Implementation of measurement uncertainties into vehicle noise regulation

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ABSTRACT

The current vehicle noise regulation UN ECE Reg.51.03 does not specify measurement uncertainties related to the measuring method for external pass-by noise. The core of the measurement method is based on ISO 362-1. For ISO standards in general, it is mandatory to include a detailed description of the expected uncertainties. This principle in ISO standards can be used for implementation in UN ECE regulations. With the introduction of the EU Market Surveillance directive ((EU) 2018/838), there is a need to understand the impact of third-party testing of vehicles against noise limits. Therefore, the UN ECE Working Party on Noise and Tyres (GRBP) in Geneva established an Informal Working Group on Measurement Uncertainties (IWG MU) in 2019, to evaluate and propose an implementation of uncertainties into noise regulations starting with UN ECE Reg.51.03 and UN ECE Reg.117 (tyres). This paper describes the principal work of the IWG concerning the contribution of the different quantities to the overall expanded uncertainties when testing vehicles according to the specifications in UN ECE Reg.51.03. The identified main contributors to the overall measurement uncertainty are variations due to the test track surface (site-to-site) and air temperature effects (day-to-day).

1. INTRODUCTION

International regulations for external noise emitted by road vehicles are primarily established by UN Economic Commission for Europe (UN ECE) in Geneva. The present regulation for the maximum permissible sound level for M and N vehicle categories is UN ECE Reg.51.03 [1]. This regulation corresponds to the EU regulation 540/2014 EU [2]. The test method and maximum sound levels are defined in these regulations. The measuring method is based on ISO 362-1 (outdoor) and ISO 362-3 (indoor). These ISO standards have recently been revised to correspond with latest amendments of Reg.51.03 concerning testing and data evaluation.

UN ECE Reg.51.03 is the basis for type-approval (market access) of vehicle types and conformity of production (COP). In both these test conditions, the vehicle manufacturer in agreement with the type-approval authority has a reasonable control of the measurement conditions, such as the selection

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of test track, preparation of test vehicle, test equipment, test crew and to a certain extend tyres and environmental condition. This ensures that major measurement uncertainties due to run-to-run, day-to-day and site-to-site variations are known. By this, the variability of the test results variation is low and known to vehicle manufacturer and technical service.

In 2018, EU adopted the market surveillance directive 858/2018 EU [3]. With this directive, third-party testing of sound and emissions of road vehicles is required. With such testing, the vehicle manufacturer and the original type-approval authorities no longer have an influence on the verification process inclusive on the selection of vehicle, tyre conditions, test site, etc.

Therefore, measurement uncertainties have become highly relevant, to ensure that any third-party testing of noise from road vehicles has recognized the possible contribution of different quantities during testing, to the overall expanded uncertainty.

2. INFORMAL WORKING GROUP ON MEASUREMENT UNCERTAINTIES

Since 2019, the UN ECE Working Party on Noise and Tyres (GRBP) is running an Informal Working Group on Measurement Uncertainties (IWG MU), with Norway acting as the chair (Mr. T. Berge) and the World Automobile Manufacturers Association (OICA) as the secretariat. The prime aim of the working group is to propose harmonized measures for evaluating systematic and random errors and to provide proposals for amendments to existing Regulation improving the test procedures for at least UN ECE Reg.51 and UN ECE Reg.117 [4] (tyre rolling sound chapter only), to reduce measurement uncertainties.

The main objectives are:

- IWG MU shall develop and propose harmonized measures for evaluating systematic and random errors based on ISO GUM 98-3 [5].
- The scope and purpose should cover at least UN ECE Reg.51 and UN ECE Reg.117. IWG MU shall develop harmonized technical requirements for these UN Regulations with consideration to their test protocols.
- IWG MU shall, where appropriate, develop a practice guide for compensation and/or correction factors.
- A general approach shall then be made in such way that it is possible to use it to improve test procedures in other UN Regulations. This approach could be either documented in the Consolidated Resolution on Construction of Vehicles (R.E.3) or as a “Document for Reference”.

According to the original timeline, the first draft of the general concept and strategy for approach was requested for GRBP during its 71st session in January 2020 and finalised work on amendments on UN ECE Reg.51 and UN ECE Reg.117, as well as the development of a Document for Reference within the 73rd session of GRBP in January 2021[6].This timeline has been modified at several stages, mainly due to the pandemic situation since 2020. This pandemic placed severe hindrance to perform tests and development of procedures to reduce the measurement uncertainties within the expected timeline.

