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NOISE COSTS FROM ROAD TRANSPORT

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Abstract

Building and improving road infrastructure in Slovakia is currently influenced by the amount of state funding. Therefore, it is necessary to determine the effectiveness of each proposed solution of road project, which is based on life-cycle costs. Besides capital costs, social costs are also important, which valued the negative impacts due to road construction and operation on road users, the environment, and the population living in the affected area. Some components of social costs have shortcomings in quantifying and valuating, which need to be resolved. The one of important components which affects human health and the value of an area, and have some shortcomings are noise costs. Improvement of this component will lead to more accurate valuation of economic efficiency of roads.

Keywords:

Road communication;
Social external costs;
Noise costs;
Economic efficiency;
Environmental costs.

1 Introduction

The development of road infrastructure is one of the main priorities of the state and it is important particularly for its economic growth. At present, the development and improvement of road infrastructure is mainly affected by insufficient amount of the state financial, which is allocated for building and improving road network. The limited amount of funds is the reason for determining the efficiency of each road infrastructure project with the aim effective expends these funds. Assessing the efficiency of the road project is based on the life-cycle costs. Cost quantification of the road project consists of the funds needed for the preparation, implementation and operation of the road, and of the social costs, which quantify the impacts on society. Social costs include the costs of the road users and the costs which will be arisen by the construction and operation the road and affected the environment and population living in the territory concerned. Their amount is specific for each project. In practice, the social costs are quite easy to identify, but their quantification and monetary valuation are difficult. For complex assessment and decision-making process on effectiveness of proposed road project is used economic analysis and its economic indicators. For the right decision on economic efficiency, it is important to accurately quantify and evaluate all cost components. At present, the quantitative and financial assessment of social costs in Slovakia has some deficiencies in some cost components. One of these components are noise costs, which important influence human health and also the value of the affected area. Removal and improvement of these deficiencies will lead to the more accurate of economic valuating and also will lead to the improving economic use of funds needed for road infrastructure.

2 Life-cycle costs of the road

The life-cycle of the road is a defined sequence of phases, which begins with the intention of the project and ends with the liquidation, respectively reconstruction of road. Individual life-cycle phases can be defined according to shown terminology in Table 1. Each phase of the life-cycle has defined its technical, economic, and time risks as well as the costs, which are incurred in the given phase [1].

Table 1: Life-cycle of road projects.

1	Acquisition										Using			Disposal
2	Prior to the investment phase		Investment phase								Phase of use			
3	Pre-project phase		Project phase			Realization phase				Completion of construction		Using of building		Change of intent
4	assignment for construction intent	construction intent	territorial decision	planning permission	realization and design documentation of the construction	tender documents	the works contract with selected contractors	construction and technical documentation of construction	documentation of real construction	protocol on trial operation	protocol on the final approval and handover of the construction	documentation of initiation and full operation of the construction	documentation of construction maintenance	documentation of construction repairs	Studies and plan for the reconstruction or disposal of the construction

Legend: 1 - basic parts of the life-cycle, 2 - phases of the life-cycle according to UNIDO, 3 - phases of the life-cycle according to Slovak terminology, 4 - stages of the life-cycle [1].

The assessment of the economic efficiency of the road is based on the life-cycle costs. These costs are not only financial flows associated with the acquisition, construction, and operation of the road, but also non-monetary components which will arise due the road construction and operation for the whole society, i.e. social costs. The life-cycle costs of road can be quantified by:

$$LCC = \Sigma\ CC + \Sigma\ SC, \qquad (1)$$

where:
LCC - life-cycle costs of the road [€],
CC - capital costs of the road [€],
SC - social costs of the road [€].

Capital costs represent amount of financial funds needed for the realization and subsequent operation of road. Social costs valued impacts, which arise from the road construction and operation for road users, wide society and environment. For road users are important costs associated with travel time and vehicle operating costs. The costs associated with affected area and its inhabitants particularly represent accident costs, noise and vibration costs, air pollution costs, climate changes costs, environment and landscape costs and others costs [2]**Chyba! Nenašiel sa žiaden zdroj odkazov.**.

Assessing the effectiveness of road is done for economic lifetime, i.e. 25 - 30 years. From this reason it is necessary to make a forecast of development operating and social costs [2].

