Proceedings of the Institute of Acoustics & Belgium Acoustical Society
Noise in the Built Environment, Ghent, 29-30 April 2010

AURALIZATION AND PSYCHOACOUSTIC ANALYSIS OF VIRTUAL ROAD TRAFFIC SCENARIOS

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1 INTRODUCTION

For a better understanding of environmental noise perception, the modeling and auralization of noise scenarios can be helpful. On the basis of synthesis technology environmental noise can be experienced, quantities calculated and reactions towards noise studied before mitigation measures are taken in reality. Prior research projects (such as HARMONOISE [1] and RoTraNoMo [2]) provided only calculations that allow for the prediction of noise generated by a given traffic scenario providing spectra or third octave spectra information. Although these spectra are sufficient to calculate standard descriptors, like L_{day}, L_{night}, L_{den}, in several cases more information is needed to study the investigated environmental noise situation more appropriate. In this context, an auralization of the environmental noise and the consideration of psychoacoustic parameters can be very helpful for the study of certain phenomena.
Furthermore, investigating traffic noise on the basis of synthesis has the advantage that traffic scenarios can be generated arbitrarily. Unwanted influences from environmental factors (e.q. whether), which cannot controlled in measurements, can be kept constant.
The development of a traffic simulation and auralization tool was realized within the research project "Quiet City Transport" [3]. One major prospect was to derive psychoacoustic maps, which allow for an improved urban planning. A further purpose of the Traffic Noise Synthesizer (TNS) is to simulate the effect of potential mitigation measures to help communities with respect to effective noise planning processes.
The auralization tool will be extended for example with respect to the simulation of hybrid cars within the new research project "City Hush" [4].

2 AURALIZATION OF VIRTUAL ROAD TRAFFIC SCENARIOS

The developed synthesis technology combines measurements with simulation. A traffic micro-simulation provides extensive data about the traffic. Such a traffic simulation was realized by KTH Stockholm University within the Quiet City research project. This traffic simulation software provides detailed information about the vehicle (vehicle type), exact position of all vehicles (x, y, gradient) and their driving conditions (rpm, speed, gear) at short time intervals.
The concept of the synthesis technology is to separate between the emission of the sources (description of sources) and the propagation from source to receiver (description of propagation). On the basis of measurements a data base of vehicle exterior noise was created, which stores the noise characteristics of measured signals of different vehicle types. The stored noise characteristics and properties are gained through near-field measurements at relevant sound sources of vehicles (e.g. engine, tires, intake, and exhaustion) that run through different operation modes. It has to be mentioned that the generated data base does not store the time signals of measured vehicle exterior noises themselves, but rather it contains only the properties (noise information) of the measured noise. This means that the synthesis is not a simple sample player, it creates synthetically every (near field) sound of certain sources (tire, engine, exhaust, intake) of a vehicle according to its driving conditions. The simulation uses this characteristic information to process the

vehicle noise emission reproducing signal properties (harmonics and orders respectively, residual noise) in dependence of the actual driving condition of every simulated vehicle within a traffic scenario. To “calibrate” the calculated emissions, each simulated vehicle contribution is adjusted to third-octave band levels (using a spectral calibration filter), which were defined in a research project called RoTraNoMo [2]. Because of the separate consideration of several sources of vehicles, the procedure also allows for the investigation of specific source contributions to the overall sound and the influence of virtual changes on specific sources to the resulting (traffic) noise. For example, the change of the road surface resulting in a different tire noise can be simulated and auralized adapting the tire/rolling noise to the new condition.

After the source-related adaptation of the third octave band levels, the propagation effects have to be considered to generate a realistic traffic sound at the defined receiver position. The different calculated contributions of each vehicle in dependence on a defined receiver position are filtered according to the DIN-ISO 9613-2 [5]. The filters were calculated from attenuation values at the octave middle frequencies defined by the standard and are applied to the “source” signals. Moreover, to generate an authentic impression of the created traffic noises, binaural filtering is applied in the TNS-technology as well. The implementation of binaural filtering was essential concerning the perception of traffic noise, because in reality a permanent localization of the vehicles occurs and with respect to reactions to noise spatial information in noise can be significant. To enhance the authenticity of the synthesized sounds further the Doppler-Effect, a frequency shift due to moving sources is also considered.

