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NOISE CLASSIFICATION METHODS FOR URBAN ROAD SURFACES

Classification Methodology

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1 Introduction

1.1 Role within SILENCE

Subproject F of the SILENCE project is concerned with the role of road surfaces in the generation of road traffic noise. The project focuses especially on noise abatement in urban areas, and consequently urban road surfaces and their noise emission properties are the main interest of subproject F. The work packages within subproject F deal with the following topics:

- WP F1: New production technologies for surfaces on urban streets
- WP F2: New production technologies for surfaces on urban main roads
- WP F3: Improved systems for the maintenance of quieter surfaces
- WP F4: Noise classification methods for urban road surfaces
- WP F5: Testing of novel road surfacing materials

Within the subproject, work package F4 plays the important part of providing tools for other work packages to assess the success of new types of road surfaces or the maintenance of existing pavements. Within F4, the tasks are distributed as follows:

- Task F4.1: State of the art
- Task F4.2: Measurement methods
- Task F4.3: Classification by type, condition and location
- Task F4.4: Corrections for local discontinuities
- Task F4.5: Noise performance development model

This document is the output of the work in task F4.2 and is concerned with providing a proposal for a classification method that can be used also for urban road surfaces. It relies on the deliverable F.D12 which describes the measurement methods and their fields of application in detail. This paper also draws on the experience from the European Project SILVIA and the acoustic road surface classification developed there.

1.2 Aim

The aim of this document is to propose a methodology for classifying the noise performance of road surfaces used in urban areas for use in noise mapping, by road authorities, city planners or architects. The accuracy aimed at makes the method not suitable for any kind of acceptance testing of works.

2 The influence of road surfaces on road traffic noise

Road traffic noise is the most important source of noise pollution in the industrialized world. No other means of transport can match its traffic volumes and the pervasiveness of the road networks. Therefore substantial efforts are undertaken to protect the population from the noise it generates. In rural areas this usually takes the form of noise barriers, but in urban areas where noise sources and residential buildings are much closer together, this is not generally possible. For this reason the interest is turning to the generation mechanisms of road traffic noise, because noise reduction at the source promises to be very effective.

The noise generated by individual road vehicles typically originates from three major sources, namely the engine and its attached components, the tyre/road contact and aerodynamic turbulence. For the typical urban speed range of 0 - 80 km/h, only engine and tyre/road noise need to be considered, with tyre/road noise dominating from 30 - 50 km/h upwards and engine noise dominating at lower speeds. Tyre/road noise is heavily dependent on the type of road surface, whereas the generation of engine noise is not influenced by the road surface. However, especially in the case of porous road surfaces, the propagation of both noise types can be influenced by the sound absorption of the pavement.

Low-noise pavements have been successfully used in the high-speed road network to reduce the noise emission of vehicles. Nevertheless the choice of road surface type can also help to alleviate noise problems in urban areas, where the construction of noise barriers is more problematic. Replacing block pavements with smooth surfaces or using modern porous road surfaces on main streets with speed limits of up to 70 or 80 km/h are possible applications. Sensible decisions in this area need to be based on well-established figures to achieve the desired noise reduction. Therefore the decision makers need a consistent and reliable classification system that provides them with a catalogue of road surfaces and their effects on noise emission.

3 Requirements for a classification of urban road surfaces with respect to noise emission

The classification methods for urban road surfaces with respect to noise emission do not necessarily need to differ very much from the methods used for high-speed roads. However, rankings may still be different due to the different weighting of noise source contributions in the different speed ranges. Therefore the following typical characteristics of urban road surfaces should be taken into account.

Urban roads and urban road surfaces can roughly be described as occurring in or close to larger residential agglomerations. This covers small lanes and municipal roads of varying traffic density up to large ring roads and city expressways and motorways. Characteristics of urban roads and urban road surfaces considered here are:

1) Speed range 0 – 80 km/h:

   Noise emission in this speed range can be characterised as follows:

   - Vehicle noise at velocities below 30 km/h is usually dominated by engine noise and shows small dependence on the road surface type.
   - Common speed limits in residential zones in Europe are around 50 km/h, which is in the middle of the range. As many drivers go at a speed close to the limit, this can also be considered as a kind of “average speed”.
   - Velocities above 80 km/h usually occur on thoroughfares or motorways in urban areas. The measurement methods already used for high-speed roads can be used for the surfaces of those roads.

2) High variability of speed:

   Urban streets usually have many intersections, roundabouts, traffic lights and road signs. The highly regulated traffic leads to frequent velocity changes and even stops.

3) Low gear setting of many vehicles:

   The vehicles circulating on urban roads often use low gear settings, leading to an increased engine noise contribution.

4) Dense traffic:

   Urban roads exhibit typically high traffic densities on the major municipal roads, especially during rush hours. Side streets are quieter, but of course they also contribute much less to the overall noise load. High traffic densities make the identification of the impact of single vehicles especially difficult.

5) Specific traffic composition:

   Most traffic on urban roads is dominated by passenger cars. Heavy trucks contribute much less to the traffic mix than e.g. on highways. Buses, light delivery trucks and motorcycles are also typical for an urban situation.

6) Short lengths of homogeneous road surface:

Due to the many intersections, buildings and the frequent maintenance and repair work the lengths of uninterrupted homogeneous road surface without too many surface discontinuities can be rather short.

7) Many reflecting surfaces and objects close to the road:

Urban streets are typically lined by buildings on both sides of the road, complemented by road signs, lamp posts, poster walls, trees and parked vehicles. These objects give rise to multitudes of reflections and create a highly complex sound field.

