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Acoustics — Measurement of the influence of road surfaces on traffic noise —

Part 2:
The close-proximity method

Acoustique — Méthode de mesurage de l'influence des revêtements de chaussées sur le bruit émis par la circulation —

Partie 2: Méthode de proximité immédiate

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

A list of all parts in the ISO 11819 series can be found on the ISO website.

Introduction

The emission and propagation of road traffic noise greatly depends on road surface characteristics, notably on texture, flow resistivity and acoustic absorption. All these characteristics influence the generation of tyre/road noise and, in addition, the acoustic absorption can influence the propagation of sound, particularly when the propagation takes place close to the surface. Power unit noise, which is usually generated at a greater height above the road surface than tyre/road noise, may also be affected during propagation by the porosity characteristics of the road surface. These effects lead to differences in sound pressure levels, associated with a given traffic flow and composition, from different road surfaces of up to 15 dB, which can have a substantial impact on the environmental quality alongside a road.

It is therefore important to be able to measure the influence of surface characteristics on tyre/road noise by a standardized method. Within the constraints of this method, this document offers an objective rating of the road characteristics to satisfy a need expressed by road planners, road administrators, contractors, manufacturers of so-called “low-noise surfaces” and other parties concerned with the control of road traffic noise.

A method satisfying the needs expressed in the foregoing, but having serious practical constraints, appears in ISO 11819-1. That method, called the statistical pass-by (SPB) method, is intended for use essentially for two main purposes. It can be used: first, to classify surfaces in typical and good condition as a type according to their influence on traffic noise (surface classification); and second, to evaluate the influence on traffic noise of different surfaces at particular sites irrespective of condition and age. However, due to severe requirements on the acoustical environment at the measurement site, the method cannot generally be used for approval of new or rebuilt surfaces at any arbitrary location. In addition, the SPB method has a number of other practical limitations, which are outlined in Annex D.

The method specified in this document, together with ISO/TS 11819-3, complements the SPB method in applications where the latter has limitations.

Acoustics — Measurement of the influence of road surfaces on traffic noise —

Part 2: The close-proximity method

1 Scope

This document specifies a method of evaluating different road surfaces with respect to their influence on traffic noise, under conditions when tyre/road noise dominates. The interpretation of the results applies to free-flowing traffic travelling on essentially level roads at constant speeds of 40 km/h and upwards, in which cases tyre/road noise is assumed to dominate (although in some countries it is possible that tyre/road noise does not dominate at 40 km/h when the proportion of heavy vehicles is high). For other driving conditions where traffic is not free-flowing, such as at junctions or under heavy acceleration, and where the traffic is congested, the influence of the road surface on noise emission is more complex. This is also the case for roads with high longitudinal gradients and a high proportion of heavy vehicles.

A standard method for comparing noise characteristics of road surfaces gives road and environment authorities a tool for establishing common practices or limits as to the use of surfacings meeting certain noise criteria. However, it is not within the scope of this document to suggest such criteria.

ISO 11819-1 defines another method: the statistical pass-by (SPB) method. The close-proximity (CPX) method specified in the present document has the same main objectives as the SPB method, but is intended to be used specifically in applications that are complementary to it, such as:

— noise characterization of road surfaces at almost any arbitrary site, with the main purpose of checking compliance with a surface specification (an example for conformity of production is suggested in Reference [1]);

— checking the acoustic effect of maintenance and condition, e.g. wear of and damage to surfaces, as well as clogging and the effect of cleaning of porous surfaces;

— checking the longitudinal and lateral homogeneity of a road section;

— the development of quieter road surfaces and research on tyre/road interaction.

NOTE This document does not describe the conditions of application for formal purposes of the measurement with the CPX method. Such conditions may be defined in other standards or legal texts. However, suggestions for the applicability of ISO 11819-1 and this document are provided in Annex D.

Measurements with the CPX method are faster and more practical than with the SPB method, but are more limited in the sense that it is relevant only in cases where tyre/road noise dominates and power unit noise can be neglected. Furthermore, it cannot take heavy vehicle tyre/road noise into account as fully as the SPB method can, since it uses a light truck tyre as a proxy for heavy vehicle tyres and does not take power unit noise into account.

The CPX method specified in this document is intended to measure the properties of road surfaces, not the properties of tyres. If the method is used for research purposes, to provide an indication of differences between tyres, the loads and inflations would normally be adjusted to other values than specified in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 11819-1, *Acoustics — Measurement of the influence of road surfaces on traffic noise — Part 1: Statistical Pass-By method*

ISO/TS 11819-3, *Acoustics — Measurement of the influence of road surfaces on traffic noise — Part 3: Reference tyres*

ISO/TS 13471-1, *Acoustics — Temperature influence on tyre/road noise measurement — Part 1: Correction for temperature when testing with the CPX method*

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61260-1, *Electroacoustics — Octave-band and fractional-octave-band filters — Part 1: Specifications*

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11819-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Road and pavement related definitions

3.1.1
road section
total stretch of the road lane subject to testing

3.1.2
road segment
part of a road section, being 20 m long and intended for normalization of sound pressure levels from the actual speed on that segment to a certain reference speed

3.2 Measurement methods and equipment

3.2.1
statistical pass-by method
SPB method
measurement procedure designed to evaluate vehicle and traffic noise generated on different sections of road surface under specific traffic conditions

Note 1 to entry: The measurements are taken from a great number of vehicles operating normally on the road. Results obtained using this procedure are normalized to standard speeds according to the category or type of road being considered. The method is specified in ISO 11819-1.

3.2.2
reference tyres
test tyres specified for the purpose of representing certain features in tyre/road sound emission, designed and constructed for use in this method with specified and reproducible standard properties

Note 1 to entry: The reference tyres are specified in ISO/TS 11819-3.

3.3 Acoustic quantities and symbols

3.3.1
close-proximity level
CPX level
L_{CPX}
time-averaged A-weighted sound pressure level (SPL) of the tyre/road noise as determined by the CPX method, either broadband or spectral bands, as required

Note 1 to entry: The CPX level is expressed in decibels. In order to provide more information, additional suffixes are used; see Table 1.

3.3.2
CPX level for passenger cars and other light vehicles
$L_{CPX:P}$
A-weighted sound pressure level characterizing the road surface under test, which is based on the tyre/road sound pressure levels of one or more tyres representative of passenger car tyres

Note 1 to entry: The $L_{CPX:P}$ is expressed in decibels. Passenger car tyres are denoted P1, P2 … .

3.3.3
CPX level for heavy vehicles
$L_{CPX:H}$
A-weighted sound pressure level characterizing the road surface under test, which is based on the tyre/road sound pressure levels of one or more tyres representative of heavy vehicle tyres

Note 1 to entry: The $L_{CPX:H}$ is expressed in decibels. Heavy vehicle tyres are denoted H1, H2 … .

3.3.4
CPX index
$L_{CPX:I}$
index composed of the weighted average of the CPX level for passenger cars and other light vehicles ($L_{CPX:P}$) and CPX level for heavy vehicles ($L_{CPX:H}$)

Note 1 to entry: The $L_{CPX:I}$ is expressed in decibels. The method is intended to describe performance of road surfaces for a certain traffic composition in a similar way to the SPB method in ISO 11819-1, although the numerical values for a given speed are higher. More information on the calculation of CPX indices is given in Annex M.

3.3.5
acoustic variability due to road surface inhomogeneities
s_t
standard deviation of the A-weighted sound pressure levels over all segments, when using reference tyre t

Note 1 to entry: The acoustic variability is expressed in decibels. This variability is normally dominated by road surface variations, although random uncertainties could add a little. Measurement speed and wheel tracks normally do not influence this value significantly. This measure is, therefore, considered to be an indication of road surface homogeneity as far as noise properties are concerned.

3.4 Symbols used for correction terms

3.4.1
measured speed
v
actual speed during a measurement

Note 1 to entry: The measured speed is expressed in kilometres per hour.

3.4.2
reference speed
v_{ref}
preferred speed for measurement

Note 1 to entry: The reference speed is expressed in kilometres per hour. Most commonly used reference speeds are 50 km/h, 80 km/h and 110 km/h, but alternative speeds may be used if required for technical, safety or legislative reasons.

3.4.3
speed coefficient
B
coefficient determining the speed dependence of the sound pressure levels, normally used for correction of the sound pressure level to a certain reference speed

Note 1 to entry: The correction for deviations from the reference speed is given by the expression $B \cdot \lg(v/v_{ref})$, expressed in decibels, where B is dimensionless. Values of B for specific pavements are given in 11.1 d).

3.4.4
temperature coefficient
γ_t
coefficient used for correcting CPX level for the effect of temperature for tyre t

Note 1 to entry: The temperature coefficient is expressed in decibels per degree Celcius.

3.4.5
rubber hardness coefficient
β_t
coefficient used for correcting CPX level for the effect of tread rubber hardness of tyre t

Note 1 to entry: The rubber hardness coefficient is expressed in decibels per Shore A. Refer to 11.1 f) for application.

3.4.6
device-dependent correction for sound reflections
$C_{d,f}$
correction for individual measuring devices in one-third-octave bands from 315 Hz to 5 000 Hz with the centre frequency f, to account for deviations from acoustic hemi-free-field conditions

Note 1 to entry: The device correction for sound reflections is expressed in decibels. Information on the determination of $C_{d,f}$ is given in A.2.

4 Symbols and abbreviated terms

Table 1 lists the symbols used in this document. All acoustic variables are A-weighted.

Table 1 — Symbols and abbreviated terms used in this document and their value or unit

Symbol	Value/unit	Explanation
$L_{\text{CPX:t},v_{\text{ref}}}$	dB	Measure of the acoustic properties of the tested road section, for tyre t, at the reference speed v_{ref}
$L'_{\text{CPX:t},w,r,i,f}$	dB	Energy-based average spectrum at the microphone positions m = 1 and m = 2 (for the subscript symbols, see below)
$L_{\text{CPX:t},w,r,i,f,m,v_{\text{ref}}}$	dB	Time-averaged tyre/road SPL (“CPX level”) over the time it takes to run a road segment (20 m)
$L_{\text{CPX:P},v_{\text{ref}}}$	dB	Measure of the acoustic properties of the tested road section, for tyre(s) “P” representing passenger cars and other light vehicles, at the reference speed, v_{ref}
$L_{\text{CPX:H},v_{\text{ref}}}$	dB	Measure of the acoustic properties of the tested road section, for tyre(s) “H” representing heavy vehicles, at the reference speed, v_{ref}
$L_{\text{CPX:I},v_{\text{ref}}} = 0{,}5 \cdot L_{\text{CPX:P},v_{\text{ref}}} + 0{,}5 \cdot L_{\text{CPX:H},v_{\text{ref}}}$	dB	“CPX index” representing the overall acoustic properties of the tested road section, for tyre(s) representing light and heavy vehicles combined (with equal weighting), at the reference speed, v_{ref}
B	Dimensionless	Speed coefficient; i.e. increase in CPX level with tenfold increase in speed, to be able to correct for deviations from the reference speed, v_{ref}
$C_{\text{d},f}$	dB	Device correction term (frequency dependent) to account for deviations from free field conditions
γ_{t}	dB/°C	Temperature coefficient for correction for tyre t to account for deviations from reference temperature of 20 °C. The value is negative for tyres P1 and H1
β_{t}	dB/Shore A	Rubber hardness coefficient for correction for tyre t to account for deviations from a reference hardness
f	315 Hz, ... 5 000 Hz	One-third-octave-band centre frequency
i	1, 2, 3 ...	Road segment number
m	1, 2 3, 4, 5, 6	Front and rear mandatory microphone positions Optional microphone positions
n	1, 2, 3 ...	Total number of runs, n_r, wheel tracks, n_w, or road segments, n_i
r	1, 2, 3 ...	Run number
H_{A}		Rubber hardness in durometer type A of test tyre tread
H_{ref}		Reference rubber hardness in durometer type A
s_{t}	dB	Acoustic variability; a measure of road surface homogeneity
t	P H	Tyre type defined for testing Passenger car tyres Heavy vehicle tyres or approximate proxy
T_i	°C	Air temperature at road segment i (index not needed if continuous temperature measurements are not made)

Table 1 *(continued)*

Symbol	Value/unit	Explanation
v	km/h	Actual measured speed
v_{ref}	km/h	Preferred nominal speed for measurement; thus a reference speed used when reporting results
w	1, 2, 3, …	The wheel tracks in a lane where test tyres are rolling. Track number 1 is closest to the road shoulder, 2 is the opposite wheel track within that same lane; 3, 4, and so on are additional tracks

5 Measurement principle

In the CPX method, the average A-weighted SPLs emitted by specified tyres are measured over an arbitrary or a specified road distance, together with the vehicle testing speed, by at least two microphones located close to the tyres. For this purpose, a special test vehicle, which is either self-powered or towed behind another vehicle, is used. Reference tyres are mounted on the test vehicle, either one by one or both at the same time. Two uniquely different reference tyres have been selected in order to represent the tyre/road characteristics which are to be studied.

Although the microphones are positioned in close proximity to the source of tyre/road noise, a substantial part of the propagation effect associated with acoustically absorptive surfaces is actually included in the microphone signal. This is demonstrated by model calculations and the results of the CPX validation experiment (References [2], [3]). See Annex D for further information.

The tests are performed with the intention of determining a tyre/road sound pressure level, here referred to as the CPX level, L_{CPX}, at one or more of the nominated reference speeds. This can be achieved by testing at a reference speed or by normalizing for speed deviations.

For each reference tyre and each individual test run with that tyre, the average sound pressure levels over short measuring distances (segments of 20 m each), together with the corresponding vehicle speeds, are recorded. The sound pressure level of each segment is normalized to a reference speed by a simple correction procedure. Averaging is then carried out according to the purpose of the measurement, i.e. measuring a particular segment or a number of consecutive segments (a section).

The CPX level, $L_{CPX:t,v_{ref}}$, is the resulting average sound pressure level for the two mandatory microphones at the reference speed, v_{ref} for reference tyre t, where t is P or H.

Where both close-proximity sound levels have been determined, the close-proximity sound index $L_{CPX:I}$ is the average of $L_{CPX:P}$ and $L_{CPX:H}$ with equal weight given to the two indices. $L_{CPX:I}$ is intended for single value comparison.

There are some issues in the method which deserve special caution when applying this method, especially under circumstances that are not the most common. Annex J provides a discussion of such issues.

6 Measuring instruments

6.1 Sound level instrumentation

Within the minimum frequency range of 315 Hz to 5 000 Hz, the sound level meter or the equivalent measuring system shall meet the requirements of IEC 61672-1, class 1. The microphones shall be of the “free-field” type.

An appropriate windscreen shall be used having a diameter of at least 90 mm. The sound properties of windscreens will deteriorate as the material is progressively exposed to dirt. It is therefore good practice to check the performance of the windscreens frequently and to replace them with new, fresh material when they show patterns of dirt coverage.

6.2 Frequency analysis instrumentation

Frequency analysis of the measured sound using one-third-octave-band resolution is mandatory. The range 315 Hz to 5 000 Hz (centre frequencies of one-third-octave bands) is the minimum range to be covered. The one-third-octave-band filters shall conform to IEC 61260-1.

6.3 Sound calibration instrumentation

At the beginning of the measurements, and following any warm-up time specified by the manufacturer, the overall sensitivity of the sound level meters or the equivalent measuring system (including the microphone) shall be checked. If necessary, adjust it according to the manufacturer's instructions. This may require use of a standard sound source, such as a calibrator or pistonphone. This check shall be repeated at the end of the measurements, and at least after every 4 h of operation. Any deviations shall be recorded in the test report. If the calibration readings differ by more than 0,5 dB between the checks, all intermediate measurements shall be considered invalid.

The sound calibration device shall meet the requirements of IEC 60942, class 1.

6.4 Vehicle speed measuring instrumentation

The average speed of the vehicle over the measured segment shall be measured, with a maximum permissible error of ±1 % of the indicated value.

For speed measurement, if a tyre is used it shall not be mounted on a drive axle.

6.5 Position monitoring instrumentation

GPS or other means of identifying the start positions of measurements are very useful in order to avoid problems in identifying a test section and to be able to return to the same place at a later occasion or for other types of measurements. It is recommended that the GPS system is of a type specified with a maximum permissible error of ±5 m.

6.6 Temperature measuring instrumentation

The air and (optional) road temperature measuring instrument(s) shall have a maximum permissible error of ±1 °C, as specified by the manufacturer. Meters utilizing the infrared technique shall not be used for air temperature measurements.

6.7 Tyre load measuring equipment

The weighing equipment used to determine the load of the test tyres shall have a maximum permissible error of ±5 %, as specified by the manufacturer.

6.8 Inflation pressure measuring equipment

The equipment used to determine the inflation pressure of the test tyres shall have a maximum permissible error of ±4 %.

6.9 Verification of measuring system and measuring instrumentation

The compliance of the sound calibrator with the requirements of the appropriate class of IEC 60942 shall be verified annually. The compliance of the sound level meter or equivalent measuring system with the requirements of IEC 61672-1 shall be verified at least every two years. This shall be performed by a laboratory authorized to perform calibrations traceable to the appropriate standards. It is recommended that all other instrumentation should be calibrated at least every two years.

7 Test sites

In performing a CPX measurement, there are a number of practical constraints which define the minimum requirements for the road section to be suitable for assessment. These can be summarized as follows.

— The approach to the road section shall be of sufficient length to allow the reference speed to be reached before reaching the road section. There shall be a run-in of at least 10 m of the same surface type before the road section begins.

— The road section (excluding the run-in) shall be at least 20 m long, and preferably longer than 100 m.

— The road section shall not include bends with a radius of curvature less than 250 m at 50 km/h and 500 m at 80 km/h.

— The surface of the road section up to a distance of 0,5 m perpendicularly from the sidewall of the test tyre facing the microphone shall be the same surface type as in the wheel track or have similar acoustical impedance characteristics.

— The limitations on background noise at the test site according to A.5 shall be observed.

— Where measurements are taken using a test vehicle without an enclosure (see 9.1), those parts of the road section where there are reflecting surfaces within a distance of 2 m from the microphone shall be excluded from the assessment. This includes guard rails, Jersey barriers or any other barriers or embankments, rocks, parked vehicles, bridges and buildings. In cases where the test vehicle includes an enclosure complying with the requirements of Annex A, no restrictions apply to objects at the roadside.

With regard to the last requirement, 2 m is selected as a precaution against the possible effect of multiple reflections between two hard surfaces: the vehicle side panel (if any) and the roadside object. If the user can show that such reflections for the vehicle configuration opposite a solid parallel wall never have any influence on the measured levels at a distance less than 2 m, the distance can be reduced to that lower distance – however, never less than 1 m. If applicable for the tested road, such reflection tests shall be referred to in the test report.