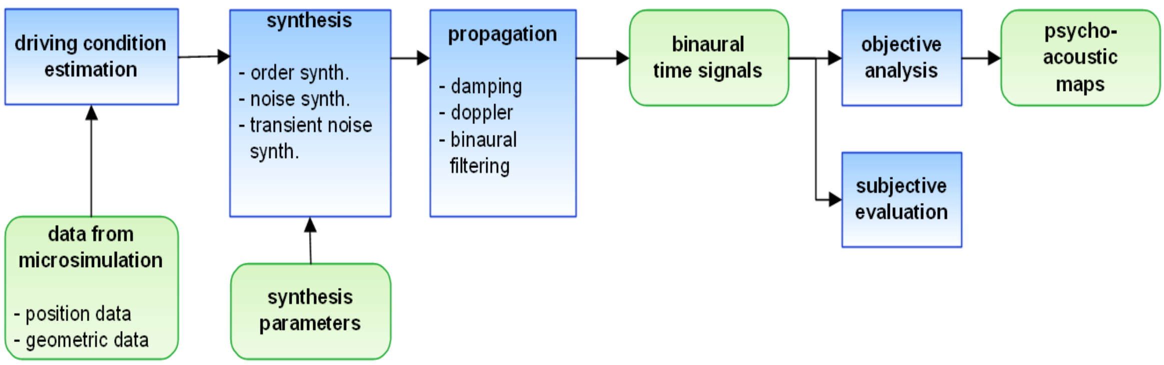

Figure 1: General concept and data flow of Traffic Noise Synthesizer

In urban context the propagation of road traffic noise is influenced by the geometric situation of the environment, such as buildings, walls and hills. As the damping of sound by walls, forest and other things can be modeled in the TNS, the reflection of sound at buildings or walls is not implemented yet. The modeling of reflections can be done by different methods like ray tracing or mirror source models. Up to now, the focus of the TNS lies on the source synthesis process.

3 GENERATION OF PSYCHOACOUSTIC MAPS

The creation of psychoacoustic maps follows a simple concept. As explained in chapter 2, for a defined receiver position the noise (time signal) is calculated considering the emission of the considered traffic and the respective propagation from source to the receiver position. This procedure is repeated for several receiver positions and respective time signals are determined for a “mesh” of receiver positions. On the basis of the diverse time signals any interesting acoustical parameter can be computed, like loudness, sharpness or roughness. Moreover, for the generation of a continuous color map the color gradient has to be calculated using the discrete values from the mesh. Of course, it is now possible to auralize the noise perceived in each receiver point with a

binaural playback. Figure 2 displays the general procedure of calculating the respective (psycho-) acoustic map of an investigated scenario. Since the time signals are calculated, further psychoacoustic maps can be determined without repeating the whole TNS-signal processing. On the basis of the time signals any relevant acoustical parameter can be calculated.
Since the calculated values of the considered acoustical quantity are time-dependent, dynamic (noise) maps changing over time can be created. Thus, for example the influence of specific traffic regulation measures on the resulting noise can be examined even over time, which means that noise variations and temporal effects can be studied in detail. The dynamic, time-variant noise maps can be visualized on the basis of videos.

