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IMPACT OF ROAD TRAFFIC NOISE FROM THE R3 EXPRESSWAY IN THE SECTIONS ORAVSKÝ PODZÁMOK – DOLNÝ KUBÍN – HIGHWAY D1

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Abstract
The components of Slovakia's integrated transport infrastructure should be designed, constructed, maintained, and decommissioned at a reasonable cost and quality, respecting the relevant requirements of users, residents in the surrounding area, and the principles of sustainable development throughout its entire life cycle. A comprehensive integrated transport infrastructure must ensure multimodal, interoperable, and safe transport with the lowest possible carbon footprint, focused on regional development and cohesion, with maximum economically feasible minimization of environmental noise induced by traffic. This article provides the basis for fulfilling this premise in environmental noise reduction along the section of the first-class road I/59 from the village of Oravský Podzámok to the village of Likavka, where the current noise levels exceed the permissible values set by legislation. The solution to this problem is expected to be the construction of the R3 expressway, which is being considered in two variants.

Keywords:
Environmental Noise;
Road Traffic;
Noise Study;
Environmental Noise Costs;
Noise Mitigation Measures.

1 Introduction

The rate of urbanization across all European countries, including Slovakia, has been significantly influenced in recent decades by economic and technological developments in the fields of transportation and industry. The changes in land use associated with urbanization and the overall development of cities meet public demands for an improved standard of living but also have negative impacts on society in the form of undesirable side effects. Among these factors are issues such as environmental pollution, waste generation, and the increasing influence of physical factors like noise and vibrations.

Noise is generally defined as unwanted or disruptive sound that has a certain duration, intensity, and source. Road traffic noise is generated by the operation of vehicles on roadways and is one of the major sources of noise pollution in the transportation sector. Noise has a negative impact on human health, potentially leading to cardiovascular diseases, psychological disorders, and more. Additionally, noise interferes with rest, enjoyment of leisure activities, and overall comfort. Noise studies are often part of the environmental impact assessment (EIA) process for road infrastructure projects.

In recent times, the economic aspects of traffic noise have come to the forefront, alongside environmental considerations.

A road infrastructure project is defined by a sequence of phases that constitute the life cycle of the road [1], [2]. The division of the life cycle into individual phases is essential for identifying the technical, economic, and temporal risks associated with the project. Each phase of the life cycle is crucial to the overall success of the project. Specific types of costs arise during each phase of the road infrastructure project life cycle (Fig. 1) [3].

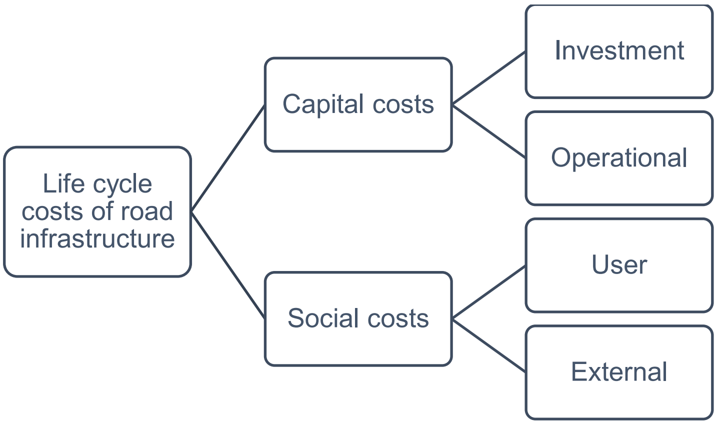

Fig. 1: Life cycle costs of road infrastructure [3]

During the operational phase, substantial capital costs are incurred for the management, maintenance, and repair of roads. In addition to the capital costs of a road infrastructure project, there are also societal costs associated with its operation. Societal costs represent the monetized negative impacts of road traffic on road users, society, and the environment. Both capital and societal costs associated with road operation are integral to the economic evaluation of road infrastructure projects.

This article continues the discussion on economically feasible minimization of environmental noise from road traffic. It focuses on assessing the negative impact of road traffic noise, quantifying and evaluating it along the section of the first-class road I/59 in the districts of Dolný Kubín and Ružomberok, with alternative solutions for the construction of the R3 expressway from Oravský Podzámok to the D1 motorway connection in the village of Likavka, and proposing measures to reduce noise levels.

2 Qualification and Valuation of Societal Costs of the Road Infrastructure Project

Quantifying and valuing the societal costs of a road infrastructure project is a complex process in practice. It is carried out based on available methodologies and their implementation in software environments. The specific negative impacts that arise from the construction and persist throughout the usage period of the road infrastructure are quantified (Fig. 2) [3].

