EUROPEAN COMMISSION
DG RESEARCH

SIXTH FRAMEWORK PROGRAMME
PRIORITY 6
SUSTAINABLE DEVELOPMENT, GLOBAL CHANGE & ECOSYSTEMS
INTEGRATED PROJECT – CONTRACT N. 516288

PRACTICALITIES OF ENFORCING NOISE CONTROLS AT THE ROADSIDE OR ON VEHICLES

Deliverable no.	H.D3
Dissemination level	Public
Work Package	WP H.2 Roadside and in-service noise test methods
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Status (F: final, D: draft)	F_20.09.2006
File Name	D_H_D§_1n_250906.doc
Project Start Date and Duration	01 February 2005, 36 months

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1 Summary

Within sub-project H practical urban traffic management techniques shall be developed that city authorities can use to reduce traffic noise. The work package will take a holistic view of the policies and legislation used to manage traffic flow, and consider the interactions between traffic management and driver behaviour. It will also examine how systems for monitoring noise emissions from vehicles can play a role in traffic management.

The objectives of Work Package H2 are the following. One important tool to reduce traffic noise is the identification of noisy vehicles in the vehicle fleet from the roadside. The development of measurement techniques needed for this identification is one of the main tasks of H2. These techniques will be developed in a way that they can be used as an enforcement and access control tool for local authorities to ensure the lowest appropriate noise levels from the vehicles operating in fleets under their direct or indirect control.

Further tasks in this context are the evaluation of the interaction between access control systems and new systems for vehicle noise monitoring and control, the consideration of methods for implementing such methodologies and the assessment of the possibilities to use the noise emission monitoring for traffic management measures aiming at a reduction of the noise exposure.

An additional task is the examination of possibilities for the interaction between access control systems (e.g. congestion charging or night time ‘lorry bans’) and vehicle noise monitoring and control (e.g. limitation of engine speed and engine load in combination with the control of vehicle speed)

The review of methods of identifying noisy vehicles to support the enforcement of noise control measures and the necessary measurement methods and techniques includes roadside fleet monitoring systems as well as in-service control methods for single vehicles selected as “noisy” by the monitoring system or roadside spot pre-checks.

Other tasks of H2 are related to the other sub-projects H1 and H3: For H1 assessments of the effectiveness of candidate noise reduction measures will be performed using the noise emission calculation model Rotranomo/Tranecam. For H3 gearshift algorithms for low noise driving behaviour will be provided.

This report gives an overview of the status of the work on the roadside monitoring system and the development of an in-service control method. In addition the concept for advanced gearshift indicators and/or engine speed and vehicle acceleration limiters is described and some results of the calculation of the effects on noise emission are shown.

2 Introduction and Tasks

The noise emission of a vehicle is composed by two major noise sources:

- Propulsion noise (engine, gearbox, drivetrain, silencers),
- Tyre/road noise,

The propulsion noise is determined by the vehicle design. Its actual level depends on engine speed and engine load. The tyre/road noise is determined by the tyre and the road surface. Its actual level depends on the vehicle speed.

Noise reduction measures at the sources (vehicles, tyres, road surfaces) are the objectives of other sub-projects of SILENCE. Sub-project H focuses on measures that are related to traffic fleet, traffic management and driving behaviour and can be applied to vehicles of today’s technology.

The “physics” or “concepts” behind these measures can be summarised as follows:

- Since tyre/road noise increases with vehicle speed, all measures that lead to a speed reduction result in lower noise emissions. The reduction effect is highest if the speed reduction can be achieved for a whole area and in combination with low speed variations. This requires a high acceptance rate or efficient monitoring systems.
- Since propulsion noise increases with engine speed and engine load, all measures that lead to low engine speeds and avoid unnecessary accelerations result in lower noise emissions. The corresponding change in driving behaviour can be achieved by the driver and/or engine speed limiters integrated in the vehicle. This type of measure is especially effective for heavy duty vehicles.
- Since the noise emission of heavy duty vehicles is significantly higher than the noise emission of cars and light duty vehicles a ban of heavy duty vehicles for certain periods of the day (e.g. night time) can be very effective.

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3 Roadside Monitoring System

The development of the roadside monitoring system is based on SINTEF’s knowledge and already available measurement equipment. SINTEF’s monitoring equipment is aimed at looking at the changes in noise emission of individual vehicles. So far, the following work has been done:

SINTEF has had meetings with 2 Norwegian companies, Norsonic AS and Aanderaa Data Instruments as (AADI). Norsonic as is the main supplier of acoustic instrumentation equipment and AADI is the supplier of traffic registration systems, including meteorological data (MET).

Together, we have planned for a monitoring system for road traffic, which allows for registration of a wide range of acoustical parameters for the pass-by of individual vehicles in the traffic. The AADI traffic registration system will give information about the category of vehicle, its lane and direction of travel, vehicle speed and length.

The MET-station will be added to the traffic registration equipment. This allows all acoustical data to be correlated with meteorological data, such as temperature, wind speed and direction, humidity, road surface condition (wet/dry, etc.), etc.

Presently, we are developing the user interface of the system. The basis of the system will be a main program, enabling a number of "sensors" to be connected, through a graphic user interface (GUI).

The main sensors will be

- PC-based sound level meter, with 2 microphone inputs.
- Traffic registration system (Dr7, from AADI)
- MET-system

In addition, there is a "Communication"-part, which define the communication between the main program and the user.

The following figures show examples of the GUI:

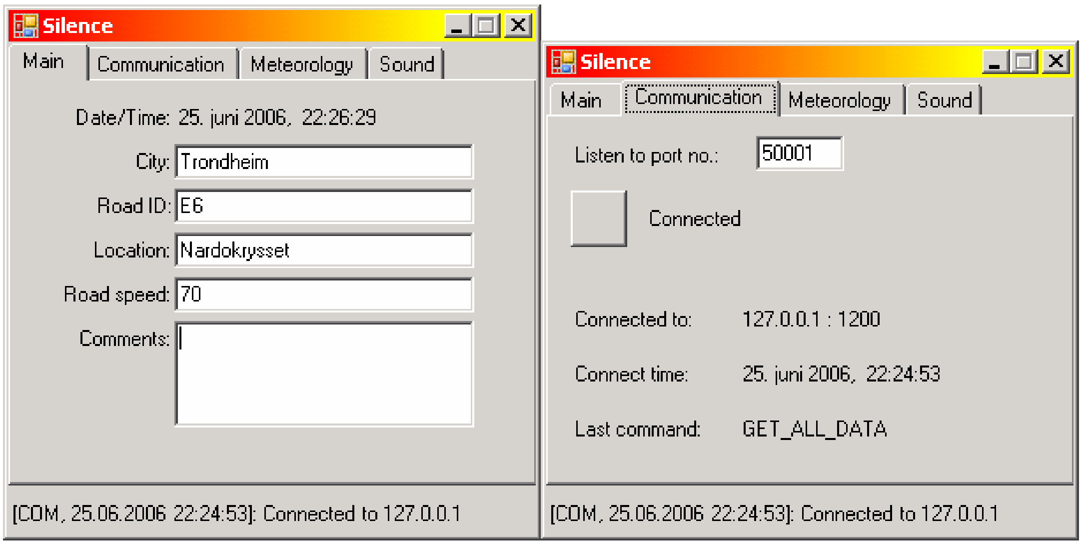

Figure 1: Examples of input masks of the GUI

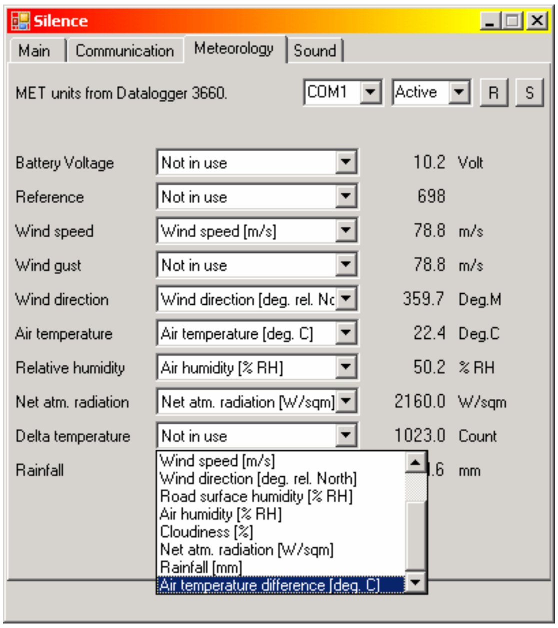

Figure 2: Example of input mask of the GUI for meteorological parameter

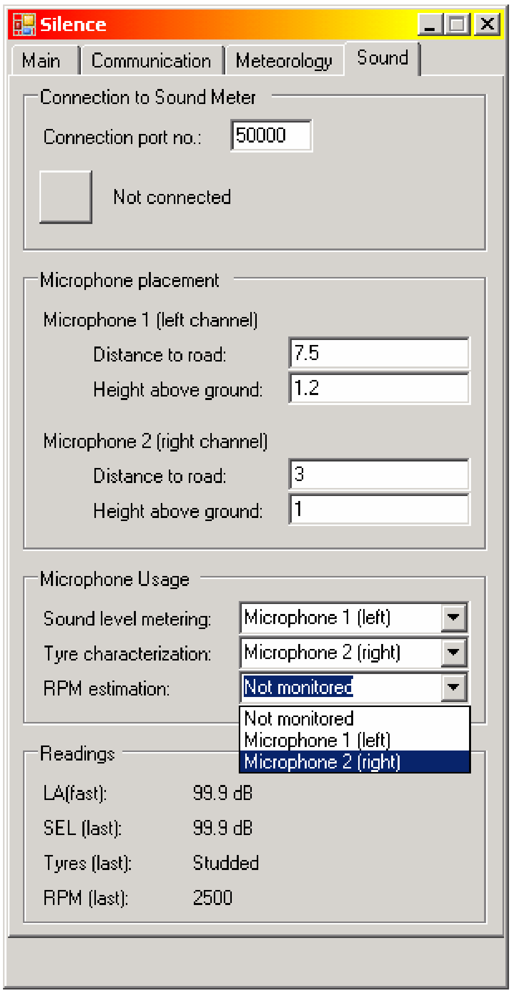

Figure 3: Example of input mask of the GUI for microphone specifications

When the GUI-program has been finalised, we will start laboratory testing of the communication part between the different sensors. Then, field testing in real traffic will be done later this autumn.