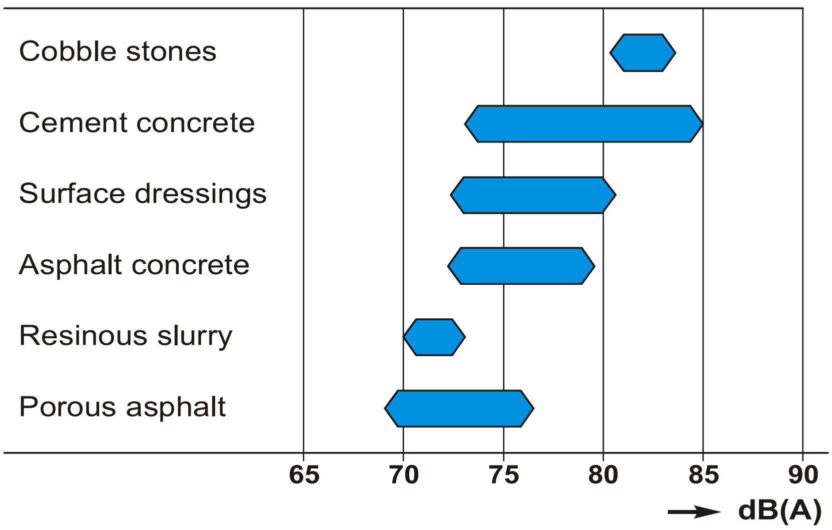
The resulting requirements for an urban classification method are:

1) General requirements

a. Accuracy and distinguishability

Accuracy in this context means that the classification procedure should yield results with a low error margin for a specific pavement type. This is important to distinguish different road surface types from each other in terms of noise emission. Strongly overlapping confidence intervals would make a choice between different surface types meaningless. It is also important to exactly characterize the road surface type in question, as there may be considerable variation within road surface categories like SMA (stone mastic asphalt) or concrete pavements. One of the major problems is that the broader categories of pavement types like DAC (dense asphalt concrete), PA (porous asphalt), SMA (stone mastic asphalt) or EACC (exposed aggregate cement concrete) usually yield noise measurement results in a broad and overlapping range. More specific definitions or proprietary names are often difficult to identify clearly, especially in different countries.

Figure 1: Range of CPB tyre/road noise measurement results for surface categories (DESCORNET, 1979)



b. Repeatability and Reproducibility

The results should not vary outside the error margins for newly laid pavements, whether the test is performed with the same equipment at different times or by different organisations according to the same standard. Of course the noise performance of pavements will vary over time, but the classification values should remain fairly constant within the valid time period for classification measurements. These requirements also rely on a very precise description of the pavement class.

c. Practicability and Cost-Effectiveness

It should be possible to carry out the measurements and procedures with reasonable constraints for effort, time and costs.

d. Compatibility with standards and noise prediction methods

Standardized procedures should be followed wherever possible. The procedures should make use of the work done in ISO and CEN to ensure that parameters and results remain as comparable as possible among different countries and testing organizations. Where national methods exist that supersede or extend the standards substantially, it is not sure whether the results will fit within an international classification scheme. Moreover the procedure should also remain compatible with the European efforts for a common noise prediction method as proposed by the HARMONOISE project. Ideally the output of a road surface classification would be values that can be directly used to calculate the effects of changing the surface on the immission levels affecting nearby residents.

e. Applicability for planning, COP and approval testing, QC and monitoring

The procedure will have to be flexible enough to be used for several different purposes. For noise policy planning, at least a rough classification is necessary. Conformity of production (COP) and approval testing will enable contracting parties to establish whether the agreed noise emission levels or legal limits have been exceeded. For manufacturers of low-noise surfaces, constant quality control and evaluation of new surface prototypes should be possible. Monitoring will provide information on the long-term evolution of road surfaces.

2) Urban-specific requirements

a. Validity in the low-speed range

In urban areas at low traffic speeds the total noise output of road vehicles will usually be a mixture of tyre/road noise and engine/powertrain/exhaust noise (here subsumed under engine noise). The transition speeds from engine noise to tyre/road noise dominance are in the range of 30 - 50 km/h and depend on vehicle type and driving condition. The road surface clearly influences the generation of tyre/road noise to a large extent, whereas engine noise can be influenced in its propagation by absorbing road surfaces, but to a much smaller extent.

b. <u>Engine noise contribution</u>

Engine noise cannot be neglected in urban driving situations. If measurements yield only tyre/road noise information they have to be complemented with other information sources to ensure a fair classification.

c. <u>Urban traffic composition</u>

Urban traffic is usually dominated by passenger cars, delivery trucks and buses, and powered two-wheeled vehicles. The proportion of heavy trucks is reduced compared to motorways. Ideally the measurement and evaluation procedures would allow tailoring the noise emission indicators to the traffic composition which can be monitored via standard traffic counting equipment.

4 Measurement methods used for classification

At the time of writing several methods for investigating the influence of road surfaces on the generation of road traffic noise exist. Apart from simple noise immission measurements taken more or less close to the roadside, two internationally standardized procedures have been produced by the working group 33 of the Technical Committee 43 "Acoustics" / Subcommittee 1 "Noise" of the International Standardization Organisation (ISO TC43/SC1/WG33 "Measuring method for comparing traffic noise on different road surfaces"). The standardized methods are:

- The **Statistical Pass-By Method (SPB)** based on **ISO 11819-1**
- The **Close-Proximity Method (CPX)** based on **ISO /CD 11819-2**

Even if one of them is still a draft, both are widely used and recognized as standard tools for investigating the noise emission properties of road surfaces. They can be applied to high-speed roads as well as to low-speed ones, albeit the use for urban roads has not been specifically addressed with all its implications in the standards.

A third widely used method, the **Controlled Pass-By Method (CPB)**, is basically a variant of the SPB method where a small number of test vehicles are chosen to represent the general types of vehicles required in the SPB method.

If no direct measurement of noise emission properties is possible, proxy measurements of some surface characteristics can help to assess the noise emission by application of appropriate models. **Surface texture**, **sound absorption** and **dynamic stiffness** are known to be the essential characteristics determining the noise performance of pavements.

4.1 ISO/CD 11819-1 Statistical Pass-By (SPB) method

The Statistical Pass-By-Method is described in the ISO 11819-1 standard (ISO 11819-1, 1997). It provides a method to determine an index which can be used to compare the noise emission impact of different road surfaces by measuring vehicle pass-bys at the roadside.

4.1.1 Principle

The Statistical Pass-By (SPB) method is based on the measurement of the maximum A-weighted sound pressure levels of a statistically significant number of individual vehicle pass-bys together with the vehicle speeds. The passing vehicles are classified into one of three vehicle categories and one of three reference speeds is chosen according to the average operating speed of the road. A regression line of the maximal A-weighted sound pressure level versus the logarithm of speed is calculated for the pass-bys of every category. This regression line is then used to determine the average maximum A-weighted sound pressure level L_{veh} at the reference speed. The L_{veh} of the three categories can be combined to give a single index called SPBI (Statistical Pass-By Index) which is indicative of the influence of the road surface on the noise emission of a mixed vehicle collective.