8 Meteorological conditions

8.1 Wind

It is recommended that ambient wind speed does not exceed 5 m/s at the microphone height during the measurement for test vehicles without an enclosure around the microphone and test tyre. If the test tyre(s) is/are enclosed, wind speeds up to 10 m/s are acceptable.

If the test vehicle manufacturer or user can prove that the vehicle can travel in higher wind speeds, in any direction, without a significant influence on the measurement result, the recommendation above can be ignored. The same conditions as in A.3.2 shall then be met.

8.2 Temperature and other weather-related issues

Measurements shall be carried out only when road surfaces are dry and ambient air temperature is within the range representative for that climatic zone:

— moderate and continental: 5 °C to 30 °C;

— tropical and subtropical: 10 °C to 35 °C.

The surfaces can be assumed to be sufficiently dry if the minimum time periods for drying-up after rainfall given in Table F.1 are observed.

NOTE 1 The allowed temperature range is related to local road materials. In the warmer zones, high temperatures are common and bitumen viscosity is adjusted to it, while the same temperature in a cooler climate can cause bleeding of the bitumen. This is known to cause extra stick-snap sound from the rolling tyre.

NOTE 2 Annex F also gives guidelines for estimating the level of moisture within the voids of porous surfaces by a simple test method.

9 Test vehicle

9.1 General design

The test vehicle may be one of the following types.

— A self-powered vehicle on which one or two reference (test) tyre(s) is/are fitted to the axle closest to the microphones. It could also be a vehicle with an extra tyre fitted for testing purposes.

— A trailer towed by a separate vehicle. There shall be one or more test tyres, which are mounted on the trailer. Additionally, the trailer may have tyres for support.

The test tyre(s) may or may not be surrounded by an enclosure covering the tyres except for a certain clearance to the road, the purpose of which is to protect the microphones from external noise and wind influences.

The requirements on the test vehicle have the objective to come as close as possible to the reference case in which a tyre is rolling on a road surface with microphones in an acoustical hemi-free-field, i.e. where there are no sound reflections except from the road surface and no background noise.

The requirements and design recommendations in the following are intended to approach this ideal situation within practical constraints.

For the purposes of this document there are three sources of unwanted contribution to the free field sound transmission from tyre to microphone:

a) background noise related to the system, consisting of sources such as wind noise and sound from the towing vehicle;

b) background noise from unrelated sources such as passing vehicles and reflections against roadside objects;

c) contributions from unwanted reflections against parts of the system, such as insufficiently absorbing enclosures and parts of suspensions systems.

The vehicle shall comply with the requirements described in Annex A. See also 10.7 regarding possibilities of discarding segments where this requirement is exceeded.

9.2 Microphone positions and mounting

At least two microphones shall be used. The two mandatory microphones shall be in operation simultaneously. The positions of the mandatory microphones under static condition relative to the test tyre shall be as follows (see Figure 1 and Table 2):

— distance horizontally from the plane of an undeflected part of the tyre sidewall shall be 0,20 m ±0,01 m;

— the height above pavement level shall be 0,10 m ± 0,01 m.

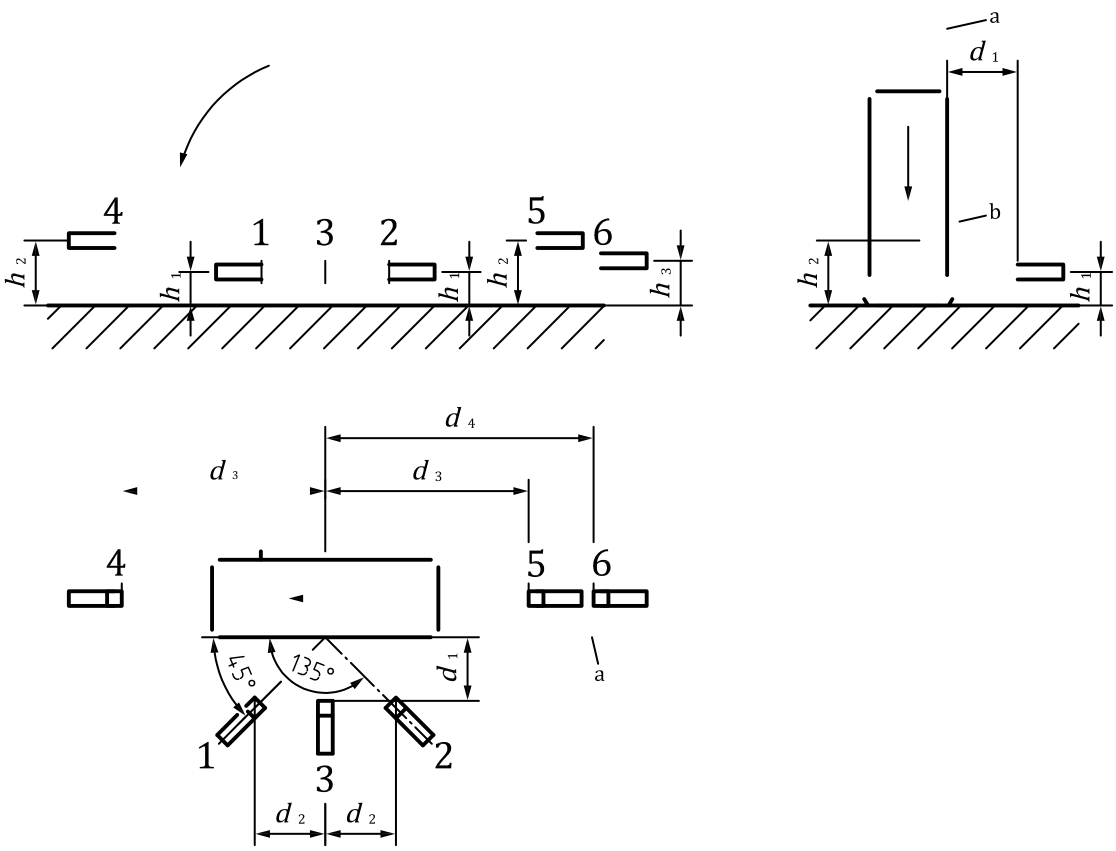
All measurements refer to the centre of the microphone diaphragm. It is recommended that the “front“ microphone (1) be turned at an angle of 45° to the rolling direction, and the “rear“ microphone (2) be turned at an angle of 135° to the rolling direction, as shown in Figure 1. However, in the case of non-enclosed systems, it may be preferable to mount the microphones parallel to the driving direction in order to reduce potential influence of air turbulence.

Optional positions at angles of 0°, 90°, and 180° to the rolling direction as indicated in Figure 1 may be used in cases where the user wants a more complete mapping of the tyre/road noise directional properties.

Figure 1 shows the microphones on the left side of the test wheel assembly. Depending on the construction of the test vehicle, the microphones may also be mounted on the right hand side, but microphones 1 and 4 shall then remain at the front position.

When mounting the microphones it is important to make sure that the mounting is robust in order that vibrations in the microphones do not affect the measurements. It has been reported in literature that vibrations may affect the measured noise levels [19].

NOTE If using reference tyres of substantially different dimensions than that of P1 and H1 (as specified in ISO/TS 11819-3), one must be aware that the sound levels in microphones 4 to 6 will be highly influenced by the distance (d_3 and d_4) between the microphones and the trailing and leading edges of the tyre/road contact patch. In case of tyre comparisons, it could then be more relevant to keep the distance between the microphones and the contact edges constant.



Key

a	Undeflected tyre sidewall.	2	rear mandatory microphone
b	Deflected tyre sidewall.	3	middle optional microphone
d_1, d_2, d_3, d_4	see Table 2	4	front optional microphone
h_1, h_2, h_3	see Table 2	5	rear optional microphone
1	front mandatory microphone	6	rearmost optional microphone

Figure 1 — Microphone positions for the measurements

Table 2 — The microphone positions in Figure 1

Microphone(s)	h_1	h_2	h_3	d_1	d_2	d_3	d_4
1, 2	0,10 m			0,20 m	0,20 m		
3	0,10 m			0,20 m	0,00 m		
4, 5		0,20 m				0,65 m	
6			0,15 m				0,80 m

9.3 Performance requirements and conformity of the test vehicle

The test vehicle and measurement system performance shall comply with the requirements in Annex A.

Additional checks on test vehicle performance related to background noise (A.3) shall be made prior to testing under the following circumstances.

— If the tyres on either the test vehicle (if self-powered) or the towing vehicle are in significantly different condition to when the test vehicle was last certified. This is of particular importance on test vehicles which do not include any form of enclosure around the test tyre.

— If the towing vehicle is of a significantly different type to that used when the test vehicle was last certified.

9.4 Reference tyres

Reference tyres are test tyres specified for the purpose of representing certain features in tyre/road sound emission, selected for use in this method with specified and reproducible standard properties.

The standard reference tyres shall be P1 and H1 as specified in ISO/TS 11819-3. Depending on the purpose of the measurement, one or both are used.

Tyres other than P1 and H1 may be used for research or special survey purposes. A description of the alternative tyres shall then be included in the test report.

NOTE The advantages of using reference tyres in comparison to using some mix of market tyres is that it ensures consistency and availability of the test tyres over time and international comparability of measurement results.

It is recognized that when this standard is implemented in individual countries, there could be a need to use reference tyres other than P1 and H1 in order to represent local conditions or to address fitment possibilities on available CPX systems. This is acceptable, but the alternative reference tyres as well as the justification for their use should be set out in the relevant national implementation guideline or system. Conversion of L_{CPX} values for the alternative reference tyres to those values equivalent to P1 and H1 is useful only for indicative comparisons.

9.5 Tyre rubber hardness

The rubber hardness of the test tyres shall be measured at least every three months. Refer to ISO/TS 11819-3 for the testing procedure.

9.6 Tyre mounting

The test tyres shall be mounted on the test vehicle such that

— any indicated rotational direction is respected, or

— any “outside” marking is respected, or

— the sidewall with the full DOT mark (including the production week/year number) faces the microphones.

Once a tyre mounting has been selected, tyres shall be mounted in this way throughout their use as reference tyres for this purpose.

9.7 Tyre run-in

Tyre run-in is important and is described in ISO/TS 11819-3.

10 Measurement procedure

10.1 Preparations for measurements

The microphone position shall be checked regularly, e.g. each time a test tyre is changed or when an acoustical calibration is made. Where a self-powered test vehicle is used one shall check the microphone positions at typical operating conditions, i.e. with driver and possible operators onboard and with typical amount of fuel in the tank, etc.

Before any standard measurement takes place the tyres shall be brought to normal operating temperature. Methods for achieving this include driving the test vehicle for at least 15 min for warm-up representative of reference speeds up to 80 km/h and at least 10 min at the higher reference speeds.

The test tyres shall be examined regularly for damage to the tread and for the presence of foreign objects in the tread. Chippings or other dirt in the tread shall be removed before testing takes place and where appropriate during testing.

10.2 Measurement of sound

The time-averaged A-weighted one-third-octave-band SPL from 315 Hz to 5 000 Hz shall be determined at each microphone position by averaging over each road segment of 20 m. This forms the basis for all further evaluations. It is mandatory to measure one-third-octave-band frequency spectra. No separate measurement of overall SPL is required.

The time-averaged SPL for an individual one-third-octave band with the centre frequency f measured at microphone position m at the wheel track w for the road segment with the index i in the run r using the tyre t and measured at reference speed v_{ref} is designated as:

$$L_{\mathrm{CPX:\,t},w,r,i,f,m,v_{\mathrm{ref}}}$$

10.3 Procedure for study of typical road section

The following requirements apply if the purpose of the measurement is to obtain a CPX level which is representative of a road section (i.e. several consecutive road segments).

After eliminating the road segments for which the test requirements are not met (e.g. due to background noise or too much deviating speed, see 10.3, last paragraph), a road section shall be considered as properly measured, i.e. the run accepted, if at least half of the road segments, with a reasonable spread over the entire section, have been measured under acceptable conditions. However, no less than five such segments shall be properly measured.

For each test condition, at least two runs in one or both wheel tracks covering the road section in accordance with the previous paragraph shall be made. If the two A-weighted overall levels representing the road section (one per run) differ by more than 0,5 dB for one tyre, at least two new runs shall be made for that tyre. The final result per tyre is then the arithmetic average of all the runs or tracks.

NOTE 1 Where simultaneous measurements are made with the same type of tyre in both wheel tracks, if the difference between the two tracks exceeds 0,5 dB, it is possible that this does not indicate an erroneous measurement, but rather a systematic track-to-track difference.

Speeds can sometimes become too high and sometimes too low due to restrictions imposed by other vehicles in the traffic and thus do not meet the requirements of 10.8.2. Discard data collected at such speeds.

NOTE 2 This subclause does not apply to the survey method described in Annex G.

10.4 Minimum number of runs for very short road sections

A road section consists of a number of road segments (normally at least five). Where the available test section is only 20 m to 100 m (plus run-in, see Clause 7), measurements according to this document can still be made, but the number of runs shall be sufficient to give a total measured distance of at least 200 m. The number of such repeated runs and the length of each run shall be reported explicitly.

10.5 Lateral position on the road

Unless the client has other requirements, measurements shall be made in one or both wheel tracks of the test lane. Selection of the wheel track (if only one is chosen) may be made based on safe driving of the vehicle. The selected wheel track (left or right) shall be reported.

For other purposes, e.g. study of lateral inhomogeneity of the surface, measurements may be made in other lateral positions. In this case, the results shall clearly identify the lateral position of the test tyre.

See further the discussion in F.3.

10.6 Longitudinal position on the road

The longitudinal position on the road of the tested section(s) is normally determined according to the requirements of the client. It is good practice to follow the suggestions regarding position monitoring in 6.5.

10.7 Consideration of disturbing noise

Given that the test vehicle has been designed according to the recommendations in Annex E and has been certified according to Annex A, there are still several sources of disturbing noise which might affect noise levels during measurements. These include:

— wind-induced noise, particularly on non-enclosed systems;

— background noise from unrelated sources such as passing vehicles and reflections against roadside objects.

More sources of disturbance and advice on how to reduce the effects of these are presented in F.4.

Road segments where noise levels are considered as disturbed or potentially disturbed shall be flagged for later processing (see Clause 11) or discarded immediately, as appropriate.

10.8 Test vehicle speed

10.8.1 Reference speeds

Preferred reference speeds are 50 km/h, 80 km/h and 110 km/h. The actual reference speed(s) shall always be noted.

10.8.2 Test speed and acceptable deviations

During each run the actual speed of the vehicle shall be measured. For each road segment, the test speed is the average vehicle speed over that road segment.

The actual test speed on each road segment shall not deviate from the reference speed by more than ±15 %. In addition, the average speed over all runs and over a tested road section for a given tyre shall be within ±5 % of the reference speed. Make a correction to the measured sound pressure level to adjust it to correspond to the reference speed (see Clause 11).

In order to avoid disturbing noise, especially for self-powered test vehicles, it is preferable to use the highest gear at which the vehicle and its speed control function well.

10.9 Tyre loads

The static load of the test tyre(s) shall be 3 200 N ± 200 N per tyre.

10.10 Tyre inflation

The test tyre(s) shall be inflated to 200 kPa ± 10 kPa, in cold condition. Cold condition is when the temperature of the tyre is close to the ambient temperature, i.e. the tyre has not yet been significantly warmed-up by rolling. If the inflation has to be changed substantially to obtain this value, then a second check of the inflation shall be made after approximately 2 minutes (with tyre at rest).

The preferred inflation gas is nitrogen. The reasons are that nitrogen inflation reduces the leakage of gas and thus reduces the need for inflation adjustments. It also causes slower change in the tyre rubber compound properties than air and the inflation pressure change during the warm-up process is normally lower than if air containing some humidity is used. See Reference [4] for further information.

The second-best choice of inflation gas is dry air, since humidity in air influences the inflation pressure stability.

If neither nitrogen nor dry air is available, normal air may be used.

The load (10.9) and inflation values are applicable to the use of reference tyres P1 and H1 only. If other tyres are used, inflation may have to be differently adapted to the load; for example, using the guidelines in Reference [18], Annex 3, paragraphs 2.5.2 and 2.5.3.

10.11 Temperature measurement

10.11.1 General

Measurements of air temperature are mandatory, whereas measurements of road surface temperature are recommended as a supplement.

The temperature measurements shall be conducted close in time to the sound measurement, either continuously or intermittently, and the result reported rounded to the nearest degree Celsius.

If possible, it is recommended that temperature measurements be made continuously. It is then recommended that temperature readings be taken in synchronization with the noise level measurements, i.e. per each road segment and indexed in the same way.

If temperature measurements are made intermittently, each temperature measurement shall have a duration sufficient to get a stable reading of the instrument. Temperatures shall be measured at least once for each road section at a location representative for that section.

It is preferred that the sensor(s) be placed on the test vehicle. If this is not practical or possible, the temperature(s) shall be measured at the wayside as close to the road as is possible and safe.

It has been found in research in areas with a lot of high-rise buildings that road surface temperature may be a better variable to base temperature corrections on (Reference [5]). Therefore, in such environments it is highly recommended that both air and road surface temperature be measured.

NOTE Surface temperature, especially, can vary substantially along a test section depending on different shading of trees, mountains, buildings, etc., as well as on cross-winds and surface light-absorbing properties.

10.11.2 Air temperature

Locate the temperature sensor so that it is unobstructed and safe, and in such a way that it is exposed to the airflow and protected from direct solar radiation. The latter may be achieved by a shading screen. The sensor shall be positioned 0,5 m to 1,5 m above road surface level.

10.11.3 Road surface temperature (optional)

Position the temperature sensor where the temperature is representative of the temperature in the wheel tracks.

10.12 Overview and summary

An overview and summary of all major measurement parameters is presented in Annex I.

11 Analysis procedure

11.1 Definition of steps in the calculation process

The primary result is $L_{\text{CPX: t},v_{ref}}$. $L_{\text{CPX:P}}$, $L_{\text{CPX:H}}$ and $L_{\text{CPX:I}}$ are only derived if using reference tyres.[1)] The resulting $L_{\text{CPX:P}}$ and $L_{\text{CPX:H}}$ levels shall be calculated from the individual measured data $L_{\text{CPX: t},w,r,i,f,m,v_{\text{ref}}}$. Annex C presents a detailed breakdown of the calculation procedures and in Annex N a flowchart illustrates the measurements and analysis procedures that have to be conducted to arrive at a final result.