As a first step, the monitoring system will be connected to fixed registration sensors laid down under the road surface. Thus, the system will only measure speed at one defined position on the road.

When experience with this part has been gained, we will start developing the system so that it will be possible to monitor the driving behaviour of a passing vehicle. That is to record the vehicle speed and acceleration/deceleration over a certain distance. In this part of the project, we will also study the possible implementation of the rpm-detecting algorithm developed by SINTEF.

Testing of the extended version of the system is expected to take place during the first half of 2007.

4 Development of an In-Service Control Method based on Roadside Pass-by Tests

Excessive noise emissions can be produced by vehicles equipped with illegal silencers, especially for motorcycles. In service controls are necessary to achieve a reduction of the noise impact. The in service controls are currently based on a stationary noise test close to the exhaust pipes. The efficiency of this test is rather poor. From field studies is known that only one third of the illegal systems can be detected by this test. A drive by test similar to the type approval test would be much more efficient.

From questionnaire surveys on road vehicle noise to roadside residents in Japan is known that 30% of the motorcycles and 6% of the cars are equipped with replacement silencers, most of them illegal and much noisier than the original equipment. The percentage for trucks is less than 1%. The mentioned percentages are daily averages, the percentages during the night time period are significantly higher than those for the day time period. It can be expected that the situation in EU member states is similar or even worse.

Two main conclusions can be drawn from the survey results: In-service control can be an effective noise reduction measure but it can be restricted to motorcycles and cars.

4.1 Summary of work already performed by BASt on motorcycles

Within BASt's investigations of stationary roadside enforcement noise tests for motorcycles (see /1/) additional pass-by measurements were carried out following the prescriptions of the measurement method, described in the current ECE R41 (type approval noise measurement method). For a limited number of motorcycles (11) these measurements were carried out twice. Once on a standard ISO test track under type approval conditions and once on a rural road under roadside enforcement test conditions.

The following deviations in comparison to test track measurements had to be accepted for the pass-by roadside enforcement tests:

1. Road surface does not meet the ISO 10844 requirements,
2. Microphones are placed on road shoulder, which might reduce the measurement result due to absorption effects,
3. Obstacles in the vicinity of the road might increase the measurement result due to reflection effects,

4. The speedometer of the vehicle was used to control the entrance speed $v_{AA'}$. This device is not as precise as required for type approval measurements.

The following observations were made / conclusions were drawn based on the comparison of both methods (test track measurement versus roadside enforcement test):

- The road surface influence is negligible as far as dense asphalt or concrete surfaces are used. Open graded surfaces and pavement stone surfaces must be excluded.
- The test track influences mentioned in 2 and 3 above can be kept acceptable small, if rural roads (see Figure 4 and Figure 5) or suburban roads are used, where the buildings are far enough distant from the road.
- The "true" vehicle speed should always be lower than the speed indicated by the speedometer of the vehicle, because the latter need a speed "lead" by legislation. The average difference between the exact speed, measured by radar and the speed indicated by the vehicle's speedometer was -3 km/h for the 11 tested vehicles. Roadside enforcement pass-by tests carried out by the police in Germany in 2003 led to an average difference of -5 km/h for 40 motorcycles.
- In order to take into account the influences of the deviations from the requirements for type approval measurements for roadside enforcement tests a tolerance is needed for the comparison of the results with the legal limit values. Although the performed roadside enforcement tests are far from sufficient in order to verify such a tolerance, it was stated by BASt that this tolerance would be in the order of 2 dB, because some of the above mentioned influences (partly) compensate each other.

Figure 4: Example of a pass-by roadside enforcement test

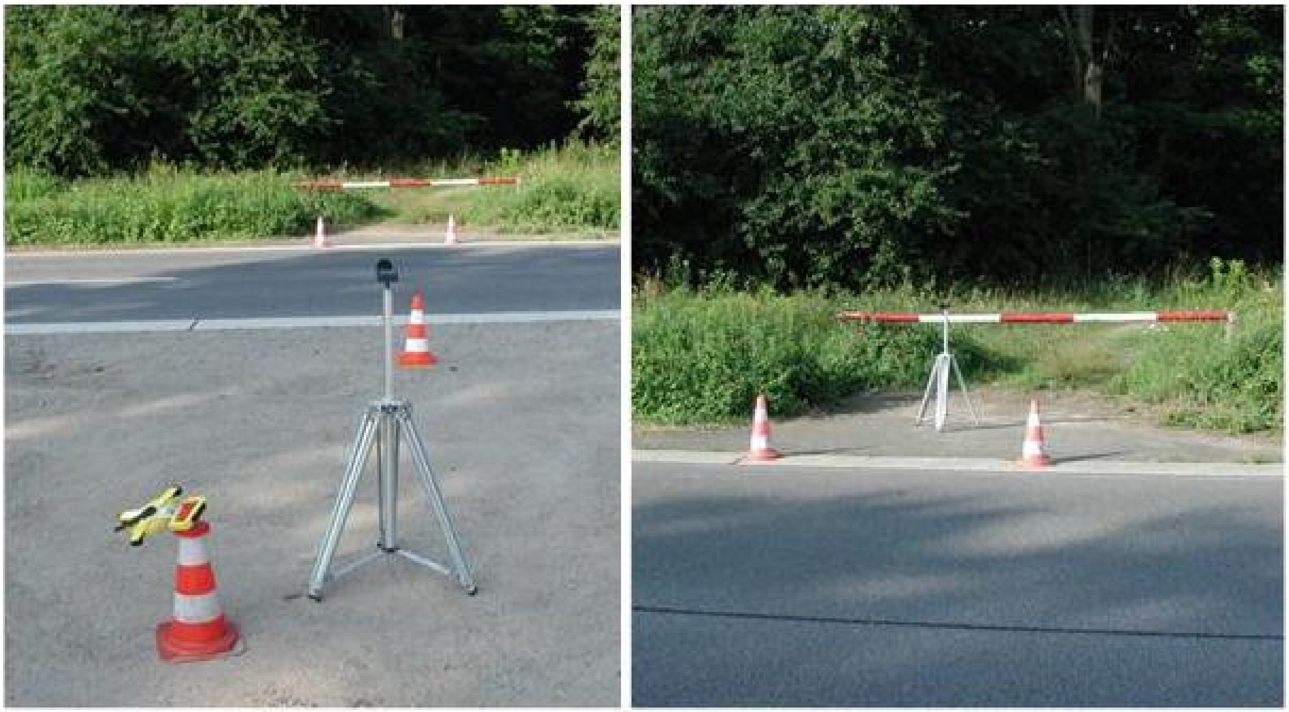

Figure 5: Microphone positions for a roadside enforcement test

The measurement results for the 11 vehicles are summarised in Table 1. Figure 6 shows the comparison of the pass-by tests carried out on a test track under type approval conditions and on a rural road under enforcement conditions. The results correlate quite well and look very promising. The differences range from -1,5 dB up to +0,5 dB.