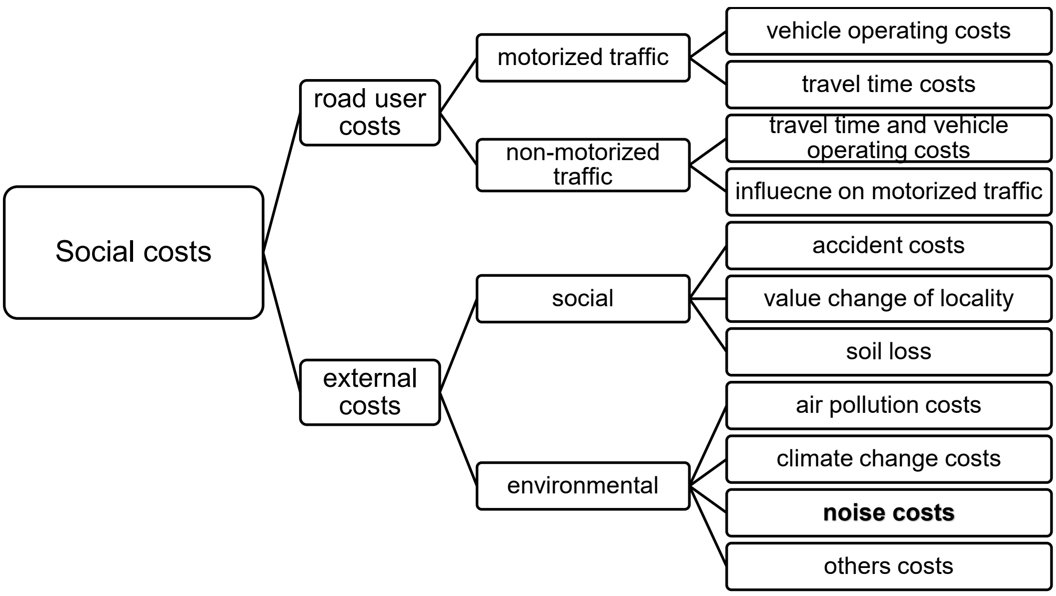

Fig. 2: Distribution of social costs in Slovakia [3]

2.1 Qualification and Valuation of Road Traffic Noise Costs

In Slovakia, the effectiveness of road infrastructure projects is assessed using tools such as the Cost-Benefit Analysis (CBA) manual [4] and the HDM-4 (Highway Development and Management System) software [5]. Additionally, the ISEH (Integrated System for Economic Evaluation) software is utilized [6]. The ISEH software is developed by the Department of Construction Technology and Management at the Faculty of Civil Engineering, University of Žilina, in collaboration with the Slovak Road Administration in Bratislava.

The quantification and valuation of road traffic noise costs based on the CBA methodology for Slovakia involves calculating the daily noise costs using equation [3], [4]:

$$NH = \sum_{i=1}^{n}\left(PVK_{n,d} * JNH_{n,d,m,l}\right), \tag{1}$$

where:
NH - Noise costs [€],
$PVK_{n,d}$ - Vehicle kilometers for vehicle category n [vkm/1000] and part of the day d,
$JNH_{n,d,m,l}$ - Unit noise costs according to vehicle category n, part of the day d, traffic intensity m, and location l [€/1000vkm].

The calculation algorithm is shown in Fig. 3 of the dissertation.

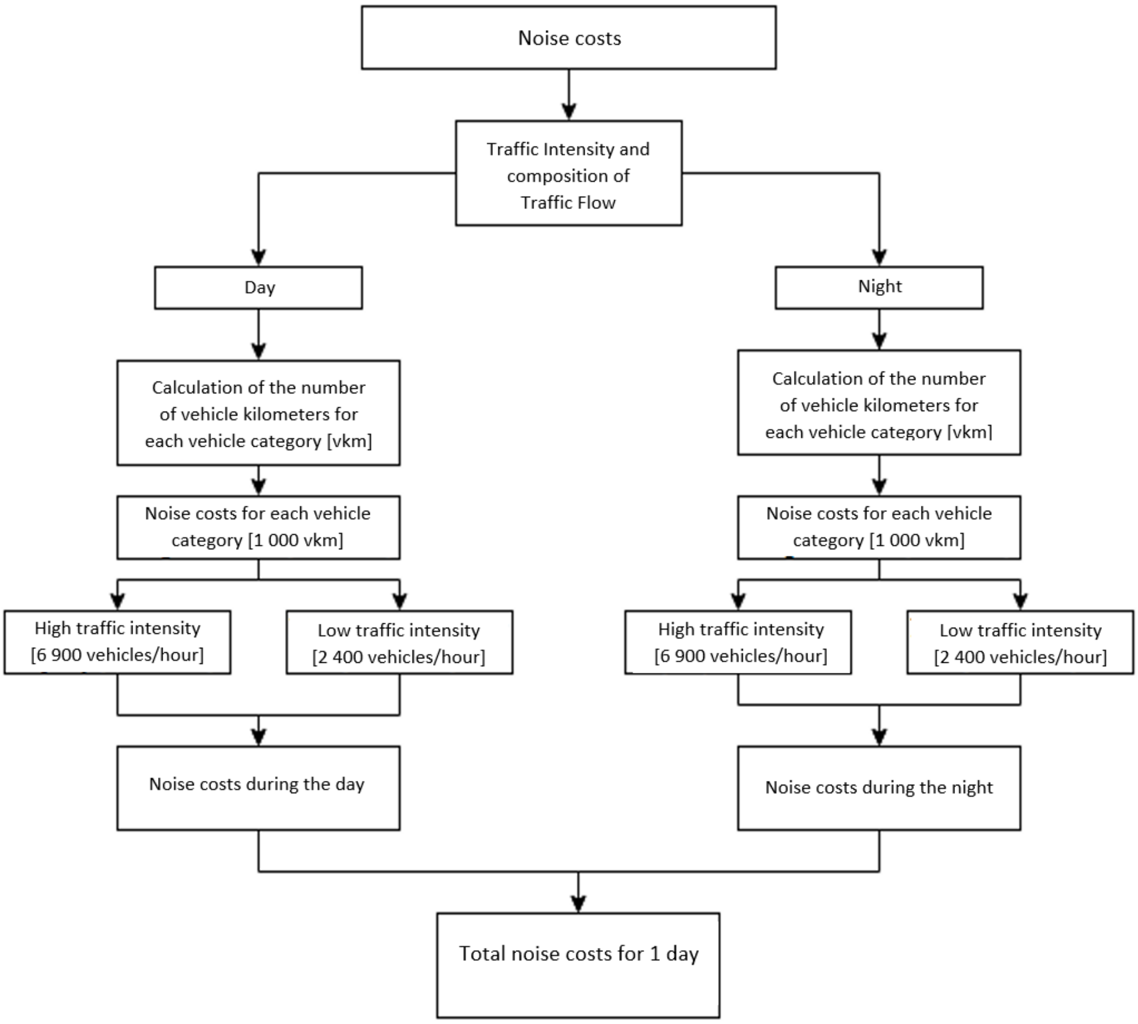

Fig. 3 Calculation of noise costs for one day [4]