Nevertheless, the Informal Working Group was able to present a first set of amendments to UN ECE Reg.51, which were adopted during GRBP in September 2021 [7] and January 2022 [8]. Presently, the work based on the above objectives is continued with the plan to be finalized by September 2023, at the 78th session of GRBP [9]. GRBP extended the scope for the Informal Working Group to enable an evaluation of other regulations concerning sound emitted by road vehicles, like UN ECE Reg.138 and UN ECE Reg.41. This will prolong the work beyond the 78th session. In addition to the amendments of UN ECE Reg.51 and UN ECE Reg.117 and the Document for reference [10], the Informal Working Group is currently working on a strategy how to implement measurement uncertainty into regulations (see chapter 6).

3. PRINCIPLE OF MEASUREMENT UNCERTAINTIES

Measurement procedures are always affected by factors causing disturbances leading to variation in the results observed on the same subject. The source and nature of these perturbations are not completely known and affect the end-result in a non-predictable way.

A measured result shall be understood as an approximation to the true result, which by itself is unknown.

- *Two measurements are deemed to provide the same result if their test results are within a given uncertainty.*

Thus, the knowledge of the measurement uncertainty is important as it provides information about the precision and repeatability of measurements.

It is important to minimize the uncertainties, e.g. by controlling ambient and test conditions either by narrowing the control range or by corrections. The residual uncertainty shall be covered by tolerances.

Sources of errors in measurements have many origins such as ambient condition variations, limitations in the sensitivity of the instruments (inclusive laboratory) or from imperfections in experimental design or measurement techniques (inclusive test crew skills). Errors are classified as random or systematic:

Random errors, which cannot be compensated for

They are always present and are from operator approximating a reading and changes in the experimental conditions. There is equal probability that the reading will be too high or too low. To minimize random error, repeated measurements are taken, and the average or mean is calculated. If the same operator gets the same results, the results are said to be reproducible, see Figure 1. Recording the precision or uncertainty is one way of representing random error:

m*easurement* ± *random error*

Systematic errors, which can be compensated for

These are typically present and are from variations in instruments, technology and operator skill. To minimize systematic errors, carefully inter-test track variations shall be minimized, instruments selected which can be calibrated, and the operator is experienced and uses the best techniques. Systematic errors lead to bias, moving the measurements away from the true value in one direction or the other, see Figure 1. Recording the bias can be represented as:

m*easurement* + *systematic error* or *measurement* – *systematic error*

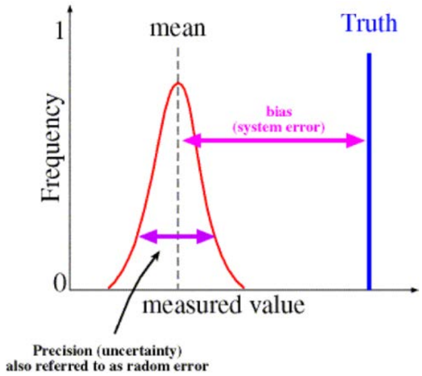

Figure 1: Graphical representation of random and systematic error.

In Figure 1, the bias is *measurement – systematic error*. Normally, only the uncertainty is reported. Systematic errors are dealt with only if the true value is known and then the % error can be calculated and discussed. *It should be noted that in the field of road vehicle noise, the "true value" is also subject to greater variations*.

Precision and accuracy in measurements

Precision reflects how reproducible the measurements are while accuracy reflects how close the measurements are to the true value. Ideally, we aim for both precision (smaller random errors) and accuracy (systematic error).

4. HOW TO HANDLE MEASUREMENT UNCERTAINTIES

4.1 General approach

To reduce measurement uncertainty, the following approach is recommended:

A. Avoidance of uncertainties

Normally, a regulation/measuring method defines certain control ranges within which the measurements shall be performed. It is important to understand the possibilities to reduce uncertainty by limiting the control range. A very narrow control range reduces uncertainty but becomes less representative for the full range.

As an example, measurements according to UN ECE Reg.117 on rolling sound shall be performed within a test track surface temperature between +5 to + 50 °C. In reality the surface temperature can range from -45°C up to more than 70°C (when classical asphalts start to melt). The limited control range enables the application of a temperature correction, which is in the given example done to 20°C.