A somewhat abridged explanation of the calculation procedures is as follows:

a) In each one-third-octave band, calculate the energy-based average of front and rear microphone SPLs (microphones 1 and 2 in Figure 1).

b) Apply the device dependent correction $C_{\text{d},f}$ (see A.2).

c) Calculate the overall SPL for a segment from the one-third-octave-band SPLs from 315 Hz to 5 000 Hz (omit this step if one-third-octave-band levels are desired).

d) Apply a speed correction for deviations from the reference speed of B times the logarithm of the quotient of the actual and the reference speed. The value of the speed coefficient B shall be:

   — B = 25 for a porous pavement in relatively new condition, or older but with no severe clogging;

   — B = 30 for a clogged porous, semi-porous or dense asphalt pavement;

   — B = 35 for a (non-porous) cement concrete pavement;

   — B = 30 for all other cases, including cases where the pavement type is unknown.

   To help distinguish between cases, one may consider a pavement as “porous” (and not clogged) if air voids are ≥18 %. If air voids are unknown or difficult to estimate, select B = 30.

   The experience is that B varies over a range of 20 to 40 depending on test tyre and pavement type. It is possible for a user to determine by his or her own measurements a specific B for a specific combination of tyre and pavement. However, the uncertainties associated with such measurements are such that they rarely give values for B closer to the true value than those given using the default values above, which have been determined based on a large number of measurements. The resulting error in the correction is negligible in relation to other measurement errors. Therefore, this document requires the use of the values listed in the foregoing.

1) As specified in ISO/TS 11819-3. See the Introduction.

e) Apply temperature coefficients γ_t for deviations from the reference temperature. The coefficients for tyre P1 and tyre H1 are given in ISO/TS 13471-1; for other tyres, coefficients will have to be determined once the tyres are selected.

NOTE 1 Please note that the influence may frequently amount to as much as −1 dB per 10 °C deviation in air temperature, see also Reference [17]. Substantial errors, therefore, could occur if no correction is applied.

f) Apply correction for the rubber hardness of the reference tyres based on hardness coefficient β_t. The coefficient β_t is given in ISO/TS 11819-3.

g) Road segments where noise levels are obviously disturbed by wind gusts or by noise from other sources, such as passing vehicles, shall be discarded (see F.4).

h) Average arithmetically over remaining road segments.

i) Average arithmetically over either repeated runs in a single wheel track or runs in left and right wheel tracks, as appropriate, to determine the CPX levels, L_{CPX}.

j) Calculate indices $L_{CPX:P}$, $L_{CPX:H}$ or $L_{CPX:I}$, as appropriate, based on the results of individual reference tyres P1 and H1 and the chosen reference speed.

Optionally, frequency spectra can be obtained by omitting step c) and performing all calculations based on one-third-octave-band levels.

There is a small difference between the total overall level of the spectrum and the calculated overall level according to the procedure described in the foregoing. See Table C.1 for an example. It is recommended that the difference be calculated and the spectral levels corrected with this difference value. In most cases, this correction is only a few tenths of a decibel.

NOTE 2 Guidance is provided for the user in 11.2 to 11.4 on navigating through all correction and averaging procedures in the correct order. If this order is not followed, results can differ. When appropriately applied in software, these formulae are useful and practical in order to obtain reproducible results.

11.2 Results expressed as overall levels

11.2.1 General

At first, the energy-based average spectrum at the microphone positions $m = 1$ and $m = 2$ is calculated as follows:

$$L'_{\mathrm{CPX:t},w,r,i,f} = 10 \cdot \lg\left[0{,}5\left(10^{0{,}1\left(L_{\mathrm{CPX:t},w,r,i,f,1}\right)} + 10^{0{,}1\left(L_{\mathrm{CPX:t},w,r,i,f,2}\right)}\right)\right]\mathrm{dB} \quad (1)$$

NOTE The symbol “lg” stands for the common logarithm (base 10) according to ISO 80000-2.

Next, the device-dependent correction factor $C_{\mathrm{d},f}$ is applied to the average spectrum and the A-weighted overall level from 315 Hz to 5 000 Hz, where speed-, temperature- and rubber hardness-corrected level over a segment is calculated as follows:

$$L_{\mathrm{CPX:t},w,r,i,v_{\mathrm{ref}}} = 10 \cdot \lg\left[\sum_{f=315}^{5\,000} 10^{0{,}1\left(L'_{\mathrm{CPX:t},w,r,i,f} + C_{\mathrm{d},f}\right)}\right]\mathrm{dB} - B \cdot \lg\left(\frac{v_{\mathrm{t},w,r,i}}{v_{\mathrm{ref}}}\right)\mathrm{dB} - \gamma_{\mathrm{t}} \cdot \left(T_i - 20\,°\mathrm{C}\right) - \beta_{\mathrm{t}}\left(H_{\mathrm{A}} - H_{\mathrm{ref}}\right) \quad (2)$$

The rubber hardness reference value H_{ref} and the rubber hardness coefficient β_t for reference tyres P1 and H1 are given in ISO/TS 11819-3 (same coefficient for both tyres).

The values of the temperature coefficient γ_t, which are negative, are given in ISO/TS 13471-1 if the reference tyres P1 and H1 are used (same coefficient for both tyres).

The next step is averaging over segments, wheel tracks and runs, according to one of the following two options:

a) case A: first averaging over segments within one run and then over the left and right wheel tracks (w = 1, 2);

b) case B: first averaging each segment over both wheel tracks (w = 1, 2) and then average over the segment values within one run.

Case A is used when measuring with only one tyre at a time and case B (probably more common) when measuring with two parallel tyres at a time.

11.2.2 Case A

Calculate the CPX level for a given tyre t and a given reference speed v_{ref} as follows:

$$L_{\mathrm{CPX:t},v_{\mathrm{ref}}} = \frac{1}{n_w}\sum_{w=1}^{n_w}\left[\frac{1}{n_r}\sum_{r=1}^{n_r}\left(\frac{1}{n_i}\sum_{i=1}^{n_i}L_{\mathrm{CPX:t},w,r,i,v_{\mathrm{ref}}}\right)\right] \tag{3}$$

11.2.3 Case B

Calculate the CPX level for a given tyre t and a given reference speed v_{ref} as follows:

$$L_{\mathrm{CPX:t},v_{\mathrm{ref}}} = \frac{1}{n_r}\sum_{r=1}^{n_r}\left[\frac{1}{n_i}\sum_{i=1}^{n_i}\left(\frac{1}{2}\sum_{w=1}^{2}L_{\mathrm{CPX:t},w,r,i,v_{\mathrm{ref}}}\right)\right] \tag{4}$$

11.2.4 Expression of CPX levels

As an example, the CPX level for light vehicles at the reference speed v_{ref} is expressed as follows, for the case when reference tyre P1 (ISO/TS 11819-3) is used, and when v_{ref} is chosen to be 80 km/h:

$$L_{\mathrm{CPX:P},v_{\mathrm{ref}}} = L_{\mathrm{CPX:P1,80}} \tag{5}$$

Correspondingly, the CPX level for heavy vehicles at the reference speed v_{ref} is expressed as follows, for the case when reference tyre H1 (ISO/TS 11819-3) is used, and when v_{ref} is chosen to be 80 km/h:

$$L_{\mathrm{CPX:H},v_{\mathrm{ref}}} = L_{\mathrm{CPX:H1,80}} \tag{6}$$

If a composite CPX level for mixed traffic is desired, $L_{\mathrm{CPX:P}}$ and $L_{\mathrm{CPX:H}}$ may be combined and the procedure in Annex M shall then be followed.

11.3 Results expressed as one-third-octave-band levels

11.3.1 General

For measurement results expressed as one-third-octave-band levels the calculation procedure is slightly different since no summation over the one-third-octave-band levels is needed. The procedure then is as follows. The first step is energy averaging of the spectrum at microphones m = 1 and m = 2:

$$L'_{\mathrm{CPX:t},w,r,i,f} = 10 \cdot \lg\left[0,5\left(10^{0,1\left(L_{\mathrm{CPX:t},w,r,i,f,1}\right)} + 10^{0,1\left(L_{\mathrm{CPX:t},w,r,i,f,2}\right)}\right)\right] \mathrm{dB} \tag{7}$$

The second step is correction for the device, the speed and temperature deviations:

$$L_{\mathrm{CPX:t},w,r,i,f,v_{\mathrm{ref}}} = L'_{\mathrm{CPX:t},w,r,i,f} + C_{\mathrm{d},f} - B \cdot \lg\left(\frac{v_{\mathrm{t},w,r,i}}{v_{\mathrm{ref}}}\right) \mathrm{dB} - \gamma_{\mathrm{t}} \cdot \left(T_i - 20\ ^{\circ}\mathrm{C}\right) - \beta_{\mathrm{t}} \cdot \left(H_{\mathrm{A}} - H_{\mathrm{ref}}\right) \tag{8}$$

The rubber hardness reference value H_{ref} and the rubber hardness coefficient β_{t} for reference tyres P1 and H1 are given in ISO/TS 11819-3 (same coefficient for both tyres).

The values of the temperature coefficient γ_{t}, which are negative, are given in ISO/TS 13471-1 if the reference tyres P1 and H1 are used (same coefficient for both tyres).

The next step is averaging over segments, wheel tracks and runs, according to case A or case B.

11.3.2 Case A

Calculate the CPX level for a given tyre t and a given reference speed v_{ref} in a given one-third-octave band as follows:

$$L_{\mathrm{CPX:t},f,v_{\mathrm{ref}}} = \frac{1}{n_w} \sum_{w=1}^{n_w} \left[\frac{1}{n_r} \sum_{r=1}^{n_r} \left(\frac{1}{n_i} \sum_{i=1}^{n_i} L_{\mathrm{CPX:t},w,r,i,f,v_{\mathrm{ref}}}\right)\right] \tag{9}$$

11.3.3 Case B

Calculate the CPX level for a given tyre t and a given reference speed v_{ref} in a given one-third-octave band as follows:

$$L_{\mathrm{CPX:t},f,v_{\mathrm{ref}}} = \frac{1}{n_r} \sum_{r=1}^{n_r} \left[\frac{1}{n_i} \sum_{i=1}^{n_i} \left(\frac{1}{2} \sum_{w=1}^{2} L_{\mathrm{CPX:t},w,r,i,f,v_{\mathrm{ref}}}\right)\right] \tag{10}$$

11.4 Correction for analysis of spectral levels

Due to the changed order of linear averaging and energy summation, the A-weighted overall level $L_{\mathrm{CPX:t},v_{\mathrm{ref}}}$ deviates from the summation over the spectral bands $L_{\mathrm{CPX:t},f,v_{\mathrm{ref}}}$ with a quantity $\Delta L_{\mathrm{t},v_{\mathrm{ref}}}$ [refer to C.8 and Formula (C.10)]. To account for this difference, the spectral bands are corrected with that difference:

$$L_{\mathrm{CPX:t},f,v_{\mathrm{ref}}(\mathrm{corr})} = L_{\mathrm{CPX:t},f,v_{\mathrm{ref}}} + \Delta L_{\mathrm{t},v_{\mathrm{ref}}} \tag{11}$$

11.5 Acoustic variability

The acoustic variability is considered to be an indication of road surface homogeneity of the surface. If required, the acoustic variability, s_{t}, shall be calculated according to Annex H.

The s_t value shall then be reported together with the length of the total test section and the calculation method used (see Annex H).

12 Measurement uncertainty assessment according to ISO/IEC Guide 98-3

The measurement procedure described in this document is affected by several influencing factors that lead to variation in the results observed for the same subject. The source and nature of these perturbations are not completely known. The measurement uncertainty shall be determined in compliance with ISO/IEC Guide 98-3.

According to ISO/IEC Guide 98-3, each significant source of uncertainty needs to be identified and corrected for. The following sources of uncertainty have been identified and require processing according to the procedure specified in ISO/IEC Guide 98-3:

— uncertainty due to operational variations;

— instrumentation uncertainty;

— uncertainty due to external disturbances.

Refer to Annex K for an example of a quantitative analysis.

The general expression for the calculation of the CPX level, $L_{\mathrm{CPX:t},v_{\mathrm{ref}}}$, at a certain reference speed v_{ref} and for a certain tyre t, is given by:

$$L_{\mathrm{CPX:t},v_{\mathrm{ref}}} = L_{\mathrm{CPX:t},v_{\mathrm{ref}}(\mathrm{det})} + \delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5 + \delta_6 \qquad (12)$$

where

$L_{\mathrm{CPX:t},v_{\mathrm{ref}}}$	is the CPX level adjusted for uncertainty;
$L_{\mathrm{CPX:t},v_{\mathrm{ref}}(\mathrm{det})}$	is the CPX level determined according to the procedure given in this document;
δ_1	is an input quantity to allow for any uncertainty due to variations in the measurement procedure;
δ_2	is an input quantity to allow for any uncertainty in the sound and speed measurement equipment;
δ_3	is an input quantity to allow for any uncertainty due to deviating environmental conditions;
δ_4	is an input quantity to allow for any uncertainty due to background noise from external sources;
δ_5	is an input quantity to allow for any uncertainty due to unwanted contributions from the test vehicle and towing vehicle;
δ_6	is an input quantity to allow for any uncertainty due to the selected reference tyre. This is included here but since its value depends on the tyre, refer to ISO/TS 11819-3 for the quantity to include in this calculation. If other tyres than those specified in ISO/TS 11819-3 are used, this quantity needs to be specified by the user.

The value of these input quantities shall be evaluated by the test operators by the procedure given in ISO/IEC Guide 98-3. It can be based on existing statistical data, analysis of tolerances stated in this document and engineering judgement. The information needed to derive the overall uncertainty is given in Table 3. Table 3 includes sensitivity coefficients c_j, the values of which are based on the procedures and formulae used to obtain the final result, as specified in ISO/IEC Guide 98-3.

The estimate of the measurand CPX level, denoted by y, is determined from a series of quantities X_j through a functional relationship $L_{CPX} = f(x_1, x_2, \ldots, x_n)$.

The combined standard uncertainty of the measured CPX level is calculated with:

$$u(y) = \sqrt{\sum_{j=1}^{6} \left(c_j u_j\right)^2} \qquad (13)$$

where

c_j is the sensitivity coefficient for input x_j; $c_j = \dfrac{\partial f}{\partial x_j}$ with $y = f(x_1, x_2, \ldots, x_6)$;

u_j is the standard uncertainty in input x_j.

The expanded uncertainty U is determined by multiplying the combined standard uncertainty $u(y)$ by the appropriate coverage factor (k) for the chosen coverage probability as described in ISO/IEC Guide 98-3.

Table 3 — Uncertainty budget for the determination of the CPX level

Quantity	Estimate	Probability distribution	Standard uncertainty, u_j	Sensitivity coefficient, c_j	Uncertainty contribution
δ_1	0	normal		1	
δ_2	0	normal		1	
δ_3	0	normal		1	
δ_4	0	asymmetric		1	
δ_5	0	asymmetric		1	
δ_6	Refer to ISO/TS 11819-3				
Combined standard uncertainty, $u(y)$					

K.4 gives a detailed listing of the standard uncertainties and sensitivity coefficients of each source and gives typical values. Using these values, the uncertainty budget analysis results in a combined standard uncertainty in the CPX level of 0,5 dB.

Table 4 presents the expanded uncertainty and coverage probability in the case where the method is applied and individual source uncertainties are consistent with Table K.1.

Table 4 — Estimated expanded uncertainty for a coverage probability (based on Table K.1)

Coverage factor k	Coverage probability %	Expanded uncertainty dB
1,3	80	0,7
2,0	95	1,0

NOTE 1 Uncertainty due to the reference tyre(s) is not included in the calculations in Table 4. Refer to ISO/TS 11819-3 for information about the uncertainty due to the tyres specified there.

NOTE 2 The temperature correction depends to some extent on the tyre used. In this document the uncertainty calculation is based on the assumed temperature correction for the P1 tyre.

NOTE 3 The uncertainties presented here are valid only for the mandatory microphone positions m = 1 and m = 2. For the other microphone positions, additional uncertainties might be present.

13 Repeatability and reproducibility: System comparison according to ISO 5725-2

Conformity of road surface acoustical properties with national standards is checked by means of CPX tests. In such cases, reliability of the measurement systems in use in a country or region is checked by regular comparison of the CPX systems. The accuracy of the measurement systems shall in that case be determined by the method specified in ISO 5725-2. The results can be expressed in terms of reproducibility and repeatability values. The reproducibility is assumed to be composed of a repeatability and laboratory component leading to a model where

$$Y = \mu + b + E \qquad (14)$$

where

Y is the measurand;

μ is the overall mean;

b is the laboratory component of the bias under repeatable conditions;

E is the random error under repeatable conditions.

The component b can be established with a regional or national organized round-robin test of CPX systems and can be attributed as a correction term to a measurement system in order to minimize the bias due to a certain measurement system. Refer to ISO 5725-2 for the set-up of such an experiment and the processing of data.

14 Test report

The test report shall include the following data (mandatory, unless indicated otherwise).

General information

1) Time of day and date of measurement.

2) Organization and operators responsible for the measurement.

3) Purpose of the test.

4) Type of measurement equipment (including test vehicle, any extra test tyre, calibrator, sound level meter or equivalent system, measuring equipment for meteorological data, microphone positions used).

5) Certification of test equipment, i.e. the vehicle system, as tested in Annex A (refer to some publicly available documents presenting types of tests and results).

Information relating to the location and appearance of the test site

6) Location of the test site and information about lateral position of tested track (wheel track and lane), as well as the measured distance (start and end positions, test section length). If available, it is good practice to include geographical coordinates of the start and end of each site.

Information relating to the type and construction of the tested surface

7) Type of surface [dense asphalt concrete (DAC), stone mastic asphalt (SMA), etc.], including any standardized or otherwise commonly used designation of the surfacing and as much as possible design data such as maximum chipping (aggregate) size, thickness of surface layer, residual air

voids content, sound absorption coefficient (depending on what type of information is appropriate and available).

Representative photo of the surface, covering an area approximately 100 mm × 150 mm, including a scale (optional).

8) Mean profile depth (MPD), which is a measure of macrotexture, according to ISO 13473-1 (if measured).

9) Attachment with surface specification (work recipe or equivalent) supplied to the contractor who has laid the surface (if available).

Information relating to the condition of the tested surface and to environmental factors

10) Age of the surface and state of maintenance (where available).

11) Any special surface treatment (where appropriate).

12) Any appropriate notes regarding the homogeneity of the surface.

13) Number of days since the latest precipitation occurred (in case of porous surface only and if available).

14) Average air temperatures (mandatory) and average road surface temperatures (optional) over each tested road section.

