DELIVERABLE D5.11

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
TITLE	Quiet City Transport
Subproject 5	Design & implementations of solutions at validation sites
Work Package 5.11	Report on "Acoustical performance of implemented quiet tyres"
	Part 3: Measurement of emitted tyre/road noise for various passenger car tyres on smooth road surfaces
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Date of issue of this report	2008-12-03

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PROJECT START DATE February 1, 2005
DURATION 48 months
Project funded by the European Community under the
SIXTH FRAMEWORK PROGRAMME
PRIORITY 6
Sustainable development, global change & ecosystems

This deliverable has been quality checked and approved by QCITY Coordinator
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0 EXECUTIVE SUMMARY

0.0 OBJECTIVE OF THE DELIVERABLE

The objective of this study is to investigate the emitted noise from different passenger car tyres when driving on a smooth road surface (Blackebergsvägen in Stockholm). The objective was to use a limited selection of tyres such that it will represent the typical variation of sound emission found in the entire population of tyre designs on the market. Since the influence from the tread pattern design will increase with decreased roughness of the road surface, then running the selected set of tyre designs on a smooth road surface will reflect the total spread in sound level obtained from the current tyre population. This will in turn also reflect the noise reduction potential by a limitation of the tyre tread designs (by e.g. creating a environmental vehicle definition which would allow only a limited amount of tyre types to be used) only to the e.g. 20 % quietest tyre designs out of the total population.

0.1 STRATEGY USED AND/OR A DESCRIPTION OF THE METHODS (TECHNIQUES) USED WITH THE JUSTIFICATION THEREOF

The investigation is based on measurements using the Close-Proximity Method (CPX) and the single wheel trailer designed and built by Acoustic Control AB. The strategy of this part of the Deliverable D5.11 is to quantify the earlier mentioned noise reduction potential by limit the tyre designs allowable to be used by environmental vehicles running on a smooth surface of 8 mm maximum stone size (such as Viacogrip 8).

0.2 BACKGROUND INFO AVAILABLE AND THE INNOVATIVE ELEMENTS WHICH WERE DEVELOPED

The tyre selected for testing was done in close cooperation with Goodyear Tire in Luxembourg. The innovative element is the idea that towards increased smoothness of the road surface the tyre tread design will play a gradually increasing role in the amount of sound power that is generated. Thus, would a limitation of tyres allowed to be used for e.g. environmental vehicles granted certain benefits (such as freedom from congestion fees) result in a substantial noise reduction as long as the road surface is smooth enough.

0.3 PROBLEMS ENCOUNTERED

0.4 PARTNERS INVOLVED AND THEIR CONTRIBUTION

Five different test tyres have been chosen in cooperation with the Acoustics Department at Goodyear in Luxembourg. Goodyear is one of the Partners (GOOD) in the project QCITY (Acronym for the EC financed project QUIET CITY TRANSPORT within the 6th framework).

0.5 CONCLUSIONS

Measurements reveal that Goodyear Eagle Vector is the most quite tyre at both urban and country road driving conditions (30-90 km/h). Goodyear Eagle F1 Asymmetric is the noisiest tyre at urban driving (30-50 km/h) while Goodyear Excellence is the noisiest tyre at country road driving (50-90 km/h). Vector has the lowest rubber hardness (60 Shore A) which may be one reason (together with the tread patter design) why Vector is the quietest tyre. The difference in emitted noise between the noisiest and the most quite tyre is about 3.5–4.0 dB-units between 40-70 km/h. The noise reduction potential (the arithmetic average of all tested tyres minus the sound level for the quietest tyre) is 1.7 - 2.1 dB(A)-units.

Michelin Primacy HP exhibit the lowest velocity exponent (n=2.86), while Goodyear Excellence display the highest velocity exponent (n=4.25). A low velocity exponent means that the total difference in noise emission between low and high speeds are low (as for Michelin Primacy HP) while higher velocity exponents means that the difference in noise emission between low and high speeds is greater (as for Goodyear Excellence).

