

Urban noise caused by road vehicle traffic: influence of pavement surface condition

Ruído urbano causado pelo tráfego de veículos rodoviários: influência da condição superficial do pavimento

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ABSTRACT

This study analyzes the influence of different pavement types on noise levels along selected urban roads in Alegrete (RS), Brazil. Noise measurements were conducted in accordance with ISO 11819-1, while pavement serviceability was evaluated according to DNIT 009 standard. Road sections featuring asphalt, cobblestone blocks, and interlocking concrete blocks were selected, each encompassing distinct conservation states. To assess pavement serviceability, six evaluators traveled along the chosen routes by car, providing subjective ratings. Vehicle sound pressure levels were measured using a sound level meter, and speeds were recorded to determine the Adapted Statistical Pass-By Index for light vehicles (SPBI_{LV}). Analysis of the results indicated that asphalt surfaces produced the lowest noise levels, independent of their conservation state. In contrast, cobblestone blocks yielded the highest noise levels under all evaluated conditions. Furthermore, findings reveal that the conservation state significantly affects ambient noise emission, indicating that pavement type alone is not the sole determinant of urban acoustic performance.

RESUMO

Este estudo analisa a influência de diferentes tipos de revestimentos nos níveis de ruído em vias urbanas selecionadas em Alegrete (RS), Brasil. As medições acústicas foram realizadas conforme a norma ISO 11819-1, enquanto a serventia do pavimento foi avaliada de acordo com a norma DNIT 009. Foram selecionados trechos com pavimentação asfáltica, paralelepípedo e blocos de concreto intertravados, abrangendo distintos estados de conservação. Para avaliar a serventia do pavimento, seis avaliadores percorreram os trajetos em veículo, atribuindo notas subjetivas. Os níveis de pressão sonora dos veículos foram mensurados com medidor de nível sonoro, e as velocidades foram registradas para o cálculo do Índice Estatístico de Passagem adaptado para veículos leves (SPBI_{LV}). A análise dos resultados indicou que os revestimentos asfálticos produziram os menores níveis de ruído, independentemente de seu estado de conservação. Em contrapartida, os pavimentos em paralelepípedo produziram os maiores níveis de ruído em todas as condições avaliadas. Além disso, os resultados demonstram que o estado de conservação afeta significativamente a emissão sonora, indicando que o tipo de pavimento isoladamente não é o único fator determinante do desempenho acústico urbano.

1. Introduction

Noise pollution from vehicular traffic on urban roads significantly impacts the entire population, particularly in densely populated areas, affecting quality of life. The constant emission of pollutants and noise, from domestic and industrial sources, directly affects cities in contemporary urban environments, with motor traffic being the primary source of noise, thereby compromising the inhabitants' quality of life. The increasing concentration of people in cities has prompted countries and organizations to consider the sustainability and quality of life provided by urban environments (Torres *et al.*, 2013; Arenas, 2025).

Modern city designs influenced by road traffic have heightened noise pollution. According to the World Health Organization report (WHO, 2018), noise pollution is the second leading environmental stressor affecting public health in Europe. Effective city planning may mitigate the impact of this environmental issue and also lead to benefits, such as reducing other atmospheric pollutants due to the established correlation between some of them (Weber, Haase & Franck, 2014; Demetgul & Lazarova-Molnar, 2026).

Economic development, industrialization, and urbanization have led to increased highway traffic and elevated noise levels. Therefore, it is necessary to evaluate the characteristics of traffic noise based on various pavement surface types, vehicle types, and vehicle speeds (Sandberg, 1987; Cho et al., 2004). Additionally, noise levels increase significantly when water is present on asphalt roads for all types of vehicles (Cai et al., 2017).

Errors in the prediction of traffic noise occur in some cases when the road surface is substantially different from that on which the prediction model is based. This is because tire-road noise, which depends heavily on the road surface, is a major component of noise from free-flowing traffic (Cho & Mun, 2008).

