Thin Asphalt Layers as a Traffic Noise Intervention

Subjects: Urban Studies
Contributor: Ablenya Grangeiro de Barros

Low-noise thin asphalt layers (TALs) are a feasible solution to mitigate road traffic noise in urban environments. Nevertheless, the impacts of this type of noise intervention are reported mostly regarding noise levels, while non-acoustic aspects influencing the population perception are still little-known. This study investigates the implementation of TALs in two streets of Antwerp, Belgium. The effectiveness of the intervention was measured via noise modelling and acoustic measurements of road traffic noise. A reduction of 2.8 dB in noise exposure was observed in Lden and Lnight, while SPB measurements showed decreases up to 5.2 dB on the roadside. The subjective impacts of the TALs were evaluated via self-administered surveys and compared to results from control streets. The annoyance indicators were positively impacted by the TALs implementation, resulting in annoyance levels similar or lower than in the control streets. The TALs did not impact the reported physical complaints, sleep quality, and comfort level to perform activities.

road traffic noise intervention | thin asphalt layers | health effects | annoyance | noise simulation | noise exposure | low-noise asphalt layers

1. Introduction

Long-term exposure to road traffic noise has been associated with non-auditory health outcomes such as cardiovascular diseases, cognitive dysfunction, sleep disorder, among others [1]. The build-up of somatic disease arises from physiological responses triggered by exposure to high levels of (road traffic) noise. These somewhat unconscious behavioral reactions to noise exposure can be subjectively measured by the “noise annoyance”. This indicator is assessed at the population level via social surveys and is more easily reported by the exposed population to describe (road traffic) noise exposure than the manifestation of somatic disease; see [2] for an elaborate review on this topic. Thus, annoyance could be considered an early warning signal for health risks, playing a key role in setting noise exposure limits and creating action plans for noise exposure mitigation [3].

Road traffic noise generation and emission are contributed by propulsion noise, tire/road noise and aerodynamic phenomena produced by each vehicle in the fleet. For urban speeds (30–50 km/h), road traffic noise is mainly generated by the tire/road interaction as rolling noise becomes already predominant over engine noise for passenger cars [4]. Considering the mechanics involved in the tire/road noise generation and propagation, pavement characteristics of acoustics impedance and surface texture are the most influential in tire/road noise generation. Other determinant factors are ageing state [4] and the surface layer material characteristics such as aggregate gradation, bitumen content, and air voids [5][6][7].

Low-noise thin surface layers (TALs) are constructed mainly as hot-mix asphalt, laid typically with a thickness ranging between 20 mm and 40 mm [8]. Asphalt mixtures applied for TALs are mostly based on a stone mastic asphalt (SMA) with increased porosity, reduced maximum aggregate size D_{max} (e.g., 6.3 mm), and an optimized texture that reduces air-pumping noise and tire-tread impact noise due to the low amplitudes of megatexture [9]. Examples of the impacts of low-noise surfaces on noise exposure include [10], where a 4 dB L_{den} reduction was observed after repaving two major roads with noise-reducing TAL. The Life NEREiDE project aimed at implementing low-noise surfaces composed of recycled asphalt pavements and crumb rubber (CR) from scrap tires. In the framework of this project, [4][11] presented the monitoring campaign results from before and after replacing an old wearing course of a segment of regional road with different low-noise pavements containing CR. The average noise exposure (L_{den}) from four stretches of this road crossing a municipality decreased by 4.7 ± 1.3 dB, while the percentage of highly annoyed people retrieved from social surveys dropped by 29.6%.

Although many studies have focused on the objective noise reduction of road traffic noise interventions, only a limited number of studies have examined the effectiveness of road traffic noise interventions on human health. In this sense, this research reports on the possible impacts of TALs as a road traffic noise intervention for an urban environment. The main goal of our study is to establish whether TALs are a valid option for noise reduction in such environments. The research questions are, therefore, two-fold: firstly, what is the objective effectiveness of the implemented TALs to reduce noise levels and noise exposure, meaning its effect on L_{den} and L_{night}? Secondly, do objectives changes in noise levels affect the perception and well-being of the exposed population?

The key to this study is the road traffic noise intervention by means of TALs implemented in two urban streets (TAL A and TAL B).

