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Psychoacoustics for the creation of acoustically green city areas

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ABSTRACT

Psychoacoustics has become increasingly important for community and environmental noise as well as soundscape research. Unfortunately, recent noise control approaches still interpret mostly sound pressure levels and do not focus on the subjects perception. However, there is growing consent about the necessity to apply further hearing-related parameters for a better understanding of environmental noise annoyance phenomena. In this context the identification of the most important psychoacoustic quantities reflecting human responses to noise is the major task. Especially with regard to the preservation and creation of quiet areas (Q-zones) according to the EC 2002/49 advanced evaluation tools and meaningful acoustic indicators are necessary to fulfil the ambitious goals regarding the creation of acoustically green city areas. Concepts of banning disturbing vehicles from quiet zones could guarantee that defined noise limits are not exceeded. In this context vehicles could be classified with respect to their noise emissions with coloured badges comparable to fine particle stickers. However, for an effectual classification of the acoustic emission of vehicles, the human perception and evaluation of vehicle pass-by noise must be studied in detail and psychoacoustic parameters applied. Furthermore, a traffic synthesis tool for the auralisation of specific traffic scenarios is developed to simulate for example the effect of new vehicle types on the resulting traffic noises. The synthesis tool could be used in principle for (a) the creation of audible maps, (b) testing the perceptual efficiency of potential noise mitigation measures and (c) examining the influences of different traffic compositions or traffic management measures on the noise and noise annoyance respectively. The current status of the development of psychoacoustic noise labelling of vehicles as well as of the traffic synthesis tool will be presented and first results introduced and discussed. In general, the potential of these approaches regarding the improvement of environment noise quality will be discussed from an ecological point of view.

INTRODUCTION

The Quiet City Transport research project (QCITY) [1] has aimed at developing tools for use by the European city administrations in order to comply with the EC Noise Directive EC2002/49 [2] in terms of Noise Maps and Noise Action Plans. QCity was an integrated EU project within the 6th framework. The consortium composed of 27 partners from 10 different European countries. The partners were consulting firms and research institutes working in the field of environmental acoustics and noise mapping, as well as manufacturers of road surfaces, tires, rails, mitigation measures etc. The main focus lies on midterm actions that the communities could take on their own, for example the communities could influence the composition of the vehicle fleet in the city, for example by tax incentives for low-noise vehicles, traffic-flow regulation or establishing quiet zones. Another main topic within QCity was calculating and further developing/ enhancing noise maps. In this context, a traffic noise synthesizer was developed, which allow for the virtual measurement and auralization of road traffic scenarios. Currently, a new research project was initiated, called CITYHUSH "Acoustically green road vehicles and city areas", which builds upon the knowledge acquired within the EC Quiet City Transport research project. It is carried out under the 7th European framework programme and will last from 2010 to 2012 [3]. The research project will support noise reduction technology to help to achieve the noise reduction goals. A special focus lies on the reduction of the overall noise levels in treated city zones - so called quiet zones - by 10-20 dB(A). For it, research work is carried out in the context of classification of quiet zones, improved hot-spot analysis, tire and road noise as well as environmental noise reduction in general. To achieve the ambitious goals and to address the increasingly widespread of alternative drive concepts, the research project is studying electric/hybrid driving with lowered tyre/road noise. Of course, with low drive-line noise from electric driving the tire noise will dominate at low speeds. Thus, to benefit from the low electric driving noise the reduction of tire-road noise becomes increasingly important. The investigation of vehicle exterior noise caused by electric/hybrid driving is new and has not been reported in literature adequately. The noise and noise annoyance potential of hybrid and electric cars will be investigated in detail in the future in order to estimate the benefit from new engine drive concepts regarding reduced noise annoyance. Here, work will be done to evaluate and compare the noise benefits from these vehicles with conventional environmental vehicles. For this purpose, a synthetis tool for the auralization of virtual road traffic scenarios and psychoacoustic evaluation will be adapted and extended to simulate the special behaviour of hybrid/electric vehicles (e.g. passenger cars, motorbikes). The present paper shows few preliminary considerations with respect to future applications and challenges in the context of alternative drive noise studies and demonstrates the use of the TNS for vehicle exterior noise-related aspects like warning signals. Here, the flexibility of the synthesizer tool auralizing virtual scenarios is valuable.