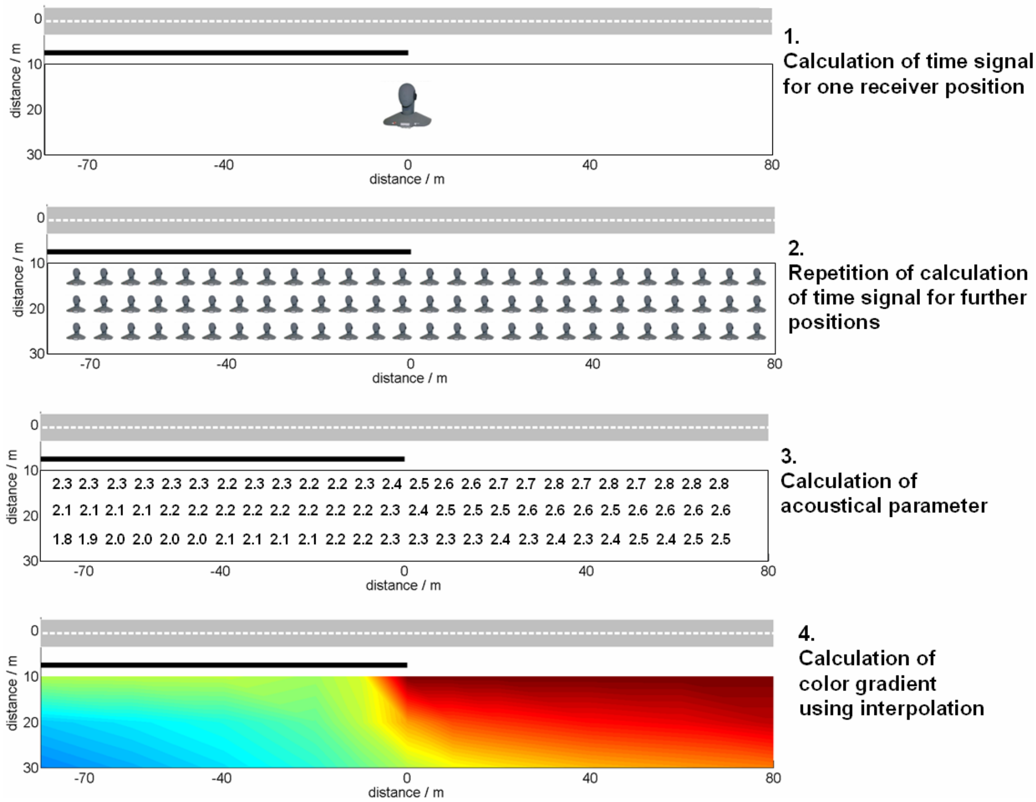

Figure 2: Procedure for the generation of psychoacoustic maps using Traffic Noise Synthesizer

4 APPLICATION OF A TRAFFIC NOISE SYNTHESIZER

To demonstrate the applicability and benefit of a traffic noise synthesizer a few simple examples are shown on the next pages. As a simple experiment, the spatial distribution of different acoustical parameters in a single street setting with a defined traffic flow is displayed. Figure 3 shows an instantaneous display of a dynamic time map.

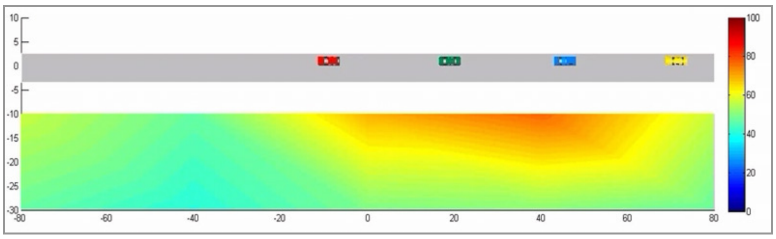

Figure 3: Instantaneous display of a dynamic noise map; x-axis: distance in [m], y-axis: distance in [m]; color scale ranges from 100 % to 0 %

4.1 Erection of a Noise Barrier

According to the EU Directive 2002/49 [6] strategic noise maps are developed and action plans created to improve the noise in cities. The synthesis technology can help to determine the efficiency of specific measures and actions, which are intended to reduce noise annoyance. Figure 4 shows the impact of the erection of a noise barrier with a height of 5 m within the considered scenario on the noise. The color scales of the figure 4 diagrams range from 100% to 25%, which means that from red to blue the value of the respective acoustical parameter is quartered, except for the last diagram, which displays the behavior of a combined parameter.

