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Development of a synthesis tool for soundscape design

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ABSTRACT

Road traffic noise is often a dominant sound source in urban settings. By means of traffic management measures and implementation of noise mitigation actions it is intended to improve the environmental noise situation, which means reduced sound pressure levels at relevant immission places. However, a soundscape is understood as a sonic environment with emphasis on the way it is perceived. In other words, this concept implies much more than only sound pressure levels. For example, hearing experiences contribute to the perception of location-related noise significantly.

To allow for the listening to environmental noise, where e.g. the effect of planned noise "protection" measures can be heard, a synthesis tool was designed. The development of the tool for the auralization of simulated traffic scenarios was done within the research project Quiet City Transport. Since the tool considers only road traffic noise so far, it covers only one aspect of soundscapes. However, a prospect of this technology is to derive psychoacoustic maps, which could improve the planning reliability in the context of the redesign of cities and their road traffic situations. Thus, it could be a helpful tool, which enables urban planners to consider the aspect of noise right from the beginning.

1. INTRODUCTION

Noise pollution leading to noise annoyance is still one of the most environmental problems. As WHO stated, the "environment is responsible for as much as 24% of the total burden of disease, which could be prevented through well-targeted interventions. [Moreover, this organization defines that] […] environmental health includes both the direct pathological effects […], and the effects (often indirect) on health and wellbeing of the broad physical, psychological, social and aesthetic environment." [1] These definitions point out two aspects: (a) the consideration of environmental noise is imperative for society, since it affects the health of people involuntarily exposed to, and (b) wellbeing concerns more than only the avoidance of direct pathological effects, it can only be ensured when psychological, social and aesthetic aspects are taken into account. Here, the soundscape approach with its interdisciplinary fundament can help to attain this challenging goal. Recent noise control measures and interprets mostly sound pressure levels and does not focus on the subject and its perception. However, intending to improve the quality of life of people instead of only reducing the amount of people highly annoyed, it is required to apply multi-dimensional methods. Only these soundscape methods are able to consider several dimensions at the same time, such as activities, expectations, meaning (of sources), social aspects, design and aesthetic. Furthermore, on the basis of these concepts knowledge can be acquired with respect to planning and design of environmental sound space. Here, the usual procedure, the combat of too much environmental noise, can be changed to a more active way of intentionally creating positive soundscapes.

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The following paper gives an account of a noise synthesis tool, which was developed with the intention to test virtually different soundscape scenario.

2. WHY IS THERE A NEED FOR A SYNTHETICAL GENERATION OF TRAFFIC NOISE IN A WORLD FULL OF TRAFFIC NOISE?

A *traffic noise synthesizer* (TNS) was developed to auralize (virtual) traffic noise scenarios. The main purposes of the TNS are (a) to auralize various traffic scenarios and (b) to simulate the effect of potential mitigation measures to help communities with respect to noise planning processes. The result of prior research projects (HARMONOISE [2] and ROTRANOMO [3]) were calculation tools that allow for the prediction of the noise generated by a given traffic scenario and measured at a specific observer position. The outputs are spectra or third octave spectra respectively. These spectra are sufficient to calculate standard descriptors (L_{day}, L_{night}, L_{den}) used/displayed in noise maps, but are not sufficient for the evaluation of the human perception and evaluation of the respective environmental noise situations. For the purpose of further advanced analysis time signals are needed to calculate more sophisticated acoustical parameters as well as to listening to the sound for virtually experiencing the environmental noise. Therefore, such a synthesis technology can help to determine/examine the efficiency of specific measures and actions, which are intended to reduce noise annoyance.
Of course, the isolated consideration of the expected environmental noise in a studied scenario is not sufficient for an adequate evaluation of environmental sound, as the soundscape concept points out. It is a tool to virtually test "abatement" measures before taken, which allows for making reliable prediction with respect to the resulting noise.

