TNAR – A NEW METHOD FOR ASSESSING ROAD NOISE ANNOYANCE LEVEL

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ABSTRACT

According to current standards, the impact of road traffic noise is represented by the A-weighted energy-equivalent sound level ($L_{A,eq}$). This quantity is easy to estimate but does not take account of subjective annoyance of sound events.

Using a dummy head measurement system (HEAD acoustics) the speed of each vehicle and the pass-by noise of different vehicles with variable speed profiles were binaurally recorded on characteristic road sections.

More then 200 persons were subjected to a hearing test with different vehicle ensembles. The "annoyance effect" of different sound ensembles was rated using a "personal noise ranking scale" PNRS from "less annoying" to "very annoying". In parallel, the psychoacoustic parameters loudness, roughness, sharpness, tonality and fluctuation strength were analysed and compared with the $L_{A,eq.}$

Results reflecting annoyance obtained with PNRS were combined with objective psychoacoustic parameters to an index defined as Traffic Noise Annoyance for Roads (TNAR). This new TNAR index represents a decided improvement upon the description accuracy of noise impacts on humans and enables engineers to construct road environments which not only reduce sound levels but, more importantly, reduce perceived annoyance to humans. Noise abatement in the future will not only be a quantitative problem, but also a qualitative solution.

1. STATUS QUO

Noise is one of the most frequently reported negative environmental effects of traffic, especially road traffic [1]. At present, according to current standards and calculation specifications, the impact of road traffic noise is usually represented by the A-weighted energy-equivalent sound level ($L_{A,eq}$). This $L_{A,eq}$ is easy to estimate by measurements or calculation with some simple input parameters. There exist some very useful tools to simulate the noise immissions caused by road traffic, but the $L_{A,eq}$ does not account for the subjective annoyance of sound events as perceived by the affected persons. Several studies have shown, that even noise events with identical $L_{A,eq}$ cause very different annoyance, depending on frequency and psychoacoustic parameters (e.g. loudness, roughness, sharpness, tonality, fluctuation strength and so on).

1.1. Technical background

For a long time only the optimisation of roadside noise reduction measures was the main goal of research. Engineers tried to find out the optimised form or the best material for noise barriers along roads to reduce noise immissions for affected people living beside roads. In recent times research projects dealing with noise abatement have altered to concentrate on reducing the noise emissions of road traffic at source. Designers and manufacturer of cars try to reduce noise of engines and noise caused by the road surface/tyre contact.

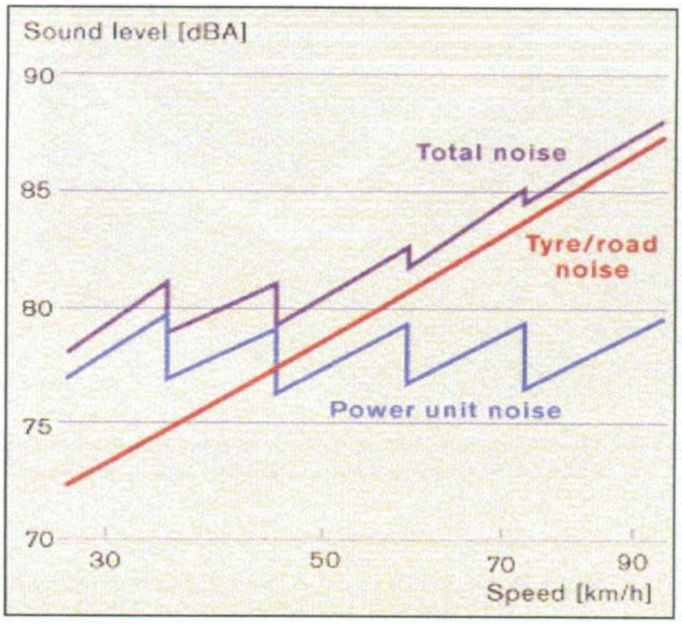

Figure 1 – Engine noise and tyre/road noise depending on speed [2]

In the last few years, engine noise was able to be reduced by almost 10 dB for passenger cars and trucks. For this reason, the main goal of research should now be to reduce noise levels caused by road surface and tyres. This is especially important for highway networks with their characteristically high speeds which make it necessary to improve the road surface and the tyre characteristics.