3 Social costs of a road project

Social costs represent the sum of costs components that quantify and monetize individual negative impacts of road for road users, environment and inhabitants living in affected area. Cost Benefit Analysis (CBA) is a complex model used to on assessing an investment projects in Slovakia. The Slovak CBA manual divides the social costs on vehicle operating cost, travel time cost, accident cost, noise, air pollution and climate change costs. Besides the CBA manual, there is following software used for quantifying and valuation of social costs in Slovakia: HDM-4 (Highway Development and Management system) and ISEH (Integrated system of design and economic assessment). HDM-4 software is the world used software which quantify and monetize travel time costs, vehicle operating costs, and accident costs. HDM-4 also quantify amount of emissions from cars, but do not monetize them. The HDM-4 manual complements the social costs on the non-motorized component. ISEH software is able to quantify travel time costs and vehicle operating costs on existing roads in cases of design technological works such as repairs and maintenance and in case of reconstruction (changing category of road) [2] [3] [4] [5].

As mentioned above, economic evaluation of roads in Slovakia has some shortcomings which were detected by analysing of social costs components in Slovakia and abroad countries. Division of social costs is a little bit different for each country. For showing the widest range of social costs components, the proposal of division was made (Fig.1), which is a combination of a few literature resources. Based on this, the comparison of social costs components in Slovakia was done and found out their shortcomings. This proposal of social costs component with highlighted shortcomings is shown in Fig.1.

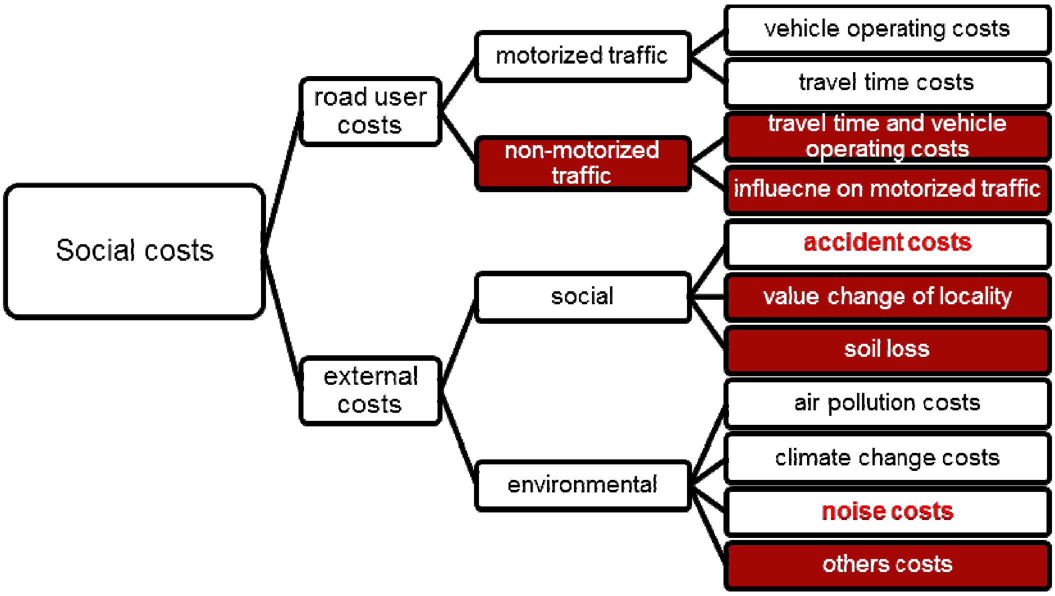


Fig. 1: Proposal of divided social costs in Slovakia with highlighted shortcomings [3] [6].

The red-coloured components of social costs are not valuated in economic assessment of road in Slovakia. From user costs they are the components of non-motorized traffic. Non valuated components of social external costs are value change of locality and soil loss. Non valuated external environmental cost components in Slovakia are vibration costs, costs for landscape and nature, water and soil pollution, costs for biodiversity loss, costs for urban separation and up and down stream costs.

The red-written cost components of external costs accident and noise are valuated in the economic assessment in Slovakia, but there are some shortcomings. The suggestion is improvement the existing evaluation methodology.

