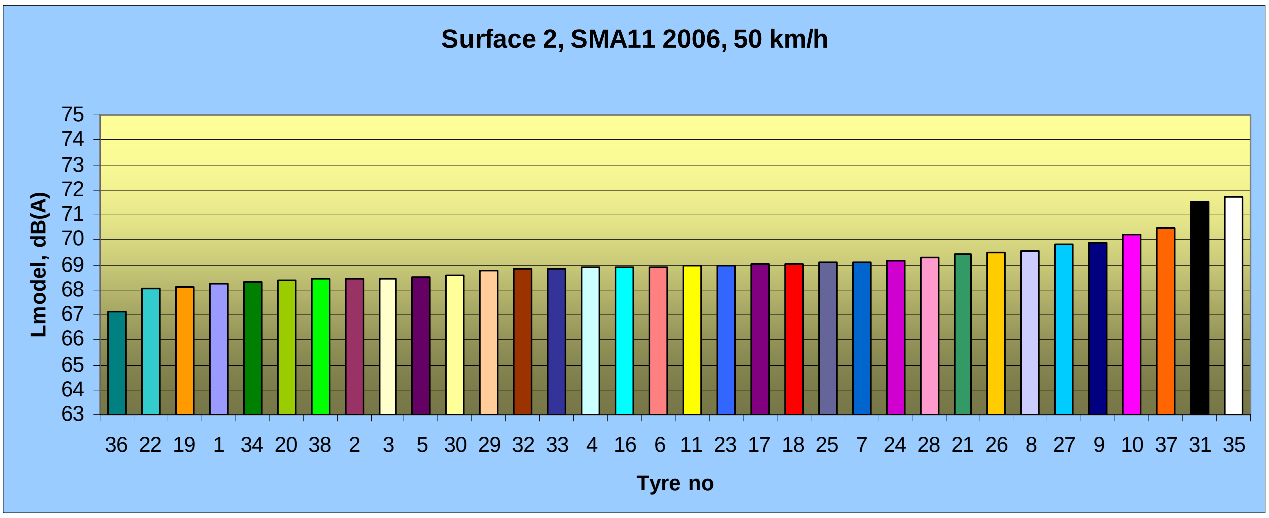


Figure 29 *SPERoN modelling results on surface 2, 50 km/h*

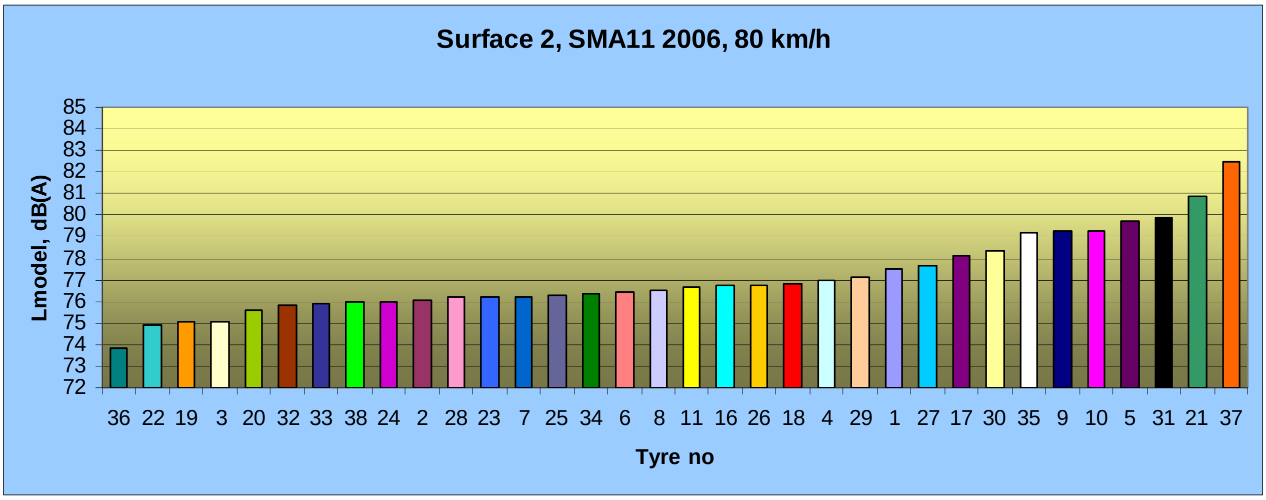


Figure 30 *SPERoN modelling results on surface 2, 80 km/h*

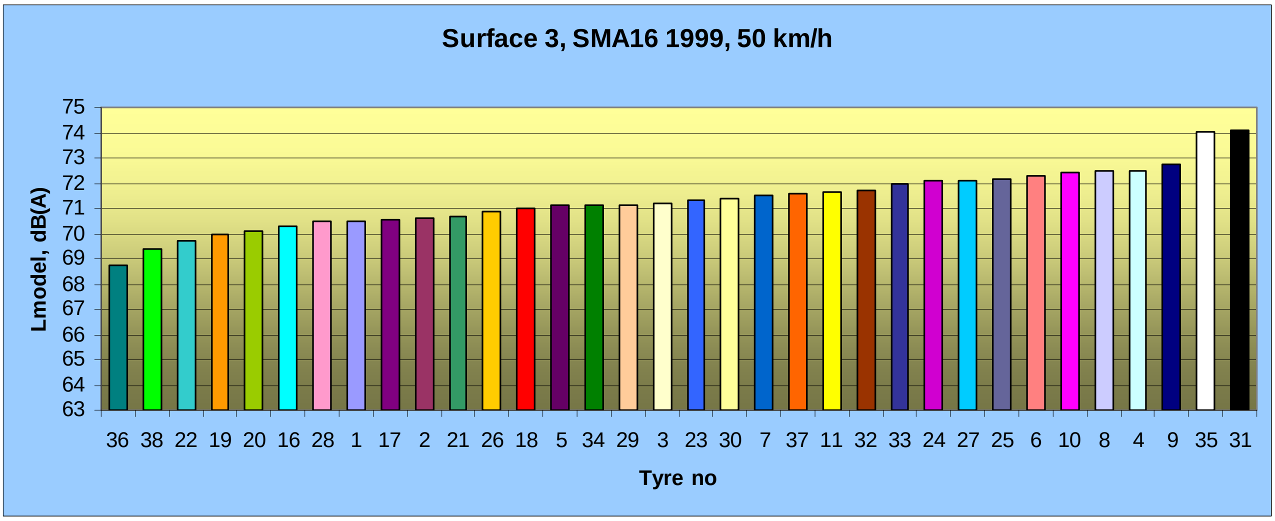


Figure 31 *SPERoN modelling results on surface 3, 50 km/h*

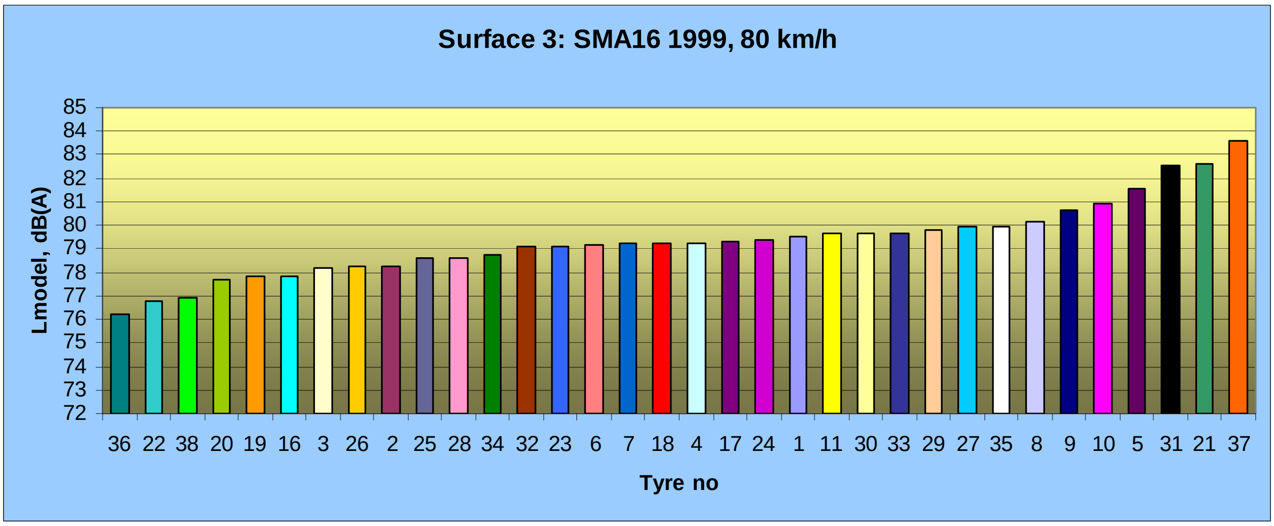


Figure 32 *SPERoN modelling results on surface 3, 80 km/h*

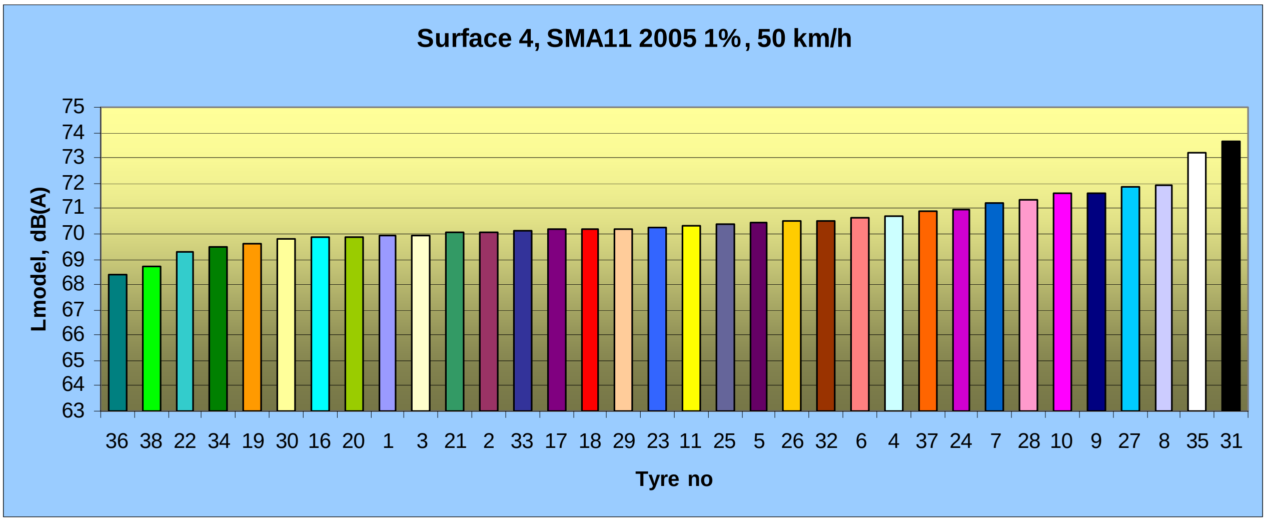


Figure 33 *SPERoN modelling results on surface 4, 50 km/h*

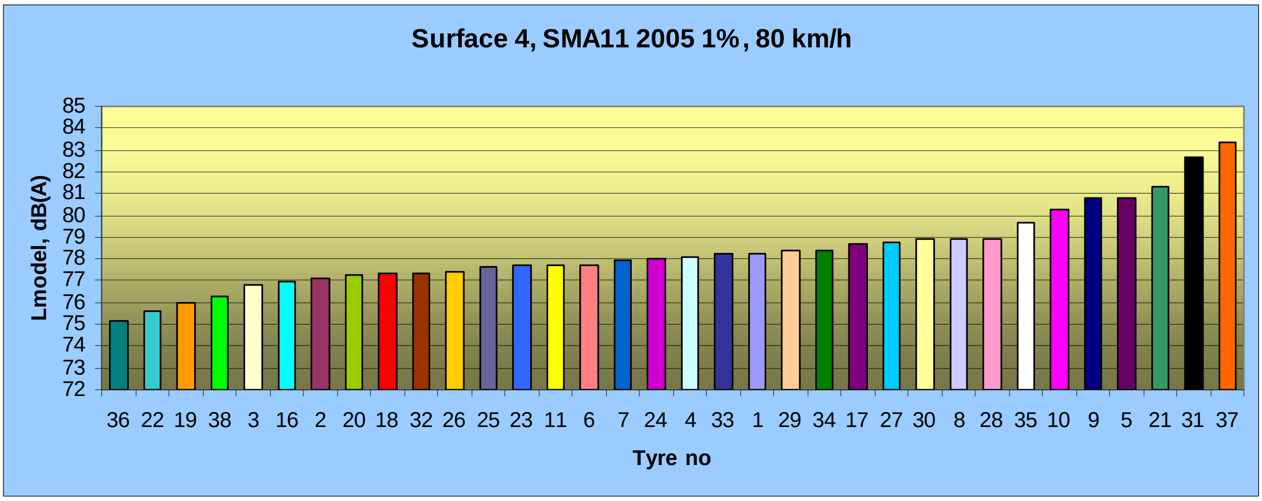


Figure 34 *SPERoN modelling results on surface 4, 80 km/h*

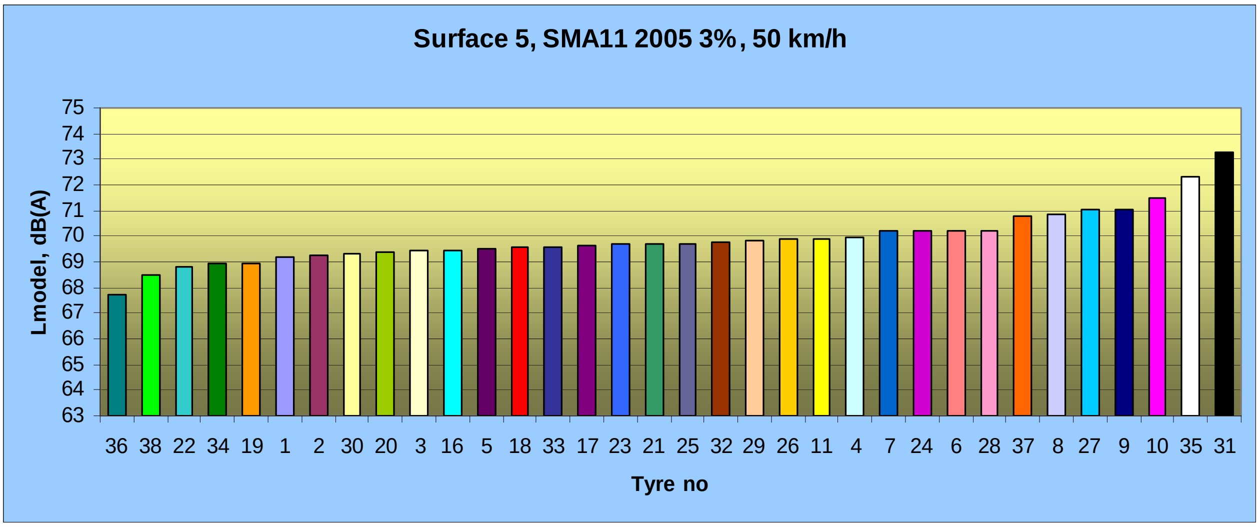


Figure 35 *SPERoN modelling results on surface 5, 50 km/h*

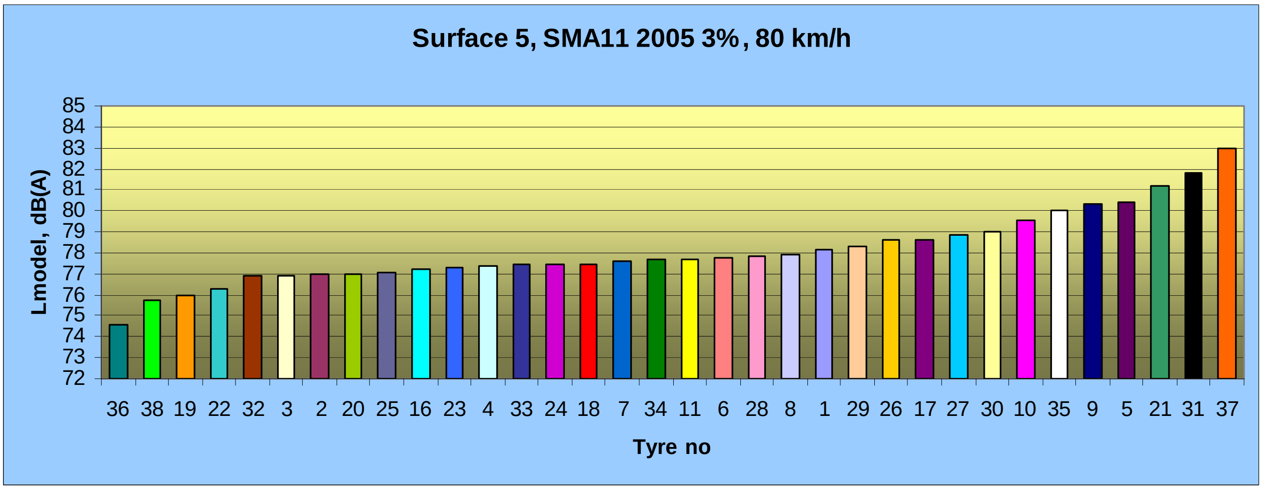


Figure 36 *SPERoN modelling results on surface 5, 80 km/h*

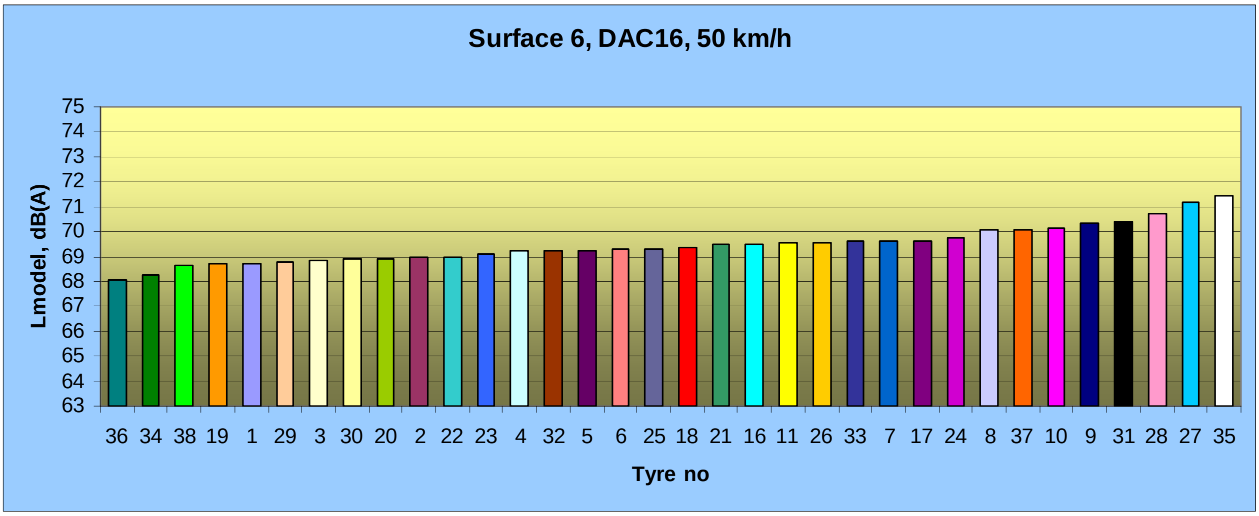


Figure 37 *SPERoN modelling results on surface 6, 50 km/h*

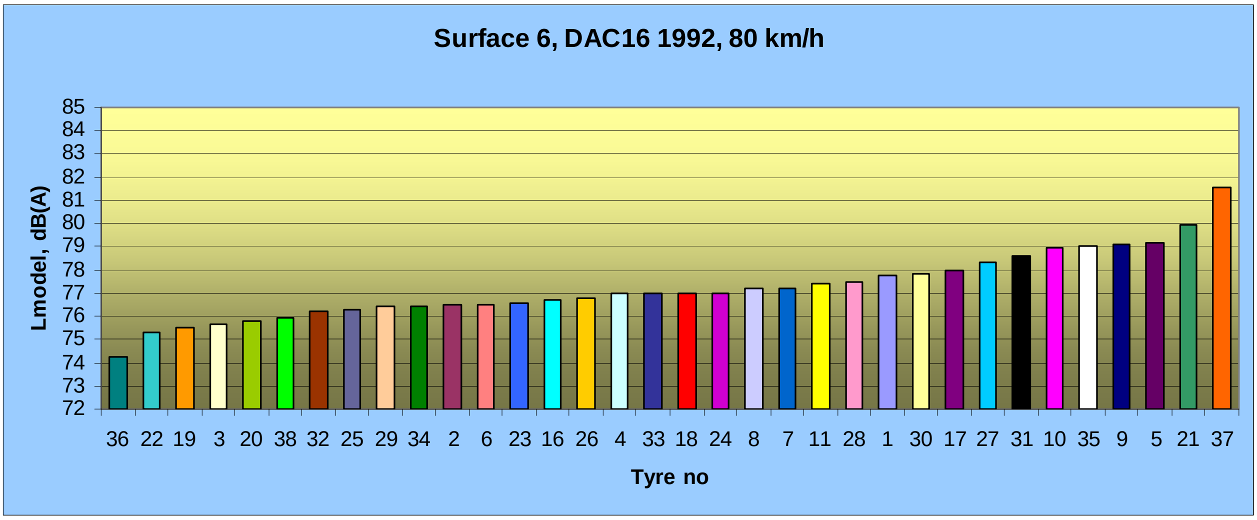


Figure 38 *SPERoN modelling results on surface 6, 80 km/h*

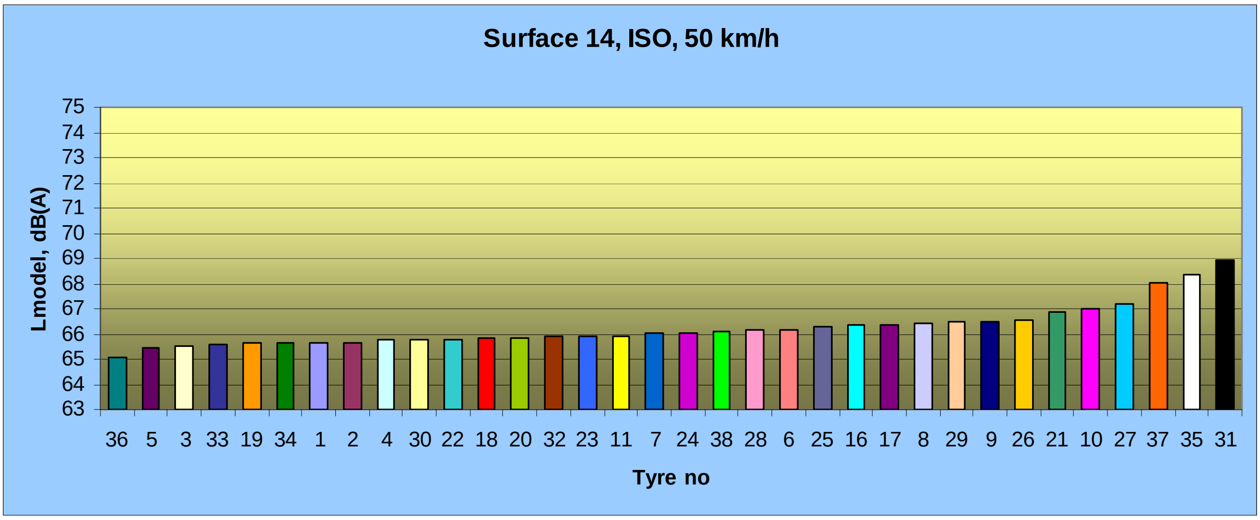


Figure 39 *SPERoN modelling results on surface 14, 50 km/h*

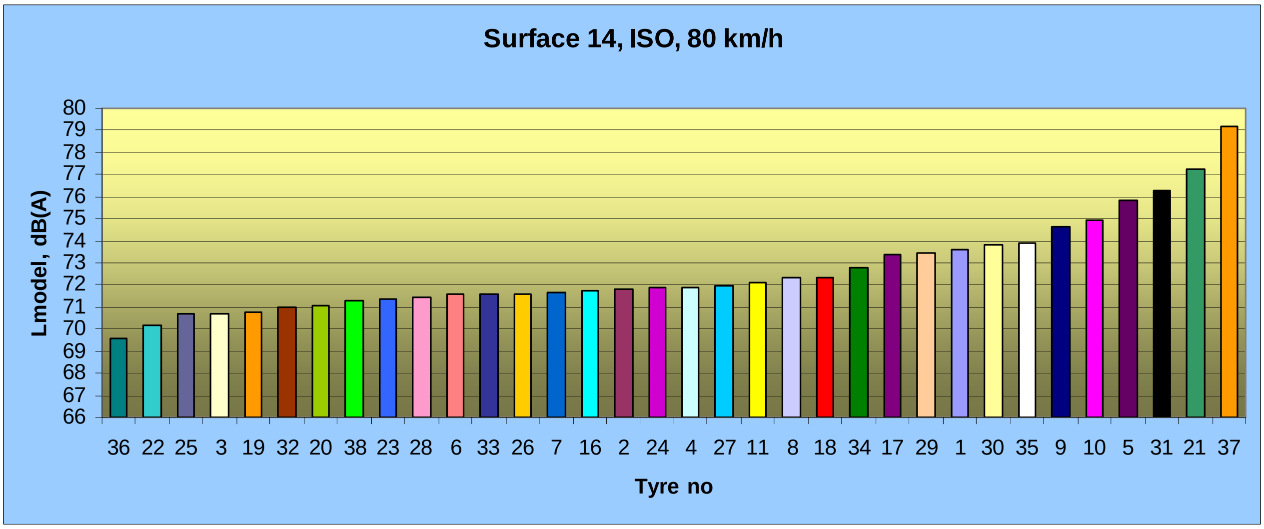


Figure 40 *SPERoN modelling results on surface 14, 80 km/h*

The main conclusions from the modelling part:

- These results show that the ranking of the tyres based on the *SPERoN* model are quite consistent.
- Some tyres, like no 5, 30 and 34 seems to be ranked in the noisier range at 80 km/h than at 50 km/h (with the exception of surface 3 and 6 – the oldest surfaces)
- Tyre 36 is the quietest tyre independent of road surface or speed. This is the Michelin MXT-tyre with the smallest width of all tyres (155 mm).