Transportation noise is an environmental stressor that leads to sleep disturbances and annoyance, with the latter being the most commonly reported effect among individuals residing in urban areas. Reducing urban road traffic noise pollution and population noise exposure is essential. Using road surfaces with low noise emission characteristics is a widely used approach globally to achieve this aim (Licitra et al., 2015). The increase in noise has become an issue in urban areas. This noise is generated from various sources, including different types of vehicles on the road, airplanes, factories, and construction sites (Damian & Foşalău (2011); Demetgul & Lazarova-Molnar (2026).

Researchers have analyzed the impact of traffic noise on health and established correlations between transportation noise levels and various adverse effects. These include speech interference, sleep disturbances, and general annoyance (Öhrström et al., 2006), as well as certain mental disorders (Damian & Foşalău, 2011). Long-term exposure to road traffic noise has been linked to an increased risk of cardiovascular diseases (Babisch et al., 2005), hypertension (Bluhm et al., 2007), and myocardial infarction (Selander et al., 2009). Additionally, high levels of traffic noise have economic impacts, increasing costs for noise abatement and reducing the value of properties situated near noisy road transport infrastructure (Zambrano-Monserrate & Ruano, 2019).

There is currently a need to develop effective noise control tools, especially in urban areas, due to the overall increase in traffic. One method to achieve lower noise levels and protect citizens' health from environmental noise pollution is to reduce emissions at the source (Arenas, 2025). Among the primary sources of noise generated by light vehicles, the interaction between vehicle tires and the road surface becomes the predominant noise source at speeds exceeding 40 km/h. At this threshold, tire-pavement noise surpasses powertrain noise regardless of the vehicle's propulsion system (whether internal combustion engines or electric motors) as the aerodynamic and rolling components become the primary contributors to the overall sound pressure level (Sandberg & Ejsmont, 2002).

Road transport plays a crucial role in the economy and daily life of Brazilian people, but it also has significant environmental impacts. These impacts occur both during road construction and vehicle operation. The devaluation index of residential properties in areas with high noise pollution is rising due to this pollution. This situation necessitates new studies to find alternatives that can reduce noise caused by road transport (Specht et al., 2009; Zambrano-Monserrate & Ruano, 2019).

Evaluations of pavement performance are conducted to verify both comfort and safety for the user. One of the methods used to assess pavement serviceability is the Current Service Value (CSV), which measures the pavement's ability to withstand traffic demand under comfortable conditions for users (DNIT, 2003).

This paper aims to evaluate the influence of three urban pavement surface types (asphalt, cobblestone blocks, and interlocking concrete blocks) in the city of Alegrete, in the state of Rio Grande do Sul (RS),