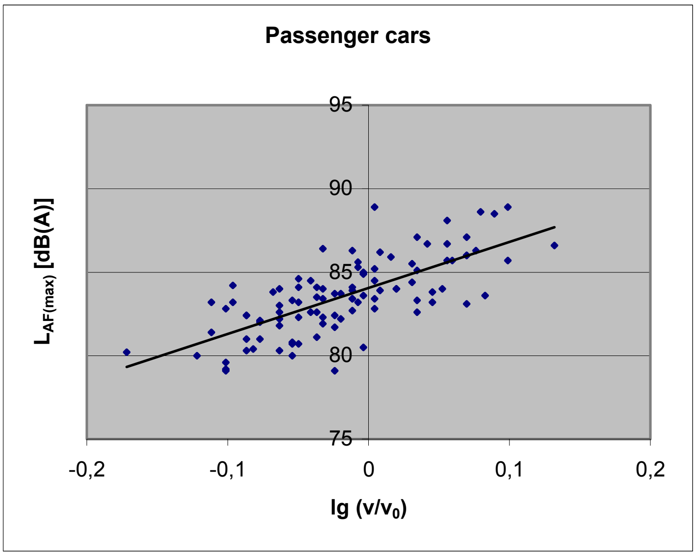
Table 1: Vehicle categories in ISO 11819-1

Category	description	Typical examples	Minimum number of pass-bys
1) Cars	2 axles, 4 wheels	Passenger cars	100
2a) dual-axle heavy vehicles	2 axles, more than 4 wheels	Light trucks, buses	30 (2a+2b = 80)
2b) multi-axle heavy vehicles	More than 2 axles	Heavy trucks	30 (2a+2b = 80)

Table 2: Road categories and reference speeds in ISO 11819-1

Category	Speed range (km/h)	Typical area	Reference speeds v_0 [km/h] for category 1) / 2a) / 2b)
Low speed road	45 – 64	Urban traffic	50 / 50 / 50
Medium speed road	65 - 99	Suburban areas, thoroughfares, rural highways	80 / 70 / 70
High speed road	100 and more	Motorways in rural or suburban areas	110 / 85 / 85

Figure 2: Regression analysis



$$L_{corr} = L_{meas} - B \cdot \lg\left(\frac{v}{v_0}\right)$$

$$SPBI = 10 \cdot \lg\left[W_1 \cdot 10^{0,1 \cdot L_1} + W_{2a} \cdot \left(\frac{v_1}{v_{2a}}\right) \cdot 10^{0,1 \cdot L_{2a}} + W_{2b} \cdot \left(\frac{v_1}{v_{2b}}\right) \cdot 10^{0,1 \cdot L_{2b}}\right]$$

4.1.2 Suitability of SPB measurements for classification purposes

SPB measurements correspond to a relatively realistic listening situation as the microphone is positioned 7.5 m from the passing vehicles at the roadside where buildings or pedestrians can be found in an urban setting. With regard to classification purposes, it has the following properties:

ADVANTAGES

1) **Measures the complete noise output of road vehicles**

Tyre/road noise as well as engine or aerodynamic noise is recorded. Nevertheless untypical sounds like excessive rattle or noise form shifting truck cargo are usually discarded. Even if it may be difficult to distinguish between engine and tyre/road noise contribution at urban speeds from an SPB measurement alone, the overall noise is recorded as it occurs.

2) **Realistic listening situation**

As mentioned above, the receiving microphone (7.5 from the centre of the lane at 1.2 m height) more or less corresponds to what a person standing at the roadside would hear.

3) **Includes vehicles of all types, especially trucks**

While few if any suitable CPX-type measurement systems for truck wheels exist and the current method only uses a proxy car tyre to account for (light) truck influence, SPB can cover the whole range from light to heavy trucks, buses and even two-wheeled vehicles if necessary.

4) **Allows for weighting of vehicle categories**

The average vehicle category levels are determined separately for each category. By using weighting factors that can be adapted to the traffic composition, an SPBI ranking of surfaces suitable to specific application can be generated.

5) **Large statistical sample**

The minimum total number of vehicle pass-bys to be is 180, with at least 100 passenger cars among them. Therefore the traffic composition at a specific site is quite well represented in the measured data.

6) **Accuracy, repeatability and reproducibility**

The 95% confidence interval around the individual L_{veh} values is given as 0.3 dB for cars and 0.7 for trucks in the standard. Repeatability is stated to be better than 1 dB. Even if the numbers will have to be treated with caution in the low-speed category, this indicates a rather good performance.

DISADVANTAGES

1) **SPB is a spot method**

SPB measurements are valid for road segments with a maximum length of 100 metres. For extended road sections the measurement has to be repeated at least every 100 metres.

2) **Stringent conditions on surface and surroundings**

The SPB method works very well when carried out on specially designed test sections where the acoustic surroundings and the surface layout can be completely controlled.

The standard requires that a very large portion of the propagation path between vehicle and microphone is covered with the surface under test. Reflecting objects and acoustic background noise must not interfere with the sound to be measured. The use of a backing board can help to alleviate these problems.

3) Traffic density

High traffic densities make the measurement of isolated pass-bys difficult.

4) Varying traffic composition

Although a statistical approach is taken, the difference in traffic composition at different sites may influence the classification. For some locations it may also be impossible to measure enough pass-bys in each of the three categories to produce an overall SPBI with the standard weighting.

5) Reference speed and covered speed range

While the standard states the reference speed for each road category, actual pass-by speeds may vary from it. A certain spread of speeds is necessary to determine the speed correction, and the average speed and the region of small confidence intervals may not lie at the reference speed.

6) Practicability and Cost-Effectiveness

Due to the problems mentioned before, SPB measurements can be very time-consuming and suitable test locations, if not specially constructed, are often difficult to find.

Despite some drawbacks, the SPB method is currently the most established and widely used method for classification. If test sites can be constructed or found that meet all the necessary requirements, it appears to be the method of choice.

4.2 Controlled Pass-By (CPB) method

The CPB method is essentially a variant of the SPB method with a different vehicle sample.

4.2.1 Principle

A description of the basic SPB method can be found in section 4.1. One of the requirements of the SPB method is to measure a certain minimum number of vehicle pass-bys for each of the three categories 1, 2a and 2b. This can lead to problems if the number of passing vehicles in one of the categories is very low or the vehicle pass-bys cannot be easily separated. The high numbers entail also a considerable time spent waiting for the pass-bys. Moreover, a certain spread in the pass-by speeds is necessary to be able to draw a regression line and the speed distribution may not be centred at the required reference speed. One way to circumvent this is not to rely on naturally occurring traffic, but to employ test vehicles and test drivers to produce pass-bys at pre-defined speeds. While the difficulty to discern the test vehicles in the ordinary traffic flow remains, significantly fewer runs will already give good results. The critical issue is of course the correct selection of representative test vehicles.