The methodology for valuating accident costs is based on an accident rate on 100 million vehicle kilometres according of the road type, locality, and type of an accident. The suggestion for improvement is to supplement the existing methodology by specifying the accident rate for traffic flow and impact of non-motorized traffic. Another important aspect in the assessment of accident costs, which is currently not taken into account, are black spots. The suggestion for improvement it the incorporate this aspect when in assessing accident costs [2].

The current valuation of traffic noise costs is based on the CBA manual for Slovakia. The valuation of noise cost is based on vehicle kilometres. The amount of noise costs is calculated according to the type of a vehicle, part of a day, traffic intensity, and locality (urban, suburban, out of urban) [2].

$$N_C = \sum A_i \cdot UC_i, \qquad (2)$$

where:

N_C - noise costs [€],

A_i - amount of vehicle kilometres for a car type (i), part of a day, traffic intensity, and locality [1000 vehkm],

UC_i - unit noise cost for a car type (i), part of a day, traffic intensity, and locality [€/1000vehkm].

The suggestion is improving the existing methodology which would more precisely define the locality (the distance from noise source in kilometres respectively meters) and the valuation would be related to the noise level in dB depending on the type and condition of a road pavement, which significantly affects the noise level. The noise effect is reflected in two cost components. In social external costs it is the component of value change of the locality. In environmental external costs it is the component of noise cost, which valuated impacts on human health.

4 Noise from road traffic

The noise pollution surroundings road is a relevant factor which determining the quality of environment. In the Slovak Law No. 355/2007 in § 27 [8]: noise, infrasound, and vibration in the environment in relation to the issue of the wide-society environmental impacts of road operation are mentioned these facts: Physical person (entrepreneur) and legal entity, who use or operate sources of noise, infrasound or vibration, the infrastructure manager, waterway operator, runway operator, and operator of others objects which generate noise from its operation are obliged to ensure that the exposure of the population and their environment will be as low as possible and will not be exceed the permissible values for the day (06:00 - 18:00), evening (18:00 - 22:00), and night (22:00 - 06:00) [7].

Noise can be defined as an unwanted or disturbing sound that has its duration, intensity, and source and causes physical or mental harm to person. Noise is an acoustic effect which takes place in time and space according to physical laws. The negative impact of noise depends on several factors. It is directly proportional to the acoustic pressure, exposure time, degree of intrusiveness, and reducing break times in a relative calm. These factors may be combined with other adverse effects such as vibration, dust, humidity and low temperatures. The noise from the road operation is linear. The basic formula for calculating the noise is [9]:

$$L = 10\log\frac{p^2}{p_o}, \quad (3)$$

where:
p - air pressure [Pa],
p_o - lower limit of audibility is $2\cdot10^{-5}$ Pa [Pa].

Sound waves from linear sources are theoretically disseminating on the cylindrical surface. Unless the sound waves overcome the distance from source to recipient, will occurs spatial attenuation of waves, i.e. decreasing of noise level. The value of decrease of noise level depends on:

- recipient's distances,
- meteorological conditions,
- surface of the environment [9].[1]

Traffic noise comes from three main sources: from the interaction between the tire and the road surface, from engine, and the exhaust of the vehicle. The level of traffic noise is influenced by many factors and is a function:

$$f\,(RCs, RC, TV, CTF, TF, VS, D, L, B, W), \quad (4)$$

where:
RCs - road class,
RC - road condition,
TI - traffic volume,
CTF - composition of traffic flow,
TV - traffic flow,
VS - vehicle speed,
D - distance (source – recipient),
L - locality (urban area, rural area),
B - type and height of barrier,
W - weather condition.

All of these factors affect the noise level of road traffic. Significant influence on the level of traffic noise has road surface condition especially texture and porosity. Both characteristics influence the noise generation between the tire and the road surface (Fig. 2).