3. THE SYNTHESIS

The most important fact of the developed synthesis technology is the combination of measurements with simulation. The TNS combines traffic simulations data, with means third octave spectra based on ROTRANOMO calculations, with pre-recorded vehicle sounds for the (artificial) noise generation of specific traffic scenarios. For the purpose of traffic noise auralizations, a traffic micro-simulation must provide extensive data about the traffic, which means the simulation must provide information about the types of vehicles and the exact position of each vehicle at short time intervals with information about their chosen driving conditions. Such a traffic simulation was realized for example by KTH Stockholm University within the Quiet City research project [4]. 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. This simulation data is used by the TNS.
The synthesis technology separates between the emission of the sources (description of sources) and the propagation from source to receiver (description of propagation) consequently. On the basis of measurements a data base was created, which stores the noise characteristics of measured signals of different vehicle types. The generated data base does not store the time signals of measured vehicle exterior noises themselves; it contains only the properties of measured noise. Therefore, the synthesis is not a simple sample player, but is creates synthetically every (near field) sound of a vehicle according to its driving conditions. The simulation uses this characteristic information to process the vehicle sound reproducing properties (harmonics and orders respectively, residual noise) in dependence of the actual driving condition of every simulated vehicle (emission) within a traffic scenario. This allows for the generation of the noise of any chosen driving mode of a vehicle within a considered scenario. The stored noise characteristics and properties are gained through near-field measurements at relevant sound sources of vehicles (e.g. engine, tires, intake, exhaustion) that run through different operation modes. To "calibrate" the calculated emissions, each simulated

vehicle contribution is adjusted to given third-octave spectra (using a spectral calibration filter), which were defined in a research project called RoTraNoMo. The general aim of this project was to build up a differentiated (microscopic) road traffic noise calculation model. After the source-related adaptation of the third octave levels, the propagation effects have to be considered to generate a realistic traffic sound at the defined receiver position. First, different calculated contributions of each vehicle in dependence on a chosen/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 sounds binaural filtering is also applied in the TNS-technology. Of course, the perception of directivity within auralization scenarios can only be realized with a binaural playback. 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.

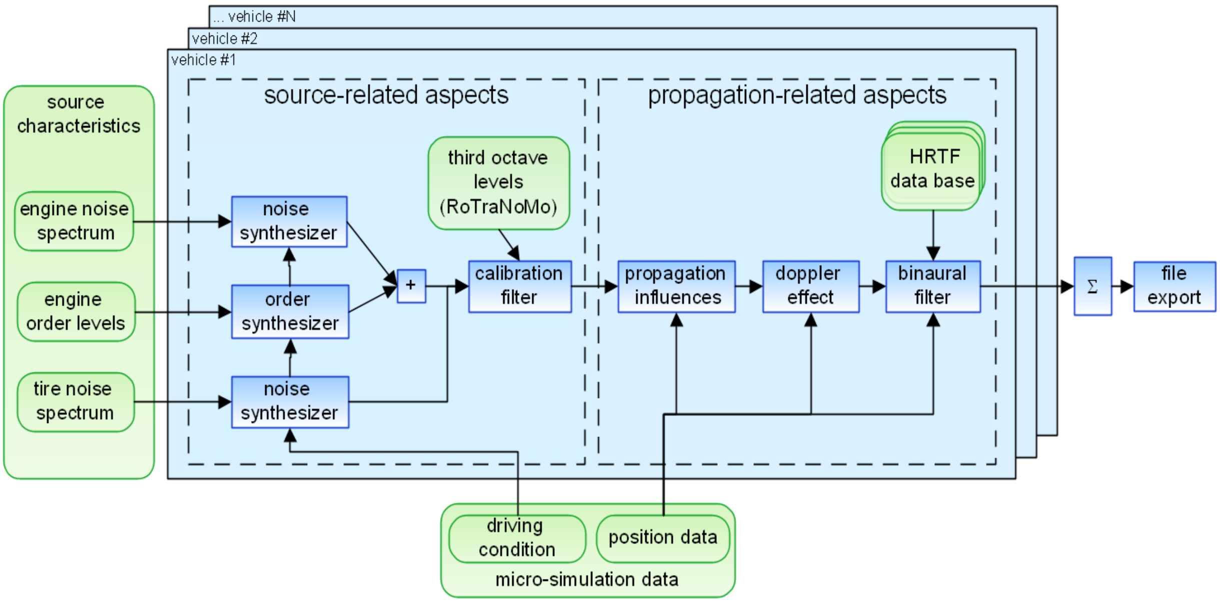

Figure 1: Signal processing network: The green boxes represent the data coming from the source model or the traffic noise application. The blue boxes display calculation nodes and arrows show the data flow.