4.2.2 Suitability of CPB measurements for classification purposes

CPB measurements are especially well suited for dedicated test installations of road surfaces not open to the general traffic. While they share some properties of the SPB measurements, the differences are listed below.

ADVANTAGES (compared to SPB)

1) **Complete control over vehicle sample**

   A small number of test vehicles can be selected to represent the statistical distribution found in practice. These vehicles can be measured rather quickly and efficiently.

2) **Controlled speed, driving and surface conditions**

   Speed and driving condition can be predetermined so that the desired ranges are covered. A large range of different driving situations (drive-by, coast-by, wet road, acceleration, etc.) can be arranged and systematically tested.

3) **Practicability and cost-effectiveness**

   The CPB method is usually faster and more cost-effective than SPB.

DISADVANTAGES (compared to SPB)

1) **Representative test vehicles required**

   The small number of test vehicles is at the same time a drawback of the method, as it reduces the information about the mix of vehicles found in the ordinary traffic. It can be very difficult to choose representative test vehicles.

2) **Test sites preferred**

   If CPB is not applied on a dedicated test site, high traffic densities or passing traffic can still present a problem.

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4.3 ISO/CD 11819-2 (CPX method)

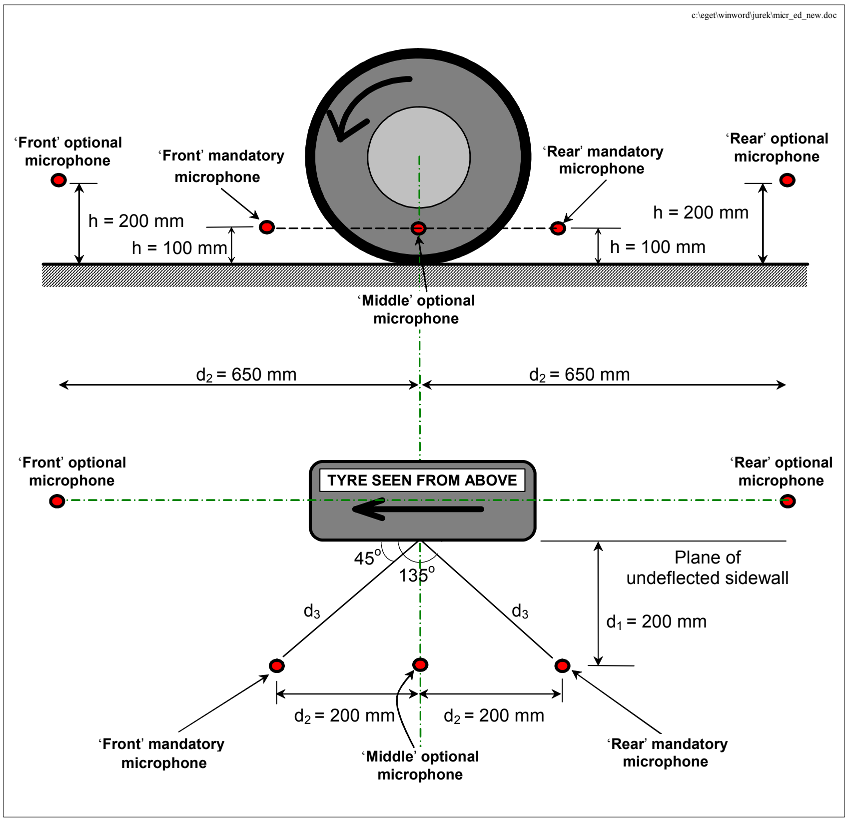
The method described in the draft standard ISO/CD 11819-2 (ISO/CD 11819-2, 2000) is intended to supplement the SPB measurements according to ISO 11819-1, which is essentially a spot method, with a procedure to check the homogeneity of the noise emission properties of road surfaces over long distances. It was also designed to overcome the serious limitations of the SPB method when measurements at arbitrary sites are required, which is usually necessary for approval testing.

4.3.1 Principle

In the CPX method the average A-weighted sound pressure levels generated by two or four specified reference tyres (A, B, C and D) running on the surface under test are measured by at least two microphones located close to the tyre/surface interaction zone. The tyres are mounted on a specially designed vehicle, which is either self-powered or a towed trailer. The tyres have been selected to represent the most important types of tyres actually in use on average cars. The vehicle speed is measured for correction purposes. By averaging the sound pressure levels over short distances, several runs and the two mandatory microphone positions, a tyre/road sound level can be determined for every tyre. By combining them into a weighted average, the Close-Proximity Sound Index CPXI is calculated, which can be used to compare different road surfaces.

$$CPXI = 0.2\,L_A + 0.2\,L_B + 0.2\,L_C + 0.4\,L_D$$

Figure 3: CPX method microphone positions (ISO/CD 11819-2, 2000, p. 9)



4.3.2 Suitability for classification purposes

CPX and CPX-like measurements are relatively easy to carry out once the equipment is available, and they can cover very long distances. Classification requires a level of accuracy and reproducibility which at the current time seems difficult to achieve, as results of the different devices across Europe still vary within a range of typically 2 dB.

ADVANTAGES

1) **Can measure long road sections**

The most obvious advantage of the CPX method is that it measures the noise emission levels of whole road section and not only of one spot. Therefore it can be used for homogeneity testing and approval testing of extended road surface areas.

2) **Isolated from background noise and reflected sound**

With the microphones placed only a few decimetres from the tyre/road contact, any disturbing sound whether from other vehicles or reflected from roadside obstacles is usually more than 10 dB lower than the direct sound wave. The measurement setup can additionally protected by a hood.

3) **Smaller traffic dependence**

The CPX measurement is not only independent of the surroundings, which makes it suitable for urban conditions, but also less affected by the traffic situation. It can usually be carried out in free-flowing traffic, as long as the speed can be kept near the desired reference speed.

4) **Allows for limited weighting of vehicle categories**

The SPBI value is a weighted average of the tyres A, B, C and D, where the first three represent car tyres and the last one a light truck tyre.

5) **Practicability and Cost-Effectiveness**

CPX measurements can be carried out very efficiently as soon as the equipment is available and can cover long distances quickly. There is no inherent need to influence the traffic to a large extent or to create special test sections or sites.