The results for vehicle 9 represent a good example for the effectiveness of the pass-by test compared to the stationary test. The measured stationary test result has exactly the same value as registered for this vehicle, while the pass by test result under type approval conditions is 7 dB higher than the registered type approval level and still 5 dB higher than the threshold level for Conformity of production (COP). The pass-by test result under roadside enforcement conditions is 0,5 dB lower than under type approval conditions. The stationary test classifies this vehicle as legal, while the roadside enforcement pass-by test classifies it as illegal.

veh no	Manufac-turer	vehicle	engine capacity in cm³	rated power in kW	rated speed in min^{-1}	noise levels in dB(A)						
						registered type approval level	result of test track measurements	result of roadside enforcement measurement	difference	measured type approval level	registered stationary test result	measured stationary test result
1	Suzuki	GSX 600R	599	85	13000	78	83.2	82.4	-0.8	82.0	93	92
2	Honda	CB 900 F Hornet	919	80	9000	79	79.8	79.7	-0.1	79.0	86	84
3	Yamaha	XVS 1100	1063	48	5500	79	80.1	80.6	0.5	79.0	86	86
4	BMW	K12	1171	96	8750	79	80.5	81.0	0.5	80.0	93	91
5	Kawasaki	ZX 900 E	899	105	11000	79	80.5	80.1	-0.4	80.0	93	93
6	Suzuki	Bandit 1200	1157	72	8500	79	80.8	79.6	-1.2	80.0	91	91
7	Suzuki	SV 650	645	53	9000	79	81.5	81.0	-0.5	81.0	90	88
8	Suzuki	SV 1000	996	88	9000	79	83.1	82.1	-1.0	82.0	92	92
9	Suzuki	DR-Z 400 SKS	398	29	7600	79	87.0	86.5	-0.5	86.0	87	87
10	Harley Davidson	VR1	1131	86	8300	80	80.1	80.4	0.3	79.0	90	94
11	BMW	R 1150 GS	1150	62	6750	80	82.6	81.1	-1.5	82.0	86	86

Table 1: Results of pass-by and stationary noise measurements for a motorcycle sample

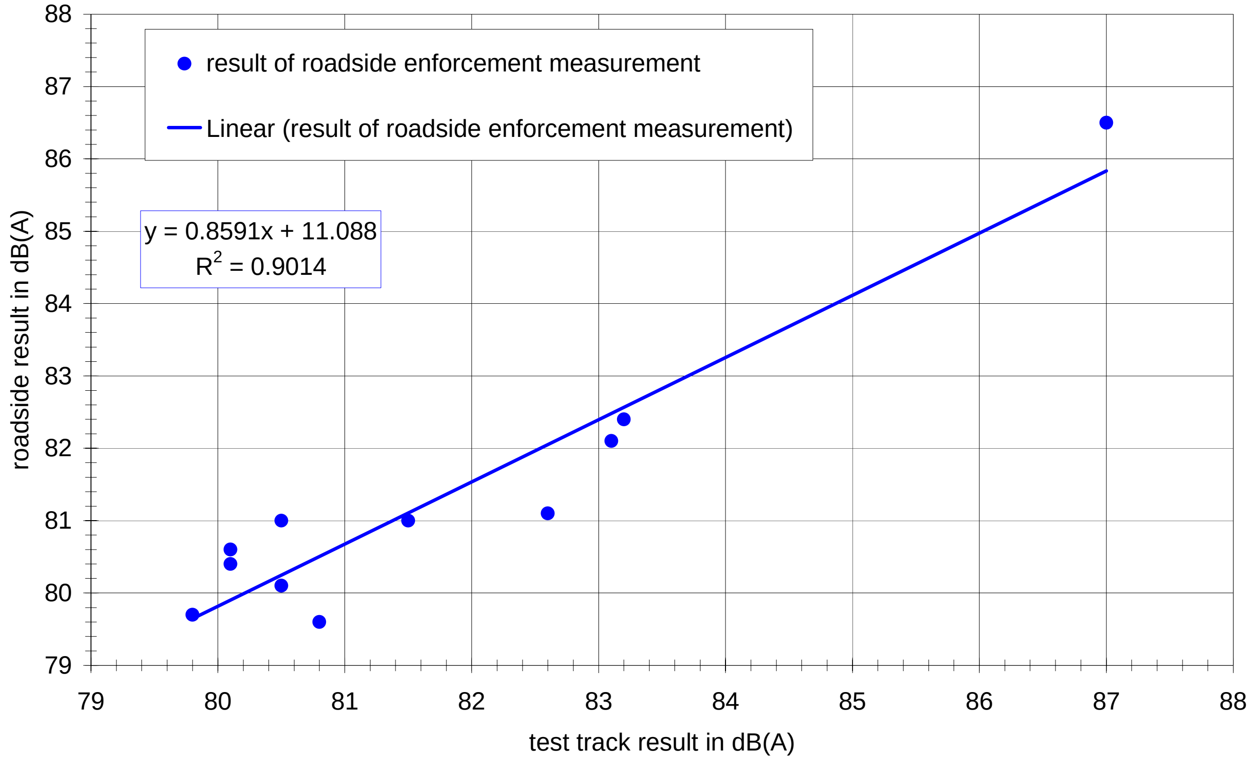

Figure 6: Results of pass-by noise measurements on a test track and a rural road

Another test series was carried out at Kisslegg. Motorcyclists were stopped by the police and stationary noise measurements as well as pass-by noise measurements were carried out on a voluntary base. The motorcycle drivers had the possibility to refuse the pass-by tests. BASt provided the measurement equipment, but the measurements were carried out by the police. The vehicle's speedometers were used to control the entrance speed of 50 km/h. BASt performed more exact speed measurements using a radar device. In total 35 vehicles could be tested.

For the pass by test up to 8 measurements were carried out per vehicle. Figure 7 shows the variance of the entrance speeds for these 35 vehicles. The entrance speeds varied from 39 km/h up to 55 km/h, but 89% of the measurements were at 50 km/h or below (see Figure 8). Speeds higher than 50 km/h should not occur when using the speedometer of the vehicle. These speeds indicate that the driver sometimes missed the target of 50 km/h.

Measured and registered levels for the stationary test and the pass by test could be compared for 31 vehicles. Average values were used for the pass by test. The comparisons are shown in Figure 9 and Figure 10. The tolerance for compliance was set to +5 dB for the stationary tests and +2 dB for the pass by tests.

22 motorcycles complied to both test with measurement results, when these tolerances were considered (marked by dark blue circles). Just 2 of the remaining motorcycles failed in both tests (marked by red and yellow circles). Another 4 vehicles failed for the stationary test but complied with the pass by test (marked by triangles). 3 motorcycles failed for the pass by test but complied with the stationary test (marked by squares). This demonstrates the poor correlation between both tests and the need for a pass by roadside enforcement test.

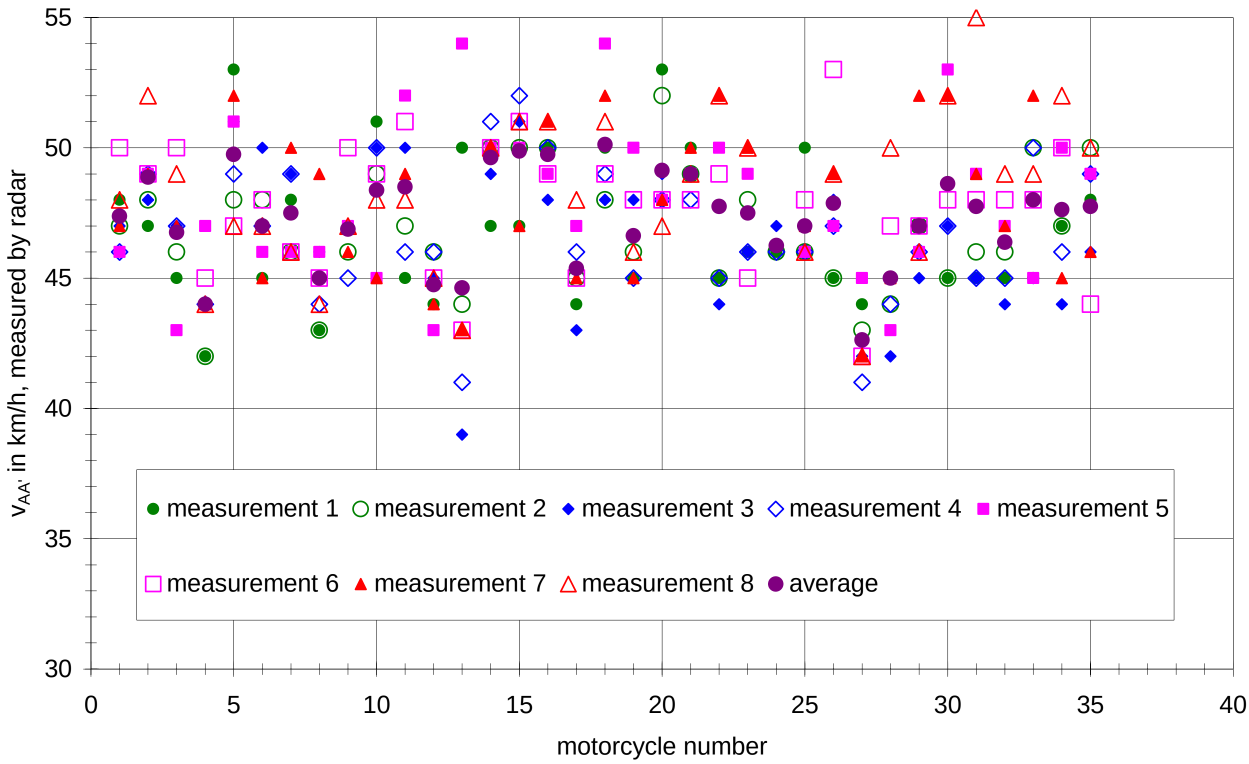

Figure 7: Variance of entrance speeds $v_{AA'}$ for the pass by noise measurements