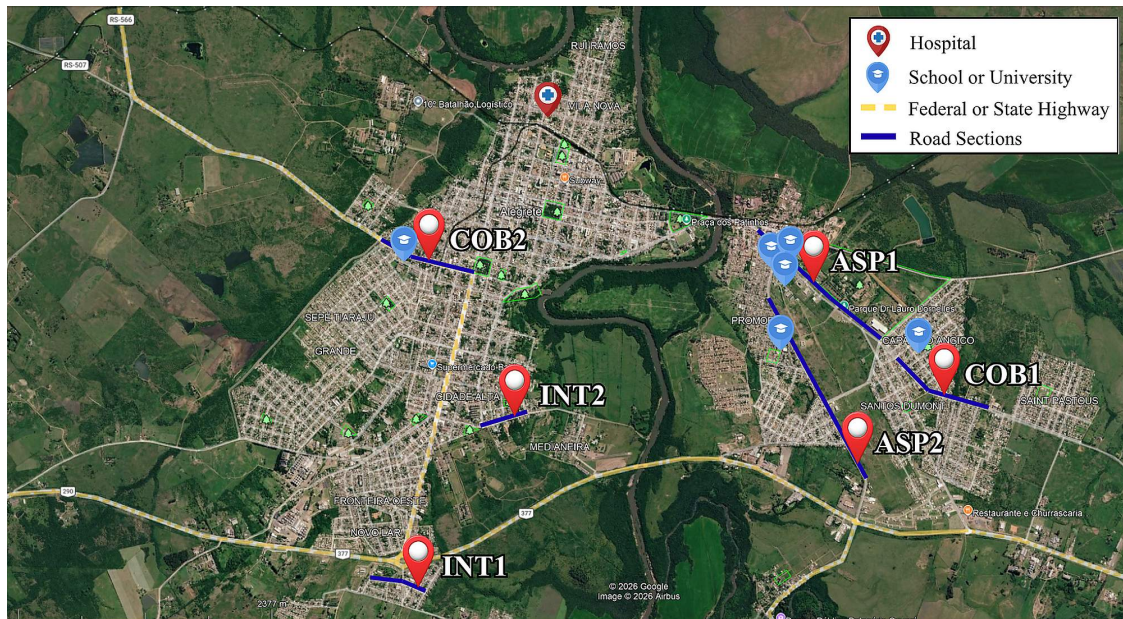


Figure 1 • Spatial distribution of the evaluated test sites and nearby noise-sensitive receptors in the urban area of Alegrete (RS) [adapted from Google Maps (2026)]

in Brazil. The study assesses pavement serviceability and surrounding noise levels, with the objective of identifying the pavement surface that provides the best acoustic performance.

2. Materials and methods

In the city of Alegrete (RS), six distinct road sections (test sites) were selected for noise and pavement serviceability analyses. The spatial distribution of these sites across the urban area, highlighting their proximity to noise-sensitive receptors such as hospitals and educational institutions, is presented in Figure 1. These sections were chosen to encompass different surface types and conservation states, adhering to the specifications of ISO (1997) for acoustic evaluation and DNIT (2003) for serviceability assessment.

Based on the requirements of these regulations, two road sections were selected for each type of surface course: asphalt, cobblestone blocks, and interlocking concrete blocks. For each pavement category, sites with both well-maintained surfaces and those in poor condition were identified. The chosen roads in the city of Alegrete (RS), each of which is illustrated in Figure 2, are described as follows:

1. Tiarajú Avenue - asphalt surface (labeled as ASP1). This section features a two-lane roadway and a significant flow of light vehicles (Figure 2a);
2. Caverá Avenue - asphalt surface (labeled as ASP2). This section features a single-carriageway road and significant flow of light vehicles (Figure 2b);
3. Tiarajú Avenue - cobblestone surface (labeled as COB1). This section features a two-lane roadway and an average flow of light vehicles (Figure 2c);
4. Daltro Filho Street - cobblestone surface (labeled as COB2). This section features a single-carriageway road and a large flow of light vehicles (Figure 2d);
5. Marechal Castelo Branco Street - interlocking concrete blocks surface (labeled as INT1). This section features a single-carriageway road and a low flow of light vehicles (Figure 2e);
6. Major João Cezimbra Jaques Street - interlocking concrete blocks surface (labeled as INT2). This section features a single-carriageway road and an average flow of light vehicles (Figure 2f).

All test sites were classified as low-speed environments, as the majority of vehicles traveled below 65 km/h within the urban perimeter.



Figure 2 • General view of the surface conditions for the evaluated sites: (a) ASP1; (b) ASP2; (c) COB1; (d) COB2; (e) INT1; (f) INT2

2.1. Noise assessment method

The sound pressure levels for the analyzed road sections were evaluated using the Statistical Pass-by Method (SPBM) as prescribed by ISO 11819-1 (ISO, 1997). This method was prioritized over other standardized procedures, such as Controlled Pass-By (CPB) and Close-Proximity (CPX), because it directly measures the impact of the road surface on the noise generated by real traffic, specifically isolating the tire-pavement interaction. While the CPB method offers low representativeness of the actual urban fleet and the CPX method requires specialized equipment not available for this study, the SPBM captures the acoustic signature of local vehicle flow under real operating conditions. A sound level meter (INSTRUTEMP ITDEC 4010 DIGITAL TYPE 2, weighting level A) was used to measure noise. In the evaluation, as defined by ISO 11819-1 (ISO, 1997), the sound level meter was positioned at 1.2 m height relative to the lane level and 7.5 m from the center of the traffic lane, as shown in Figure 3. In addition to the sound pressure level measurement, vehicle speed was recorded.