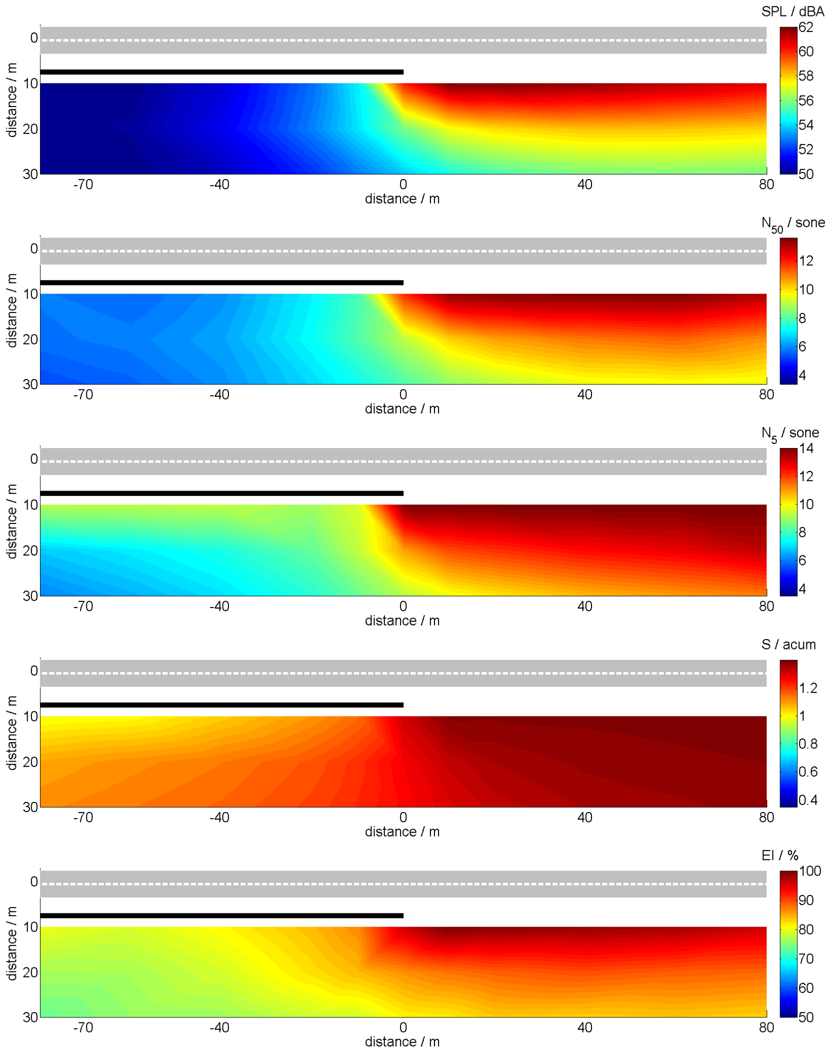

Figure 4: Psychoacoustic maps (time averaged) of a single street with a low traffic density and a speed limit of 50 km/h. The black line symbolizes the noise barrier. From top to bottom: L_{Aeq}, N_{50}, N_5 (DIN 45631/A1), sharpness (DIN 45692), the value of an Evaluation Index [7] combining loudness, sharpness, roughness, impulsiveness and Relative Approach [8]

It can be seen that using further acoustical parameters the expected decrease of noise annoyance behind the noise barrier is presumably lower than suggested by the L_{Aeq}-decrease. The spatial behavior of the displayed acoustical parameters does not completely correspond to the behavior of the sound pressure level. As Nilsson and Berglund have shown "*for road traffic noise exposures >50 dB L_{Den}, the percentage of residents who were annoyed or highly annoyed outdoors was much larger than predicted from Miedema and Oudshoorn's (2001) synthesized exposure-response curves*" [9]. This conclusion indicates that a decrease of sound pressure level does not automatically lead to the expected annoyance reduction using dose-response curves. By using further data such perceptual effects can be understood. In particular, the opportunity to auralize the resulting noise can also help to make reliable noise annoyance predictions. Although the absolute SPL is considerably decreased, the typical traffic noise patterns (single pass-by noise) are clearly audible. In listening tests these recognizable vehicle pass-bys result in annoyance ratings.

4.2 Change of Road Surface

Figure 5 illustrates the results of the TNS simulation comparing before and after situations. The example demonstrates the difference caused by the implementation of a typical low noise pavement (open porous asphalt) to a standard asphalt road surface. The synthesizer simulates a straight road with a high traffic volume. However, the speed and the load of the diverse vehicles vary in a typical way to enhance the authenticity of the generated sound files. A sound pressure level reduction of almost 3 dB is achieved due to the change of the road surface (fig. 5).

