Economic aspects of pavement surface degradation in terms of noise pollution in their surroundings

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Abstract. The morphology of the road surface is changing in time which has a consequence in increasing noise levels in areas near the roads. This fact was determined by measurements on two road sections. The measurements were done using the Statistical Pass-By method. Different types of asphalt surfaces were used on the road sections. The Statistical Pass-by Index (SPBI) was quantified from the measurements, which were carried out over the years. Functions of road surface noise evolution in time were calculated from quantified values of SPBI for both measured road surfaces.

1. Introduction

For the purpose of objectification of noise from road transport, currently, the decisive codified regulations are Act no. 355/2007 Coll. [2] and Decree of the Ministry of Health of the Slovak Republic no. 549/2007 Coll. [3]. Act o. 355/2007 [2] in Section 27 Noise, infrasound and vibration in the environment in relation to the described issue states the following facts:

- a natural person-entrepreneur and a legal person using or operating noise, infrasound or vibration sources, a road manager [1], a waterway operator, a rail operator, an airport operator, and operators of other objects producing noise (hereinafter referred to as " the operator of sources of noise, infrasound or vibration ") shall ensure that the exposure of the occupants and their environment is as low as possible and does not exceed the permissible values for day, night and night provided for in the implementing regulation;
- in the design, construction or substantial reconstruction of traffic structures and infrastructure, noise in related external or internal environments shall not exceed the permissible values at the assumed traffic load,
- in the design, construction or substantial renovation of buildings, it is necessary to ensure the protection of the indoor environment of buildings from noise from the external environment
- municipalities are authorized to objectify the exposure of the population and their environment to noise and vibration in accordance with the requirements laid down in the implementing regulation. Only those skilled in the business who hold an accreditation certificate can objectify the exposure of residents and their noise, infrasound and vibration environments.

The Decree of the Ministry of Health of the Slovak Republic 549/2007 Coll. [3], of December 1, 2007, prescribes the details of permissible values for determining noise quantities and requirements for the objectification of environmental noise. The Decree determines individual noise limits for:

- the external environment,
- the indoor environment of buildings.

Section 3 [3] states that the protection of health against noise is ensured if the assessed values of the determining quantities of noise are not higher than the permissible values (table 1). In relation to the issue addressed, the decisive provisions are presented in Section 6, which states:

- noise shall be assessed at the locations covered by the permissible values as follows:
    - outside noise outside buildings shall be assessed at the height of 1.5 m ± 0.2 m above the ground,
    - external noise in front of the perimeter wall shall be assessed at a distance of 1.5 m ± 0.5 m from the wall and at the height of 1.5 m ± 0.2 m above the floor of the relevant story,
- the measured value shall be increased by the value of the expanded measurement uncertainty determined in accordance with the metrological practice and, if necessary, in further corrections in accordance with the Annex. If necessary, it is determined for the relevant reference time interval. The obtained assessment value is compared with the permissible value.

Table 1. Permissible values of determining quantities in the external environment according to the Decree of the Ministry of Health of the Slovak Republic 549/2007 Coll. [3].

Area category	Description of the protected area or an external environment	Ref. time interval	Admissible values[a)] (dB)				
			Traffic noise				Noise from other sources
			Road and water transport [c)] $L_{Aeq,p}$	Railways [c)] $L_{Aeq,p}$	Air transport		
					$L_{Aeq,p}$	$L_{ASmax,p}$	$L_{Aeq,p}$
I.	Areas with special noise protection, e.g. spas, spa and health resorts	day	45	45	50	-	45
		evening	45	45	50	-	45
		night	40	40	40	60	40
II.	Areas in front of windows of residential rooms of residential houses, area in front of windows of the protected rooms of school buildings, medical facilities and other protected buildings, [d)] outdoor area in residential and recreational areas	day	50	50	55	-	50
		evening	50	50	55	-	50
		night	45	45	45	65	45
III.	Areas as in category II near motorways, roads of I. and II. class, local public transport roads, railways, and airports, city centres	day	60	60	60	-	50
		evening	60	60	60	-	50
		night	50	55	50	75	45
IV.	Non-residential and unprotected outdoor areas, manufacturing zones, industrial parks, factory premises	day	70	70	70	-	70
		evening	70	70	70	-	70
		night	70	70	70	95	70

[a)] The permissible values apply to dry road surfaces and terrain not covered in snow,
[b)] Inland transport is transport on the road, including tramways,
[c)] Stops for local public transport, bus, rail, waterway, and taxis intended for embarkation and disembarkation shall be assessed as part of land and waterway transport,
[d)] The permissible values in front of the facade of non-residential buildings shall be applied at the time of their use; schools during class times.