1.2. Legal Considerations

In Austria the noise emissions of passenger cars and trucks are regulated by laws related to the technical standard of cars. During the last 20 years, in line with technological developments in the automobile industry, these limits for noise emissions have been reduced by about 10 dB.

Noise abatement in the areas located near highways is regulated by an environmental law. This law includes the following criteria or provisions [3]:
- Measurement and calculation of noise immissions
- Limits for noise immissions
- Measurements along the road
- Measurements immediately in front or inside buildings

The estimation and evaluation of noise is carried out on the basis of physical values. Subjective evaluation by affected citizens cannot presently be considered. Relevant values are the $L_{A,eq}$ during the night and the $L_{A,eq}$ for day-evening-night as a weighted mean value.

$L_{A,eq,night}$ = 50dB
$L_{A,eq,day\text{-}evening\text{-}night}$ = 60dB

The World Health Organisation (WHO) recommends a limit of 45 dB for noise immissions during the night to avoid the associated health risks to the affected population [4].

2. DEFINITION OF THE PROJECT, RESEARCH DESIGN

The requirements of the research project may be determined from those recognized disadvantages in the current procedures being adopted in noise protection.
Primarily, it was necessary to fulfil the aim that the objective noise parameters be effectively contrasted with that effect felt by humans (disturbance). This should then result in the development of a new assessment parameter which better describes the disturbance created by traffic noise (and especially the road noise) than is the case with the current value, $L_{A,eq.}$
This remit required the collaboration of an interdisciplinary team. The following institutes were part of the research project team:

- Institute of Highway Engineering and Transportation Planning, Graz University of Technology (Project Leader)
- Institute of Hygiene, Department of Environmental Medicine, Medical University Graz
- Institute of Electronic Music and Acoustics, University of Music and Dramatic Arts Graz
- Institute of System Physiology, Medical University Graz
- Department of Neurology, ENT Clinic, Medical University Graz

As mentioned previously, the aim of the research project is to develop a method which allows the comparison of the objective measured and calculated values with the subjective reactions of affected trial participants, i.e. to establish the correlation between these influence variables.
With the variation in road surfaces characteristics, combination of vehicles (number and mode of vehicles), speed scenarios and weather conditions the main influence components on traffic noise annoyance should be estimated. The results could provide advanced knowledge for selection of suitable measures and for the practical work for planning and dimensioning of noise barriers.
If planners have this additional information measures could be installed, which not only reduce noise pollution (measured or calculated as $L_{A,eq}$) but also have the effect of reducing noise annoyance for those affected living or working along roads with heavy traffic. These more efficient measures may also in turn reduce overall costs for noise abatements measures.

3. DURCHFÜHRUNG DER UNTERSUCHUNG

3.1. Sound recording technique

The Austrian road network is essentially made up of asphalt concrete, concrete and split-mastix asphalt road surfaces. The routes were chosen for inclusion in the pass-by noise for passenger cars and trucks survey in accordance with these road surface categories. The locations for the pass-by noise measurements were selected so that a minimum length of 600m road section displayed a homogeneous noise characteristic. At a distance of 100m from the road axis the criteria for free sound propagation must also be met.