Because of the separate consideration of several sources of vehicles, the procedure also allows for the consideration of specific source contributions to the overall sound and the influence of virtual changes on specific sources to the resulting (traffic) noise. For example, a road surface change can be simulated and auralyzed adapting the rolling noise to the new condition. 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.
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.

4. THE APPLICATION OF THE TRAFFIC NOISE SYNTHESIZER

The TNS can be applied in principle for (a) the creation of audible maps, (b) testing the perceptual efficiency of potential noise mitigation measures before actually taken and (c) general urban planning.

A. Audible Noise Maps

Conventional noise maps are based on sound pressure level calculations. These maps show coloration indicators, such as L_{day}, L_{den} and L_{night}). The displayed values are interpreted as indicators for noise exposure and annoyance level. Unfortunately, noise annoyance depends on several aspects and cannot be explained on the basis of sound pressure levels alone. It is partially observed that further noise properties can evoke annoyance almost independent from the sound pressure level as well [6]. To study those effects, more (acoustical) data is needed than only information about time-averaged sound pressure levels. Since the TNS provides time signals for respective receiver positions, the calculation of any acoustical parameter is possible. The spatial behavior of considered parameters can also, of course, be displayed on maps. Such advanced maps allow to listening to the environmental noise and to study further acoustical parameter besides the sound pressure level as well. It is even possible to generate dynamic maps, where noise variations and temporal effects are shown. Figure 2 shows an instantaneous display of a dynamic time map with the opportunity to listen to the resulting sound at diverse receiver points indicated by the loudspeaker symbols. The simulation scenarios are not limited to special conditions; all vehicles and the observer positions can move freely in all three dimensions.

The figure illustrates a straight street with road traffic and the relative change of an acoustical parameter over space, which is indicated by the color.

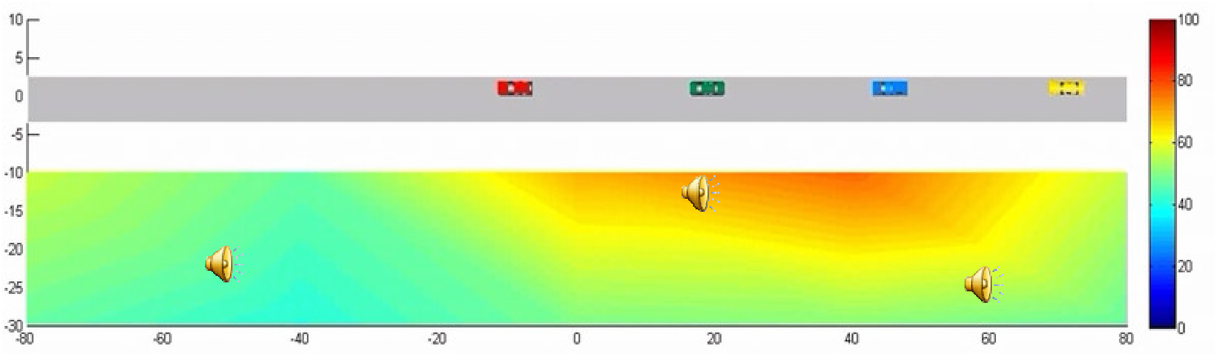

Figure 2: Instantaneous display of a dynamic time map (video); x-axis: distance in [m], y-axis: distance in [m]; color scale ranges from 100% (corresponds to 20 sone) to 0%

Based on this technology psychoacoustic maps can be developed, where the spatial distribution of (psycho-) acoustical parameters is depicted. Figure 3 demonstrates this opportunity with respect to the simple experiment – straight street with two lanes, no buildings, and a defined road traffic (1400v/h, speed limit 50km/h) – with and without a noise barrier for few acoustical parameters. The color scales for figure 3 and the upper three pictures range from 100% to 50%, which means that from red to blue the value of the respective acoustical parameter is halved.