DISADVANTAGES

1) **Does not cover engine noise contribution**

CPX measurement can only account for tyre/road noise, not engine noise. That is sufficient at higher speeds where tyre/road noise dominates.

2) **Incomplete coverage of heavy vehicle noise**

The only way that heavy vehicle noise is included is via the D tyre, which can only represent light trucks.

3) **Does not account for propagation effects**

Due to the microphone location close to the tyre/road contact sound propagation occurs only over a very short distance. Absorption of engine or tyre/road noise can only play a minor role. Additionally, the sound field around the tyre is complex and does not necessarily represent what a person at the roadside would hear.

4) Low general correlation with SPB measurements

The results of the SILVIA project indicate that a general correlation between CPX and SPB measurements for an arbitrary range of road surfaces yields a low correlation, especially when porous surfaces are included. The correlation improves when only sub-categories of road surface types are considered.

7) Representativeness of test tyres

The chosen test tyres may not fully represent even the car tyre population at a specific site. The typically used tyres also vary over time.

8) Accuracy, repeatability and reproducibility

The draft standard currently estimates a random error in the range of 0.3 dB and a repeatability of 0.5 dB, which is very good. However, the systematic deviations that govern reproducibility, especially with different measuring devices, yield a range of typically 2 dB, probably mainly due to variations in the test tyres. Therefore certification efforts for the CPX equipment have been initiated.

Nevertheless the CPX method seems to be well suited for urban road surfaces at least in terms of usability and as a tool to assess the tyre/road component of road traffic noise. At the moment it is only considered as a secondary method for classification purposes, but it can still provide an assessment of the situation at specific urban sites with road surface types already classified by a combination of SPB and CPX measurements.

4.4 Comparison of test methods

Table 3: Comparison of measurement methods for urban road surfaces

Criterion	ISO 11819-1 (SPB)	CPB	ISO/CD 11819-2 (CPX)
Speed range 30-80 km/h covered	++	++	++
High speed variations possible	++	++	+
Sensitive to influence on engine noise	++	++	--
Resistance to background noise	--	--	+
Usable for urban traffic composition	++	+	+
Accounts for heavy vehicle noise	++	++	-
Short homogeneous test sections possible	++	++	+
Reflections and screening	--	--	++
Close to or on the road	++	++	++
Length of measured road surface section	-	-	++
Low time consumption	--	+	++
Comparability to other locations	++	+	++
Useful for classification	**++**	**+**	**+**

The SPB method is especially suitable for general classification purposes and whenever the complete road traffic noise emission including engine noise and tyre/road noise from heavy vehicles is important.

The CPB method can be used at dedicated test sites to investigate specific driving conditions and when representative test vehicles are available.

The CPX method is very well suited to mobile measurements even within urban areas. It however shows two disadvantages: It cannot account for engine noise neither can it completely assess tyre/road noise from truck tyres.

4.5 Texture measurements

The main surface characteristics that determine tyre/road noise are macro- and megatexture. Modern profiling devices using lasers are now able to measure the whole range of macro- and megatexture at once. There are static versions, transportable or mobile, as well as dynamic devices capable of measuring at traffic speed. That type of equipment is subject to a set of ISO standards either already published or in development (EN ISO 13473-1:2004, ISO 13473-2:2002, ISO 13473-3:2002, ISO/DTS 13473-4:2006, ISO/CD 13473-5:2005),

In addition to those measurements a model for transforming the measured texture levels into estimated noise emission levels is necessary. One of the several examples is the calculation model proposed in SILVIA (see PADMOS et al., 2005)

4.6 Sound absorption measurements

The sound absorption coefficient is the fraction of sound energy absorbed by a material when a sound wave is reflected by its surface. It generally depends on the frequency of the sound considered (or its spectrum when it is not a tonal sound) and the angle of incidence of the sound wave.

The sound absorption coefficient of a surface is usually evaluated for plane wave incidence conditions. It can be measured by various methods:

- the so-called impedance tube method also referred to as the “Kundt’s tube”: the basic principle is that when the lateral dimensions of a tube are small compared to the wavelength of the acoustic signal, only planes waves will propagate. The sample, placed at one end of the tube is submitted to normal incident wave fronts. The absorption coefficient is derived from the shift of the nodes of the stationary wave in presence of the sample. Two variants of the method are ISO standard (ISO 10534-1, 1996 and ISO 10534-2, 1998).
- the external point source method: if a point source is far enough from the measured surface, the spherical wave front geometry can be approximated by a plane wave front. Depending on the relative positions of the source and the microphone, normal or oblique incidences can be considered. This impulse method is in fact an ISO standard (ISO 13472-1, 2002) for the on-site determination of the absorption coefficient of absorbing materials used in the construction of noise screens.
- the reverberant room method: in a room with very reflective walls (no absorption) the spatial sound distribution becomes diffuse. A sample placed in such a room is submitted to an acoustically diffuse field (random incidence distribution of plane waves). The absorption coefficient is derived from the decrease of the reverberation time and from the relative area of the sample and the room walls. The method is an ISO/CEN standard (ISO 354, 2003).

The external point source method is the most suitable for field use. It can be either mounted on a static frame or attached to a van, in which case the measurements can be made moving (stop, measure and go) or dynamic (non-stop, repeated measurements).

The sound absorption of road surfaces influences the sound field in the tyre/road contact patch as well as the propagation of both tyre/road and engine noise to the microphone position.

4.7 Mechanical impedance measurements

Mechanical impedance is the complex ratio between the dynamic force and the resulting displacement of a surface submitted to that force. For simplicity and understanding one uses the term “stiffness”. Poro-elastic road surfaces (PERS) made of rubber from scrap tyres show a dynamic stiffness comparable to that of a tyre, which is required for tyre/road noise to be significantly affected. Now, if that innovative material proves effective and starts spreading, a test method for its stiffness will become necessary. That is why, in SILVIA, tentative measurement methods have been proposed (KUIJPERS et al., 2005). Further developments are still needed for a method to be ready for standardisation.

5 The SILVIA classification procedure

In the EU project SILVIA a very comprehensive general classification methodology for the noise emission of road surfaces was developed (see PADMOS et al., 2005, and FEHRL, 2006). It mainly relies on the well-established SPB and CPX measurement methods, while supplementing them with other values if necessary. As the SPB method is the only measurement method that can take into account the complete noise emission of road vehicles especially in the low-speed range, it is the primary method of choice for classification purposes. Nevertheless the performance and interpretation of SPB measurements can be difficult, especially when dedicated test sites are unavailable and the tests have to be performed in urban areas. Variations like CPB or SPB with a backing board may have to be used.