Figure 2 – Measurement location on the A2-Highway [5]

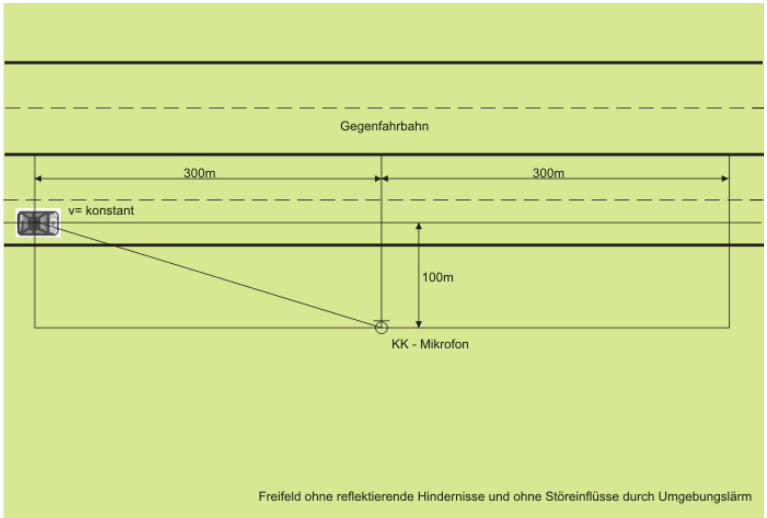

Figure 3 – Diagram showing the characteristic situation during measurement [5]

The pass-by noise for passenger cars and trucks was binaurally recorded with a dummy head measurement system from HEAD Acoustics. Parallel to the noise measurement, the speed of each vehicle was determined per radar at the exact same time and cross-section of measurement. The measurements during the night, where traffic volume was low, were carried out for individual passing vehicles. It should be mentioned here that all the measurements were carried out under almost identical weather conditions (i.e. temperature, atmospheric pressure, atmospheric humidity) and there was no wind.

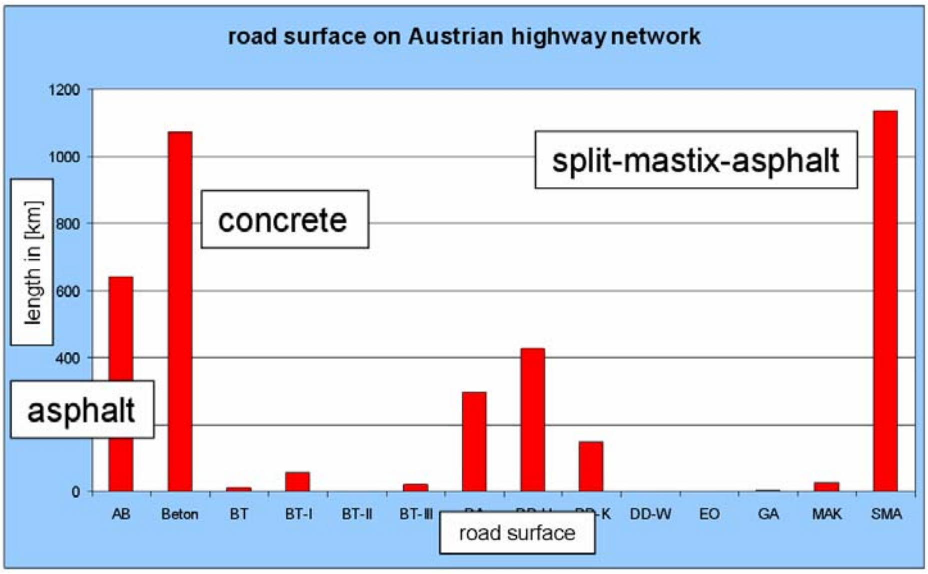

Figure 4 – Distribution of road surface types in the Austrian highway network [5]

Using the single passing vehicles recordings various "traffic ensembles" were composed by employing corresponding audio editing software. These ensembles represent road surfaces which are typical for the Austrian highway network (asphalt concrete, concrete and split-mastix asphalt), as well as the various speed scenarios for passenger cars and trucks and the scenarios for vehicle combinations on Austrian Highways (shares of passenger cars and trucks).