The 2012 dissertation [10] presented an overview of permissible road noise limits for EU countries. The overview of the permissible values of the determining quantities of noise in the Member States of the European Union shown in figure 1 [11] was prepared for a similar type of built-up areas and affected areas (new constructions in the area) and for transregional transport (motorways, expressways, bypasses, railway lines). The data on permissible values for determining noise quantities were obtained from foreign websites, foreign literature and the competent authorities of the Member States. The methodological tool for drawing up such an overview of limits was the document [7] (Inspection of the implementation of the Directive 2002/49 / EC on environmental noise), issued in 2010.

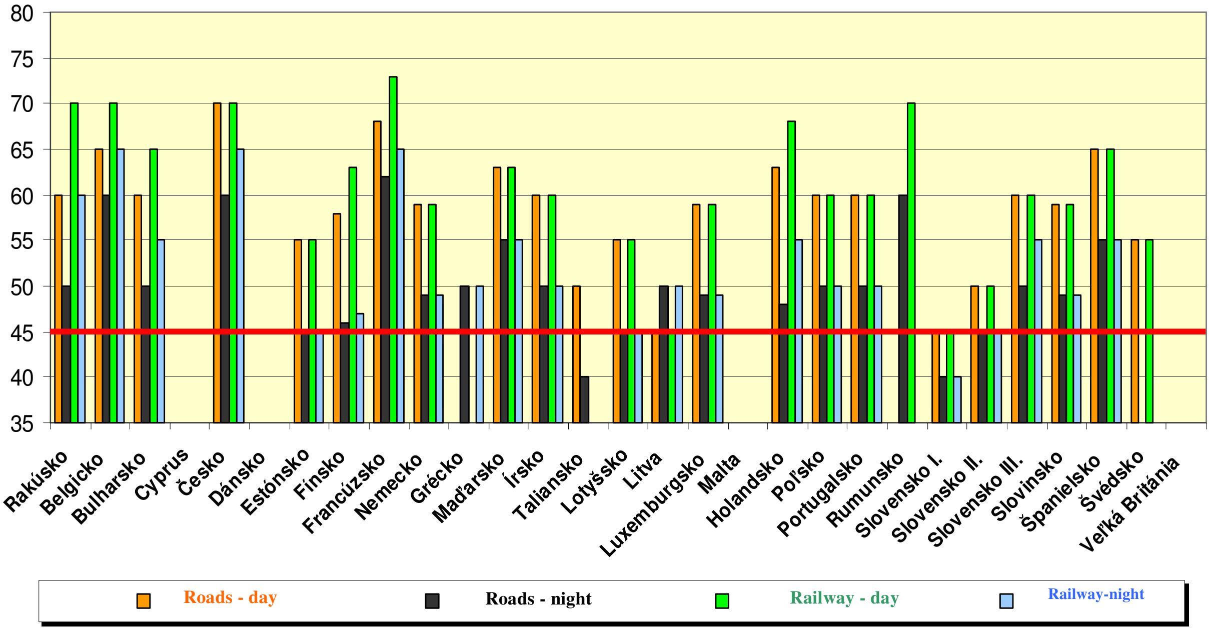

Figure 1. Permissible values of noise emissions from road and rail transport in EU countries EU [6].

Specific levels of noise and particle pollutions [8, 9] from road traffic are determined mainly by the intensity and composition of traffic flow [4, 5, 16], the state of road surface morphology [10, 12, 15] and vehicle-road interaction [6, 13]. Noise limits presented in table 1 and figure 1 do not take into account the increase in the noise load around the roads induced by a change in the morphology of the road surface. And this is exactly the problem discussed in this article.

2. Measurement of the influence of road surfaces on traffic noise.

Traffic noise measurements were performed by using Statistical Pass-By-Method (SPB) that is described in the ISO 11819-1. It provides a method to determine an index that can be used to compare the noise emission impact of different road surfaces by measuring vehicle pass-bys at the roadside. The SPB method is based on the measurement of the maximum A-weighted sound pressure levels of a statistically significant number of individual vehicle pass-by (table 2) together with the vehicle speeds.