While the ISO 11819-1 (ISO, 1997) standard prescribes a composite index including both light and heavy vehicles to represent general traffic noise, the specific traffic regulations in the central area of Alegrete (RS), which restrict heavy vehicle movement, necessitated a targeted methodological adaptation. This approach is technically justified for urban noise management as it isolates the tire-

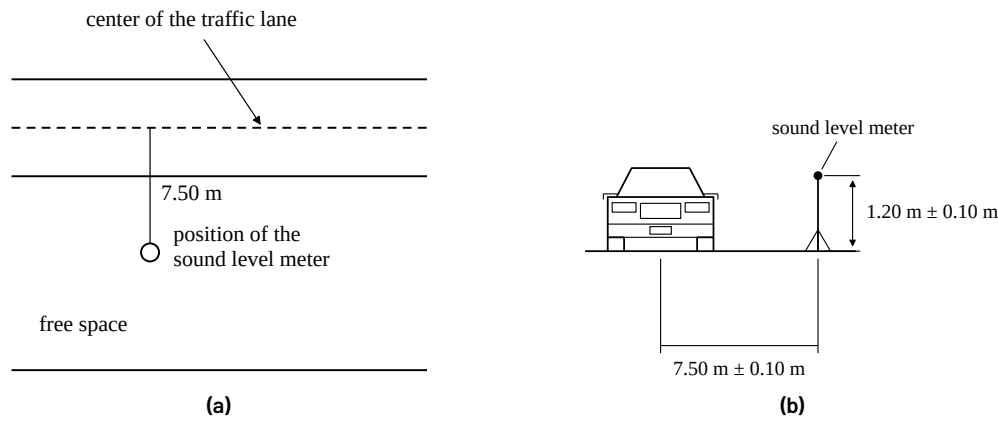


Figure 3 • Positioning of the sound level meter: (a) Top view; and (b) Front view [(]adapted from ISO 11819-1 (ISO, 1997)]

pavement interaction noise of the predominant vehicle category. To maintain technical rigor and clearly distinguish this localized evaluation from the full normative index, the term Adapted Statistical Pass-By Index for light vehicles ($SPBI_{LV}$) is adopted. This nomenclature acknowledges the specific methodological scope while providing a robust basis for relative acoustic comparisons between the analyzed pavement surfaces.

The complete formulation prescribed by ISO 11819-1 (ISO, 1997) was retained in Equation 1. However, because the present study considered only light vehicles, the weighting factors associated with vehicle categories 2a and 2b were set equal to zero. Consequently, the second and third terms of Equation 1 did not contribute to the calculated index.

$$SPBI_{LV} = 10 \times \log_{10} \left[\left(W_1 \times 10^{\frac{L_1}{10}} \right) + \left(W_{2a} \left(\frac{V_1}{V_{2a}} \right) \times 10^{\frac{L_{2a}}{10}} \right) + \left(W_{2b} \left(\frac{V_1}{V_{2b}} \right) \times 10^{\frac{L_{2b}}{10}} \right) \right] \quad (1)$$

Where $SPBI_{LV}$ is the Adapted Statistical Pass-By Index for light vehicles, in dB(A); W_1 , W_{2a} and W_{2b} are the weighting factors assigned to light vehicles and heavy-vehicle categories 2a and 2b, respectively; L_1 , L_{2a} and L_{2b} are the sound pressure levels for the respective vehicle

2.2. Pavement serviceability assessment

The subjective assessment of the road sections was conducted according to DNIT (2003) to determine the Current Service Value (CSV). A team of six evaluators, familiar with the standard's objectives, examined each section to document the pavement's ability to meet traffic requirements.

To conduct the evaluation, the evaluators adhered to the conditions outlined in DNIT 009/2003 (DNIT, 2003), which included: assessing only the current condition of the surface and classifying as "good" despite possible future failure; disregarding geometric aspects of the evaluated lane section; evaluating the sections based on the assumption that the geometric design was appropriate for any type of traffic; and not considering the surface slip resistance during the evaluation.