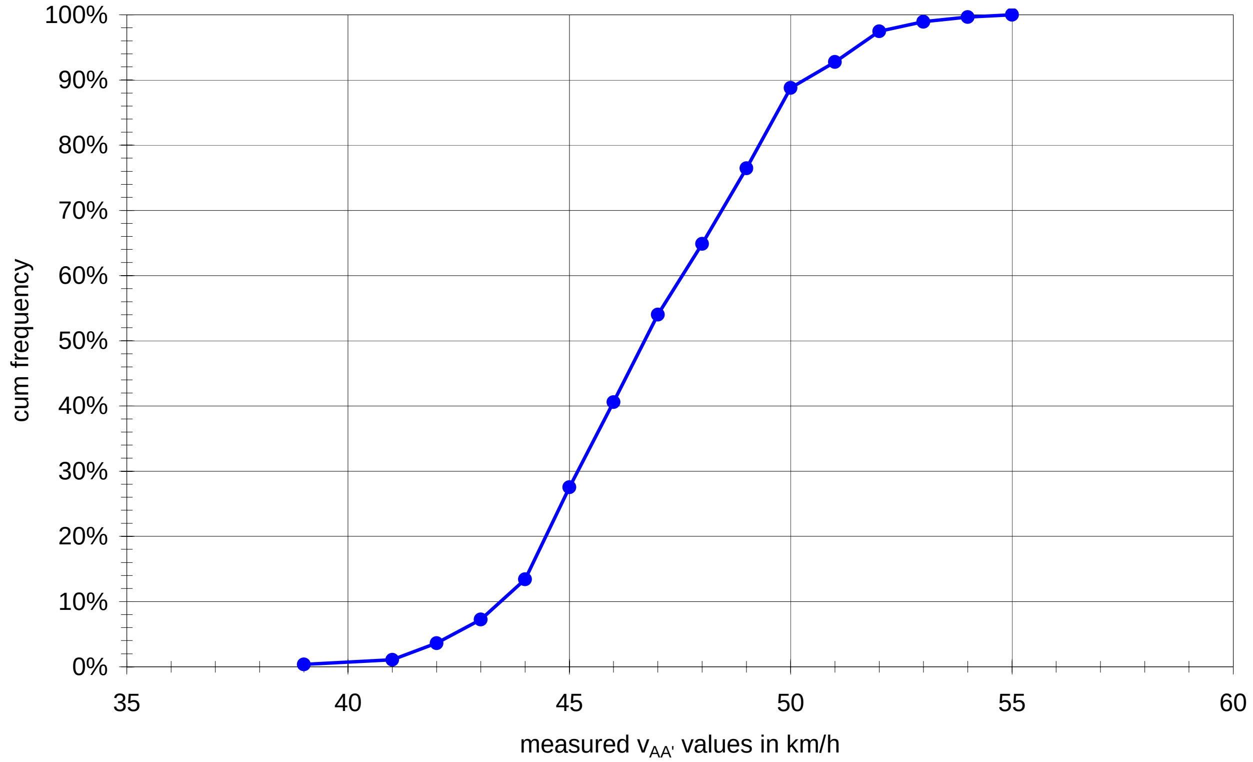

Figure 8: Cumulative frequency distribution of the $v_{AA'}$ values

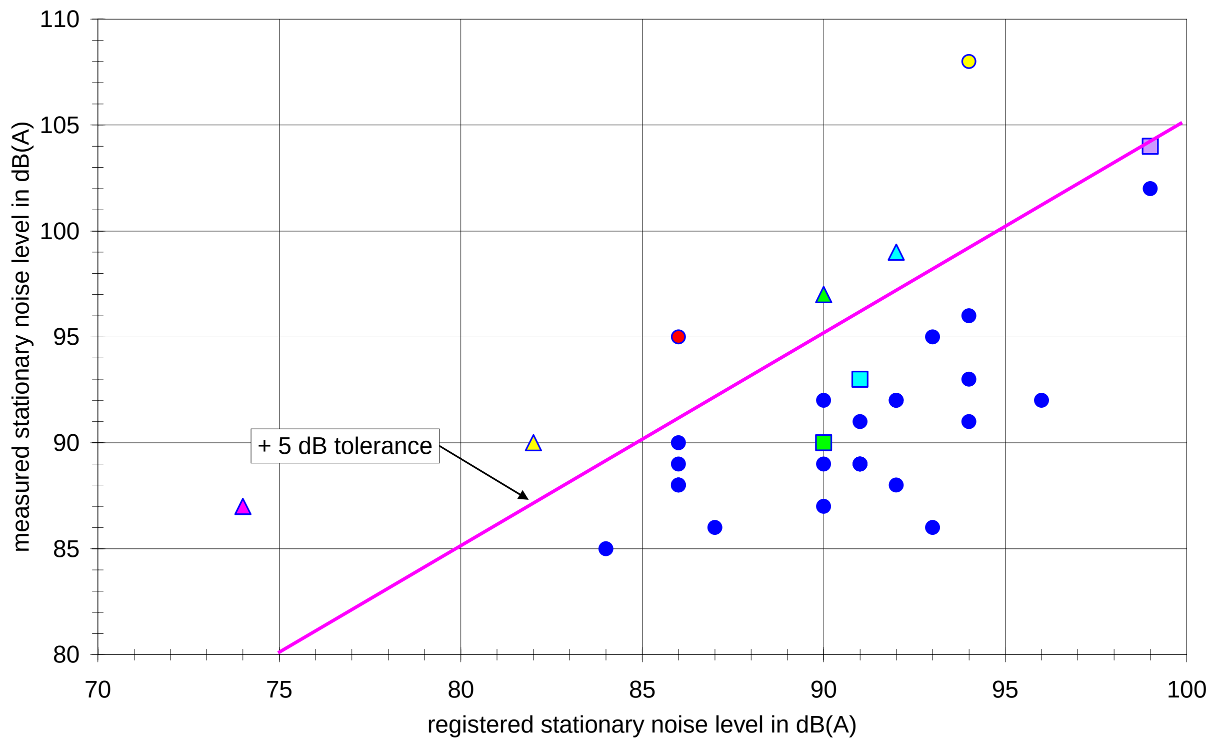

Figure 9: Comparison of measured and registered levels for the stationary test

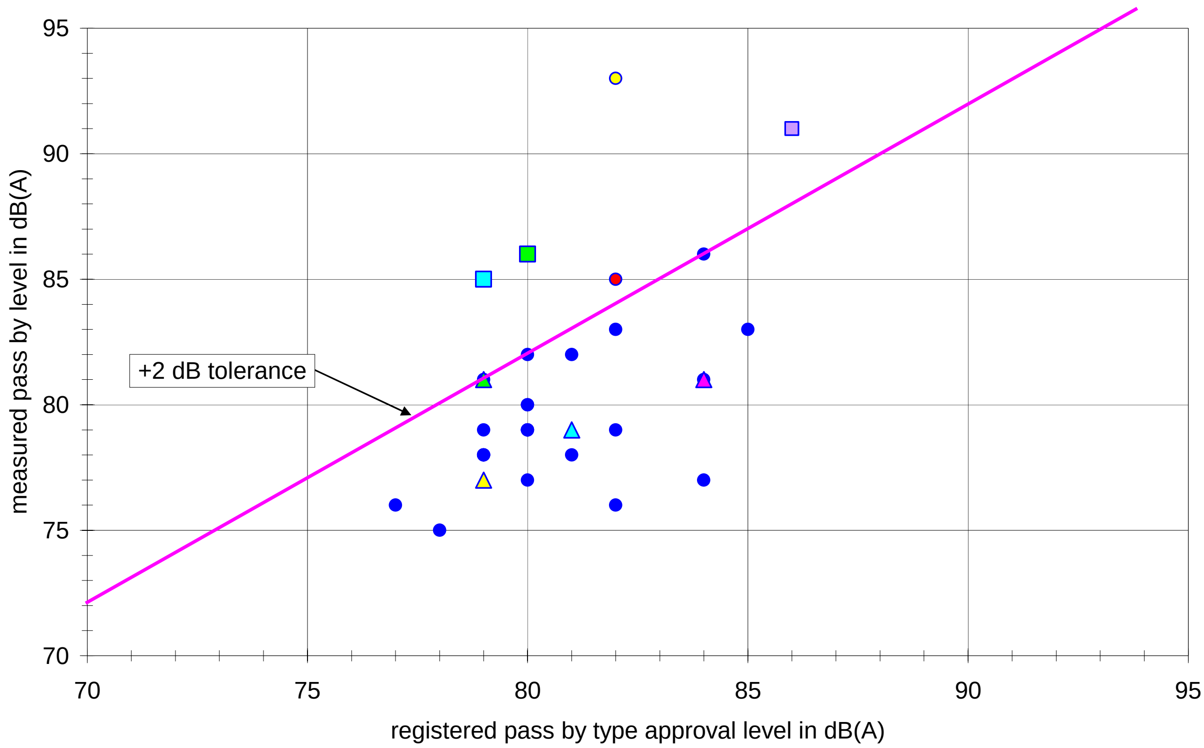

Figure 10: Comparison of measured and registered levels for the pass by test

4.2 Layout for a more representative roadside pass-by enforcement test for motorcycles

The type approval noise measurement test procedure for motorcycles is currently under revision in an ECE working group (Informal group R41). The "layout" of an updated regulation foresees the following parts:

- Updated type approval noise test procedure for compliance with legal limit values,
- Additional provisions for "off-cycle" emissions,
- Roadside enforcement test procedure for roadside in-use compliance tests.

