



## PSYCHOACOUSTICAL EVALUATION OF TRAFFIC NOISE

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Genuit, Klaus<sup>1</sup>; Guidati, Sandro<sup>1</sup>; Rossberg, Sebastian<sup>1</sup>

<sup>1</sup>HEAD acoustics GmbH; Ebertstrasse 30a, Herzogenrath, 52134, Germany

[klaus.genuit@head-acoustics.de](mailto:klaus.genuit@head-acoustics.de)

### ABSTRACT

The legal relevant parameters for the evaluation of vehicle noise as well as traffic noise are mostly based on the A-weighted sound pressure level, e.g. the  $L_{Amax}$  for pass-by noise or the  $L_{Aeq}$  for environmental noise. Since these parameters do not regard the perception of noise sufficiently the abundance of respective noise limits does not prevent the occurrence of highly annoyed residents. This was the motivation for investigations in the framework of the EU project "Quiet City Transport" (QCity) concerning additional objective methods for vehicle noise evaluation that include psychoacoustic parameters.

Following numerous listening tests based on a broad database of pass-by noises correlations between annoyance and (psycho-)acoustic parameters were studied in detail. It proved true that the description of noise based on sound pressure levels does not sufficiently grasp the noise features relevant to subjective evaluations. Specific psychoacoustic parameters improved the reproduction of the subjective evaluations.

The research will be continued considering traffic flow noise. Before conducting further listening tests the effect of overlaying single pass-by events on psychoacoustic parameters is studied in a preliminary investigation.

### QCITY

In 2002 the European Union has issued the EU Noise Directive 2002/49/EC to avoid, prevent and reduce harmful impacts caused by environmental noise [1]. Its concept is the generation of noise maps for large urban agglomerations which are the basis for the detection of hot spots and the development of action plans to improve the respective acoustic situation. To support the cities and communities concerning the implementation of the EU Noise Directive the EU initiated the research project Quiet City Transport (QCity) [2]. The main focus of QCity lies on the improvement of tools for noise map generation / hot spot detection and the development of mitigation measures. QCITY is an integrated EU project within the 6<sup>th</sup> framework. The consortium is composed of 27 partners from 10 European countries. The partners are consulting firms and research institutes working in the field of environmental noise and noise mapping as well as manufacturer of road surfaces, tires, rails, mitigation measures etc.

The aim of QCITY is to support cities and communities. The investigated mitigation measures should be applicable midterm by the communities on their own. Therefore, emission reduction directly at the source – e.g. passenger vehicles – is not considered. Applicable measures to influence traffic noise are changing the composition of the vehicle fleet in the city, e. g. by tax incentives for low noise vehicles, traffic flow regulation or establishing quiet zones. Furthermore, the application of noise barriers or low noise road surface can reduce noise propagation. An important contribution to the inner city noise comes from trams, metros etc. Here the communities can directly influence the noise generation by choosing low noise trains and rails. Thus a sub-project within QCity is working on that topic.

### Psychoacoustic evaluation of vehicle and traffic noise

Noise maps generally display the occurring dB(A)-levels within the considered area. This information is not sufficient for the detection of relevant acoustic hot spots [3]. Therefore, rating systems considering the number of inhabitants in an area, the orientation of the buildings or the effect of noise on the value of real estates are investigated. However, these rating systems are still based on the  $L_{Aeq}$ ; the spectral composition and time structure of traffic noise are not considered, although they are highly important for the human perception of urban noise [4].

Here, a further sub-project of QCITY deals with the psychoacoustic assessment of annoyance caused by traffic noise. Parts of the results of this sub-project will be presented and discussed in this paper. One of the main goals is to develop an objective description of traffic noise annoyance with the help of jury testing and psychoacoustic parameters. At first, a large number of single pass-by events relevant for urban driving are recorded. Jury testing and acoustic analyses of these events lead to the objective description of their perception. Successively, the single events are synthesized to complex traffic flow scenarios which again are investigated regarding their subjective perception. The auralization uses the results of traffic flow simulations performed within QCITY. The effect of changing traffic flows due to mitigation measures is hereby also investigated.

## **MEASUREMENTS**

The measurements for this sub-project form the basis for investigations that focus on the subjective perception of noise; therefore time signals have been recorded. The subjective evaluation of a pass-by event depends among others on how the single noise sources of a vehicle – engine, exhaust, tyres, etc. – contribute to the overall noise. Therefore, the emission of the components was measured as well. Two different approaches have been pursued (a detailed description is given in [5]).