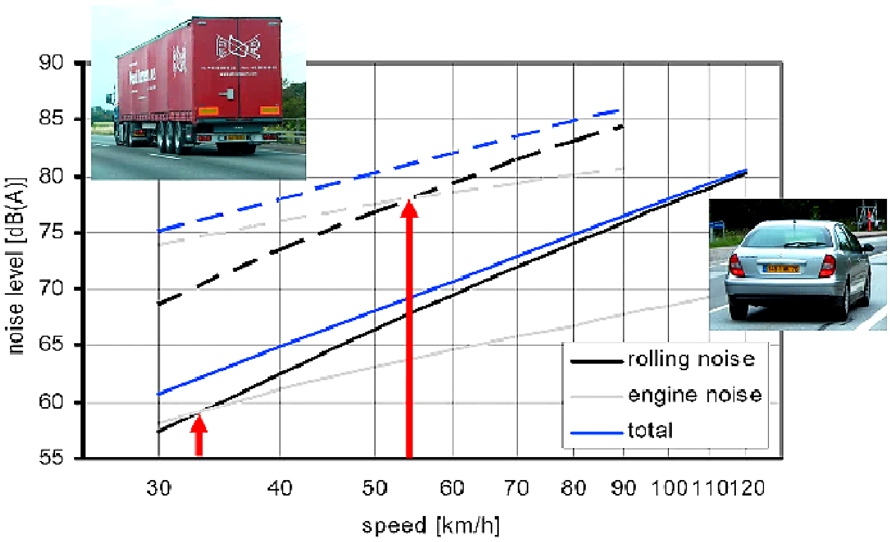


Fig. 2: Graph of noise sources for two types of vehicle category [10].

Engine noise is usually generated at higher height over road surface as rolling noise. This noise can be affected during spread by road surface porosity. These facts lead to differences in noise levels at the same traffic intensities and composition of traffic flow pending to 15 dB. This may have a significant impact on the quality of the environment of the road surrounding and the resulting prices of real estate. The measurement of rolling resistance noise based on road surface characteristics is carried out by using a standardized method. International Standard ISO (International Organization for Standardization) 11819 consists of two basic parts:

- Part 1: Statistical Pass-By method (SPB),
- Part 2: Close-proximity method (CPX) [11] 12].

Statistical Pass-By Method was got into in Slovak technical standards by STN EN ISO 11819-1, which is primarily designed to compare noise levels of different road surfaces. This standard provides to administrative authority for road and environmental a tool for establish common procedures or restrictions on the use of road surface courses, which are meeting certain noise criteria. This standard does not specify assessment criteria. In order to obtain the overall road surface impact on traffic noise for a representative vehicles composition (1 – personal cars, 2a – two axles heavy cars, 2b - three and more axles heavy cars) must calculate the statistical index by formula [11]:

$$SPBI = 10 \cdot \log\left[W_1 \cdot 10^{\frac{L_1}{10}} + W_{2a} \cdot \left(\frac{v_1}{v_{2a}}\right) \cdot 10^{\frac{L_{2a}}{10}} + W_{2b} \cdot \left(\frac{v_1}{v_{2b}}\right) \cdot 10^{\frac{L_{2b}}{10}}\right], \quad (5)$$

where:

$SPBI$ - statistical Pass-by Index for a standardized composition of light and heavy vehicles,

L_1, L_{2a}, L_{2b} - level of acoustic pressure of vehicle categories 1, 2a, 2b,

W_1, W_{2a}, W_{2b} - weight factors, which corresponds to the assumed ratio of vehicle categories in traffic flow,

v_1, v_{2a}, v_{2b} - reference speeds of individual vehicle category [11].

In the Slovak technical standard STN EN ISO 11819-1 it is stated that the level of acoustic pressure measured at the temperature Ti [ºC] are be corrected to a reference temperature 20 °C. The correction is done by formula [10]:

$$L_{eq}^{T=20°C} = L_{eq}^{T_i} - 0.04 \cdot (20 - T_i). \quad (6)$$

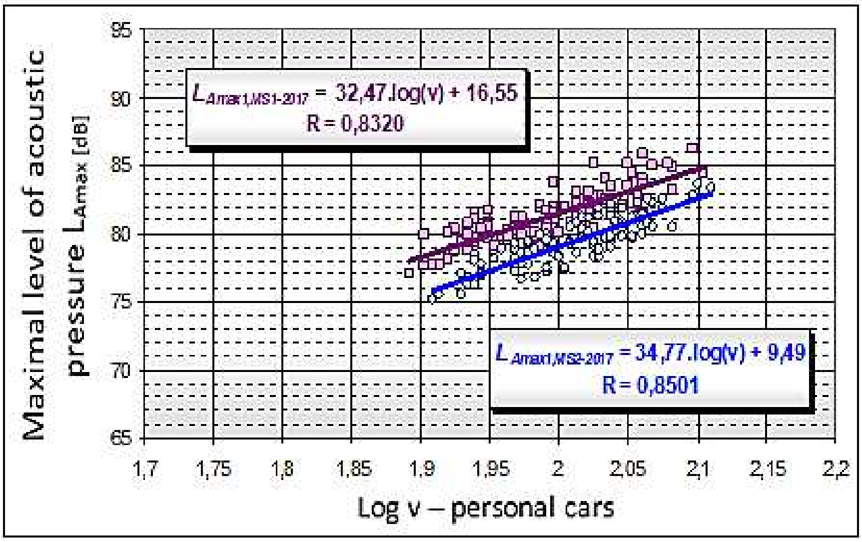
The SPB method is used for two main purposes: on surfaces classification and for assessment of different road surfaces and their impact on traffic noise.

