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Indicator Method of Assessing Acoustic Impact of Railway Vehicles

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Summary
The following article constitutes an attempt to solve the problem of the interpretation of results based on a comparison of measured values to permissible values. When exceeded limits are observed, the recipients of acoustic analyses (mainly non-specialists) are frequently uncertain as to how to interpret the results. At the moment, there is no unambiguous way of defining acceptable, alarming or unacceptable values of noise but an original indicator methodology, which allows a clear and easy interpretation of the results obtained, has been proposed. The suggested noise load factor (NLF), based on measurements of physical quantities, enables conducting a broader assessment of the nuisance of noise originating from railway vehicles.

Keywords: noise, environmental impact assessment, acoustic impact

1. Introduction

The acoustic impact generated by means of transport is a significant problem for the immediate and distant surroundings. The degree of acoustic nuisance caused by railway transport is influenced by a number of factors. The most relevant include the technical condition of the rolling stock and the railway infrastructure, the volume of traffic and the lie of the land. Currently, the proximity of (acoustically protected) dwellings to railway areas also greatly affects the acoustic climate in the vicinity of the track. Furthermore, increasing traffic volumes and fluctuations in their daily distribution have led to an extension of peak hours [1].

The construction and modernisation of railway infrastructure may also cause changes in the acoustic climate. In most cases, alterations require conducting an environmental impact assessment by preparing a project information sheet or an environmental impact report. Apart from the characteristics of the entire project, these documents should include, among other things, an evaluation of the impact on acoustically protected areas. According to the requirements specified in the national regulations, the acoustic assessment should be conducted by means of field measurements, on the basis of which further analyses are performed. Most of the time, these analyses are limited to an indication of the exceeded values. There is no unambiguous methodology for interpreting the results – by introducing a rating system (very good, acceptable, alarming, unacceptable) – that would determine the scale of the impact of noise on protected areas. Moreover, a study of the available national and foreign literature has not revealed a similar approach to the interpretation of the obtained results of acoustic signals generated by railway vehicles.

The following paper attempts to identify new criteria for the evaluation of noise produced by railway vehicles and to determine an appropriate scale of acoustic impact levels. Moreover, it presents the main assumptions of the noise load factor, interpretation of the results and calculations based on the obtained values of the equivalent sound level A.

2. Assessment of acoustic nuisance in Poland

Acoustic nuisance caused by railway transport in Poland is determined on the basis of noise levels permissible in the environment. These values are indicated in the Regulation of the Minister of Environment of 14 June 2007 on allowable environmental noise levels (consolidated text, Journal of Laws of 2014, item 112) [2]. Permissible noise levels have been determined for the following types of areas:
a) for residential development,
b) for hospitals and social care homes,
c) for buildings associated with a permanent or temporary stay of children and youth,

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Table 1

Permissible values of environmental noise for railway lines [2]

No.	Intended use of the area	Permissible noise level [dB]	
		Roads or railways	
		LAeqD Daytime $t = 16$ h	LAeqN Nighttime $t = 8$ h
1.	a) Spa protection areas A b) Hospital premises outside urban areas	50	45
2.	a) Single-family housing development areas b) Developed areas associated with a permanent or temporary stay of children and youth c) Social care homes d) Hospital premises in urban areas	61	56
3.	a) Multi-family and collective housing development areas b) Homestead areas c) Recreation and leisure areas d) Residential and service areas	65	56
4.	Areas in the inner-city zone of cities with more than 100 thousand inhabitants	68	60

d) for spa purposes,
e) for recreational and leisure purposes,
f) for residential and service purposes.

The aforementioned types of areas have been divided into four groups with similar intended use, for which various permissible noise levels have been defined (Table 1).

The classification of areas specified in Table 1 is based on the intended use of the land, as specified in the local spatial development plan. In the absence of such a plan, the classification is performed by the competent authority according to the actual development and use of this and neighbouring areas [3].

The last group of areas allows the creation of an inner-city zone, characterised by compact residential development with a concentration of administrative, commercial and service facilities in urban areas with more than 100,000 inhabitants. The said area has significantly higher permissible noise levels than the other groups.