The starting point for the calculation is the predicted noise level values from the noise study for the evaluated section of the first-class road I/59, the adjacent section of road I/70, and the variants of the planned R3 expressway section Oravský Podzámok – Dolný Kubín Central – Likavka. The quantified noise levels were processed using Excel.

3 Study of the Coordination of the Technical Solution for the R3 Expressway in the Sections Oravský Podzámok – Dolný Kubín – D1 Motorway

The technical study is divided into three separate parts [7]:

1. Section – Road I/59,
2. Section – R3 Expressway in the segments Oravský Podzámok – Dolný Kubín – D1 Motorway in a two-lane configuration,
3. Section – Intersection on Road I/70 in the town of Dolný Kubín.

3.1 Technical Solution for Road I/59

The evaluated section of the first-class road I/59 begins in the village of Široká, just before it intersects with the existing section of the R3 expressway—bypassing the village of Oravský Podzámok. The route continues through the Orava River valley into Dolný Kubín, where it intersects with Road I/70, which leads to the village of Kraľovany, via an interchange in the "Dolný Kubín – Central" area. The route then passes through Vyšný Kubín, bypasses the village of Jasenová, skirts the edge of the village of Valaská Dubová, and ends in the village of Likavka (Fig. 4).

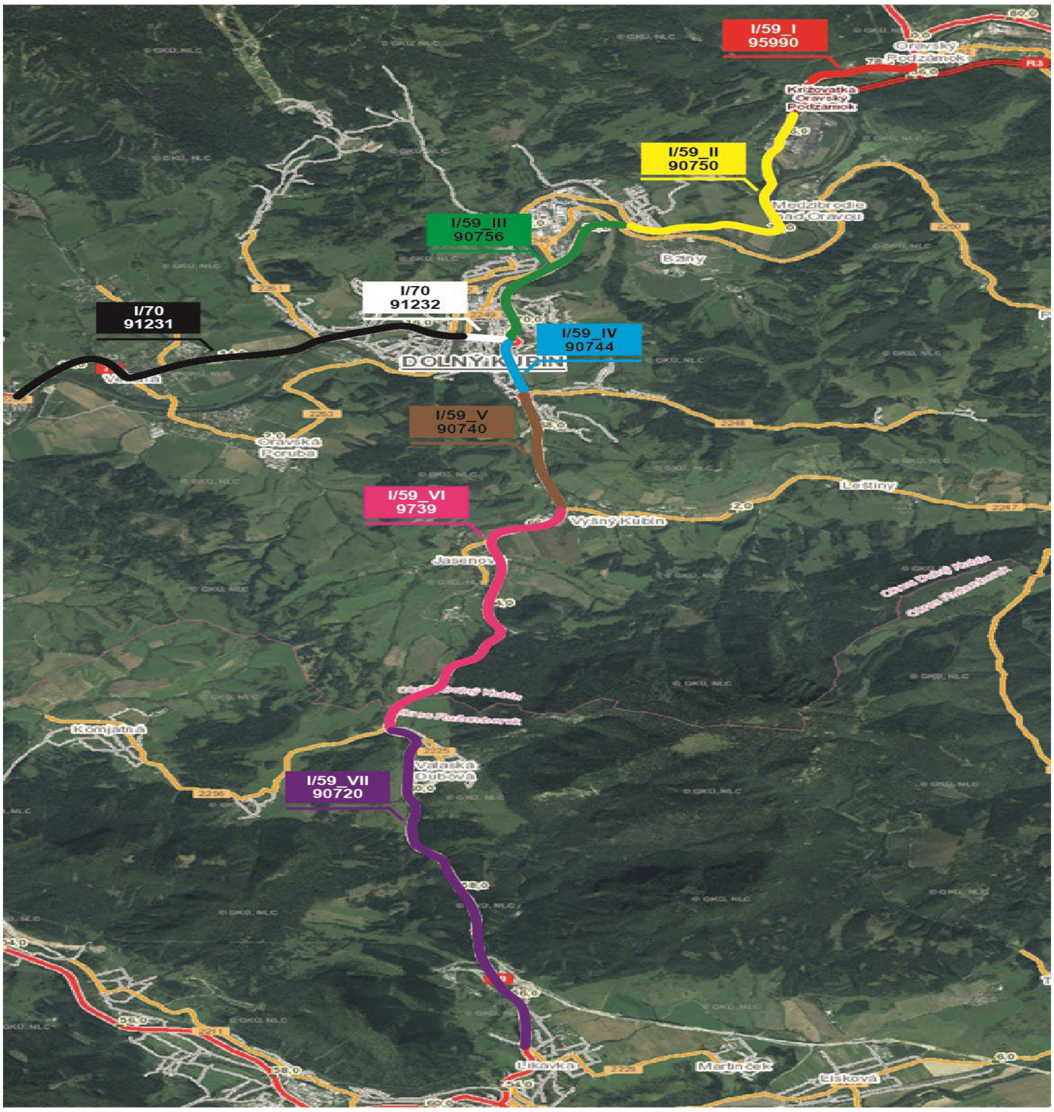

Fig. 4: Section of Road I/59 and Individual Counting Sections [8]

The study assesses a Zero variant, which represents the state of traffic on the road network without the construction of the R3 expressway. Under this scenario, all traffic would continue, both currently and in the future, to use the existing I/59 road and the adjacent third-class roads.

