A paper on how to include noise in the ARTISTS project

1. Content

In the ARTISTS project strategies for the development and reconstruction of arterial roads in urban areas are developed and evaluated. Various factors that are important for the road users and the people living along the roads as well as planners and decision-makers are also going to be monitored and evaluated by different techniques. One of these important factors is noise. In this paper it is discussed, how noise can be handled in the project. The demands to the estimated noise levels are presented and methods to obtain these levels are discussed. Finally a procedure to handle noise is suggested for further discussion and approval in the ARTISTS project group.

2. About ARTISTS and noise

The roads of ARTISTS
40 arterial roads from 9 cities with more than 100.000 inhabitants in 9 European countries are included in the project. Out of these roads 7 are selected for special demonstration purposes. In relation to traffic and geometry these 40 roads can be characterized by the following data:

- Average annual daily traffic: 10.000 - 60.000 vehicles pr day.
- Speed: 20 – 70 km/h.
- Two thirds of the roads have congestion problems in some periods during the day. And out of these a few has congestion problems during the whole day.
- The width of the roads from facade to facade varies form 20 to 40 meters.
- Most parts of the roads are situated in build up areas with buildings on both sides of the roads. As an exception there are beach areas and green areas at the side of some segments of the roads.
- The buildings along the roads have typically 5 to 10 storeys.
- There are trams on some roads in Porto, Freiburg, Brussels and London.

A corridor at width of 250 m on both sides of the road will be taken into consideration in the project. But in ARTISTS there is a decision only to look at the noise levels along the actual arterial road itself and at the houses facing this road. The noise in the whole corridor will not be predicted, even though all the houses in the 500 m wide corridor will be exposed to noise from other streets in the corridor as well as to some extent to noise from the arterial road.
Noise levels
To give an indication of the levels of noise of these urban arterial roads, a first rough estimate will be, that the 24 hour energy equivalent noise level \((L_{eq,24h})\) 10 m from the centreline is in the interval between 68 dB and 81 dB. These noise levels can be related to perceived annoyance as follows:

- At 55 dB 10 to 15 % of the people exposed to this noise level are highly annoyed. In many countries 55 dB is the guideline recommended by the environmental protection authorities.
- At 65 dB around 50 % of the people exposed to this noise level are highly annoyed.
- At 65 dB the risk for cardiovascular diseases is increased by 20 % (according to German literature).
- At 75 dB nearly everybody exposed are highly annoyed.
- An increase of noise by 8 – 10 dB is generally experienced as a doubling of the hearing level of noise.

About ARTISTS
In ARTISTS there is generally a need to perform different kinds of evaluations:

1. To be able directly to compare and evaluate all the 40 roads in the different cities against one another.
2. To evaluate the effects of redesigning and rebuilding the individual roads in relation to the original situation for this road.

In order to describe the situation and the problems on the 40 roads a lot of very different data will be measured, predicted and collected. The data will be stored in a common database. In the project these data will be analysed against one another in order to look for relations and coherence. In relation to noise the following relations might be investigated:

1. Differences and similarities between the noise environment along the roads.
2. The effect on noise of redesigning and rebuilding the road.
3. Relations between the noise levels and the way people use the urban space along the roads (as pedestrians, for recreation (going on outdoor cafés) and for shopping).
4. Relations between socio economic characteristics of the people living along the roads and noise levels.
5. Relations between real estate prices and noise levels.

Location of prediction points for noise
In order to make it possible to investigate and highlight these relations, it is necessary to define the proper noise indicators to be used. To do so, noise levels describing the noise environment at three different locations seem to be relevant:

1. The noise at the façade of the dwellings, as an indicator for the noise inside each residence.
2. The noise at the middle of the footway, as an indicator for the noise exposure of people walking along the road and of people sitting on outdoor cafés or shopping in outdoor markets.
3. The noise in the middle of squares and other open public areas along the roads as an indicator for the noise exposure of people using such areas.

A recent Danish research project on noise annoyance [Larsen; Bendtsen, 2002] has shown, that people can be very annoyed by noise at all these three situations. The noise on the outdoor areas such as the resident’s balcony, courtyard or garden, could also be a relevant indicator for the noise exposure. But in the ARTISTS project information on the presence of such areas is not collected.