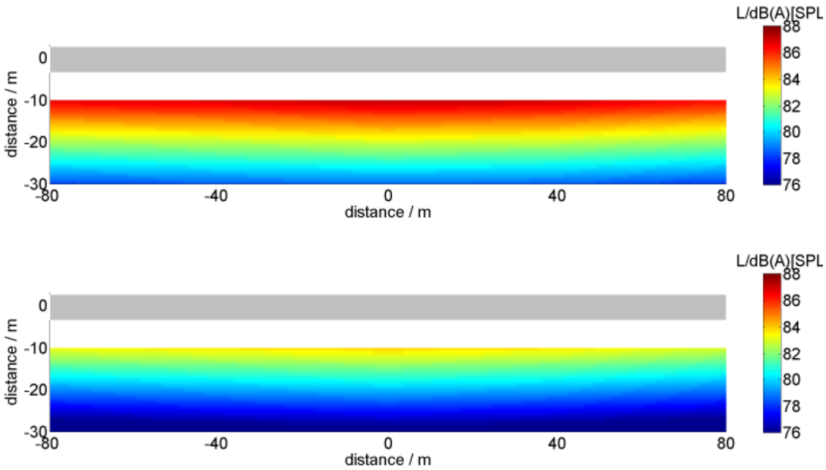

Figure 5: SPL(A) maps of a single street with a high traffic density and a speed limit of 50 km/h; top: standard road surface, bottom: low noise pavement (OPA)

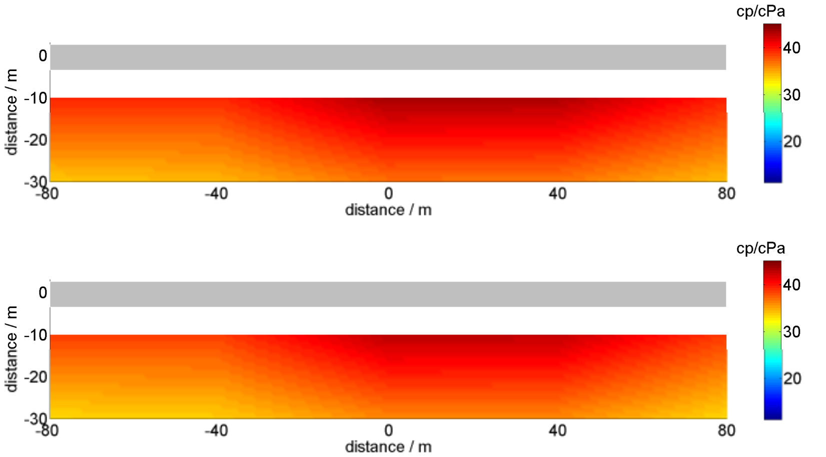

Figure 6: Relative Approach Analysis-maps of a single street with a high traffic density and a speed limit of 50 km/h; top: standard road surface, bottom: low noise pavement (OPA)

Further acoustical analyses, such as Relative Approach analysis, show the changed acoustical situation due to the virtually implemented road surface. It can be observed that perceivable acoustical patterns, quantified with the Relative Approach analysis, are not greatly reduced by the considered mitigation measure (fig. 6). By means of diverse acoustical analyses the efficiency of certain measures can be determined and even experienced; thus, it is not only a simple consideration of dB(A) values.

4.3 Change of Traffic Composition - Electric Cars with and without Warning Signals

Studies [10] have shown that due to quiet cars the pedestrian safety can decrease. In particular, blind persons seem to be at risk. Therefore, few countries, like Japan or USA, are discussing laws to guarantee a certain noise level of vehicle exterior noise and to ensure the audibility of quiet cars for visually handicapped persons. Potential warning sounds of quiet vehicles at low speed can remarkably influence the traffic noise and can increase the level of noise annoyance. To avoid this phenomenon, the creation of warning signals must also reflect a smallest possible annoyance, besides the audibility and recognizability of vehicles. Using simulation techniques (TNS) the impact of potential warning sounds on the resulting overall noise and on the noise annoyance can be studied. To demonstrate this possibility, two different vehicle warning sounds have been created and analyzed. The first warning signal consists of synthesized gauss impulses which are looped. This leads to an impulsive sound which shows many orders (harmonics) in the frequency domain. The second warning signal is composed by a set of two sine orders. In both cases the frequencies of the synthesized signals are linked to the engine speed, whereas in idle condition no warning sound is synthesized. Of course, the general nature of potential warning sounds for quiet cars is still open. However, to study in principle perceptual influences of warning signals on the overall traffic noise, exemplary warning signals are created.