In order to evaluate the effectiveness of this intervention, social and socioacoustic aspects were investigated before and after the TALs were laid. The objective impacts were assessed via acoustic measurements of road traffic noise, the Close-ProXimity (CPX) and Statistical Pass-By (SPB) methods, and noise modelling. The subjective impacts caused by the change in noise levels were quantified via social surveys distributed to the residents of the streets in question. The main parameters retrieved from this survey were the annoyance indicators (namely Annoyance, ΔAnnoyance, and RTA) and the subjective noise indicators (physical complaints, sleep quality and comfort level to perform activities). Furthermore, a control group of (quiet) urban streets was selected to serve as a comparison for the survey's results.

2. Effectiveness of the Noise Intervention

All five TAL sections presented L_{CPX} lower than the DAC 10 reference surface (REF - B). These differences ranged between 2.3 and 2.8 dB(A) for the P1 tyre and 0.7 to 1.9 dB(A) for the H1 tyre. SPB measurements revealed noise reductions ranging between 3.8 and 5.2 dB(A). These decreases should be significant enough for the residents close to the road to perceive the difference after the TALs construction.

In the original condition, the residents were exposed to an average L_{den} of 64.3 ± 0.9 dB(A) and 53.8 ± 1.1 dB(A) for L_{night}. After the TALs were laid, the average L_{den} dropped to 61.5 ± 0.8 dB(A), while L_{night} was reduced to 51.0 ± 0.9 dB(A). Thus, the TALs placement led to a reduction of 2.8 dB(A) in both indicators.

3. Effects of the Noise Intervention

This section discusses the effects associated with reducing noise exposure levels enabled by the TALs placement. These impacts are expected to be reflected in the respondent's perceptions within the social survey results.

3.1. Direct Subjective Perceived Noise: Annoyance Indicators

To assess the impacts of the TAL implementation on the annoyance indicators, we pooled the data from the two experimental streets (TAL A and TAL B) after finding no statistically relevant difference for the annoyance indicators of the pre-survey via the Mann–Whitney U test. Consequently, differences in the annoyance indicators after the intervention can be attributed to the TAL construction itself, not to differences between the two experimental cases.

The average and standard deviation of the annoyance indicators are presented in **Table 1**. The mean ranks' differences among the conditions were tested with Kruskal–Wallis tests with Dunn's post-hoc pairwise tests and significance levels were adjusted by the Bonferroni correction for multiple tests (see **Table 2**).

Table 1. Average annoyance indicators (standard deviation).

Indicator	Case			
	Control	TAL		
		Pre	Post 1	Post 2
Annoyance *	2.23 (0.99)	2.75 (1.11)	2.48 (1.01)	2.42 (0.75)
ΔAnnoyance ×	0.46 (0.85)	0.87 (0.79)	0.16 (1.07)	0.00 (1.22)
RTA *	2.29 (1.08)	2.86 (1.10)	2.51 (0.92)	2.41 (0.99)

* Response scale: Not annoyed at all = 1; Slightly annoyed = 2; Moderately annoyed = 3; Very annoyed = 4; Extremely annoyed = 5. × Response scale: Greatly reduced = −2; Slightly reduced = −1; Remained the same = 0; Slightly increased = 1; Greatly increased = 2.

Table 2. Pairwise multiple comparisons results for the noise annoyance indicators.

Contrast		Annoyance	ΔAnnoyance	RTA
		***p*-Value**		
Control	Pre	<0.01	0.02	<0.01
	Post 1	n.s.	n.s.	n.s.
	Post 2	n.s.	n.s.	n.s.
Pre	Post1	n.s.	<0.01	n.s.
	Post2	n.s.	<0.01	n.s.
Post 1	Post 2	n.s.	n.s.	n.s.
		$\chi^2(3) = 12.62$, $p = 0.006$	$\chi^2(3) = 19.17$, $p = 0.000$	$\chi^2(3) = 4.17$, $p = 0.006$

n.s. = not significant at a 5% significance level.