Concerning the lower diagrams of figure 3, the same situation with the introduction of a 5m noise barrier is considered. Here, the color scales range from 100% to 25%, which means that from red to blue the value of the respective acoustical parameter is quartered. The spatial behavior of the displayed acoustical parameter does not completely correspond with the behavior of the sound pressure level. In particular, the relative reduction of the parameters sharpness and roughness is not comparable to the sound pressure level behavior. This could be important with respect to the effect of reduced noise annoyance behind the noise barrier. 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.*" [8] This conclusion indicates that a decrease of sound pressure level does not automatically leads to the expected reduce of the annoyance using dose-response curves.

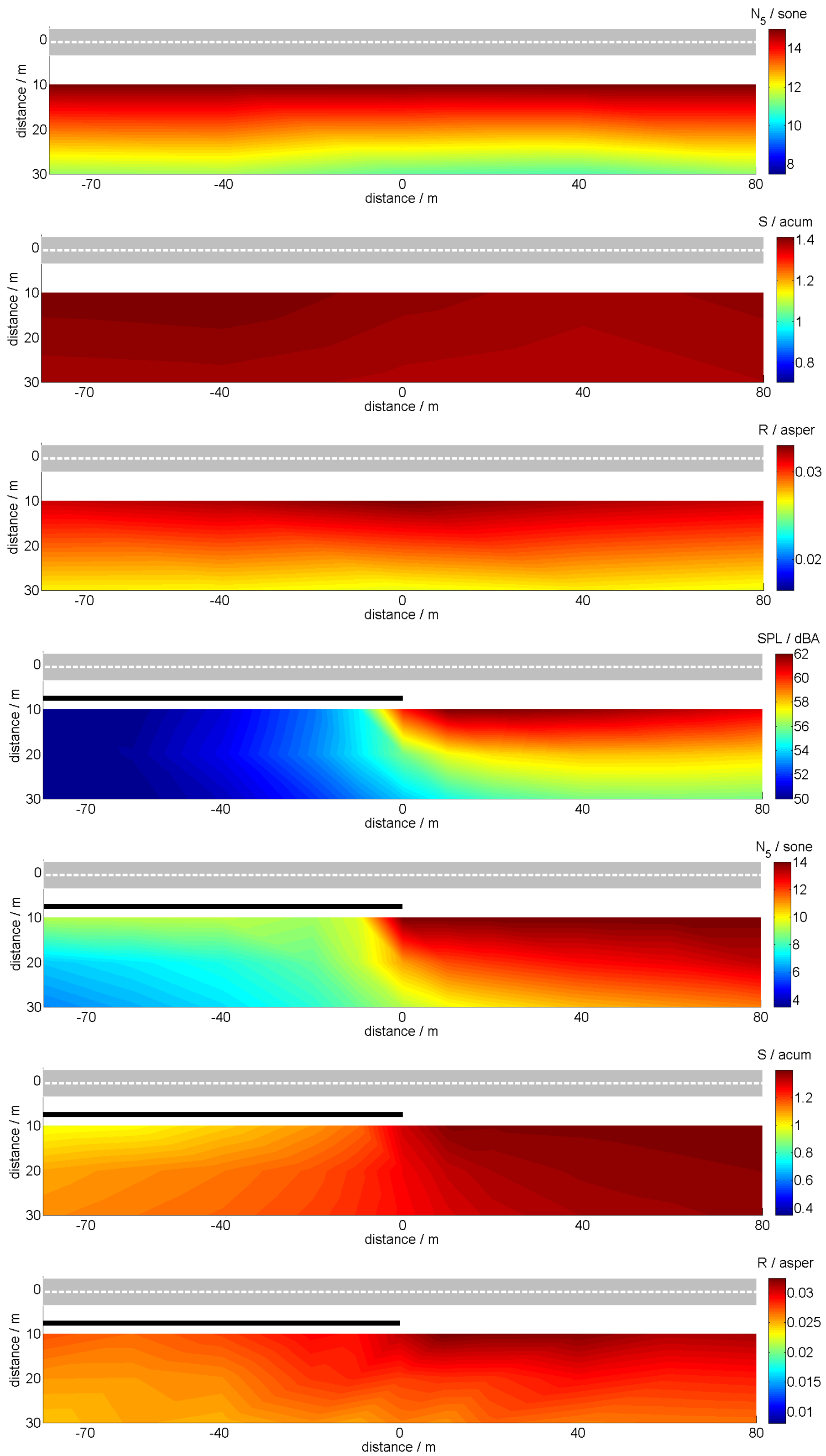

Figure 3: Psychoacoustic maps (time averaged) of a single street with a traffic volume of 1400 vehicles/h displaying N_5 (DIN 45631/A1), sharpness (DIN 45692), roughness (Hearing Model) [7] and with noise barrier displaying dB(A), N_5 (DIN45631/A1), sharpness (DIN45692), and roughness (HM) distance in [m]