The parameters of the existing I/59 road in the affected area are inconsistent, particularly regarding the road width and design speed, which vary along the entire length of the route. The basic paved width ranges from 8.0 to 10.5 meters. Several sections lack safety barriers, or the existing ones are in poor condition. Another negative aspect in the road vicinity is the increased vegetation, which affects visibility and overtaking opportunities, further impacting the road's capacity and safety. With the expected increase in traffic, these factors will have an even greater negative impact on the road's traffic characteristics. Based on traffic development predictions, the total volume of heavy vehicles constitutes 16% of the total number of vehicles using the I/59 road section.

3.2 Technical Solution for the R3 Expressway

The I/59 road is already inadequate in terms of capacity in several sections, and a continuous increase in traffic is anticipated. In the coming years, it is expected that the situation will continue to deteriorate. For this reason, in addition to implementing measures on the existing I/59 road, the construction of the R3 expressway must also be considered. The study on the coordination of the technical solution for the R3 expressway in the sections Oravský Podzámok – Dolný Kubín – D1 Motorway, configured as a two-lane road, presents two alternative routing solutions for the R3 expressway segment. The aim of the study was to propose a route for a new high-capacity expressway that would meet both current and future transportation demands in the area. (Table 1, Fig. 5) [7].

Table 1: Basic technical parameters of the variants of the R3 expressway in the section Oravský Podzámok – Dolný Kubín – Highway D1 [7]

Basic technical parameters	**Variant V1 (Blue)**	**Variant V2 (Green)**		**Subvariant 2a (to Green Variant)**
Category	R 11.5/80 (60)[1)]			R 11.5/60[1)]
Route length [km]	18.692	19.500		1.114[2)]
Min. directional arc radius [m]	190			170
Max. longitudinal slope [%]	7,50			6.02
Min. longitudinal slope [%]	0.95			1.47
Min. radius of convex height arc [m]	2 500	1 500		2 500
Min. radius of the concave height arc [m]	2 100			1 500
Lane width [m]			3.50	
Guide strip width [m]			0.25	
Width of the emergency lane [m]			1.50	
Basic clear road width [m]			11.50	
[1]Speed of 80 km/h is designed for sections where the RC R3 overlaps with the existing road I/59 [2]Standalone length of the route for subvariant 2a.				

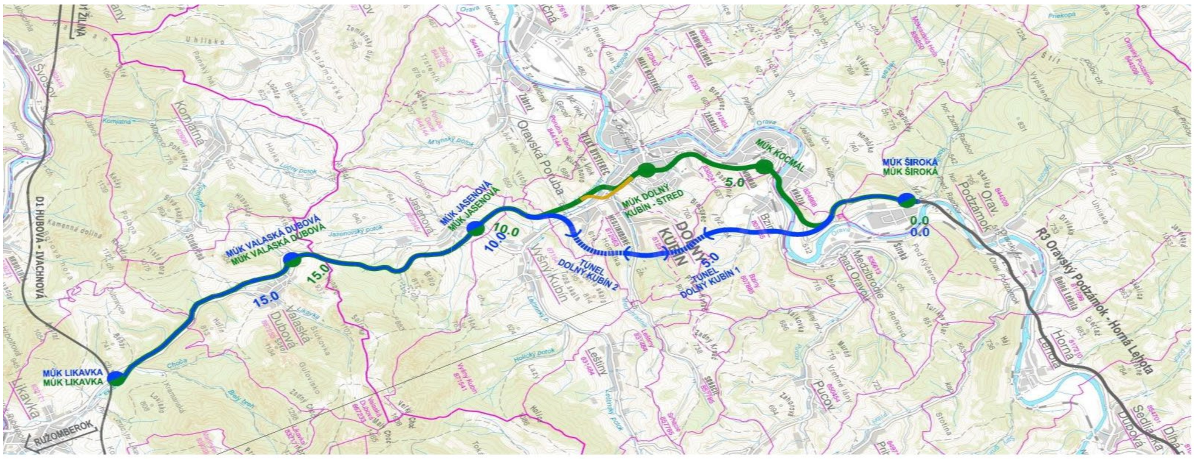

Fig. 5: Clear situation of wider relations [7]

The evaluated section is part of the international road corridor E77 and serves as a connection between the north-south corridor through central Slovakia. The R3 expressway begins at the Poland-Slovakia border crossing, Trstená – Dolný Kubín – Kraľovany – Martin – Turčianske Teplice – Žiar nad Hronom – Zvolen – Krupina – state border Hungary-Slovakia, Šahy. The routing of the expressway is considered in two basic variants:

- Blue variant V1 (tunnel option**),**
- Green variant V2 (urban option),
- Subvariant 2a of the Green variant.

4 Traffic Forecast

Understanding the development and current state of the traffic situation in an area is a crucial condition for planning and project preparation. Knowledge of the current state is essential for analysing the causes of existing problems. It is necessary to approach each project individually, considering all available information, to ensure that the documentation closely reflects the possible real-life traffic conditions in the area.

The proposed technical solution has the potential to not only address and improve transportation conditions in the near future but also in the long term. For these reasons, it is essential to consider data on expected demands in the context of broader transportation relationships.