The main results to be found in **Table 1** and **Table 2** are the following:

- The average Annoyance in the control streets (2.23 ± 0.99) indicates that respondents are ‘slightly annoyed’, compared to an average of 2.75 ± 1.11 (close to ‘moderately annoyed’) in pre-survey on the experimental streets. A similar condition is reported for RTA. For both indicators, the mean ranks difference is statistically significant. This contrast partially justifies the implementation of a noise intervention;

- After the TAL construction, the ΔAnnoyance scores reveal that the residents experienced a lesser increase in annoyance by noise over the 1-year window prior to the post-surveys than before the pre-survey. Therefore, the residents report positively experiencing a change in Annoyance and RTA, most likely attributed to the noise intervention;

- In the first post-survey, Annoyance and RTA have decreased in comparison to the pre-survey and are no longer significantly different from the control groups, where the average noise annoyance is close to the Flemish average reported in SLO-4 [12] (Annoyance = 2.11 and RTA = 2.19; based on >5000 respondents). This effect appears to be sustained even at the time of the second post-survey;

- The three noise indicators did not differ statistically between post 1 and post 2. Thus, the lower traffic intensity might not be as influential on the reported subjective indicators as we anticipated, at least not in the short term;

- Similar means for Annoyance and RTA across all cases possibly indicate that either the respondents did not differentiate between the noise sources causing annoyance or road traffic noise is clearly identified as the main source of Annoyance in general. The last option is more reasonable, as RTA is distinguishably the highest among the annoyances from the different noise sources: the second higher reported mean annoyance comes from ‘priority vehicles (ambulances, fire trucks, etc.)’, ranging from 1.64 to 1.78 across the three cases.

The percentage of highly annoyed people (%HA) is used to correlate annoyance to L_{den}, via ERRs. The %HA corresponds to the answers at a high position on the annoyance response scale. The cut-off point between "highly annoyed" and "not highly annoyed" differs among studies. Two often-cited ERRs for road traffic noise created based on large datasets are those of Guski et al. [2] and Miedema and Oudshoorn [13]. For the first, the cut-off lies at 75% on a 0–100 scale, meaning those who selected the 25% higher part of the response scale compose the %HA; for [13], this is at 72%.

To adapt this study's verbal 5-point response scale to the most common definitions of %HA found in the literature, two cut-offs were used: 60% (very and extremely annoyed respondents) and 80% (extremely annoyed only). Additionally, the %HA was calculated using the simulated L_{den} as input for the ERRs proposed by Refs. [2][13] (in this case, the data set excluding the Alpine and Asian studies). The results are presented in **Table 3**.

Table 3. Measured and calculated %HA with existing ERRs.

		Measured %HA		Calculated %HA	
		80%	60%	[2] 75%	[13] 72%
Control streets		2.5	15.5	.	.
TAL	Pre	7.1	26.8	17.5	15.2
	Post 1	2.2	13.1	13.2	11.8
	Post 2	2.5	10.0		
Reduction pre to post (average)		4.8	15.2	4.3	3.4

The %HA (60%) dropped on average 15.2 percentage points (pp) from the pre-survey (26.8%) to the post-surveys (10–13.1%), resulting in a value smaller than the control streets (15.5%) and similar to the SLO-4 data (12.0%). %HA (80%) presents the same tendency but with smaller reductions (4.8 pp on average) due to the stricter cut-off. For the 2.8 L_{den} drop, these reductions are considerably more significant than those observed by [14], where 11.4% fewer people were highly annoyed by road traffic noise in streets presenting noise levels of $L_{A,eq,24h}$ < 55 dB(A) than in streets where these levels were higher than 65 dB(A).

Considering the differences in the cut-off, it can be argued that the ERRs by [2][13] are fairly reasonable in predicting the %HA with the L_{den} from before the TALs installation. The L_{den} after the TALs implementation led to calculated %HA higher than those obtained from the surveys, meaning that the actual drop in %HA due to the reduction in L_{den} is higher than the existing ERRs could predict. It is important to remark that the L_{den} calculated as per the CNOSSOS-EU method after the TALs implementation did not account for the increased absorption of these surfaces layers, resulting in a reduction of L_{den} smaller than it actually might have been. However, even if we recalculate the %HA with a L_{den} 1.5 dB(A) lower than simulated after the TALs implementation in an attempt to compensate for the underestimation, the ERRs still give a %HA higher than measured with the surveys.