Test tyre and other test conditions

15) Test tyres used, identification of tyres and date of manufacture.

16) The temperature correction coefficients γ_t used in the temperature correction procedure.

17) Rubber hardness of the test tyres (no more than 3 months old values).

18) The number of runs on which the L_{CPX} is based.

19) The reference speed v_{ref} used.

20) The actual measured test speeds, as an average over a test section.

Measured and calculated sound pressure level data

21) $L_{CPX:t,v_{ref}}$ for each reference tyre at reference speed v_{ref}, equal to $L_{CPX:P,v_{ref}}$ and $L_{CPX:H,v_{ref}}$, corrected for temperature.

22) $L_{CPX:I,v_{ref}}$ (optional).

23) The A-weighted sound pressure level variability, s_t, of the surface (optional; see H.2).

24) The expanded uncertainty of the test result together with the coverage probability (optional).

Others

25) The speed coefficient B used for speed corrections.

26) Frequency spectrum as determined from Formula (10) (optional).

27) Details of special provisions taken to ensure conformity with this document.

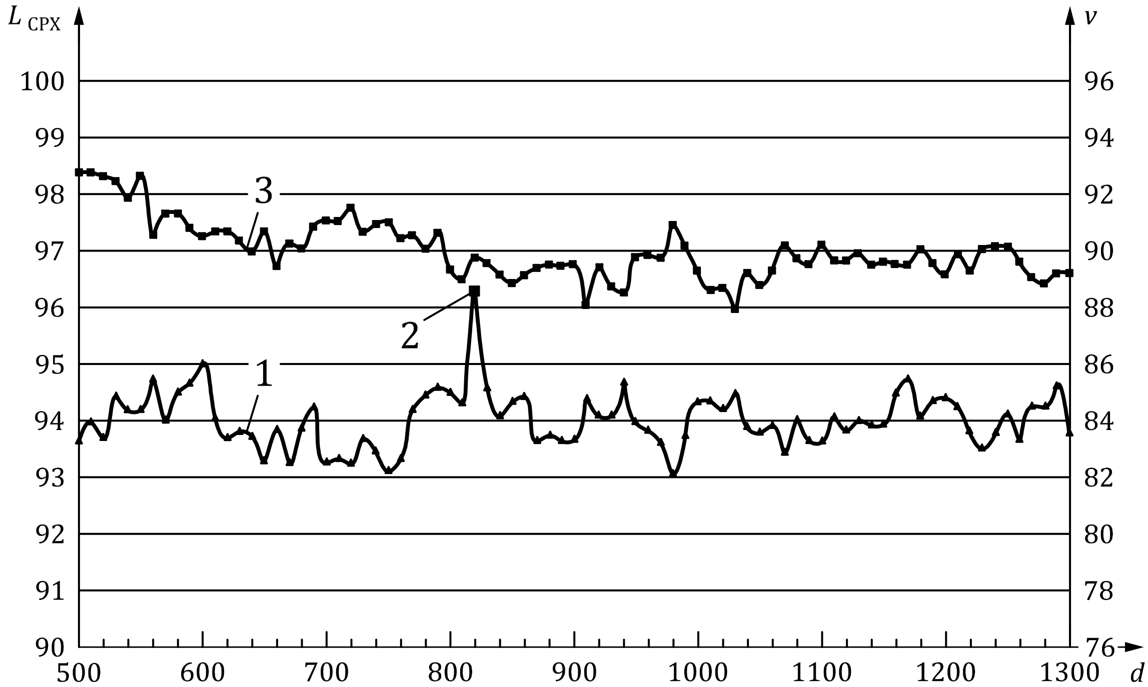
Example of useful graphs or tables (optional)

28) The speed recorded along the test section.

29) L_{CPX} recorded for one or both reference tyres along the test section (either one run or average of all runs).

See Annex O which includes an example of a completed report form.

Figure 2 shows an illustration of a single measurement L_{CPX} along an 800 m long road section, with indications per each 20 m segment, and with one segment subject to a disturbance. If all the measurements for this case (normally two runs) are averaged, one obtains the CPX level.



Key

L_{CPX}	A-weighted sound pressure level, in dB	1	recorded $L_{CPX:P1,90}$
v	speed, in km/h	2	point to be excluded
d	distance, in m	3	actual speed

NOTE The noise level scale is on the left side of the graph and the speed scale is on the right. The nominal speed was obviously 90 km/h in this case, which is not one of the reference speeds.

Figure 2 — Illustration of a measurement along an 800 m long road section, with indications of CPX level (corrected for speed) and actual speed per each 20 m segment

Annex A
(normative)

Certification of the test vehicle

A.1 General

Noise from the power unit of the measuring vehicle or its towing vehicle shall be below the background noise requirements in this annex during testing. The sound reflection effect of the vehicle body, the enclosure and supporting structures shall meet the requirements in this annex. Design criteria which shall be met to assist the test vehicle in meeting these performance requirements are presented.

The test vehicle and measurement system performance shall be certified prior to the initial use of the system.

Subsequent certification of the enclosure and tyre and wheel alignment shall be repeated at least once every two years. This may require replacement of aged or damaged components prior to re-certification.

For the two mandatory microphone positions, the requirements shall be met as an average, but reported data shall also include results for the individual microphones. The requirements shall also be met for any other optional microphone position used. The description and the results of the tests performed shall be reported in a publicly available report.

A.2 Sound reflections against an enclosure (if any) and other objects close to the microphones

A.2.1 Performance requirements

Measurements shall be made to determine the influence of sound reflections on the measured sound pressure levels in the one-third-octave bands from 315 Hz to 5 000 Hz. Such reflections could occur against an enclosure around the test tyre and the microphones (if any) or against objects such as tyre axle, frames, microphone holders or tyre housing (if any), in the vicinity of the microphone. Reflections against the test tyre and the test surface are not considered here. The resulting effect shall be reported in every one-third-octave band from 315 Hz to 5 000 Hz.

In all one-third-octave bands from 315 Hz to 5 000 Hz, the effect of unwanted reflections shall not be larger than 3,0 dB.

See also Annex E.

A.2.2 Certification test method

The test tyre and its wheel are replaced by an artificial sound source manufactured to have approximately the same geometry and exhibiting similar source geometry, with the main source close to the leading and trailing edges of the tyre/road contact area. A specification is given in A.2.3.

Preferably the microphones and artificial sound source shall be mounted on a single plate in order to fix the relative locations of the sound source and the receivers. The plate shall be totally sound reflecting. Then apply the following test procedure:

— While other parts of the CPX vehicle remain as they are mounted when making measurements, apply a white or pink noise signal to the artificial sound source and measure the sound signal at the two microphone positions until a stable level is obtained.

— Next perform the same measurement, but now with the artificial sound source in a hemi-anechoic environment stripped of all parts of the CPX vehicle.

— Calculate the one-third-octave-band level for each microphone position. Then calculate the energetic average over the two microphone positions in both the original and the hemi-anechoic environment.

— Subtract the one-third-octave-band spectrum in the original position from the spectrum in the hemi-anechoic environment.

— Repeat the measurement. If the deviation in any one-third-octave band between the first and the second result is larger than 0,5 dB, do a third measurement and average those results that are within 0,5 dB.

The final result defines the device correction $C_{d,f}$.

For a two or multi-wheel trailer, perform the certification test at each separate wheel and report the spectrum of $C_{d,f}$ for each wheel separately.

NOTE "Wheel" means the rim and the wheel disc, according to ISO 3911. The tyre is mounted on the wheel.

A.2.3 Specifications for the artificial sound source

For radiation of sound in the test method for sound reflections, it is suitable to use a "standard", artificial sound source. An example of such a sound source is presented in Figure A.1. Figure A.2 further illustrates how this sound source can be realized. It is advised to place the tyre mock-up on a plate simulating the road surface and also to fit a wheel inside the simulated tyre which is the same as the wheel used for the reference tyre(s), as shown in the right part of Figure A.2. Of course, the enclosure or any other large object near the reference tyre shall also be fitted in a position relative to the tyre mock-up representative of on-road measurements.

It is recommended that the microphones, base plate, tyre mock-up and sound source be bolted together into a single system, so that moving the set-up does not cause changes in the geometry, since such changes easily jeopardize the requirement of 0,5 dB repeatability.

This mock-up can be the same for both tyre P1 and tyre H1, although they differ a little in dimensions. The use of this particular sound source is optional, although it is recommended that the one presented or something similar be used.

A.3 Background noise from the test vehicle itself or its operation

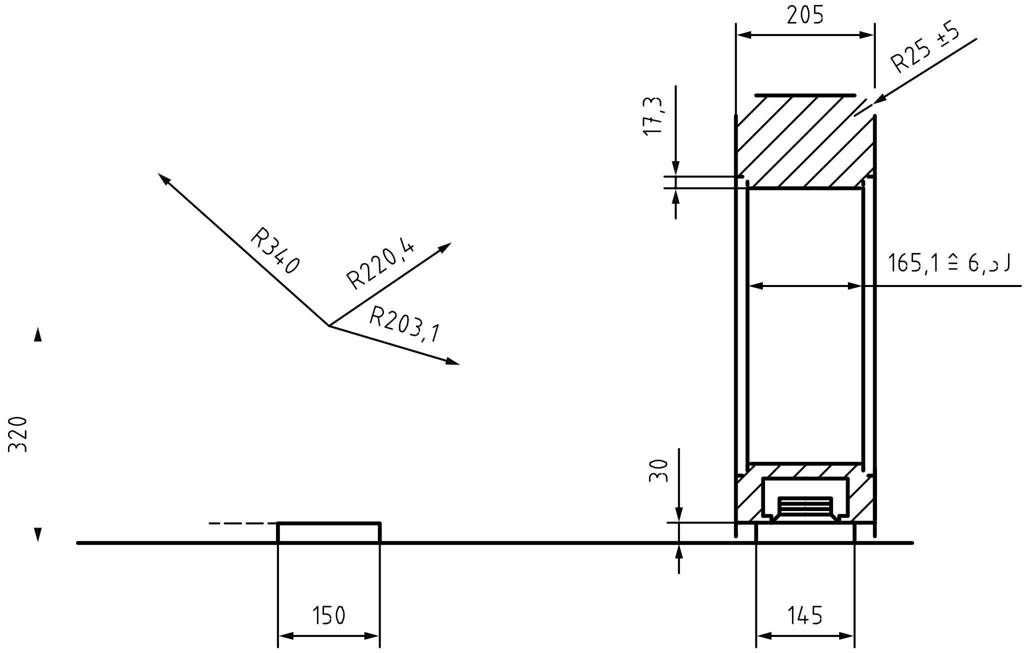
A.3.1 Design requirements for the mounting of the test tyre(s)

Test tyre(s) shall not be mounted on a steered axle or on an axle that is driven during the measurement. Tyres on the test vehicle other than test tyres shall be of the quietest design available, while still maintaining the appropriate safety standards.

Any brakes close to the test tyre(s) shall be in such condition that they are totally released when measurements are made.

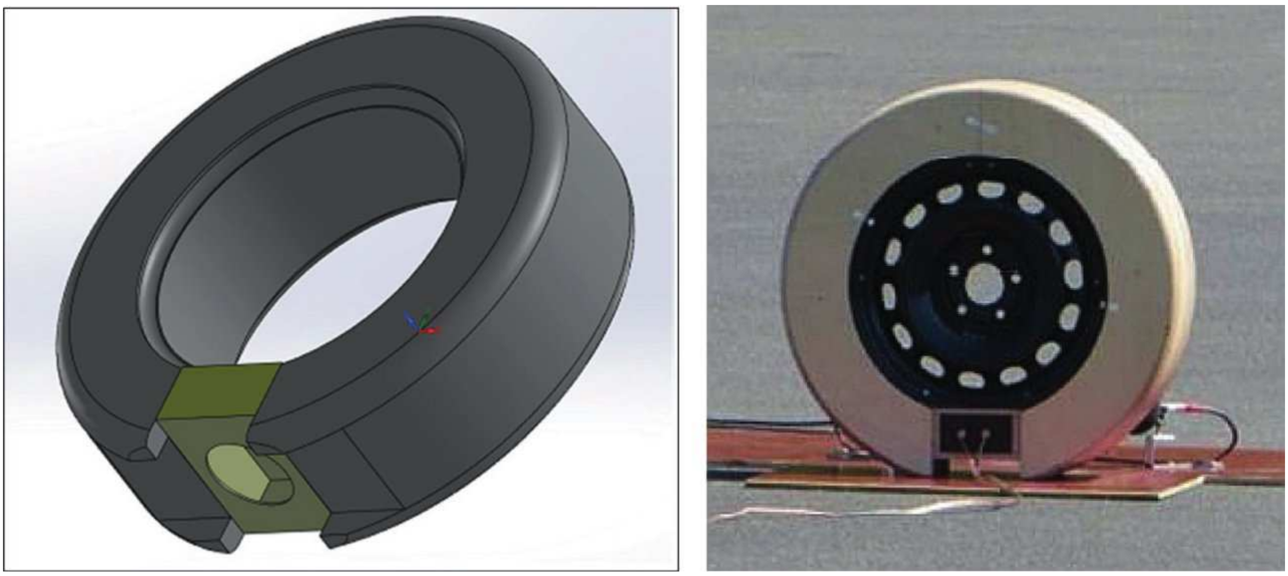
Supporting tyres on a trailer (if appropriate) may be of a special narrow type to reduce tyre/road noise, if possible.

Dimensions in millimetres



NOTE The wheel width is indicated as the standard designation 6.5 J.

Figure A.1 — Outline of a recommended tyre mock-up with artificial sound source suitable for testing the effect of sound reflections (example)



(a) **(b)**

NOTE For loudspeaker mounting and dimensions, see Figure A.1. The right part of the figure shows how reflective conditions may be improved by mounting a wheel in the middle.

Figure A.2 — Examples of tyre mock-up for artificial sound source

A.3.2 Performance requirements

The unwanted noise (background noise, including air flow noise) of the entire test vehicle system shall not influence one-third-octave-band levels by more than 1,0 dB in the 500 Hz to 5 000 Hz frequency range and more than 2,0 dB in the 315 Hz to 400 Hz range.

NOTE Since it is unlikely that all frequency bands are influenced by 1 dB at the same time, this requirement is assumed to be approximately equivalent to at least 10 dB signal/noise ratio in overall A-weighted levels.

A.3.3 Certification test methods

A.3.3.1 General

Three alternative methods (A.3.3.2 to A.3.3.4) may be used.

NOTE With regard to air flow noise, some published data may be useful, such as Reference [16]. A French standard, Reference [25], includes a method for determining air flow noise.

A.3.3.2 Lifted/removed tyre method

Where the test vehicle construction makes this practical, a useful method is to perform a test where the measuring tyre is lifted up above the road surface or removed from the test vehicle. The resulting level is compared with that from normal measurements with tyre/road contact. If the overall A-weighted level is then reduced by at least 10 dB in relation to when the vehicle is equipped with its reference tyres run on the most “quiet” road surface to be studied, and the one-third-octave-band levels are reduced by at least 6 dB in the 500 Hz to 5 000 Hz frequency range (4 dB in the 315 Hz to 400 Hz range), then the requirement above is met. However, in this method the bearing noise is not measured in loaded condition, which would then require an extra test. An upper limit to the bearing noise can be obtained by running the test tyre, including its normal bearing, on a laboratory drum using a smooth tyre and a smooth steel drum.

A.3.3.3 Laboratory drum method

This method is particularly recommended for four-wheeled self-powered vehicles, for which the lifted/removed tyre method (A.3.3.2) cannot be applied. The tyres of the vehicle, mounted as in normal operating conditions, are run in a hemi-anechoic room consecutively on a laboratory drum, having a diameter of at least 1,7 m, covered with an artificial road surface, and their sound contribution in the measurement microphones is recorded. The surface is recommended to be an epoxy replica of a surface according to ISO 10844. The drum shall be able to load the power unit of the vehicle to approximately typical load of the engine during constant-speed driving on a road. This test is performed separately for three different configurations:

a) the test tyre run alone;

b) the other tyre of the same axle run alone (this is possible only if the test axle is not powered);

c) the two tyres of the other (driven) axle run together.

In the third configuration, the vehicle is powered and the most relevant gear setting for the test speed is used, and the engine speed is progressively increased until the engine begins to drive the drum. The noise level then to be recorded is that corresponding to the highest engine speed still meeting this requirement; it accounts for the influence of the tyres of the driven axle and the engine together. The noise levels measured in the two last configurations are energetically added. If the resulting A-weighted level is at least 10 dB lower than the A-weighted level measured in the first configuration, and the resulting one-third-octave-band levels are at least 6 dB lower within 500 Hz to 5 000 Hz (4 dB within 315 Hz to 400 Hz), then the requirement above is met.

A.3.3.4 Customized method

Any other method designed in accordance with good acoustical practice may be used, provided it is judged to be as good as or better than the methods in A.3.3.2 and A.3.3.3, and provided it gives as a result the influence of background noise on the sound measured in the standard microphone positions. This method could for example involve determination of insertion loss of the enclosure (if any) combined with measurement under some representative conditions of the contribution of each potential background noise source. If the customized method is used, it shall be clearly noted in the certification report why it is better than any of the other methods and how this is achieved.

A.4 Background noise from towing vehicle

A.4.1 Sources of noise

Noise sources on the towing vehicle may include, in particular, the following:

Power unit noise: Most sources of power unit noise are likely to be located at the front of the towing vehicle and can then normally be neglected. However, often the exhaust outlet and the related silencer(s) are located at the rear of the towing vehicle and may then contribute to the background noise. This is of particular importance when the vehicle is running with an engine load which is higher than during "normal" operation of this vehicle and in the lower frequency range.

Tyre/road noise: Depending on the distance between the towing vehicle and the microphones, tyre/road noise from the tyres on the towing vehicle, especially the rear axle tyres, may contribute significantly to the background noise. The contribution may be much more important than when considering the towing vehicle tyres and the test tyres as omni-directional point sources, since tyres usually have a directivity which increases noise emission towards the front and the rear, for which the horn effect plays a leading role. Note also that tyre/road noise may be higher than expected due to the extra slip induced when the driving tyres on the towing vehicle run at increased slip conditions due to the load caused by towing.

Air turbulence noise: The air turbulence from the towing vehicle may create background noise in the microphones, especially if there is no enclosure around the test tyre and the microphones.

A.4.2 Performance requirements

The requirements in A.3.2 shall also apply to any influence from the towing vehicle (if appropriate).

A.4.3 Certification test methods

The power unit noise, including exhaust noise, may easily be tested by running the towing vehicle at an engine load typical of a more "loaded" condition, such as when going uphill, and comparing the microphone signals to a condition when the towing vehicle engine is set at idling.