B. Use of compensations (reducing systematic errors)

Staying with the UN ECE Reg.117 example, the measured sound level at a certain surface temperature shall then be corrected to a reference temperature of + 20 °C, based on a defined correction between road surface temperature and measured sound level. However, the temperature correction by itself is only an approximation as tyres have very different temperature sensitivity under rolling sound. Most accurate would therefore be testing close to 20°C which narrows the practicability in performing tests.

C. Use of an uncertainty model

As there is never a "true" value for the final result, there is a need to use an uncertainty model to define the tolerances (as expected residual variance) of the measured value which can neither be further reduced by narrowing of the control range or by compensations. Such uncertainty models are defined in ISO 5725 [11] and in the ISO/IEC Guide 98-3 (GUM) [5].

D. Repetition of measurements

In a regulation/measuring method, a certain number of repetitions of a test condition can be defined, as a mean to reduce uncertainties. Therefore, by repeating measurements under equal boundary conditions, using the mathematical average of the measurement results help to improve the uncertainty, as the influence of random errors will be reduced. An example of this practice is the use of four measurement runs in UN ECE Reg.51.03, which are then mathematically averaged. The principal steps of how to handle measurement uncertainties are thoroughly described in the Document for Reference [10].

4.2 Stages of uncertainty evaluation

There are in principle two stages to consider:

1. The formulation stage:

a) defining the output quantity *Y* (the measurand)

b) identifying the input quantities on which *Y* depends

c) developing a measurement model relating *Y* to the input quantities

d) on the basis of available knowledge, assigning probability distributions – Gaussian, rectangular, etc - to the input quantities (or a joint probability distribution to these quantities that are not independent)

2. The calculation stage consists of propagating distributions for the input quantities through the measurement model to obtain the probability distributions for the output quantity *Y* and summarizing by using distribution to obtain:

a) the expectation of *Y*, taken as an estimate *y* of *Y*

b) the standard deviation of *Y*, taken as the standard uncertainty of $\mu(y)$ associated with *y*

c) the coverage interval containing *Y* with a specific coverage probability.

The procedure used in the evaluation of the uncertainties in UN Regulation No.51 is based on the GUM principles and the theoretical approach of this procedure is described in [5,10].

In Figure 2, a flowchart of the principal stages for uncertainty calculations is shown [12].

