The Potential and Benefit of Audible Noise Maps

K. Genuit[1], A. Fiebig[1], P. Marla[1]

[1] HEAD acoustics GmbH, Ebertstr. 30a, 52134 Herzogenrath, Email: klaus.genuit@head-acoustis.de

Introduction

Within the European Noise Directive 2002/49 [1] the creation of strategic noise maps, the identification of hot spots and the development of action plans are important goals. However, it is known that the characterization of environmental noise on the basis of A-weighted energy-equivalent sound pressure levels is partially insufficient. Therefore, beyond the general tasks defined in END 2002, the known methods and tools for the characterization of environmental noise should be widened enhanced step by step to improve the explanatory power of noise maps. Altogether, on the basis of recent noise maps it must be assumed that few noise annoyance phenomena cannot be fully covered, since these maps do not offer detailed information about temporal aspects or about occurring noise patterns and properties in environmental noise leading to noise annoyance.

In the following, approaches and ideas are shown and discussed, which go beyond the current methods regarding the development of noise maps. The presented study was initiated within the European research project Quiet City Transport [2].

Development of a Traffic Noise Synthesizer

For the sake of shortness of the article the following remarks on the Traffic Noise Synthesizer (TNS) have to be rather summary. The traffic noise synthesizer software calculates a time signal of the respective traffic scenario using traffic simulation data, which would be perceived at a certain receiver position.

The synthesis technology separates between, on the one hand, the emission of the sources and, on the other hand, the propagation from source to receiver. Thereby, the TNS combines the advantages of measurements with simulation. This is done by creating a data base that stores only the noise characteristics of measured signals of different vehicle types and not the measured (time) signal itself. The simulation uses these data sets to process the vehicle sound reproducing characteristics (harmonics and orders respectively, residual noise) in dependence of the actual driving condition of every simulated vehicle (emission) within a traffic scenario. (see figure 1)

The data base consists of the noise characteristics and properties gained through near-field measurements at relevant sound sources of vehicles that run through different operation modes. This procedure allows for the consideration of specific source contributions (and changes of these) to the overall sound. For example, the virtual change of the road surface can be auralyzed adapting the rolling noise to new conditions.

To enhance the authenticity of the synthesized sounds the Doppler-Effect is considered. The Doppler-Effect is caused by the finite value of the speed of sound. When sound waves are radiated from a moving source or are received by a moving observer, the perceived sound has a modified frequency.

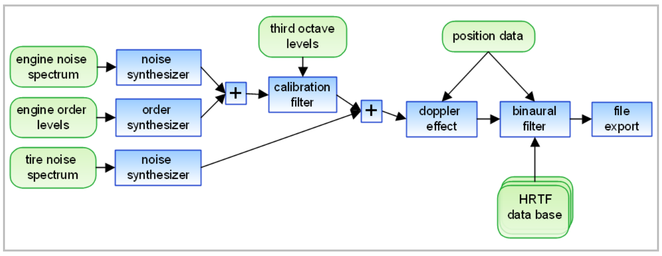

Figure 1: Part of the signal processing network: The green boxes represent the data coming from the source model or the traffic noise application. The blue boxes display calculation nodes and the arrows show the data flow.

The calculated contributions of each simulated vehicle within a traffic scenario are adjusted to given third-octave spectra (using a spectral calibration filter), which were defined in the RoTraNoMo research project. [3] Data from RoTraNoMo specifies the noise emission of simulated vehicles.

Subsequently, the contributions of each vehicle are filtered in dependence on a chosen receiver position. For that filtering specific influences have to be considered. The propagation is modeled using FIR-filters, which are mainly based on the DIN-ISO 9613-2 [4]. The filters were calculated from attenuation values at the octave middle frequencies defined by the standard and are applied to the "source" signals. Figure 2 shows examples of relevant propagation paths in context of traffic noise studies.

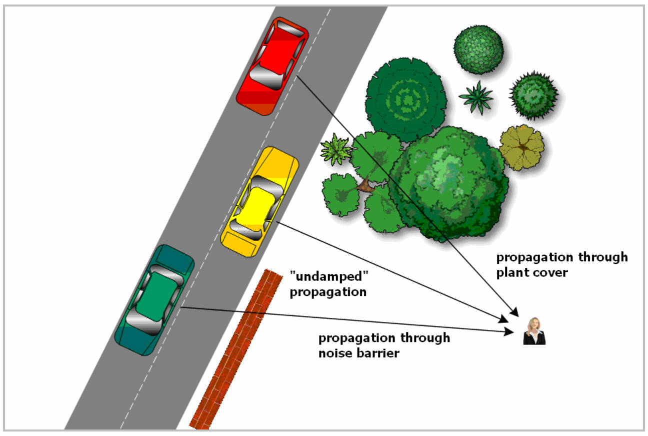

Figure 2: Depending on the investigated area specific damping filters must be calculated and applied to the source signals.