For approval testing and monitoring of long road sections CPX usually is the method of choice. For classification purposes CPX is used to back up SPB measurements with data on the homogeneity of the surface under test. Unfortunately the SPB-CPX relationship is not stable enough to use CPX alone for classification. This is of course due to the inability to account for engine noise and to fully account for truck tyre noise. Nevertheless CPX is a direct measurement of the acoustic surface properties and to be preferred to more indirect methods.

Absorption, texture and mechanical impedance measurements can be used to complement or even to replace the CPX measurements.

5.1 Description of the procedure

The SILVIA approach foresees two possible labelling procedures:

- LABEL 1: Labelling using SPB and CPX measurements (recommended);
- LABEL 2: Labelling using SPB measurements and the measurement of intrinsic road surface properties that are related to the noise generation and propagation of that surface type.

The SPB data generated during labelling can also be used for determining road surface correction terms for national prediction methods and the surface correction term Δ_{road} used in the HARMONOISE model.

The following tables show the general system of required measurements and the requirements for a test site of at least 100 m length which is considered suitable for classification purposes. It has to be stated that the test sites for road surfaces intended for urban use do not necessarily have to lie in urban areas, as long as representative measurements can be carried out.

The results of indirect measurements have to be converted into noise level differences by using the conversion algorithms developed in SILVIA (FEHRL 2006, Appendix C).

When road surface corrections relative to a reference surface are to be determined, the use of the HARMONOISE reference surface is recommended.

Table 4: Recommended labelling system for assessing the acoustic performance of different types of road surfaces (taken from PADMOS et al., 2005)

Type of road surface		Methods and checks for the purpose of			
		Determining Label Values		Assessing COP	
		LABEL 1	LABEL 2	LABEL 1	LABEL 2
Dense graded	Rigid†	SPB and CPX	SPB and Texture	Homogeneity check and CPX	Homogeneity check and texture
	Flexible‡		SPB, texture and mechanical impedance		Homogeneity check and texture and mechanical impedance
Open graded	Rigid†		SPB, texture and absorption		Homogeneity check and texture and absorption
	Flexible‡		SPB, texture, mechanical impedance and absorption		Homogeneity check and texture, absorption and mechanical impedance

† Rigid surfaces are defined as normal asphalt (dense and open graded) and concrete;

‡At the time of writing this document (2005) the only flexible surface is poro-elastic asphalt.

Table 5: Requirements for tolerances for acceptance of a 100 m test section for labelling (adapted from PADMOS et al., 2005)

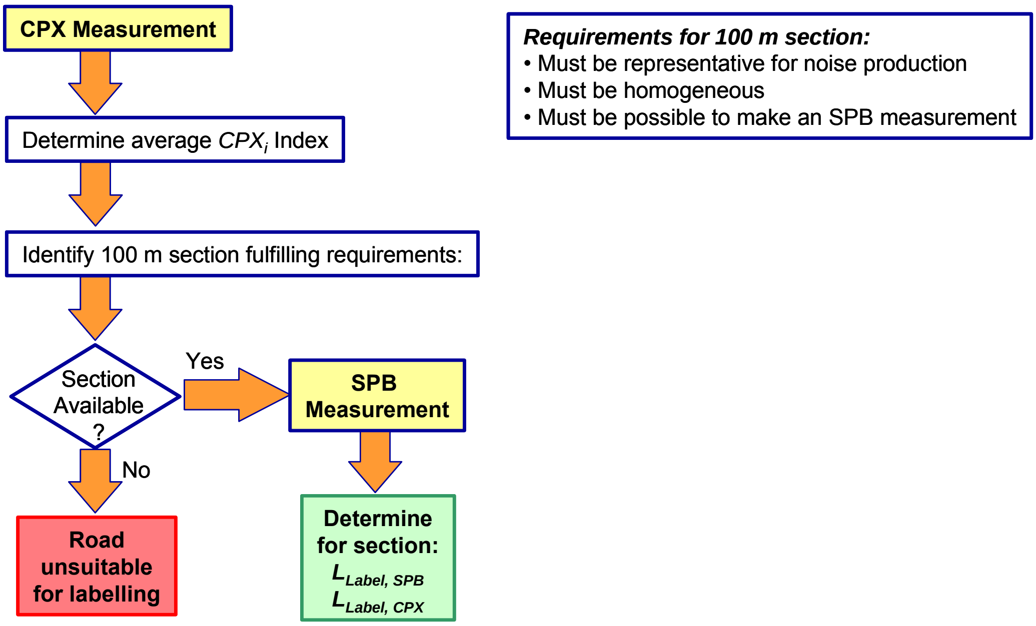
	CPX (mobile)	Absorption (spot measurement) ISO 13472-1	Texture (static) ISO 13473-1	Texture (mobile) ISO 13473-1
Peak to peak interval around average value	0,5 dB(A) [90%]	1,0 dB(A) [90%]	1,0 dB(A) [90%]	1,0 dB(A) [90%]
Segment length	20 m	-	-	20 m
Distance between spots	-	10 m	10 m	-

Additional requirements are:

- In order to reduce the influence of different aggregate types and variations in the laying procedures the complete set of measurements has to be carried out on at least 5 different locations.
- The SPB values should be stated separately for individual vehicle categories and should be valid in the relevant speed intervals. These SPB values will be referred to as $L_{Label,SPB}$.
- The CPX value that should be stated is the CPX_i according the description in the draft ISO Standard 11819-2. This CPX_i value will be referred to as $L_{Label,CPX}$.
- The other label values are properties of the road surface. The absorption and texture results should be presented as a single value in dB(A). The values will be referred to as $L_{Label,Absorption}$, $L_{Label,Texture}$ and $L_{Label,Mech\ Imp}$.