"Off-cycle" emissions are noise emissions that occur in real traffic but are not covered by the type approval noise test. The provisions are intended to ensure that the noise emission under these conditions comply with what one could expect from the type approval test result.

A proposal for a roadside enforcement test procedure was made by TUEV Nord in the Informal R41 group. BASt has already tested some motorcycles according to this proposal within the SILENCE project and will continue these tests during the second half of 2006.

Roadside enforcement tests cannot be performed under ideal conditions and with highly advanced measurement techniques. Therefore the following requirements have to be considered for the development of such a test:

1. Test track design as for type approval tests (length, acceleration starting point at AA', microphone positions at PP', end of acceleration at BB'), but less stringent requirements for road surface, test site and ambient noise.
2. Test shall be vehicle speed based in order to avoid engine speed measurements. In order to keep the test as simple as possible the vehicle's speedometer should be

used for speed control. The speed range covered shall be low for safety and handling reasons.

3. Test must be applicable for all transmission types.

The specification of minimum requirements must be based on extensive practical tests including a wide variety of test sites and vehicles. The tolerance to be applied to such measurement results is correlated with the test site specifications and inaccuracies caused by the use of the vehicle’s speedometer.

A roadside enforcement test cannot be based on the updated type approval noise measurement procedure, because this is far too complicated and time consumptive. On the other hand, it seems also to be inappropriate to use the current R41 procedure for the test, because the vehicle speeds are too high.

It would be more appropriate to base the test conditions on the gearshift prescriptions that are used for test bench measurements within the WMTC procedure (Worldwide Harmonised Motorcycle Exhaust Emissions Certification Procedure, see /2/). These gearshift prescriptions are derived from a gearshift analysis of motorcycle in-use driving behaviour data. Therefore, it is proposed to perform wide open throttle acceleration tests in 2. gear (for vehicles with manual transmission) with a starting speed $v_{AA'}$ that is identical with the WMTC shift speed during acceleration phases from 1. to 2. gear ($v_{1->2}$).

This shift speed is defined as follows:

$$v_{1\rightarrow 2} = ((0.5753 \bullet e^{(-1.9 \bullet \frac{P_n}{m_k + 75kg})} - 0.1) \bullet (s - n_{idle}) + n_{idle}) \bullet \frac{1}{ndv_1}$$

Equation 1

Where

P_n is the rated power in kW,

m_k is the kerb mass in kg,

n_{idle} is the idling speed in min^{-1},

s is the rated engine speed in min^{-1},

ndv_1 is the ratio between engine speed in km/h and vehicle speed in min^{-1} in gear 1.

The roadside enforcement test for motorcycles with a manual transmission is then performed as follows:

For vehicles with automatic transmission the entrance speed is calculated using the following equation:

$v_{AA'} = 8,1225 * (P_n / (m_k + 75 \text{ kg})^{0,2285}$ in km/h

Equation 2

Where

P_n is the rated power in kW,

m_k is the kerb mass in kg,

This formula represents the approximation function between v_AA’ and the power to mass ratio ($P_n/(m_k + 75$ kg)) for more than 80 motorcycles with manual transmissions.

The vehicle enters the line AA’ with a constant speed calculated by Equation 1. To make the test simple, this entrance speed should be stated in the registration document or something equivalent. A wide open throttle acceleration is then carried out until the rear of the vehicle passes the line BB’. The maximum noise level is measured during this acceleration process. The decision how many test are needed and how the final result is calculated is an open question that should be answered on the basis of results of practical tests.

4.3 Measurement programme for motorcycles

Within the SILENCE project BASt as a FEHRL member will perform measurements on 14 different motorcycles. For more details see Table 1.

veh no	manufacturer/type	year of production	mileage in km
1	Kawasaki ZZ-R 600 ZX 600 E	2006	129
2	Honda CBF 600 PC38	2004	4977
3	Honda Deauville NT700V/VA	Nov 05	
4	Kawasaki ZZR ZXT40A (140 kW, 1,4 l)	2006	200
5	Peugeot Leichtkraftrad, A2, 125 cm³	Apr 03	43000
6	Aprilia 650 VD	Jun 05	
7	Yamaha TDM 600	Feb 05	6424
8	BMW K 12S	Sep 05	5000
9	BMW F800	Mrz 06	262
10	Honda CB 1300	Mrz 06	1536
11	Piaggio, M45, Automatik	Mai 06	326
12	Honda VT125, 125 cm³	Mrz 06	570
13	Suzuki Bandit	Mrz 06	7036
14	Honda CFB 1000A	Feb 06	7411

Table 2: Motorcycle sample to be investigated by BASt

These vehicles are subject to noise emission measurements on BASt’s test track as described in chapter 4.2. Some of them are additionally measured on an ordinary road. Stationary tests and type approval pass-by tests complete the programme in order to check the compliance with the registered type approval levels.

5 of the 14 vehicles have already been measured. The measurements for the others are currently ongoing and will be finalised till September 2006. The data analysis is just about to start. First results can be presented by the end of 2006.

4.4 Measurement programme for cars

TUEV Nord will perform roadside enforcement tests on 12 different cars. The final vehicle selection has not yet been decided, but half of the vehicles have already been measured (see Table 3.

veh no	registration year	manufac-turer	brandname	engine type	capacity in cm³	no of cyl.	rated power in kW	rated speed in min-1	idling speed in min-1	max. speed in km/h	trans-mission	no of gears	kerb mass in kg
1	2005	Opel	Astra 1.9 CDTI Kombi	Diesel	1910	4	110	4000	850	207	manual	6	1450
2	2002	Audi	A3 8L	Diesel	1896	4	96	4000	850	205	manual	6	1275
3	2003	Citroen	C	petrol	1749	4	85	5500	900	190	manual	5	1320
4	2001	Skoda	Octavia 1.9 TDI	Diesel	1896	4	81	4150	900	184	manual	5	1365
5	1999	Ford	Galaxy WGR	petrol	2295	4	107	5500	900	192	manual	5	1724
6	2004	BMW	X53	Diesel	2993	6	160	4000	1000	210	manual	5	2180

Table 3: Technical data of the cars already measured by TUEV Nord

Since the variation range of technical characteristics is much smaller for cars than for motorcycles, a more simplified measurement method for roadside enforcement tests is proposed. The vehicles perform a wide open throttle acceleration test with an entrance speed (v_AA') of 30 km/h. Vehicles with manual transmission are measured in 2. gear, vehicles with automatic transmission in D-range.

With respect to the data analysis the situation is the same as for the BASt measurements. The data analysis is just about to start. First results can be presented by the end of 2006.

5 Low noise driving behaviour

As already mentioned a significant propulsion noise reduction is achieved by using low engine speeds and avoiding unnecessary high acceleration and vehicle speed values. But for safety reasons it must be ensured that there is enough power available for necessary accelerations. This requires the driving resistance power and the full load power curve of the vehicle.

The driving resistance power is a function of vehicle speed. For a propulsion noise control system it should be sufficient, if the driving resistance power is calculated by the prescriptions used for test bench settings for the exhaust emission tests.

For cars, light duty vehicles and motorcycles the running resistance curves are derived from running resistance coefficient tables used for exhaust emission measurements on roller benches. For motorcycles the recently updated table from ISO 11486 is used, for cars and light duty vehicles the table from EU directive 98/69/EG.

Cars:

$$\mathbf{P_{tot} = a_1 * v + a_2 * v^2 + a_3 * v^3,}$$

Equation 3

a_1, a_2 and a_3 are linear functions of the vehicle mass.

Motorcycles:

$$\mathbf{P_{tot} = a_1 * v + a_3 * v^3,}$$

Equation 4

$a_1$and a_3 are linear functions of vehicle mass

The full load power curve should be available from the manufacturer.

The following figures show examples for a medium sized car.