The following scenario was considered: A few cars stand at a traffic light at 0 m for a few seconds. Then, after the traffic light indicates green, the vehicles accelerate and drive along the considered road section from left to right. The scenario lasts 20 seconds.
In figure 7 the resulting loudness maps of the investigated scenario are displayed for different “vehicle types”. The noise of vehicles with conventional combustion engines, of complete electric cars (as an initial approach only tire noise is synthesized) and electric cars with two warning signals are considered. The loudness maps show the expected results, the vehicles with combustion engines lead to highest N_5-values, the electric cars to lowest N_5-values and the scenarios of electric vehicles with warning signals lie in between, since the warning signals are added to the tire noises.

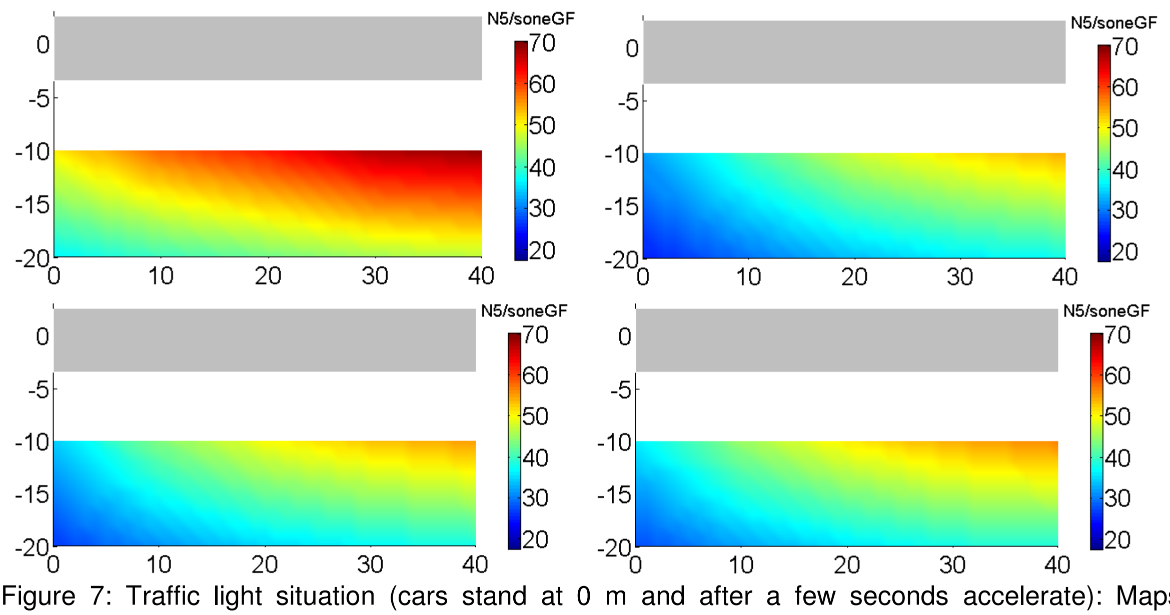

Figure 7: Traffic light situation (cars stand at 0 m and after a few seconds accelerate): Maps displaying the N_5; top: vehicles with combustion engines (left), electric vehicles (right); bottom: electric vehicles with warning signal 1 (two orders) (left), electric vehicles with warning signal 2 (Gauss impulses) (right)

Figure 8 shows the analysis of the traffic noises with respect to the psychoacoustic parameter roughness. The vehicles with the warning signal 2 lead to very rough noises, which is presumably more ear-attracting as well as annoying. The influence of warnings signals on the resulting overall traffic noise can be studied on the basis of several parameters. The preliminary studies yielded that a cacophony of warning sounds can negatively contribute to the perceived annoyance of the traffic noise. Therefore, the introduction of potential warning signals for the protection of visually impaired persons must also consider the resulting noise and noise annoyance. Warning signals should not conflict with the endeavors to reduce noise exposure and noise annoyance caused by road traffic noise. In particular, with respect to the creation and preservation of quiet zones in cities potentially emerging noise problems related to potential warning sounds must be discussed and avoided right from the beginning.

