The Sound Power Level of Cities

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This article describes the process of creating noise maps for cities. City noise mapping includes determining the sound emission of all sources (including road traffic, railways, industrial facilities and airports), calculating the noise levels caused by these sources, and assessing the noise levels with certain noise indicators. This yields the summed sound power levels of cities. Normalizing for the area leads to an area related sound power level, PWL´´. This proves to be a very useful descriptor, because it shows the basic noise problem of a city. Used together with indicators showing the number of people annoyed at a certain noise load, area related sound power level gives a quick overview to rank noise problems and improves the strategy for noise abatement.

Noise mapping has become an important tool for noise assessment and reduction in cities. Noise maps provide an overview of the noise distribution for large areas and enable ranking of the necessary noise abatement measures. Such a mapping project begins with developing a computer model of the city. This model is a numerical, virtual picture of the real-world environment and noise sources including roads, railway tracks, industrial facilities and even airports. All objects influencing sound propagation such as topography (floor heights), buildings, mounds, walls and barriers as well as foliage or built-up areas are approximated by defining their 2D-shape as open or closed polygons, then adding height information as z-coordinate ats each point of this polygon.

There are two main steps to a mapping project. The first is to determine the sound emission of all the sources. With appropriate software it is not necessary to define these emissions in acoustical terms like sound power levels, but rather as parameters like traffic flow, road surface or number of flights on a flight path. For calculating emission values from these parameters it is helpful if the software uses relevant standards and guidelines according to national regulations, if they exist. In all other cases procedures should be chosen that support the use of modern computer techniques. The result of this first step is a complete model of the city with all its sources.

In the second step, the immission* values are calculated as sound pressure levels. In most European countries there are separate, equivalent sound pressure levels for day and night. ISO 9613-2[1] describes a method for deriving the immission values from the emission values by considering the objects mentioned above that influence sound propagation. There are also many national regulations for calculating noise from specific sources that also define equations for calculating the sound propagation. Unfortunately these national standards are often very rough approximations, derived when computers were far less powerful. This calculation of sound propagation is done for many points arranged on a grid for the whole area of the city. A colored noise map is developed from the results showing the noise level for each surface area.

For a ranking of different alternatives, it is useful to reduce all these data to a one-number criterion that measures the complete noise situation. Such a criterion can be the number of persons living in an area with noise levels above a given limit, or another value derived from the number of people and the difference between the noise level and the limit.[2]

The following example uses the sound power level of all noise sources in an area to give a one-number description of the noise production. This can lead to a successful city noise strategy by using noise reduction measures on the propagation path. With successful planning, the difference between the immission and the sound power level should be relatively high. The area related sound power level (the sound power level of each square meter in the average for a given area) is a normalized value that provides more insight into the noise problems.

*Note: Noise immissions are noises propagated *to* a single object (receiver) and noise emissions are noise propagated *from* a single object (source).

Figure 1. 2D-view of the detailed model of a car production factory.

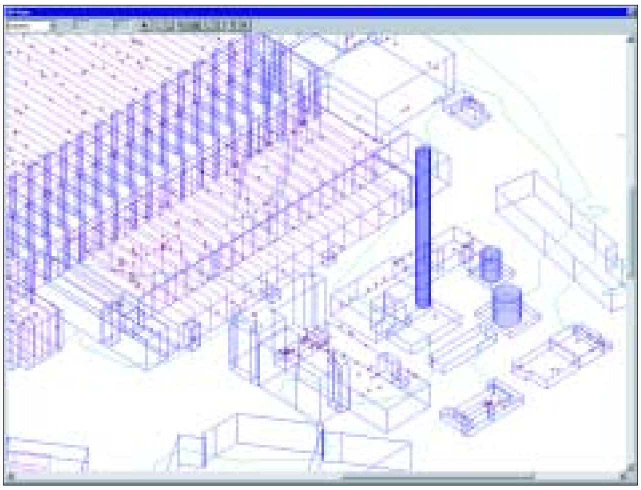

Figure 2. 3D-wire presentation of the model.