Moreover, binaural filtering is also implemented in the TNS-technology. The perception of directivity within auralization scenarios can only be realized with a binaural playback. This appears to be essential concerning the perception of traffic noise, where in reality a permanent localization of the vehicles occurs. The binaural perception is based on three effects: (a) the interaural time delay, which describes the delay of sound waves arriving at the ears, (b) the interaural level difference, which is caused by the "attenuation" of the sound by the head and the additional distance. The third effect (c) is the modification of the sound spectrum by the torso, head and pinna of the listener. All these effects can be represented by dynamic filtering of sound signals. The needed FIR filters for the binaural processing have been recorded related to the different spherical angles defining the incidence direction of the sound wave. These measurements have been done with an artificial head. During the simulation the direction of sound is calculated and the according filter is loaded and applied to the signal.

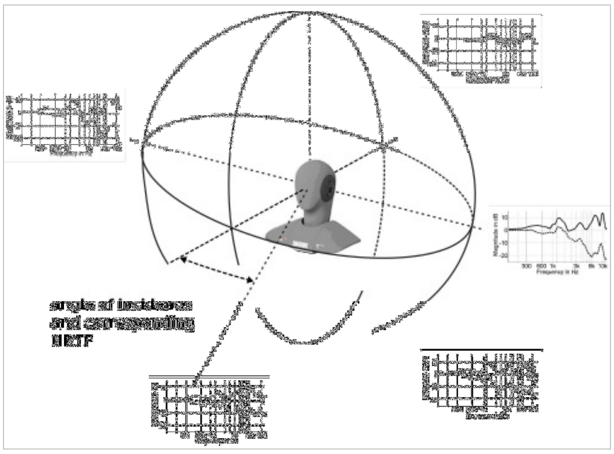

Figure 3: Each direction of sound incidence is represented with a HRTF. During the calculation of the simulation the corresponding HRTF's of the relative source position to receiver are determined and applied to the signal.

Finally, the filtered contributions of the different simulated vehicles (immission contributions) within a traffic scenario are superposed to a sum (traffic) signal, which occurs at the ears of the virtual receiver.

Use of Traffic Noise Synthesizer with Respect to Specific Receiver Positions

On the basis of the developed TNS tool specific traffic scenarios can be auralized and evaluated. For it, a traffic simulation must provide data about traffic details, which means information about the exact position of vehicles and the type of respective vehicles and information about the chosen driving conditions of the vehicles. 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, road surface) and their driving conditions (rpm, speed, gear) at short time intervals. This simulation data is used by the TNS. The advantage of such a simulation is for example that the efficiency of specific measures and actions, which are intended to reduce noise annoyance, can be evaluated before actually taken. In this case, not only information about reduced (averaged) sound pressure levels, as usually calculated on the basis of noise maps, is obtained, but also details about further interesting acoustical parameters are available. It is even possible to experience the (change of) noise of different scenarios by listening to them. As an example, figure 4 displays the effect of the virtual change of the road surface from a "standard road surface" to open porous asphalt (OPA) on the noise.

On the basis of the generated traffic noises different sound analyses can be carried out. In the context of the Quiet City research project an Evaluation Index (EI) was developed which has correlated very well with the subjective ratings of road traffic noises. The index combines several (psycho-) acoustical parameters, which appear to be important with respect to noise annoyance evaluations. Such perception-related metrics and indicators can also be applied to analyze the noise of different scenarios with a special focus on annoyance evaluation. [5]

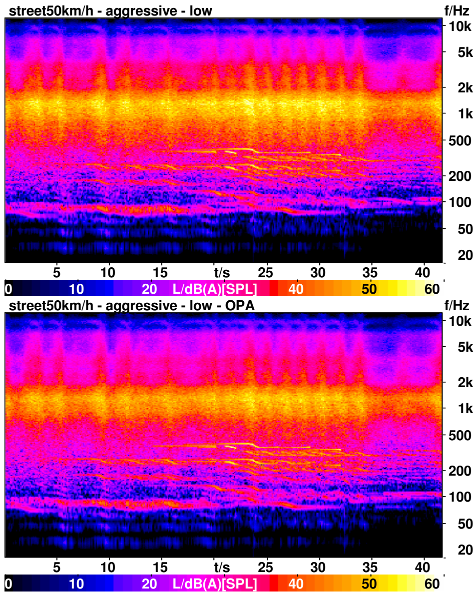

Figure 4: Auralized traffic scenarios: Noise of single street with low traffic volume and standard road surface (top) compared to same setting and same traffic volume with a low noise pavement (OPA) (bottom)

Using the TNS-technology decisions for or against specific noise mitigation measures can be well grounded. The general procedure of "testing" certain noise mitigation measures is described in figure 5.