Surveys organized in Copenhagen (2870 answers) on the annoyance levels before and after repaving two major roads with noise-reducing TAL, accounted for 10% fewer persons highly annoyed (at a 70% cut-off) after the TAL installation [10], as the result of a 4 dB L_{den} reduction (calculated per the Nord2000 calculation method). Dose–response curves constructed for both situations revealed that the respondents reacted to the noise levels they were exposed to, regardless of whether it was before or after the repaving. However, by comparing our measured %HA with the calculated, it does seem that the TAL implementation made the noise exposure–%HA relation more tilted. As noise annoyance is a subjective indicator that relies on the individual's state of mind, the measured decrease in %HA may be attributed to an increased satisfaction regarding investments placed in infrastructure to enhance the resident's quality of life. Additionally, the construction of TALs reduces noise levels without impacting, for example, the traffic flow or the environment aesthetics.

3.2. Indirect Subjective Perceived Noise: Physical Complaints, Quality of Sleep and Comfort Level to Perform Activities

The respondents indicated to what extent they were suffering from physical symptoms (Domain 1), sleeping quality (Domain 2), and difficulties performing activities indoors and outdoors (Domain 3). Kruskal–Wallis tests revealed no significant differences among the mean ranks of any indirect subjective indicator in three domains, neither for the different cases (control and experimental streets) nor conditions (pre- and post-surveys). Therefore, a direct link between the TAL implementation and the indirect subjective perceived noise could not be drawn. Ref. [15] stated that assessing potential health effects triggered by noise exposure should be mediated by annoyance indicators or other appraisal measures. This observation is also made in previous studies summarized in [16], all citing insufficient evidence to show direct links between noise interventions and sleep disturbance or cardiovascular effects.

Specifically for our research, we think three possible explanations can be given for the insignificant correlation between these indicators and the noise intervention. Firstly, the post-surveys might have been distributed too shortly after the intervention to find a measurable (health) effect. Physical complaints resulting from prolonged exposure to environmental noise will not immediately disappear after the noise levels have decreased. Secondly, the noise exposure reduction was limited (in the order of 3 dB). The third explanation is the sample size being insufficient to measure a reduction in complaints in the given research design.

Nonparametric Kendall's τ_b correlation was used to determine whether there is a correlation between noise annoyance indicators and physical complaints, quality of sleep and comfort level to perform activities (**Table 4**). For that, the answers from the control streets and the pre-survey in the experimental streets were merged (recall that the two post-surveys are likely to present a significant number of double respondents and should not be included in computing correlations).

Table 4. Kendall's τ_b correlations between indirect subjective perceived noise and annoyance indicators.

Domain	Indicator		Annoyance	ΔAnnoyance	RTA
Physical complaints (1)	Headaches				
	Fatigue		0.14 * (*n* = 220)		0.13 * (*n* = 211)
	Dizziness		0.		0.15 * (*n* = 210)
	Insomnia		0.22 ** (*n* = 224)		0.16 ** (*n* = 214)
	Heart palpitations		0.14 * (*n* = 221)		0.15 * (*n* = 213)
	Gastrointestinal complaints		0.13 * (*n* = 223)		0.12 * (*n* = 215)
Sleep quality (2)	Sleep duration (night)				
	Sleep duration (day)			−0.13 * (*n* = 212)	
	Time to fall asleep				
	Waking up too early		0.15 ** (*n* = 221)		0.14 * (*n* = 213)
	Difficulty waking up				
	Feeling well-rested		−0.14 * (*n* = 220)		
Comfort level to perform activities (3)	Concentration during reading	In	0.21 ** (*n* = 223)		0.20 ** (*n* = 214)
		Out	0.56 ** (*n* = 222)	0.16 ** (*n* = 209)	0.20 ** (*n* = 213)
	Concentration during working or studying	In	0.22 ** (*n* = 218)		0.13 * (*n* = 210)
		Out	0.31 ** (*n* = 218)	0.13 * (*n* = 205)	0.18 ** (*n* = 208)
	Concentration during watching TV	In	0.18 ** (*n* = 223)		0.14 * (*n* = 213)
	Speech intelligibility during a conversation	In	0.20 ** (*n* = 221)		0.12 * (*n* = 213)