Noise from Industrial Facilities

Industrial plants and factories are modelled with point-, line- and area-sources as shown in Figures 1 and 2. If a computer model is used to calculate the noise levels in short distances (e.g., at surrounding residential areas), a very precise modeling with accurate positions, emission values and directivities of all sources is necessary. If such a detailed model exists, it can show how the noise levels will change from the erection or deletion of technical facilities. For example, if a new cooling tower is planned, its sound power level can be obtained from the supplier, then a point source with this sound power level and an apparent directivity is positioned on the model and the calculation of noise levels in the surrounding residential areas is repeated. This procedure is the same for all planning decisions when noise must be considered.

Figure 3 shows a city model with over 3500 sound sources. A typical display of the sound power level of each of these

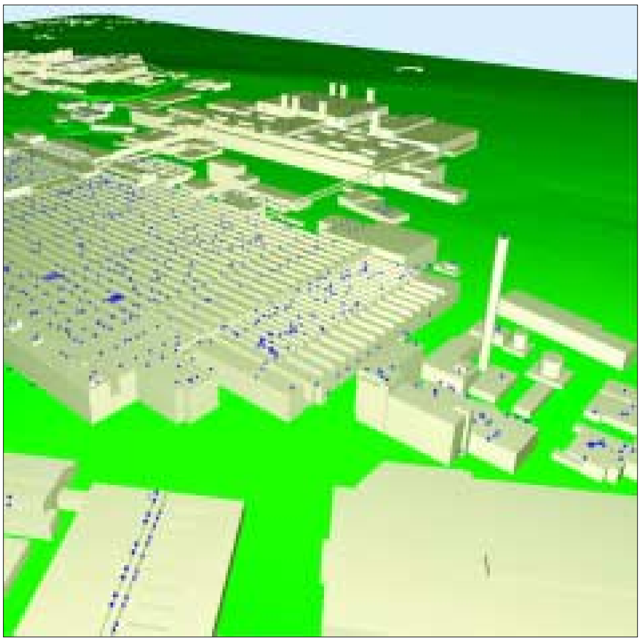

Figure 3. 3D-view of the model using hidden line algorithms (photorealistic view).

Figure 4. A typical window that defines all the parameters necessary to describe a point source.

sources is shown in Figure 4. Using CadnaA software[3], it is possible to sum the sound power level of all sources in the model with one command. If noise is produced inside the building and the radiation is influenced by the transmission loss of radiating elements like walls, roof, windows and doors, then the resulting level of the sound power radiated from these elements is used in the summation. Note that time of day is also considered; the calculated sound power level is the mean for either day or night. If the sources are grouped (e.g., with respect to the different buildings or different plants), then the resulting sound power level of all groups is calculated separately.

A car-producing factory gives the following results . . .
Sound power level – day .... 124 dBA
Sound power level – night .... 122 dBA
Total area .... 1.58 km²
Area related sound power level .... 62 dBA

If the noise produced by this factory is taken into account on a noise map of the whole city, it is sufficient and even advantageous to use one or just a few area sources with the apparent emission. The emission of this area source is given by the area related sound power level described previously.

If these two models exist – the detailed model and the simulating area source – then the noise from the factory can be taken into account in all planning decisions. For noise mapping reasons or city planning decisions, the area source is imported into the project file. If changes in the factory design need to be evaluated, then the detailed model is imported. See Reference 4 for some hints on how measurement results should be corrected if sound power levels for use in prediction models have to be determined.

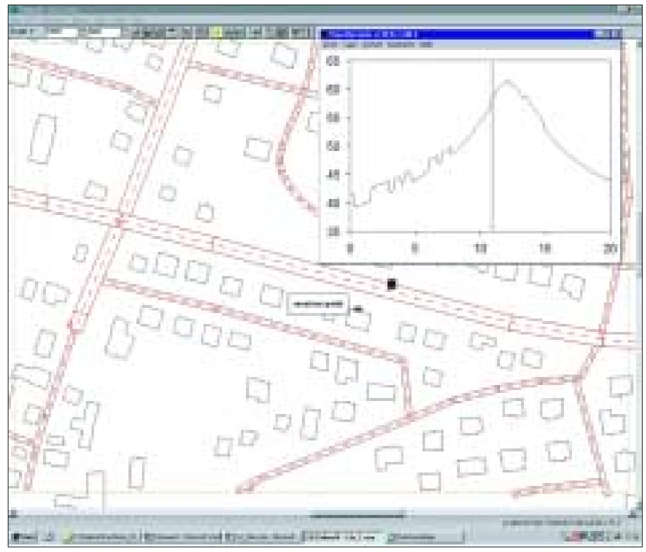

Figure 5. Level versus time calculated for the passing of a car at the receiver point (screen presentation with CadnaA).