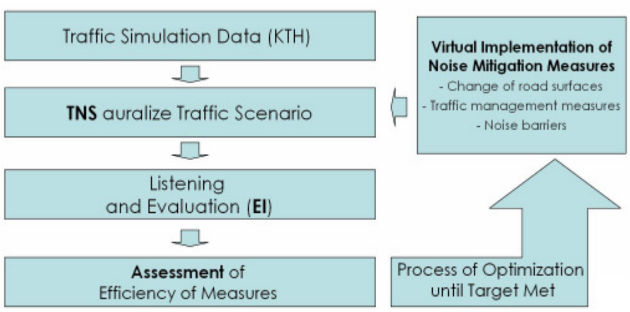

Figure 5: Schematic use of TNS for the assessment of virtually implemented mitigation measures

The status quo of the traffic noise synthesizer technology is that arbitrary traffic scenarios can be auralized using traffic simulation data, for example provided by the KTH Stockholm University. Starting from that the influences of different causes on the noise perception and evaluation can be examined. These are: (a) influence of traffic flow and traffic composition, (b) influence of road surfaces and (c) influence of noise mitigation measures.

Within the further development of the TNS additional vehicle types such as heavy vehicles, motorbikes, scooters will be recorded and processed. In addition, further syntheses models will be developed to adequately synthesize transient noises (e.g. diesel knocking). Moreover, the developed propagation path models could be extended. It is planned to refine and extend the present technology in the future.

All in all, the presented technology could be a helpful planning tool, which enables urban planners and decision-makers to consider the aspect of noise annoyance caused by traffic right from the beginning.

Use of the Traffic Noise Synthesizer for the Development of Audible Noise Maps

By means of the TNS-technology time signals resulting from specific traffic situations can be generated which data can be applied with respect to advanced noise maps. Conventional noise maps provide detailed information about the spatial distribution of time-averaged A-weighted sound pressure levels, but they do not integrate further acoustical parameters so far. Moreover, noise variations and temporal effects are not sufficiently considered due to for example a simplified source modeling or noise averaging procedures.

The TNS provides time signals related to specific receiver positions in a certain setting. These time signals can be analyzed with respect to any interesting acoustical parameter. These calculated values can be displayed on a map. On the basis of this data dynamic, time-variant noise maps with respect to any hearing-related parameter can be created. This means that the usual "static", averaged noise maps could be transferred to dynamic maps. These maps can be visualized on the basis of videos.

As a simple example, the spatial distribution of different acoustical parameters in a single street setting with a defined traffic flow is shown in several diagrams. (figure 6 and 7). The color scales range from 100% to 50%, which means that from red to blue the value of the respective acoustical parameter is halved. The displayed maps are time averaged maps, which means that the studied acoustical parameter is averaged over time.

It can be clearly seen that the behavior of the different analyzed acoustical parameters is different. The psychoacoustic parameters sharpness, roughness and the hearing-related parameter Relative Approach do not decrease in the same way than SPL or loudness does. These parameters show only a slight decrease of the respective values with distance. In case that these parameters reflecting certain noise properties have an impact on noise annoyance, than the decrease of annoyance with distance is most probably lower than expected using the SPL-related distance law and interpreting only on the basis of these values the annoyance decrease. [6]

Some studies suggest that the sensory dimension roughness can be important with respect to reactions to environmental noise, as for example observed in the calculation of the psychoacoustic annoyance index developed by Fastl [7]. Furthermore, the importance of the Relative Approach analysis with respect to the prediction of noise annoyance was also shown in several studies. [8]

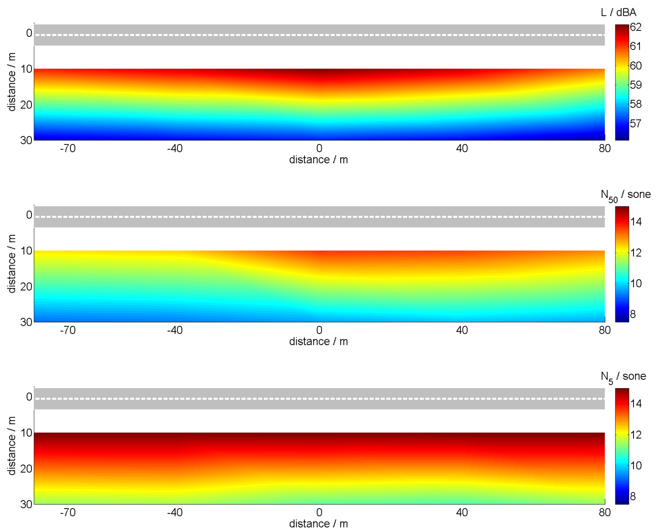

Figure 6: Noise maps of a single street with a traffic volume of 1400 vehicles/h displaying dB(A) (top), N_{50} (middle) and N_5 (DIN) (bottom) [9]; distance in [m]