3.2. Psychoacoustic analysis and tests

Noise ensembles were analysed for the psychoacoustic parameters loudness, roughness, sharpness, tonality, fluctuation strength and for $L_{A,eq.}$. Using this analysis an objective characterization of noise events is possible.

The subjective rating of the noise events by the test persons was carried out by using the Personal Noise Ranking Scale. This PNRS is scaled from 1 (a little annoying) to 11 (very annoying). Each vehicle ensemble could be chosen several times; the test persons could repeat each vehicle ensemble as often as they wanted. Only when they have finished the assessment of the noise scale is their judgement fixed.

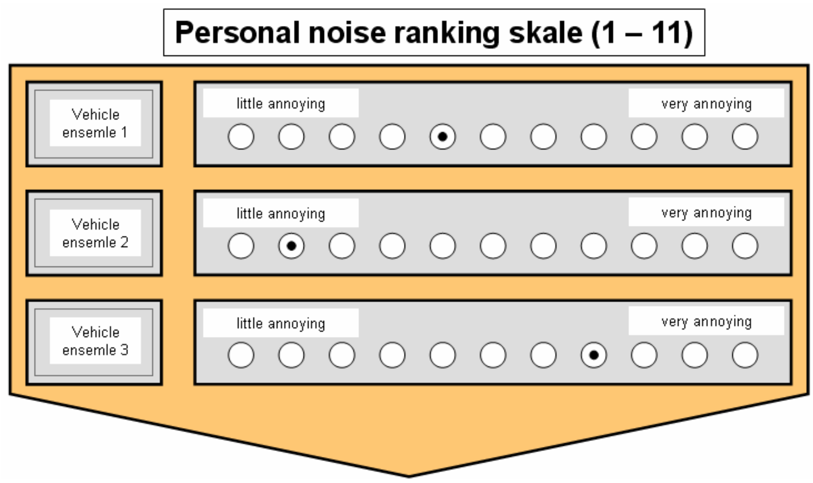

Figure 5 – Personal noise ranking scale for psychoacoustic tests [5]

3.3. Physiological tests

In addition to the psychoacoustic tests several physiological tests were carried out during the noise event at the psychoacoustic laboratory at Graz University of Technology. In this way the influence of traffic noise on the vegetative system of people can be estimated.

These physiological tests employ the parameters „heart rate variability“ and „respiratory frequency“. At the beginning of this test, people were connected to an electronic impedance monitor. The electro-cardiograph for monitoring the heart consisted of three electrodes with a splicer.

The intervals of noise pollution (180 seconds) were separated by neutral phases (180 seconds). During these neutral phases only pictures with landscapes without any noise pollution were shown to the test person.

The physiological tests and the psychoacoustic test were carried out on different days, to ensure unprejudiced assessment by the test persons.

3.4. Statistical analysis

The results of the single tests (subjective psychoacoustic test, physiological test, objective psychoacoustic parameters and $L_{A,eq}$) were submitted to a comparative statistical analysis. Comparison of the subjective assessment of PNRS with the psychoacoustic parameters, the physiological parameters and $L_{A,eq}$ allows conclusions, which parameters describes the subjective annoyance most accurately.

This analysis shows, that loudness, sharpness (for wet road surface) and low frequency fluctuation strength (a newly designed parameter for big shares of trucks) has the most significant influence on traffic noise annoyance. These parameters were combined into the Traffic Noise Annoyance Index.