- Tyres 5, 9, 10, 21, 31 and 37 are ranked among the noisiest (at 80 km/h), independent of road surface, including the ISO-surface. However, on the ISO-drum (figure 19), tyres 5, 9 and 10 are ranked among the quietest tyres.
- Tyres 26, 27 and 28 are slick tyres, but these tyres are not ranked among the quietest tyres. In fact, they are ranked as average tyres.
- It is interesting to note that tyre 35 is modelled as the noisiest or the second noisiest tyre at 50 km/h on all the road surfaces, while at 80 km/h it is somewhat quieter than the noisiest ones. Tyre 35 is the new standard reference test tyre (SRTT) to be used for CPX-measurements, This is quite different from the ranking of this tyre, using the CPX-trailer (see chapter 4.1), especially on the low noise road surfaces.

In figures 41-43, the correlation between the modelled results on the ISO-surface (surface 14) and the modelled results on surface 1, 3 and 5 are shown. All results are at 80 km/h.

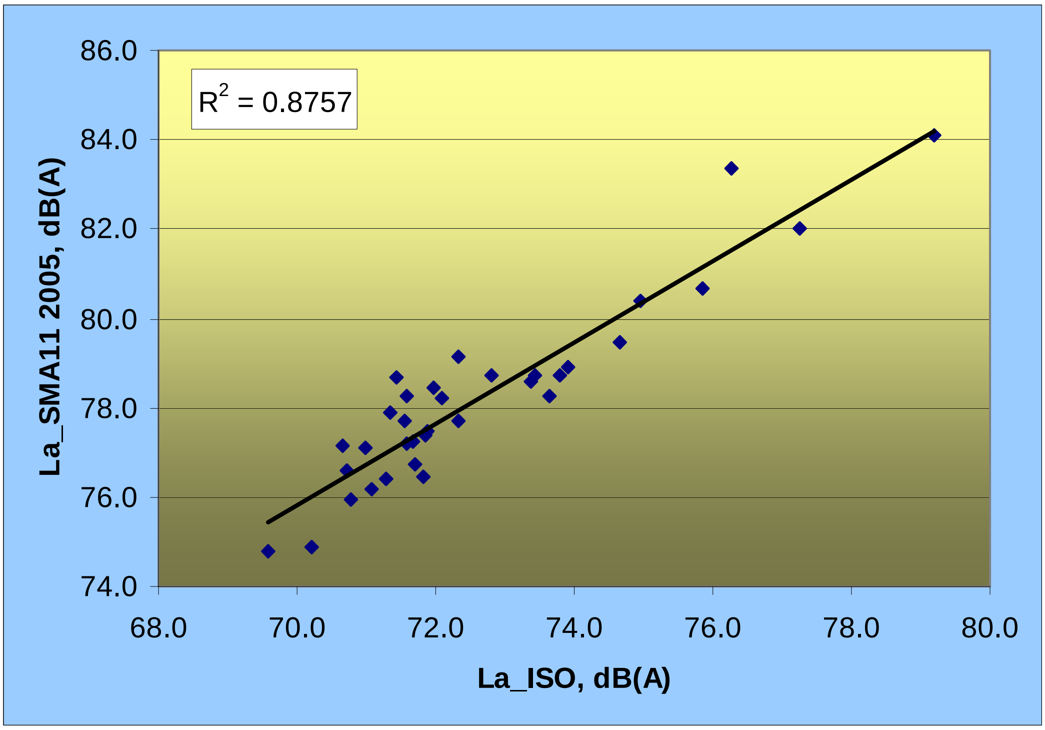


Figure 41 *SPERoN-model: correlation between ISO-surface and surface 1. 80 km/h*

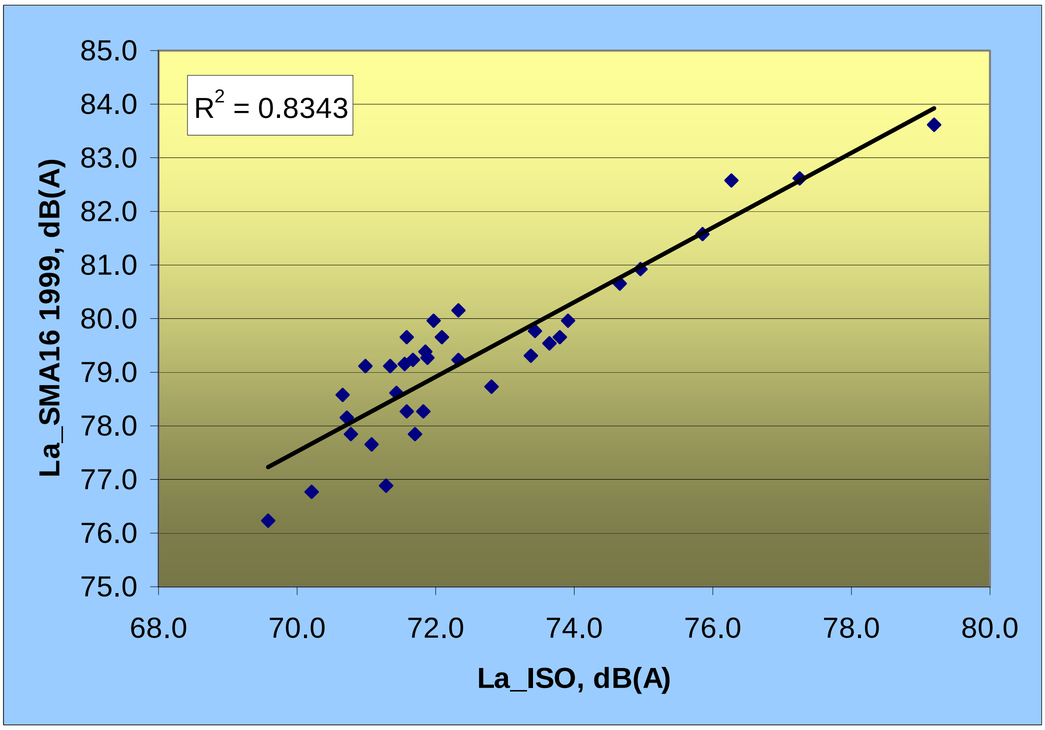


Figure 42 *SPERoN model: correlation between ISO-surface and surface 3. 80 km/h*

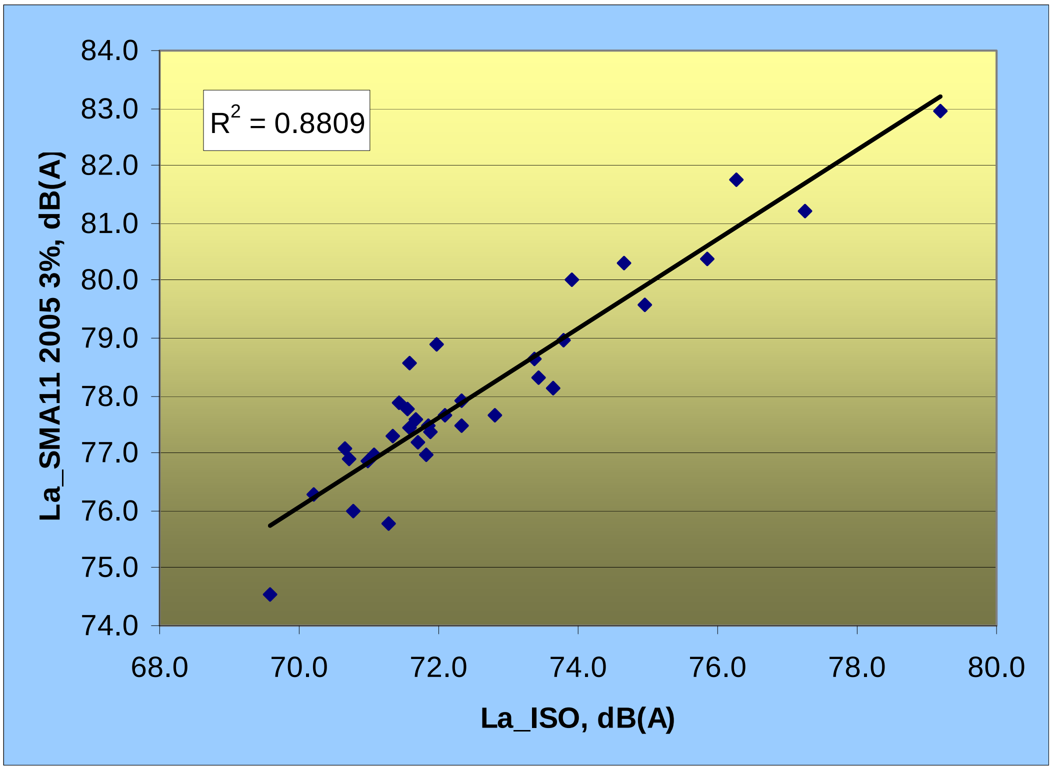


Figure 43 *SPERoN model: correlation between ISO-surface and surface 5. 80 km/h*

The correlation between the ISO-surface and the other surfaces show similar results at 50 km/h, as shown in these figures.
Only based on the *SPERoN* modelling results, one can conclude that there is a good correlation between the ranking of the tyres on an ISO-surface (Sperenberg) and on the dense SMA-surfaces in Norway.

