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New Approach to the Uncertainty Assessment of Acoustic Effects in the Environment

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The acoustic climate assessment needed for the selection of solutions (technical, legal and organisational), which will help to minimise the acoustic hazards in the analysed areas, is realised on the basis of acoustic maps. The reference computational algorithms, assigned to them, require very thorough preparation of input data for the considered noise source model representing – in the best possible way – the acoustic climate. These input data are burdened with certain uncertainties in this class of computational tasks. The uncertainties are related to the problem of selecting proper argument values (from the interval of their possible variability) for the modelled processes. This situation has a direct influence on the uncertainty of acoustic maps.

The idea of applying the interval arithmetic for the assessment of acoustic models uncertainty is formulated in this paper. The computational formalism assigned to the interval arithmetic was discussed. The rules of interval estimations for the model solutions determining the sound level distribution around the analysed noise source – caused by possible errors in the input data – were presented. The application of this formalism was illustrated in uncertainty assessments of modelling acoustic influences of the railway noise linear source on the environment.

Keywords: interval arithmetic, uncertainty, railway noise.

1. Introduction

One of the most significant legal issues of the Directive 2002/49/WE (European Parliament [EP], 2002) related to the assessment and management of environmental noise, which were transferred to domestic legislation, is an obligation of the acoustic maps preparation. Their results constitute the bases for acoustic hazard assessments in the analysed zones and the decisions related to them for environment protection programs. They have to be reported to the respective agencies of the European Union.

The preparation of acoustic maps (being illustrations of long-term noise indicators: day-evening-night L_{DEN} and night L_N in the analysed environment) has, from the technical side, several model indications and realization recommendations (European Commission Working Group Assessment of Exposure to Noise [WG-AEN], 2006). They contain reference a model of noise propagation both of communication (railway, road traffic, airport) and industrial noises.

A credible application of their software realization (Cadna/A, SoundPLAN, IMMI, Mithra, Predictor-LimA) requires a sound acoustic knowledge of models of the analysed noise hazard sources, conditions of their propagation as well as various computational techniques, which generate a virtual knowledge characteristic of the informative civilization and knowledge based economy (WG-AEN, 2008).

The basic problems and methods of the uncertainty analysis of modelling railway noise hazards, when the acoustic model of railway noise has uncertain input data, are presented in the paper. The Dutch RMR method (Ministry of Housing, Spatial Planning and the Environment [MHSPE], 1996) was assumed as the model base recommended for calculating railway noise by the legislator. Parameters describing the properties of: railway subgrade of the analysed track section, kind of rolling stock, traffic structure, were given the *'soft property'* status. In practice, it means that these parameters can assume values from some intervals. The need of such approach to the model variables results from the impossibility of their accurate defining. This fact generates a question how such parameters will be reflected in the modelling results and in the conformity of noise hazard assessments by environmental measurements. This problem was already signalled in the previous papers of the authors (Batko, Pawlik, 2011a; 2011b).

The application of an interval arithmetic formalism, which could become the formal tool for uncertainty analysis of the railway noise acoustic modelling, was proposed for solving the above formulated question. Its presentation constitutes the contents of the hereby paper. Variables and parameters of the modelled acoustic hazard effect, caused by the determined noise sources, are expressed by intervals (interval numbers). Taking them into account in model relations, together with adequate relations of the interval arithmetic (Moore, 1966) describing the railway noise propagation, generates the possibility of the assessment of the range of the acoustic modelling errors. The modelling uncertainty assessments obtained in this way can be treated as a generalisation of the classic method of the error propagation analysis in uncertainty assessments. The model formalism, proposed in this paper, can constitute the basis for the creation of the coherent computational domain for uncertainty assessments of environmental hazards.

The basic notions and relations concerning the interval arithmetic are given in the first part of this paper. They are supplemented by the analysis of functional properties of the proposed solution on an example of modelling noise levels around the selected track section and by the corresponding uncertainty assessment (in the second part).

2. Model formalism of the interval arithmetic

Taking into account an imprecise knowledge of the parameters of the modelled process of noise generation, the authors propose to assume the values representation in the form of an interval, within which they will be contained. Such treatment forces the requirement of the application of the interval arithmetic formalism.

The characteristic features of the interval arithmetic are the operations on intervals, not on numbers. Operations on the intervals have been started in 1950, however it was only in the sixties that they were named the interval arithmetic in Moore's papers (1962; 1966). In literature developments of this arithmetic can be found as well, for example in (Skrzypczyk, 2010).

In this paper, the intervals describe the measurement or calculation uncertainties and are determined in such a way as to warrant that the resultant value will be within a given interval.