0.6 RELATION WITH THE OTHER DELIVERABLES (INPUT/OUTPUT/TIMING)

Results from this Deliverable can be directly used by the Deliverable D5.8 on creating environmental zones only allowing low noise vehicles such as e.g. hybrid electric cars (in electric mode) to enter the area. Such low noise cars must be supplied with a system which ensures a reduced tyre/road noise in order to fully exploit the noise reduction potential of the concept. One way of ensuring reduced tyre/road noise by e.g. 5 dB(A) units would be to reduce to roughness of the road surface by lowering the maximum stone size of the stone ballast. Reducing the max stone size from 16 mm down to 6 mm would give at least 3 dB(A) units in reduction only from reducing the road roughness. On top of that, a limitation to the 20 % most quiet tyre designs would give at least an additional 2 dB(A) units resulting in a total tyre/road noise reduction of 5 dB(A) units.

1 OBJECTIVES AND SCOPE OF WORK

The objective of this study is to investigate the emitted noise from different passenger car tyres when driving on a smooth road surface (Blackebergsvägen in Stockholm). The investigation is based on measurements using the Close-Proximity Method (CPX) with a single wheel trailer. Five different test tyres have been selected in cooperation with the Acoustics Department at Goodyear in Luxembourg.

The objective was to use a limited selection of tyres representing the typical variation of sound emission found in the entire population of tyre designs on the market. Since the influence from the tread pattern design will increase with decreased roughness of the road surface, running the selected set of tyre designs on a smooth road surface will reflect the total spread in sound level obtained from the current tyre population on the market. This will in turn also reflect the noise reduction potential by a limitation of the tyre tread designs (by e.g. creating a environmental vehicle definition which would allow only a limited amount of tyre types to be used) only to the e.g. 20 % quietest tyre designs out of the total population.

The scope of work of this part of the Deliverable D5.11 is to quantify the earlier mentioned noise reduction potential by limit the tyre designs allowable to be used by environmental vehicles running on a smooth surface of 8 mm maximum stone size (such as Viacogrip 8).

2 TEST SITE

The CPX measurements are performed on an approximately 300 m long road section on Blackebergsvägen in Stockholm, see Figure 1. The road surface is the Thin Layer VIACOGRIP 8, see Figure 2.

Figure 1. Photo of the test site (Blackebergsvägen in Stockholm).

Figure 2. Close up photo (taken during the measurements) of the Thin Layer VIACOGRIP 8, with a Swedish 5 kronor coin as reference.

3 MEASUREMENT METHODOLOGY – THE SINGLE WHEEL TRAILER

All measurements are performed with a single wheel trailer using the Close-Proximity Method (CPX). The single wheel trailer has the advantage of measuring the noise at very well defined and standardized locations relative to the test wheel and with minimum influence of driveline noise. The sound pressure is measured in the free field with a minimum influence of reflexes from the suspension devices and bearing boxes. This means that the measured sound pressure levels are the emission levels with correct undisturbed frequency spectra and can easily be related to any other measurement results where the same measurement procedure has been used. Parameters like load, microphone positions, type of test tyre, tyre pressure, temperature etc. can be carefully controlled and recorded.