Domain	Indicator		Annoyance	ΔAnnoyance	RTA
		Out	0.30 ** (*n* = 223)	0.24 ** (*n* = 210)	0.26 ** (*n* = 213)
	Speech intelligibility on the telephone	In	0.18 ** (*n* = 224)	0.15 * (*n* = 211)	
		Out	0.29 ** (*n* = 222)	0.21 **(*n* = 209)	0.22 ** (*n* = 212)
	Relaxing or unwinding	In	0.23 ** (*n* = 223)	0.17 ** (*n* = 210)	0.16 ** (*n* = 214)
		Out	0.38 ** (*n* = 222)	0.26 ** (*n* = 209)	0.24 ** (*n* = 213)

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

A large number of the indirect subjective noise indicators correlate weakly but significantly with the three annoyance indicators. In general, except for headaches, people who experience annoyance from (road traffic) noise are more likely to report physical complaints than people who are not. The perceived change ΔAnnoyance does not show correlation across Domain 1. In ref. [15], RTA is also related to fatigue, but not to chest pain.

The questionnaire data from a population-based study in Oslo [17] points out an association between road traffic noise and waking up too early. The present study further indicates that besides the actual noise levels, the noise annoyance indicators (Annoyance and RTA) may also aid in assessing this discomfort. Increasing levels of noise annoyance go with a lower likelihood of feeling well-rested in the morning. The other indicators in Domain 2 did not correlate significantly with the noise annoyances.

The strongest correlations in **Table 4** were found in Domain 3. Without exception, it is more difficult to perform these activities when feeling annoyed by noise in general and specifically from road traffic (with the only exception of speaking to the phone). In general, the correlations were slightly stronger for outdoor activities. In the surveys conducted by [18], where 48.4% of the respondents reported experiencing noise-related annoyance (via a yes/no question), 49.8% reported feeling noise-induced discomfort to perform activities such as watching television, resting, talking and performing activities that require concentration.

Except for some of the correlations for comfort to perform outdoor activities, the τ_b values are generally low, which means that annoyance levels are contributing but certainly are not the only factor playing a role in the extent to which the respondents experience their sleeping pattern, physical complaints, or how comfortable they are to perform certain activities.

4. Conclusions

This study aimed to quantify the effectiveness of low-noise thin surface layers (TALs) as an intervention on road traffic noise and its impacts on the residents' perception. Objectively, a noise exposure reduction of 2.8 dB(A) for both L_{den} and L_{night} was obtained.The noise exposure after the TALs placement still could not meet the recommended levels by the WHO [19] (L_{den} 61.5 dB and L_{night} 51.0 dB compared to the limits of 53 dB and 45 dB, respectively). However, this is where the subjective impacts of the noise intervention become relevant, as the literature suggests that the impact of noise exposure on the build-up of non-auditory health disorders can be better assessed by the annoyance indicators rather than the actual noise levels.

Firstly, both the annoyance levels caused by noise in general and specifically by road traffic noise were significantly reduced after the TALs placement. The percentage of highly annoyed people (%HA) was reduced by 15.2% and 4.8%, for the cut-offs between highly annoyed and not highly annoyed at 60% and 80%, respectively. These reductions are considerably higher than based upon calculations using exposure–response relationships (ERRs) found in the literature ([2][13]). Perhaps the residents' satisfaction was increased by the implementation of a policy to enhance their well-being.

The indirect subjective noise indicators, which included physical complaints, sleep quality, and comfort level to perform activities indoors or outdoors, did not present a change after the noise intervention. However, the annoyance indicators presented weak but still significant relation with physical complaints and a strong correlation with difficulty to perform most of the activities outdoors and indoors.

The results support the policies of (road) authorities in general and in cities such as Antwerp in particular, to continue investing in projects that reduce road traffic noise annoyance, provided that sufficient residents in the region can benefit from the intervention and that it is technically feasible.