Noise at dwellings
The noise levels at the facade of the dwellings vary from storey to storey. When the distance between the road and a dwelling is increased, the noise is reduced. But this reduction is not very high. At roads with geometrical cross sections like the roads included in the ARTISTS project the noise is 1,0 to 1,5 dB lower at the fifth floor than at the first floor, and at a ten-story building the difference is 2,5 to 3,5 dB. On this background it does not seem reasonable to make predictions of the noise at each individual storey. Instead it is recommended to predict the noise only at the middle storey of a house and use this as an indicator for
the noise at all the stories. For five-storey buildings this will introduce an inaccuracy of not more than 0.5 to 0.8 dB, which in a planning project like ARTISTS must be regarded as acceptable.

Data on the sound insulation standard of the housing estates will not be collected. The project will not focus on the exact noise levels indoor. It is considered sufficient to predict the noise levels in front of the facade of the buildings. For planning purposes, it is normally the noise level in front of the facade that is used.

As the noise level in front of the facade is used as an indicator for the noise inside the buildings, this noise level shall be predicted exclusively of the noise reflection from the actual facade. This reflection normally causes an increase of the noise of approximately 3 dB. But the noise outside on the footway and the balconies facing the road is affected by these reflections. Therefore the noise outside in urban roads is generally about 3 dB higher than the noise exposure on the facade of the buildings.

At most urban roads the geometry of a cross section of the road is the same on the right and the left hand side of the road. Meaning that the distance to the three locations for noise predictions is the same on both sides of the road. If this is not the case, the noise shall be predicted individually at each side of the road.

Different measures
In the ARTISTS project different strategies and measures to improve the quality of the areas along the arterial roads will be analysed. In relation to noise abatement it is necessary to be able to predict the effect of different measures that might influence the noise levels like:

- Changing the speed.
- Changing or regulating the traffic composition (light/heavy vehicles).
- Changing the traffic flow from congestion to free flowing traffic.
- Improvement of public transportation like buses, trams or light rail systems.
- Improving the facilities for pedestrians and people on bicycles.
- Changing the geometry of the road.
- Changing the road surface (using paving stones, noise reducing surface).
- Planting vegetation (has usually none or limited effect on noise).
- Noise barriers to reduce noise on buildings and on sidewalks, cycle lanes, outdoor cafés or green areas.
- Total covering of the road to reduce noise.
- Sound insulation of facades.
- Other measures.

3. Discussion on noise indicators

Existing noise indicators
The best knowledge of the author is, that the 24 hour energy equivalent noise level (LAeq,24h) is used for planning and administrative purposes in all the 9 countries participating in the project. In many international studies it is showed, that there is a rather good correlation between LAeq,24h and the general nuisance from road traffic noise experienced by people living along roads [Larsen, Bendtsen 2002 and European Commission, 2002].

Sweden and maybe some other countries also use a nighttime maximum level (Lmax), which is probably a good indicator in relation to sleep disturbance. Detailed information on indicators used in the participating countries could be collected from the members of the project group.

New EU indicators
EU has passed a new directive on noise in June 2002 [EU, 2002]. The main purposes of the directive are to ensure that uniform noise maps are drawn up in the member states and that noise action plans are developed [Larsen, Lars Ellebjerg, 2002]. According to the directive two new noise indicators shall be used instead of LAeq,24h. These indicators are:

- LDEN (Day, Evening, Night).
- LNight.
LDEN (Day, Evening, Night) is an energy equivalent noise level like $L_{Aeq,24h}$, but where the 24 hours of the day, is split in 3 periods, which are weighted differently. A 12 hour day period with no weighting factor, a 4 hour night period where 5 dB is added to the noise and an 8 hour night period where 10 dB is added to the noise level. The noise is predicted separately for these three periods, the weighting factors are added and LDEN is calculated by adding the noise levels of the three periods on a logarithmic basis [EU, 2002]. The member countries can, according to tradition and the local way of living, decide when the three periods starts. The standard periods are the day from 7 to 19, the evening from 19 to 23 and the night from 23 to 7. The length of the periods is normally fixed but the individual countries can decide to reduce the length of the evening period and enlarge the length of either the day or the night period.

The background for using LDEN is the assumption, that people are more annoyed by the noise when they are at their home in the evening and especially while they are sleeping. With a kind of “average” distribution of road traffic over the day LDEN will typically be 2-4 dB higher than $L_{Aeq,24h}$. But if a big proportion of the traffic is driving in the evening or at night or if the speed is much higher LDEN will be even higher. The maximum difference between LDEN and $L_{Aeq,24h}$ is around 10 dB. This occurs in the unusual situation where all the traffic runs at nighttime.