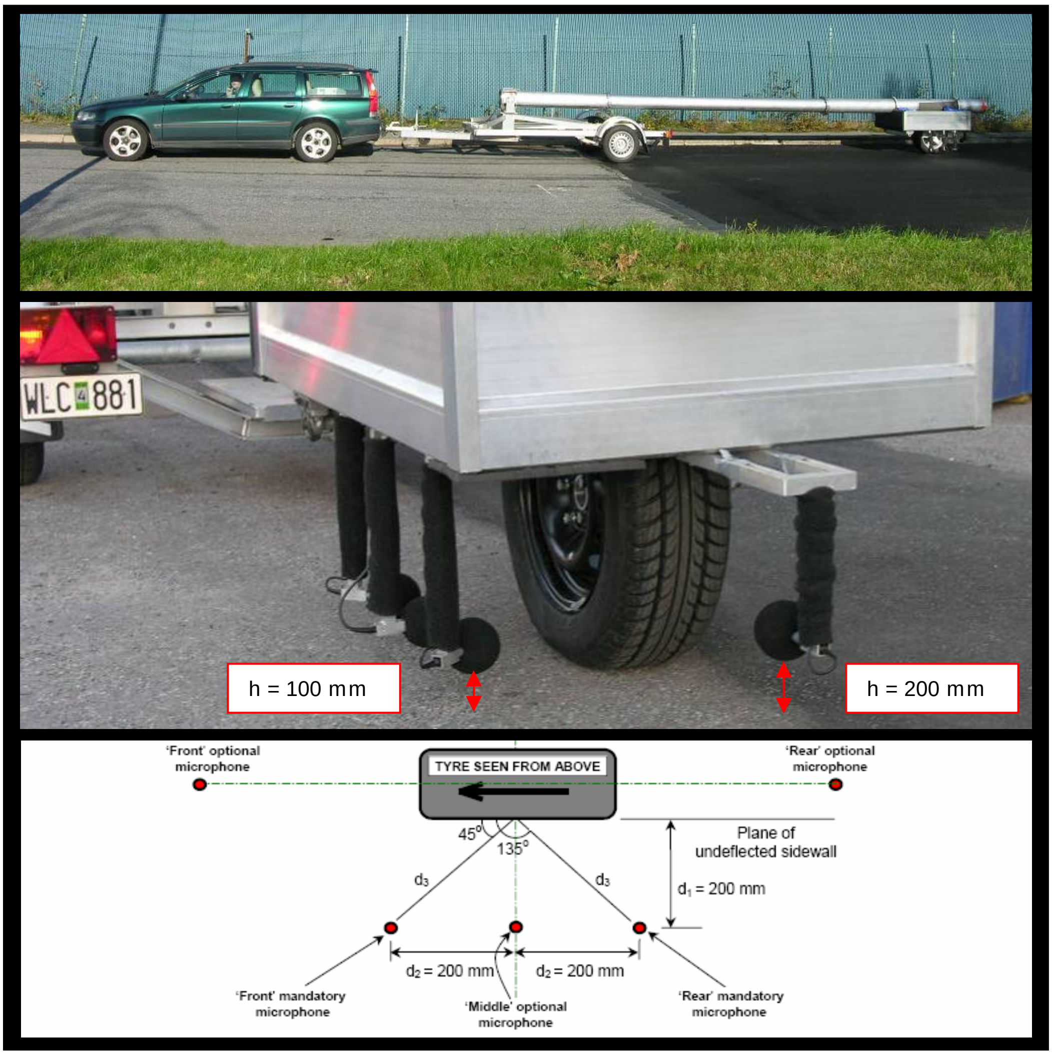

Figure 3. Microphone positions (extract from draft standard ISO/CD 11819-2) and the single wheel trailer for tyre/road noise measurements.

4 TEST TYRES

Measurements are performed on five tyres with different tread patterns; see Table 1. The dimensions of all tyres were 225/45R17 i.e. 225 mm wide; the height of the side rubber is 45 % of the width (225 mm). The rim diameter is 17”. All test tyres have been chosen in cooperation with the Acoustics Department at Goodyear in Luxembourg.

Table 1. Test tyres for investigation.

Goodyear Eagle F1 Asymmetric
Goodyear Eagle Vector
Goodyear Excellence
Michelin Primacy HP
Pirelli P7

Close up photos of the tread pattern on the test tyres are shown in Figure 4 below.

Goodyear Eagle F1 Asymmetric

Goodyear Eagle Vector

Goodyear Excellence

Michelin Primacy HP

Pirelli P7

Figure 4. Close up photo of the tread pattern on each test tyre.

5 MEASUREMENTS

5.0 PROCEDURE AND SET-UP

The measurement set-up and testing methodology is, to applicable extent, performed according to the draft proposal to a new standard, ISO CD 11819-2. All measurements are performed with the single wheel trailer using the Close-Proximity Method (CPX). The presented sound pressure is the logarithmic average of the measured sound pressure at the three side positions plus the optional position behind the trailing edge of the contact patch. The average sound pressure level during constant speed was evaluated for each trailer passage. Several trailer passages with different constant speeds were registered for each test tyre. A least square curve fit was then performed in each 1/3-octave band which enables the presentation of the Sound Pressure Level (for each 1/3-octave band) at any given speed. The speed is monitored during the whole measurement procedure using a GPS-system that stores the speed, position and time simultaneously on a flash memory. The uncertainty of the speed measurement is ±0.2 km/h. Data is sampled every 10 milliseconds. The measurements were performed 2008-10-03 at Blackebergsvägen in Stockholm under dry road conditions.

5.1 MEASUREMENT EQUIPMENT AND TEST PARAMETERS

Measurement equipment and test parameters are presented in Table 2 and Table 3 respectively.