For tyre/road noise due to the towing vehicle, refer to the test methods for the test vehicle. For air turbulence, refer to the note in A.3.3.1.

A.5 Background noise from external vehicles

A.5.1 Performance requirements

The test vehicle shall be designed in order to ascertain that the influence of other vehicles (in the normal traffic) is no more than what is required regarding background noise, i.e. the sound pressure levels from such vehicles shall not be higher than recommended in F.4.

A.5.2 Certification test method

The vehicle shall be tested under static conditions, at a location such as the road shoulder where vehicles in the regular traffic stream can pass in the adjacent lane, so that its relative position is representative of normal operation on public roads. The average speed of the traffic in the adjacent lane shall be 70 km/h to 90 km/h and the maximum permitted distance between the test vehicle and the adjacent traffic shall be 1,5 m.

The measurements shall be made on at least one road surface type. As a minimum, this shall include a dense asphalt surface (DAC or SMA) with as fine and dense texture as is available.

For typical passing vehicles, measure the maximum A-weighted sound pressure levels and frequency spectra in the two microphones of the test vehicle, as well as the speed of each vehicle. Include in the resulting database no less than 20 passenger cars and 10 heavy vehicles. The latter shall be category 2b vehicles (trucks, buses or coaches with more than two axles) as specified in ISO 11819-1. Use the time weighting F (IEC 61672-1). Any enclosure or screen shall then be in the position used during CPX measurements. The reference speed v_{ref} shall be 80 km/h.

Correct the sound pressure levels (including spectra) for speeds to the reference speed of 80 km/h using a speed coefficient B of 30 on the DAC or SMA surfaces, according to 11.1. Compare measured sound pressure levels from the reference tyre(s), on the same type of surface(s), with those of the fleet of the passing vehicles.

If the difference in total A-weighted level is equal to or higher than 10 dB, the test vehicle qualifies for use without any special treatment or flagging for passing vehicles in in-traffic measurements (see F.4), at the reference speed of 80 km/h and higher. For reference speeds lower than 80 km/h, the speed of adjacent traffic shall be approximately equally low for the qualification to be valid.

NOTE The DAC or SMA fine-textured surface is usually the most "noisy" one for the heavy vehicles and therefore gives a conservative value for the background noise influence.

A.6 Alignment of the test tyre

The camber angle of the test tyre(s) shall be no more than 1,5° and (static) toe-in no more than ±1°. These shall be checked at least once every two years.

A.7 Certification report

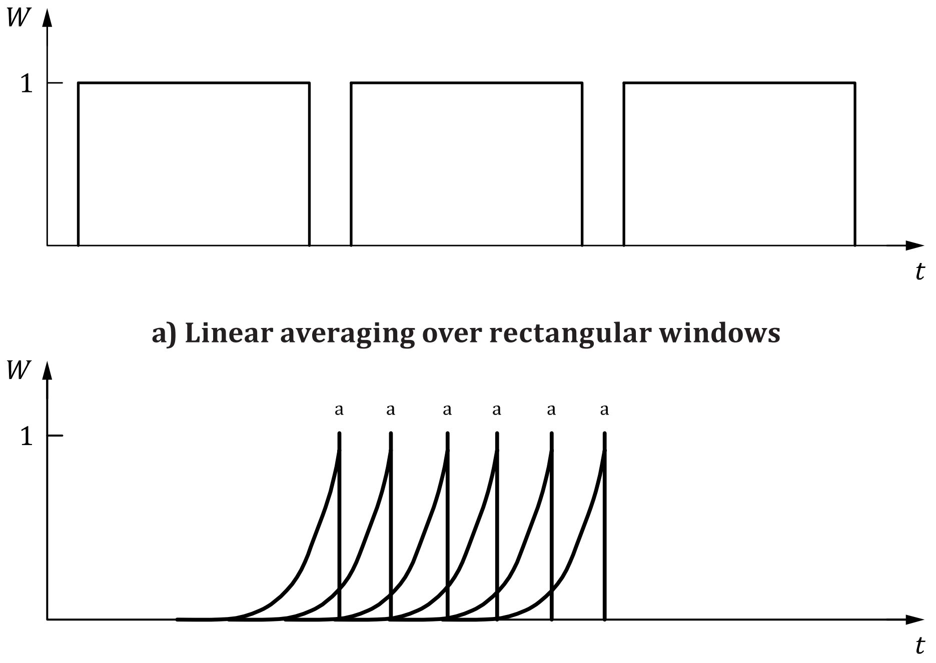
The results of the certification tests, described in the foregoing, and a description of the system and the properties of the mandatory required items (such as acoustic lining in the enclosure) shall be reported in a document that is, by request, made available for third parties in relation to a certain measurement project, or is available for example for download from a website. A.2 to A.5 shall be included in the certification report.

Annex B
(normative)

Averaging within each road segment

B.1 General

The measured one-third-octave-band levels shall be averaged over each 20 m road segment. Averaging over a segment shall be made according to the equal-energy principle ("energetically"). Various set-ups make use of and allow only certain types of averaging procedures, so it is necessary to accept more than one type. The following are acceptable averaging procedures, giving essentially similar results (see illustrations in Figure B.1).



b) Exponential averaging each 1/8th of a second with a moving exponential window

Key

W weight of signal

t time

a sampling instances.

Figure B.1 — Illustration of the averaging procedures

B.2 Linear average

Averaging of the signal within a linear (rectangular) window, covering at least 75 % of the length of a segment (15 m).

B.3 Exponential averaging

In this case, the signal is exponentially averaged with the time weighting F. The signal is sampled at regular intervals and the average sound pressure level is calculated arithmetically. The sampling rate shall be at least one sample per 0,125 s. In this alternative, there is a certain influence of the signal before the current segment.

The result of this averaging is the equivalent SPL for an individual one-third-octave band with the centre frequency *f*, measured at microphone position *m*, for the road segment with the index *i*, in the run *r*, using the tyre t, in wheel track *w,* with the symbol: $L_{\mathrm{CPX:t},w,r,i,f,m,v_{\mathrm{ref}}}$.

Annex C
(informative)

Detailed explanation of the calculation procedure

C.1 Calculation of microphone-averaged levels

The microphone-averaged spectral levels are calculated in each frequency band between 315 Hz and 5 000 Hz of the sound pressure levels at the front and rear microphones, m = 1 and m = 2, by energy-based averaging of the spectral levels measured by the microphones:

$$L'_{\mathrm{CPX:t},w,r,i,f} = 10 \cdot \lg\left[0{,}5\left(10^{0{,}1\left(L_{\mathrm{CPX:t},w,r,i,f,1}\right)} + 10^{0{,}1\left(L_{\mathrm{CPX:t},w,r,i,f,2}\right)}\right)\right]\mathrm{dB} \quad \text{(C.1)}$$

C.2 Device-related correction of frequency spectra

Correct the microphone-averaged spectral levels for the device-related frequency-dependent properties $C_{\mathrm{d},f}$:

$$L_{\mathrm{CPX:t},w,r,i,f} = L'_{\mathrm{CPX:t},w,r,i,f} + C_{\mathrm{d},f} \quad \text{(C.2)}$$

The device-related correction factor $C_{\mathrm{d},f}$ is defined in each one-third-octave band between 315 Hz and 5 000 Hz. The procedure for determining the values of $C_{\mathrm{d},f}$ is given in A.2.

C.3 Calculation of overall levels from one-third-octave-band levels

The corrected spectrum is aggregated into an overall A-weighted sound pressure level by means of summation of energy over the spectral range 315 Hz to 5 000 Hz:

$$L_{\mathrm{CPX:t},w,r,i} = 10 \cdot \lg\left[\sum_{f=315}^{5\,000} 10^{0{,}1\left(L_{\mathrm{CPX:t},w,r,i,f}\right)}\right]\mathrm{dB} \quad \text{(C.3)}$$

C.4 Correction for deviating speed, temperature and tyre rubber hardness

Corrections are applied for deviations from the targeted reference speed v_{ref} and from the reference temperature of 20 °C using coefficients B for the speed coefficient and γ_{t} for the temperature effect. A further correction is applied for deviation from the reference tyre rubber hardness of 66 Shore A (for tyres P1 and H1). These corrections lead to the corrected equivalent CPX level over road segment i, for run r and tyre t.

For speeds which are lower than the preselected reference speed, the speed correction is positive and for speeds higher than the nominal ones the correction is negative.

For the value of the speed coefficient B please refer to 11.1.

The SPLs for tyres shall be corrected to a reference air temperature of T_{ref} = 20 °C using a temperature coefficient γ_{t}. The corrected levels (L_{CPX}, i.e. for each tested road section) shall be reported together with the value of the coefficient γ_{t}.

The SPLs for tyres P1 and H1 shall also be corrected to a reference tyre rubber hardness of 66 Shore A using a rubber hardness coefficient β_{t}.

The correction procedures are combined as follows:

$$L_{\mathrm{CPX:t},w,r,i,v_{\mathrm{ref}}} = L_{\mathrm{CPX:t},w,r,i} - B \cdot \lg\left(\frac{v_{\mathrm{t},w,r,i}}{v_{\mathrm{ref}}}\right)\mathrm{dB} - \gamma_{\mathrm{t}} \cdot \left(T_i - 20\,^\circ\mathrm{C}\right) - \beta_{\mathrm{t}} \cdot \left(H_{\mathrm{A}} - H_{\mathrm{ref}}\right) \quad \text{(C.4)}$$

The rubber hardness reference value H_{ref} and the rubber hardness coefficient β_{t} for reference tyres P1 and H1 are given in ISO/TS 11819 -3 (same coefficient for both tyres).

The values of the temperature coefficient γ_{t}, which are negative, are given in ISO/TS 13471-1 if the reference tyres P1 and H1 are used (same coefficient for both tyres).

C.5 Removal of segments affected by disturbances from other sources

Several types of disturbances may affect the measured CPX level. These are usually transient events of rather short duration, therefore affecting measurements on only a few road segments. All 20 m road segments potentially affected by disturbances shall be discarded from the CPX calculation procedure. The identification of disturbance levels which are too high is specified in F.4.

The following averaging steps assume that all affected road segments *i* have been removed from the evaluation.

C.6 Averaging procedures

C.6.1 General

The following phase can be processed in two ways. The first option is the averaging over all segments in the wheel track and then averaging over the runs. Finally, averaging over the wheel tracks may be an option, depending on the purpose of the measurements. The second option, suitable for two-wheeled systems, allows averaging of the CPX level of a segment over both wheel tracks and after that averaging of the whole section and over the runs. This approach has the advantage that a graphical presentation of the CPX level versus distance shows less scatter. The final results are the same, irrespective of the method chosen.

NOTE Arithmetic averaging is applied here instead of energy-based averaging since it reduces the effect of occasional transient-like disturbances.

C.6.2 Alternative 1: averaging over section length (“serial averaging”)

The series of CPX levels of the consecutive segments are checked with respect to disturbing sound contributions and segments which are affected are discarded. The resulting segments are averaged over the section length, then over the number of runs and (if requested) over the wheel tracks:

$$L_{\mathrm{CPX:t},v_{\mathrm{ref}}} = \frac{1}{n_w}\sum_{w=1}^{n_w}\left[\frac{1}{n_r}\sum_{r=1}^{n_r}\left(\frac{1}{n_i}\sum_{i=1}^{n_i} L_{\mathrm{CPX:t},w,r,i,v_{\mathrm{ref}}}\right)\right] \quad \text{(C.5)}$$

If single wheel track information is to be calculated, the averaging over n_w is omitted.

C.6.3 Alternative 2: averaging over wheel tracks (“parallel averaging”)

In certain cases, especially with two-wheeled systems, it is advantageous to average each segment over both wheel tracks. For instance, the reliability of the CPX level plotted versus distance is improved by this procedure. In this case the order of averaging given in Formula (C.5) is modified. First, the CPX levels of a segment of the left and right wheel tracks are averaged and then averaging is performed over the length of a section and if necessary over more runs. Also in this case, segments with disturbances which are too high are discarded. In this procedure, however, both left and right wheel track data are omitted, leaving a blank in any CPX versus distance plot.

The calculation is as follows:

$$L_{\text{CPX:t},v_{\text{ref}}}=\frac{1}{n_r}\sum_{r=1}^{n_r}\left[\frac{1}{n_i}\sum_{i=1}^{n_i}\left(\frac{1}{2}\sum_{w=1}^{2}L_{\text{CPX:t},w,r,i,v_{\text{ref}}}\right)\right] \quad \text{(C.6)}$$

C.7 Calculation of frequency spectra

For research purposes, or to meet other specific requirements, the frequency spectrum may be calculated in addition to the total CPX level. For these purposes the calculation procedure is slightly modified in such a way that the energy-based summation over the relevant frequency bands is omitted. Correction for the properties of the device and any deviations from reference speed and reference temperature are still applied. The spectrum of the CPX signal over a segment is then calculated as follows:

At first, the energy-based average spectrum at the microphone positions 1 and 2 is calculated as follows:

$$L'_{\text{CPX:t},w,r,i,f}=10\cdot\lg\left[0{,}5\left(10^{0{,}1\left(L_{\text{CPX:t},w,r,i,f,1}\right)}+10^{0{,}1\left(L_{\text{CPX:t},w,r,i,f,2}\right)}\right)\right]\text{dB} \quad \text{(C.7)}$$

After this, correction for the device properties $C_{\text{d},f}$ is applied as follows:

$$L_{\text{CPX:t},w,r,i,f}=L'_{\text{CPX:t},w,r,i,f}+C_{\text{d},f} \quad \text{(C.8)}$$

NOTE These steps are identical to those in C.1 and C.2.

Then, corrections for deviations from the target speed and reference temperature are made:

$$L_{\text{CPX:t},w,r,i,f,v_{\text{ref}}}=L_{\text{CPX:t},w,r,i,f}-B\cdot\lg\left(\frac{v_{\text{t},w,r,i}}{v_{\text{ref}}}\right)\text{dB}-\gamma_{\text{t}}\cdot\left(T_i-20\ ^{\circ}\text{C}\right)-\beta_{\text{t}}\cdot\left(H_{\text{A}}-H_{\text{ref}}\right) \quad \text{(C.9)}$$

The rubber hardness reference value H_{ref} and the rubber hardness coefficient β_{t} for reference tyres P1 and H1 are given in ISO/TS 11819-3 (same coefficient for both tyres).

The values of the temperature coefficient γ_{t}, which are negative, are given in ISO/TS 13471-1 if the reference tyres P1 and H1 are used (same coefficient for both tyres).

C.8 Correction for effect of order of averaging

The resulting spectrum in Formula (C.9), $L_{\text{CPX:t},w,r,i,f,v_{\text{ref}}}$, generally exhibits an overall A-weighted level that is slightly different from the calculated results of the total A-weighted levels made according to Formulae (C.5) and (C.6). See example in Table C.1. The reason is the reversed order of arithmetical averaging and energy-based summation. When following the procedure in Formulae (C.5) and (C.6), the energy is summed over the frequency bands, and then averaging over sections, runs, and wheel tracks is performed. In the procedure in this clause, the energy-based summation takes place after arithmetical averaging over section, runs and wheel tracks has been made.

It is recommended that this effect be corrected for by adding the difference in total sound pressure levels between the two procedures to the spectral values

$$L_{\text{CPX:t},w,r,i,f,v_{\text{ref}}(\text{corr})}=L_{\text{CPX:t},w,r,i,f,v_{\text{ref}}}+\Delta L_{\text{t},v_{\text{ref}}} \quad \text{(C.10)}$$

where

$$\Delta L_{\mathrm{t},v_{\mathrm{ref}}} = L_{\mathrm{CPX:t},v_{\mathrm{ref}}} - 10 \cdot \lg \left\{ \sum_{f=315}^{5\,000} 10^{\frac{0,1}{n_w} \sum_{w=1}^{n_w} \left[\frac{1}{n_r} \sum_{r=1}^{n_r} \left(\frac{1}{n_i} \sum_{i=1}^{n_i} L_{\mathrm{CPX:t},w,r,i,f,v_{\mathrm{ref}}} \right) \right]} \right\} \mathrm{dB} \tag{C.11}$$

in which $L_{\mathrm{CPX:t},v_{\mathrm{ref}}}$ is derived from Formula (C.6).

After this, averaging over the section or over the wheel tracks is performed, according to C.6.2 and C.6.3.

Table C.1 — Example of effect of difference due to order of averaging

Segment number	One-third-octave band centre frequency, Hz													Energy sum of one-third-octave bands dB[a]
	315	400	500	630	800	1 000	1 250	1 600	2 000	2 500	3 150	4 000	5 000	
	Third-octave band sound pressure levels, dB													
1	63,2	68,9	78,1	79,1	80,0	78,0	74,4	71,1	70,6	70,8	67,5	62,5	59,0	85,9
2	64,7	70,0	78,9	79,5	79,8	77,8	74,0	69,8	70,7	71,1	67,5	61,4	57,8	86,1
3	62,4	67,8	77,0	79,4	79,1	76,3	72,6	71,3	72,1	71,8	67,5	61,6	58,4	85,3
4	63,5	69,0	77,4	80,4	81,0	79,1	77,3	72,0	69,0	68,8	66,2	61,7	58,1	86,8
5	62,9	69,1	78,4	79,7	79,8	76,9	72,9	70,4	70,8	70,7	66,6	60,7	57,2	85,8
6	62,6	68,8	78,3	80,0	79,6	76,7	71,9	69,9	70,9	70,4	65,8	59,8	57,2	85,7
7	62,3	69,1	79,5	79,5	79,4	76,1	72,5	71,2	71,6	70,2	65,2	60,3	57,5	85,8
8	62,0	68,6	78,2	80,4	80,3	77,6	72,7	70,3	71,3	70,7	65,8	60,5	57,9	86,1
9	63,0	68,1	78,1	78,8	77,7	74,9	74,6	73,8	73,0	70,6	65,9	61,3	58,2	85,2
10	63,0	69,2	77,7	77,0	75,9	72,9	74,5	74,6	72,9	70,0	65,8	61,1	57,6	84,3
11	62,9	69,2	79,2	79,7	79,4	74,8	70,6	71,5	71,8	69,9	64,2	59,7	56,8	85,5
12	62,9	69,0	78,7	79,5	78,8	74,2	71,3	72,2	71,7	69,1	64,2	60,2	57,3	85,2
13	63,1	68,9	78,1	78,9	77,6	74,2	73,5	73,0	71,3	69,2	65,3	61,0	58,2	84,8
Arithmetic average over all segments	**63,0**	**68,9**	**78,3**	**79,4**	**79,1**	**76,1**	**73,3**	**71,6**	**71,4**	**70,2**	**66,0**	**60,9**	**57,8**	

[a] The average over the right column is 85,6 dB; the energy sum over the lower row is 85,5 dB. The level difference $\Delta L_{\mathrm{t},v_{\mathrm{ref}}}$ is 0,1 dB. This figure shall be added to the value of each of the one-third-octave-band levels. Preferably, corrections are made with two decimals, before the result is presented with one decimal.