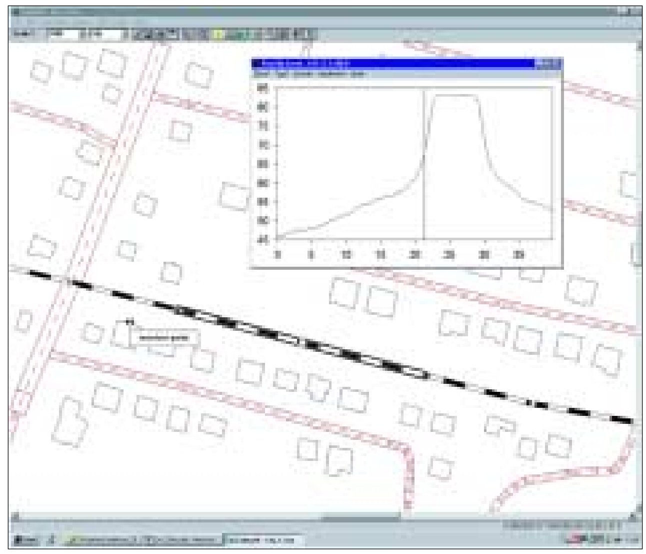

Figure 6. Time history of sound pressure level when a train is passing the receiver point (screen presentation with CadnaA).

Road Traffic Noise

Roads are noise sources. Modeling them as lines with moving point sources allows the time history of the sound pressure level at a receiver point to be calculated. Figure 5 shows the calculated time history of the sound pressure level when a car passes the receiver point at 80 km/h. The window with the time history shows the typical level variations caused by first order reflections at the opposite buildings.

Table 1. Emission values that lead to the same sound pressure level at a distance of 10 m.

Country	Emission Quantity	Value in dBA
International	L_{WA} (1m)	100
Germany	$L_{m,e}$	80.8 (–12.2)
Austria	$L_{1A,eq}$	96.5 (–3.5)
Switzerland	$L_{r,E}$	96.6 (–3.4)
Scandinavia (Nordic Standard)	$L_{awq,10m}$	86.4 (–13.6)

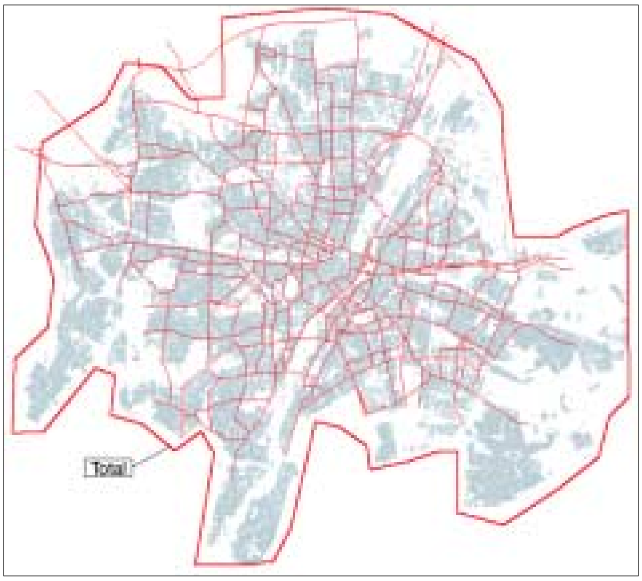

Figure 7. City of Munich (only main roads).