The advantage of the availability of the time signals is that any interesting acoustical parameter can be calculated and shown on a map. Partially, noise metrics are determined, which include several acoustical parameters. The parameters are weighted and combined in dependence of their relevance for perception. For example Fastl has defined a Psychoacoustic Annoyance Index (PA), which is valid for the estimation of the annoyance level of vehicle exterior noise [9]. In the European research project “Quiet City Transport” [4] an index representing the annoyance caused by road traffic noise was developed [10]. This index includes the parameters loudness (N5), sharpness, Relative Approach [11], roughness (hearing model) and impulsiveness (hearing model) predicting the subjective responses to road traffic noises. The equation weights the parameters of Relative Approach and loudness at a ratio of 4 to 1. The weighting of the two parameters was optimized for maximum correlation with the subjective evaluations collected in the research project. The parameters Sharpness (average), Hearing Model Roughness (average) and Hearing Model Impulsiveness (average) contribute also to the metric with a slightly lower importance than the loudness parameter.

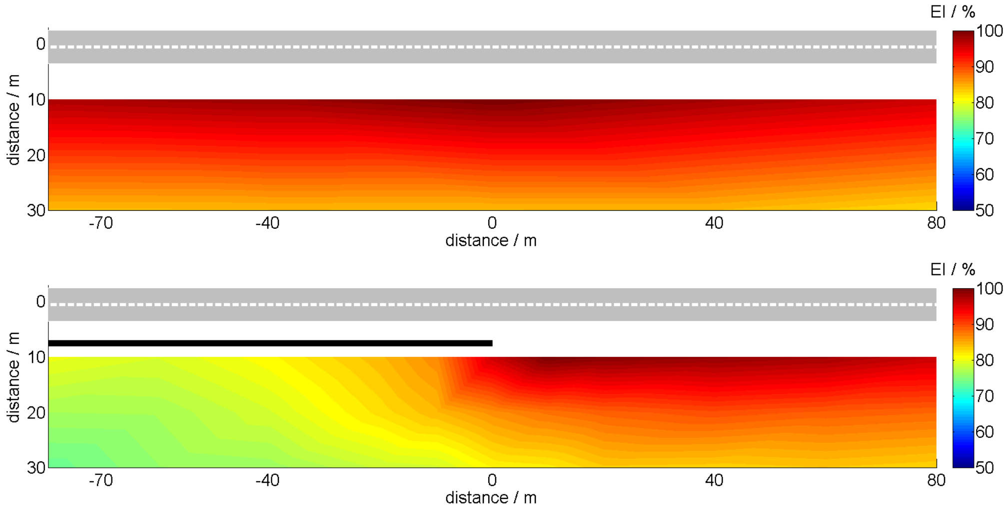

Figure 4: Noise maps (time averaged) of single street without (top) and with noise barrier (bottom) and with a traffic volume of 1400 v/h displaying the value of an Evaluation Index combining loudness, sharpness, roughness, impulsiveness and Relative Approach

Figure 4 demonstrates the change of the Evaluation Index, which combines several acoustical parameters for both scenarios. It can clearly be seen that the reduction of the annoyance (red corresponds to high annoyance and green corresponds to low annoyance) is not identical with the reduction of the sound pressure level behind the noise barrier (figure 3). The meaning of the reduced annoyance level indicated by the decreased Evaluation Index value should not be discussed here, since the interpretation of a “20% reduced annoyance” appears challenging. This example is shown to demonstrate the potential of advanced noise maps, because such psychoacoustic and combined maps offer an additional interpretation help with respect to environmental noise, its annoyance potential and allow for an improved identification of perception-related hot spots.