INTRODUCTION TO ALTERNATIVE DRIVES

Several versions of new engine concepts and alternative drives come or will come into the market in the near future, such as micro-hybrids, mild hybrids, full (parallel or 'power-split') hybrids, plug-in hybrids, extended-range electric vehicles, battery-electric vehicles. These concepts will be applied to all kinds of vehicles, such as passenger cars, motorcycles, buses, small transporters, heavy vehicles, etc. However, despite of all euphoria with respect to hybrid cars and electric vehicles, the combustion engine will be the dominant engine concept within the next years. Electric cars seem to be adequate for special needs and applications (second car, „city cars", local public transportation), but appear insufficient to fulfill all costumer needs so far. Concerning the combustion engine further optimization measures can be expected (turbo charging, direct injection, exhaust gas recycling, advanced regulating systems). However, since alternative drives will gain in importance, it is imperative to look into acoustical problems and conflicts regarding new engine concepts and find intelligent solutions right from the beginning.

AURALIZATION OF VIRTUAL ROAD TRAFFIC SCENARIOS

The traffic noise synthesizer (TNS) technology combines measurements with simulation [4]. A traffic micro-simulation provides detailed data about the traffic situation; 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 is provided. The synthesizer uses this information and simulates the emission of each vehicle separately.

The general concept is to separate between the source emission and the propagation from source to receiver. 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 (harmonics, residual noise and transients) 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. This differentiation is made to have the opportunity to distinguish between the contribution of the different sources in order to study for example the effect of changing engine noise or tire noise on the overall traffic noise. The generated data base with the noise property information does not store the time signals of measured vehicle exterior noises, but rather it contains only the properties of the measured noise. It is not a sample player; it creates synthetically every sound of certain sources of a vehicle according to its driving conditions. To "calibrate" the calculated noise emissions, each simulated vehicle contribution is adjusted to third-octave band levels (using a spectral calibration filter), which were defined in RoTraNoMo [5].

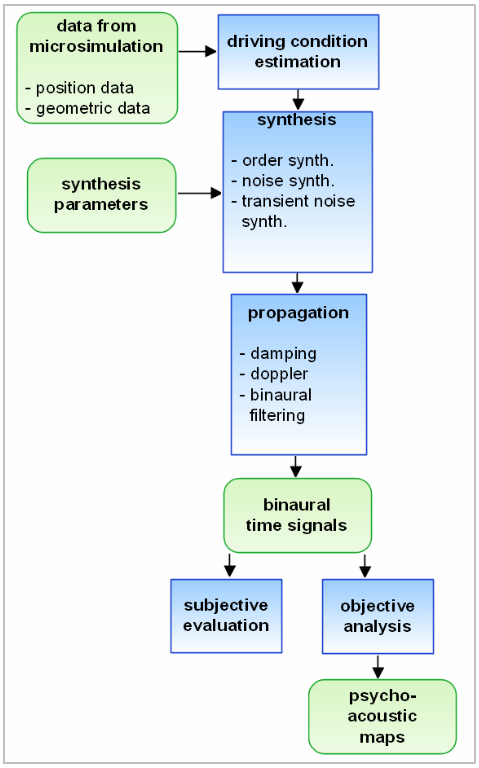

Figure 1. General concept and data flow of Traffic Noise Synthesizer

After the source-related adaptation of the third octave band levels, the propagation effects are considered to generate the traffic sound at a 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 [6]. 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 also considered. The implementation of binaural filtering was essential concerning the perception of traffic noise, because in reality a permanent localization of the vehicles occurs and spatial information in noise can be significant with respect to specific human reactions to noise. To enhance the authenticity of the synthesized sounds further the Doppler-Effect, a frequency shift due to moving sources is also implemented. 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.

GENERATION OF PSYCHOACOUSTIC MAPS

The creation of psychoacoustic maps follows a simple concept. As explained in the chapter above, for a defined receiver position the noise (time signal) is calculated considering the emission of the traffic and the respective propagation from the diverse moving sources 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, acoustical parameters, like loudness, sharpness or roughness, can be computed and displayed in maps. For the generation of a colored map the color gradient is calculated using the values from the mesh. Of course, it is also possible to auralize the noise perceived in each considered receiver point with a binaural playback. Since time signals are calculated, further psychoacoustic maps can be determined without repeating the whole TNS-signal processing.

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. The dynamic, time-variant noise maps can be visualized on the basis of videos.