### **Qualitative Measurements**

To assess a high number of different vehicles a measurement procedure was developed that guarantees a short instrumentation phase and a low measurement effort. Five microphones are placed in the near field of the main components intake, engine, exhaust, leading edge of one tyre and trailing edge of one tyre. Five typical urban driving conditions are selected for the measurements: constant speed 30 km/h (const30), constant speed 50 km/h (const50), average acceleration from 30 km/h (med\_acc30), rolling from 50 km/h (roll50) and traffic light situation (stop\_start). The exterior pass-by noise is recorded with an artificial head at the standard ISO 362 measurement position (7.5 m distance, 1.2 m height). 25 vehicles (mainly passenger cars) have been measured and analysed with this method so far.

This method is called “qualitative” since the near field recordings do not allow a direct conclusion about their contribution to the far field noise. But, by objective and subjective comparison the dominant noise source can be identified.

### **Quantitative Measurements**

To assess the exact contribution of each noise source of a vehicle a procedure developed within the EU project SVEN is extended and applied [6]. The emission of all relevant noise sources are recorded in their near field: intake, engine (6 positions), exhaust, differential, gear box, leading edge and trailing edge of all four tyres. Additionally, the airborne transfer paths between the near field microphones and far field observer positions and the far field pass-by noise are measured.

By filtering the near field signals with the transfer paths it is possible to generate pass-by signals of each source or any combination of them [7]. These signals represent the genuine contribution of a source or a combination of sources to the far field noise and can thereby be subject to subjective evaluation. The addition of all source contributions creates a synthesized time signal that corresponds to the far field recording.

## **EVALUATIONS AND ANALYSIS OF SINGLE PASS-BY EVENTS**

Extensive listening tests have been carried out to assess the annoyance of the recorded pass-by sounds. The sounds were grouped in sets which were then evaluated by judges. Within a sound set the judge has the possibility to listen to each sound arbitrarily often and to compare the sounds among one another. The annoyance ratings were given on a 9-point scale for each sound. To minimize biases a typical context was provided in the instructions. Each sound set was evaluated by 11 – 18 judges. The application of the principal component analysis on the subjective evaluations and correlation calculations identified the main acoustic analyses representing the annoyance perception. First of all, the Relative Approach (RA) [8] proved to be most important followed by the 5 % loudness percentile and the Sharpness. The optimal linear combination of these parameters lead to a correlation coefficient of  $r = 0.91$ , whereas the A-weighted  $SPL_{max}$  (following ISO 362) correlates only with  $r = 0.54$ . Verification tests with new and unused sounds were also conducted and confirmed the developed metric [9].

## SUPERPOSITION OF PASS-BY EVENTS

So far, the developed metric applies only for single pass-by sounds recorded directly at the street. Further investigations within QCity will analyse traffic flow scenarios. Here, it will be interesting how superposition effects and the more stationary character will influence the subjective evaluations and therefore the metric.

This temporal structure of the traffic noise will presumably have an important influence on the evaluation. The challenge is to select sound files that represent those effects and could be reliably evaluated by test persons. The following exemplarily considerations will help to define the design of future listening tests and will support the selection of relevant parameters during the analysis and metric development.

Two scenarios have been investigated. In Scenario 1 each sound file consists of four single pass-by recordings of one vehicle at a specific driving condition (const30, const50, stop\_start). The variable parameter is the time-offset between the four recordings. It ranges from simultaneous pass-by (offset 0 s) to values where the passing vehicles are clearly perceived as single events (const30: 6 s (50 m vehicle distance), const50: 4 s (55 m vehicle distance), stop\_start: 16 s). For reasons of comparability it was decided to fill the sound files with low level background noise to a uniform length that is defined by the sound file with the highest offset between the single pass-by events (see Figure 1). This scenario is comparable to a street with constant traffic density (4 vehicles per time unit) but varying temporal distribution of the vehicles (e.g. by traffic lights or roundabouts). In Scenario 2 the length of the sound files is the same as in scenario 1 but the number of pass-by events is adjusted accordingly to offset and sound file length (see Figure 2)). This simulates the effect of traffic reduction under the premise of uniformly distributed pass-by events; the traffic density varies between the sound files.