In addition, when completing the form, the evaluator had in mind the following aspects:

- The performance of the analyzed pavement section over a 24-hour period, considering its intended purpose;
- What would be the comfort of the pavement if you drove the vehicle for 8 hours;
- How would you feel driving for 800 km on the analyzed pavement.

Evaluators used a form to rate the pavement from "poor" (0) to "great" (5). Four evaluators used the vehicle Chevrolet Cobalt 1.8, with 15-inch rims. The other two evaluators used a Ford Fiesta Sedan 1.6, with 16-inch rims. Both vehicles met the requirements imposed by DNIT 009/2003 for evaluation.

Table 1 • $SPBI_{LV}$ and CSV of the test sites under study

Site identification	Denomination	Noise	Pavement Serviceability	
		$SPBI_{LV}$ (dB(A))	CSV (average)	Rating
Tiarajú Av.	ASP1	69.12	4.6	Great
Caverá Av.	ASP2	69.85	2.9	Regular
Tiarajú Av.	COB1	75.54	3.3	Good
Daltro Filho St.	COB2	80.62	1.2	Bad
Marechal Castelo Branco St.	INT1	72.79	3.7	Good
Major João Cezimbra Jaques St.	INT2	75.97	2.7	Regular

The results of each section of evaluated pavement were individually recorded, and the mean of all ratings was then calculated to determine the CSV of each site.

3. Results and discussion

Figure 4 presents the relationship between sound pressure level and vehicle speed for each test site. In addition to the adjusted linear regression equations, the plots provide the sample size (n), the coefficient of determination (R^2), and the standard deviation (SD). These parameters allow for an evaluation of the extent to which vehicle speed explains the variation in the measured noise levels (R^2), while the SD represents the intrinsic variability within each pavement surface. Based on the regression lines, the average sound pressure level was determined for a reference speed of 50 km/h. Using these values and the specified correction coefficient ($W_1 = 0.9$), the $SPBI_{LV}$ for each site was calculated according to Equation 1.

It is important to highlight the results for INT1 (Figure 4e), where 19 light vehicles were observed due to the low traffic volume in the area. This site was strategically selected as it is one of the few road sections in Alegrete (RS) featuring an interlocking concrete block surface in good condition. Although the ISO 11819-1 (ISO, 1997) recommends a minimum of 100 light vehicle passes, the sample sizes in this study (ranging from 19 to 94) reflect the operational constraints and traffic characteristics of the local urban network.

Despite these totals falling below the standardized threshold, the results remain scientifically relevant for the study's comparative objectives. The calculated R^2 and SD values in Figure 4 indicate that the linear regression models adequately capture the relationship between speed and noise emission. Specifically for INT1, the technical necessity of evaluating a well-maintained interlocking surface to enable a comparative analysis of acoustic deterioration outweighed the strict requirement for high sample volume, which would be unfeasible given the site's traffic restrictions.

From Figure 4, the $SPBI_{LV}$ values for the sites under study were obtained. The CSV values were calculated by averaging the scores from six evaluators who analyzed the sections. Therefore, the $SPBI_{LV}$ and CSV results for each of the streets or avenues under study are presented in Table 1.

As shown in Table 1, the selected road sections met the planned requirements for surface quality diversity. For each pavement type, different CSV values were obtained. For the two sections analyzed for each surface type, one section was classified as good or excellent, while the other was rated as poor or fair. For comparative purposes, $SPBI_{LV}$ data were juxtaposed with results obtained by Tassinari *et al.* (2013) in an urban study in Santa Maria (RS), as depicted by the light gray columns (ASP3, COB3 and INT3) in Figure 5.