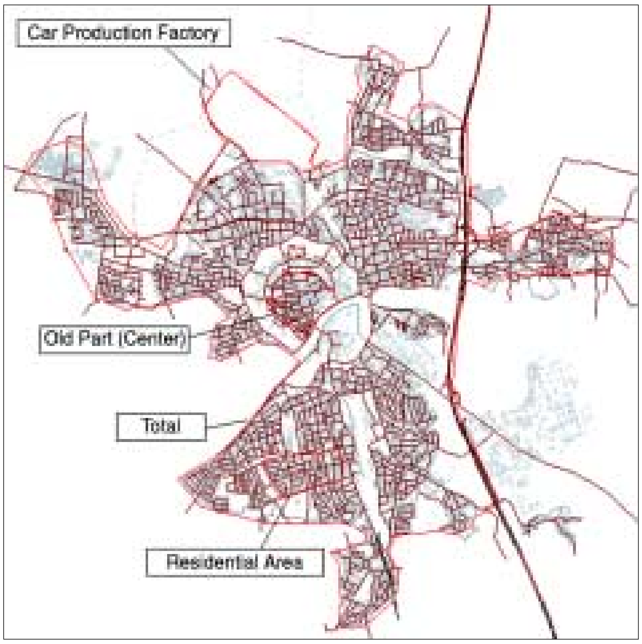

Figure 8. City of Ingolstadt.

Noise maps of cities use equivalent day and night sound pressure levels. For this calculation a road with moving cars can be simulated by a line source. In acoustical terms, the length related sound power level of an element of the line source is the sound power level of all cars driving over this element. This includes day/night corrections for each pass, while the time for each car to cross the element is the operating time of the

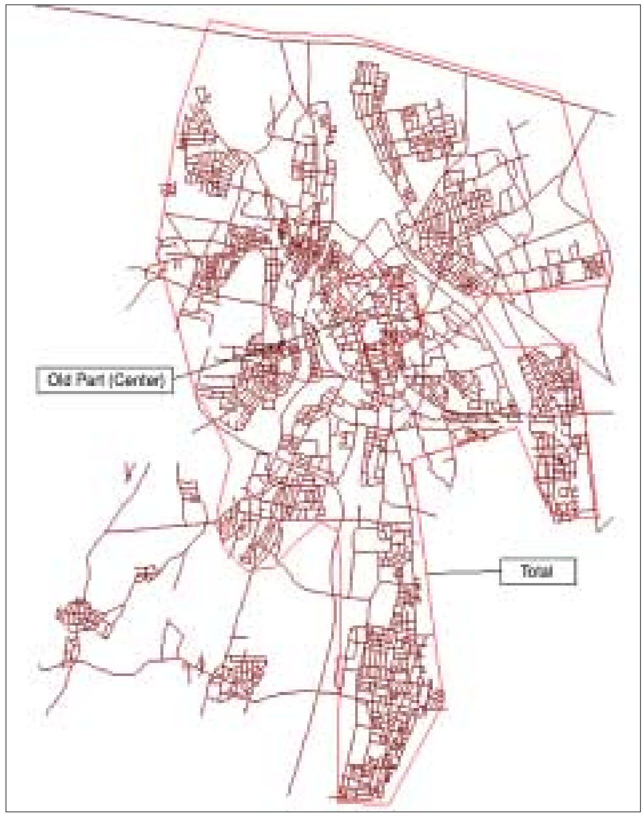

Figure 9. City of Augsburg.

source.

Unfortunately, all the standards that define how to calculate noise emission of a road use different quantities to describe the emission. Curiously, none of these regulations uses the sound power level or the length related sound power level PWL´ (PWL of one meter), which is the correct and internationally standardized value to quantify the emission of a line source.

To sum the emission of all roads in a city, the emission values must be transformed to sound power levels. As an example, Table 1 shows the emission quantity for 4 countries and the value that produces the same equivalent sound pressure level for a 10 m distance at a height of 3 m.

Railway Noise

The situation with railway noise is similar. Each train is a line source with the length of the train, and this segment of the line source moves with the speed of the train along the track. The time history of the sound pressure level in Figure 6 shows a flat maximum because it takes some time for the train to pass the receiver point. Calculating levels as a function of time with a given standard makes it easy to develop corrections for specific trains when measured results for these trains are available. These corrections can be derived by comparing measured and calculated level-time functions.

Table 2. Emission indicators for some German cities.