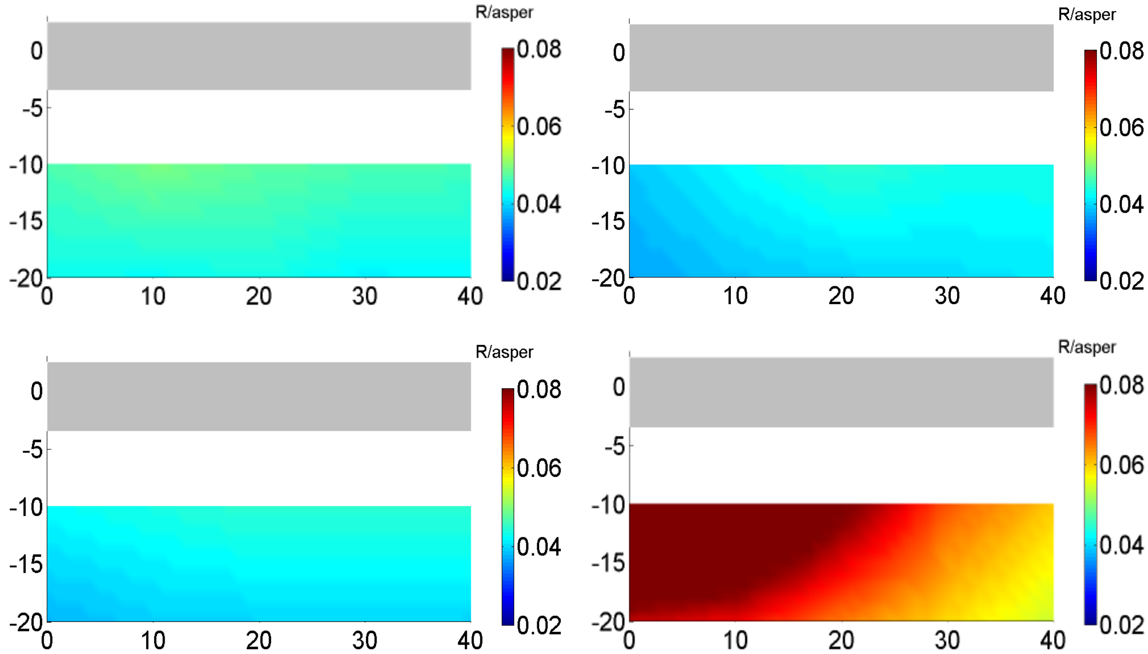

Figure 8: Traffic light situation (cars stand at 0 m and after a few seconds accelerate): Maps displaying the Hearing Model Roughness [11]; top: vehicles with combustion engines (left), electric vehicles (right); bottom: electric vehicles with warning signal 1 (two orders) (left), electric vehicles with warning signal 2 (Gauss impulses) (right)

5 CONCLUSIONS

On the basis of the TNS-technology road traffic related aspects can be studied in detail, it allows for an auralization of the considered scenario as well as the development of psychoacoustic maps. Recently, the noise synthesis is focused on road traffic noise; however, an extension to other important environmental noise sources, such as rail traffic, is possible. Furthermore, it can be a tool for city planning and urban development with special focus on noise. It could be help to transport knowledge from acousticians to urban and traffic planners, which can experience effects of several measures by themselves and learn to intentionally use certain measures for environmental noise optimization. Moreover, variations in the traffic flow (e.g. traffic lights or roundabout) and traffic management measures can be directly experienced by the listener and analyzed by engineers. In particular, with respect to emerging and spreading new alternative drives the resulting noise can be auralized and virtually experienced.

Of course, the presented technical approach for simulating traffic noise does not allow the investigation of the sensational representation of the considered urban space with its typical sound.

It cannot be achieved without asking how residents feel about their surrounding, without experiencing the place with its visual elements. This requirement cannot be fulfilled with physical models based on calculations.

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