Analysis of Figure 5 shows that the surface with the highest noise level is the cobblestone surface, followed by the interlocking concrete block. The asphalt surface has the lowest noise level, showing a difference of 7.51 dB(A) compared to the cobblestone pavement. According to technical guidelines from the Federal Highway Administration (FHWA, 2017), this difference corresponds to an approximately 82.28% lower acoustic intensity. While Tassinari *et al.* (2013) provided valuable insights into noise levels in various urban road surfaces, they did not consider pavement condition, which can impact noise generation. This study also examines noise relative to pavement state, as shown in Table 1 and illustrated

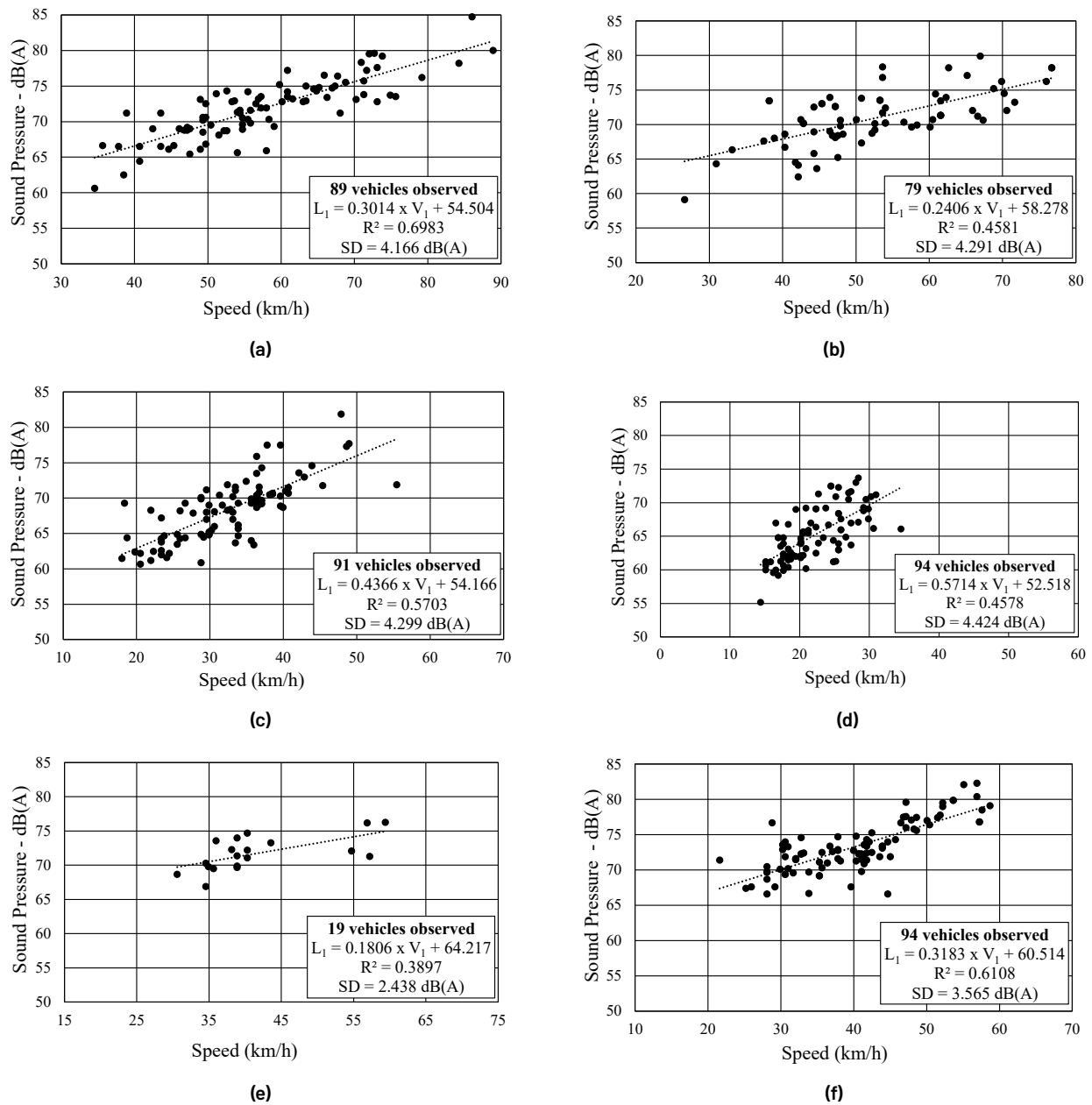


Figure 4 • Sound pressure level versus vehicle speed: (a) ASP1; (b) ASP2; (c) COB1; (d) COB2; (e) INT1; (f) INT2