References

1. Basner, M.; Babisch, W.; Davis, A.; Brink, M.; Clark, C.; Janssen, S.; Stansfeld, S. Auditory and non-auditory effects of noise on health. Lancet 2014, 383, 1325–1332.
2. Guski, R.; Schreckenberg, D.; Schuemer, R. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance. Int. J. Environ. Res. Public Health 2017, 14, 1539.
3. Brink, M.; Schäffer, B.; Vienneau, D.; Foraster, M.; Pieren, R.; Eze, I.C.; Cajochen, C.; Probst-Hensch, N.; Röösli, M.; Wunderli, J.-M. A survey on exposure-response relationships for road, rail, and aircraft noise annoyance: Differences between continuous and intermittent noise. Environ. Int. 2019, 125, 277–290.
4. Gateano, L.; Mauro, C.; Elena, A. Noise monitoring within LIFE NEREiDE: Methods and results. In Proceedings of the Inter-Noise 2019: The 48th International Congress and Exhibition on Noise

Control Engineering, Madrid, Spain, 16–19 June 2019.

5. Bianco, F.; Fredianelli, L.; Castro, F.L.; Gagliardi, P.; Fidecaro, F.; Licitra, G. Stabilization of a p-u Sensor Mounted on a Vehicle for Measuring the Acoustic Impedance of Road Surfaces. Sensors 2020, 20, 1239.
6. Del Pizzo, A.; Teti, L.; Moro, A.; Bianco, F.; Fredianelli, L.; Licitra, G. Influence of texture on tyre road noise spectra in rubberized pavements. Appl. Acoust. 2020, 159, 107080.
7. Biligri, K.P. Effect of pavement materials' damping properties on tyre/road noise characteristics. Constr. Build. Mater. 2013, 49, 223–232.
8. Merskaa, O.; Mieczkowski, P.; Żymełkaa, D. Low-noise Thin Surface Course—Evaluation of the Effectiveness of Noise Reduction. Transp. Res. Procedia 2016, 14, 2688–2697.
9. Vaitkus, A.; Andriejauskas, T.; Vorobjovas, V.; Jagniatinskis, A.; Fiks, B.; Zofka, E. Asphalt wearing course optimization for road traffic noise reduction. Constr. Build. Mater. 2017, 152, 345–356.
10. Pedersen, T.H.; Le Ray, G.; Bendtsen, H.; Bendtsen, J. Community Response to Noise Reducing Road Pavements. Rapport Nr. 502; Danish Road Directorate (Vejdirektoratet): Copenhagen, Denmark, 2014.
11. Lo Castro, F.; Iarossi, S.; Massimiliano, L.; Bernardini, M. Life NEREiDE project: Preliminary evaluation of road traffic noise after new pavement laying. In Proceedings of the Inter-Noise 2019: The 48th International Congress and Exhibition on Noise Control Engineering, Madrid, Spain, 16–19 June 2019.
12. Environment Department. Schriftelijk Leefomgevingsonderzoek SLO-4 (2018). Available online: https://www.lne.be/schriftelijk-leefomgevingsonderzoek-slo-4-2018 (accessed on 29 September 2021). (In Dutch).
13. Miedema, H.M.E.; Oudshoorn, C.G. Annoyance from transportation noise: Relationships with exposure metrics DNL and DENL and their confidence intervals. Environ. Health Perspect. 2001, 109, 409–416.
14. Paunovic, K.; Jakovljević, B.; Belojevic, G. Predictors of noise annoyance in noisy and quiet urban streets. Sci. Total. Environ. 2009, 407, 3707–3711.
15. Fyhri, A.; Klæboe, R. Road traffic noise, sensitivity, annoyance and self-reported health—A structural equation model exercise. Environ. Int. 2009, 35, 91–97.
16. Brown, A.L.; van Kamp, I. WHO Environmental Noise Guidelines for the European Region: A Systematic Review of Transport Noise Interventions and Their Impacts on Health. Int. J. Environ. Res. Public Health 2017, 14, 873.
17. Evandt, M.J.; Oftedal, B.; Krog, N.H.; Nafstad, P.; Schwarze, P.E.; Aasvang, G.M. A Population-Based Study on Nighttime Road Traffic Noise and Insomnia. Sleep 2016, 40.

18. Paiva, K.M.; Cardoso, M.R.A.; Zannin, P.H. Exposure to road traffic noise: Annoyance, perception and associated factors among Brazil's adult population. Sci. Total Environ. 2019, 650, 978–986.
19. WHO. Environmental Noise Guideline for the European Region; WHO: Copenhagen, Denmark, 2018.