Table 2. Equipment used for the CPX measurements.

Equipment	Brand	Type
Single wheel trailer for tyre/road noise measurements	HECO	ACL
12-channel signal analysis system	Brüel & Kjaer	Portable PULSE
Microphones	Brüel & Kjaer	4189 A21
Microphone wind shields	Brüel & Kjaer	
Sound level calibrator	Norsonic	1251
GPS speed and position logging system	Race Technology	DL1

Table 3. Test parameters for CPX measurements.

Test parameters	Value	Unit
Test tyre pressure	210	kPa
Load on test tyre	3500	N
Air temperature	9-12	ºC

6 RESULTS

6.0 TOTAL EMITTED SOUND LEVEL AS FUNCTION OF SPEED

The total measured A-weighted Sound Pressure Level (SPL) is presented in Figure 5 below for all test tyres as function of vehicle speed. The presented data are the average from the three side positions plus the optional position at the trailing edge of the contact patch.

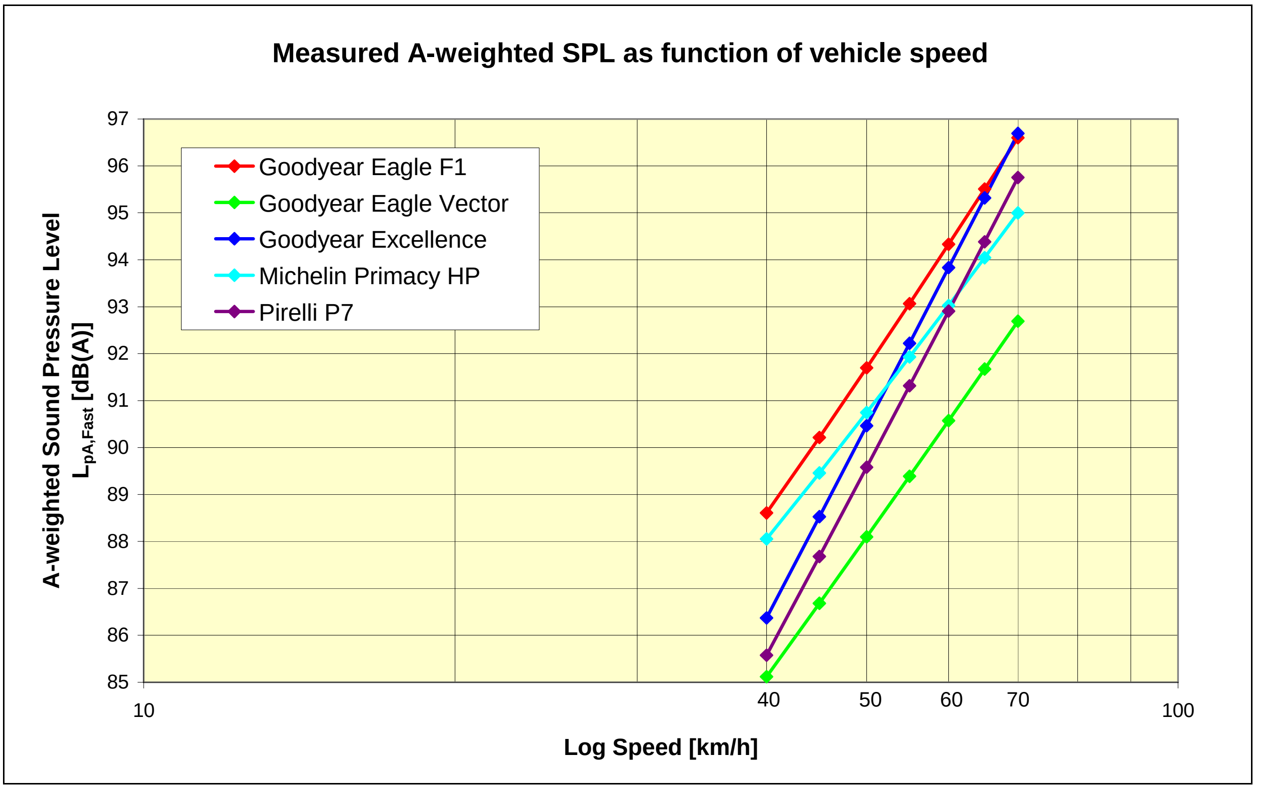

Figure 5. The least square curve fit of the CPX measured A-weighted SPL as a function of speed. The speed axis is presented in logarithmic scale.