Intervals are determined as closed limited sets of real numbers, e.g.:

$$\mathbf{x} = [\underline{x}, \overline{x}] = \{x \in R : \underline{x} \leq x \leq \overline{x}\}, \tag{1}$$

where $\underline{x}$ is the lower interval limit – infimum, while $\overline{x}$ is the upper interval limit – supremum.

The basic arithmetic operations are defined on the intervals set:

$$\mathbf{x}\diamondsuit\mathbf{y} = \{z = x\diamondsuit y : x \in \mathbf{x}\ y \in \mathbf{y}\}, \tag{2}$$

where $\diamondsuit$ is one of the operators of: additions, subtractions, multiplying or division. Apart from division, these operators are defined for arbitrary intervals. For division, it should be assumed that: $0 \notin \mathbf{y}$.

Additions and subtraction of intervals is being done by operations at the interval ends, according to Eqs. (3) and (4):

$$\mathbf{x} + \mathbf{y} = [\underline{x} + \underline{y}, \overline{x} + \overline{y}], \tag{3}$$

$$\mathbf{x} - \mathbf{y} = [\underline{x} - \overline{y}, \overline{x} - \underline{y}]. \tag{4}$$

The interval, which is the multiplication result, is determined on the grounds of the smallest and largest product of the two ends of intervals $\mathbf{x}$, $\mathbf{y}$:

$$\mathbf{x} \cdot \mathbf{y} = [\min(\underline{x}\underline{y}, \underline{x}\overline{y}, \overline{x}\underline{y}, \overline{x}\overline{y}), \max(\underline{x}\underline{y}, \underline{x}\overline{y}, \overline{x}\underline{y}, \overline{x}\overline{y})]. \tag{5}$$

The division operation is determined by the following reciprocal:

$$\frac{\mathbf{x}}{\mathbf{y}} = \mathbf{x} \cdot \frac{1}{\mathbf{y}}. \tag{6}$$

While the interval reciprocity is presented by Eq. (7):

$$\frac{1}{\mathbf{y}} = \left[\frac{1}{\overline{y}}, \frac{1}{\underline{y}}\right]; \quad \text{when} \quad \underline{y} > 0 \quad \text{or} \quad \overline{y} < 0. \tag{7}$$

At the numerical realisation of interval operations, we are limited to use only the results of the finite precision. Thus, the elementary functions are implemented by means of the Taylor's expansion, where the errors related to omitting expressions of a higher order are taken into account in the result. The resulting interval for monotonic functions (e.g. exponential, logarithmic) is determined with the estimation of the kind of rounding at performing the elementary functions (Galias, 2003).

3. Application of the proposed concept for modelling railway noises by the RMR method

The Directive 2002/49/WE of the European Parliament and Council of June 25th 2002, concerning the assessment and management of the environment noise level, requires the applications of unified methods of the noise assessment (EP, 2002). It is allowed – in the transient period – to assume one of two solutions: application of transient methods or the own domestic ones, however, under the condition of their adaptation to the calculation of new noise indicators defined in the Directive. The Dutch method published in "Reken- en Meetvoorschrift Railverkeerslawaai '96" (MHSPE, 1996) is recommended as the transient method concerning the rail-vehicle noise assessment. It contains indications of assessment rules of the acoustic power levels of railway noise sources and the related to them algorithms of the noise level estimation in an open space. The correctness of such an assessment is – in this solution – determined by the problem of an adequate estimation of the acoustic power level of component sources representing noises: contact 'wheel-rail', traction and aerodynamic noise, or engine noises. The substitute level of those sources of railway noises depends essentially on the kind of train, its speed and the railway subgrade type. Due to the essential differences between data describing the noise emission for the same categories of the railway sources noise in various EU countries, the natural question constitutes the likelihood of the results obtained in this way.

The determination of the computational uncertainty in modelling the railway noises by the SRM method was proposed in this paper. This method is reduced to the time-averaged sound level L_{Aeq} determination. The first step at the modelling is the qualification of vehicles moving on a given railway track. The method differentiates 9 train categories. Then the value of the emission level is determined according to the dependence (8):

$$E = 10\log\left(\sum_{c=1}^{y} 10^{E_{nr,c}/10} + \sum_{c=1}^{y} 10^{E_{r,c}/10}\right), \qquad (8)$$

where $E_{nr,c}$ – emission level of not braking trains, belonging to the discussed category, $E_{r,c}$ – emission level of braking trains, c – train category, y – number of existing categories.