B. Testing of Noise Mitigation and Traffic Management Measures

The TNS enables the testing of different traffic management measures (e.g. change from traffic lights to roundabout, ban of heavy vehicles) as well as noise mitigation measures (low noise pavement, noise barriers). It can help to identify the most promising noise mitigation measures with respect to costs and annoyance decrease.

Figure 5 and 6 illustrate the results of the TNS simulation comparing two before and after situations. The first example demonstrates the difference caused by the introduction of a typical low noise pavement (OPA) to a standard asphalt road surface. The TNS simulates a straight street with a traffic volume of approx. 1400 vehicles per hour and a speed limit of 50km/h. However, the speed and the load of the diverse vehicles vary in a typical way to enhance the authenticity of the generated sound files. It has to be mentioned that only different kinds of passenger cars were considered.
A sound pressure level reduction of almost 3 dB is achieved due to the change of the road surface. Further acoustical analyses, such as Relative Approach analysis or sharpness analysis (Aures), show the changed acoustical situation due to the virtually implemented new road surface. 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.

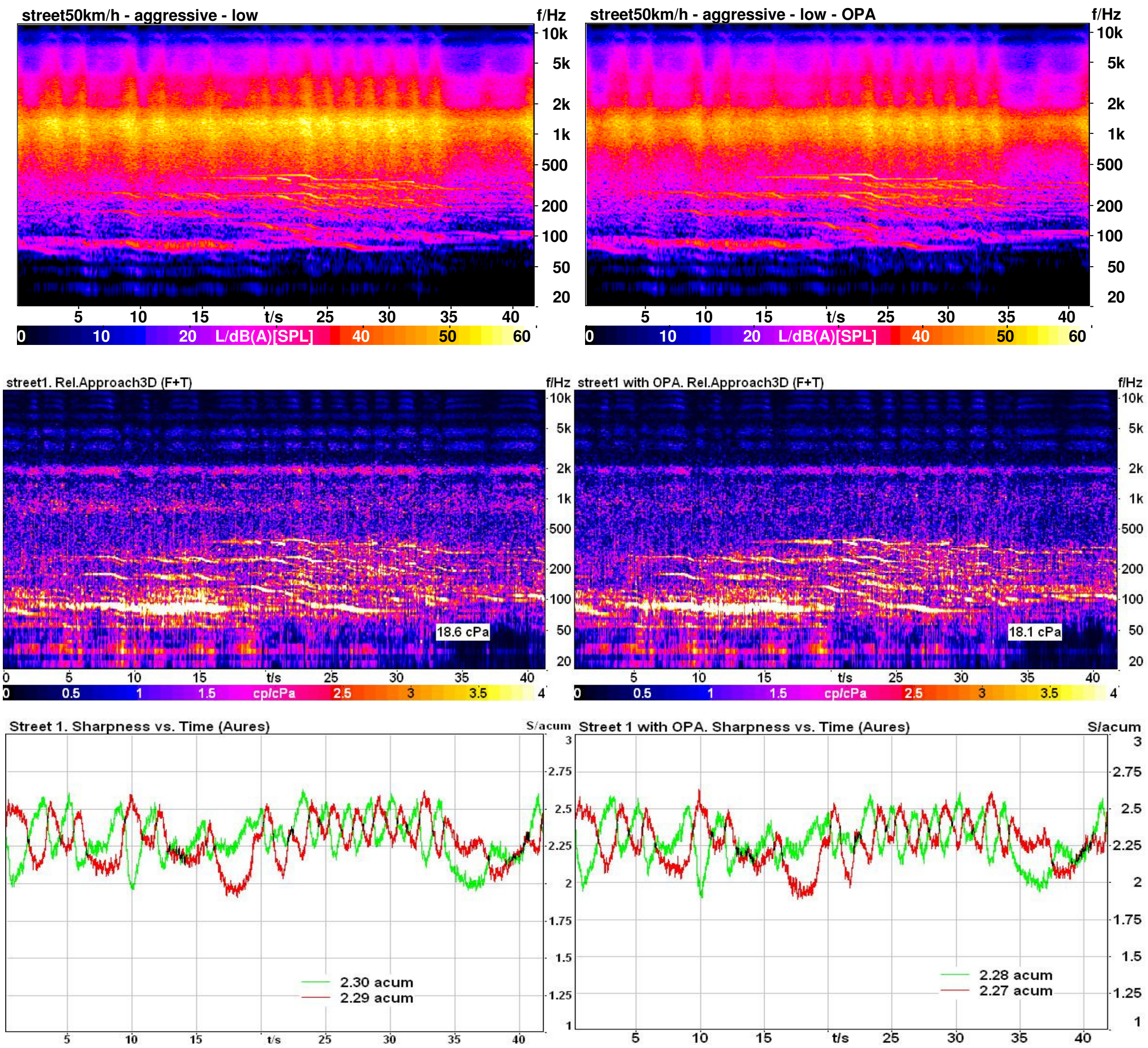

Figure 5: Auralized traffic scenarios: Noise of single street with low traffic volume and standard road surface (left) compared to same setting and same traffic volume with a low noise pavement (OPA) (right); top: FFT vs. Time; Middle: Relative Approach Analysis; Bottom: Sharpness (Aures) vs. Time

The second example demonstrates the influence of a noise barrier on traffic noise. The SPL of the traffic noise behind the barrier is of course considerably lower compared to the traffic noise situation without a noise barrier. However, the Relative Approach analysis results indicate that the reduction of the annoyance could be different than expected interpreting only the SPL decrease [8]. Although a noise barrier is implemented, acoustical patterns are still present and could lead to unexpected high noise annoyance [8].

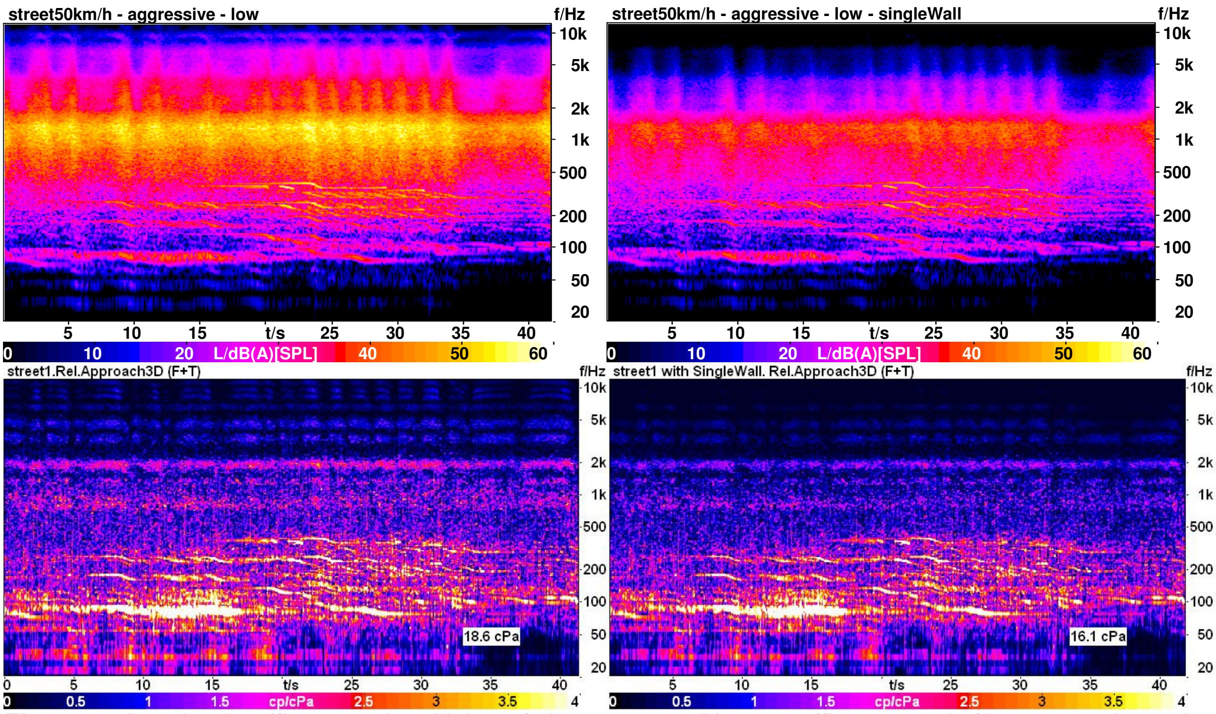

Figure 6: Auralized traffic scenarios: Noise of single street with low traffic volume (left) compared to noise of same street with a virtual implementation of a noise mitigation measure: noise barrier wall (right) top: FFT vs. Time; Bottom: Relative Approach Analysis