Annex D
(informative)

Applicability of ISO 11819 methods

The most suitable areas of application for the SPB method (ISO 11819-1) and CPX method (this document) are presented in Table D.1. See Reference [1] for a proposed classification method for road surfaces in which both SPB and CPX measurements are required. Note, in particular, that the expected good absolute stability with time of the CPX method may be used to check long-term stability of the SPB method, as discussed in ISO 11819-1:1997, Annexes C and D.

The CPX method measures sound in the near field, which means that the noise-reducing effect of porous surfaces arising from sound absorption during propagation close to the porous surface from the source to the receiver are not fully addressed. Nevertheless, an experiment to study this effect (among other things) did not indicate this to be a severe restriction of the method (References [2], [3], [9]). According to this and other experience, the noise-reducing effect of porous surfaces is generally well estimated when using this method and the associated reference tyres. One potential reason for this may be a compensating effect in the CPX method, which favours porous surfaces more than when using the SPB method. Such an effect might be the higher sensitivity to texture by worn tyres (Reference [6]), which may give rough-textured porous surfaces a kind of penalty, and worn tyres are of course used on vehicles included in SPB testing.

Supplementary information with regard to sound absorption effects and their influence on propagation may be obtained by applying the sound absorption measuring method specified in ISO 13472-1.

When measuring on a porous surface, but close to a dense surface, be aware that it is common that clogging generally is more severe the closer the measurement is to a dense surface. This becomes more pronounced with time, as clogging progresses from the surface joint until approximately 50 m to 100 m away from the joint before the noise-reducing effect becomes independent of location. This effect can be seen if the CPX level is plotted against distance away from the joint.

Table D.1 — Usefulness of the statistical pass-by method (SPB) and the close-proximity method (CPX)

	SPB method	CPX method
Advantages	Results representative of actual traffic noise emission Good assessment of road influence for all vehicle types including heavy vehicles Uses a representative traffic composition (e.g. may differ in the Netherlands from North America or Japan) Accurately describes source and propagation effects	Easily applicable in most cases Inexpensive and fast to use, once the equipment is available Both overall level for an extended length of surface and its spot-to-spot variation can be studied Applicable under a wide range of conditions (dry surface required, however) Gives an “absolute level“ (i.e. free of fleet or propagation components)
Disadvantages and limitations	Time-consuming measurement procedure Measures road surface properties only at one location, recognizing that large variations from spot to spot may occur Only applicable within strict conditions (traffic intensity not too high, no reflective objects close to the microphone, “normal“ driver behaviour) Stability with time depends on how the noise characteristics of the vehicle fleet develop	Medium representativity for surface influence on passenger car noise Low-to-medium representativity for surface influence on truck tyre noise Propagation effects not fully included Effect only restricted to tyre/road noise Strict specifications for the enclosure design and background noise required Investment in measuring vehicle needed Dependent on availability and close control of reference tyres
Application fields	Accurate and representative assessment of acoustic properties of road surfaces, at the chosen spot and for sites meeting stringent acoustic requirements; e.g. “type testing“ and general evaluation Spotwise check of state of maintenance and condition Useful for research purposes	An approximate assessment of acoustic properties of road surfaces, at a wide range of sites Conformity of production test Homogeneity check of road surfaces Check of state of maintenance and condition Check of long-term performance of test tracks (e.g. ISO 10844 tracks) Check of long-term stability of the SPB method Useful for research purposes

Annex E
(informative)

Guidelines for design and use of the test vehicle

E.1 General

The guidelines in this annex are provided to assist in the design and operation of test vehicles. The guidelines can assist in ensuring that the performance requirements in Annex A are satisfactorily achieved.

E.2 Design guidelines for enclosures

For test vehicles incorporating an enclosure, it is preferable that the enclosure, including any skirts, reach down to within 50 mm of the ground level. However, in urban areas a clearance of 50 mm may cause frequent contact between the enclosure and the road; therefore, in such cases the clearance can be increased to a maximum of 100 mm. The lowest part may consist of flexible material which does not flutter when the vehicle is in motion.

E.3 Use and protection of sound absorptive materials on test vehicles

E.3.1 General information regarding the fitment of sound absorptive materials

Parts of the vehicle may be covered by an enclosure which screens the test tyre(s) and the microphones from unwanted noise sources. A.2.1 specifies the requirements for any sound-absorbing materials used to line the enclosure or to cover other sound reflective surfaces in order to reduce sound reflections. Suitable materials include lightweight acoustic panels with high-absorptive open-cell material shaped as pyramids, wedges or sharp waves, sometimes referred to as “acoustic foam”. Materials such as melamine and polyurethane are also available.

Sound-absorbing materials should be protected from dirt and water during travel to/from site as far as is practical. Examples of how this can be achieved are given in E.3.3.

Note that the sound absorption properties of sound absorptive materials deteriorate as the materials are progressively exposed to dirt. It is therefore good practice to test the performance of these materials frequently and to replace them with new, fresh material when they show patterns of substantial dirt coverage.

Vehicles which do not incorporate an enclosure around the test tyre(s) and the microphones may not need such sound absorptive material, except where sound reflections from solid objects are likely to reach the microphones.

E.3.2 Design requirements for sound absorptive materials

The inside walls of the enclosure shall be covered by acoustically absorptive material to make the influence of sound reflections negligible. Sound-absorbing materials having a total thickness of (for example) 75 mm may give sound absorption coefficients of 0,6 or higher in the range 315 Hz to 400 Hz and 0,90 or higher in the range 500 Hz to 5 000 Hz, which is the minimum performance recommended.

If other reflective surfaces inside the enclosure that might result in reflected sound affecting measured levels are treated with sound absorptive materials, these should meet the same specifications.

E.3.3 Protection of sound absorptive materials against dirt and water

CPX measurements are normally not made when there is a risk for dirt and water being pulled up from the pavement. However, the test vehicle and its microphones may be affected by dirt and water during transportation to or from a test site. To avoid such exposure during transportation, the following presents some examples of how this might be achieved.

— The test vehicle or that part of it having sensitive materials could be pulled up onto another vehicle (trailer or truck) in order to avoid exposure to water or dirt (if appropriate based on the design of the test vehicle).

— Sensitive parts of an enclosure around the tyre(s) could be folded up or dismounted to avoid them being hit by water and dirt (if appropriate based on the design of the test vehicle).

— The test tyre could be pulled up from its contact with the pavement in order to avoid water or dirt being pulled up by the tyre and spread to the absorbing material around it (if appropriate based on the design of the test vehicle).

Whenever the sound-absorbing material is soaked with water and dirt or covered with a significant amount of dirt, its sound-absorbing properties may be substantially worse than intended and any corrections for sound reflections may be inappropriate. To dry a water-soaked absorbing material may take several hours or even more than a day. The following recommendations apply if risks for water or dirt contamination are apparent.

— Sensitive parts of the sound-absorbing materials may be covered with a suitable watertight material which protects it from being hit by water and dirt. This may be made as a separate measure or in combination with any other measure (if appropriate with regard to the design of the system).

— If the above recommendations do not apply to the particular vehicle design, the test tyre may be covered with a suitably tight enclosure which reduces the spread of water and dirt around it. The same applies to any outer supporting trailer tyres (if appropriate with regard to the design of the system).

E.4 Design guidelines applicable to all types of test vehicle (self-powered and trailers)

When designing a test vehicle, the dimensions should be sufficient to allow an appropriate distance between microphones and reflecting surfaces, including sound-absorbing materials; see further 9.2. This distance is recommended to be at least 0,2 m.

To identify the potential influence of noise from passing vehicles or from wind gusts, it is a good idea to add an extra microphone, placed appropriately, in order to monitor the noise in the system away from the test tyre.

Vehicles designed to measure in both wheel tracks simultaneously should have a distance between the right and left side test tyres (between tread centres) of between 1,5 m and 1,9 m.

For “open” test vehicles, which do not incorporate an enclosure around the test tyre(s), it is very important to observe the risks for wind turbulence-induced noise in the microphones or around objects close to them.

During transportation to/from test sites it is good practice to protect sensitive parts of the measurement systems, e.g. by applying the following measures:

— removal and storage of the microphones in a dry and clean place inside the vehicle;

— coverage by some watertight protection material of any devices connected to the microphones, which cannot practically be brought into the vehicle, such as cables or preamplifiers and their connectors.

E.5 Design concerns for self-powered test vehicles

For vehicles where the test tyre(s) are subject to braking, observe that this results in the tyre(s) being subjected to extra wear, which in severe cases may cause unacceptable unevenness. If a test tyre has been subject to "hard braking", i.e. with blocked wheel or with anti-blocking systems in operation, it is recommended that the condition of the tread be closely inspected. If any abnormal wear (as compared to that typical of a free-rolling tyre) is visible, the tyre should be replaced with a new one.

When the vehicle is not used for testing, such as during transportation to and from the measured site, it is recommended that tyres other than test tyre(s) be used in order to avoid excessive wear of test tyre(s) due to braking or cornering. Exceptions are allowed if the driving distances are short and if hard braking does not occur.

The distance between the microphones and tyres other than that/those under test should be at least 1,5 m. It is not necessary to meet this requirement if a vehicle with an extra test tyre is used, provided this system can be tested with the lifted tyre principle (A.3.3.2) and the background noise requirement is then met.

Normally, the underbody of the vehicle is covered with sound-absorbing material, in order to avoid reflections of sound on the underbody coming from tyres other than test tyre(s). Exceptions are accepted only if the construction is such that reflections from the underbody are prevented from reaching the microphone positions.

NOTE Depending on the safety standards that the vehicle is required to meet, the use of nearly worn-out or extra narrow tyres on the vehicle, except for the test tyre(s), can be considered, with a view to keeping sound emission from them as low as possible, in particular in the direction of the microphones. However, note that tyres with tread thickness reduced (by wear) to near the legal limit, while being relatively "quiet" on smooth surfaces, are "noisy" on rough-textured surfaces (Reference [6]).

E.6 Design concerns for a trailer

In this case, the test vehicle consists of two parts: the towing vehicle and the trailer. In addition to the test tyre(s), the trailer may have tyres for support, which should be mounted as far away from the microphones as possible, but at least 1,5 m away, and be of a type quiet enough in order to be insignificant in relation to the test tyre noise. Trailers with support tyres do not necessarily have to meet this distance requirement if background noise from the test vehicle and the towing vehicle can be tested with the lifted tyre principle (A.3.3.2) and the background noise requirement is then met.

It is recommended that a distance of at least 3 m be maintained between the towing vehicle tyres and the microphones. Reduction of tyre/road noise from the towing vehicle may also be achieved by adding a noise screen at the rear of the towing vehicle or adding an enclosure around the test tyre and microphones. Background noise may be tested, when possible, with the lifted tyre principle (A.3.3.2).

Any load package or supporting structure for load should be placed outside the enclosure. If brakes are used in connection with the test tyre(s), which is not recommended, but might be required for meeting safety standards, the same restrictions should be observed with respect to braking and wear as specified in E.5.

The suspension of the trailer should be designed in such a way as to have a spring rate and damping coefficient similar to those of the suspension of a car.

NOTE Depending on the safety standards that the vehicle is required to meet, the use of slick, worn or extra narrow tyres on the towing vehicle, or as supporting tyres on the trailer, can be considered, with a view to keeping sound emission from them as low as possible, in particular in the direction of the microphones. However, note that smooth (patternless) tyres, while being "quiet" on smooth surfaces, are often the noisiest tyres on rough-textured surfaces, and tyres with tread thickness reduced (by wear) to near the legal limit are also "noisy" on rough-textured surfaces (Reference [6]).

E.7 Operational guidelines

If power unit noise has a significant influence on the test results, the effect can be reduced by coasting the test vehicle or towing vehicle (whichever applies) during the measurement. The constraints on speed variation and correction for speed shall then be observed.

Annex F
(informative)

Guidelines for measurements

F.1 General

It is advisable to listen to the sound picked up by the microphones during the measurements.

NOTE Some types of road surfaces may change their noise characteristics rather quickly, e.g. after opening for traffic or due to the effect of ageing (wear, clogging, etc.). Attention is drawn to the fact that the measurement results have limited representativity in time.

F.2 Recommendations on surface wetness

The surfaces can be assumed to be sufficiently dry for measurements, if the minimum time periods for drying up after rainfall given in Table F.1 are observed (Reference [7]). However, note that the times depend very much on wind and sunshine conditions, so the values given may be adjusted accordingly.

Table F.1 — Recommended time periods between rainfall and measurement

Surface type	Recommended time before measurements	Comments
Dense, non-permeable surfaces, e.g. hot rolled asphalt (HRA), DAC, cement concrete (CC)	No special time	Make visual judgement
Negatively textured surfaces, potentially containing deep troughs, e.g. SMA and thin asphalt layers	3 h	Make visual judgement
Porous (permeable) surfaces	24 h to 48 h	The lower value is acceptable only if there is sunshine during the day, and significant air movement over the surface either by wind or by traffic. Furthermore, the daytime should not be short

Unless more than 2 days have passed since the latest precipitation, a check of whether a surface assumed to have a significant porosity still contains residual moisture is recommended.

Compressed air is blown into the road surface, e.g. using a standard pistol-grip air jet or a spray can with compressed air, directed vertically towards the surface. Any remaining moisture is revealed in a clearly visible spray cloud. The surface can be regarded as dry if five tests at representative points along the length of the road surface fail to show a spray cloud (blotting paper can also be used to indicate presence of water).

NOTE 1 Experience with sound measurements on porous road surfaces has shown that A-weighted levels can be influenced by up to 2 dB due to residual moisture in an apparently dry surface.

NOTE 2 This test can be carried out using a portable compressor. A short pulse of compressed air at 0,5 kPa to 0,8 kPa is sufficient for the test.

F.3 Preferred lateral measurement position on road

If it is suspected that there might be a difference in noise properties between the right and left wheel track, the preferred option for accuracy and representativity is to perform measurements in both wheel tracks. If measurements are made in only one wheel track, choose the track which is closest to the road shoulder. Note also that making measurements with two tyres simultaneously rather than one at a time can decrease the time needed to yield a certain precision due to statistical properties.

F.4 Identification of disturbing noise

F.4.1 General

Disturbing events in the CPX time history can be caused by passing or oncoming external vehicles, especially motorcycles, heavy trucks or light vehicles travelling at very high speeds. Particularly for non-covered CPX vehicles, wind gusts from other vehicles or the ambient wind are also a common source. Other disturbances can come from construction machines on or near the road, markings of pedestrian crossings, reflections against objects near the road, joints between concrete slabs, road damage or changes in surfacing. These can be identified and flagged as described in F.4.2 to F.4.5.

F.4.2 Listening to the sound of the CPX microphones and watching the traffic

The operator listens to the sound from the two microphones – one earphone per front and rear microphone (located on the side of the test tyre facing the most disturbing traffic). While simultaneously watching passing and oncoming traffic, the operator flags events when he or she can hear sound from another vehicle. The operator should mark the total time when the disturbing sound can be heard. Later, such events are identified in the CPX level time history and road segments where the CPX level is clearly higher than surrounding levels (where “clearly” may be 1,5 dB above the median CPX level), accompanied by flags of the operator, are disregarded in the evaluation. Then consider the likely possibility that the segment immediately before the flag is also disturbed, as it may take a second or so until the operator can decide whether he or she heard the vehicle or not. Another possibility is to automatically delete road segments associated with a flag and the segment immediately before it.

F.4.3 Flagging all or part of the passages of external vehicles

In this case, all events in passing and oncoming traffic when an external vehicle is in the vicinity of the CPX vehicle are flagged (by vicinity one may consider the closest exterior noise source being within 10 m of the microphones). Such road segments are then automatically disregarded in the evaluation. This option may of course remove data which are not significantly disturbed. To limit such unnecessary removal, the operator may use his or her experience and possible prior testing to avoid flagging events which are unlikely to affect the results. Wind gusts caused by ambient wind are impossible to detect in this option, but they may be negligible if a proper enclosure is used around the microphones and test tyres.

F.4.4 Monitoring external noise by a dedicated microphone

To identify the potential influence of noise from external sources, it is a good idea to add an extra microphone, placed appropriately, in order to monitor the noise in the system away from the test tyre. When the noise level in this microphone is less than 6 dB below that of the test tyre(s), then the CPX level of the road segment should be discarded.

F.4.5 Post-processing of CPX level time history

In this case, it is assumed that the noisiest events in the CPX level time history are caused by disturbances. These noisiest events are then detected in the time history by a suitable criterion and road segments representing these events are discarded in the final evaluations. A suitable criterion is that road segments having a CPX level that is more than 1,5 dB above the median CPX level of the test section (per run) may be considered as having been disturbed.

Annex G
(informative)

Application of the CPX method for surveying large road networks

G.1 General

This annex reviews the adaptation of some of the attributes in this document when implementing the CPX method for surveying large networks. Typical applications are the study of ageing effects on road surfaces, assessment of the state of maintenance, e.g. wear of and damage to surfaces, or the development of databases to help network managers in their strategies for road resurfacing.

The survey method is optional in this document, intended to be used in cases where the number of measurements or the distance travelled during all measurements is exceptionally high, e.g. when surveying a major part of the road network in a region or a country. In such cases, a simplified and more adapted procedure substantially reduces the time and cost spent on the measurements. This simplified version leads to less accurate results and should not be used for assessing compliance with legal or contract requirements, e.g. conformity of production.

G.2 Review of the network and definition of reference speed zones

A review of the network is strongly recommended prior to testing. Several speed limits may apply on the network and the corresponding zones of each reference speed should be defined, together with the lane to be tested.

Parts of the network on which the measurements may not be valid or possible should also be identified prior to the measurements, e.g. junctions, roundabouts, low-speed limit zones or roadworks.

G.3 Site conditions

The following site conditions need to be identified as they may have an influence on measurement results:

— Measurements performed in tunnels: reflections from tunnel walls are likely to increase background noise levels. Non-enclosed systems are vulnerable to this type of disturbance. Application of an enclosure has a remedial effect on this problem but cannot totally exclude it.