This data is provided by a traffic forecast, which, to the greatest extent possible, corresponds to current knowledge, characterizes and structures information about the anticipated development of traffic, as well as the requirements and demands on transportation services.

During the project documentation phase, it is important to work with the results of a noise study that considers the potential development of traffic and the related noise. This aspect has been particularly emphasized since the Environmental Impact Assessment (EIA) process was implemented into Slovak legislation.

The increase in noise over recent decades has become a serious problem that needs to be addressed with noise reduction measures and measures targeting the noise source.

The legislation of the Slovak Republic and the European Union contains several laws, decrees, and directives that address the impact of road traffic noise on public health and the possibilities for resolving noise-related issues.

When assessing and designing road infrastructure projects, the following must be adhered to:

- Directive 2002/49/EC of the European Parliament and the Council relating to the assessment and management of environmental noise,
- Government Regulation No. 43/2005 Coll., which establishes details on strategic noise maps and action plans for noise protection,
- Act No. 355/2007 Coll. on the protection, promotion, and development of public health and on the amendment and supplementation of certain laws,
- Decree of the Ministry of Health of the Slovak Republic No. 549/2007 Coll.

The legislation is based on conducted studies.

4.1 Noise Study

The noise burden in the affected area surrounding the I/59 road is determined by the composition of traffic flows and traffic intensities in both directions and across the various sections of this road.

It is also important to consider the acoustic and technical parameters of the roadway, such as surface type, elevation, width, and similar factors. The primary source of noise in the affected area is the I/59 road and a section of the I/70 road from the intersection with I/59 in Dolný Kubín towards the village of Kraľovany [9], [10].

The noise study was conducted for the following scenarios:

- Zero variant,
- Blue variant V1,
- Green variant V2,
- Subvariant of green variant V2a.

5 Quantification and Valuation of Road Traffic Noise Costs Using Excel

The quantification and valuation of road traffic noise costs were conducted to assess the noise burden on people from the transportation technical solution of the R3 expressway in the sections Oravský Podzámok – Dolný Kubín – D1 Motorway.

The calculation was performed using Excel.

The primary inputs for the calculation were the predicted traffic intensity values for the assessed section of I/59 and the estimated traffic intensity for the planned section of the R3 expressway. Tables 2, 3, and 4 list the inputs for the noise cost calculation. In addition to traffic intensity data, the Excel program requires inputs for the percentage of vehicles operating at night, the length of the road section under repair, and the noise level at a point 7.5 meters from the centerline of the road [9], [11], [12]. Based on these inputs, the noise costs for one day were quantified.

Table 2: Intensity of the traffic load of the assessed section I/59 for the year
Zero variant - planned year 2030

Road - Section	Passenger cars/24 hours	Trucks/24 hours	Total/24hours
I/59_I - before ZU v kr. Široká	5 044	870	5 914
I/59_II – kr. Široká - kr. s III/2446	10 012	2 489	12 501
I/59_III - kr. s III/2446 - kr. s I/70 v D. Kubíne	9 998	2 513	12 511
I/59_IV - kr. s I/70 D. Kubín - kr. s c. III/2248	9 194	1 375	10 569
I/59_V - kr. s III/2248 - c. III/2247 Vyšný Kubín	10 055	1 919	11 974
I/59_VI - kr. s III/2247 Vyš. Kubín – kr. Valašská Dubová	8 406	2 062	10 468
I/59_VII - kr. Valašská Dubová - kr. s D1	7 118	1 595	8 713
Road I/70 Dolný Kubín towards Kraľovany	14 225	1 580	15 835
	14 580	1 571	16 151

Table 3: Percentage distribution of trucks into categories used in the calculation of road traffic noise costs

Traffic data	Trucks	Trucks	Total
	796	4 452	5 248
% of the total number of truks	up to 3.5 t	over 3.5 t	buses
	41.98	45.93	12.1

Table 4: Input data for the evaluation of road traffic noise costs

Traffic intensity data					**Share vkm/day/night**	
Vehicle type	**Vehicle intensity (veh/day)**	**% share of vehicles at night (10:00 p.m. - 6:00 a.m.)**	**Vehicle intensity day**	**Vehicle intensity night**	**vkm/day**	**vkm/night**
Car	4 452	25	3 339	1 113	7 779.87	2 593.29
Bus	96	2	94	2	219.02	4.66
up to 3.5 t	334	25	250	84	582.5	195.72
nad 3,5 t	366	48	190	176	442.7	410.08
Length of road (km)		2.33				

Table 5 provides the unit costs for a suburban area, which were taken from the CBA manual applicable to Slovakia. The result is the daily noise cost for the evaluated section.

Table 5: Unit costs of noise and their quantification for the assessed section of road I/59 in the suburban area

Suburb	**95990**	**I/59_I - before ZU in the Široká area**		**Year 2020**
Vehicle type	Part of the day	Traffic intensity	Noice costs €/1000 vkm	Costs €/day
Passenger car	day	high	0.4	3.11 €
		low	1.0	7.78 €
	night	high	0.6	1.56 €
		low	1.9	4.93 €
Buses	day	high	1.8	0.39 €
		low	5.0	1.10 €
	night	high	3.3	0.02 €
		low	9.3	0.04 €
Truck up to 3.5 t	day	high	1,8	1.05 €
		low	5.0	2.91 €
	night	high	3.3	0.65 €
		low	9.3	1.82 €
Truck over 3.5 t	day	high	3.3	1.46 €
		low	9.3	4.12 €
	night	high	6.1	2.50 €
		low	17.0	6.97 €
		Total €/day high intensity		10.73 €
		Total €/day low intensity		29.67 €

5.1 Quantified Noise Costs for the Technical Solution of the R3 Expressway in the Sections Oravský Podzámok – Dolný Kubín – D1 Motorway

The selection of a suitable variant from the perspective of noise burden was carried out in two steps:

- Comparison of the noise cost development for road sections I/59 and I/70,
- Comparison of the noise cost development for the section of the R3 expressway from Oravský Podzámok – Dolný Kubín Central – Likavka.