3. Indicator assessment of the acoustic impact

According to the author, an assessment of the acoustic impact of railway transport based solely on the analysis of exceeded permissible values is insufficient. More detailed verification of the acoustic impact is possible by means of the indicator method [4]. Due to the lack of detailed interpretation of results (exceeded limits), the author attempted to develop an indicator based on measured physical quantities and taking into account a more transparent explanation and presentation of results.

In order to carry out a broader assessment of the nuisance of noise emitted by railway vehicles, an original noise load factor (NLF) was constructed to define the relationship:

$$NLF = 20\log\frac{L_{Aeqzm}}{L_{Aeqdop}}, \text{ [dB]} \qquad (1)$$

where:
L_{Aeqzm} – measured sound level A,
L_{Aeqdop} – permissible sound level A.

An appropriate scale of values has been adopted to assess the noise generated by railway vehicles. Table 2 presents the system of evaluation of the normative values defining the scale of noise impact on acoustically protected areas. The values of the noise load factor were determined according to the perception of noise by the human ear, which is not able to distinguish changes in sound pressure levels within the range of 0.5 to 2 dB [5] / 3 dB [6].

Table 2

Values of the noise load factor (NLF)

Factor level	NLF value	Sound level in relation to the permissible levels (PL) [dB]
Very good	NLF ≤ –0,42	PL < 3
Acceptable	–0,42 < NLF ≤ 0	3 < PL ≤ 0
Alarming	0 < NLF ≤ 0,42	0 < PL ≤ 3
Unacceptable	NLF > 0,42	PL > 3

[Own elaboration]

The specific values of the NLF have been assigned appropriate sets of colours to enable unambiguous interpretation of the results. Dark green indicates very good levels (no exceedances – measured values are at least 3 dB below the PL), while light green represents acceptable values (index value from –0.42 to 0), i.e. measured values are between 0 dB and 3 dB below the permissible levels (no exceedances). Orange identifies alarming values (exceedances of the normative levels of up to 3 dB), while red designates indicator values (above 0.42) defining exceedances above 3 dB.

4. Verification of the NLF using actual measurement results

Verification of the original noise load factor was carried out on the basis of the obtained results regarding the equivalent sound level A (L_{Aeq}) for railway vehicles travelling at 200 km/h. The study was conducted on Pendolino – an Alstom vehicle of type ETR610 series ED250 (Fig. 1). During the conducted tests, the equivalent sound level of increased speed railway vehicles moving on a straight section and along a curve was estimated. The measurements were carried out at four distances (5 m, 10 m, 20 m and 40 m) from the railway to enable the most accurate identification of the acoustic signature of the analysed object. Measurements of acoustic signals were performed on the railway line No. 4 Grodzisk Mazowiecki – Zawiercie, on the section Grodzisk Mazowiecki – Idzikowice, in two locations:

- straight section – approx. km 21+300 (city of Szeligi, ul. Dojazdowa)
- curve – approx. km 18+600 (city of Świnice, ul. Długa).

Fig. 1. Study object: Alstom vehicle type ETR610, series ED250 – Pendolino [photo by K. Polak]

A detailed description of the methodologies of the measurements is included, among other things, in papers [7, 8].

In order to verify the NLF, the results obtained at the measurement point, located at a distance of 40 m and a height of 4 m above rail head level, were used to best represent the impact assessment of acoustically protected areas. These assumptions stem from the fact that in developed areas, the measurement points are most often located at a height of 4 m (±0.2 m) above the ground surface, resulting from the provisions of the Regulation [9], and the requirements of the Act [9], which requires that the location of buildings be at a distance of not less than 20 m from the axis of the outer track. The calculations of the noise load factor were conducted in areas allocated for multi-family housing development, for which, in accordance with the Regulation [2], the normative values were set at 65 dB for the daytime (8:00 a.m. – 4:00 p.m.).

Table 3 presents five selected results for 20-second trips of the tested vehicles travelling at 200 km/h on a straight section and a curve. As mentioned earlier in the article, specific values of the NLF were assigned to the respective sets of colours:

- dark green – very good levels; measured values are at least 3 dB below the permissible levels,
- light green – acceptable values; measured values are between 0 dB and 3 dB below the permissible levels,
- orange – alarming values; exceedance of the normative levels by up to 3 dB,
- red – unacceptable values; exceedances of the normative levels by more than 3 dB.