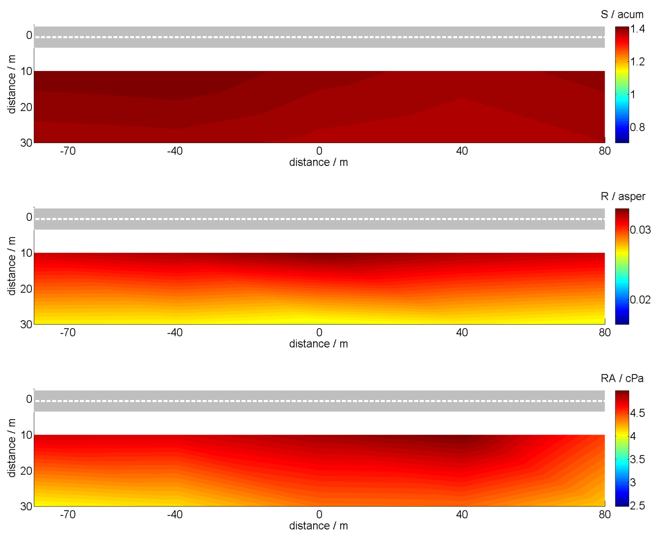

Figure 7: Noise maps of a single street with a traffic volume of 1400 vehicles/h displaying Sharpness (DIN) (top), Roughness (Hearing Model) [10] (middle) and Relative Approach (bottom) [11]; distance in [m]

Figure 8 displays the relative change of acoustical parameters with increasing distance. These results were gained by means of field measurements in Berlin [12]; the first measurement position (MP1) was very close to a busy street, MP2 was farther away and MP3 had the biggest distance to the considered street. The effects observed in figure 6 and 7 are confirmed by these field measurement results.

The decrease of the considered parameters is comparable to the calculated changes of the parameters using the TNS-technology.

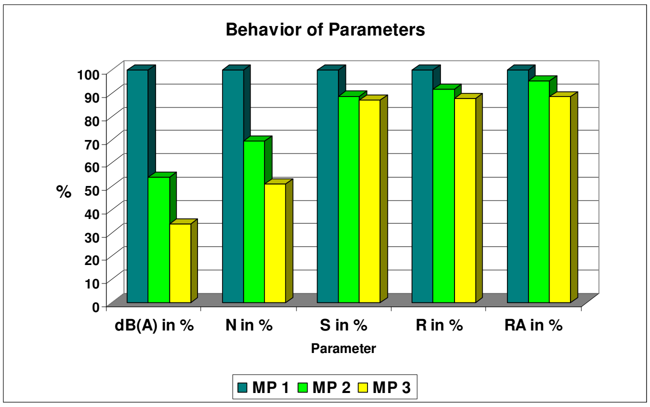

Figure 8: Decrease of specific acoustical parameters with increased distance to a source (busy street) in % [6]

Another interesting aspect concerns the use of the indicator loudness. Loudness provides meaningful information with respect to the annoyance potential of environmental noise beyond the sound pressure level, since spectral and temporal aspects, masking effects, etc. are considered. However, it has to be mentioned that the new DIN 45631/A1 proposes the 5 percentile loudness (N_5) for the adequate description of perceived overall loudness of time-varying noise. Taking this fact into account, it cannot be excluded that averaged values (L_{Aeq}, N_{ave}) (sometimes) underestimate noise annoyance, since the human cognitive stimulus integration does not follow simple averaging processes. It seems that loud noise events dominate our perception and the memory of it. However, with respect to the cognitive integration of noise stimuli the use of percentiles reflecting human introspective processing must be investigated further.

Conclusions

Psychoacoustic maps, which were schematically developed and shown in this paper, can provide comprehensive information with respect to environmental noise and its annoyance potential. Such noise maps can supplement the already existing noise maps based on L_{Aeq}-values. For it, sound sources and their acoustical characteristics have to be scrutinized further to collect valid data for (psychoacoustic) noise-mapping.

All in all, such advanced noise maps providing further information concerning the noise situation can help to reliably identify perception-related hot spots. For that purpose, static noise maps must be transferred to dynamic maps, which can also give information about temporal aspects and about variations of specific parameters.

However, even advanced noise maps do not relieve from studying soundscapes closely with respect to non-acoustical influences. For example, context-effects, socio-cultural influences, group composition of affected people, etc. are variables, which can only be handled on the basis of socio-empirical field studies.

Finally, further research is required to determine the link between certain noise properties, partially reflected by the known psychoacoustic parameters, and specific noise reactions, which can cause health effects. This knowledge is needed to adequately interpret psychoacoustical maps.

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