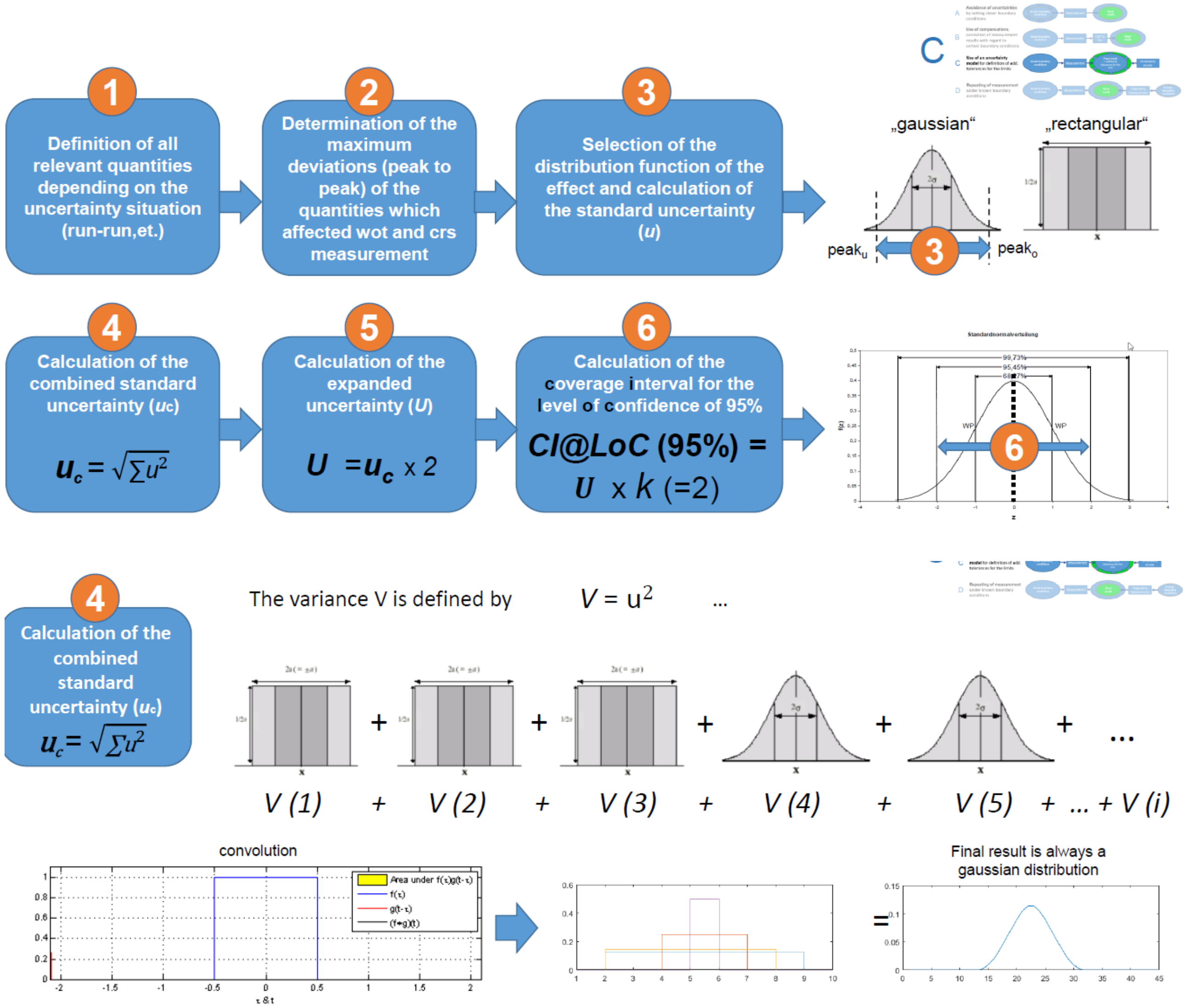

Figure 2: Flowchart for calculation of measurement uncertainties [12]

5. EVALUATION OF THE UNCERTAINTIES IN UN ECE REG.51.03

5.1 Round Robin Test on ISO test tracks

A Round Robin Test program by the VDA in Germany was accomplished in 2016, [13]. The sound performance of 13 ISO test tracks in Europe was evaluated, using 5 sets of summer C1 tyres, one set of slick tyres and one set of the SRTT tyres. All tests were performed with the same vehicle, a full electric passenger car to suppress any power train influence. In addition to the rolling sound measurements additional parameter per test track were taken, such as texture and absorption. Two of the test tracks did have absorption levels outside the allowed range according to the specifications of ISO 10844:2014. With these two tracks included in the analysis, the spread in sound levels (at 50 km/h cruising) was in the range of 5.0 -5.7 dB, depending on tyre. Without the two tracks with too high absorption, the spread is in the range 3,2 - 4,4 dB.

Such a large variation is unsatisfying, so there is still a need to minimize this variation. The latest revision of ISO 10844 may reduce this somewhat, but there should be additional means to reduce variability. There are several options available:

- Introduce a correction procedure based on the VDA study provided formula (given in [13], but since further developed), which includes texture-based data (MPD and g-factor) and absorption data for the individual test track.
- Introduce a calibration procedure, based on reference tyres, such as the SRTT tyre. Such a procedure has been proposed within the STEER project [14], based on the available data from the RRT of VDA. By this method, the variation between test tracks was reduced from 5,5 to 1,4 dB (average for all tested tyres).
- Introduce indoor (drum) measurements on a replica of an ISO 10844 surface. Within this option, there should be a development to enable 3D printing of a test surface on the drum, to minimize variations between drum testing facilities.

Any of the above listed approaches have merits but as well drawbacks. The VDA provided formula is not validated for any test track and not applicable to all tyre designs (summer, winter, all-season, off road, different widths). The SRTT reference is dependent of the variability of the SRTT tyres and the actual transient to a new SRTT reference and it increases the measurement time. The drum test method is only applicable to coast-down measurements, torque load will quickly degrade to drum surface.

This investigation (and other previous RRT tests) identifies the most important quantities to the overall uncertainty, as described in the next chapter.