The emission level, for each category, is determined according to (9) and (10):

$$E_{nr,c} = a_c + b_c \log v_c + 10\log Q_c + C_{b,c}, \qquad (9)$$

$$E_{nr,c} = a_{r,c} + b_{r,c} \log v_c + 10\log Q_{r,c} + C_{b,c}, \qquad (10)$$

where Q_c – average number of not braking trains, belonging to the discussed category, $Q_{r,c}$ – average number of braking trains, belonging to the discussed category, v_c – average train speed, a_c, b_c, $a_{r,c}$, $b_{r,c}$ – standard values of the emission level depending on the category, from paper (MHSPE, 1996), $C_{b,c}$ – coefficient of correction dependent on the category and type of tracks, from paper (MHSPE, 1996).

The equivalent sound level L_{Aeq} for the railway noise is determined from the dependence:

$$L_{Aeq} = E_S + C_{\text{reflection}} - D_{\text{distance}} - D_{\text{air}} - D_{\text{soil}} - D_{\text{meteo}}, \qquad (11)$$

where $C_{\text{reflection}}$ – correction for possible reflections from buildings or other vertical surfaces, D_{distance} – correction taking into account r (distance between the receiving point and the source line), D_{air} – correction taking into account the sound damping in air, dependent on r, D_{soil} – correction taking into account the sound absorption by soil, dependent on r, h_w (height of the receiving point referred to the local height), h_{bs} (the rail head height referred to the assessment surface) and on B – the soil coefficient, D_{meteo} – meteorological correction, dependent on h_w and h_{bs}, E_s – complex value of the emission level, determined by the dependence:

$$E_s = 10\log\frac{1}{127}\sum_{i=1}^{n} \Phi_i 10^{E_i/10}, \qquad (12)$$

where E_i – emission level for the section i determined from the dependence (8), Φ_i – angle, at which the section is seen from the receiving point.

Due to the fact that some input parameters are taken as average values (v_c, Q_c, $Q_{r,c}$), the natural question is the problem of their proper representability and influence on the modelling result. In addition, the parameters related to the measuring distances, heights or angles are measured with a determined accuracy, which can also influence the estimate of the discussed noise levels.

The authors applied the computational formalism of the interval arithmetic for the determination of the input parameters uncertainty on the modelling result uncertainty. The parameters: v_c, Q_c, r, h_w, h_{bs} were determined by means of interval numbers representing their possible variability range and the simulation of their influence on the result of the equivalent sound level was performed. The diagram below (Fig. 1)

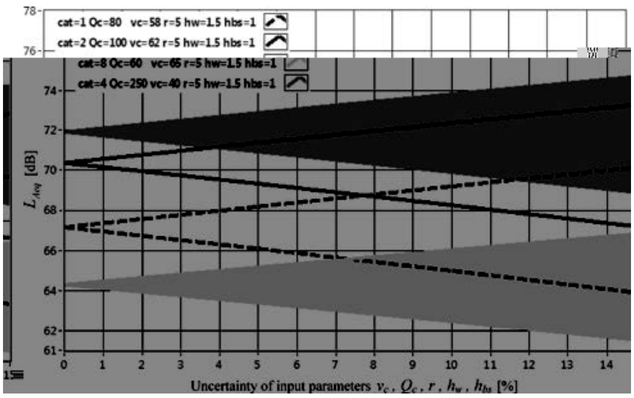

Fig. 1. Variability range of the estimated sound levels in dependence on the uncertainty of input parameters.

presents the variability range of the equivalent sound level in dependence on the uncertainty of input parameters for 4 cases.

As can be seen from the presented simulations, the uncertainty of the input parameters has a significant influence on the estimation results. Table 1 presents the results uncertainty, expressed in percentages, in dependence of the percentage uncertainty of the input parameters.

Table 1. Percentage uncertainty of the estimated sound level in dependence on the input parameters uncertainty: v_c, Q_c, r, h_w, h_{bs}.

Case	Uncertainty of input parameters		
	5 [%]	10 [%]	15 [%]
1	1.6 [%]	3.1 [%]	4.7 [%]
2	1.5 [%]	2.9 [%]	4.4 [%]
3	1.3 [%]	2.7 [%]	4.0 [%]
4	1.4 [%]	2.8 [%]	4.2 [%]

A successive input parameter at the sound level modelling by means of the RMR SRM method is the coefficient $C_{b,c}$, dependent on the railway subgrade for the given train category. In the Dutch method, eight types of railway subgrades were singled out. However, it is difficult to find in this collection an equivalent for the Polish conditions. Therefore, the authors carried out an analysis of the influence of not proper selection of this parameter on the estimation results. In the simulation experiment, the variability interval of the parameter $C_{b,c}$ containing all possible railway subgrade types was assumed. In such conditions, the analysis of the scatter of the sound level results at the assumed uncertainty range of the $C_{b,c}$ parameter was performed and is presented in Fig. 2.