$L_{Night}$ is an energy equivalent noise level similar to $L_{Aeq,24h}$, but is predicted separately for the 8 hour night period.

According to the EU directive LDEN and $L_{Night}$ shall be estimated as averages over the 365 days of the year. In principle the yearly fluctuations in the number of vehicles (passenger cars and trucks), speed, weather conditions (influences the propagation of noise), the temperature of the road surface (influences the generation of tire-road noise), if the road surfaces are wet (generating higher noise levels) and so on shall be taken into consideration. This is in contradiction to the estimation of $L_{Aeq,24h}$ which is normally just based on a dry situation and neutral weather conditions and the average annual daily traffic, which is an average traffic level over the whole year.

To include these yearly fluctuations a lot of special data has to be measured. It is the judgment of the author that estimating the noise close to a road in an urban area including the meteorological effects will not improve the correlation between noise indicators and the investigated effects. It is therefore recommended for the ARTISTS project to predict LDEN and $L_{Night}$ by only using data on the yearly daily traffic and excluding yearly meteorological effects. But to do so traffic data separately for the day, evening and night periods must be available.

**Selection of indicators**

To summarise, there are 4 noise indicators to be selected among:

1. $L_{Aeq,24h}$
2. $L_{Amax}$
3. LDEN
4. $L_{Night}$

ARTISTS is a project where indicators from many different areas like traffic safety, visual impact, congestion, use of roads, noise are dealt with comprehensively. In such a framework just one noise indicator should be most appropriate. This leads to a suggestion using the well known $L_{Aeq,24h}$ and not LDEN (the new EU noise indicator) because traffic data will in the ARTISTS project only be available for the whole day, and will not be measured for each hour of the day.

**Noise Load Number**

It could also be of relevance to describe what can be called “the total amount of noise nuisance” along a road. In Denmark this is done by calculating the so-called “Noise Load Number” (NLN) [Road Directorate, 1989]. NLN is defined as the number of residences multiplied by a factor that corresponds to noise annoyance caused by the actual noise level. The factors are drawn from doses-response relations on noise. In this way the nuisance caused by the actual noise level weights the number of exposed residences. The factors can be seen in table 1.
It will be most meaningful to predict NLN per unit length of 100 m of road. NLN is specially a good indicator for the individual roads to predict the noise consequences of rebuilding the roads or changing the traffic. NLN is also a good indicator to describe the development over time for a specific road. It is not the best indicator to describe the differences between the 40 arterial roads having different number of dwellings along the roads even though it might give an indication on the variation of the concentration of noise problems along the different roads.

NLN might also be used in an adapted form to describe the noise total noise load on pedestrians using the pavements along the roads.

### 4. Prediction methods

**One common or different national methods**

Noise levels can be procured either by measurements or by predictions. It is normally much more time consuming to carry out good and precise noise measurements than to calculate noise. And it is not possible to use measurements to evaluate the effect of different measures to reduce noise that are on a planning stage and are not carried out in full scale. Good and precise prediction methods are available. These methods are developed on the background of a lot of controlled noise measurements and acoustical theory. It is therefore recommended, that predictions of noise shall be used in the ARTISTS project.

The prediction method shall be easy to use it shall be able to evaluate the effect of the different measures on traffic and reconstruction of the roads that are described in section 2. In some of the countries national prediction methods are available. Sweden and Denmark are both using the Nordic Prediction method. The author doesn’t know all the national methods, and therefore can’t give a detailed evaluation of these methods. There are two possibilities. The different national methods can be used or one method can be used in all the 9 countries.

Presumably the vehicle fleets in the 9 countries are not very different from one another regarding noise emissions today, and in a future situation 10 or 20 years ahead with the open market of Europe these differences must be even smaller. This points at using one common model. A survey could be carried out to investigate possible differences in noise emissions.

The real differences in noise between the 40 roads shall be evaluated. It is better to use one common model to ensure that the predicted differences are not due to the use of different national methods.

On the other hand an argument for using the different national models is, that in every country there is a tradition for using these national models.

On this background the author will suggest to use one common method. A good suggestion for such a method is the Nordic Road Noise Prediction Method [Nordic Council of Ministers, 1996]. But this decision should be discussed and taken by the ARTISTS project group. The Nordic method can be used to predict the effect of the measures to change and reduce noise that are outlined in section 2.