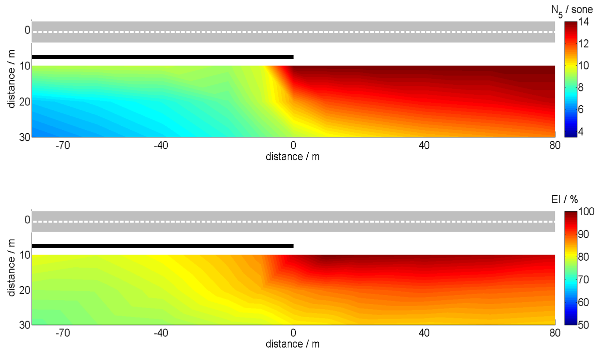

Figure 2. Psychoacoustic maps (time averaged) of a single street with a low traffic density and a speed limit of 50 km/h. The black line symbolizes a noise barrier. Top: N_5 (DIN 45631/A1 [7]); Bottom: Evaluation Index [8] combining loudness, sharpness, roughness, impulsiveness and Relative Approach [9]

Figure 2 shows exemplarily the impact on the noise caused by the erection of a noise barrier with a height of 5 m within the scenario of a straight road. It can be seen that the expected decrease of noise behind the noise barrier is modelled by the TNS and the psychoacoustic parameter loudness indicates this changed noise situation. The second colored map shows the behaviour of a combined parameter, where several psychaocustic quantities were combined to predict annoyance [8].

Electric Cars with and without Warning Signals

Studies have shown that due to quiet cars the pedestrian safety can decrease [10]. 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. However, table 1 shows that the vehicle exterior noise for an electric driven car compared to a quiet car with a combustion engine does not considerably vary with respect to loudness. The measured sound pressure levels and loudness values display only short differences; the quiet luxury car with combustion engine is only marginally louder for the considered driving conditions. In fact, the discussion about required warning signals for an increase of pedestrian safety must also reflect quiet cars with conventional drives in order to guarantee a sufficient safety for visually handicapped persons.

Table 1. Analysis of pass-by noise of two cars: Car 1 (medium class car with hybrid drive (only in electric mode)) and car 2 (luxury class car with combustion engine)

	Road surface 1		Road surface 2	
	Car 1	Car 2	Car 1	Car 2
	constant speed 20km/h			
L_{Aeq} (left, right) in dB(A)	56.8 / 55.8	57.0 / 56.0	56,4 / 57,4	58.5 / 58,5
N5 (left, right) in sone	13.5 / 12.8	15.1 / 14.8	16.0 / 15.9	15.2 / 15.1
	slight acceleration			
L_{Aeq} (left, right) in dB(A)	56.3 / 58.8	58.1 / 56.1	58.6 / 58.0	57.2 / 58.2
N5 (left, right) in sone	13.3 / 13.1	15.9 / 15.1	15.6 / 14.9	17.2 / 17.0

Figure 3 shows the mid- and high frequency spectra of two vehicles passing-by, a hybrid car driving in electric mode and a car with combustion engine. High frequency tonal components due to the converter can be clearly identified in the spectra on the left side. These tonal components can lead to annoyance and should be reduced as much as possible.

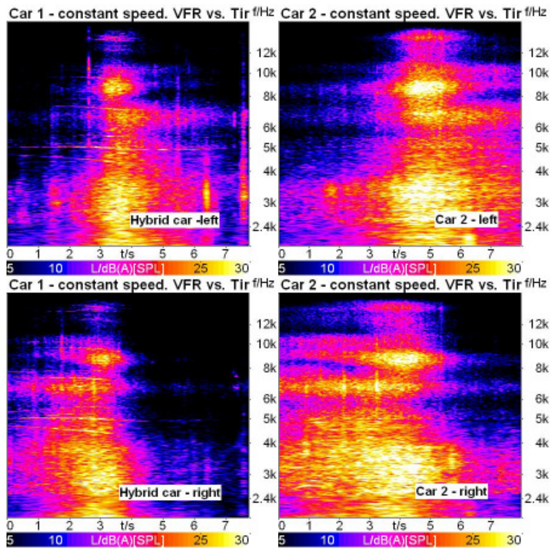

Figure 3. Pass-by of passenger cars, VFR vs. time; left: medium class car with hybrid drive (only in electric mode) with constant speed (20 km/h); right: luxury class car with combustion engine with constant speed (20 km/h)

Figure 4 displays orders due to the operating noises of the electric drive and the power inverter, which run in opposite directions. This behaviour leads to a permament change of the modulation frequency in the frequency range around 5 kHz as figure 5 shows. This figure illustrates the analysis of the modulation factor (modulation degree) over the modulation frequency and carrier frequency. A modulation analysis delivers the envelope spectra of partial bands of an analyzed signal and thus, allows for the recognition of modulations including their frequency and strength. The observed phenomenom here, the run of tonal components in opposite directions is untypical for vehicles equipped with combustion engines and attract attention in spite of the relative low sound pressure levels of the tonal components.