5.2 Uncertainty budget

The development of an uncertainty budget has primarily been based on input from vehicle industry (OICA), from standardization body (ISO), and from independent companies (UTAC CERAM and others).

The measuring method in UN ECE Reg.51.03 is based on ISO 362-1 (Outdoor test method for M and N-categories of vehicles). In the latest publication of this method (ISO/FDIS 362-1: 2022), there is a separate annex dealing with measurement uncertainties including a table showing the contribution of the different quantities to the overall expanded uncertainties. This table is developed in close co-operation with IWG MU, as the convenor of ISO working group TC43/SC1/WG42 (responsible for ISO 362-1) is as well a member of the IWG MU.

The justifications of the contribution of the different quantities are based on the following three approaches:

1. By ***measurement*** (or simulation) results from specific experiments, e.g. investigations on power-train noise on indoor test bench
2. By classic ***statistical methods***, e.g. parameter studies and correlation analysis (ACEA tyre study [15])
3. By ***theoretical*** deviations based on physical relations, e.g. distance law (deviations from centred driving)

The main uncertainty budgets for vehicles of categories M1, N1, and for vehicles of category M2 with less than 3500 kg maximum permissible laden mass are shown in Table 2.

Table 2: Estimation of the impact on L_{urban} [dBA] for the most important quantities (M1, N1, and M2 with less than 3500 kg maximum permissible laden mass.

Quantity	**Justification**	**L_{urban}, [dBA]**
Microclimate wind effects (< 5 m/s)	Measurements	1,57
Deviation from centred driving (driver infl.)	Theoretical derivation	0,50
Start of acceleration (driver infl.)	Measurements	0,40
Speed variations, ± 1 km/h (driver infl.)	Theoretical derivation	0,50
Load variations during cruising	Statistical methods	0,34
Varying background noise	Measurements	0,40
Varying operating temp. vehicle and tyres	Measurements	0,80
Barometric pressure (Weather ± 30 hPa)	Measurements	0,40
Air temperature effect on tyre noise (0-40°C)	Measurements	2,67
Air intake temperature variations	Measurements	1,06
Residual humidity on test track surface	Measurements	1,31
Altitude (Location of test track) – 100 hPa/1000 m	Measurements	0,70
Test track surface	Measurements	4,11
Microphone Class 1 IEC 61672	Measurements (calibr.)	1,00
Sound Calibrator IEC 60942	Measurements (calibr.)	0,50
Speed measuring equipment at PP	Theoretical derivation	0,10
Acceleration calculation from vehicle speed meas.	Theoretical derivation	0,50
Prod. var. of tyres, incl. aging of tyres until 1 year	Measurements	1,04
Prod. variability in engine power output	Theoretical derivation	0,40
Prod. var. of sound reduction components	Measurements	0,73
Vehicle mass variation from mass in running order	Measurements (simul.)	1,60

For other categories of vehicles, N2, N3, and M2 with a maximum permissible laden mass greater than 3500 kg and M3, there is a similar table given in ISO/FDIS 362-1:2022.

The uncertainties are grouped as follows:

a) Single run-to-single run: variations expected for L_{urban} within the same test laboratory and slight variations in ambient conditions found within consecutive run test series

b) Day-to-day: variations expected for L_{urban} within the same test laboratory but with variation in ambient conditions and equipment properties that can normally be expected during the year

c) Site-to-site: variations expected for L_{urban} between test laboratories where, apart from ambient conditions, equipment, staff, and road surface conditions are also different

d) Vehicle-to-vehicle: uncertainty for L_{urban} due to production variances of sound relevant components and different equipment.

Within the work of the IWG MU, a table has been developed based on the input of the quantities and the grouping above, showing the percentage contribution to the overall expanded uncertainties. By doing this, two most important quantities have been identified as:

- the influence of the test track surface (although restricted by the provisions of ISO 10844)
- air temperature effect on tyre rolling sound (although already limited to an air temperature range during the test between +5°C and +40°C)

These two quantities are responsible for nearly 75% of the total expanded uncertainties.

During type-approval and conformity of production (COP), the vehicle manufacturer and the associated type-approval authorities have control over the testing conditions including as well to a certain extend the environmental conditions. This enables reducing the variations in sound levels, given by run-to-run and day-to-day variations.

With regard to the Market Surveillance Directive [3] it is important to evaluate the expected sound variation for different test purposes. IWG MU has therefore developed a table as shown in Table 3 for measurement uncertainties, showing the expected expanded uncertainties separately for type-approval, COP, and so-called “field testing”.