The examples point out the possibilities with respect to the identification of most efficient noise mitigation measures and actions, which can be virtually experienced. The efficiency can be assessed not only on the basis of a dB(A)-reduction, but also on the basis of listening (personal experience) and the reduction of further hearing-related parameters besides the L_{Aeq}. This means that decisions for or against specific noise mitigation measures can be well grounded. Of course, the adequate interpretation of the acoustical analyses obtained by using such technology has to be investigated in further studies. The meaning and importance of psychoacoustic parameters (and the consideration of combinations) for the perception and evaluation of environmental noise is not sufficiently clarified so far.
Moreover, within the further development of the TNS additional vehicle types such as heavy vehicles, motorbikes, scooters must be recorded and processed to consider all relevant road traffic-related sources. In addition, further syntheses models must be developed to adequately synthesize transient noises (e.g. diesel knocking) [12].

C. Urban Planning

The perceptive efficiency of noise protection measures can be determined with the TNS. So, it can be a tool for town planning and urban development with special focus on noise. As already shown in part B it allows for the verification of measures intending to reduce the noise exposure of residents before they are actually taken. The reliable calculation of the decrease of the sound pressure level due to planned noise mitigation measures is also possible. However, sometimes

this information is not sufficient with respect to a reliable prediction of the change of annoyance in the considered environment.
The developed tool 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.

5. TRAFFIC NOISE SYNTHESIZER - IS THERE A LINK TO THE SOUNDSCAPE APPROACH

Under the soundscape approach multi-dimensional, interdisciplinary approaches are subsumed with the general aim of appropriately examining the perceptual reality of listeners in a specific environment. Often, qualitative data as well as quantitative data are collected, analyzed, interpreted and merged together to get access into the world of human sound (-scape) perception.
It is known that physical descriptions of environmental noise do not explain the complex perception of a specific environment and ambiance within a certain acoustical setting sufficiently. Aspects, such as the meaning of the sound sources, the combination of sources, the attitudes, experiences and expectations of the listener's are significant aspects, which have to be considered to comprehend the perceptions of urban space. Feelings, emotions and sensations of residents have to be explored and analyzed and additionally, the hidden background of their evaluations must be determined.
However, the investigation of the physical aspects of environmental noise is inevitable. It remains an important part of an exhaustive investigation of a soundscape. The developed synthesis tool must be understood as an opportunity to study certain effects caused by typical environmental noise sources, such as road vehicles, more closely. It can help to comprehend links between human reactions and noise characteristics, which often cannot be explained on the basis of simple dose-response relationships, by copying or generating specific acoustical situations and examining their physical particularities. Therefore, such a synthesis technology can be an integrative part of soundscape investigations, which provides insights into the auditory perception of environmental noise, which cannot be discovered with traditional methods.

6. CONCLUSIONS

The TNS technology can be used to generate psychoacoustic maps. This would be a step forward to reach the challenging goal, the development of „noise maps“ instead of „sound pressure level maps”. Moreover, the presented technology could be a helpful planning tool, which enables urban planners and decision-makers to consider the aspect of noise (annoyance) in their considerations.
However, to enhance the authenticity of the generated sounds and the “validity” of the created traffic noises, the typical traffic sound sources and their acoustical properties the synthesis technology and the models and algorithms behind must be refined. Vehicle types, such as heavy vehicles, motor bikes, scooters have to be included in the data base to create most realistic (road) traffic scenarios.

Another aspect concerns the general explanatory power of maps. It has to be assumed that even advanced noise maps providing information about several acoustical parameters do not relieve from studying soundscapes and the perception of complex sonic environments more closely. The acoustical measurement (or calculation) of environmental noise constitutes only the physical representation of the urban place with the sources only considered with their acoustical emissions. The determination of the sensational representation of the investigated urban space with its typical sound 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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