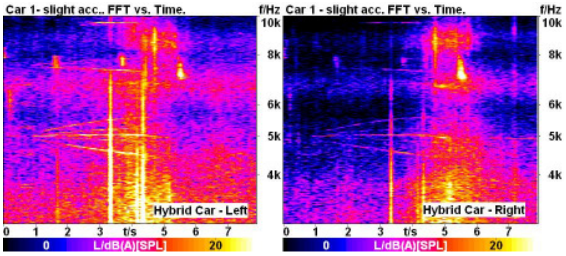

Figure 4. Pass-by of a passenger car with slight acceleration: Medium class car with hybrid drive (only in electric mode); FFT vs. time (3 kHz to 10 kHz)

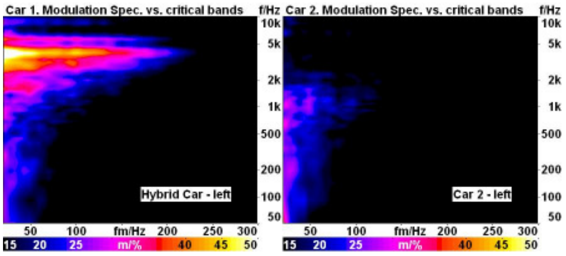

Figure 5. Pass-by of passenger cars: Medium class car with hybrid drive (only in electric mode) with slight acceleration (left) and luxury class car with combustion engine with slight acceleration (right); Modulation Spectrum vs. band (critical bands) for the left channel

Figure 6 and 7 shows a psychoacoustic analysis of the pass-by noise of the hybrid vehicle driving only in electric mode and of the luxury class vehicle equipped with a combustion engine for two driving conditions. It can be seen that with respect to the considered parameters the differences between the pass-by noises are small. The vehicle with the conventional drive possesses almost the same loudness, is marginally sharper. This appears stable for both driving conditions. This means that at least with respect to low vehicle speeds and by comparing these cars the psychoacoustic properties of the vehicle exterior noise are similar.

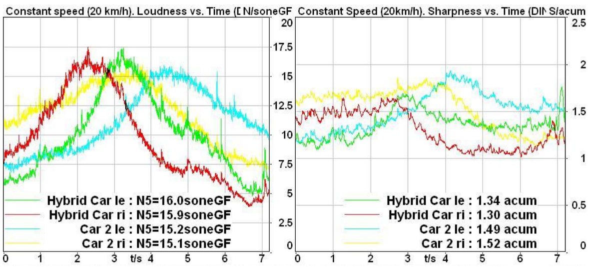

Figure 6. Pass-by of passenger cars with constant speed (20 km/h) (hybrid car and luxury class car with combustion engine); Loudness vs. time (DIN 45631/A1) (left) and Sharpness vs. time (DIN 45692) (right)

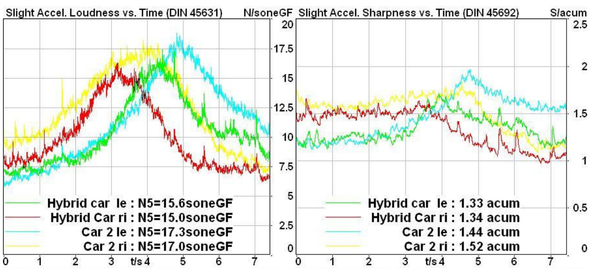

Figure 7. Pass-by of passenger cars with slight acceleration (hybrid car and luxury class car with combustion engine); Loudness vs. time (DIN 45631/A1) (left) and Sharpness vs. time (DIN 45692) (right)

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 TNS simulation techniques 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 perceptual influences of warning signals on the overall traffic noise in principle, exemplary warning signals were 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.