Table 3: Measurement uncertainty table for M1, N1, and M2 with less than 3500 kg maximum permissible laden mass

Situation	Input Quantity	estimated deviations of the meas. result (peak-peak)		Impact on Lurb	Probability Distribution	Variance	Standard deviation	Share [%]	Combined standard uncertainty	Uncertainty Budgets			95% uncertainty
		Lwot	Lcrs							Type Approval	CoP	Field Tests	
single Run to single Run	Micro climate wind effect	1,60	1,50	**1,57**	gaussian	0,15	0,392	5,6%	**0,53**	**0,53**	**0,53**	**0,53**	**1,1**
	Deviation from centered driving	0,50	0,50	**0,50**	rectangular	0,02	0,144	0,8%					
	Start of acceleration	0,60	0,00	**0,40**	rectangular	0,01	0,114	0,5%					
	Speed variations of +/- 1km/h	0,50	0,50	**0,50**	rectangular	0,02	0,144	0,8%					
	Load variations during cruising	0,00	1,00	**0,34**	gaussian	0,01	0,085	0,3%					
	Varying background noise	0,40	0,40	**0,40**	rectangular	0,01	0,115	0,5%					
	Variation on operating temperature of engine and tyres	0,80	0,80	**0,80**	rectangular	0,05	0,231	2,0%					
Day to Day	Barometric pressure (Weather +/-30 hPa)	0,40	0,40	**0,40**	gaussian	0,01	0,100	0,4%	**1,06**	**0,53**	**1,06**	**1,06**	**2,1**
	Air temperature effect on tyre noise (5-10°C)	0,00	0,00	**0,00**	rectangular	0,00	0,000	0,0%					
	Air temperature effect on tyre noise (0-40°C)	2,20	3,60	**2,67**	rectangular	0,60	0,772	21,9%					
	Varying background noise during measuremnt	0,00	0,00	**0,00**	rectangular	0,00	0,000	0,0%					
	Air intake temperatuire variation	1,60	0,00	**1,06**	rectangular	0,09	0,305	3,4%					
	Residual humidity on test track surface	0,90	2,10	**1,31**	rectangular	0,14	0,377	5,2%					
Site to Site	Altitude (Location of Test Track) 100 hPa/1000m	0,70	0,70	**0,70**	rectangular	0,04	0,202	1,5%	**1,63**		**0,82**	**1,63**	**3,3**
	Test Track Surface	3,40	5,50	**4,11**	rectangular	1,41	1,187	51,8%					
	Microphone Class 1 IEC 61672	1,00	1,00	**1,00**	gaussian	0,06	0,250	2,3%					
	Sound calibrator IEC 60942	0,50	0,50	**0,50**	gaussian	0,02	0,125	0,6%					
	Speed measuring equipment continuous at PP	0,10	0,10	**0,10**	rectangular	0,00	0,029	0,0%					
	Acceleration calculation from vehicle speed measurement	0,50	0,50	**0,50**	rectangular	0,02	0,144	0,8%					
Vehicle to Vehicle	Production Variation Tyre and aging of tyres	0,80	1,50	**1,04**	gaussian	0,07	0,259	2,5%	**1,73**		**1,73**	**1,73**	**3,5**
	Production Variation in Power	0,40	0,40	**0,40**	rectangular	0,01	0,115	0,5%					
	Battery state of charge for HEVs	0,00	0,00	0,00	rectangular	0,00	0,000	0,0%					
	Production Variability of Sound Reduction Components	1,10	0,00	**0,73**	gaussian	0,03	0,182	1,2%					
	Impact of variation of vehicle mass	1,60	1,60	**1,60**	rectangular	0,21	0,462	7,8%					
						2,72		110,4%					
					Coverage Factor		**Overall Combined Uncertainty +/-**	**Expanded uncertainty (95%) +/-**		**Type Approval**	**CoP**	**Field Tests**	
					k=2 (95%)		**1,73**	**3,46**		**1,5**	**4,5**	**5,3**	
Run to run	Variations expected within the same test facility and slight variations in ambient conditions found within a single test series												
Day to day	Variations expected within the same test facility but with variations in ambient conditions and equipment properties that can normally be expected during the year												
Site to site	Variations between test facilities where, apart from ambient conditions, equipment, staff, and road surface conditions are different												
V to vehicle	Variations of vehicles												

While the expanded uncertainty for type approval test is within the know magnitude, for CoP and field testing the uncertainty is significantly higher. Without any test track compensation, the expected uncertainty is more than 5 dB. While UN R51.03 applies an additional tolerance of 1 dB(A) during CoP tests, the market surveillance regulation is unclear with regard to tolerances. It is highly important to be aware of this level of uncertainty when "third party" testing according to UN Regulation 51.03 is performed. Means to reduce the uncertainties as shown in this table is of high importance for the future.