The analysis of the tested railway vehicle (ED250) by means of the original noise load factor allows characterising the exceedances generated in relation to the permissible values laid down in the Regulation. The results of the analysis show that on the straight section, the increase in sound levels is rather sudden, causing the factor values to rise sharply from very good (dark green colour) to unacceptable values. Alarming values appear only one second before and after the appearance of unacceptable values. Railway vehicles travelling along a curve exhibit greater linearity in the accumulation of the NLF. During the approach of the object, the indicators gradually change their values from very good, acceptable and alarming to unacceptable. When the vehicle departs, unacceptable values significantly increase (relative to the straight section by 2–3 seconds) and the NLF drops more slowly to very good values.

Taking into account the results of the analysis, the original noise load factor allows adopting a more comprehensive approach to the interpretation of the acoustic impact of railway vehicles.

Table 3

Noise load factor on straight section for selected trips (Pn) at a distance of 40 m

Travel time [s]	Noise load factor at adistance of 40 m, *h* = 4 m									
	Straight section					Curve				
	P1	P3	P4	P8	P9	P1	P3	P4	P8	P9
1	−2.42	−2.74	−2.97	−3.43	−3.31	−1.48	−1.36	−0.68	−1.42	−1.42
2	−2.44	−2.16	−3.02	−3.21	−3.31	−1.34	−1.28	−0.68	−1.20	−1.40
3	−2.30	−1.63	−2.33	−2.49	−2.74	−1.13	−1.20	−0.62	−0.87	−0.96
4	−1.76	−1.71	−1.82	−2.23	−1.90	−0.74	−0.81	−0.44	−0.45	−0.62
5	−1.48	−1.58	−1.14	−1.79	−1.63	−0.57	−0.55	−0.22	−0.27	−0.20
6	−0.83	−1.20	−0.48	−0.84	−1.05	−0.23	−0.23	0.07	−0.04	0.00
7	0.30	−0.71	0.31	−0.07	−0.40	0.24	0.05	0.30	0.44	0.38
8	1.67	0.15	1.06	1.07	0.85	0.95	0.74	1.21	1.34	1.18
9	2.32	2.17	2.20	2.02	2.64	2.05	1.86	2.19	2.24	2.15
10	2.36	2.26	2.32	2.30	2.70	2.38	2.34	2.42	2.38	2.34
11	2.35	2.25	2.34	2.30	2.65	2.39	2.35	2.42	2.38	2.39
12	1.98	2.02	2.05	2.19	2.24	2.31	2.34	2.17	2.07	2.22
13	1.11	1.20	0.48	1.63	0.35	1.29	1.58	0.88	0.69	0.94
14	0.16	0.20	0.20	−0.04	−0.20	0.21	0.25	0.16	0.13	0.40
15	−0.26	−0.45	−0.59	−0.42	−0.87	−0.24	−0.40	0.07	0.20	0.21
16	−0.74	−0.94	−0.99	−0.83	−0.84	−0.31	−0.24	−0.29	0.34	0.20
17	−0.99	−1.31	−1.74	−0.92	−1.36	−0.44	−0.74	−0.30	−0.27	−0.16
18	−1.20	−1.37	−2.24	−1.42	−1.72	−1.26	−0.81	−0.90	−0.77	−0.57
19	−1.40	−1.39	−2.42	−1.42	−2.07	−2.28	−1.63	−1.34	−1.20	−1.10
20	−1.58	−1.47	−2.69	−1.74	−3.31	−2.58	−2.19	−2.42	−1.66	−1.47

[Own elaboration]

4. Conclusion

The paper is an attempt to identify a new approach to the evaluation of noise generated by railway vehicles by means of an indicator method. It presents the main assumptions of the noise load factor, interpretation of the results and calculations based on the obtained values of the equivalent sound level A.

The author of the study proposes a solution for a comprehensive assessment of the impact of railway noise on the surrounding areas. The paper includes a description of the assumptions and the possibility of using the noise load factor (NLF) to evaluate the acoustic impact of railway vehicles. The introduction of an indicator assessment with a labelling system (colours) enables the identification of places at risk with respect to any search area. The results showed that the author's solution makes it possible to carry out the analysis for a single point, several points of a selected measurement cross-section, as well as for the entire surveyed section of the railway line. Furthermore, the transparent presentation of data allows the verification of the results by persons without expert knowledge.

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