It has to be mentioned that besides the temporal distribution further inherent aspects of the sound scenarios will possibly affect the evaluations. In the first scenario there are partially long periods of quiet background noise. This possibly makes it difficult for the judges to evaluate the sounds. In the second scenario the overall loudness increases with the number of events affecting the evaluation of sounds as well.

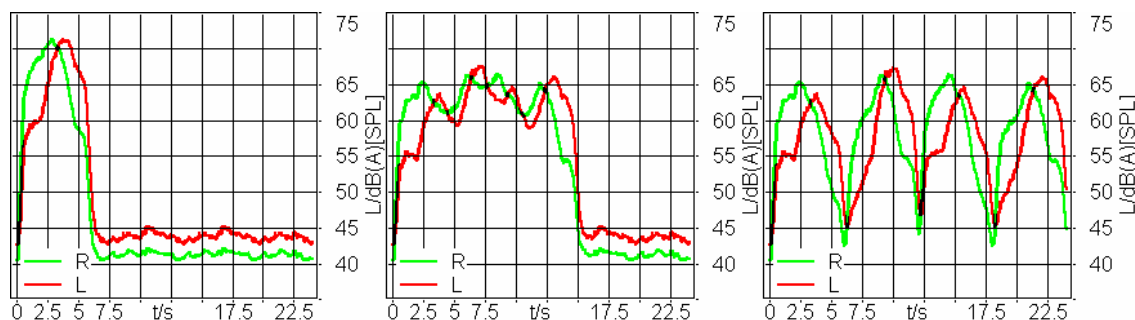


Figure 1.-Level vs. time (fast): Scenario 1 for const30, offset 0 s (left), 3 s (middle), 6 s (right)

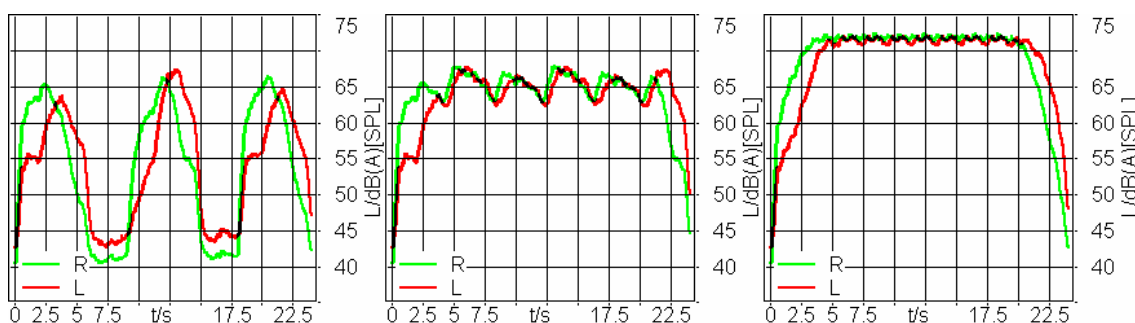


Figure 2.-Level vs. time (fast): Scenario 2 for const30, number of vehicles 3 (left), 10 (middle), 37 (right)

The loudness is calculated according to the time-variant loudness as described in the current draft of the DIN 45631. Two loudness parameters are gained: the time averaged loudness and the 5 % loudness percentile, which is recommended in the current draft of the DIN 45631 to best represent the subjective perceived average loudness. The stationary loudness (ISO 532) is

not considered since the stationary loudness is not capable of displaying the superposition parameters. At scenario 1 the stationary loudness does not change for varying offsets. At scenario 2 its values rise linearly with doubling the number of vehicles. The consideration of the time variant loudness (time-average and percentiles) appears much more promising. The  $L_{Aeq}$  is also calculated for every sound file to display the differences between A-weighted sound pressure level and loudness.

### Scenario 1 – Different Temporal Distribution of 4 Pass-By Events

As expected the  $L_{Aeq}$  for every driving condition is not influenced by the different offsets (see Figure 3). The sum of the sound energy of the four pass-by events remains constant independent of the way of superposition. In contrast, the time averaged values of the loudness, rise slightly with increasing offset. This effect is mainly caused by the decreasing length of the added background noise. The shorter these phases the higher are the time averaged loudness values. Of course, within the actual pass-by phases the loudness decreases with less superposition (higher offsets).