Specific measurements of A sound levels L_A were conducted by sound analyser NOR-121 (Norsonic, Norway - ID 31211) accuracy Class 0. The sound analyser was calibrated prior to each set of measurements by microphone calibrator NOR N-1251 (Norsonic, Norway - ID 31069), accuracy Class 1. Applied measuring string of noise emissions and pollution had separate verification for own sound level meter, measuring microphone Nor-1225 (Norsonic, Norway - ID 48045), one-third-octave filters, acoustic calibrator. Velocity measurements were realised by speed radar gun Bushnell Speedster (table 1) and meteorology conditions by Wireless weather station - WS 888 set.

Table2. Vehicle categories in STN EN ISO ISO 11819-1 and results of measurements made 4.11.2008 and 23.6.2020 at measuring station by the road I/61 in Dolný Hricov (figure 2).

Category	Typical examples		Number of pass-by				
			minimum	4.11.2008		23.6.2020	
				No.	$L_{category}$	No.	$L_{category}$
1) cars	2 axles, 4 wheels passenger cars		100	102	76.6	175	80.9
2a) dual-axle heavy vehicles	2 axles, more than 4 wheels, light trucks, buses		30 (2a+2b = 80)	35	79.6	35	85.0
2b) multi-axle heavy vehicles	heavy trucks more than 2 axles		30 (2a+2b = 80)	48	84.5	54	86.6
SPBI (dB) corrected to reference temperature 20ºC				82.7 dB		78.7 dB	

Figure 2.Views of the measuring station on the BUS stop by the road I/61 in Dolný Hričov on 8.6.2008 and 23.6.2020 with an indication of measuring distances.

This regression line was then used to determine the average maximum A-weighted sound pressure level L_{veh} at the reference speed. The L_{veh} of the three vehicle categories ($L_{veh,1,regression} \equiv L_1$, $L_{veh,2a,regression} \equiv L_{2a}$, $L_{veh,2b,regression} \equiv L_{2b}$)can be combined to give a single index called SPBI (Statistical Pass-By Index) which is indicative of the influence of the road surface on the noise emission of a mixed vehicle collective

$$SPBI = 10 \times \log\left[W_1 \times 10^{\frac{L_1}{10}} + W_{2a} \times \left(\frac{v_1}{v_{2a}}\right) \times 10^{\frac{L_{2a}}{10}} + W_{2b} \times \left(\frac{v_1}{v_{2b}}\right) \times 10^{\frac{L_{2b}}{10}} \right] \quad (1)$$

where:

SPBI	- the Statistical Pass-by Index, for a standard mix of light and heavy vehicles	(dB)
L_1, L_{2a}, L_{2b}	- the Vehicles Sound Levels for vehicle categories 1, 2a, 2b (figure 1)	(dB)
W_1, W_{2a}, W_{2b}	- the weighting factors, which are equivalent to the assumed proportions of vehicle categories in the traffic (table 2)	(-)
v_1, v_{2a}, v_{2b}	- the reference speeds of individual vehicle categories (table2)	(km·h^{-1})

The passing vehicles were classified into one of three vehicle categories and one of three reference speeds was chosen according to the average operating speed of the road (table 2).

Table 3. Reference speeds and weighting factors (W_x) in the different road aped categories.

Vehicle category		Road speed category					
		Low		Medium		High	
Name	No.	Ref. speed (km/h)	W_x	Ref. speed (km/h)	W_x	Ref. speed (km/h)	W_x
Cars	1	50	0.900	80	0.800	110	0.700
Dual-axle heavyvehicles	2a	50	0.075	70	0.100	85	0.075
Multi-axle heavyvehicles	2b	50	0.025	70	0.100	85	0.225

A regression line of the maximal A-weighted sound pressure level versus the logarithm of speed was calculated for the pass-bys of every category (Figure 3 to 5).