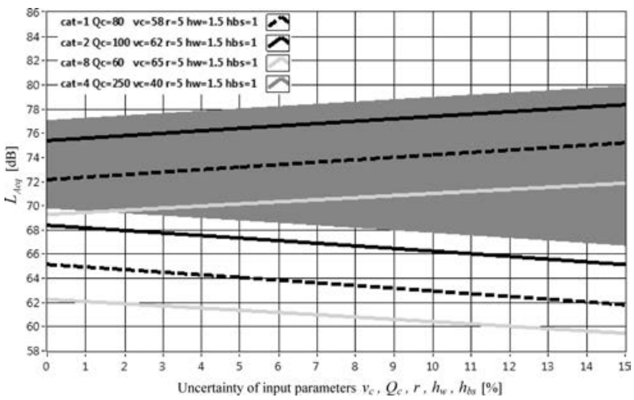

Fig. 2. Variability range of the estimated sound level in dependence on the input parameters uncertainty when taking into account the variability of the $C_{b,c}$ parameter

When the uncertainty of the parameter determining the railway subgrade type was taken into account, the uncertainty of the obtained results increased by app. 5%, which indicates the high sensitivity of model to this particular parameter.

4. Conclusions

The problems of assessments of acoustic maps uncertainties determining the reliability of acoustic calculations in the environment protection practice are very important. Such assessment – related to the acoustic maps realisation – is necessary. The uncertainty can correspond to non adequacy of the assumed input data for the acoustic maps calculation as well as to empirical parameters of the computation method. The results related to its analysis generate information on the possible scatter of the estimated acoustic hazard levels, which are significant for the rationality of environment protection programs and for bearing of costs.

The uncertainty analysis problem in strategic acoustic maps did not find satisfactory solutions in the references (WG-AEN, 2006).

The formalism based on interval numbers proposed in this paper, seems to be a promising tool for solving such problems. It does not create any limitations and does not require restricting assumptions.

The performed calculations indicated the essential dependence of the result of modelling the railway noise on possible errors of parameters assigned to this noise. The assumed computational formalism allows to solve several problems resulting from not fully determined input data related to noise sources and noise propagation conditions. Its broader implementation in practice should be recommended since various procedures provided in this formalism enable the assessment of the uncertainty of different layers (emissive, imissive etc.) of acoustic maps. It can be also applied for other noise models, including: road traffic noise, airport noise or industrial noise. However, these problems require separate investigations and will be contained within the domain of further studies of the authors.

References

1. Batko W., Pawlik P. (2011a), *Application of the interval arithmetic in the reverberation time uncertainty assessment*, DAGA 2011 'Sounds good' The 37th Annual Conference for Acoustics in Düsseldorf.

2. Batko W., Pawlik P. (2011b), *Application of interval arithmetic to uncertainty evaluation in modelling of effects with uncertain parameters*, XVIII Conference on Acoustic and Biomedical Engineering, Kraków – Zakopane.

3. Calculations and Measurements of Railway Traffic Control '96 [in Dutch: Reken-en Meetvoorschrift Rail-

verkeerslawaai '96] Ministry of Housing, Spatial Planning and the Environment [in Dutch: Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer], 20 November 1996.

4. Directive 2002/49/WE of the European Parliament and of the Council of 25 June 2002, Relating to the assessment and management of environmental noise, Official Journal of the European Communities, 18 July 2002.

5. Galias Z. (2003), *Interval arithmetic for investigations of nonlinear systems* [in Polish: *Metody arytmetyki przedziałowej w badaniach układów nieliniowych*], AGH University of Science and Technology Press, Kraków.

6. Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure. Ver. 2., European Commission Working Group Assessment of Exposure to Noise (WG-AEN), 13 January 2006.

7. Moore R.E. (1962), *Interval Arithmetic and Automatic Error Analysis in Digital Computing*, Ph.D. Thesis, Stanford University.

8. Moore R.E. (1966), *Interval Analysis*, Prentice-Hall, Englewood Cliffs, NJ, USA.

9. Presenting Noise Mapping Information to the Public. A Position Paper from the European Environment Agency Working Group on the Assessment of Exposure to Noise (WG-AEN), March 2008.

10. Skrzypczyk J. (2010), *Perturbation methods 1, New Algebraic Methodology, Applications in Mechanics and Acoustics* [in Polish: *Metody perturbacyjne 1, Nowa metodologia algebraiczna, Zastosowanie w mechanice i akustyce*], Silesian University of Technology Press, Gliwice.