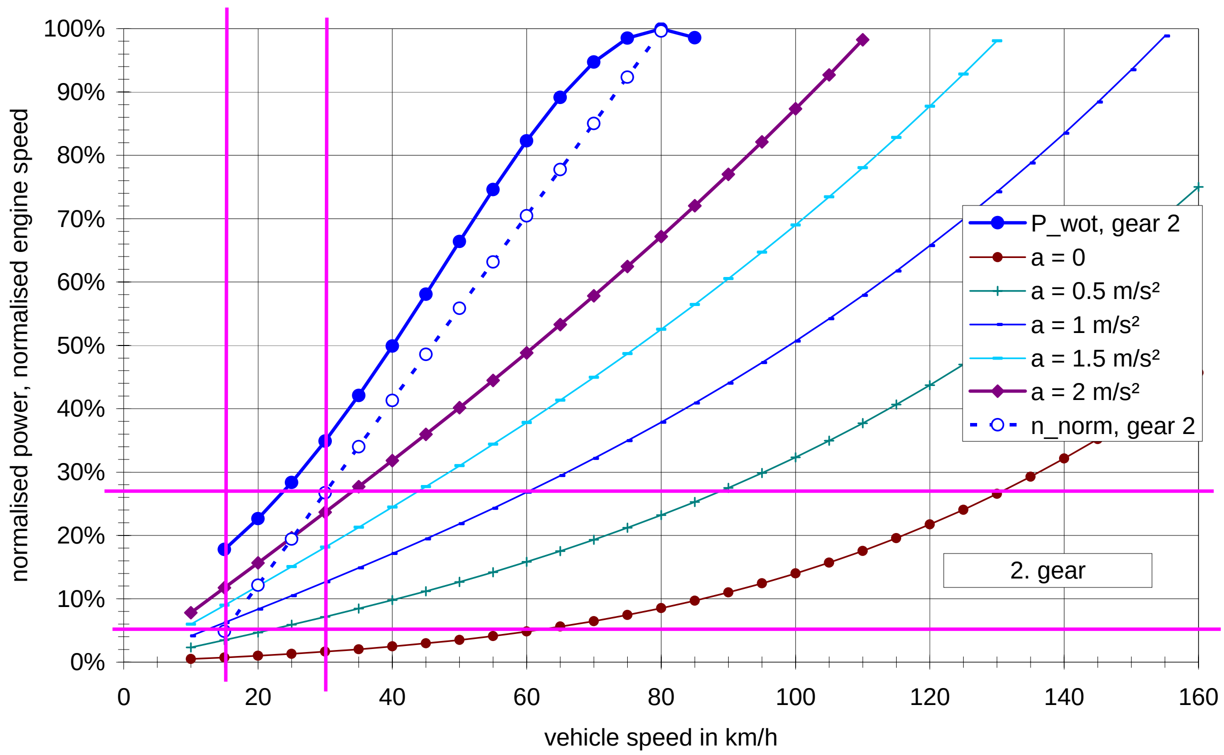

Figure 11: Available normalised power (P_wot) and necessary normalised power for different acceleration values for a medium sized car in 2. gear

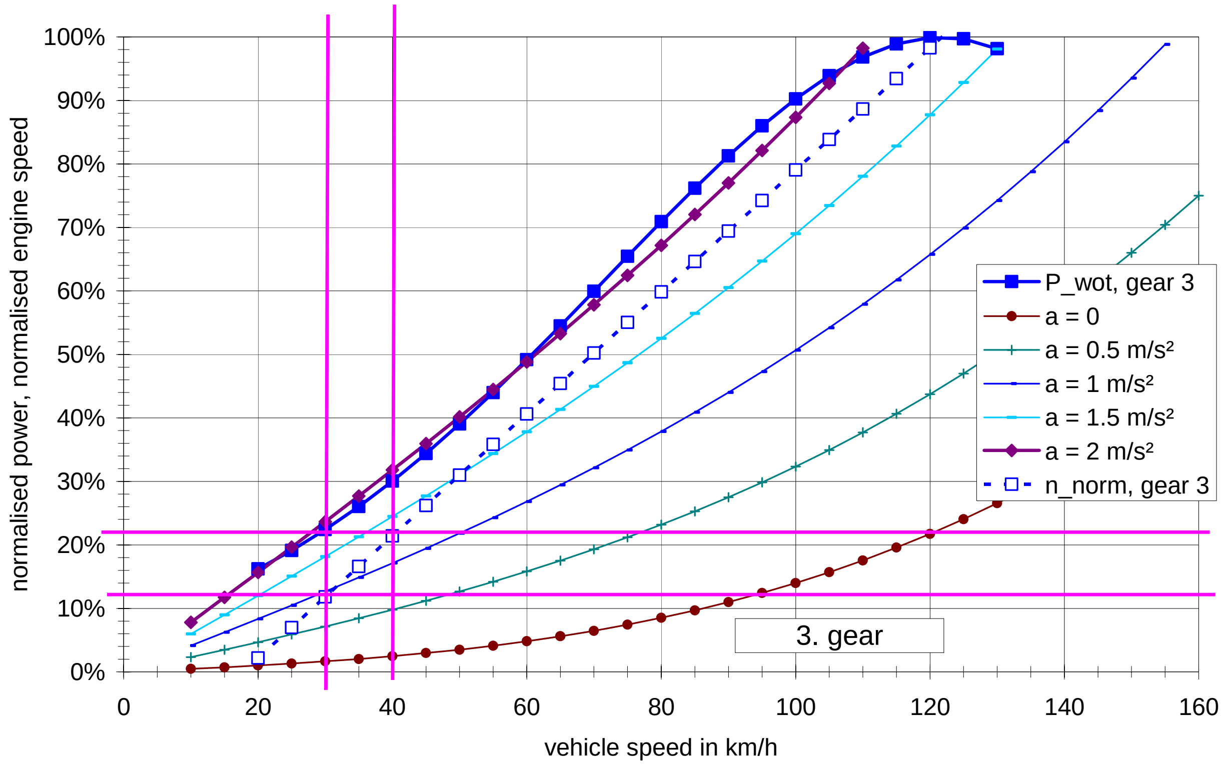

Figure 12: Available normalised power (P_wot) and necessary normalised power for different acceleration values for a medium sized car in 3. gear

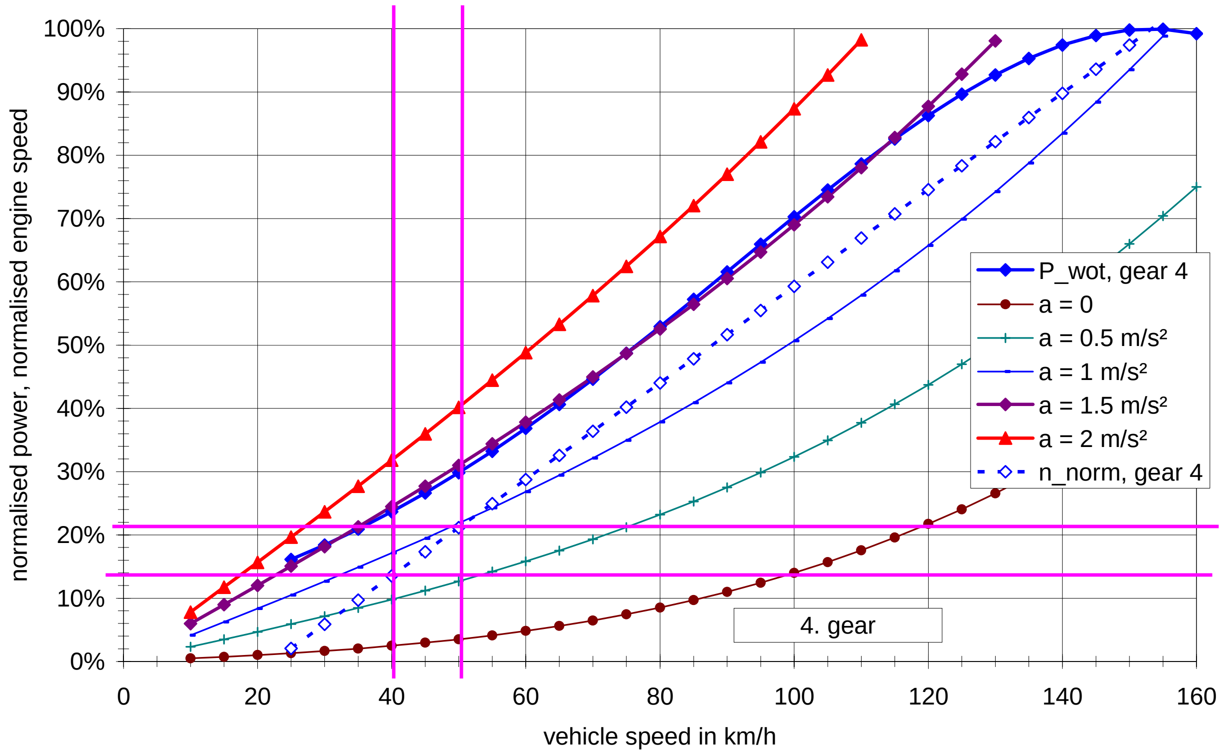

Figure 13: Available normalised power (P_wot) and necessary normalised power for different acceleration values for a medium sized car in 4. gear