6. PROCEDURE FOR IMPLEMENTATION OF MEASUREMENT UNCERTAINTIES

In Reg.51.03 there are several means to reduce expected sound level variations:

- Repetition of measurements and use of averaging
- Limitation of the ambient air temperature (+5° to +40°C)
- Accuracy of environmental monitoring instruments, including acoustic instruments, vehicle speed measurement device, temperature, wind speed, and barometric pressure.
- Precise specifications on the preparation of a vehicle tyres before testing
- Revised test track specification (present tracks shall meet specifications of ISO 10844:2014 but will be changed to the 2021 version for future amendments of UN ECE Reg.51.03).

The work of the two Informal Working Groups MU and ASEP has now been aggregated into a new supplement 7 to UN ECE Reg.51.03 (ECE-TRANS-WP.29-2022-84 Rev.1). This supplement replaces the previous supplements 7 and 8 [7, 8] and includes newly a temperature correction procedure for the pass-by measurements, based on air temperature. With this, further improvements should be feasible, to reduce the measurement uncertainties as given in Table 3.

A first approach is made to enable test track compensations as well, but this is in a first stage foreseen as an option selectable by the manufacturer, as the test track compensation requires intensive witnessed testing of tyres used by a manufacturer in production.

Up to now there is no separate annex dealing with measurement uncertainties in UN ECE Regulations as it is the case with ISO-standards. IWG MU will present an Informal Paper to the September 2022 session of GRBP, with a proposal how to implement such a table as a new annex to UN ECE Reg.51.03

As stated in chapter 2, IWG MU was given the task to develop a generic approach for the assessment of uncertainties applicable to other UN Regulations. This approach could be either documented in the Consolidated Resolution on Construction of Vehicles (R.E.3) or as a Document for Reference.

To fulfil this objective, IWG has proposed to GRBP and to UN ECE WP.29 a general approach how to implement measurement uncertainties into ECE regulations. A separate annex shall give a systematic description of the contribution of different measurement quantities to the overall expected expanded uncertainty, as demonstrated for Reg.51.03 (and for Reg.117 for the future).

The recommended procedure is:

- A table of uncertainties shall be attached as an annex to every regulation that deals with measurements based on a standardised test method (for example based on an ISO standard).
- Every time a regulation will be amended according to the test methods the "Annex of Measurement Uncertainties" shall be updated, too.
- If there is up to now, no "Annex of Measurement Uncertainties" available, this has to be added within a future amendment of this regulation.

7. CONCLUSIONS

Every measurement procedure leads uncertainties connected to the final measured value. This paper describes an approach to assess the contribution of different measurement quantities to the overall expanded uncertainties. The validation was made for UN ECE Reg.51.03, which relates to the measurement of external sound levels of vehicles of categories M and N. The procedure to establish this overall uncertainty is primarily based on ISO 98-3 (GUM). By this approach it was possible to rank the various influence factors according to their contribution to the overall uncertainty, by using the calculation of an uncertainty budget.

The most important being the known test track surface sound variations, as shown in chapter 5.

The UN ECE Informal Woking Group on Measurement Uncertainties propose to amend all regulations that includes any test procedure, to be amendment with an annex showing the influence of measurement quantities to the overall expanded uncertainties, for example in form of a table. Such a table can then be updated whenever the regulation is amended in a way that the measurement uncertainty can be reduced. As an interim solution, the UN ECE GRBP has decided to publish the actual result of the IWG MU as document for reference on the UN ECE website, so that “third parties” can benefit from the results and are aware of uncertainties when performing pass-by sound measurements related to UN ECE Reg.51.03 or Regulation (EU) 540/2014/EC.

8. ACKNOWLEDGEMENTS

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