6 Shore hardness

The Shore hardness has been measured on the tyres 1-11 by Chalmers University in 2007 (as part of the modelling). In 2008, the same tyres and tyres 12-15, were measured both by SINTEF and by TUG in Poland.

Table 24 show the results of these measurements. All data refers to measurements in the tread pattern.

Table 24 *Shore hardness of tested tyres*

Tyre no	Name	Dimensions	Chalmers, 2007, Shore A	SINTEF, 2008, Shore A	TUG 2008, Shore A
1	Dayton D110	175/70 R14	68	68	68
2	Sportiva G70	175/70 R14	67	65	67
3	Barum Brillantis	185/65 R15	67	67	67
4	Toyo 330	185/65 R15	72	70	70
5	Goodyear Excellence	195/65 R15	72	69	71
6	Conti PremiumContact 2	195/65 R15	71	70	70
7	Toyo Proxes T1R	205/55 R16	70	69	70
8	Nokian Hakka H	205/55 R16	70	69	69
9	Michelin Pilot Primacy HP	215/55 R16	70	68	70
10	Firestone Firehawk TZ200	215/55 R16	69	66	68
11	Conti EcoContact 3	195/65 R15	62	71	71
12	Yokohama dB V500	185/65 R15	-	73	73
13	Michelin Energy Saver	205/65 R15	-	66	68
14	Hankook Ventus Prime K105	205/65 R15	-	67	70
15	Pirelli P7	205/65 R15	-	64	65

As can be seen from the table, there is quite a good agreement between the measured values. The only exception is a rather low value for tyre 11, at the Chalmers measurements in 2007.
It is not known if this rather low value influences the modelling results. According to the levels in tables 22 and 23, this tyre has an average noise level.

Recent findings show that the rolling noise level depends on the Shore hardness of a tyre [Sandberg, Ejsmont[9]].
These data relates to the performance of the same tyre as the value of the Shore A increases over time.
If one compares the relationship between the Shore hardness measured by Chalmers on tyres 1-11 with the modelling results on surface 1 (SMA11 2005), the correlation is poor, as shown in figure 44. Similar results can be found for the correlation between the Shore hardness results for tyres 1-15 measured by TUG and the ISO-drum results, as shown in figure 45. Here, the correlation even seems to be negative. According to Sandberg[9], the noise is generally more related to hardness for rough surfaces than smooth, as figures 44 and 45 also indicates.

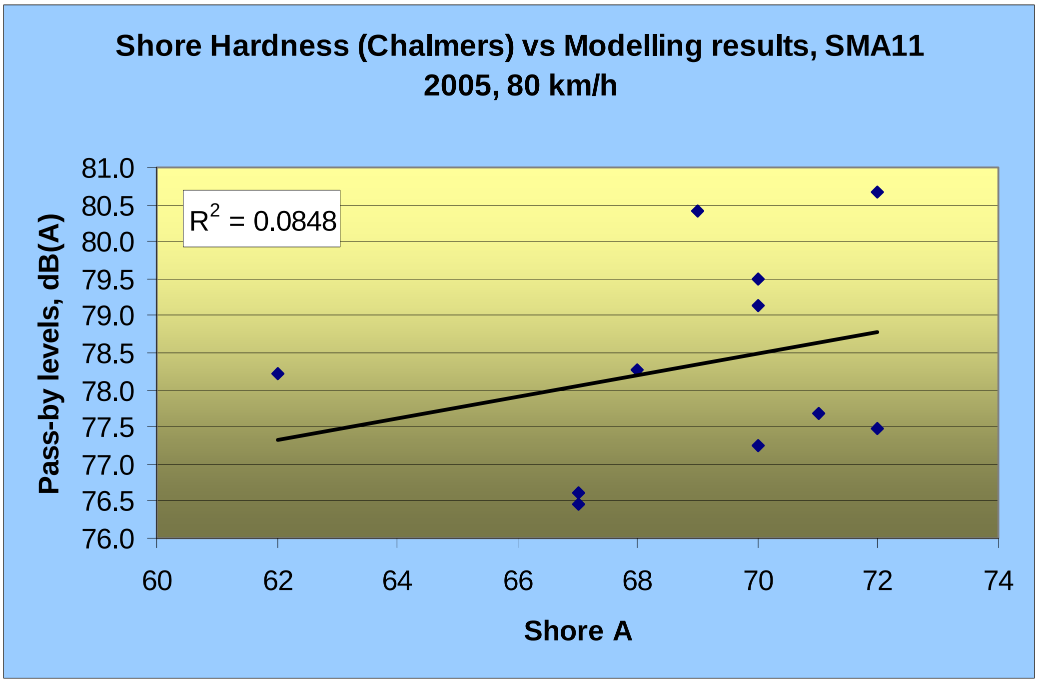


Figure 44 *Correlation between Shore hardness and SPERoN-results on surface 1*

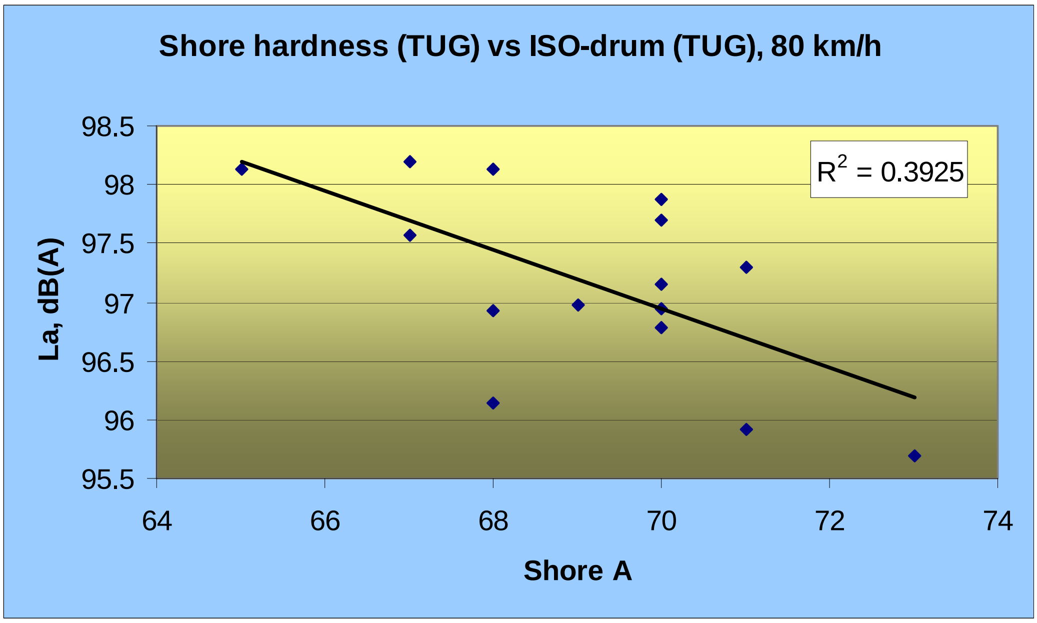


Figure 45 *Correlation between Shore hardness and ISO-drum results*

7 Rolling resistance

Classification of tyre rolling resistance is determined from the rolling resistance coefficient $c_{R,}$, Calculated from the average values of the rolling resistance force in Newton [N], divided by the test load in [kg] and g [m/s^2], multiplied by 100 [%].

The rolling resistance (ISO 8767) of tyres 1-15 has been measured by TUG at two different replicas of road surfaces; a safety walk surface (SW- very smooth surface) and on the APS-4 (rough) surface. The rolling resistance was measured at three speeds; 50, 90 and 120 km/h. The results are shown in table 25. The table show that the absolute values of the rolling resistance is higher on the rough surface, than on the smooth, but the variation of the values is the same within each of the surfaces. Tyre design parameters are clearly influencing the rolling resistance.

Table 25 *TUG rolling resistance results,* c_R [%]

		Results							
		Safety Walk			APS (rough)				
Tyre	**Hardness**	**50**	**90**	**120**	**50**	**90**	**120**	**P [N]**	**p [kPA]**
1	68	1.06	1.06	1.07	1.46	1.52	1.52	4120	210
2	67	0.98	0.98	0.98	1.38	1.45	1.47	4120	210
3	67	1.05	1.07	1.07	1.49	1.57	1.56	4120	210
4	70	0.99	1.05	1.13	1.51	1.58	1.59	4120	210
5	71	1.05	1.04	1.01	1.48	1.50	1.44	4120	210
6	70	0.91	0.92	0.92	1.39	1.40	1.38	4120	210
7	70	1.12	1.08	1.06	1.50	1.51	1.52	4120	210
8	69	1.00	0.99	0.97	1.38	1.42	1.43	4120	210
9	70	0.98	1.02	1.01	1.50	1.53	1.53	4120	210
10	68	1.17	1.15	1.11	1.60	1.63	1.62	4120	210
11	71	1.05	1.04	1.06	1.43	1.44	1.42	4120	210
12	73	1.05	1.04	1.06	1.51	1.54	1.52	4120	210
13	68	0.80	0.84	0.86	1.30	1.31	1.33	4120	210
14	70	1.11	1.11	1.11	1.59	1.62	1.58	4120	210
15	65	0.97	1.04	1.05	1.39	1.44	1.43	4120	210

Tyre 13, Michelin Energy Saver, has been labelled as a “green” tyre with low rolling resistance. The table confirms that this tyre has the lowest rolling resistance of the measured tyres under these laboratory conditions. The results also show that the rolling resistance very much depend on the roughness of the road surface. On the Safety Walk, tyre 13 has a rolling resistance coefficient of 0.8 at 90 km/h, while the coefficient on the APS-4 is 1.3. According to a Danish investigation [Bendtsen[10]], this can increase the fuel consumption in the order of 10-12 %.

In figure 46, the correlation between the rolling resistance values at 90 km/h on the two drum replica surfaces are shown.

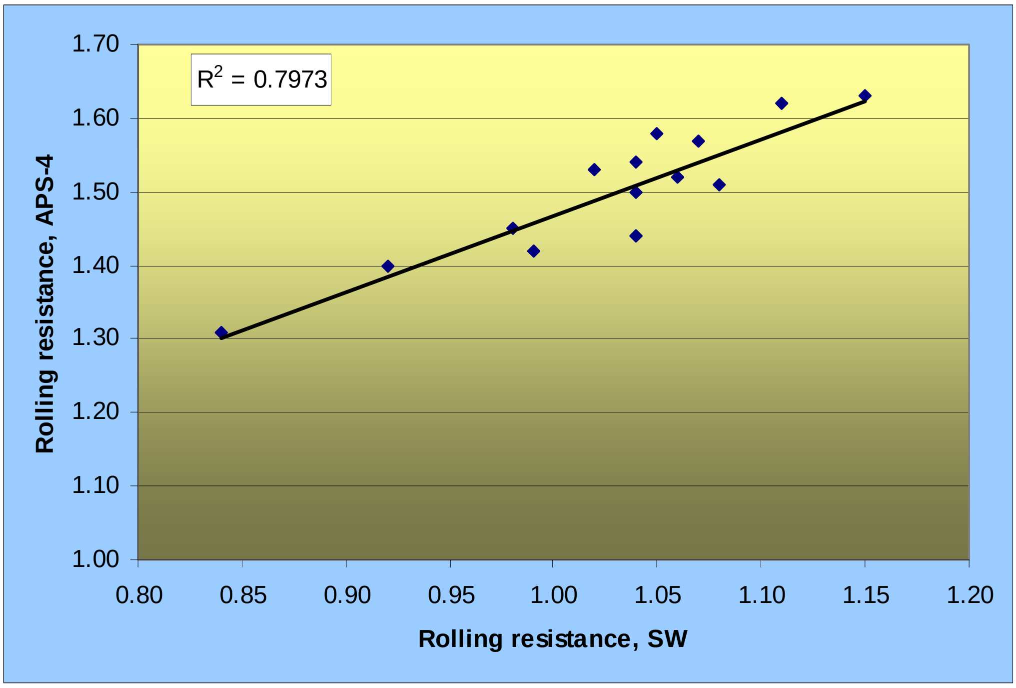


Figure 46 *Correlation between rolling resistance c_R on Safety Walk (SW) and APS-4, 90 km/h*

In figure 47, the rolling resistance c_R at 90 km/h measured on the rough APS-4 surface is correlated with the drum measurements of noise levels on the same surface (80 km/h).

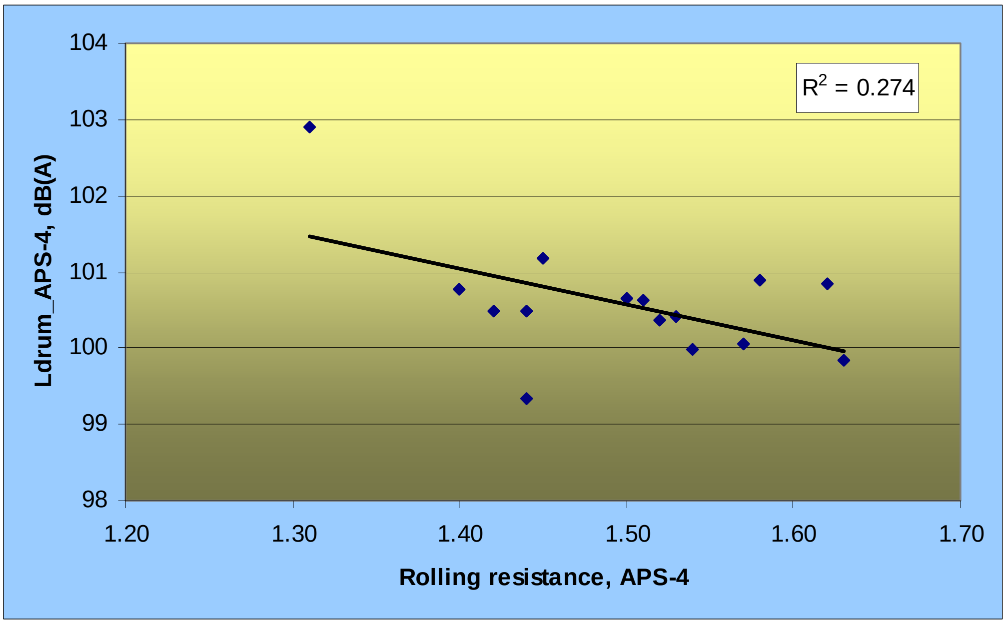


Figure 47 *Rolling resistance c_R (90 km/h) and noise level (80 km/h) on the APS-4 surface*

As can be seen from figure 47, there is a slight negative correlation. However, the slope is very much decided by one single tyre; tyre 13 (Michelin Energy Saver). If this tyre is excluded from the samples, the correlation would be approximately zero (r^2 = 0.009).

In figure 48, the relationship between the rolling resistance on the APS-4 surface and the measured CPX-levels on surface 7 (the oldest of the SMA-surfaces measured in 2008) is shown.