5.1.1 The LABEL 1 procedure (SPB + CPX)

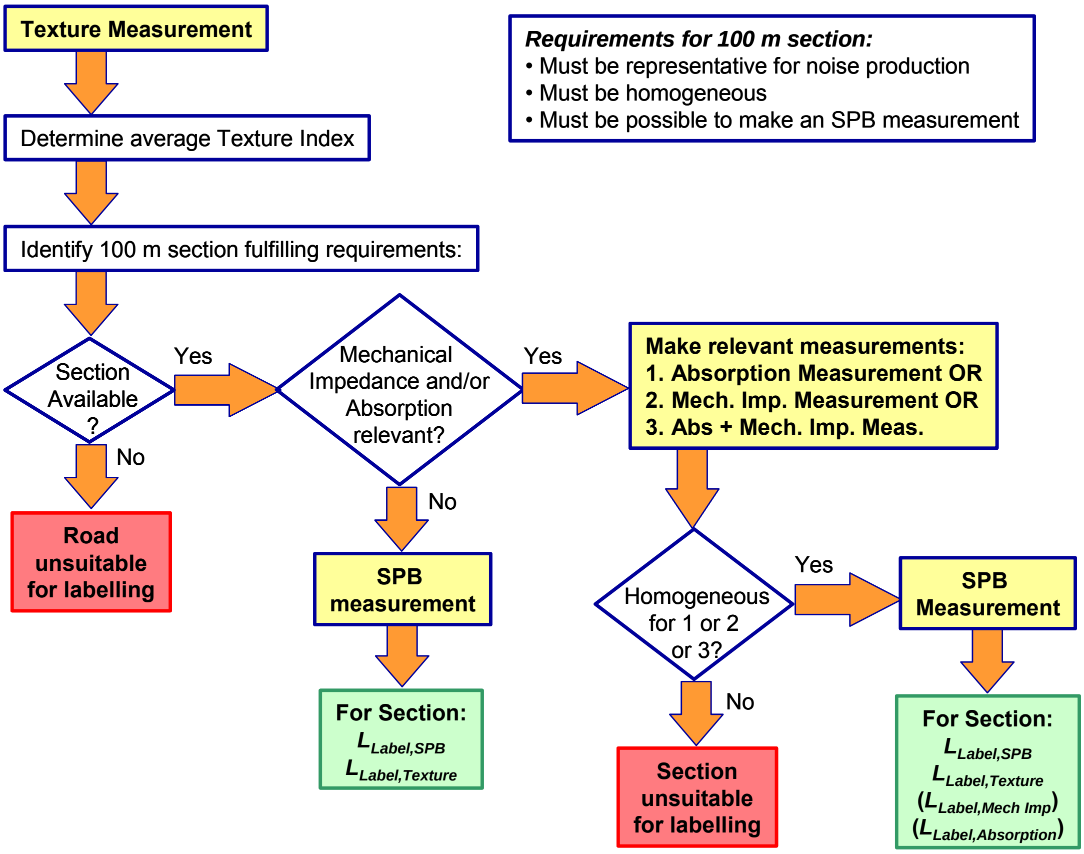
Figure 4: Procedure for determining LABEL 1 values (taken from PADMOS et al., 2005)



As can be seen in Table 4, the LABEL 1 consists of combined SPB and CPX values. This is based on the assumption that SPB yields very reliable values which can be connected to the less reliable CPX values. If this assumption holds, the CPX value can be measured where it is not possible or impractical to perform SPB measurements and still gives a sufficient indication of possible **changes** in the basic SPB value. That assumption still has to be treated with caution wherever changes in heavy vehicle or engine noise influence are suspected. If changes in the heavy vehicle proportion compared to the original testing situation are to be expected, this can be accounted for by changing the respective weighting factors.

5.1.2 The LABEL 2 procedure (SPB + texture/absorption/dynamic stiffness)

Figure 5: Procedure for determining LABEL 2 values (taken from PADMOS et al., 2005)



The LABEL 2 procedure is based on SPB measurements together with texture measurements and complemented if necessary with absorption and mechanical impedance measurements. Given that mobile texture measurements have already reached a high degree of accuracy and practicability, the main drawback compared to LABEL 1 consists in the fact that apart from SPB no direct measurement of the sound emission is carried out. Instead the additional element of conversion algorithms has to be inserted, which can be more or less appropriate and introduces additional measurement uncertainties.

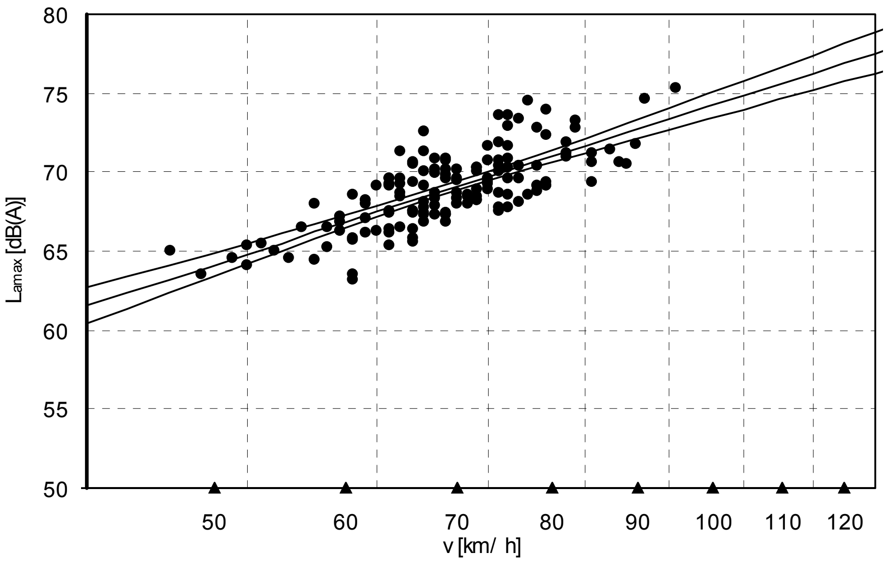
5.1.3 Evaluation of SPB results (according to PADMOS et al., 2005)

The temperature corrected $L_{A,max}$ values are plotted against the logarithm of the vehicle speed in a scatter diagram. The linear regression line through the measurement data is determined together with the accuracy of the regression line in terms of the 95% confidence interval at speed intervals of 10 km/h. The regression line is of the following form:

$$L_{SPB}(v,m) = \alpha_m + \beta_m \times \log_{10}(v / v_{0,m}) \qquad (5.1)$$

where m denotes the vehicle class and v_0 is the reference speed.

Figure 6: Confidence interval of an SPB measurement (taken from PADMOS et al., 2005)



The SPB-results are considered to be valid when the 95% confidence interval at a certain speed is ≤ 0.6 dB(A).

The average spectrum is determined by averaging the measured spectra at $L_{A,max}$ of only those vehicle passages within the valid speed range. Before averaging, the measured spectra are normalized to an overall value of 0 dB(A). No further speed correction is applied. The resulting average spectrum is in effect also normalized to 0 dB(A).