— Uphill slopes steeper than 1:20: in such situations the vehicle may be running with an engine load which is higher than during “normal” operation. This may lead to increased background noise levels. Non-enclosed systems are vulnerable to this type of disturbance. Application of an enclosure has a remedial effect on this problem but cannot totally exclude it.

— Curves inducing significant lateral forces: bends with a radius of curvature less than 250 m at 50 km/h and 500 m at 80 km/h may lead to lateral forces which can have significant influence on measurement results.

G.4 Meteorological conditions

The meteorological conditions can change significantly along the network and should be checked regularly during the measurements. It is recommended that measurements be avoided when:

— air temperature is below +5 °C or above +35 °C;

— wind speed exceeds 10 m/s on average.

For road wetness and for porous surfaces, reference is made to Annex F.

G.5 Number of runs

For very long networks, the repetition of runs is impractical in terms of measurement time and volume of data, and dramatically increases the cost of measurements. Therefore, only a single run is required for survey measurements. However, whenever it is acceptable in terms of time, volume of data and economical issues, more runs can be performed in order to increase the reliability and the completeness of results.

G.6 Choice of reference tyre

For survey measurements, only one reference tyre is required (P1)[2)], which normally should run in the wheel track closest to the edge of the road. Measurements in the other wheel track can be used to supplement the measurement data and improve the representativity of the measurements.

The use of the second reference tyre allows the surface properties related to both light and heavy vehicles to be considered and is therefore optional in the survey method.

G.7 Survey segment length

Data sampling on 20 m long segments when only one run is performed can lead to a poor reliability of the results (Reference [8]). Therefore, for survey measurements, the acoustic signal should be averaged over composite segments of a minimum length of 100 m averaging a minimum of five 20 m segments; see Annex B and Annex C for the averaging procedure. Segments which are dominated by road surface discontinuities should be omitted.

G.8 Localization of measurements

The synchronization of acoustic measurements with positional data is an important feature in the large network survey. It is recommended that the acoustic measurements be synchronized with GPS data. In this case, ensure that the accuracy of the system is better than or equal to 20 m. The accuracy of the GPS system should be checked prior to the measurements, e.g. by checking the GPS coordinates at certain fixed points such as bridges or major intersections.

G.9 Temperature measurement

The air temperature can change significantly over a day and along the network. It is recommended that it be measured continuously. In the case of intermittent measurements, they should be performed at least every 10 km. Locate the temperature sensor so that it is unobstructed and safe, and in such a way that it is exposed to the airflow and shielded from direct solar radiation. The latter may be achieved by a shading screen. The sensor shall be positioned 0,5 m to 1,5 m above road surface level. Measurement of surface temperature is optional.

G.10 Vehicle operating speed

In each reference speed zone, vehicle speed variation should not exceed ±10 km/h from the reference speed in each composite segment. When speed is adjusted from one speed zone to another, the composite segments subject to large speed changes should be omitted from the averaging. Other segments with strong acceleration or deceleration should also be identified and removed.

2) As specified in ISO/TS 11819-3. See the Introduction.

In some places, the traffic conditions can prevent the test vehicle from driving at the required speed without changing lane or overtaking. It is recommended that the way to treat this situation be decided prior to the measurements. For instance, data can be eliminated for the corresponding sections or the reference speed at which results are calculated can be adapted to the actual driving speed in the post-processing. The procedures for handling these issues should be stated in the report.

G.11 Output results

The final output is the CPX level averaged over composite segments covering a minimum length of 100 m, together with the corresponding reference speed.

G.12 Reliability

This is addressed in Annex K.

Annex H
(informative)

Application of the CPX method for other objectives

H.1 Procedure for acoustic labelling or classification

Acoustic labelling of road surfaces is most commonly performed using SPB measurements. However, in order to use an acoustic classification system of the type described in Reference [1], which addresses labelling and conformity of production assessment, the use of CPX measurements is required.

H.2 Procedure for studying sound pressure level variability and surface homogeneity of a test section (acoustic variability)

This annex gives guidelines for measuring the variability in tyre/road sound emission characteristics along a road surface test section. It is recommended that the tests and analyses be conducted as follows.

Measure the A-weighted sound pressure level (SPL) for the test tyre on each road segment in accordance with 10.2 and apply the data processing procedures specified in 11.1 to 11.3, with the addition of the following:

a) For each run, wheel track, speed and tyre combination, calculate the standard deviation of the SPLs for the segments. Report the arithmetic average of these standard deviations separately for each tyre type (Case A in 11.2);

b) If the SPLs are first averaged over all wheel tracks for each segment, calculate the standard deviation of the values for the segments. Report the arithmetic average of these standard deviations separately for each tyre type (Case B in 11.2).

Normally, both reference tyres should be used for this test. The averaged standard deviation, for each of the reference tyres t used in this study, is the final result describing the A-weighted sound pressure level variability, s_t, of the surface, expressed in decibels. This is considered to be an indication of road surface homogeneity.

The s_t value should be reported together with the length of the total test section and the reference speeds. The calculation method (A or B) shall also be stated in the report.

NOTE 1 Shorter segment lengths than the 20 m specified in this document give values more influenced by statistical sound pressure level fluctuations than by the relevant surface inhomogeneity, and longer lengths risk overlooking the inhomogeneities. A 20 m distance is also rather close to the effective travelled and measured road length when measuring maximum sound pressure levels according to the SPB method.

NOTE 2 It is often illustrative to include a graph showing the variation of $L_{\text{CPX:t},v_{\text{ref}}}$ along the test section, i.e. from segment to segment, for each reference tyre or (if possible) averaged for these tyres, see Figure 2.

Annex I
(informative)

Summary of measurement parameters

Table I.1 summarizes all major measurement parameters and their tolerances as specified in this document.

Clause 6 refers to the required accuracy of the systems used to measure these parameters.

Table I.1 — Summary of the most important measurement parameters

Parameter	Specified value	Tolerances	Alternatives
Reference conditions			
Reference tyres	P1 and H1	—	
Reference speeds	50 km/h, 80 km/h and 110 km/h	—	Alternative speeds may be used if required for technical, safety and legislative reasons
Reference air temperature	20 °C		
Measurement speeds			
Average test speed	Reference speeds	±5 %	
Actual speed per segment	Reference speeds	±15 %	
Frequency range	315 Hz – 5 000 Hz		
Tyre properties			
Inflation pressure	200 kPa	±10 kPa	
Load	3200 N	±200 N	
Tread depth	Refer to ISO/TS 11819-3		
Rubber hardness	Refer to ISO/TS 11819-3		
Microphones (see Figure 1)			
Number of positions	Two mandatory (1,2):		Four optional (3, 4, 5, 6):
Angle with respect to rolling direction	45° (1); 135° (2)	±5°	0° (4) ; 90° (3) ; 180° (5,6)
Height above road	0,10 m (1, 2)	±0,01 m	0,10 m (3); 0,20 m (4, 5); 0,50 m (6)
Distance from undeflected sidewall	0,20 m (1, 2)	±0,01 m	On tyre centreline
Distance from wheel axis (Figure 1)	0,20 m (1, 2)	±0,01 m	0 m (3); 0,65 m (4, 5); 0,80 m (6)
Weather conditions			
Wind speed	< 5 m/s	—	
Air temperature	5 °C to 30 °C	—	Up to 35 °C in climates where average temperatures are >30 °C

Annex J
(informative)

Validity and stability of the method

J.1 General

The CPX method has limitations regarding the validity, which result in uncontrolled systematic uncertainties in the following respects:

— the measured characteristics are restricted to only tyre/road noise; power unit noise is not considered;

— there is limited representativity for surface influence on light vehicle tyre/road noise, due to the use of only one test tyre (P)[3], although this tyre is selected based on its good correlation with noise emission of a fleet of light vehicle tyres on a range of surfaces;

— there is medium representativity for surface influence on heavy vehicle tyre/road noise, since heavy vehicle test tyres are not used at all. However, one of the test tyres (H)[4] is selected in order to represent the acoustic response to road surfaces of heavy vehicle tyres in an approximate way;

— there may be a lack of representativity of lateral and longitudinal forces applied to the tyres during testing compared to tyres on vehicles in operation;

— the selected microphone positions are partly representative of the far-field noise emission;

— sound propagation effects are not accurately comprised.

This method is valid only in cases when vehicles in the traffic travel at a constant speed of 40 km/h and upwards. It has been found that in such cases tyre/road noise dominates vehicle noise emission and power unit noise is of limited importance. In other cases, power unit noise may be a major part of the overall noise emission and the values obtained with the CPX method are representative of only a smaller part of the overall noise. On roads with high longitudinal gradients and a high proportion of heavy vehicles, interpretation of the results may also be questionable, since power unit noise may be significant and longitudinal forces on drive axle tyres may cause excessive tyre/road noise.

NOTE 1 Here, light vehicles is category 1 and heavy vehicles is category 2 according to ISO 11819-1.

NOTE 2 In regions outside Europe and East Asia, where vehicle noise standards are less stringent, power unit noise of heavy vehicles has higher importance and the representativity of this method is low at low speeds (<50 km/h) as well as at medium speeds (50 km/h to 70 km/h) when heavy vehicle proportion is higher than approximately 10 %.

J.2 Selection of test tyres

Two reference tyres are used in this method. Although they have been selected with representativity of tyre/road noise of a fleet of vehicles in actual traffic in mind, noise emission from only two tyre types is never fully representative of the tyre/road noise of actual traffic. One of the reference tyres has been chosen in order to represent as well as possible the characteristics of tyre/road noise from light vehicles, primarily cars.

3) Refer to ISO/TS 11819-3; see the Introduction.

4) Refer to ISO/TS 11819-3; see the Introduction.

The method obviously relies on only car tyres for testing. It is shown in References [2], [3], [9] that the road surface influence on traffic noise emission for a fleet of cars is not well correlated with that of a fleet of heavy vehicles. It follows that a method using tyres representative of a fleet of cars is not useful for characterizing heavy vehicle traffic noise emission. However, the surface influence of heavy vehicle traffic is rather small – only about half that of light vehicles. It follows that if heavy vehicles do not dominate overall noise, represented by the measure L_{eq}, which is commonly the case in Europe and East Asia, surface influence due to heavy vehicles is rather limited and mainly tends to somewhat reduce surface influence on overall noise.

This method attempts to address the heavy vehicle problem by selecting one of the reference tyres with heavy vehicle influence in mind. Tyre H1[5)], although its dimension fits larger cars, is manufactured to be a light truck tyre. By its special tread pattern, this tyre has empirically been found to give a surface influence which is reasonably similar to that of heavy vehicle traffic (References [2], [3], [9]).

In some countries or regions, studded tyres are used in winter. Studded tyres interact with road surfaces in a very different way to non-studded tyres. When studded tyres constitute a substantial proportion of the tyre fleet, it therefore means that road surface classification is different from that of non-studded tyres. As it is difficult to find or define studded tyres with reproducible properties over a long period, the effect of studded tyres is neglected in this document. For countries that find this unacceptable, definition of a supplementary procedure and supplementary reference tyre(s) with studs are required.

J.3 Representativity of new versus worn and aged tyres

During its life cycle, a tyre undergoes degradations due to mechanical wear and chemical ageing, which affect not only durability and safety, but also tyre/road noise emission and rolling resistance. Tests have shown that the wear and age effect is relatively low on smooth-to-medium-textured surfaces but dramatic (noise increased with wear) on rough-textured surfaces and high but opposite on an extremely smooth surface (Reference [6]).

It follows that classification of road surfaces is different if worn rather than new tyres are used. To represent real traffic, the use of a mix of new and worn tyres is therefore preferred. However, at the time of publication, the specification of worn tyres in a reproducible way is not possible. Therefore, in this document, it is accepted that the representativity of results in relation to roads with real traffic has the mentioned disadvantage.

J.4 Microphone location

The number and location of microphones is always a compromise. The selected mandatory locations in this method are very close to the optimum positions for two microphones according to Reference [10]. If four rather than two microphones had been chosen, i.e. two microphones on each side of the tyre, the uncertainty in relation to pass-by measurements at 7,5 m from the traffic flow could have been reduced by some 30 %, but this would at the same time have created problems in terms of space and economy, which would have made the method less suitable. By using the additional microphones according to Figure 1 and Table 2, the representativity increases, but it also puts much more severe requirements on the test equipment in terms of space, etc.

Finally, since the method measures sound in the near field, the noise-reducing effect of porous surfaces arising from sound absorption during propagation close to the porous surface from the source to the receiver is not fully addressed. Generally, sound pressure levels on porous surfaces are overestimated in relation to dense surfaces, when utilizing the CPX rather than the SPB method. This problem is discussed further in Annex D.

5) Refer to ISO/TS11819-3; see the Introduction.

J.5 Stability of measured results

Despite the various validity problems discussed in J.1 to J.4, the method also has major advantages which makes it suitable in many applications, see Annex D.

Stability with time of this method is good in some respects and poor in others. The reference tyres are assumed to have relatively stable noise emission characteristics, provided they are properly stored and exchanged at suitable intervals[6)]. This ensures that results of measurements made many years apart and perhaps in different parts of the world are comparable.

Yet the experience is that without the control required in this document, variability related to tyres, in combination with meteorology, is a huge problem. Without observing these tyre-related requirements and recommendations, as well as weather-related influences, the CPX method is almost useless.

Another aspect of time influence is that the fleet of vehicles and the fleet of tyres used on them changes with time, and such an effect cannot be picked up with this method. This may be both an advantage and a disadvantage. If *representativity* of actual traffic noise is of primary concern, it is necessary to consider the effect of changes with time in tyre design for tyres used in actual traffic; in particular, to study if such effects significantly affect the surface influence.

6) Refer to ISO/TS 11819-3; see the Introduction.

Annex K
(informative)

Measurement uncertainty

K.1 General

The result of the application of the procedure described in this document is subject to disturbance by several factors and processes. The cause and nature of these disturbances are either known, but randomly distributed in an uncontrollable way, or are of a systematic nature, but affect the result in an unpredictable way.

In accordance with ISO/IEC Guide 98-3, the effects are evaluated on the base of their contribution to the combined standard uncertainty and then a coverage probability is defined, resulting in a coverage factor k by which the combined standard uncertainty is multiplied, yielding the expanded uncertainty.

K.2 Expression for the calculation of the CPX level

The general expression for the determination of the CPX level is given by Formula (13).

K.3 Sources of uncertainty

K.3.1 δ_1. The measurement procedure assumes driving at the reference speed with test tyres located in the wheel track. The sound pressure levels ideally are recorded on the basis of its equivalent level during the total length of the segment. In reality, deviations from these conditions occur. Speed deviations can partly be corrected for; other sources of deviations cannot be corrected for. Segments subjected to disturbing noise are removed from the analysis.

K.3.2 δ_2. The equipment used for measuring the sound pressure level, the air temperature and the vehicle speed exhibit limited accuracy. Although calibration of the sound measuring chain limits the error, it does not cancel out a residual error.

K.3.3 δ_3. The environmental conditions are assumed to be a temperature of 20 °C and a road surface in dry and debris free condition. In reality, deviations from this situation occur. A correction procedure for deviating temperature is given, but the coefficient may be different for other road surfaces as the reference.

K.3.4 δ_4. The effect of disturbing noise is limited with the requirement of a signal-to-noise ratio of 8 dB, but still affects the overall result, especially since detection of disturbed segments is based on an increment of 3 dB. Non-enclosed systems are vulnerable to this type of disturbance. Application of enclosure has a beneficial effect on this source, but cannot totally exclude it.

K.3.5 δ_5. The test vehicle or towing vehicle may give unwanted contributions due to reflections from the vehicle structure and enclosure and to rolling noise and propulsion noise from the (towing) vehicle. Although the device specific correction covers most of the systematic effect, a residual effect remains.

K.3.6 δ_6. The selected reference tyre may change its properties with time and wear. Some of these properties depend on temperature and stiffness of the rubber, but these are compensated for by the correction procedures. There is also a certain spread in noise properties between different samples of the same tyre type.

NOTE The input quantities in Table K.1 to allow for uncertainties are those thought to be applicable according to the state of knowledge at the time of publication of this document, but further research could reveal that there are others.

In K.4, an example is given for a typical measurement of a road section and with a system meeting the requirements stated in the main body of this document.

K.4 Estimation of uncertainties

In the procedure in this document, the sources of uncertainty and the resulting spread in the end result listed in Table K.1 can be distinguished. For information about the interpretation of the probability distributions, refer to ISO/IEC Guide 98-3. The terms “enclosure” and “no enclosure” refer to the type of test vehicle (trailer or self-powered, according to Clause 9).

Table K.1 — Typical values of standard uncertainties due to variations in measurement equipment, operating conditions and environmental conditions

Sources of uncertainty	Estimate	Probability distribution	Sensitivity coefficient	Uncertainty contribution
Measuring procedure (speed variations, stability of measurement system, lateral tyre position)	0	normal	1	0,2 dB
Uncertainty in equipment (calibrator, sound measuring system, speed measuring system)	0	normal	1	0,3 dB
Effect of environmental conditions (after correction for temperature)	0	normal	1	0,3 dB
Background noise from external sources	0	asymmetric	1	0,1 dB (enclosure) 0,2 dB (no enclosure)
Background noise/reflection from the measuring vehicle, geometry of mic. positions	0	partly asymmetric/partly normal	1	0,2 dB (enclosure) 0,1 dB (no enclosure)
Combined standard uncertainty				0,5 dB (enclosure) 0,5 dB (no enclosure)

The total spread in measurement results expected in this procedure leads to the expanded uncertainties listed in Table K.2.

Table K.2 — Typical values for the expanded uncertainty in this document

Coverage probability	Expanded uncertainty
80 %	0,7 dB
95 %	1,0 dB

With regard to the tyre uncertainty contribution, δ_6, refer to ISO/TS 11819-3 for the quantity to include in this calculation. If other tyres than specified in ISO/TS 11819-3 are used, this quantity needs to be specified by the user.

NOTE 1 The estimates are essentially based on an experiment reported in Reference [11], where only two-wheeled CPX trailers were used, and measurements were made in both wheel tracks and averaged.

NOTE 2 The two largest sources of uncertainty are the uncertainties in the measuring equipment for sound and speed and the effect of environmental conditions, mainly wind effects. It has been assumed in this calculation that the temperature effect on noise emission from the test tyres is known.

NOTE 3 The effect of variations within the population of reference tyres is not included in the calculation[7].

7) These uncertainties are estimated in ISO/TS 11819-3; see the Introduction.

K.5 ISO 5725-2 Guide to laboratories on how to express measurement uncertainties

K.5.1 Repeatability. Refer to ISO 5725-2 for estimation of the intra-laboratory spread in measurement results.