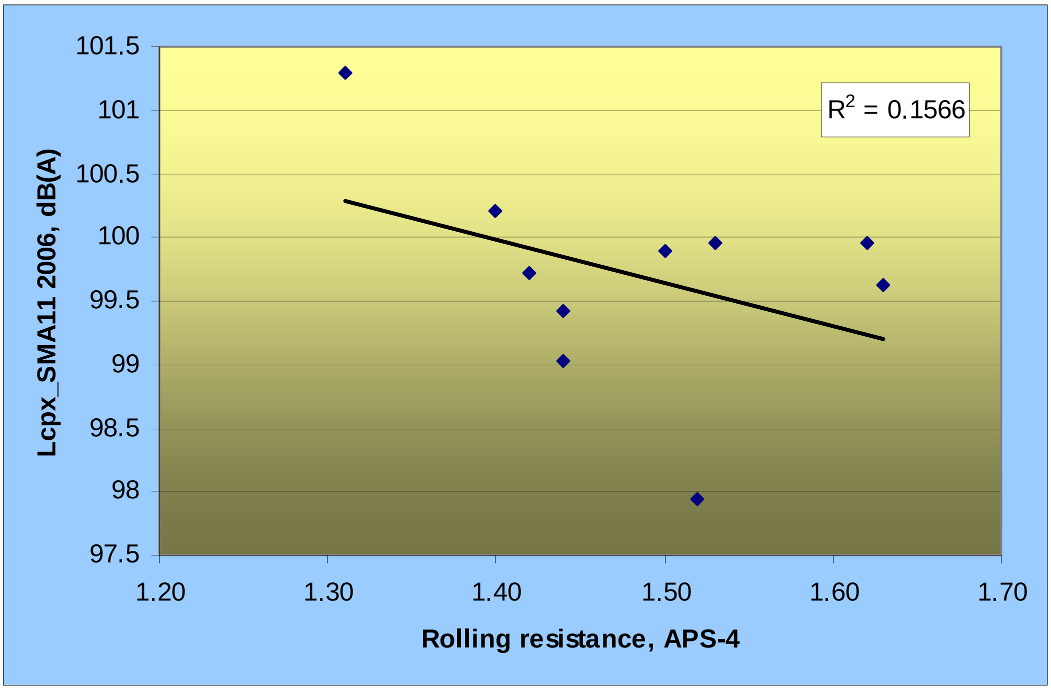


Figure 48 *Rolling resistance on APS-4(90 km/h) and CPX-level on surface 7 (80 km/h)*

Again, the correlation is somewhat negative, but mainly decided by tyre 13. If this tyre is removed from the samples, the correlation is approximately zero.

In figure 49 and 50, the relationship between the rolling resistance on the smooth surface (SW) and the CPX-levels on a two year old double layer surface, no 10 (figure 49) and a new, double layer porous surface, no 12, (figure 50) is shown.

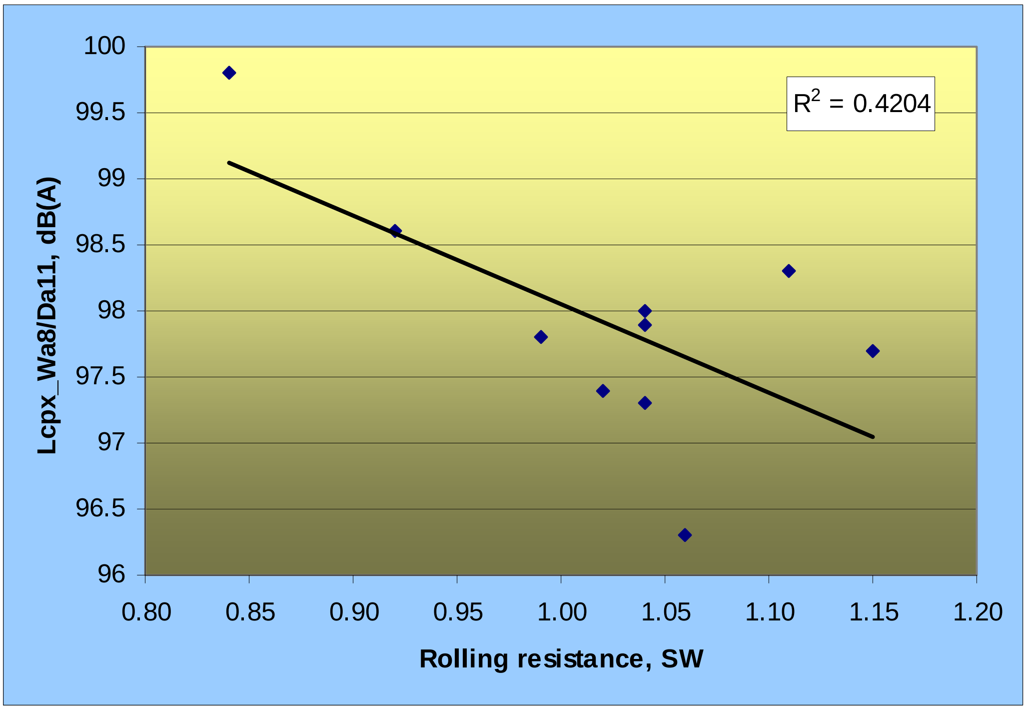


Figure 49 *Rolling resistance on Safety Walk (90 km/h) and CPX-level on surface 10 (80 km/h)*

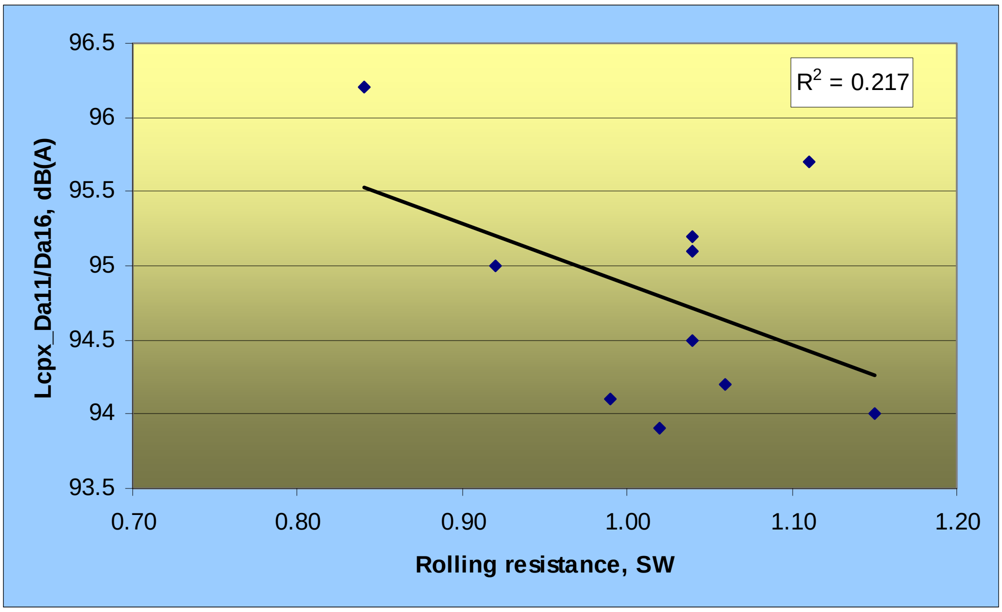


Figure 50 *Rolling resistance on Safety Walk (90 km/h) and CPX-level on surface 12 (80 km/h)*

The results for tyre 13 certainly influence the correlation, also on the smooth surfaces. On the two year old porous surface (no 10), the negative correlation seems to be a little stronger (figure 49).

8 Correlations

In the previous chapters, correlations of results within the same mode of operation have been presented.

It is of interest to study if there is any correlation between the modelling results and CPX-measurements, between modelling and drum measurements, and between CPX-measurements and drum measurements. The correlation analysis is based on linear regression of overall dB(A)-levels only. The correlation is then restricted to identify linear relationship between two parameters only. This introduces some restrictions and concerns, as the generation mechanisms of tyre/road noise is very complex and influenced by a wide range of parameters. The correlation analysis presented here is selected to study if there is a possibility to rank tyres on an overall dB(A)-level by using different modes of operations, see also chapter 8.4.

8.1 Correlation between *SPERoN* modelling results and CPX-measurements.

Tyres 1-11 have all been measured with the CPX-trailer on surfaces 1-6, as well as been modelled on the same surfaces. The correlation between measured CPX-levels (overall dB(A)) and modelled levels for surface 1 (SMA11 2005) is shown in figure 51 for 50 km/h and figure 52 for 80 km/h.

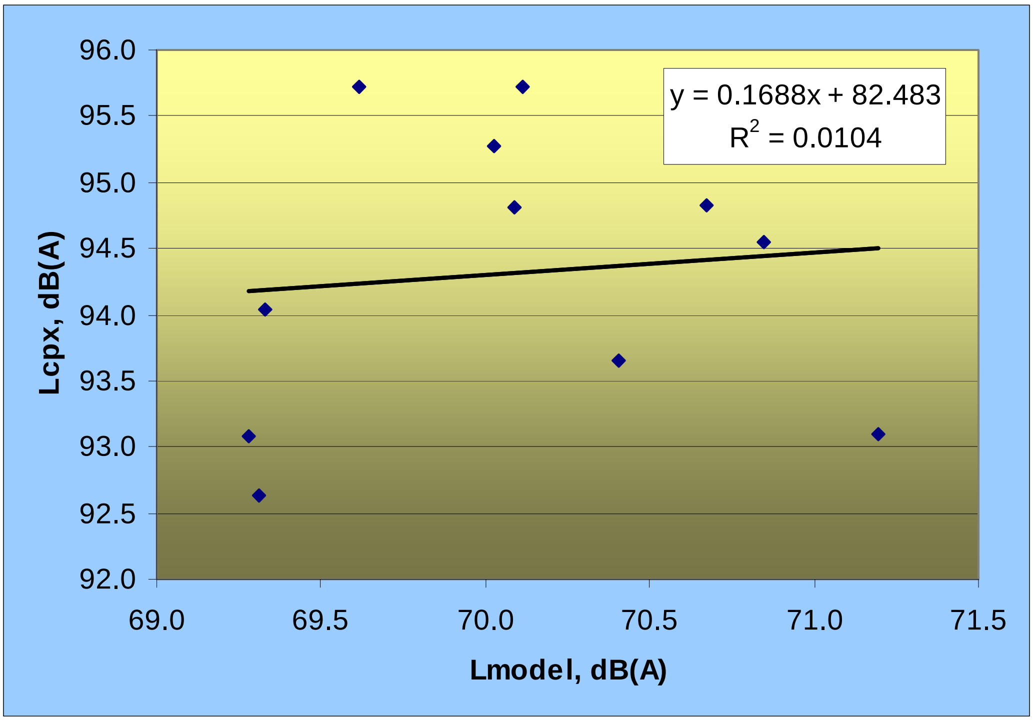


Figure 51 *Surface 1, SMA11 2005, Correlation between modelling and CPX-measurements, 50 km/h*

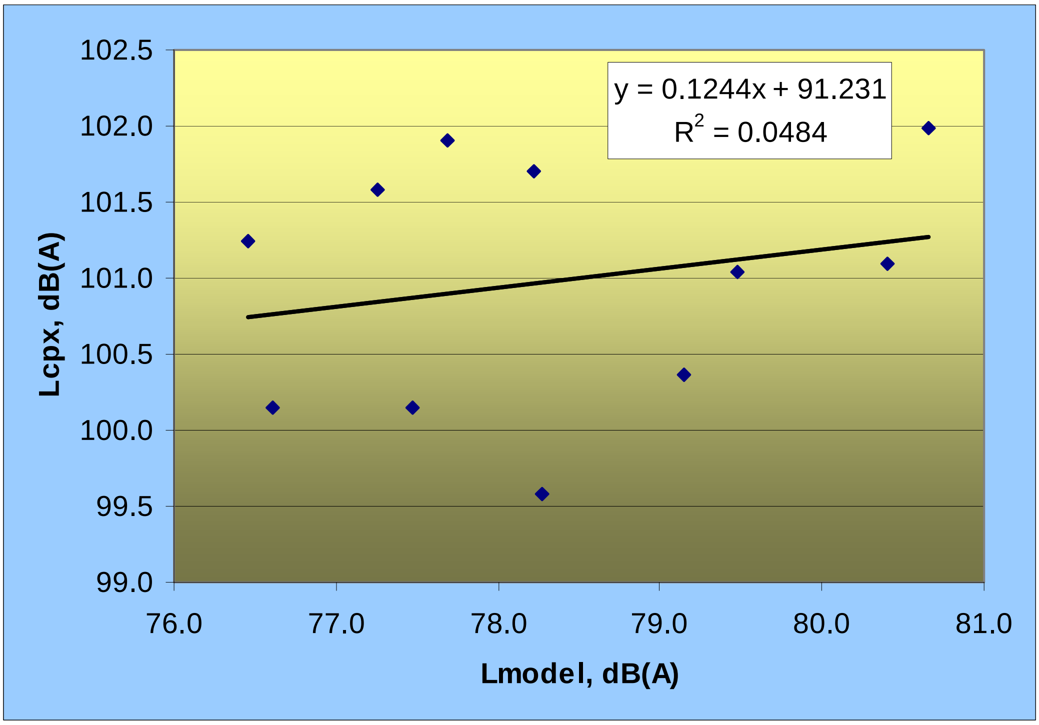


Figure 52 *Surface 1, SMA11 2005, Correlation between modelling and CPX-measurements, 80 km/h*

As these results show, there is no clear correlation between the modelled and measured results for these 11 tyres if only the overall dB(A)-levels of the modelling part is taken into account and where the uncertainty is not included (see chapter 11). Similar results for correlation were found for all the other 5 road surfaces. See chapter 8.4 for general comments on the lack of correlations.

In figures 53 and 54, the correlation between the modelled results on the ISO-surface (Sperenberg) and the measured CPX results on surface 1 (SMA11 2005) at 50 and 80 km/h are shown.

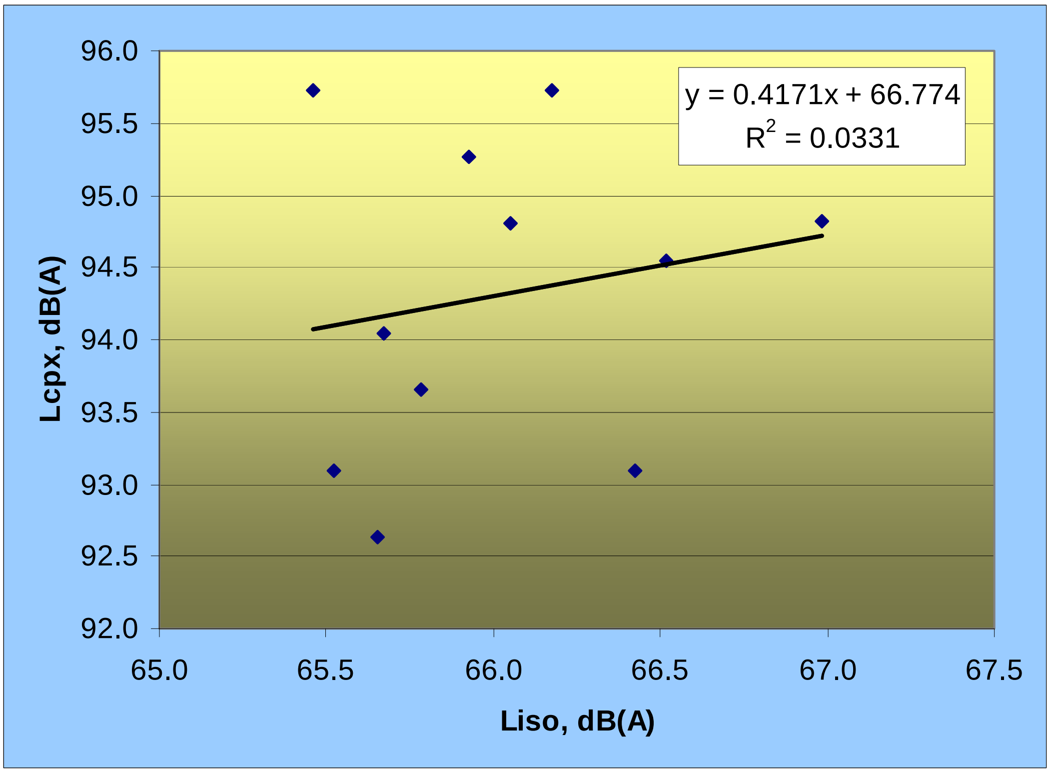


Figure 53 *Correlation between modelling results on ISO-surface and CPX-measurements on surface 1, 50 km/h*

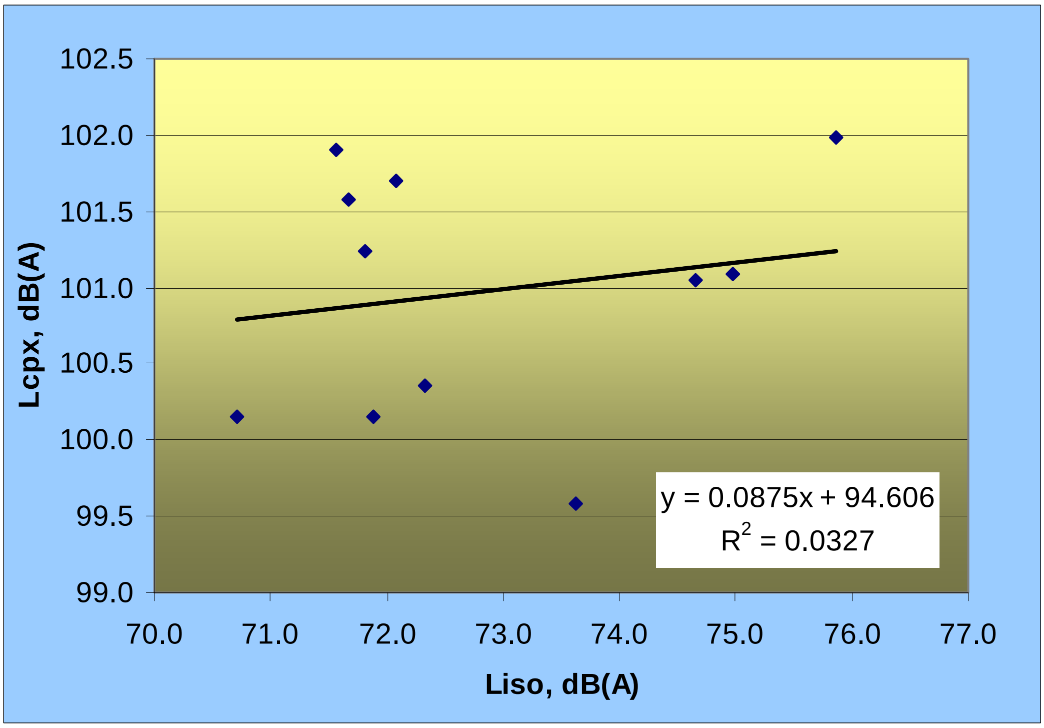


Figure 54 *Correlation between modelling results on ISO-surface and CPX-measurements on surface 1, 80 km/h*

As these figures show, there seems to be a poor correlation between the ranking of the tyres on the ISO-surface, and the CPX-measurements on a SMA-surface.