The final result of a SPB measurement contains:

- (i) Information on measurement location, date of both road surface construction, road opening and SPB-measurement, road surface type, air and road surface temperature during the SPB-measurement;
- (ii) Values for the parameters α and β of the regression line through the temperature corrected measurement data;
- (iii) The minimum and maximum value of the speed at which these parameters are valid;
- (iv) The shape of the average spectrum.

The analyzed results are provided for light vehicles and heavy vehicles separately.

5.2 Different procedure for Conformity of Production (CoP) testing, approval testing and monitoring

Classification tests have to meet very stringent requirements and can also require more extensive efforts, as they are carried out only rarely or even only once to establish a set of reference values. Much more frequently a specific installation of a road surface has to be tested to answer the question if it still corresponds to the initial classification.

That is the question in one of the following cases:

- CoP testing: Two contracting parties have agreed on delivery of a road surface with a specific classification. The testing needs to establish quickly and at a reasonable price if the contractual obligations have been fulfilled.
- Approval testing: The road surface is subject to legal or otherwise binding noise emission limits. The road authority is required to ensure that the limit values are not exceeded.
- Monitoring: The long-term development of the noise emission levels of a road section shall be monitored for administrative, research or other purposes.

The SILVIA procedure foresees that:

- the road that will be checked will be divided in 100 m sections;
- All the values, either being it CPX, texture, absorption and/or mechanical impedance, will be determined for each 100 m section. In case of static measurements these measurements are carried out in the middle of the 100 m section. The decision for approval or failure will be made for each 100 m section.
- CPX (and, if applicable, SPB) measurements will be done two months after opening of the road to traffic; texture, absorption and mechanical impedance measurements will be done before the opening of the road.

In this scheme, the **SPB measurements are no longer mandatory**. Conformity is checked based on the assumption that equivalent e.g. CPX values are a sufficient indication that the basic SPB values would not be too different from the original classification values if they were measured. The results are only valid for the tested road section.

LABEL 1 classifications are checked by CPX measurements, whereas LABEL 2 classifications are checked by the same mix of texture, sound absorption and mechanical impedance measurements as was carried out in the original classification. The allowed variation is stated in Table 6.

Table 6: Tolerances for COP approval of a road section of 100 m

Measurement Type	COP criteria required for approval of 100 m road section
CPX (mobile)	$L_{COP,CPX} \leq L_{Label,CPX}$ + 1.5 dB(A)
Texture (mobile)	$L_{COP,Texture} \leq L_{Label,Texture}$ + 1.5 dB(A)
Texture (static)	$L_{COP,Texture} \leq L_{Label,Texture}$ + 1.5 dB(A)
Absorption	$L_{COP,Absorption} \leq L_{Label,Absorption}$ + 1.5 dB(A)
SPB	$L_{COP,SPB} \leq L_{Label,SPB}$ + 2.0 dB(A)

6 Methodology for the noise emission classification of urban road surfaces

The SILVIA classification procedure described in the previous chapter presents a very comprehensive approach to the classification of road surfaces in general. Due to its recent nature, no full application is known at the time of writing, although elements of it are present in various national regulations. This chapter deals with its application to road surfaces intended for use in urban surroundings.

The basic requirement for classification to exactly and narrowly identify the road surface type to be tested remains valid for urban road surfaces, even more so because some of the tests may not be carried out in urban areas.

At high speeds of 80 km/h and above, which are typical for motorways and rural roads, the total noise output is dominated by tyre/road noise, which simplifies the application of the classification procedure somewhat. The disadvantages of the CPX method are less important and usually at least some suitable SPB measurement sites can be found.

In urban areas especially the use of the SPB method becomes much more difficult. Dense traffic, roadside building, high background noise and a special traffic composition can make the SPB measurement on which the procedure relies a tedious task. Yet due to the speed range in question of up to 80 km/h, it cannot be omitted, as engine noise and heavy vehicle noise has to be taken into account to achieve a valid classification at low speeds.

The following procedure shall only be used as a general guideline on the choice of suitable surface types or for monitoring purposes, while taking into account the local situation. In these applications, the following **adaptations** of the SILVIA labelling procedure are proposed for **urban conditions**:

1) **For both SPB and CPX measurements the low speed category with a reference speed of 50 km/h should be used.**

   This in itself is still within the scope of the standards, but data on the accuracy, repeatability and reproducibility of the results tend to be scarce as most measurements up to date have been carried out on high-speed roads.

2) **If the length of the test section is below 100 m, increase the number of CPX runs, until the requirements of Table 5 can be met. Test sections shorter than 40 m are still not acceptable.**

3) **SPB-results are considered to be valid when the 95% confidence interval at a certain speed is ≤ 2 dB(A).**

   Speed and sound level variations in the low-speed range can be expected to be high. At the very low-speed end at about 30 km/h the logarithmic speed-noise level relationship could cease to hold.

4) **Determine at least $L_{veh,\ 1,\ cars}$ and $L_{veh,\ 2,\ HVs}$ without distinguishing between 2a and 2b.**

5) **Use the adapted weighting factors for the low speed road category according to Table 7.**

Table 7: Weighting factors W_x

Vehicle category	Weighting factor	Road speed category: Low	Minimum number of vehicles
1) Cars	W_1	0.900	**100**
2) Heavy vehicles	W_2	0.100	**15**

6) **Testing can also be carried out on a test track outside the urban area, if valid measurements in the low-speed range are possible (e.g. when speed limits apply).**

7) **If only a dedicated test site is available, CPB measurements can be substituted for SPB measurements with the same number of required pass-bys covering the speed range from 30 km/h to 70 km/h. In that case, the vehicles and tyres used have to be as representative as possible of the real urban traffic mix. A minimum of 3 different car/tyre combinations and 1 heavy vehicle is recommended. They have to be exactly described in the test report. For each vehicle and speed the optimum gear setting recommended by the manufacturer shall be used. The result should be marked as a LABEL 3 classification.**

If the adaptations mentioned above have to be used, it is to be expected that the accuracy of the classification will be lower than in a full LABEL 1 procedure. This should be clearly stated and an estimation of the resulting measurement uncertainties shall be given. Nevertheless the procedure will still give an indication of what to expect from a specific road surface.

Most urban road surface types are also used on high-speed roads, where an exact noise classification is easier. When classifying a road surface, it should be attempted to classify for all three road categories, if practicable. If that is impossible, the high-speed classification can at least give an indication of the tyre/road noise contribution at lower speeds. For dense-graded road surfaces that should not influence the engine noise contribution very much, this could be sufficient.

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