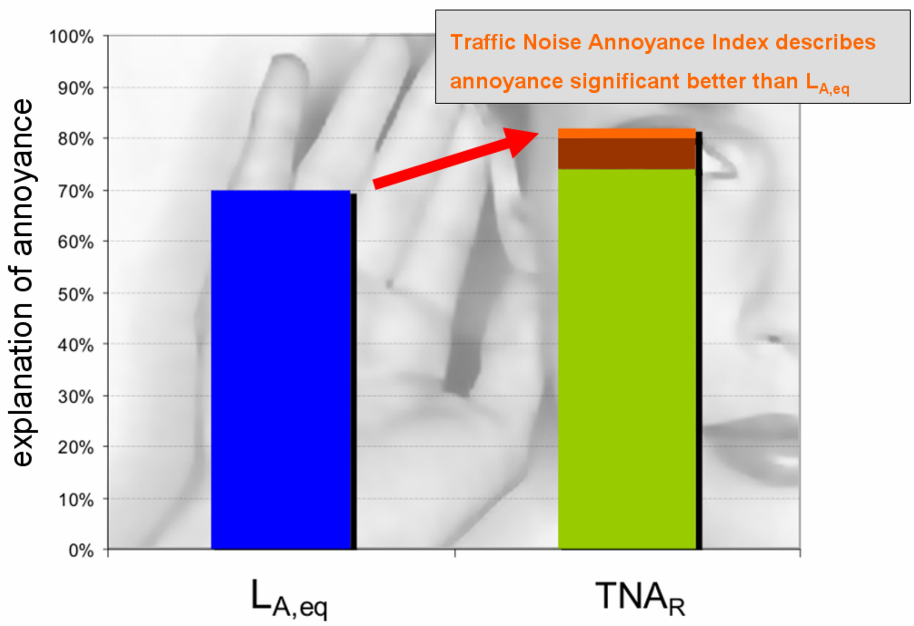

Figure 6 – Explanation of Traffic Noise Annoyance [5]

4. PRACTICAL APPLICATION FOR NOISE ABATEMENT

With the state of art research into traffic noise annoyance an analysis of the current situation of traffic noise is now possible.
From the results of detailed analysis the most relevant noise components und their influence on annoyance can be estimated.

- Tyres
- Quota of heavy vehicles
- Speed
- Road surface

The results of the studies can be used to develop affirmative actions to reduce not only noise pollutions but also the noise annoyance.
Wit respect to further plans and measures for special projects it would be a priority in th e future to examine ways of reducing the subjective annoyance rate for affected persons.
The knowledge gained so far in the course of this research shows that the most import ant aspect will be to focus on research and development of new tyre profiles and road surfaces [6].

Reducing the limits for noise emissions of tyres will be necessary. This will create incentives for companies to enforce the development of new materials and new types of tyres.
Regarding the development of new road surfaces it will be important, to fulfil the requirements of noise abatement in addition to durability in order to obtain the optimum configuration with respect to life-cycle-costs.

CONCLUSION AND FUTURE OUTLOOK

The main focus of this study was to improve sound analysis methods in order to include subjective effects as experienced by the population at large. In particular that means annoyance caused by traffic noise. This has been accomplished by consideration of psychoacoustic research findings. The result is joint target measure index termed traffic noise annoyance on roads (TNA_R). This TNA_R should be considered for future use in road- and rail traffic planning and therefore may serve construction engineers in addition to traffic planners as a supplemental tool.

With the employment of this **T**raffic **N**oise **A**nnoyance on **R**oad it will be ensured that not only the results of technical measurements and calculated results of simulation models for noise immissions may be considered in environmental problems caused by road traffic but also the subjective effects. Design and dimensioning of environmental protection measures on roads should also be implemented to reduce annoyance caused by road traffic noise. This will improve the effects of noise reduction measures for the affected persons and make the measures more efficient and possibly more cost effective for the operating companies of road networks. As a result, in the future, with the help of the $TNA_{R,}$ engineers should be able to find an optimum balance between the following measures:

- noise-measurement reduction at the vehicle level (engines and tires),

- traffic organisation (e.g. speed limits, coordinated traffic lights)
- road construction methods (material for road surface)
- measures along the roadside (noise barriers)
- measures on buildings (noise reduction using special windows).

The future-oriented noise abatement will not only have the goal to observe a technical limit of noise immissions, but more importantly it will also be able to address subjective human perception of traffic noise (level of annoyance) which must also be taken into account when implementing noise reduction measures [7].

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