Similar lack of correlation between the ranking on the ISO-surface and CPX-measurements was found on all the other surfaces (surfaces 2-6).

The ISO-surface is a smooth surface. Tyres 1, 5, 6, 8, 9, 10 and 11 have all been modelled on the ISO-surface, as well as measured with the CPX-trailer on two new road surfaces (not exposed to winter conditions); surface 12 (two layer porous asphalt) and surface 13 (SMA11 2008).

In figure 55 and 56 the correlation between the modelled results on the ISO-surface and CPX on surface 12 is shown for 50 and 80 km/h.

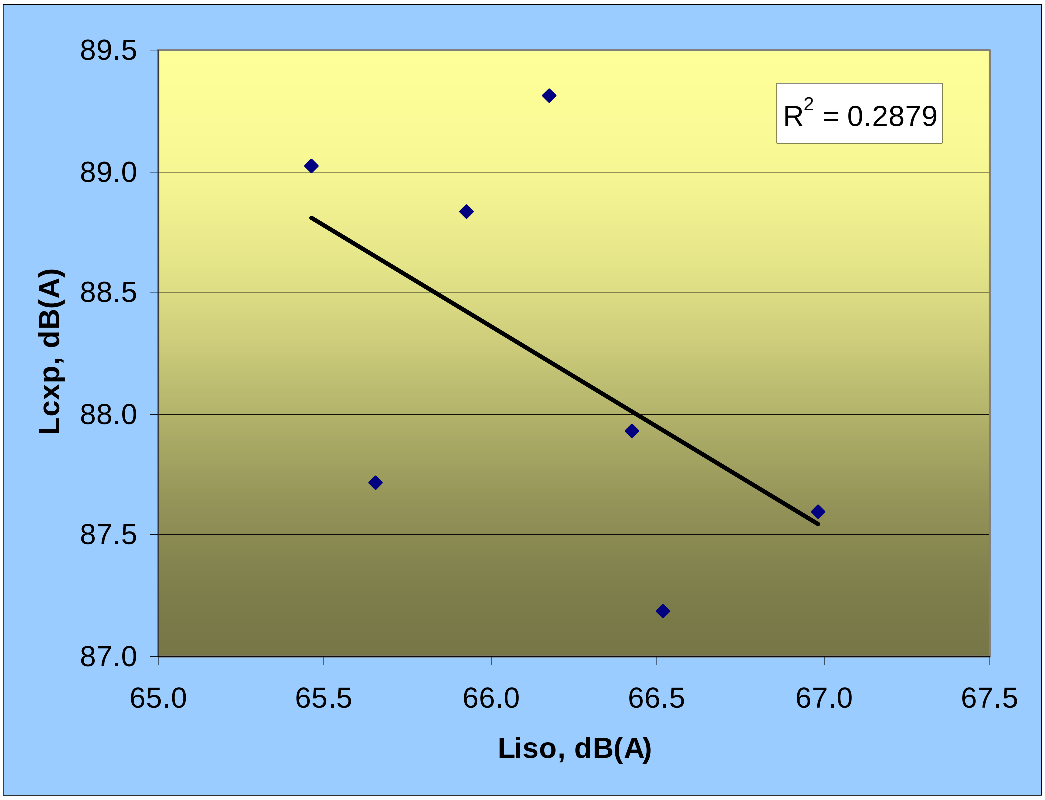


Figure 55 *Correlation between modelling results on ISO-surface and CPX-measurements on surface 12, Da11/Da16, 50 km/h*

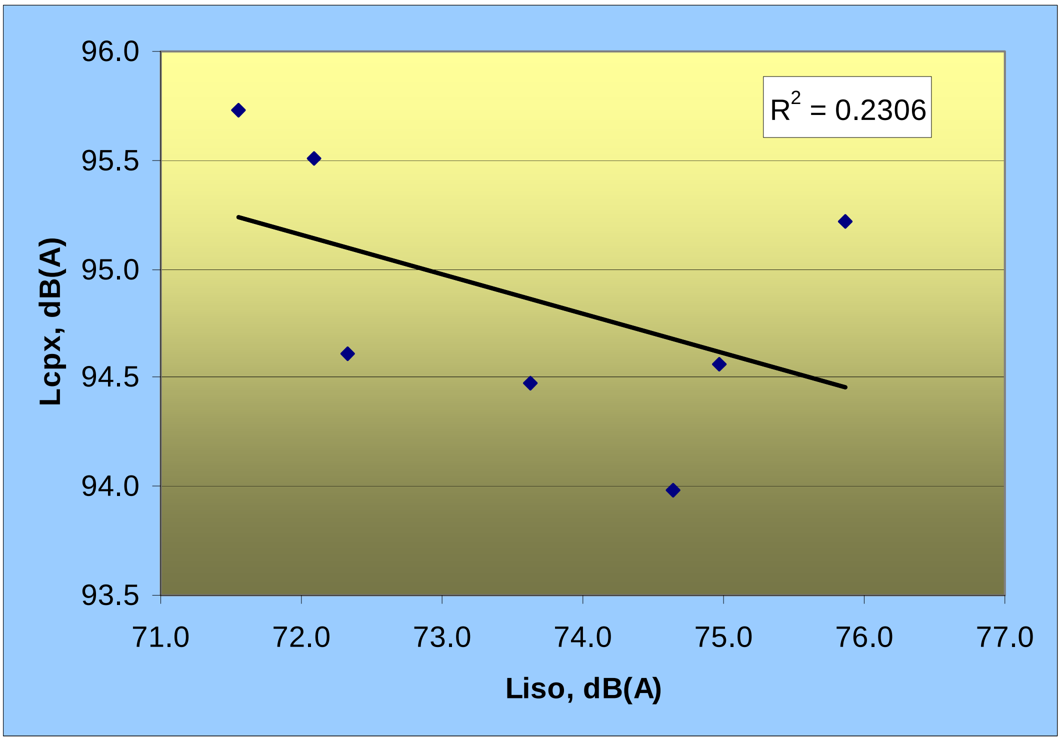


Figure 56 *Correlation between modelling results on ISO-surface and CPX-measurements on surface 12, Da11/Da16, 80 km/h*

In both these cases, there is a negative correlation between the modelled results and the CPX-measurements.
The same results can be found if we correlate the ISO-results with CPX-measurements on any of the other porous surfaces (surfaces 8, 9, 10, 11) or with the new SMA11-surface (no.13).

8.2 Correlation between *SPERoN* modelling results and drum measurements

The tyres 1-11 are all modelled in the *SPERoN* model and measured on the TUG drum facilities.

In figure 57 and 58, the correlations between modelled results on the ISO-surface and the drum measurements on the ISO-surface are shown for 50 and 80 km/h.

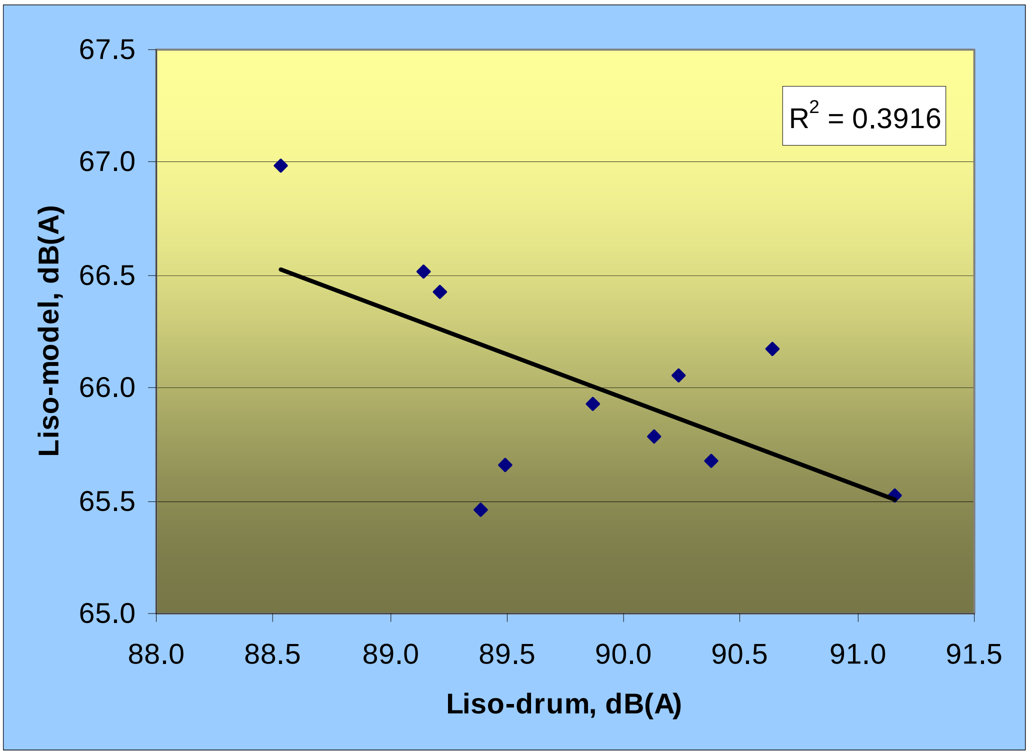


Figure 57 *Correlation between modelling on ISO-surface and drum measurements on replica of ISO-surface, 50 km/h*

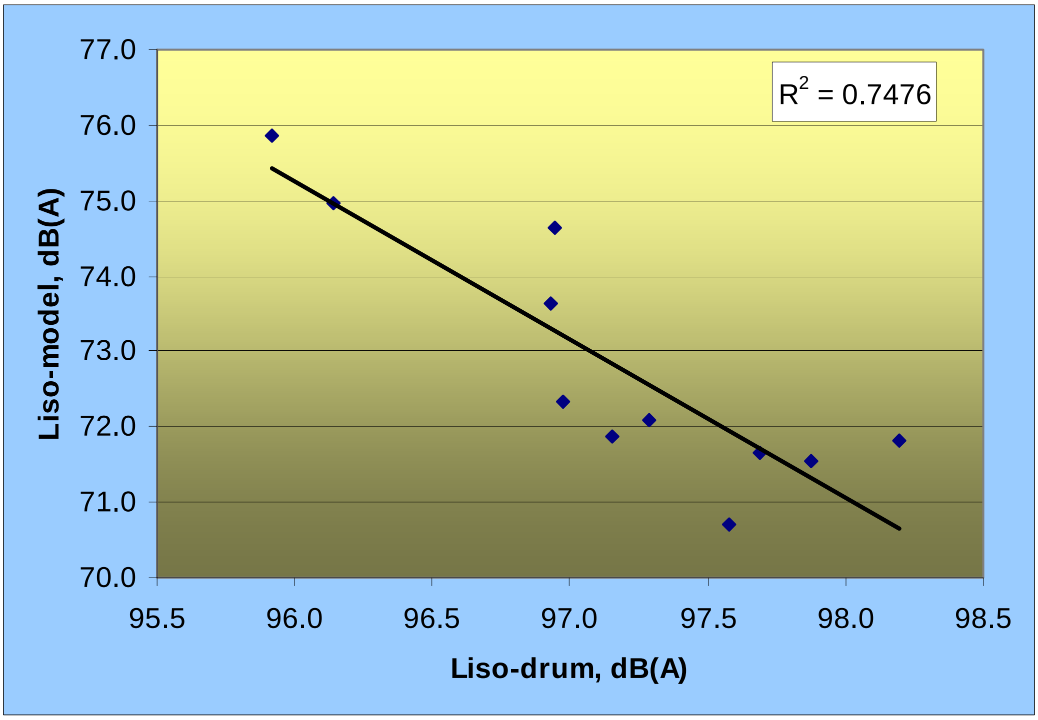


Figure 58 *Correlation between modelling on ISO-surface and drum measurements on replica of ISO-surface, 80 km/h*

Again, the correlation is negative, and especially at 80 km/h, there is quite a strong negative correlation. It means that the some of the tyres modelled with the lowest levels on the ISO-surface of Sperenberg indeed have the highest levels on the ISO-drum surfaces.

In figures 59 and 60, the correlations between the modelled levels (ISO-surface) and the drum measurement results for the other two surfaces; the DAC-surface (GRB-S) and the rough surface (APS-4). The speed is 80 km/h.