Presented results above, show that Goodyear Eagle Vector is the most quite tyre for speeds between 40-70 km/h. Goodyear Eagle F1 Asymmetric is the noisiest tyre for vehicle speeds between 40-65 km/h while Goodyear Excellence is the noisiest tyre above 65 km/h. The difference in radiated noise between the noisiest and the most quite tyre is about 3.5-4.0 dB-units between 40-70 km/h.

Vehicle speeds between 30-50 km/h are representative for urban driving conditions while vehicle speeds between 50-90 km/h are representative for country road driving conditions.

6.1 NOISE REDUCTION POTENTIAL

The noise reduction potential of the tested tyre population (only 5 tyres) is 1.7 -2.1 dB(A)-units when running the tests on a dense asphalt surface with max ballast stone size of 8 mm, see Table 4. The noise reduction potential is calculated as the arithmetic average of all tested tyres minus the sound level for the quietest tyre.

Table 4 . The noise reduction potential by selecting only the 20 % quietest tyres.

Tyre type	**Sound level dB(A) at 40 km/h**	**Sound level dB(A) at 45 km/h**	**Sound level dB(A) at 50 km/h**
Goodyear Eagle Vector	85	86,8	88
Pirelli P7	85,6	87,8	89,5
Goodyear Excellence	86,4	88,5	90,5
Michelin Primacy HP	88,0	89,5	90,8
Goodyear Eagle F1A	88,6	90,1	91,8
Average sound level from all tested tyres.	86,7	88,5	90,1
Noise reduction potential from average to the most quiet tested tyre	1,7	1,8	2,1

6.2 RANKING OF THE QUIETEST TO THE NOISIEST TYRE

The ranking of the most quite to the noisiest tyre at typical urban and country road driving conditions is shown in Figure 6 below.

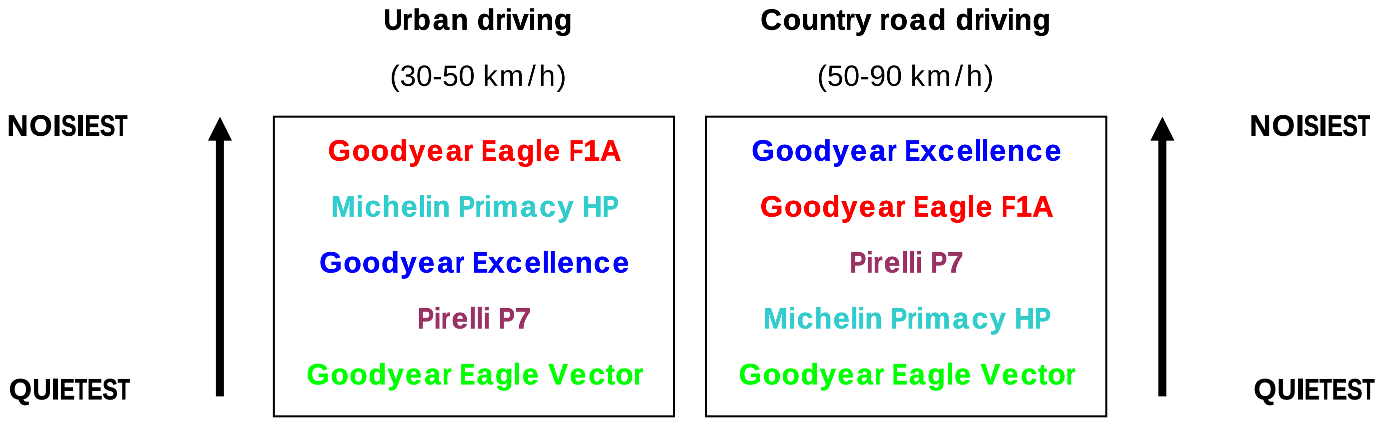

Figure 6. Ranking of the quietest to the noisiest tyre at typical urban and country road driving conditions.

6.3 VELOCITY EXPONENTS

Note that the noise increase due to speed is slightly different for all tested tyres, see Figure 5 and 6. The amount of noise increase (the slope) as function of speed can be described by the velocity exponent, n, see Table 5 below.

Table 5. The velocity exponent, n, for all test tyres.