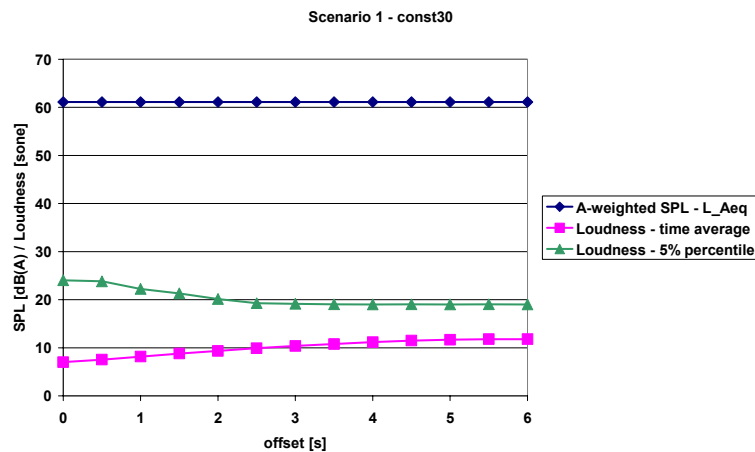


Figure 3.-Time averaged loudness, 5% loudness percentiles and  $L_{Aeq}$  of Scenario 1 for const30

The 5 % percentile values of the loudness are higher for small offsets (more superposition), but reach stable values when the central parts of the pass-by events are sufficiently separated, meaning that each pass-by is also audible separately. Hence, only small offsets cause variations of this parameter.

The temporal distribution of the single pass-by events has only little influence on the considered loudness parameters. In [10] it is suggested that relative changes of loudness can highly influence the perception of sounds. The higher these fluctuations are the more annoying a sound is possibly perceived. Those relative changes can be assessed by a comparison of parameters that represent peak values of a sound with parameters that represent average values. Therefore, the difference between the 5 % percentile loudness and the time averaged loudness will be investigated to possibly assess the effects of the different offsets on the temporal structure of the single sound files.

Figure 4 depicts the difference of the two loudness parameters in dependence of the offset. The influence of the offset on the difference values is more obvious as on the loudness parameters alone. Low offsets generate a distinctive temporal structure (expressed as high difference values) with one loud event at the beginning and a following quiet background noise. With rising offsets the effect of the following quietness is reduced and the difference values decrease. At higher offsets the changes are only marginal, since the single pass-by events are already clearly separated.

Concluding for scenario 1 it can be stated that the temporal distribution of a specific number of vehicles within a constant time span affects the investigated psychoacoustic parameters. The time averaged loudness values show a direct dependence on the length of the low background noise added to the sound files for comparability. The values are linked to the gap between successional events and also to the different loudness of the actual pass-by phases. The variable parameter offset influences significantly the 5 % loudness percentile for strong

superposition / low offsets. The investigation of the difference between these two parameters shows a higher sensitivity than the two loudness parameters alone, but is also strongly influenced by the quiet phases within a sound file.

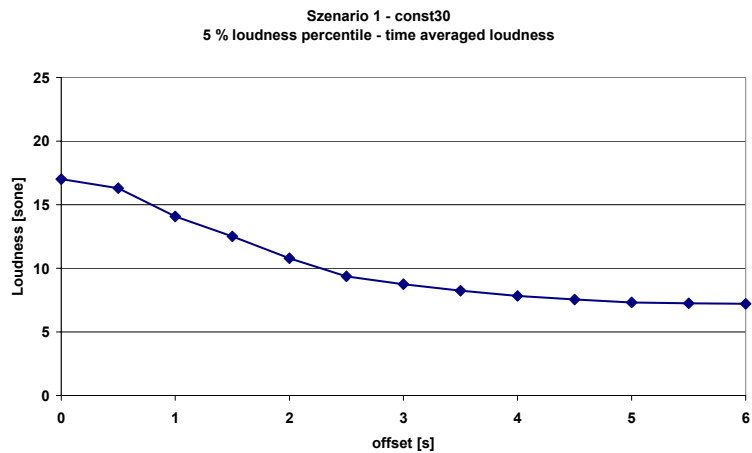


Figure 4.-Difference between 5% loudness percentile and time averaged loudness of Scenario 1 for const30

### Scenario 2 – Different Traffic Densities

For Scenario 2 the driving situations stop\_start is not considered, since a permanent traffic light situation at a single observer point is not reasonable. The variable parameter is the number of single pass-by events which range from 1 to 37 for const30 and 41 for const50. (see Figure 5). Since the length of the sound files corresponds to the ones of scenario 1, sound files with less than 4 single pass-by events are again filled with background noise only now between the events.