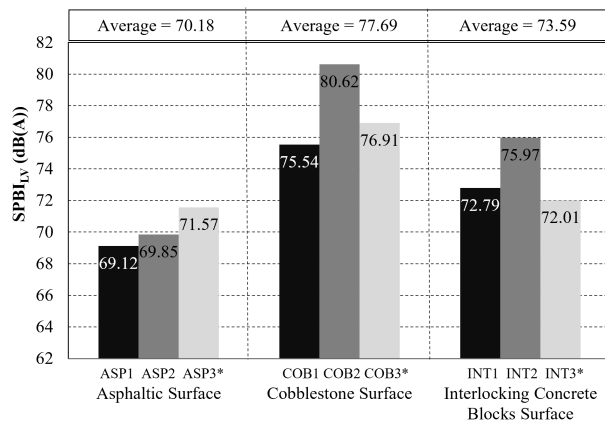


Figure 5 • $SPBI_{LV}$ values obtained in this study and reported by Tassinari et al. (2013)

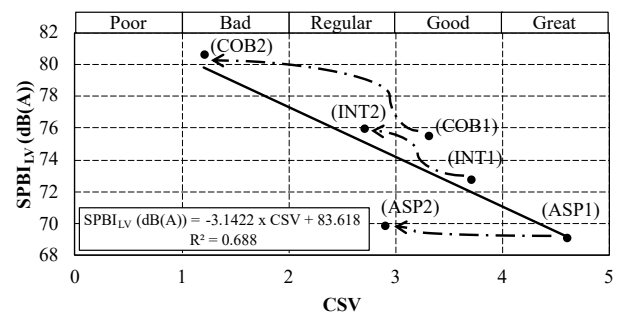


Figure 6 • Noise ($SPBI_{LV}$) versus pavement serviceability (CSV)

in Figure 6, with arrows indicating the progression from least to most deteriorated surfaces.

Table 1 and Figure 6 illustrate that asphalt surfaces (ASP1 and ASP2), regardless of their conservation state, produce less noise compared to the other pavement types examined in this study. Notably, the interlocking concrete block in good condition (INT1) exhibits an acoustic performance very similar to that of asphalt surfaces. Conversely, cobblestone surfaces in poor condition (COB2) yielded the highest $SPBI_{LV}$, with an increase of 11.50 dB(A) relative to the well-maintained asphalt surface (ASP1). This difference corresponds to an approximately 92.92% lower acoustic intensity (FHWA, 2017). This phenomenon is primarily attributed to surface irregularity, which induces greater vibration in the tire and vehicle structure, as well as during acceleration and braking processes. Consequently, these irregularities not only increase fuel consumption and operating costs but also generate additional noise from the engine system and exhaust.

The significantly higher noise levels observed for cobblestone pavements (COB1 and COB2) compared to interlocking concrete blocks are rooted in their distinct surface morphologies. Cobblestone surfaces typically feature high macrotexture and wide, uneven joints between the stone blocks, which induce intense radial vibrations in the tires. In contrast, interlocking concrete blocks are manufactured with tighter tolerances, providing a more uniform rolling surface with narrower joints, which minimizes the excitation of the tire structure. Regarding asphalt surfaces (ASP1 and ASP2), their superior acoustic performance is due to their continuous and relatively smoother texture. The absence of joints eliminates the periodic impact noise characteristic of segmental pavements. Although direct measurements of macro and microtexture were not conducted due to the focus on the functional acoustic response ($SPBI_{LV}$) and its correlation with subjective serviceability (CSV), the results align with theoretical expectations that surface regularity and the reduction of impact mechanisms are the primary drivers for lower noise emissions.