To compare the noise levels of different types of asphalt was done measurements on highway R1 Zvolen - Banská Bystrica on two sections with different types of asphalt on surface course. On the first measuring section MS1 was used SMA 11 O asphalt on surface course. The trial section MS2 has the surface course of SMA 11 / PMB 45 / 80-55, on which was used rubber granulate from used tires. Measurements on these sections were done on 4 November 2011 and 14 September 2017. In Table 2 are evaluated SPBI indexes for both sections and both dates.

Table 2: Measured SPBI indexes on MS1 and MS2 on 4 November 2011 and 14 September 2017.

Date of measurement	**Measurement section**	**Reference and average speeds [km/h]**					***SPBI* [dB] calculated at *T* = 20 ºC**		
		Evaluated value		**1**	**2a**	**2b**	$SPBI_{MS1}$	$SPBI_{MS2}$	$SPBI_{MS1}$ - $SPBI_{MS2}$
14 September 2017	**MS1** SMA 0 11	v_{ref}	**[km·h^{-1}]**	**110**	**85**	**85**	86.0 dB		**3.3 dB**
		v_{sk}	[km·h^{-1}]	98.8	84.4	82.7			
		L_i	[dB]	82.8	84.8	88.7			
	MS2 SMA 0 11; PMB	v_{sk}	[km·h^{-1}]	103.0	82.3	84.2		82.7 dB	
		L_i	[dB]	80.4	82.2	85.0			
4 November 2011	**MS1** SMA 0 11	v_{sk}	[km·h^{-1}]	82.8	84.0	88.3	85.1 dB		
		L_i	[dB]	102.0	83.1	82.9			
	MS2 SMA 0 11; PMB	v_{sk}	[km·h^{-1}]	79.4	81.2	85.2		81.9 dB	**3.2 dB**
		L_i	[dB]	79.4	81.2	85.2			

The following graphs show the regression lines for the dependence of the maximum level of acoustic pressure from the decimal speed logarithm for the different vehicle categories on measurement sections MS1 and MS2 on 14 September 2017.