Figures 6 and 7 illustrate the development of road traffic noise costs under high (6900 vehicles/hour) and low (2400 vehicles/hour) traffic intensities. The highest costs are produced by the

Zero Variant, which represents the state without the implementation of any noise reduction measures. The variants that consider the construction of the R3 expressway would significantly improve the noise situation in the assessed area. Of the two variants considered, the Blue Variant V1 is more favourable in terms of noise costs for the I/59 and I/70 road sections.

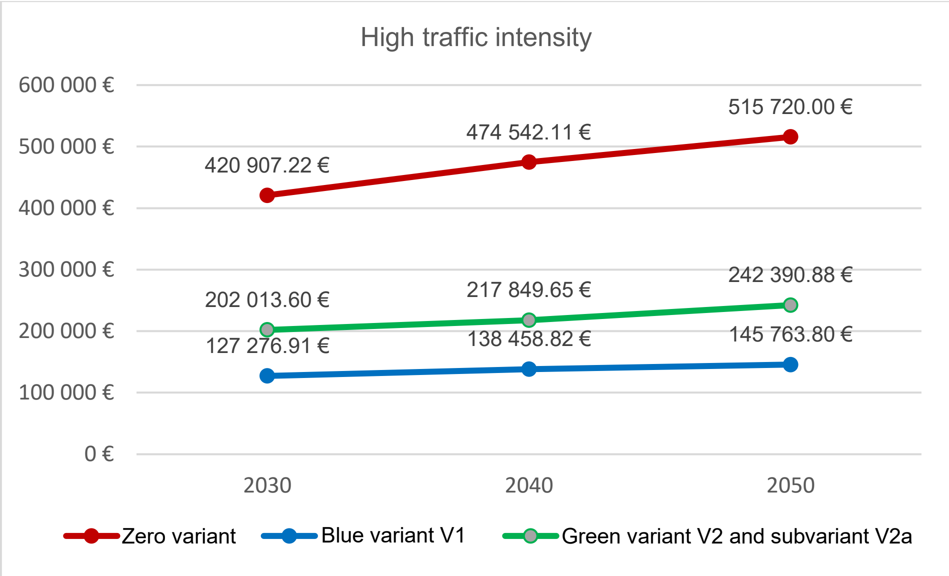

Fig. 6: Development of noise costs from road traffic along the I/59 road section and the related part of the I/70 section under high traffic intensity

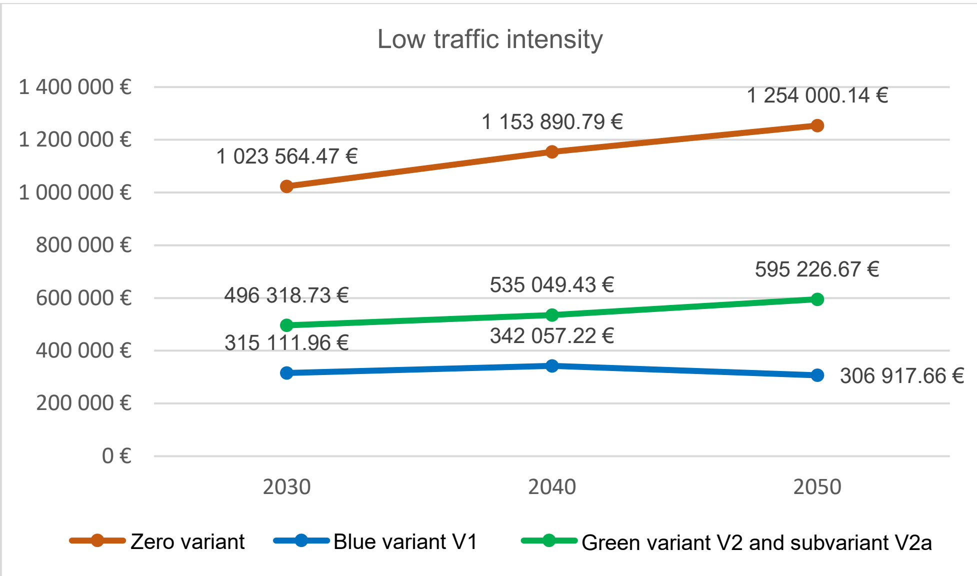

Fig. 7: Development of noise costs from road traffic along the I/59 road section and the related part of the I/70 section under low traffic intensity

The development of noise costs for road traffic using the planned R3 expressway section is shown in Figures 8 and 9. These figures indicate that lower noise costs would be produced by road traffic following the Blue Variant V1. This is primarily because this route is located outside the built-up areas of towns and villages. Additionally, the construction of tunnels would reduce noise levels and the expected noise costs in the vicinity of Variant V1. The CBA methodical manual does not consider this type of road route management [4].