City	Source	Region	Area, km^2	Buildings	PWL Day, dBA	PWL Night, dBA	PWL″ Day, dBA	PWL″ Night, dBA
Munich	Road Traffic*	Total	386.00	146238	144.2	136.8	58.3	50.9
		Old Part (Center)	19.78	6529	136.3	128.9	63.3	55.9
Ingolstadt	Road Traffic	Total	40.96	25970	138.0	131.1	61.9	55.0
		Old Part (Center)	0.74	1855	118.6	109.2	59.9	50.5
		Residential Area	0.66	729	113.3	103.8	55.1	45.6
	Industry	Total	40.96	25970	133.7	130.1	57.6	54.0
Augsburg	Road Traffic	Total	68.74	68396	144.6	138.3	66.2	59.9
		Old Part (Center)	1.65	4043	122.3	113.6	60.1	51.4
Ravensburg	Road Traffic	Total	9.58	10974	131.1	123.2	61.3	53.4
		Old Part (Center)	0.30	874	118.1	110.1	63.3	55.3

*The analysis for Munich is preliminary and only based on the traffic data for the main roads.

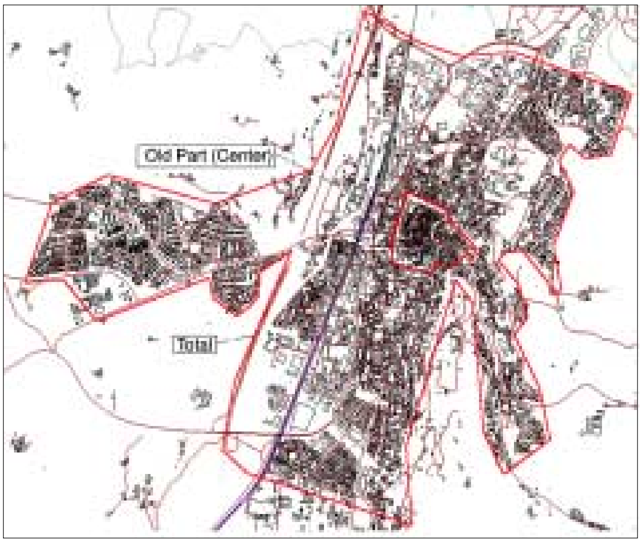

Figure 10. City of Ravensburg.

Regarding equivalent sound pressure levels, it is again sufficient to not consider the time dependence of the emission but only use line sources with a given sound power level. These sound power levels must be calculated from the emission quantities used in the model.

The Sound Power of All Sources

To sum the sound power for a large area or even for complete cities, all source emissions are transformed to sound power levels. With airports, certain assumptions have been made, such as the time needed for takeoff and landing. The results for some cities are presented in Table 2. The particular regions that were analyzed are shown in Figures 7-10.

The analyzed areas are quite different in shape and size, therefore the absolute values cannot be compared. However, normalizing these results with area yields some very interesting comparisons. Dividing the area by the number of buildings shows that the mean area for one building is about 900 m² in residential areas and about 400 m² downtown (Munich is an exception, because the data for buildings have been imported from a mobile phone provider – these data are less detailed and terrace houses are combined to single blocks).

While the total sound power level PWL of all roads varies clearly with size, the daytime area related sound power level PWL´´ is between 60 and 66 dBA in each of these examples. Remember, these are the overall values – there is certainly more variation in smaller regions. In residential areas the PWL´´ from road traffic is about 55 dBA during the day and 45 dBA at night.

These results show that the basic noise problem – the emission of all sources – can easily be ranked by a one-number indicator. From Table 2 it is clear that Augsburg has more tightly packed traffic noise sources than Munich, Ingolstadt or Ravensburg. Further comparing of the immission indicators additionally shows how the cities handle these noise problems and how successful they are in reducing the noise. Noise mapping is an important tool in this never-ending battle.

References

1. ISO 9613-2: 1996(E) "Acoustics – Attenuation of Sound During Propagation Outdoors – Part 2: General Method of Calculation," International Organization for Standardization.
2. Probst, W., Huber, B.,"Calculation and Assessment of Traffic Noise Exposure," *Sound and Vibration*, July 2000, pp 16-20.
3. CadnaA, Software Program for Noise Prediction, DataKustik GmbH, Gräfelfinger Str. 133A, D-81375 Munich, Germany, info@datakustik.de.
4. Probst, W., "Modelling of Industrial Plants in the Framework of Sound Immission Plans," inter-noise 2000, Nice, France.

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