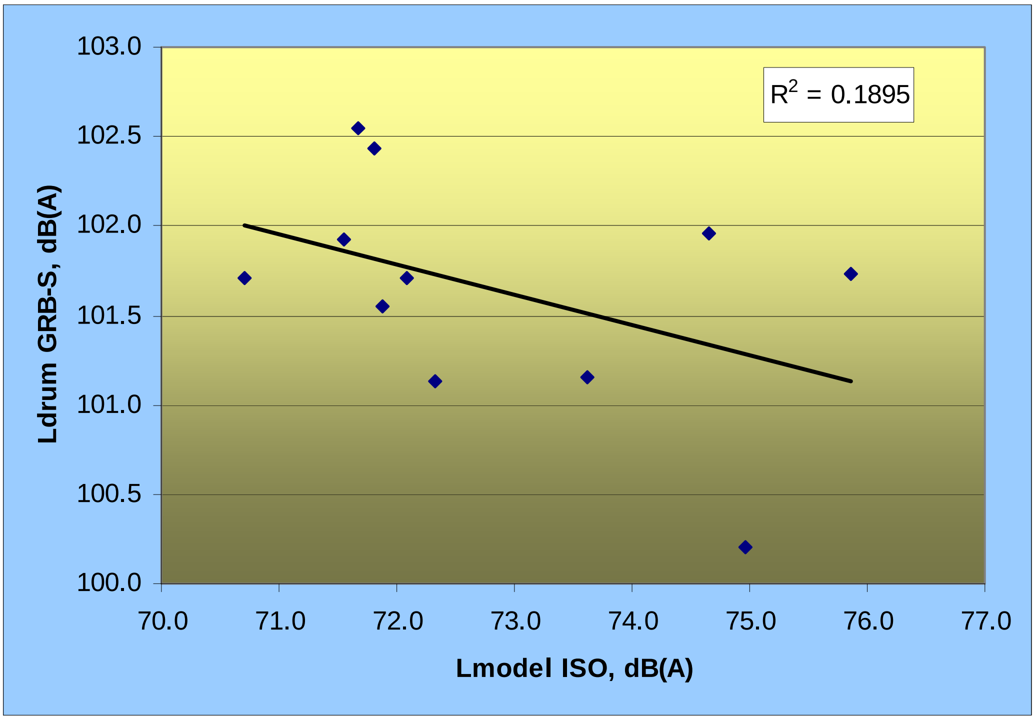


Figure 59 *Correlation between modelling on ISO-surface and drum measurements on the GRB-S surface, 80 km/h*

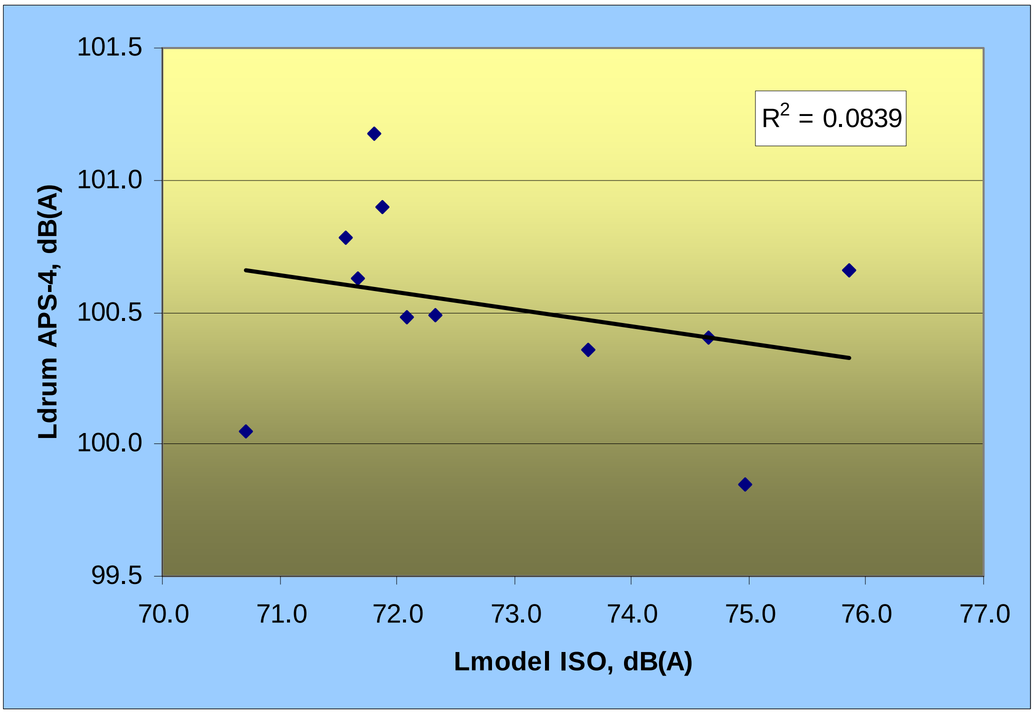


Figure 60 *Correlation between modelling on ISO-surface and drum measurements on the APS-4 surface, 80 km/h*

As both figure 59 and 60 shows, there is no significant correlation between the modelling results on the ISO-surface and the drum measurements on these two surfaces.

The lack of correlation can probably be explained by the following (see also 8.4):

- The two ISO-surfaces can have differences in the texture spectra and thus influence the noise levels.
- The excitation processes are influenced by the methodology; on the drum, there is a strong influence of the drum curvature, as it influences the attack angle, the pressure distribution, the horn effect, etc [Sandberg, Ejsmont[11]]. The TUG drum has a radius of 1.5 m and it has been shown that a small drum diameter can influence the standard deviation in the area of 0.7 dB(A), compared to a large drum diameter of 6.5 m [Sandberg[12]].

8.3 Correlation between CPX and drum measurements

The drum measurements are comparable to the CPX-measurements in that way that the microphones are in similar positions, close to the tyre.

As table 2 shows, tyres 1-15 have been measured on surfaces 7-13 using the CPX-trailer and have also been measured on the TUG drum facilities.

Surface 7 is the oldest SMA-surface (in the 2008 measurement program), with two years of winter exposure and thus assumed to be the roughest surface. In figure 61, the correlation between the CPX-measurement on this surface and the drum measurements on the APS-4 surface is shown for 80 km/h.

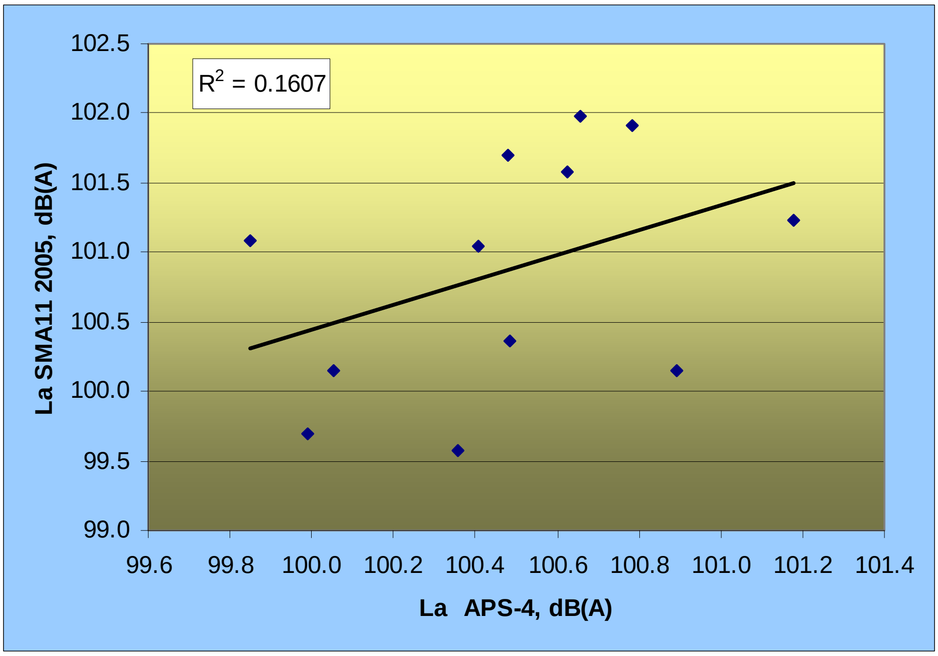


Figure 61 *Correlation between CPX-measurements on surface 7 and drum measurements on the APS-4 surface, 80 km/h*

The difference in levels on the APS-4 surface is small, only about 1.3 dB(A) and this can influence the correlation, which is very low.

In figure 62, the correlation between the GRB-S surface (DAC-type) and surface 7 is shown for 80 km/h.

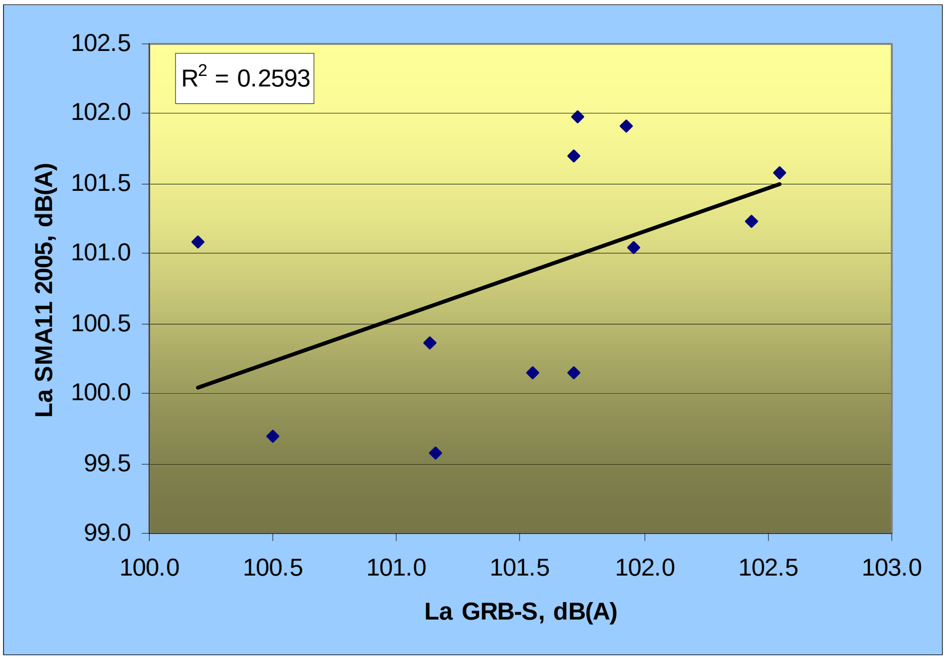


Figure 62 *Correlation between CPX-measurements on surface 7 and drum measurements on the GRB-S surface, 80 km/h*

For the GRB-S surface, the correlation with CPX is somewhat better than for the APS-4 surface.

The correlation between the drum measurements on the smooth ISO-surface and the new and relatively smooth SMA11 surface (surface 13) is shown in figure 63. In figure 64, the correlation between the ISO-surface and the two layer porous surface (surface 12) is shown. For both cases, the speed is 80 km/h.

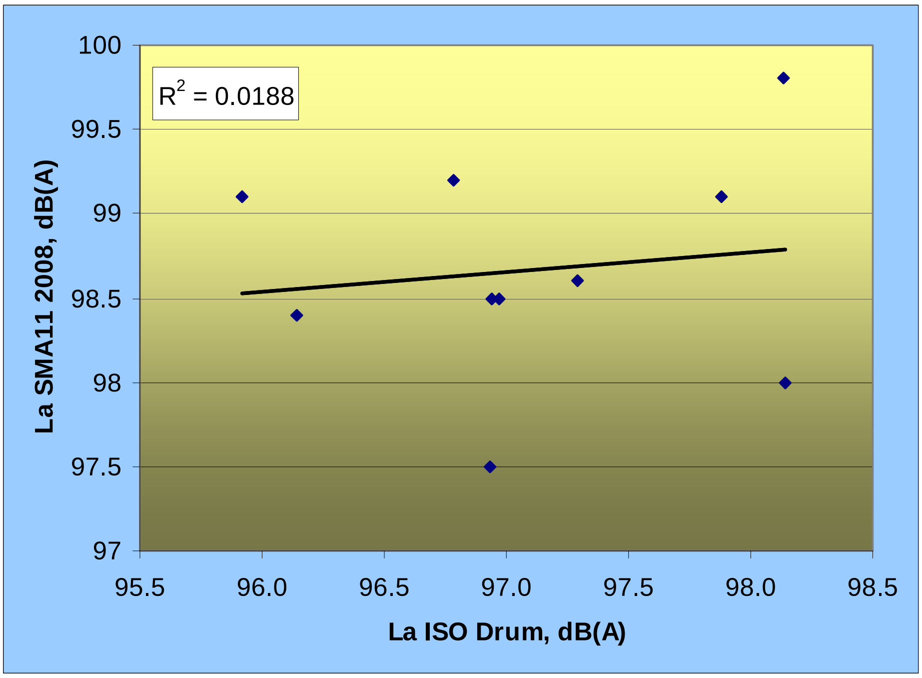


Figure 63 *Correlation between CPX-measurements on surface13 and drum measurements on the ISO-surface, 80 km/h*

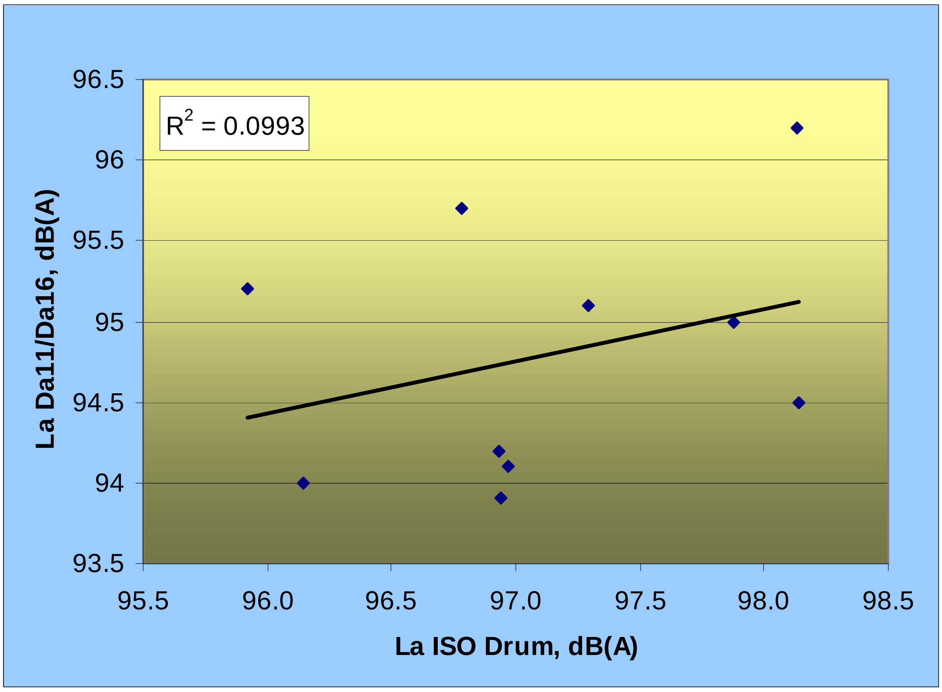


Figure 64 *Correlation between CPX-measurements on surface12 and drum measurements on the ISO-surface, 80 km/h*

All figures 61 to 64 show that the correlation between the drum measurements and the CPX-measurements are poor, when only the overall dB(A)-levels are considered.

8.4 General comments on the correlation results

The correlation based on linear regression of the overall dB(A)-levels between the different modes of operation is based on an assumption that there exist such a linear dependency.
All the results above show that such a linear correlation for tyre/road noise does not exist, where different tyres, road surfaces and modes of excitations (CPX, drum, and model) are compared.

Beckenbauer and Kropp[18] have shown that one single tyre on one single surface (surface dressing with 8 mm stone size) can have a linear correlation between the coast-by noise level and with speed in a range from 30 to 120 km/h, while the same tyre on another surface (ISO) have a non-linear relationship in the same speed range. This demonstrates the non-linearity of the noise generation mechanisms.

When comparing for instance CPX-measurements and drum measurements, it is clear that the generation mechanisms are strongly dependent on the testing facilities. On the drum, with a relative small curvature, the shape of the horn will be different from the road, and this changes the radiation conditions severely. Also on a small-diameter drum, the shape of the footprint on a tyre is different from a tyre tested on a flat road. This means that the angle of attack of the rubber blocks of the tyre is different on these two conditions, and this influences the generation of noise.

In general, the correlation procedure used is not able to distinguish where the differences of the two variables (overall dB(A)-levels) come from. This underlines the need to do comparable tests, when noise ranking of tyres on ISO-surface and normally used road surfaces in Norway is investigated on the basis of maximum dB(A)-levels.

It is likely that a regression analysis between important frequency components (for tyre/road noise) would be more successful, when comparing different modes of operations.

Frequency spectra from CPX-measurements and from the *SPERoN* model are available from 11 of the tyres, and further analyses of any correlation between selected frequency components are recommended.

9 Comparison with other data

The selection of the tyres used for CPX and drum measurements was based on a representativity of aftermarket tyres in Norway, as well as some OE-tyres of new vehicles. The choice was coordinated with a national organization of tyre importers in Norway.

In order to investigate the representativity of the selected tyres, the modelled ISO-levels at 80 km/h was adjusted according to the EU-directive 2001/43/EC (rounding down to the nearest integer and reduced with -1 dB(A)). The ISO-levels of the 11 selected tyres for modelling and the 23 other tyres that is part of the *SPERoN*-database, have been compared to three other available statistics:
a) FEHRL-report[13]: 34 tyres in the size range from 155/70 R13 to 225/60 R16. These data includes measurements of 20 tyres by SINTEF and M+P in 2005[14].
b)A list of low noise tyres from M+P in the Netherlands[15]: 105 tyres in the size range from 155/60 R14 to 225/45 R17.
c) Published data from a test conducted by ADAC (Germany) in 2008[19]: 18 tyres of the size 185/60 R14 and 17 tyres of the size 205/55 R16.

In figure 65, all these data are presented, representing class C1 of tyres.