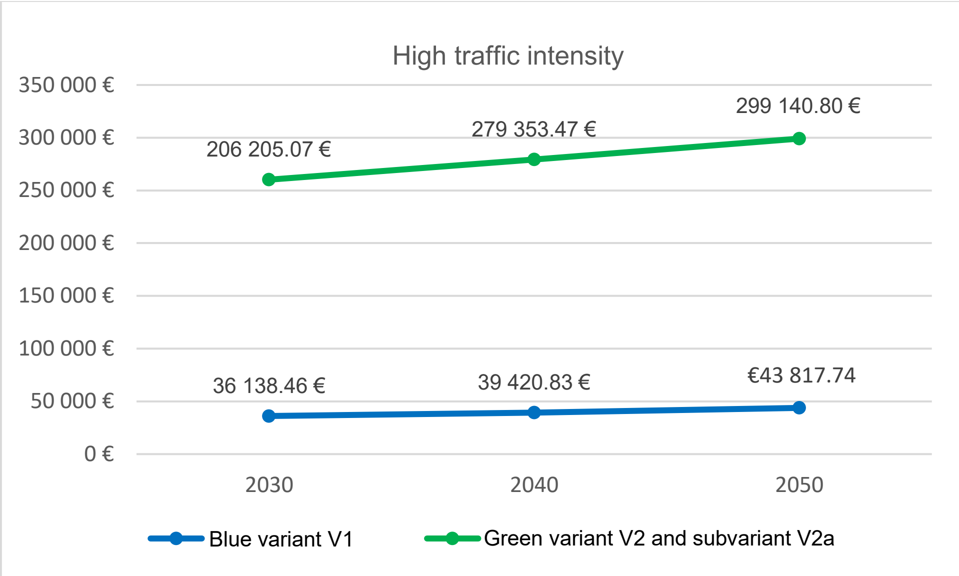

Fig. 8: Development of noise costs from road traffic on the assessed planned section of the R3 expressway in two variants under high traffic intensity

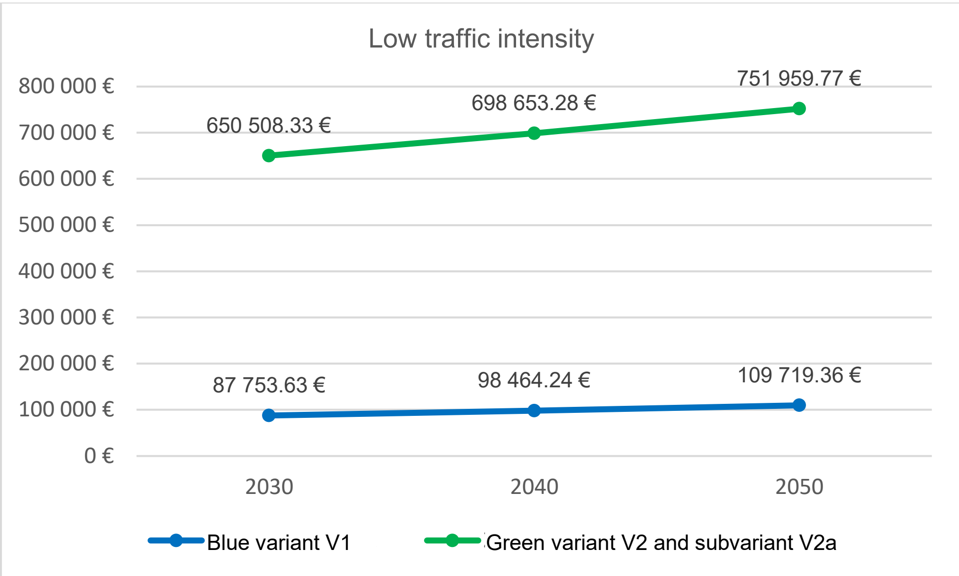

Fig. 9: Development of noise costs from road traffic on the assessed planned section of the R3 expressway in two variants at low traffic intensity

6 Noise Mitigation Measures

Collaboration between urban planners, traffic engineers, designers, and acousticians in protecting against road traffic noise should be standard practice from the early stages of project documentation preparation. Protecting the environment from road traffic noise requires a conceptual approach to project documentation in the vicinity of roadways. The reason for proposing noise mitigation measures is the exceedance of permissible noise levels in the assessed protected outdoor environment. This exceedance can be determined either by direct measurement of traffic noise or by calculation [13], [14], [15], [16].

If the hygiene criteria according to Decree No. 549/2007 Coll. of the Ministry of Health of the Slovak Republic are not met [17], noise mitigation measures can be proposed. The present study addresses two potential noise mitigation measures:

- Construction of noise barriers,
- Implementation of low-noise road surfaces.

6.1 Noise Barriers

The noise study includes proposals for noise barriers, detailing their acoustic parameters, length, height, and location along the route. The proposal was developed for Variants V1, V2, and Subvariant V2a. Additionally, the implementation of noise barriers along the I/59 road was considered, identifying locations where these barriers could be constructed. All noise barriers are designed with sound-absorbing surfaces [9].

Based on the construction and technical design of the noise barriers, the cost of implementing these barriers for each variant was calculated using Excel, including the implementation of noise mitigation measures along the I/59 road.

Three types of noise barriers with sound-absorbing surfaces were evaluated:

- Concrete noise barrier with single-sided absorption,
- Aluminum noise barrier with double-sided absorption,
- Solid PVC noise barrier.

Table 10 presents the implementation costs for the noise barriers for the variants of the planned R3 expressway section and the I/59 road, where locations for their construction were identified.