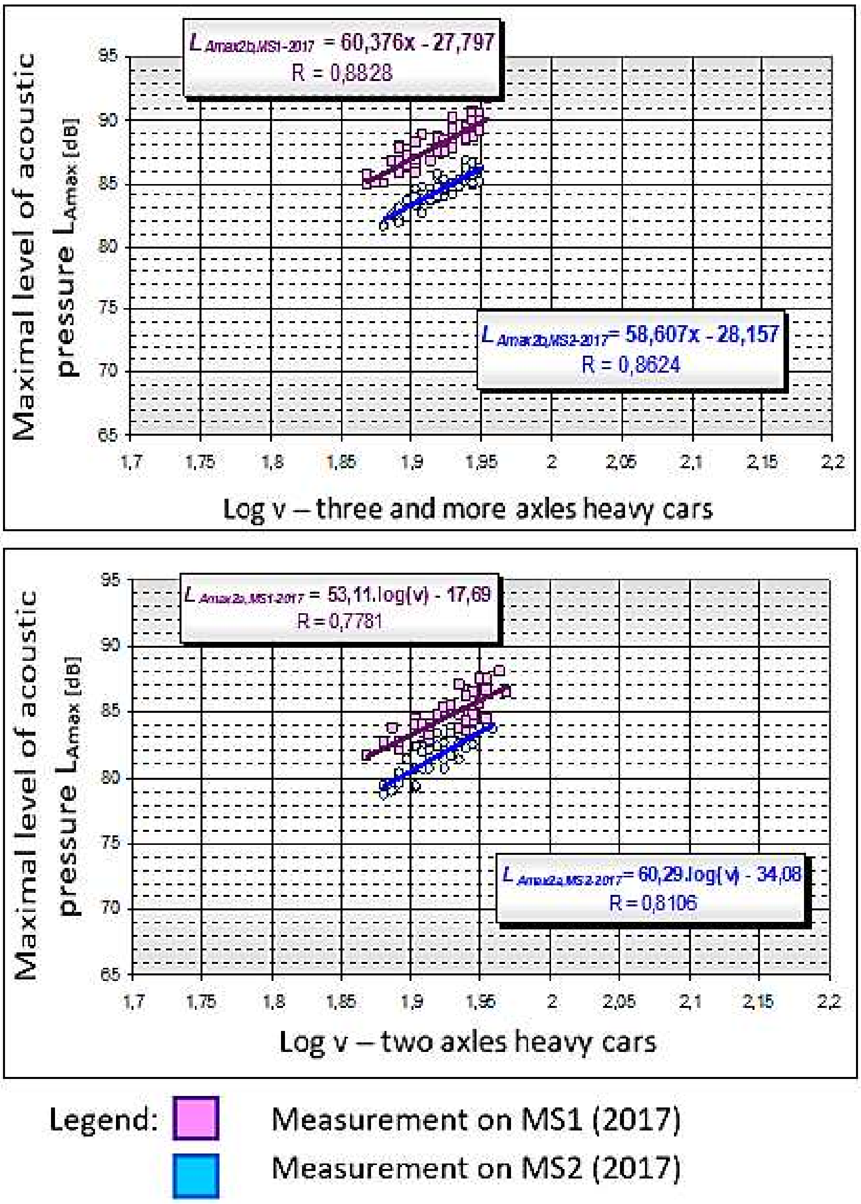


Fig. 3: Regression lines of the maximum levels of acoustic pressure from the decimal speed logarithm for vehicle categories 1, 2a, and 2b on measurement sections MS1 and MS2 evaluated from measurements on 14 September 2017.

We can state on the measurements from sections MS1 and MS2 that the influence of road surface has significant impact on noise level. Surface course SMA 11 (MS1) for the high-speed road category showed that SPBI index is 3.2 dB higher than SMA O 11 (MS2) in 2011. Measurement which was done after 6 year showed that the road degradation caused increase noise level on both sections. On MS1 was the noise level higher about 3.3 dB than on MS2.

The current methodology for assessing noise costs which is mentioned above is based on the type of a vehicle, part of a day, traffic intensity, and locality. Suggestion for more accurate quantification and valuation of noise costs should be taken into account type and condition of road surface.

5 Conclusion

Social costs are an important component in the economic evaluation of roads projects. These costs are quantifying negative impacts caused by the construction and operation of the roads for its users, the environment, and the population living in the affected area, and therefore it is important their quantifying and valuating as accurately as possible. Some of social costs components have shortcoming and some of these are not at all quantifying and valuating in Slovakia.

Computing of road project costs are calculated for its economic lifetime therefore must be taken into account the development of economic costs in time. The costs are influenced by many factors and one of them is the condition of a road surface. This factor influences not only amount of operating costs, but also amount of social costs. Development prognosis of road surface condition is based on degradation models according road type. Not all social components are quantified and valuated with respect to road types and their degradation, even if they are significant influence. The authors of this contribution highlight on problematic places in quantifying and valuating of noise costs caused by road transport.

The type and condition of road surface has a considerable impact on the noise level from road transport, which was demonstrated by noise measurements on highway R1 Zvolen – Banská Bystrica. There were two measurement sections: MS1 and MS2. The difference in these sections was in used asphalt on the surface course. The surface course on section MS1 was of SMA O 11 and on section MS2 was of SMA O 11; PMB.The measurements showed that the rubber-modified asphalt has had lower noise level by 3.2 dB (2011) respectively 3.3 dB (2017). Two measurements were done on both sections: the first measurement in 2011 and the second one in 2017. Comparing the measurements from 2011 and 2017 it was found that due to time was increased the noise level on MS1 by 0.9 dB and on MS2 by 0.8 dB.

We can state according to measurements that the road type and surface condition has an important impact on the traffic noise level. For this reason, it is necessary to incorporate these factors in assessing noise costs.

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