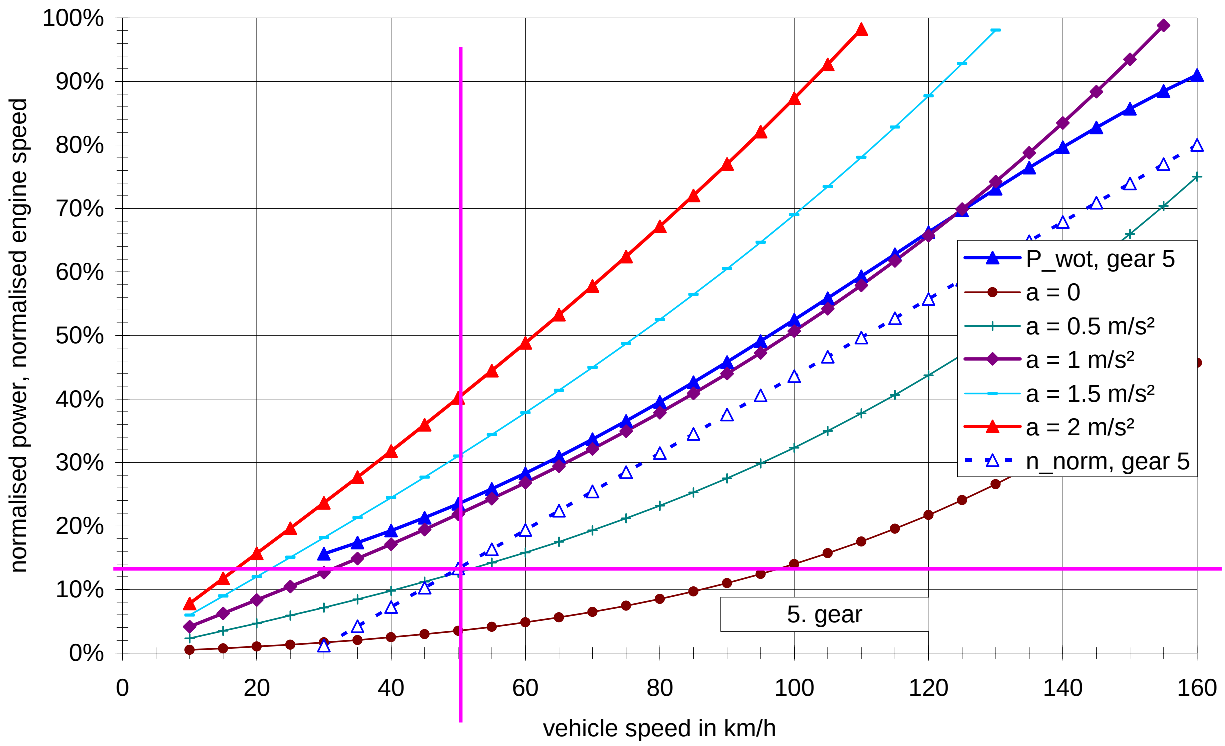

Figure 14: Available normalised power (P_wot) and necessary normalised power for different acceleration values for a medium sized car in 5. gear

This example clearly shows that it is possible to drive with very low engine speeds, if one does not use the full acceleration potential of the vehicle. The acceleration values that are necessary to follow the traffic flow are normally much lower than the full acceleration potential of the vehicle.

That means it is possible to design a highly effective gearshift indicator or an engine speed limiter on the basis of the full load power curve, the vehicle mass, the actual vehicle speed and the road gradient.

A simulation model for motorcycles, cars and light duty vehicles has been developed within the project that allows calculation of the effects of different driving behaviours on the noise emission of a particular vehicle. This tool will also be available for other partners of sub-project H.

Examples of the results are shown in the following figures. In these figures the low noise driving behaviour is called "economic", because it results also in lower fuel consumption and CO_2-emissions.

The ideal reduction measure under the scope of sub-project H is the combination of the roadside monitoring system with vehicle based engine speed and acceleration limiters. The limiters could then be activated by the monitoring system when the vehicle enters a noise sensitive area and could be deactivated when this area is left.

The evaluation of the interaction between monitoring systems and vehicle noise control systems, the consideration of methods for implementing such methodologies and the assessment of the possibilities to use the noise emission monitoring for traffic management measures aiming at a reduction of the noise exposure are subject of the further work of sub-project H2.