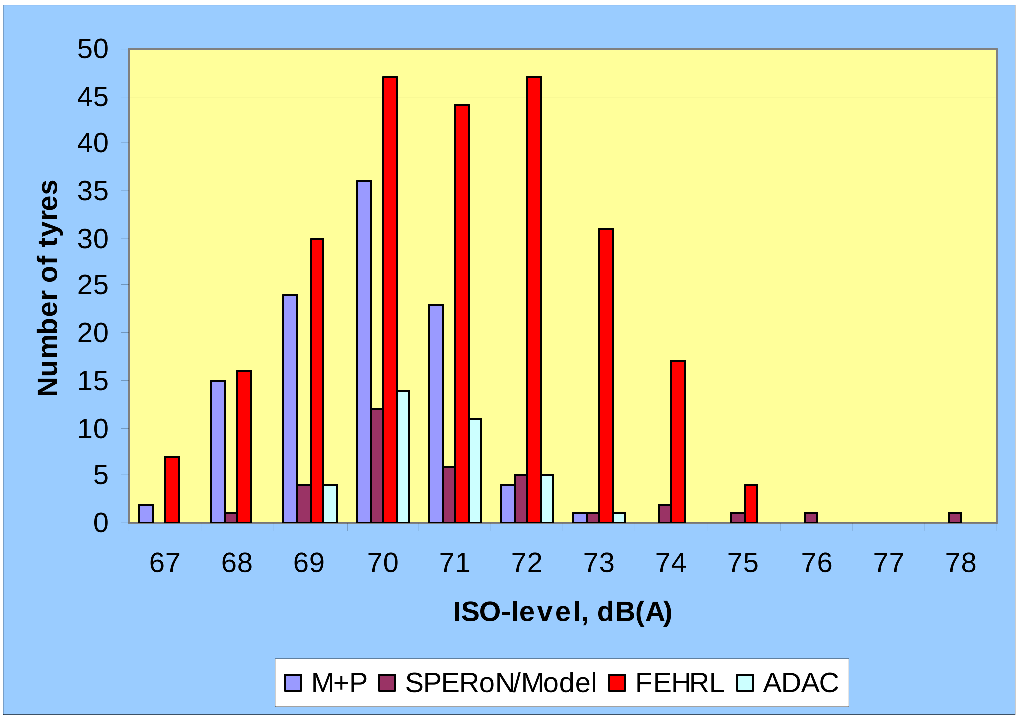


Figure 65 *Comparison of ISO-levels from M+P, FEHRL, ADAC and SPERoN model. Class C1-tyres*

One of the tyres (no. 37) has been modelled with a rather high ISO-level of 78 dB(A). According to Beckenbauer and Kropp[20] this tyre has some strange features relating to the tread pattern, and is not representative for a normal tyre.
Except for this tyre, the modelled data on the Sperenberg ISO-surface seems to be quite similar to the ADAC-data, and also in the same range as the FEHRL and the M+P-data.

The representativity of the ISO-surface was also studied in the FEHRL-report[13]. As part of the study, the SINTEF/M+P-data from 2005[14] and TRL were included. Measurements on SMA8-SMA14 and HRA surfaces were compared with results on ISO-surfaces. The correlation was quite good on the smooth surfaces like SMA8/SMA11 (in NL), but poor on the rougher surfaces like HRA (UK) and SMA11/SMA14 (Norway).

10 Noise ranking

The noise ranking of tyres in this investigation is solely based on the CPX-measurements. This is mainly due to lack of correlation in the overall dB(A)-levels, between the other two modes of operations and the CPX-results.

The ranking has been done for tyres 1-15 and 39-40 (table 2). It should be pointed out that the tyres have different dimensions and the influence of this is discussed in chapter 11.4.

The tyres are ranked according to the measured noise level at 50 and 80 km/h on the 13 different road surfaces listed in table 3. Not all tyres have been measured at all road surfaces.

Figures 66 and 67 show the ranking of the tyres based on the measured levels at the two reference speeds. The data includes measurements in 2007 (surfaces 1-6) and in 2008 (surfaces 7-13). The road surfaces are sorted according to age (oldest to the left).

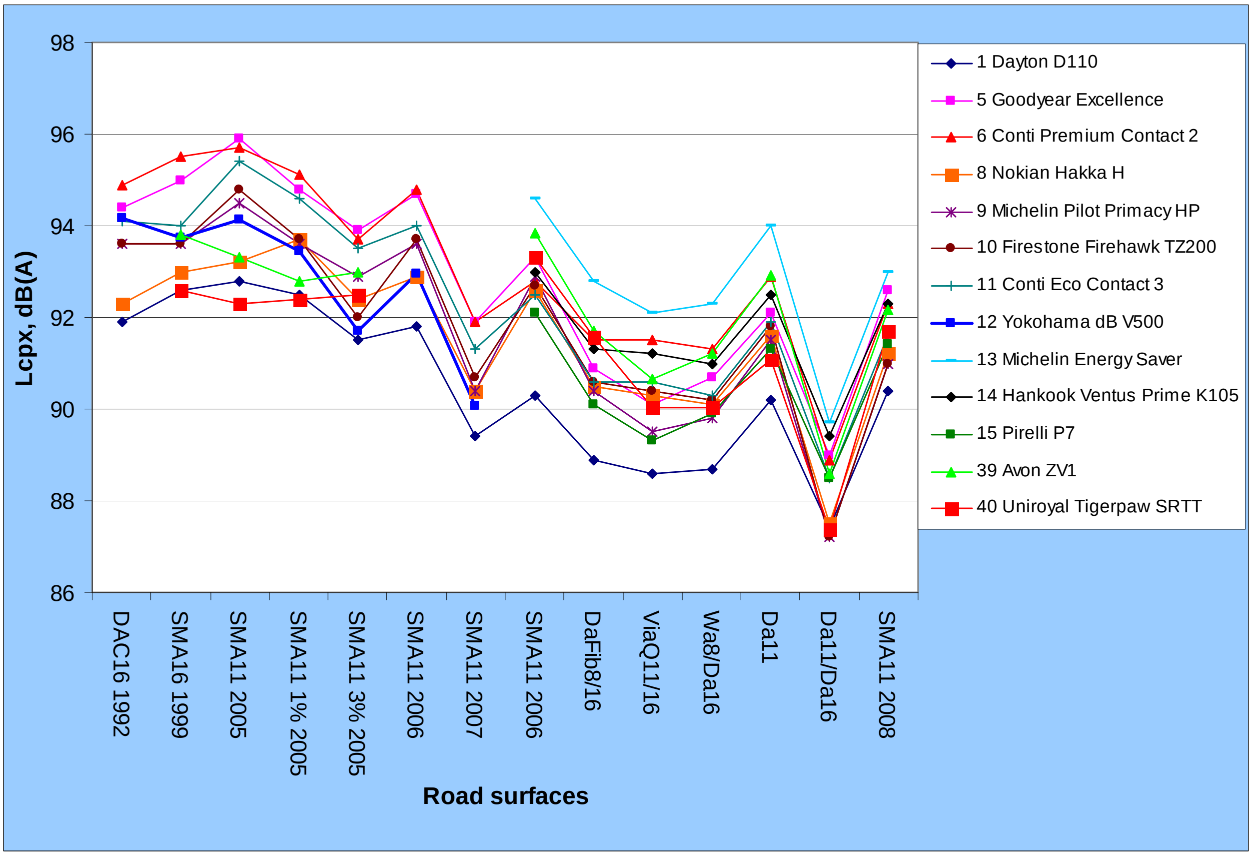


Figure 66 *CPX-measurements: noise ranking of tyres at 50 km/h*

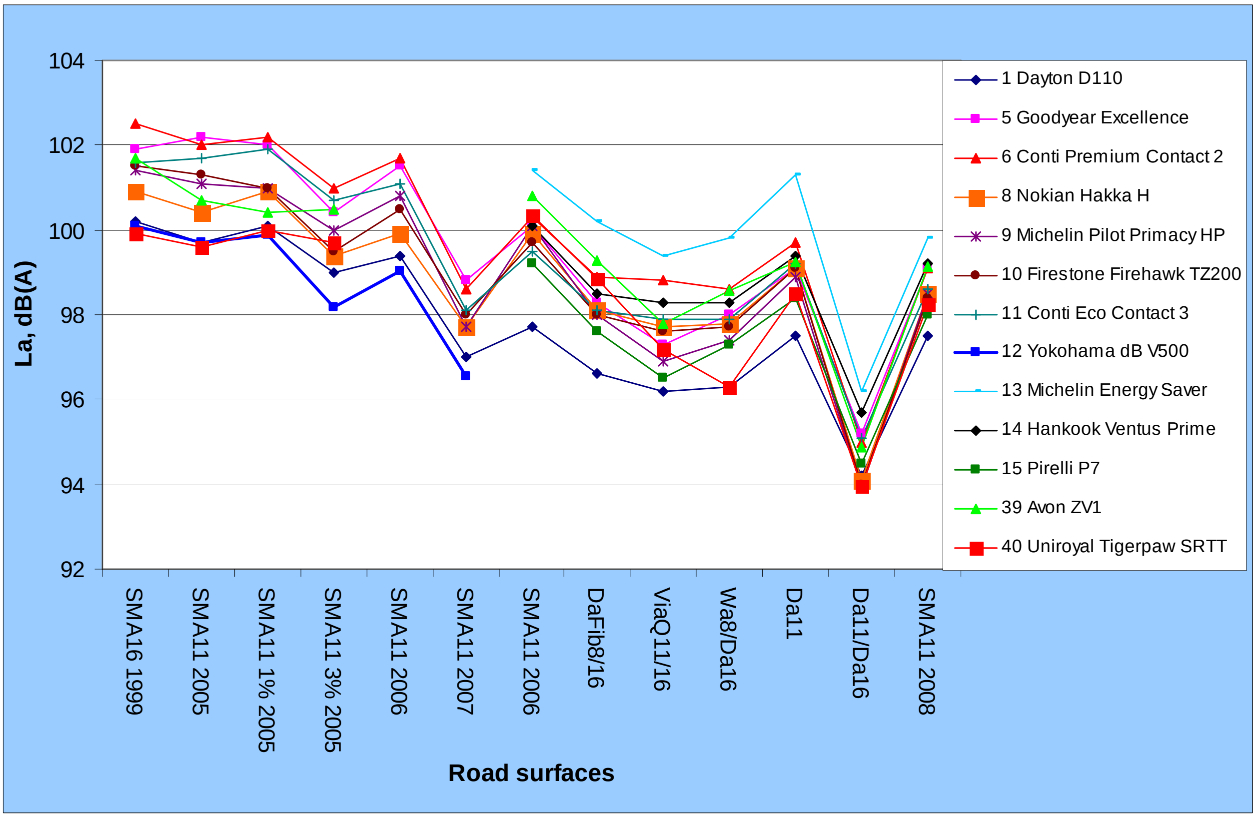


Figure 67 *CPX-measurements: noise ranking of tyres at 80 km/h*

For all CPX-measurements, the noise levels varies over the measured distance (approximately 300 m), resulting in a certain standard deviation. The 95 % confidence interval based on the standard deviation defines the expected variation of the measured level within this confidence interval. This confidence interval needs to be taken into account when a ranking of the tyres is performed.

A chosen classification system for the ranking is shown in table 26. From the table, it can be noted that both classes A and C have a wider range of levels (1.4 dB(A)) compared to Class B (1 dB(A)). This is due to the measured range of levels on the different surfaces.

Table 26 *Noise classes of tyres*

Class A	0.6 – 2 dB(A) more silent than average
Class B	Average, ± 0.5 dB(A)
Class C	0.6 – 2 dB(A) more noisy than average

The classification results are given in table 27 for 50 km/h and in table 28 for 80 km/h. The measured confidence intervals are included in the classification. It the confidence interval gives an overlap between two classes, the main part of the interval defines the class.

The ***average*** level (in Class B) is based on all the tyres measured on the specific surface.

No CPX-measurements were performed at surface 6 at 80 km/h, due to a speed limit of 60 km/h.

Table 27 *Noise classification of tyres, 50 km/h*

Tyre no	**Surface 1**	**2B**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	A	A	A	A	A	A	A	A	A	A	A	A	A
2	B	C	B	B	B	B	-	-	-	-	-	-	-
3	A	B	A	B	B	A	-	-	-	-	-	-	-
4	A	B	B	B	B	B	-	-	-	-	-	-	-
5	C	C	C	C	C	B	B	B	B	B	B	B	C
6	C	C	C	C	B	C	B	C	C	C	C	C	B
7	B	B	C	C	C	B	-	-	-	-	-	-	-
8	A	B	B	A	A	A	B	B	B	B	B	B	A
9	B	B	B	A	B	B	B	B	A	A	B	A	A
10	C	B	B	B	A	B	B	B	B	B	B	A	A
11	C	B	B	B	C	B	B	B	B	B	B	B	B
12	B	A	B	A	A	B	-	-	-	-	-	-	-
13	-	-	-	-	-	-	C	C	C	C	C	C	C
14	-	-	-	-	-	-	B	B	C	B	B	C	B
15	-	-	-	-	-	-	A	A	A	A	A	B	B
39	-	-	-	-	-	-	C	C	B	C	C	B	B
40	-	-	-	-	-	-	C	B	B	B	A	A	B

= dense surfaces   = porous surfaces

Table 28 Noise classification of tyres, 80 km/h

Tyre no	Surface 1	2B	3	4	5	7	8	9	10	11	12	13
1	A	A	A	A	A	A	A	A	A	A	B	A
2	B	C	B	B	B	-	-	-	-	-	-	-
3	A	B	A	B	B	-	-	-	-	-	-	-
4	A	B	B	B	B	-	-	-	-	-	-	-
5	C	C	C	C	C	B	B	B	B	B	B	B
6	C	C	C	C	C	B	B	C	C	B	C	B
7	C	B	B	C	C	-	-	-	-	-	-	-
8	B	B	A	B	A	B	B	B	B	B	B	B
9	B	B	B	B	B	B	B	B	B	B	B	B
10	B	B	B	B	A	B	B	B	B	B	B	B
11	C	B	B	B	C	B	B	B	B	B	B	B
12	A	A	A	A	A	-	-	-	-	-	-	-
13	-	-	-	-	-	C	C	C	C	C	C	C
14	-	-	-	-	-	B	B	C	B	B	C	B
15	-	-	-	-	-	A	A	A	B	A	A	A
39	-	-	-	-	-	C	C	B	C	B	B	B
40	-	-	-	-	-	C	B	A	A	B	A	B

In the following, each of the tyres is evaluated based on the classifications in tables 27 and 28.

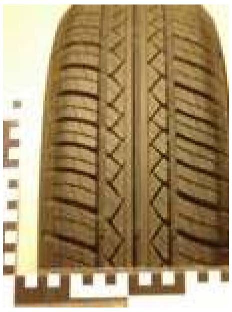
Tyre 1: Dayton D110 175/70 R14 84T

Comments:
This tyre is a Class A tyre on almost all surfaces, (except surface 12 at 80 km/h), independent of speed and type of road surface (dense/porous).

Tyre 2: Sportiva G70 175/70 R14 84T

Comments:
This tyre is a Class B on all dense surfaces and at both speeds, except for surface 2B (Class C).

Tyre 3: Barum Brilliantis 185/65 R15 88T



Comments:
This tyre is a Class A on half of the dense road surfaces and Class B on the other half, independent of speed.

Tyre 4: Toyo 330 185/65 R15 88T

Comments:
Except for road surface 1 (Class A), this is a Class B tyre on the dense surfaces, independent of speed.

Tyre 5: Goodyear Excellence 195/65 R15 91H

Comments:
This is a Class C on most of the dense surfaces, except surface 6, 7 and 13, but changes to Class B on the porous surfaces. The shift in classes is independent of speed.

Tyre 6: Conti Premium Contact 2 195/65 R15 91V

Comments:
On the majority of the road surfaces, this is a Class C-tyre. However, at some of the dense and porous road surfaces, the classification is shifted to Class B, predominantly at 80 km/h.

Tyre 7: Toyo Proxes T1R 205/55 R16 91W

Comments:
This tyre is a Class B on half of the dense surfaces and a Class C on the other half, independent of speed.

Tyre 8: Nokian Hakka H 205/55 R16 94H

Comments:
On the majority of the road surfaces, this is a Class B-tyre, especially at 80 km/h. However, at 50 km/h it is classified in Class A on 5 of the dense road surfaces.

Tyre 9: Michelin Pilot Primacy HP 215/55 R16 93H

Comments:
At 80 km/h, this is a Class B-tyre on all road surfaces. However, at 50 km/h it shifts to Class A on 2 of the dense surfaces and 3 of the porous.

Tyre 10: Firestone Firehawk TZ200 215/55 R16 97H

Comments:
At 50 km/h, this tyre shift from being Class B on most of the surfaces, to Class A on 3 of the dense surfaces, and even to Class C on surface 1. At 80 km/h, however, this tyre is Class B on all surfaces, except for surface 5 (Class A).

Tyre 11: Conti EcoContact 3 195/65 R15 91T

Comments:
This is a Class B-tyre on all road surfaces, independent of speed, except on surfaces 1 and 5 where it is a Class C-tyre.

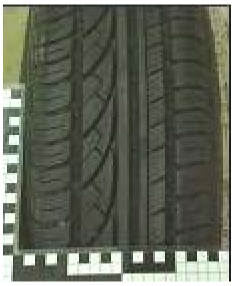
Tyre 12: Yokohama dB V500 185/65 R15 92H

Comments:
This tyre was launched as a special low noise tyre by the company. At 50 km/h it is a Class A-tyre on half of the surfaces (only measured on dense), and a Class B on the other half. However, at 80 km/h, it is a Class A on all the dense surfaces. This tyre was produced in 2004.

Tyre 13: Michelin Energy Saver (Green) 205/65 R15 94T

Comments:
As shown in table 25, this is a tyre with a low rolling resistance. However, it is the noisiest tyre on all the road surfaces (including the rough APS-4 surface at the TUG-drum) and is a Class C at both speeds.