The noise calculation work can be carried out by each of the 9 national partners using a standard PC program or a specially developed spreadsheet. Another approach is that all the input data can be collected nationally and the calculations can be performed by one of the partners with special expertise. The latter approach is recommended. The Danish partner Atkins will be able to perform such calculations. This is also a decision to be discussed and taken by the ARTISTS project group.

**Input data**

There are some general demands to the input data used for noise calculations of $L_{Aeq,24h}$. (If $L_{DEN}$ is used instead, the distribution on the day, evening and night periods is also needed):

- The average annual daily traffic of passenger cars and vans less than 3½ ton.
- The average annual daily traffic of trucks and busses over 3½ ton.
- The real average speed of each of these two vehicle categories over the 24 hours of the day.
- Geometrical data on the cross section of the road and its surroundings.
- Geometrical data on a longitudinal section of the road.
- Location and height of noise barriers if any.
- The number of storeys of the buildings along the road.

In situations where there are big variations in the speed because of periods with traffic congestion, the best way to monitor the noise effect of these fluctuations will be to use data on speed and traffic monitored hour by hour.

**Mopeds and motorbikes**
Mopeds and motorbikes are not handled separately in all prediction methods. This is due to the fact that in many cities the amount of these two-wheeled vehicles is very limited. If there is a need to include the noise from mopeds and motorbikes, it is recommended to treat them like heavy vehicles in the noise predictions. Another approach could be to investigate if detailed emission data are available in some of the participating countries, and include this in the selected prediction method.

**Intersections**
It is a special case to handle the noise from road intersections with and without traffic lights. At most of the intersections the arterial road will be the main noise source, as the arterial road will carry more traffic than the crossing road. And in many situations the buildings along the arterial road will act as noise barriers for long sections of the crossing road. The noise from the crossing road will therefore be limited in most cases. To simplify the data collections and the predictions it is recommended only to include the noise from the arterial road and to exclude the noise from the crossing roads.

At an intersection the average speed is often lower than at the rest of the road but acceleration and braking will occur and introduce more noise. To compensate for the noise caused by acceleration and to make things simple it is recommended to use the speed level of the free-floating vehicles also at the intersections. It is recommended to handle roundabouts in the same way.

**Trams and light rail systems**
In many cities road traffic is running in conjunction with light rail systems, such as trams and subways. In the ARTISTS project it is believed that trams are most important and likely to consider together with road traffic. Vibrations generated by tram motion cause structure-borne noise in addition to air-borne noise. Such vibrations are transmitted in the ground to the building foundation and thereby causing the inside walls to vibrate and to emit noise to the inside of the building. Structure borne noise may also occur if the tram power lines have fixed connections in buildings. Since the ARTISTS project primarily concerns the outside noise levels the main effort of treating tram noise should be the air-borne noise. The air-borne noise from trams occurs from a range of different sources:

<table>
<thead>
<tr>
<th>Source of Noise</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling noise</td>
<td>Caused by interaction between rail and wheel roughness and random defects (&quot;Undulations&quot;)</td>
</tr>
<tr>
<td>Impact noise</td>
<td>Caused by discontinuities in either wheel or rail (rail joints, poor quality welds, points and crossings, wheel surface flats etc.)</td>
</tr>
<tr>
<td>Brake noise</td>
<td>Caused by braking system</td>
</tr>
<tr>
<td>Squeal noise</td>
<td>Caused by rail/wheel in curves with small radii</td>
</tr>
<tr>
<td>Bridge noise</td>
<td>Caused by radiation due to train induced vibration in the bridge and amplification of other noise sources</td>
</tr>
<tr>
<td>Noise from other sources</td>
<td>Caused by: Engines, heating and exhaust systems, auxiliary equipment (e.g. fans), shunting, maintenance activities, etc.</td>
</tr>
</tbody>
</table>

Like road traffic, a number of factors affect the resulting noise level based upon the basic source level of emitted noise at a point say 10 metres near the rail system. These factors include: geometrical spreading of the sound, air and ground absorption, noise barriers and skirts and other obstacles, cuttings, wind and temperature gradients, atmospheric turbulence and reflections from surfaces.
For a first practical approach, which corresponds to the road traffic approach, it is believed that valuable information can be achieved by considering only the rolling noise from the trams. This requires noise emission data collection for a number of relevant tram systems at a given speed. Data on driving conditions such as average tram speed, average number of trams per day are necessary to predict the noise level as $L_{Aeq,24h}$ from the tram traffic on a road.