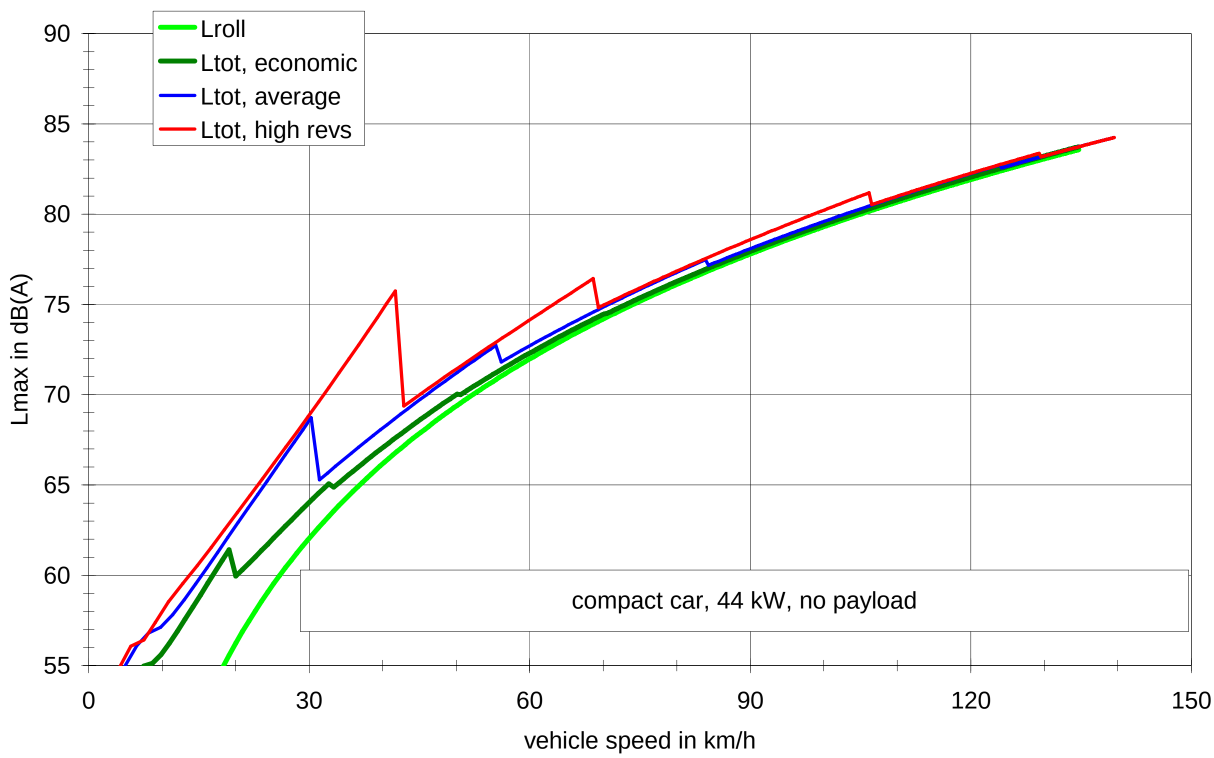

Figure 15: Noise emission of a compact car for different driving styles

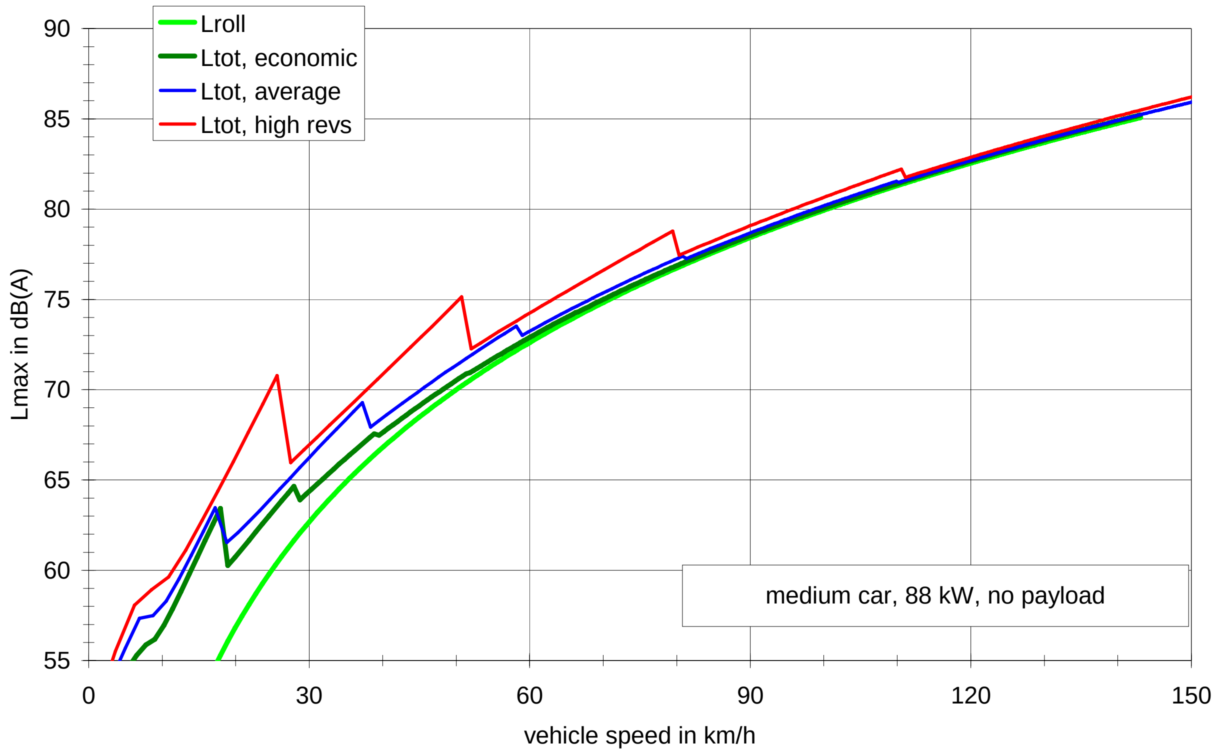

Figure 16: Noise emission of a medium sized car for different driving styles

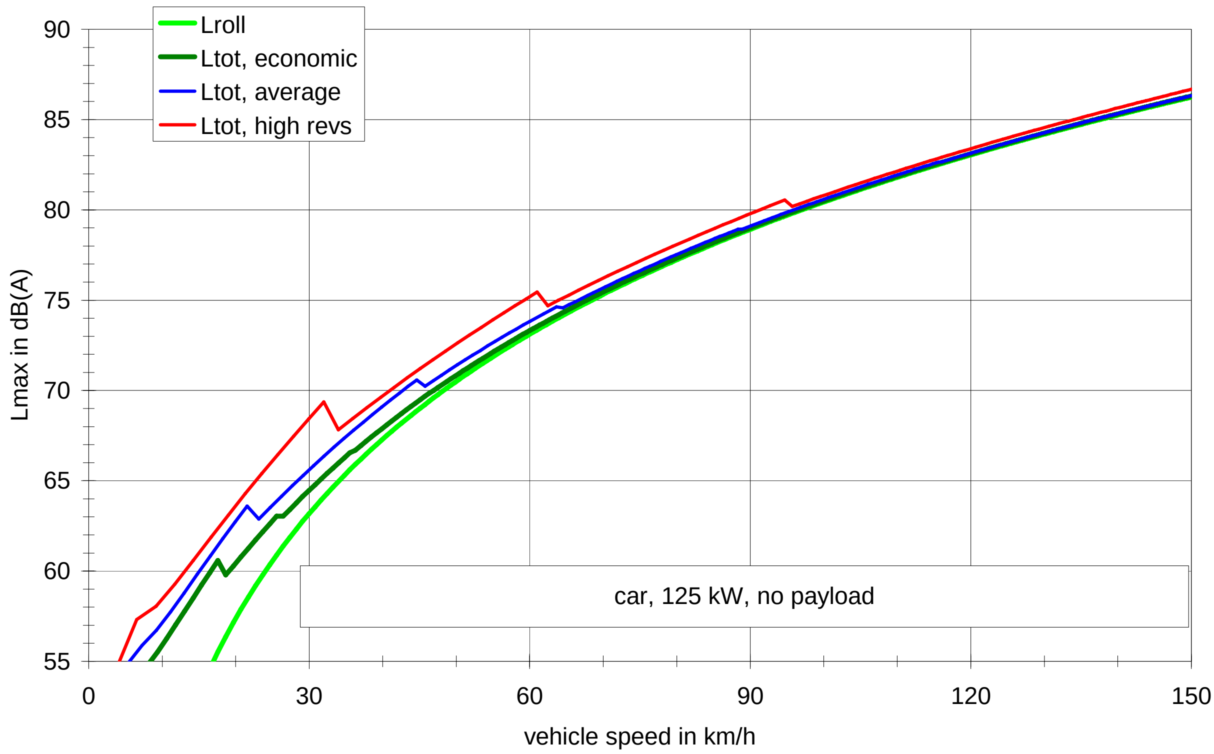

Figure 17: Noise emission of a high powered car for different driving styles

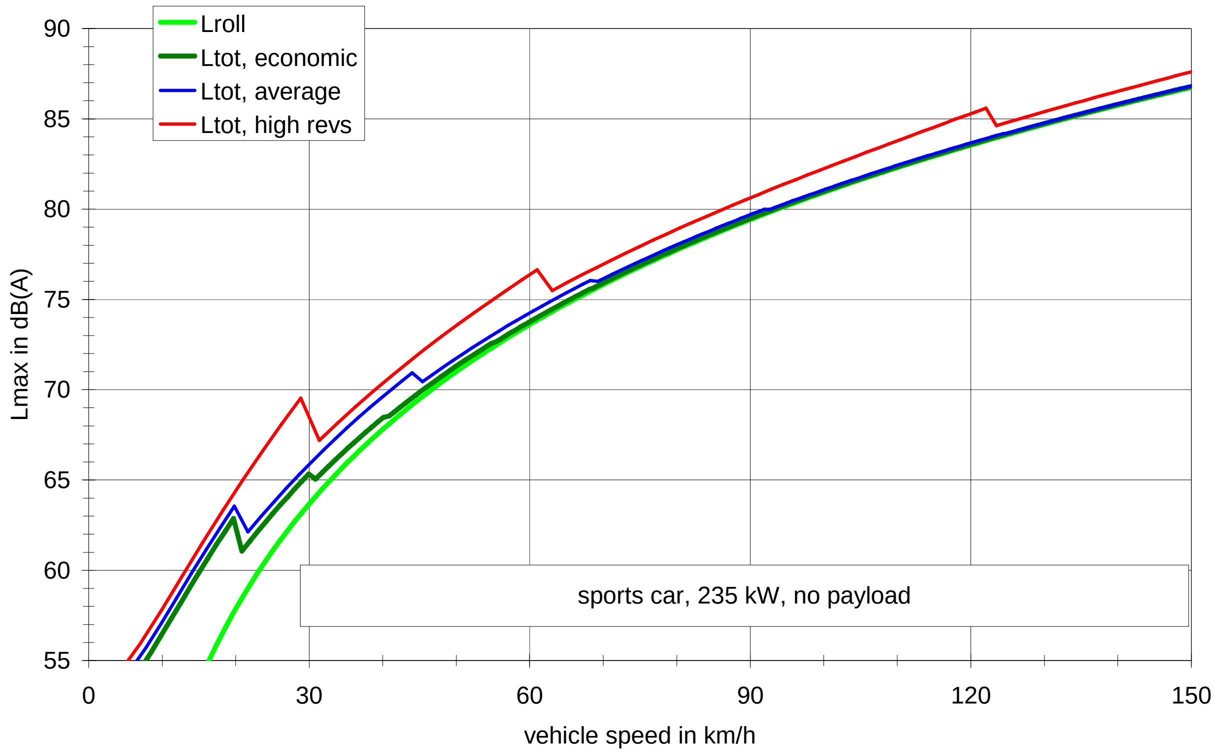

Figure 18: Noise emission of a sports car for different driving styles

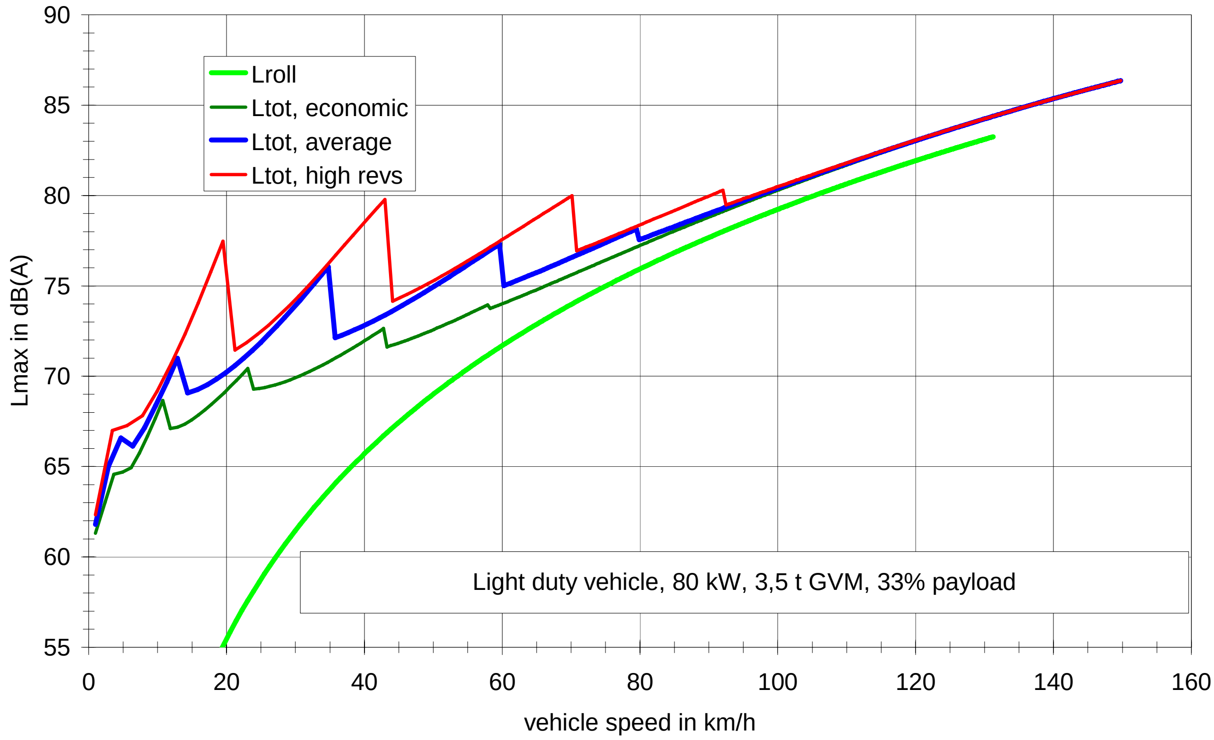

Figure 19: Noise emission of a light duty vehicle for different driving styles

6 Literature

/1/ E. Pullwitt, S. Redmann, Stationary noise tests on motorcycles during roadside checks and during annual inspections (§ 29 StVZO)

/2/ TRANS/WP.29/GRPE/2004/11

UNIFORM PROVISIONS CONCERNING THE MEASUREMENT PROCEDURE FOR MOTORCYCLES EQUIPPED WITH A POSITIVE – OR COMPRESSION IGNITION ENGINE WITH REGARD TO THE EMISSION OF GASEOUS POLLUTANTS, CO2 EMISSIONS AND FUEL CONSUMPTION BY THE ENGINE, March 2004