K.5.2 Reproducibility. Refer to ISO 5725-2 for estimation of the inter-laboratory spread in measurement results.

K.6 Uncertainty of the survey method described in Annex G

The uncertainty of the survey method, as described in Annex G, according to the procedure described in Reference [8], is estimated to be:

Repeatability limit

$r = 1$ dB

Reproducibility limit

$R = 2$ dB

NOTE The estimates above are based on experiments where the tyre contribution to uncertainty is included (which is not the case in K.4) and where only one wheel track was measured. If both wheel tracks would be measured and the results averaged, the uncertainty estimates would become lower.

Annex L
(informative)

Reference road surface

L.1 General

When reporting the measured result for a certain road surface, it is common to compare it to some reference case, i.e. the corresponding results measured on a surface type which is considered as being a reference surface. This annex contains recommendations regarding the choice of such surfaces, in order to avoid the use of very different references.

A virtual reference surface concept was defined in the EU HARMONOISE project (Reference [13]) which developed a prediction model for predicting noise emission and immission from road and railway traffic. In this one, a reference case was defined, including a reference surface. The surface was chosen to be an average of a DAC and an SMA surface, each one having a maximum aggregate size of 11 mm and with an age of at least one year. The reason for this choice was that either an SMA or a DAC surface with approximately 11 mm maximum aggregate size is very common, and rather easy to find, in each of the European countries. Certain corrections were introduced in cases where the 11 mm aggregate size is difficult to find, enabling maximum aggregates from 10 mm up to 16 mm to be used, plus correction for age. This allowed the use in a particular case of an actual reference surface which deviated slightly from the reference, provided corrections were applied to account for the deviations from the ideal and virtual referenced. The procedure, including the corrections to bring an actual case to the virtual reference case, is described in some detail in Reference [14].

Later, the same concept was taken over by the IMAGINE project and is also the concept used in the European method according to the CNOSSOS project (Reference [15]).

The options in L.2 to L.4 apply.

L.2 Virtual reference surface

The reference surface is a surface not existing as such in reality, but being considered as an “average” of a DAC and an SMA surface with a maximum aggregate size of 11 mm. Ages shorter than one year should be avoided; also the surface should not be old enough to be subject to ravelling, cracking or other mechanical defects. The virtual reference case depends strongly on the representativity of the actual reference surface used in relation to its nominal values. When this concept is used the procedure is as specified in a) to d).

a) In the series of measurements considered, make sure that at least one surface which is as close in construction and condition to the virtual reference surface as possible is measured (either DAC or SMA; maximum aggregate size shall be between 10 mm and 16 mm, ideally 11 mm; its condition shall be good but not new).

b) Use the correction procedure in Reference [14] to determine what the nominal noise level difference (correction ΔL_{ref}) is between the actual reference used [as identified in L.2 a)] and the virtual reference surface.

c) Apply this correction to the measured level(s) of the actual reference surface used and use these corrected level(s) as the level(s) representing the virtual reference surface (be careful to use the correct plus or minus sign).

d) Using the virtual reference surface as a zero reference level in decibels, all other similarly measured surfaces can be compared to this one, presented as a difference in noise level compared to the virtual reference surface (i.e. a noise reduction).

L.3 Normalized reference case

The reference surface is a fictitious surface on which the levels L_{CPX} for each reference tyre are defined by convention. This can, for instance, be based on the average results of a great number of CPX measurements on asphalt concrete surfaces, after which a certain level is decided upon which would represent this case; corrected to the reference temperature 20 °C. The reference surface is then an average of all surfaces included in the test. The normalized reference case depends strongly on the stability of the reference tyres and accuracy in correction for temperature.

L.4 Arbitrary reference case

The reference surface is any arbitrary surface, other than above, that the testing organization selects. In this case measurements are useful only for comparisons between the particular, selected surfaces.

L.5 Conclusion

The virtual reference case (L.2) has the advantage of being aligned with the HARMONOISE, IMAGINE and CNOSSOS methods for noise prediction, used European-wide. As is pointed out in Reference [14], this reference case is also close to references used in the Nord2000 (Reference [12]), as well as in Japanese and US prediction models, which makes it suitable for worldwide use in cases wherever the use of a reference is of interest. If this case is used, whenever a noise reduction is calculated, the results are reasonably comparable worldwide.

Annex M
(informative)

Calculation of close-proximity sound indices

In order to obtain an aggregate (overall) level of road surface influence on traffic noise for a mix of tyres and vehicles, a CPX sound index ($L_{CPX:I}$) may be calculated for a certain speed v_{ref} as follows:

$$L_{CPX:I,v_{ref}} = 0{,}50 L_{CPX:P,v_{ref}} + 0{,}50 L_{CPX:H,v_{ref}}$$

where

$L_{CPX:P,v_{ref}}$ is the CPX level representing light vehicles in the traffic stream at reference speed v_{ref}, determined using test tyre P (refer to ISO/TS 11819-3; see the Introduction);

$L_{CPX:H,v_{ref}}$ is the CPX level representing heavy vehicles in the traffic stream at reference speed v_{ref}, determined using test tyre H (refer to ISO/TS 11819-3; see the Introduction);

$L_{CPX:I,v_{ref}}$ is the CPX index representing noise from mixed traffic at reference speed v_{ref}.

The reporting of $L_{CPX:I,v_{ref}}$ is optional, but recommended, in order to facilitate the comparison of measured values.

NOTE 1 The weighting factors used to calculate the $L_{CPX:I,v_{ref}}$ have been chosen in order to represent a mix of light and heavy traffic with equal contributions of tyre/road noise from light and heavy vehicles. This is approximately the case for a highway with 80 % light vehicles and 20 % heavy vehicles (80 km/h for all vehicles assumed) or a motorway with 75 % light vehicles and 25 % heavy vehicles (115 km/h for light and 85 km/h for heavy vehicles assumed). See further Reference [12].

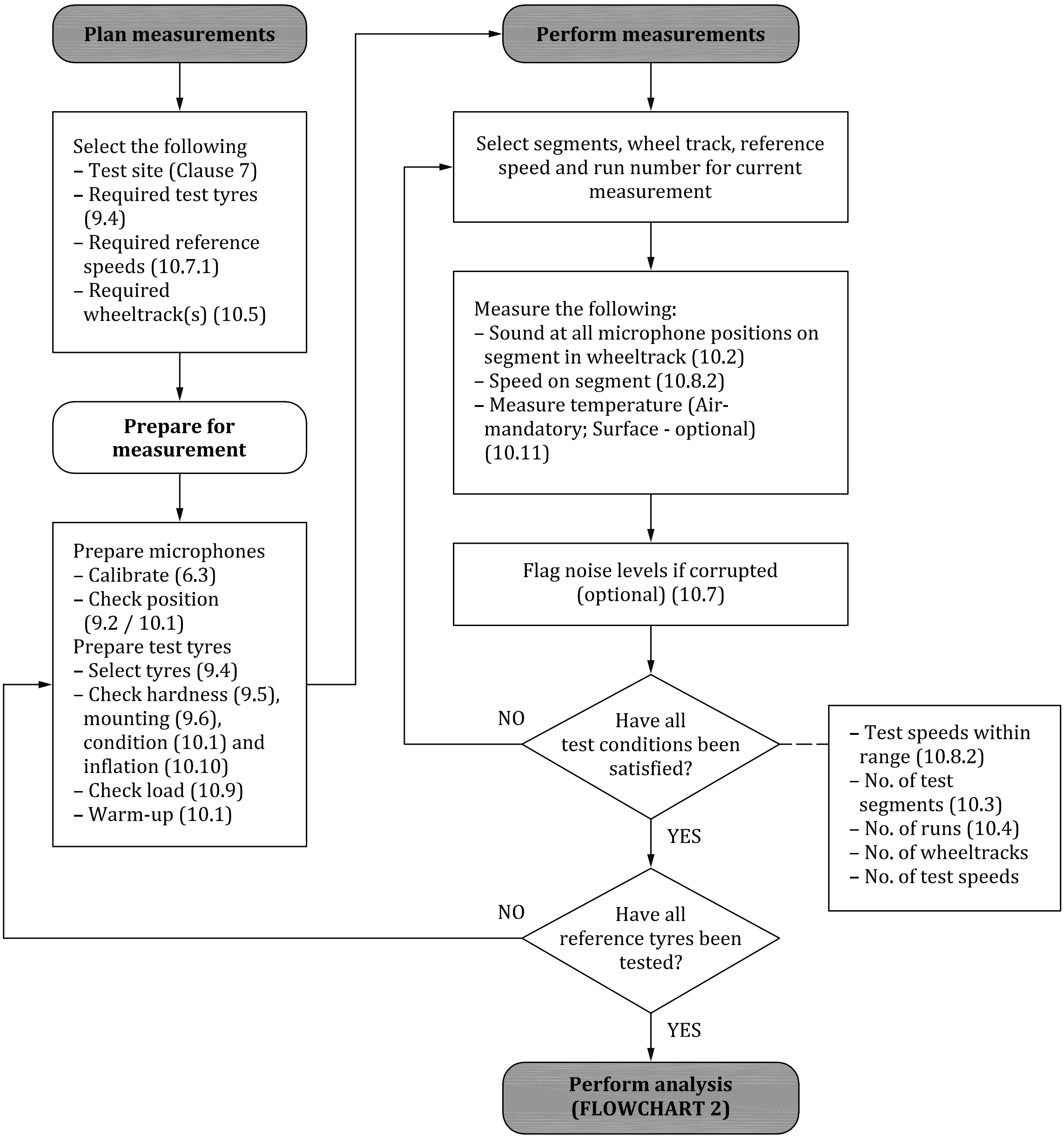
NOTE 2 The CPX index $L_{CPX:I,v_{ref}}$ is not an equivalent level, L_{eq}, of traffic noise, but can be used to rank different road surfaces. For example, in many cases, the main use of the $L_{CPX:I,v_{ref}}$ is to compare a certain surface with a reference surface according to Annex L (L.2), and to present the result as a difference value. $L_{CPX:I,v_{ref}}$ and the corresponding index (SPBI) measured with ISO 11819-1 are not numerically equal.

Annex N
(informative)

Summary of measuring and data-processing procedures

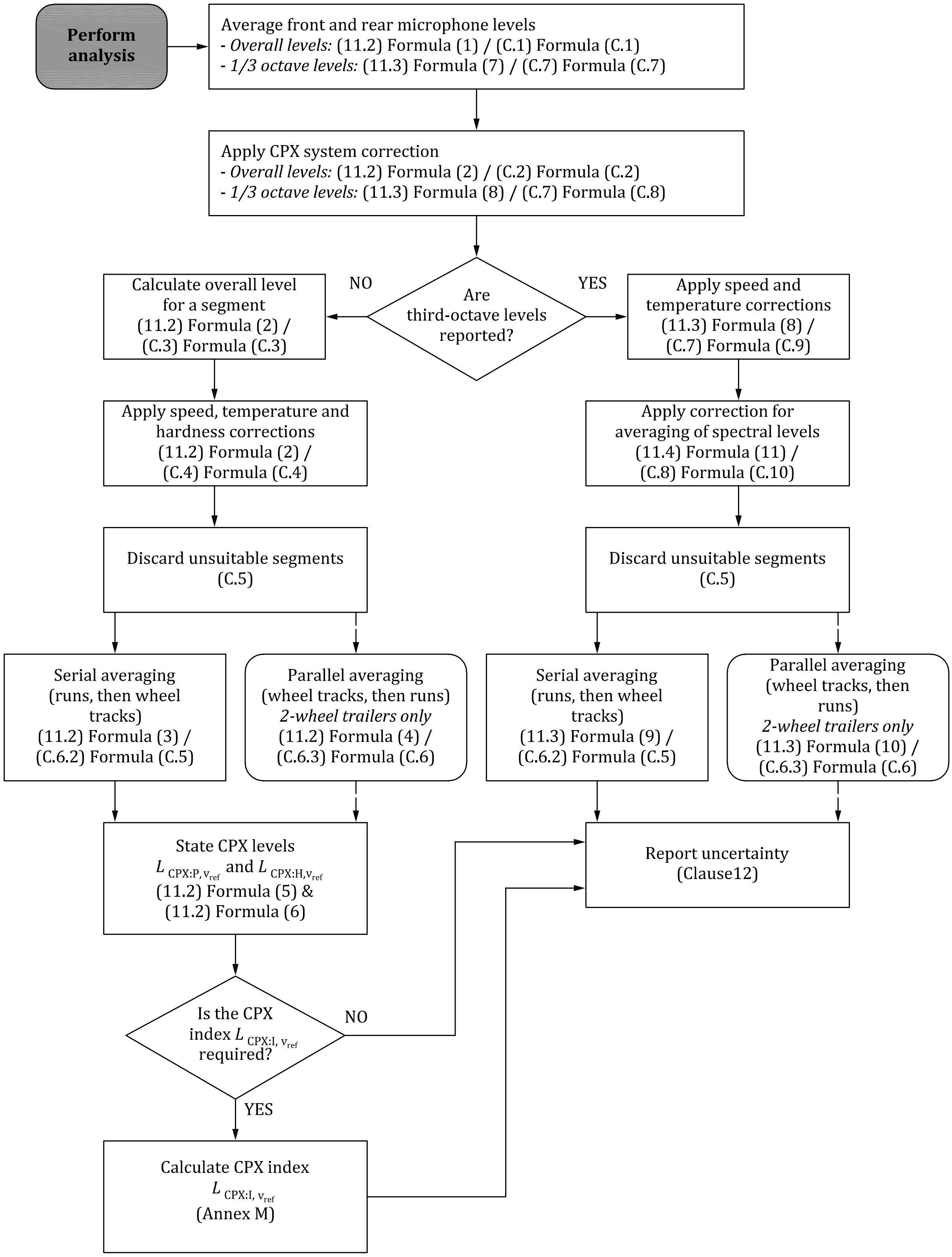
Figure N.1 and Figure N.2 are flowcharts illustrating the measurement and data-processing procedures, respectively. Figure N.1 illustrates the most common types of measurements, albeit not necessarily all types possible according to this document. The order of calculating averages may not necessarily be that in Figure N.2; other orders are also possible without obtaining significantly different results.

Figure N.2, together with Formulae (1) to (11), or (C.1) to (C.11), may be useful as a model for making automatic or semi-automatic data processing by use of an onboard computerized data processing system.



NOTE The numbers refer to the corresponding subclauses.

Figure N.1 — Flowchart 1, illustrating measurement procedures



NOTE The numbers refer to the corresponding subclauses.

Figure N.2 — Flowchart 2, illustrating the analysis procedures

Annex O
(informative)

Example of test report

This annex shows an example of how a test report may appear. An attempt has been made to include most options in it. In certain cases, it is possible to remove items from the report which are not mandatory and not applicable to the tested case.

TEST REPORT FOR MEASUREMENT OF THE INFLUENCE OF ROAD SURFACES ON TRAFFIC NOISE WITH THE CLOSE-PROXIMITY METHOD

General information

1. ***Date and time of measurements:*** 2009-11-18. Start 09:00; finish 11:25
2. ***Organization/operators responsible for measurements:*** Technical University of Gdansk (J. Ejsmont) and Swedish Road and Transport Research Institute (U. Sandberg)
3. ***Purpose of the measurement:*** General survey

Type of measuring equipment

4a. Test vehicle: One-wheeled trailer towed by car (user designation of test vehicle: TUG Trailer, Mark III)

4b. Test tyres: Reference tyres P1 and H1

4c. Noise measuring system: B&G 5788 system

4d. Calibration equipment: B&G type 4157

4e. Speed measuring equipment: Metrilogic type 97AB

4f. Meteorology equipment: Thermometric type D34

4g. Microphones used: Positions 1 and 2

4h. Certification of test vehicle: Refer to TRL report no. XXX

Information relating to the location and appearance of the test site

5a. Location of test site: 27,5 km from exit Kaparp on road RV34 running south from Linkoping, Sweden

5b. Posted speed limit: 90 km/h

5c. Longitudinal gradient: 1:100

5d. Crossfall: 2 %

5e. Site plan: See enclosed Figure X1 (not shown in this example but assumed to be added in the report)

5f. Total measured distance: 300 m

5g. Start position: Add GPS data

5h. End position: Add GPS data

5i. Lateral measurement position on road: Lane 1, left wheel track only

Information relating to the type and construction of the tested surface (where available)

6a. Type of surface and its design parameters: Single surface dressing, Swedish designation Y1 (12-16)

6b. Thickness of surface layer: N.A. (thickness of one layer of chippings: ≈ 16 mm)

6c. Maximum chipping size: 16 mm

6d. Residual air voids content: Not measured

6e. Sound absorption coefficient according to ISO 13472-1***:*** Not measured

6f. Representative photo of the surface: See Figure X2 (not included in this example)

6g. Texture depth (MPD) according to ISO 13473-1***:*** 1,52 mm

6h. Work recipe for surface: Not available

Information concerning condition of the tested surface and environmental factors (if available)

7a. Age of surface and state of maintenance: 4 years, significant rutting in wheel tracks

7b. Any special surface treatment: None

7c. Any notes regarding the homogeneity of the surface: None

7d. Number of days since the latest precipitation: 2 days before measurements (surface is not porous)

7e. Average air and road surface temperatures over the test section: 22 °C (air) and 28 °C (road)

7f. Temperature correction coefficients used: −0,1 for both tyres

Test tyre and other test conditions

8a. Test tyres used, identification of tyre and date of manufacture: Tyre P1, DOT number XXXXXX, manufactured Week 27 2011. Tyre H1, DOT number ZZZZZZ, manufactured Week 2 2011.

8b. Rubber hardness of the test tyres (no more than three months old): 64 for P1, 66 for H1

8c. Number of runs on which the L_{CPX} ***is based:*** 2 runs

8d. Reference speed used: 80 km/h

8e. Actual measured test speeds as an average over the test section: See primary test protocols

Measured and calculated sound pressure level data

9a. L_{CPX} ***values (at 80 km/h)***:

L_{CPX} ***for tyre P1 =*** $L_{CPX:P1,80}$ **=** 91,2 dB

L_{CPX} ***for tyre H1*** = $L_{CPX:H1,80}$ **=** 93,1 dB

9b. $L_{CPX:I,80}$ ***(at 80 km/h) =*** 92,2 dB

9c. Acoustic variability, s_t***, of the surface:*** 0,8 dB for tyre P1 and 1,1 dB for tyre H1

9d. Expended uncertainty of the L_{CPX} ***values (estimation for 95 % coverage):*** 1,0 dB for both tyres

Others

10. Speed constant, B, used for speed corrections: 30

11. Details of special provisions taken to ensure conformity with ISO 11819-2***:*** None

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