In most countries the rail bound noise and road noise is evaluated separately and it is likely that there are different noise limits to road traffic and tram noise. However, there are proposed methods on how to evaluate noise contributions originating from different kinds of traffic and it should be decided in the ARTISTS project whether tram noise should be treated separately or whether it should be "added" to the road noise. In many countries the noise guidelines for rail traffic is 5 dB higher than the noise guidelines for road traffic. The reason for this is, that surveys shows, that the level of annoyance from for example 55 dB from road traffic is equal to 60 dB from rail traffic. It is suggested to use a method for adding the noise from trams and road traffic, where the noise from the trams is reduced by 5 dB and is added to the road traffic noise on logarithmic basis.

**Break down in road sections**
As a starting point the noise shall be predicted in a cross section that is representative for the road. But the noise levels along the arterial roads might vary, because of variations in the traffic or the geometry of the road. Vehicles might for example leave the arterial road at an intersection, an extra lane might remove congestion and increase speed or a noise barrier might reduce the noise. Therefore it may be necessary to subdivide the roads in shorter sections, with uniform noise levels. A criterion for this subdivision could be, that when the noise level at the facade is changed by 1 dB or more, a new road section is defined and a new prediction of noise in a cross section of the road is carried out. This will match the following criteria:

- The amount of traffic is changed by more than +/- 35 %.
- The speed is changed by 10 km/h or more.
- The distance from the centreline of the road to the point where the noise is predicted is changed by more than +/- 35 %.
- Beginning or end of noise barrier or another noise reducing devise.
- The slope of the road is changed by 2.0 per cent or more.

The height of the buildings and the number of storeys might vary on the road sections defined using these criteria. It is recommended to use the average number of storeys along a given road section when calculation the noise at the facade of the buildings.

**Historical data**
In ARTISTS there can be a need to look back in history, also with regard to the noise levels in the former years. For some of the 40 roads traffic data as old as 30 years are available. Since the 1970’th EU have tightened up the emission standards for new vehicles by around 10 dB. But because of the use of a type approval method under full acceleration (which is a very unusual driving pattern for ordinary road traffic) and other reasons, the tightening up of these standards has not resulted in significant noise reductions form road traffic [Road Directorate, 1998]. This is also the experience of other European countries. It is therefore recommended to use the emission factors of the current prediction methods to predict the historical noise levels. An exception can be trams. If new silent trams have replaced older material, the noise might have been reduced.

**Forecast of noise**
It is expected that the EU noise emission regulations will only have a minor effect on the noise on urban roads in a future situation in year 2010. In this situation the noise levels predicted by the current methods can be reduced around 1 dB for urban roads [Nordic Council of Ministers, 1994]. If new silent trams have replaced older material, the noise might have been reduced.

EU has recently introduced a new regulation on noise from tires. But due to the present limit values, this will only have marginal effect on the noise emission from road traffic [Sandberg, 2001].
5. Recommendations

To summarise this paper it is recommended to handle noise in the ARTISTS project in the following way:

- The noise shall be estimated using predictions and not measurements.
- \( L_{\text{Aeq,24h}} \) is used as the preferred noise indicator of the project.
- \( L_{\text{Aeq,24h}} \) is predicted by only using data on the average annual daily traffic.
- The arterial roads are subdivided in sections with similar noise levels.
- The Nordic Road Noise Prediction Method shall be used for the estimation of noise in all 9 participating countries.
- For each of these road sections the noise as \( L_{\text{Aeq,24h}} \) is predicted in three positions:
  1. The noise in front of the facade at the middle storey of a building (without reflections from the façade itself) as an indicator for the noise in the dwellings.
  2. The noise at the middle of the footway as an indicator for the noise exposure of the people walking along the road and of people sitting on outdoor cafés or shopping in outdoor markets.
  3. The noise in the middle of squares and other open public areas along the roads as an indicator for the noise exposure of people using such areas.

These recommendations have to be discussed and decided upon in the ARTISTS working group.

6. References

- Road Directorate, 1989. Støjhensyn ved nye vejanlæg (Consideration of noise at new roads (in Danish)). Published by the Danish Road Directorate in 1989.