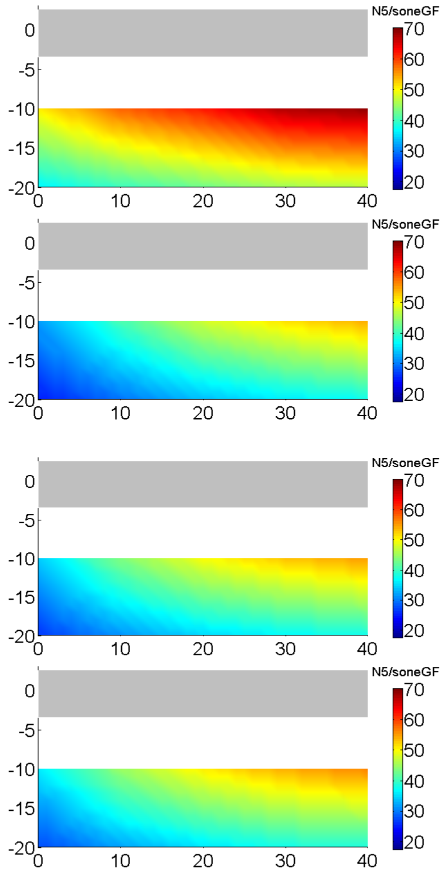

Figure 8. Traffic light situation (cars stand at 0 m and after a few seconds accelerate), Maps display N_5; from top to bottom: vehicles with combustion engines, electric vehicles; electric vehicles with warning signal 1 (two orders), electric vehicles with warning signal 2 (Gauss impulses)

In figure 8 the resulting loudness maps of the investigated scenarios are displayed for different "vehicle types". The noise of vehicles with conventional combustion engines, of complete electric cars (as 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. The loudest vehicle noise is produced 30 to 40 m behind the virtual traffic lights because of the acceleration process of the cars.

Figure 9 shows the A-weighted sound pressure level distribution for the considered traffic scenario. Due to the computation of the energy-equivalent sound pressure level the local position showing the highest noise exposure (with respect ti the averaged level) for the different traffic scenarios differs to the identified on-site positions with loudest noise displayed in loudness maps in figure 8. Thus, this simple experiment shows already the difficulties in applying valid indicators, because in dependence of the chosen indicator different interpretations result.

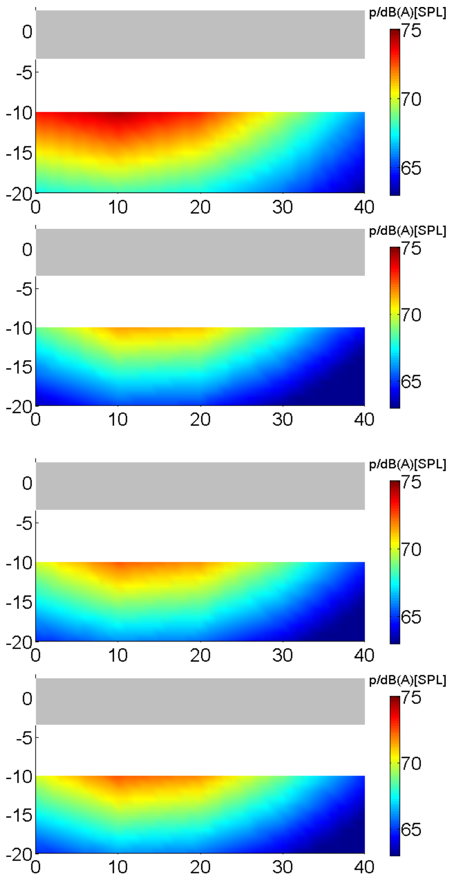

Figure 9. Traffic light situation (cars stand at 0 m and after a few seconds accelerate), Maps display L_{Aeq}; from top to bottom: vehicles with combustion engines, electric vehicles; electric vehicles with warning signal 1 (two orders), electric vehicles with warning signal 2 (Gauss impulses)

Figure 10 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.