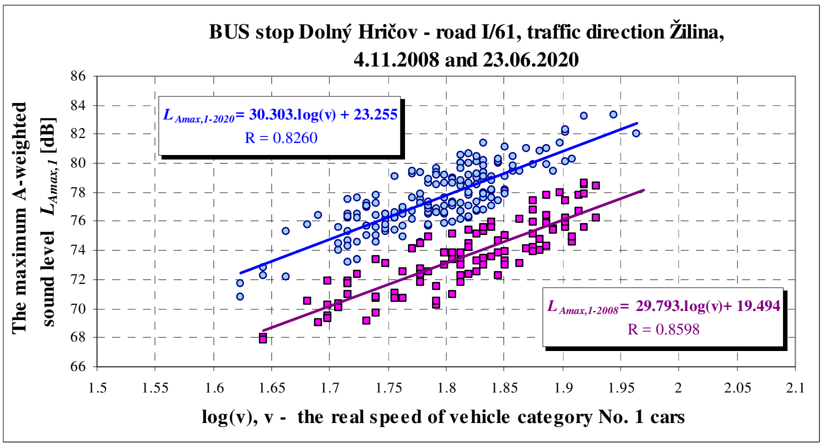

Figure 3. Correlation dependences of the maximum A-weighted sound level on the logarithm of the real speed vehicles of category 1 cars.

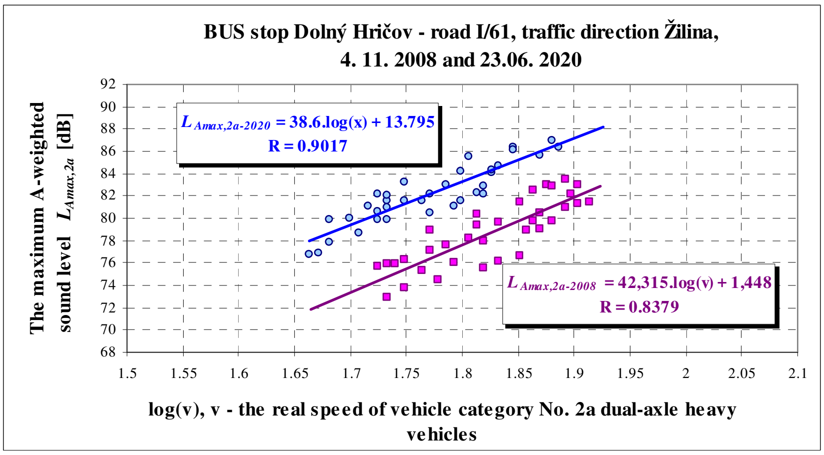

Figure 4. Correlation dependences of the maximum A-weighted sound level on the logarithm of the real speed vehicles of category 2a dual-axle heavy vehicles.

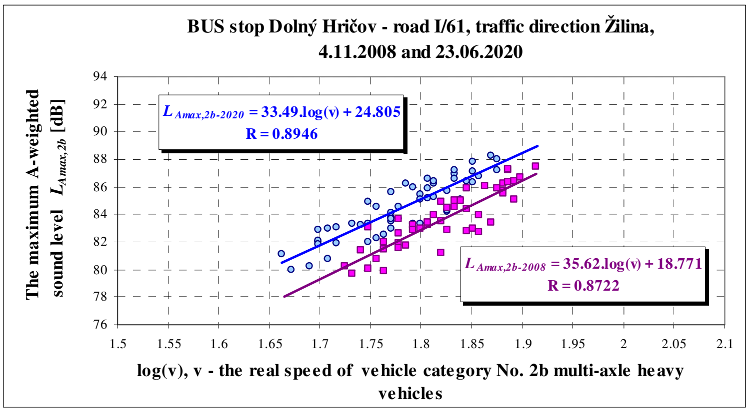

Figure 5. Correlation dependences of the maximum A-weighted sound level on the logarithm of the real speed vehicles of category 2b multi-axle heavy vehicles.

3. Valuation of noise costs

The monetary valuation of the negative impacts that arise from the use of the road expresses society-wide costs. Impacts caused by the use of the road by its users are referred to as user costs. External costs value the negative impacts that arise during the construction and operation of the road and have an impact on society and the environment. The principle of design quantification and valuation of the costs of road traffic noise is elaborated in Fig.6 Principle of quantification and valuation of noise costs.