Test tyre	Velocity exponent, n
Goodyear Excellence	4.25
Pirelli P7	4.19
Goodyear Eagle F1A	3.29
Goodyear Eagle Vector	3.12
Michelin Primacy HP	2.86

Note that Michelin Primacy HP has the lowest velocity exponent (n=2.86), while Goodyear Excellence has the highest velocity exponent (n=4.25). A low velocity exponent means that the total difference in noise emission between low and high speeds are low (as for Michelin Primacy HP) while higher velocity exponents means that the difference in noise emission between low and high speeds is greater (as for Goodyear Excellence).

6.4 FREQUENCY SPECTRA

The measured A-weighted SPL as function of frequency at 40 km/h (urban driving) and 70 km/h (country road driving) is presented in Figure 7 and 8 below.

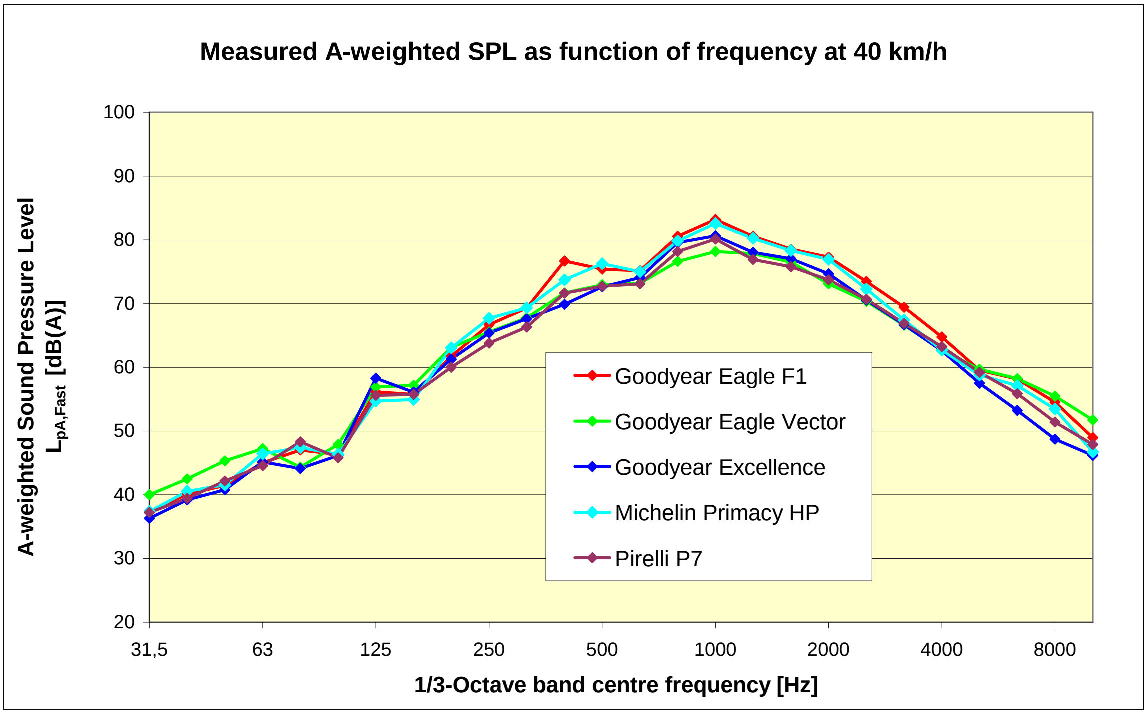

Figure 7. CPX measured A-weighted SPL in third octave bands at 40 km/h (urban driving). Note: Eagle Vector is quieter at and around 1000 Hz.