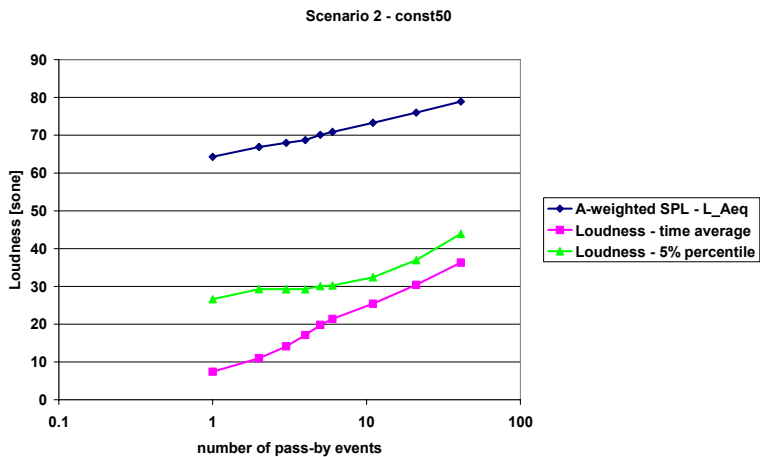


Figure 5.- Time averaged loudness, 5% loudness percentiles and L<sub>Aeq</sub> of Scenario 2 for const50

The L<sub>Aeq</sub> rises linearly as expected. The time averaged values of the loudness show a less steep developing for the sound files with a high number of vehicles. This suggests again a high sensitivity for the gaps between the single pass-by events. The 5 % percentile values of the loudness are more sensitive to high numbers of vehicles (above 10) or to small offsets respectively. This supports also the findings at scenario 1.

Figure 6 shows the difference values for the two loudness parameters. The values develop contrarily to the ones of the single parameters. A rising number of pass-by events leads to decrease of the difference values, meaning that the temporal structure of the sound files tends to a more stationary character when the traffic density is increased.

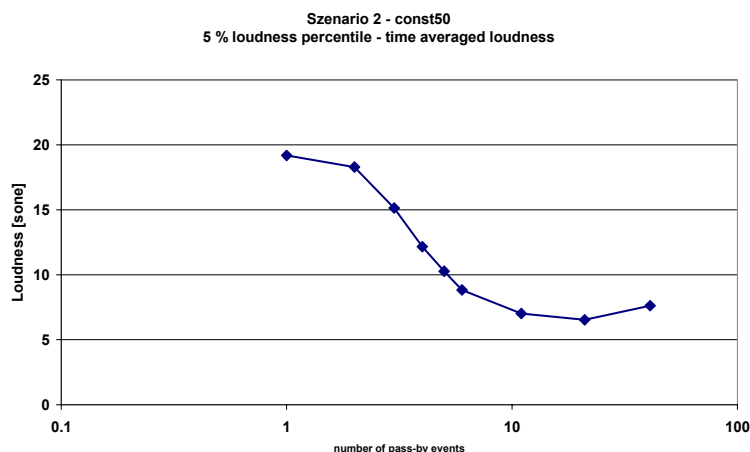


Figure 6.-Difference between 5% loudness percentile and time averaged loudness of Scenario 2 for const50

## CONCLUSIONS

For the subjective evaluation of traffic noises the distribution of single pass-by events is expected to be important due to masking effects, level fluctuations and the occurrence of quiet periods. Thus, parameters have to be defined that detect these effects. For the identification of the parameters listening test have to be carried out. Before starting with extensive, time-consuming listening tests possible traffic noise scenarios have been investigated. In the first scenario the constant number of events is superposed with decreasing delay. In the second scenario the number of events increases within a constant time span. Two standard parameters (time averaged loudness and 5% loudness percentile) have been considered. Additionally, the difference between the two loudness parameters was defined to detect the degree of loudness fluctuation within the sound file. As expected, the last value decreases in scenario 1 the more the events are evenly distributed; in scenario 2 the value decreases with a higher number of events meaning when the sound becomes more stationary.

Both scenarios will be used in the listening test within QCITY project. In particular, the effect of quiet periods must be deliberately scrutinized, because it will presumably influence the subjective evaluation of the traffic flow sounds.

This investigation considers only loudness as a standardized psychoacoustic parameter which is already deeply investigated. For the future work in QCITY it will be also interesting to analyse the perception and parametric behaviour of further psychoacoustic parameters, like sharpness, roughness, etc.

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