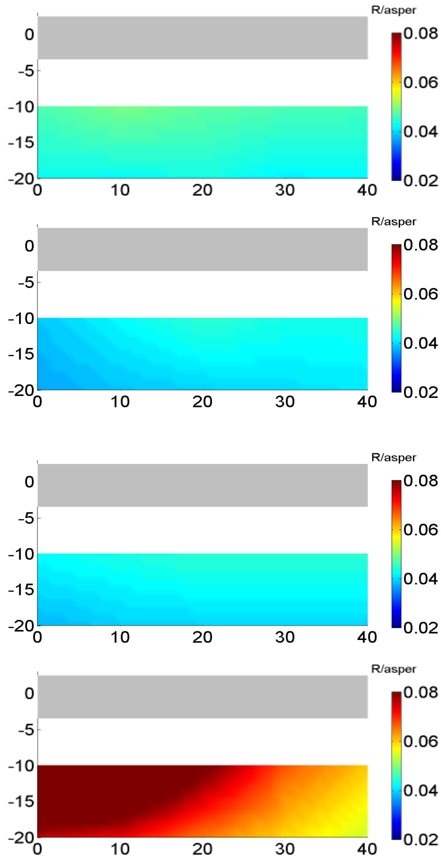

Figure 10. Traffic light situation (cars stand at 0 m and after a few seconds accelerate), Maps display the Hearing Model Roughness [11]; from top to bottom: vehicles with combustion engines, electric vehicles; electric vehicles with warning signal 1 (two orders), electric vehicles with warning signal 2 (Gauss impulses)

Figure 11 displays the results of the experiment with respect to the acoustical quantity Relative Approach [12]. The Relative Approach Analysis has been proven in prior investigations to detect specific, obtrusive, attention-attracting noise features [13]. The Relative Approach Analysis simulates the ability of the human hearing to adapt to stationary sounds and to react on the other hand to variations and patterns in the time and frequency structure of a sound. Figure 11 underlines the already described observations. The traffic noise caused by conventional drive concepts leads to noise with the highest Relative Approach-values, which means that a lot of perceivable patterns occur in this scenario presumably leading to annoyance. However, it is also clearly observable that by adding warning signals to the vehicle exterior noises an increase of perceivable noise patterns in the resulting traffic noise is provoked. Besides the fact of an enhanced pedestrian safety, this would lead to increase of noise annoyance at the same time.

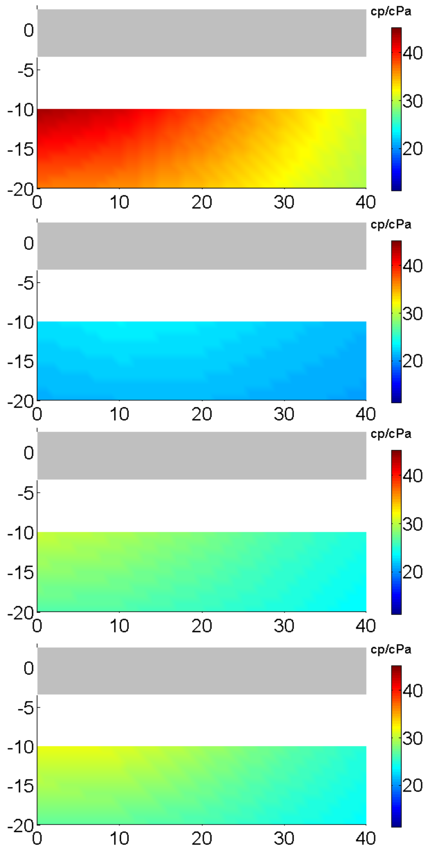

Figure 11. Traffic light situation (cars stand at 0 m and after a few seconds accelerate), Maps display Relative Approach values; from top to bottom: vehicles with combustion engines, electric vehicles; electric vehicles with warning signal 1 (two orders), electric vehicles with warning signal 2 (Gauss impulses)

CONCLUSIONS

On the basis of the TNS-technology road traffic noise related aspects can be studied in detail. It allows for an auralization of the considered traffic scenario as well as the development of psychoacoustic maps. Recently, the noise synthesis is focused on alternative drives, which will be increasingly important in the future. The german government estimate the number of electric driven cars of already 1 million cars in 2020 in Germany [14]. The traffic noise synthesizer will allow for the auralization of new alternative drives and resulting noise scenarios in the near future. This will be realized within the European research peoject “City Hush”. The complex traffic scenarios with different traffic compositions can be virtually experienced. For example, the synthesis tool can be used to investigate the impact of potential warning sounds of quiet vehicles at low speed on the level of noise annoyance.

Of course, the presented technical approach for simulating road traffic noise does not allow the investigation of the sensational representation of the considered urban space with its typical sound. The human reactions towards the noise of new vehicle types cannot be predicted without asking how residents feel about it, without reflecting the (visual, contextual, acoustical) elements of a quiet zone. This requirement cannot be fulfilled with physical models only based on calculations. With respect to quiet areas, evaluation strategies of residents and visitors have to be studied to create areas perceived as a “quiet zone”.

ACKNOWLEGDMENTS

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