Tyre 14: Hankook Ventus Prime 205/65 R15 95W



Comments:
On two of the porous surfaces (9 and 12), this is a Class C-tyre. For the other porous surfaces and two of the dense surfaces (7 and 13), this tyre is Class B. The classification is the same at both speeds.

Tyre 15: Pirelli P7 205/65 R15 94V

Comments:
At 50 km/h, this is a Class A-tyre at most of the surfaces, except for the two new surfaces (12 and 13), where it is Class B. At 80 km/h, it is a Class A on all surfaces, except for surface 10 (Class B).

Tyre 39: AvonCooper ZV1 185/65 R15 88H

Comments:
This is the old reference tyre A of the CPX-method and has been in use for measurements in Norway since 2003. It was chosen to be a representative tyre for the rolling noise of passenger car tyres. The measurements on surfaces 7-13 show that the classification varies between Class B and Class C at both speeds and by that seems a little noisier than the average tyres. However, the measurements of the shore hardness show a value of 75 Shore A, and this could probably explain the reason for being on the noisier side.

Tyre 40: Uniroyal Tigerpaw SRTT 225/60 R16 97S

Comments:
This is the replacement tyre for the “old” tyre A (tyre 39) as the reference tyre representing passenger car tyres in the CPX-method. The noise classification of this tyre is very much depending on the road surface. As table 27 and 28 show, it can be classified in Class A on some surfaces, in Class B on some others and as Class C on one dense surface (no.7). The classification can also depend on the speed category. On some of the porous surfaces, it is even the quietest tyre (see figure 13).

In general, there are only 3 tyres that can be classified as Class A on most of the surfaces included.
This means that these tyres are from 0.6 to 2 dB(A) quieter than the average of the tyres tested.

These three tyres are:

- Tyre 1: Dayton D110
- Tyre 12: Yokohama dB V500
- Tyre 14: Pirelli P7

Note that tyre 12 is no longer in production and was replaced by the tyre Yokohama C-Drive. At a recent visit to the Yokohama factory in Japan, new versions of the dB-tyre was shown, with similar tread pattern as the “old” dB-tyre, but with improved performance characteristics. The new dB-tyres are also available in Europe.

Only one of the tyres; tyre 13, Michelin Energy Saver has been classified as Class C on all the surfaces. In addition, tyre 6; Conti Premium Contact 2, is ranked as Class C on a majority of the roads.

It means that the majority of the tyres tested (12 out of 17), can be classified as average tyres, Class B, i.e. within ± 0.5 dB(A) of the average level for all tyres tested on the specific road surface.

11 Uncertainties

11.1 General uncertainty

Both the measurements and the modelling results are influenced by uncertainties.

For the CPX-measurements, the uncertainties can be grouped into two categories:

1. Uncertainty due to changes in vehicle/trailer operation within consecutive runs (position of the trailer in the lane), changes in weather conditions (temperature), changes in background noise levels (passing of other vehicles), and measurement system uncertainty; (run-to-run variations), including acoustic calibration.

2. Uncertainty due to changing properties of a test location over time (measurement on the same pavement at different times) and changes in measurement system performance over longer periods; (day-to-day variations).

In [Sandberg[12]] analysis of the uncertainty of CPX, drum and coast-by measurements are presented in more detail.

11.2 Influence of temperature

In [Berge et al.[4]], the uncertainty of CPX-measurements is more thoroughly discussed. In general, the uncertainty is in the range of ± 0.5 dB(A), mainly due to variations in noise level over the measured distance.

It is well known that the temperature (air and road surface) influence the measured levels. All the CPX-measurements have been temperature corrected to the reference value of +20 °C using a generic correction formula of:

-0.05 dB/°C for dense surfaces
-0.03 dB/°C for porous surfaces

SINTEF has done some investigations on the temperature influence of tyre 39 (The old CPX-reference tyre A). For two tyres of this type, it was found that the air temperature dependence was in the range of -0.10 – 0.13 dB/°C for dense surfaces [Berge et al.[6]].

The CPX-measurements have been performed at an air temperature range from + 11 to + 24 °C, as shown in table 29.

Table 29 Air temperature during CPX-measurements

Surface No.	Surface type	Air temp. °C
1	SMA 0/11	15
2	SMA 0/11	15
2B	SMA 0/11	15
3	DAC 0/16	15
4	SMA 0/11 1%	13
5	SMA 0/11 3%	13
6	DAC 0/16	11
7	SMA 0/11	24
8	DaFib8/DaFib16	24
9	ViaQ11/ViaQ16	24
10	Wa8/Da16	24
11	Da16	24
12	Da11/Da16	19
13	SMA 0/11	19

If one assumes that the real temperature dependence is in the range of 0 to -0.13 dB/°C for all the tyres involved, the uncertainty of the measured levels will be in the range shown in table 30.

Table 30 Maximum uncertainty

Surface No.	Max uncert. dB(A)
1-3	0.7
4-5	0.9
6	1.2
7-11	0.4
12-13	0.1

11.3 Modelling uncertainty

According to Beckenbauer and Kropp, who developed the *SPERoN* model, the uncertainty of the model is in the range of ± 1.0 dB(A).
In figure 54, the correlation between modelling on ISO-surface and CPX-results on surface 1 is shown. The correlation coefficient $r^2 = 0.03$.

If the uncertainty of the modelling is ± 1.0 dB(A) and the uncertainty of the CPX-measurements is ± 0.5 dB(A), the following theoretical calculation can be done, assuming maximum influence of errors in a “favourable” way (It should be stressed that this is just an “theoretical exercise”).:

- all the modelled results below the trend line are added + 1.0 dB(A) and CPX-results with + 0.5 dB(A)
- all the modelled results above the line are subtracted – 1.0 dB(A), and the CPX-results with – 0.5 dB(A).

Figure 68 show the “modified” correlation, with $r^2 = 0.49$. The correlation is improved considerably, but still show the linear regression of the two variables is not sufficient to explain the differences between the two modes of operations.

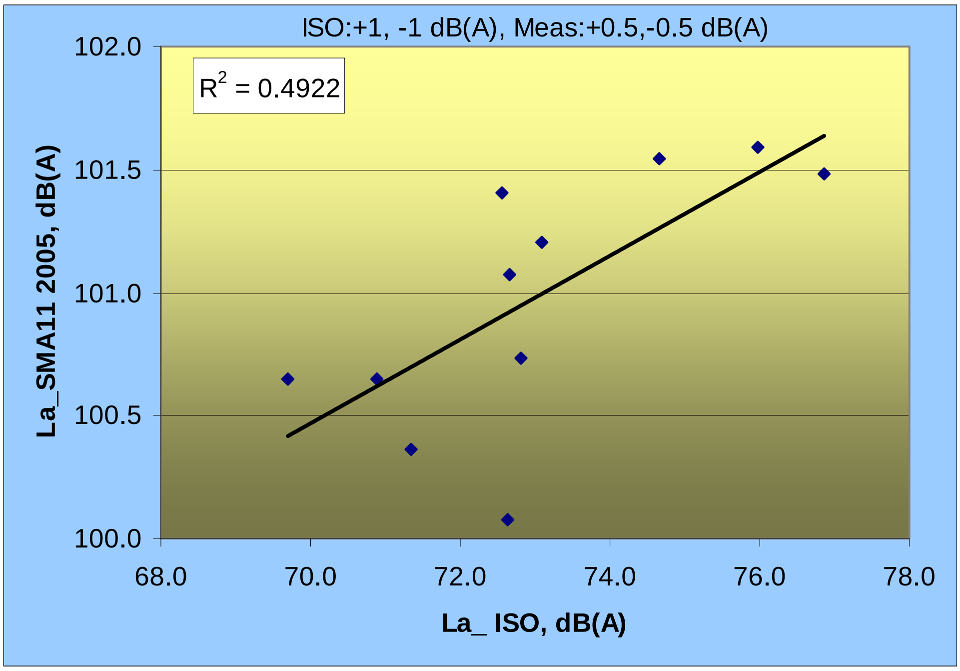


Figure 68 *Modified correlation between modelling on ISO-surface and CPX- measurements on surface 1. 80 km/h*

11.4 Tyre width

As can be seen from table 1, the width of the tyres under investigation varies from 155 to 225 mm in the modelling part, a difference of 70 mm, and from 175 to 225 mm in the measurement part.

Previous studies [Storeheier/Sandberg[16]], [T&E[17]] have indicated an increase in noise level of about 1 dB(A) pr 100 mm tyre width. In figure 69, the influence of the tyre width on the modelled results on the ISO-surface (80 km/h) is shown.

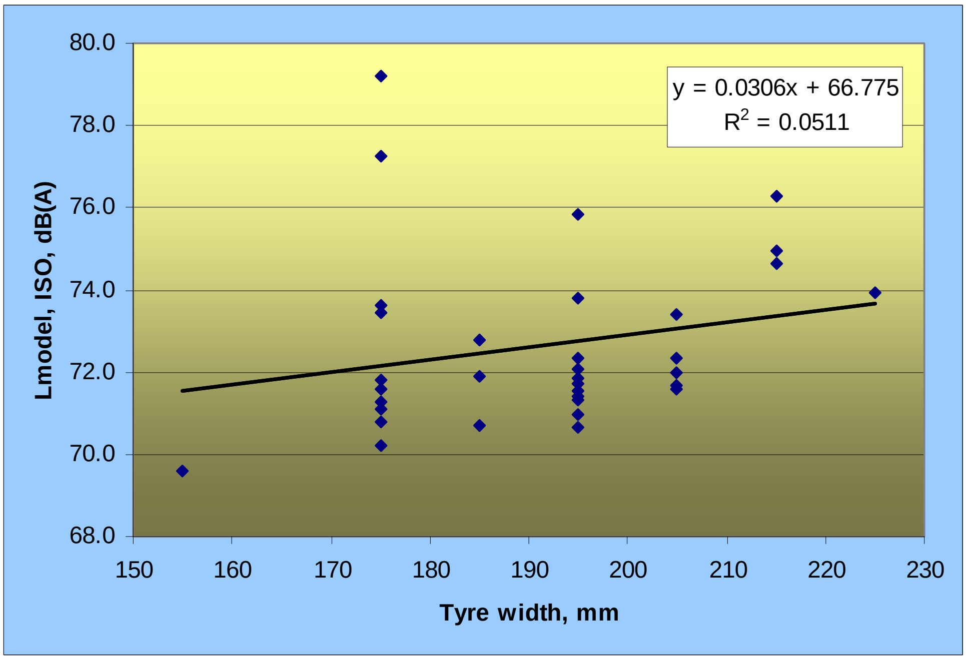


Figure 69 *The influence of the tyre width on the modelled ISO-levels, 80 km/h*

These results indicates a somewhat stronger relationship, about 3 dB(A) pr 100 mm. However, the measurements on the ISO-drum do not support this relationship, as there is no influence on the width of the tyres of the 15 tyres measured here. This can probably explained by the lack of correlation between these two modes of operations.
The quietest tyre of all the 34 modelled tyres is a tyre with dimensions 155/70 R13. This is to be expected as tyre width is one of the main input parameters of the *SPERoN* model.
Also, the quietest tyre of the CPX-measurements, tyre 1, is one of the tyres with the smallest tyre width (175/70 R14). It indicates that the influence of the tyre dimensions should be taken into account when comparisons between the tyres are made for noise performance.

12 Recommendations

Type approval measurements of tyres are performed on an ISO-surface, and the results presented in this report, based on modelling or drum measurements on ISO-surfaces, are not sufficient to fully evaluate the effect of the tightening of the EU tyre noise directive on the tyre/road noise situation in Norway. Neither is the results clear enough to be used to evaluate the effect of the proposed directive on tyre noise labelling. Nor are the results conclusive enough to evaluate any effect of economic incentives of tyres, based on type approval levels.

It is therefore recommended to do noise measurements of the 15 tyres used for CPX-measurements in this investigation on a real ISO-track. Such an investigation is important to fully establish a correlation between noise behaviour on Norwegian road surfaces and on an ISO-track used for type approval. These results can then be used for predictions of the efficiency of the proposed tightening of the EU directive on tyre noise.

One of the tyres in this investigation, tyre 13, is introduced in the market as a “green” tyre with low rolling resistance. The drum measurements confirm this. This should still be checked on some of the road surfaces included in this study. Rolling resistance measurement on all or a selection of the 15 tyres on some of the 13 road surfaces is therefore recommended.

The noise measurements results of tyre 13 on all the road surfaces give a concern, as it is clearly the tyre with the highest noise levels. According to press information [BIL[18]], this tyre is fitted as OE-tyres of at least 16 new vehicle models (by 2008). If the measured tyre is representative for the general noise behaviour of this tyre type (including all dimensions), it could delay or be counterproductive for the process of reducing the traffic noise annoyance in Norway.

It is therefore recommended to do some further investigation of this tyre. For this project two samples of this tyre was bought, but only one used for noise measurements. It is recommended to buy two more of this tyre and to do both CPX and coast-by measurements (CPB) (with the 4 tyres fitted on a vehicle) on an ISO-track and some selected road surfaces in Norway.

Since the regression analysis based on the overall dB(A)-levels is not suitable for comparing the different modes of operation, it is recommended to a further analysis of the data based on the third octave band spectra, to see of this gives a better agreement. Since frequency spectra were measured during CPX and modelled, such a comparison is easily available.

It is recommended to do further research on the CPX/CPB translation. Some investigations have been carried out in various projects in Europe (e.g. SILENCE, IPG/AOT), but a systematic parameter study is still missing. The effects of tyre width, air flow resistivity, rolling speed and vehicle design should be investigated. A more comprehensive investigation could be to organise CPB measurements on a limited number of Norwegian roads in order to obtain a well documented data set for streamed comparisons with the *SPERoN* output. This can also assure the validation of *SPERoN* for this project.

Furthermore, to make *SPERoN* calculations with texture data from the various TUG replica roughnesses as input data, to make a better basis for comparisons.

13 References

[1] 2001/43/EC: amending Council Directive 92/93/EEC relating to tyres for motor vehicles and their trailer and to their fitting, June 27th 2001.

[2] ISO 10844:1994 "Acoustics – Specification of test tracks for the purpose of measuring the noise emitted by road vehicles and their tyres.(Under revision)

[3] ISO/WD 11819-2: 2008. Acoustics – Method for measuring the influence of road surfaces on traffic noise – Part 2: The close proximity method. Geneva, Switzerland: International Organisation for Standardisation.

[4] T. Berge, A. Ustad, F. Haukland: Tyre/road noise modelling – noise measurements of 12 passenger car tyres. SINTEF Report A5424, February 2008.

[5] T. Berge: Tyre/road noise modelling – results from noise and texture measurements in Norway. SINTEF Report A935, January 2007.

[6] T. Berge, F. Haukland, A.Ustad: Environmentally friendly pavements: Results from noise measurements 2005-2008. SINTEF Report A9721. February 2009.

[7] T. Beckenbauer, W. Kropp: Prediction of tyre/road noise. Application of the *SPERoN* model. MüllerBBM in collaberation with Chalmers University, Gothenburg. Report M68 231/1. 2007-11-30.

[8] T. Beckenbauer, W. Kropp: Prediction of tyre/road noise. Application of the *SPERoN* model. Project phase 2. Investigation of aftermarket tyres. MüllerBBM in collaberation with Chalmers University, Gothenburg. Report M68 231/4. 2009-03-30.

[9] U. Sandberg, J. A. Ejsmont: Influence of rubber hardness on tyre/road noise emission. Proceedings of Internoise 2007 in Istanbul.

[10] H. Bendtsen: Rolling resistance, fuel consumption – a literature review. Danish Road Institute. Technical note 23. 2004.

[11] U. Sandberg, J. A. Ejsmont: Tyre/road noise reference book. Informex, 2002.

[12] U. Sandberg: Possibilities to Replace Outdoor Coast-by Tyre/Road Noise Measurements with Laboratory Drum Measurements. SILENCE Milestone Report C.MS8, 2005.

[13] FEHRL Report: Tyre/road noise, Volume 1: Final report. Study S12.408210, 2006.

[14] T.Berge, S.Å.Storeheier, A. Ustad: Measurements of tyre/road noise from passenger car tyres according to the EU-directive 2001/43/EC, on a number of different road surfaces. SIINTEF Report STF90 A05135, Nov.2005.

[15] M+P: IPG-lijst Stille Personenwagenbanden. 18 April 2005.

[16] S.Å. Storeheier, U. Sandberg: "Vehicle Related Parameters Affecting Tyre/Road Noise". Proceedings if the International Tire/Road Noise Conference 8-10 August 1990. Gothenburg.

[17] European Federation for Transport and Environment (T&E): Quieter tyres: a cost effective way to protect public health. Part 1 of 2, Brussels, October 2007.

[18] BIL No.5-2008, pages 50-51 (In Norwegian).

[19] Forbrukerrapporten 2/2009, pages 38-41 (In Norwegian).

[20] Personal communication with Thomas Beckenbauer and Wolfgang Kropp, April 2009.