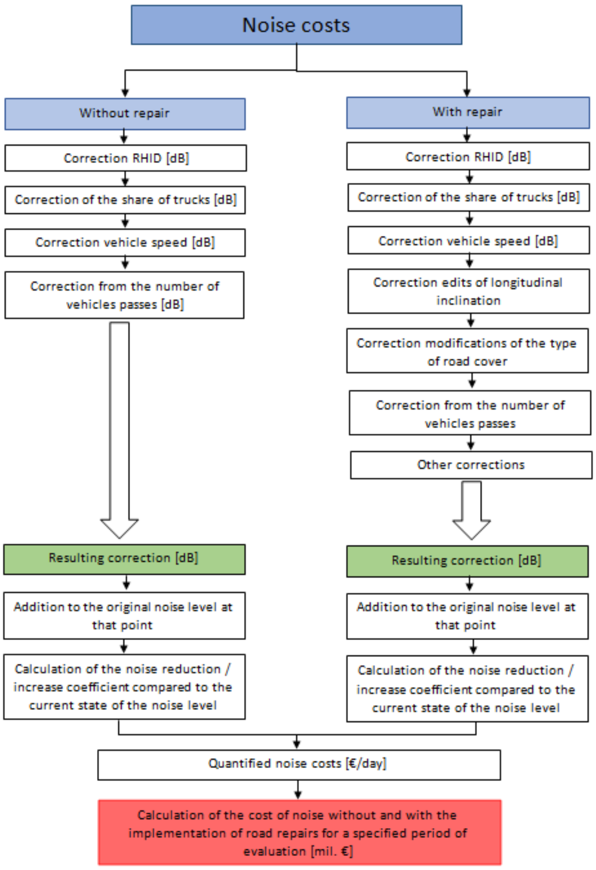

Figure 6. Principle of quantification and valuation of noise costs [14].

Quantification and valuation of society-wide costs are relatively complicated in practice. The society-wide costs in a given year are calculated according to the formula (2)

$$CN_t = \sum_{t=tu}^{T} UN_t + \sum_{t=0}^{T} EN_t \qquad (2)$$

where:

CN_t	- the Society-wide costs in the considered year	(€)
UN_t	- the User costs in the considered year	(€)
EN_t	- the External costs in the year under consideration	(€)
t	- the year considered	(years)
t_u	- the start of road use	(years)
T	- thenumber of years of the road life cycle	(years).

On the selected section of the road I/61, the asphalt cover was replaced due to unsatisfactory parameters of the road cover. Table 4 shows the quantified noise costs for the site of road I / 61 without road repair and with road repair. Valuation of costs for noise from road traffic on this road was processed in the excel program. [14]

Table 4. Cost of noise without repair and with repair.

Without repair		With repair	
Low intensity	High intensity	Low intensity	High intensity
11 778.39	4 184.79	7 852.26	2 789.86
11 778.39	4 184.79	7 852.26	2 789.86
11 778.39	4 184.79	8 314.16	2 953.97
11 778.39	4 184.79	8 314.16	2 953.97
11 778.39	4 184.79	11 085.55	3 938.63
11 778.39	4 184.79	11 085.55	3 938.63
11 778.39	4 184.79	11 085.55	3 938.63
11 778.39	4 184.79	11 085.55	3 938.63
11 778.39	4 184.79	11 085.55	3 938.63
11 778.39	4 184.79	11 085.55	3 938.63
11 778.39	4 184.79	11 085.55	3 938.63
129 562.32	46 032.71	109 931.66	39 058.06

Conclusions

The article presents comparisons of traffic noise measurements performed according to requirements STN EN ISO 1819-1:2002 Acoustics. Measurement of the influence of road surfaces on traffic noise. Part 1: Statistical Pass-By method [17] from the years 2008 and 2020. Measurements of SPBI were realised 5 months (4.11.2008) and 12 years (23.6.2020) after the rehabilitation of wearing course of asphalt pavement of road I/61 in Dolný Hričov. Degradation of the surface morphology of asphalt concrete wearing source during 12 years operation caused the SPBI index the increase 4 dB (table 2).

The total cost of noise without road repairs is € 129,562.32. In the case of road repairs, the total cost of noise for the evaluation period of 10 years would reach € 109,931.66. The cost savings are € 19,630.65. For comparison, if the road were located in an urban location, the cost of noise would reach (low traffic intensity) the value of € 2,953,206.61 without repair of the road and € 2,505,751.07 with the repair. The cost savings would be € 447,455.55.

Acknowledges

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