Table 10: Total price of anti-noise walls with a sound-absorbing surface for RC R3 and C I/59

	V1	V2	V2a
Concrete noise barrier with single-sided absorption	7 119 521.44 €	12 085 372.09 €	12 813 175.58 €
Aluminum noise barrier with double-sided absorption	4 595 348.36 €	7 788 939.59 €	8 251 566.02 €
Solid PVC noise barrier	8 991 197.48 €	15 271 179.65 €	16 195 612.13 €

6.2 Low-Noise Road Surfaces

Relevant factors concerning the roadway that influence acoustic descriptors in the environment, in interaction with the type and condition of the tyre, include the texture of the road surface, the type or character of the texture, and the porosity of the surface treatment [18].

For passenger vehicles, tyre/road noise begins to dominate at speeds around 34 km/h. For heavy vehicles, the critical speed is around 54 km/h. Therefore, the use of low-noise road surfaces can reduce noise on local roads (speed 40 to 60 km/h) as well as on roads outside built-up areas and highways (speed over 60 km/h) with a higher proportion of heavy traffic (Fig. 10).

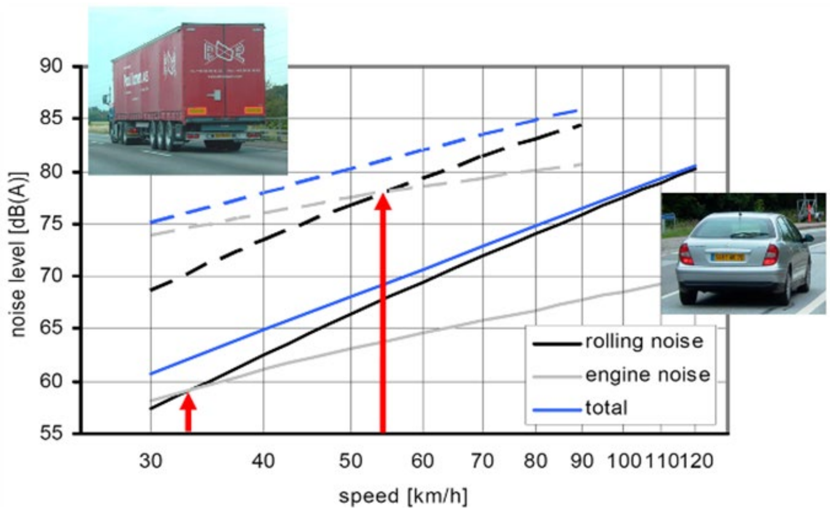

Fig. 10: Noise sources: rolling noise, engine noise, total noise from road traffic at constant speed [19]

Fig. 10 highlights the construction of road surfaces that reduce noise emissions during vehicle passage, (known as low-noise road surfaces).

In the study, two types of low-noise road surfaces were evaluated:

- Very thin asphalt concrete (BBTM) under the trade name Colsoft by COLAS,

• Stone mastic asphalt (SMA).

The cost of Very Thin Asphalt Concrete under the trade name Colsoft by COLAS is approximately 40% higher than that of conventional asphalt surfaces, with a price of 140 € per ton of material. At a bulk density of 2200 kg/m³, the material costs (excluding costs related to transportation, laying, compaction, etc.) for one kilometer of road in category 11.5 with a 3 cm thick surface layer would be 106 260 € [20].

The cost of Stone Mastic Asphalt is approximately 11% lower than that of BBTM Colsoft, with a price of approximately 124.17 € per ton of material. Under the same conditions (C 11.5, 3 cm thick layer, bulk density 2200 kg/m³), the cost for one kilometre of road would be 94 245 € [20].

When selecting a low-noise road surface, it is necessary to consider not only the cost but also the noise reduction achieved in the assessed section. BBTM Colsoft can reduce road traffic noise by up to 7 dB, while SMA provides a noise reduction of 4 dB. However, simply laying a low-noise surface does not guarantee a long-term noise reduction effect, as is the case with noise barriers. To extend the lifespan and functionality of low-noise road surfaces, regular and precisely defined maintenance is required.

7 Conclusion

The evaluation of the effectiveness of road infrastructure projects is not solely based on the financial resources required for construction, management, and maintenance, but also significantly includes non-monetary costs, which assess the negative impacts arising from the construction and operation of road infrastructure on users, society, and the environment. These quantified and monetized negative impacts are referred to as societal costs.

Road traffic noise is the most extensive source of noise within the transportation sector, adversely affecting people and their health.

The legislation of the European Union and the Slovak Republic places a strong emphasis on the assessment and management of environmental noise.

The evaluation of noise burden on specific road sections and the quantification of noise costs provide essential information for decision-making and infrastructure planning.

By comparing the road traffic noise costs for the assessed section of the first-class road I/59, the adjacent section of road I/70, and the variants of the planned R3 expressway section Oravský Podzámok – Dolný Kubín Central – Likavka, the noise costs are found to be the lowest in the case of the construction of the Blue variant V1 (36 138.46 € - projected year 2030 - high traffic intensity).

The proposal for noise mitigation measures demonstrates varying levels of noise absorption (10 to 30 dB). The lowest cost for constructing a noise barrier is for the Blue variant V1 using aluminium barriers, at 4 595 348.36 €. The most expensive alternative is the construction of a noise barrier along the R3 expressway in Subvariant V2a, with a PVC option costing 16 195 612.13 €.

An effective protection strategy against road traffic noise in the vicinity of the assessed road variants involves a combination of aluminium noise barriers, which can reduce noise levels by up to 25 dB, along with surface treatment of the I/59 road using the Very thin asphalt concrete (BBTM) under the trade name Colsoft, which can reduce road traffic noise by up to 7 dB.

Among the evaluated variants, the Blue (Tunnel) variant V1 of the R3 expressway is the most cost-effective in terms of road traffic noise costs and noise mitigation expenses.

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