Upon examining Figure 6, where arrows indicate the transition from the best to the worst surface conditions, the correlation between noise variations and pavement state becomes evident. For segmental pavements, an interlocking concrete block in good condition (INT1) results in less noise than a cobblestone pavement in a similar state (COB1). However, as deterioration progresses, an interlocking concrete block in regular condition (INT2) exhibits noise levels that surpass those of a well-maintained cobblestone pavement. This indicates that the structural deterioration of interlocking surfaces results in a more rapid increase in noise levels compared to traditional cobblestone surfaces.

A comparison of noise levels and pavement serviceability across different surfaces reveals a clear inverse relationship. The highest CSV was associated with the asphalt pavement in excellent condition (ASP1), which also presented the lowest $SPBI_{LV}$. Conversely, the poorly maintained cobblestone pavement (COB2) showed the highest noise level and the lowest CSV. By comparing the conservation states across all studied surfaces (Figure 6), a consistent increase in noise and a reduction in serviceability is observed when transitioning from good to poor conditions.

To quantify this relationship, a linear regression analysis was performed across all test sites, yielding a coefficient R^2 of 0.688. This indicates that 68.8% of the observed variability in noise levels across the studied sections is associated with pavement condition. These findings indicate an inverse association between pavement serviceability and the measured noise level. These results should assist urban managers in selecting appropriate pavement materials and prioritizing maintenance interventions, especially in areas sensitive to noise pollution, such as those housing schools and hospitals.

4. Final considerations

The experimental results and statistical analysis demonstrate that asphalt pavement is the acoustically superior option, consistently yielding the lowest noise emissions independent of its state of conservation. Conversely, cobblestone surfaces exhibited the highest noise levels under all evaluated conditions. The results of the pavement serviceability assessment were closely aligned with the acoustic data; asphalt surfaces showed superior conditions and higher ratings, identifying them as the most comfortable and safe choice for road users. In contrast, poorly maintained cobblestone pavements were classified as inadequate, offering the lowest levels of user comfort and safety.

The findings establish that surface condition significantly influences noise levels in the roadway vicinity, confirming that pavement type alone is not the sole determinant of acoustic performance. Despite the consistency of these results, certain limitations must be acknowledged. The analysis was based on a specific sample of six road sections in Alegrete (RS), where each pavement type was represented by two sites with inherent variations in geometry, traffic volume, and urban context.

To bolster these findings, future investigations incorporating larger datasets and a broader diversity of test sites are warranted to validate these trends across different urban scenarios and provide even more definitive conclusions. Therefore, while these results offer significant insights into the acoustic performance and serviceability of urban pavements, they should be interpreted as representative of the specific segments evaluated. Caution is advised when generalizing these conclusions to other urban environments without accounting for localized technical and environmental variables.

Ultimately, these findings provide useful evidence for urban managers in selecting pavement materials and prioritizing maintenance interventions. This is particularly critical in noise-sensitive urban areas, such as those housing schools and hospitals, where the strategic choice of surfacing and proactive conservation are essential for mitigating public health impacts.

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CRediT authorship contribution statement

Juliano de Almeida Zacarias: Writing – original draft, Visualization; *Paulo Henrique Cima*: Conceptualization, Data curation, Writing – original draft; *Jaelson Budny*: Project administration, Conceptualization, Funding acquisition, Writing – review and editing; *Diego Arthur Hartmann*: Project administration, Conceptualization, Writing – review and editing; *Alisson Simonetti Milani*: Supervision, Methodology, Writing – review and editing; *Luciano Pivoto Specht*: Validation, Writing – review and editing; *Rodrigo André Klamt*: Methodology, Writing – review and editing.

Use of artificial intelligence-assisted technology

The authors used ChatGPT (OpenAI) solely to assist with language editing, reference formatting, and verification of compliance with the journal's author guidelines. All suggested changes were critically reviewed and validated by the authors, who assume full responsibility for the final content.

Competing interests statement

No competing interests have been declared with regard to this paper or its contents.

Data availability statement

The data, models, and code supporting the findings of this study may be made available by the corresponding author, Juliano Zacarias, upon request.

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