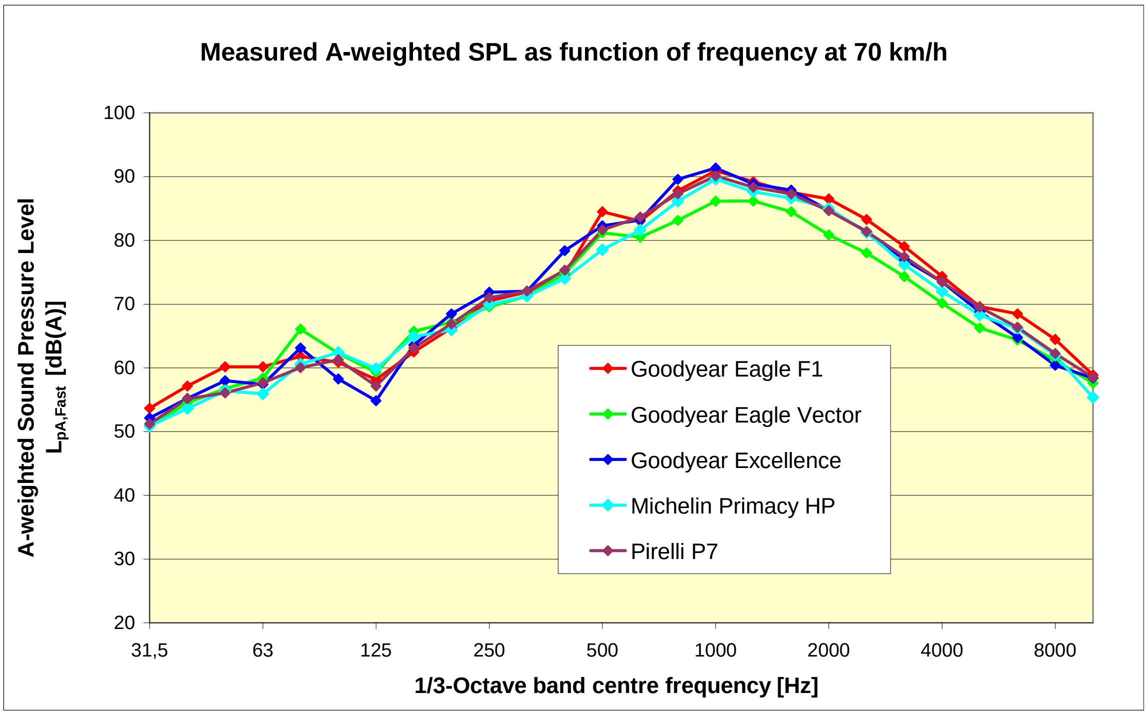

Figure 8. CPX measured A-weighted SPL in third octave bands at 70 km/h (country road driving). Note: Eagle Vector is quieter at and around 1000 Hz.

6.5 RUBBER HARDNESS (SHORE A)

The rubber hardness in the tread area can be described by its Shore A value. The measured Shore hardness for each tyre is presented in Table 6 below.

Table 6. Measured rubber hardness in the tread area (Shore A). Mean value of three samples per tyre.

Type of tyre	Shore A
Goodyear Eagle F1A	70
Pirelli P7	68
Goodyear Excellence	67
Michelin Primacy HP	66
Goodyear Eagle Vector	60

7 CONCLUSIONS AND DISCUSSION

Measurements reveal that Goodyear Eagle Vector is the most quite tyre at both urban and country road driving conditions (30-90 km/h). Goodyear Eagle F1A is the noisiest tyre at urban driving (30-50 km/h) while Goodyear Excellence is the noisiest tyre at country road driving (50-90 km/h). Vector has the lowest rubber hardness (60 Shore A) which may be one reason (together with the tread patter design) why Vector is the quietest tyre. The difference in emitted noise between the noisiest and the most quite tyre is about 3.5–4.0 dB-units between 40-70 km/h. The noise reduction potential (the arithmetic average of all tested tyres minus the sound level for the quietest tyre) is 1.7 - 2.1 dB(A)-units.

Michelin Primacy HP display the lowest velocity exponent (n=2.86), while Goodyear Excellence display the highest velocity exponent (n=4.25). A low velocity exponent means that the total difference in noise emission between low and high speeds are low (as for Michelin Primacy HP) while higher velocity exponents means that the difference in noise emission between low and high speeds is greater (as for Goodyear Excellence).

The results presented here can be exploited by e.g. prescribing special low noise tyres with silent tread patterns which has proven to give low noise emission driven on smooth road surfaces. By formulation of the specification for environmental vehicles granted with special favours (like entering a restricted zone without paying fees) a substantial noise reduction can be achieved especially for hybrid vehicles in electric drive mode.

The usage of smooth road surfaces in restricted zones could be enhanced if the definition of the requirements for the environmental vehicles also would include the stud-free winter tyres (which is a special problem for the Scandinavian countries but is of less importance in the rest of Europe).