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Memo AKU 001

Project:		Date:	**24. February 2009**
Subject:	**Speech levels in rooms**	Project No.:	**900402**
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Summary:

Using the relationship between speech level and background noise found in the literature, a new simple prediction model has been derived for the average A-weighted noise level due to many people speaking in a room with assumed diffuse sound field. Due to the feed-back influence of noise on the speech level (the Lombard effect), the speech level increases in noisy environments, and the suggested prediction model gives a 6 dB reduction of the noise level by doubling the equivalent absorption area of the room. This is in contrast to the lowering by 3 dB by doubling of the absorption area for a constant power sound source.

A note on the sound pressure level in rooms, caused by speech

Introduction

It is a well known phenomenon that many people speaking in a room can create an increasing sound level, because the ambient noise from the other persons speaking means that everyone raises the voice, which again leads to a higher ambient noise level. This effect is called the Lombard effect, because Lombard was the first to describe the observation that persons with normal hearing started to shout when subjected to noise by means of headphones (1911). The average relationship between speech level and ambient noise level was derived by Lazarus (1986).

A simple prediction model is suggested for the A-weighted level of the noise due to a number of people speaking as a function of the equivalent absorption area of the room.

Speech level in background noise

Lazarus (1986) made a review of a large number of investigations, and he found that the relationship between speech level and background noise can be described by the rate *c* as described in the following.

The increase of the A-weighted speech level L_{SA} (in a distance of 1 m, on axis in a free field) as a function of the A-weighted ambient noise level L_{NA} was found to occur at a rate c = 0,5 to 0,7 dB / dB.

This increase was found to start at an ambient noise level around L_{NA} = 45 dB, and a speech level L_{SA} = 55 dB. Assuming a simple linear relationship, this can be expressed in the equation:

$$L_{SA} = 55 + c \cdot (L_{NA} - 45)\,, \quad \text{(dB)} \qquad (1)$$

In a free sound field the relation between sound power level and sound pressure level is:

$$L_{SA} = L_{WA} + 10 \log Q - 10 \log(4\pi r^2)\,, \ \text{(dB)} \qquad (2)$$

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where Q is the directivity factor and r is the distance from the sound source (in m). For the speech is assumed Q = 2 and r = 1 m, so the A-weighted sound power level for one person speaking is:

$$L_{WA} = L_{SA} + 8\,\text{dB} \qquad (3)$$

A suggested prediction model

In order to estimate the sound pressure level of noise sources in a room, the simplest assumption is that of a diffuse sound field. If there are N_S noise sources active at the same time and the sound power level of each is L_{WA}, the average sound pressure level in the room is calculated thus:

$$L_{NA} = L_{WA} + 10\log N_S - 10\log\left(\frac{A}{4}\right), \ \text{(dB)} \qquad (4)$$

where A is the equivalent absorption area (in m^2) of the room.

Insertion of (1) and (3) in (4) yields:

$$L_{NA} = \frac{1}{1-c}\cdot\left(69 - c\cdot 45 - 10\log\left(\frac{A}{N_S}\right)\right), \ \text{(dB)} \qquad (5)$$

This is the main result giving the noise level that can be estimated from the number of people speaking and the equivalent absorption area of the room. If the room has the volume V (m^3) and the reverberation time in unoccupied state T_0 (s), the Sabine equation gives the following estimate of the equivalent absorption area including the contribution from N persons:

$$A = \frac{0{,}16\cdot V}{T_0} + a\cdot N, \quad (\text{m}^2) \qquad (6)$$

where a is the absorption area per person. Introducing the group size as the average number of people per speaking person, $g = N / N_S$, insertion of (6) in (5) yields:

$$L_{NA} = \frac{1}{1-c}\cdot\left(69 - c\cdot 45 - 10\log\left(g\cdot\left(\frac{0{,}16\cdot V}{T_0\cdot N} + a\right)\right)\right), \ \text{(dB)} \qquad (7)$$

The noise levels predicted by eqn. (5) are shown in Fig. 1 for different values of the c-factor. c = 0 denotes a sound source with a constant sound power, whereas c values of 0,5-0,7 dB / dB are in the range found by Lazarus (1986). Correlation with the measured results from a number of studies (see below) shows that a c-factor of 0,5 gives good agreement between measured and calculated data. c-factors above 0.5 seem to yield far too high noise levels in the examples considered.

This means that the noise level is lowered by 6 dB if the equivalent absorption area is doubled. This is in contrast to the lowering by 3 dB per doubling of the absorption area for a constant power sound source.

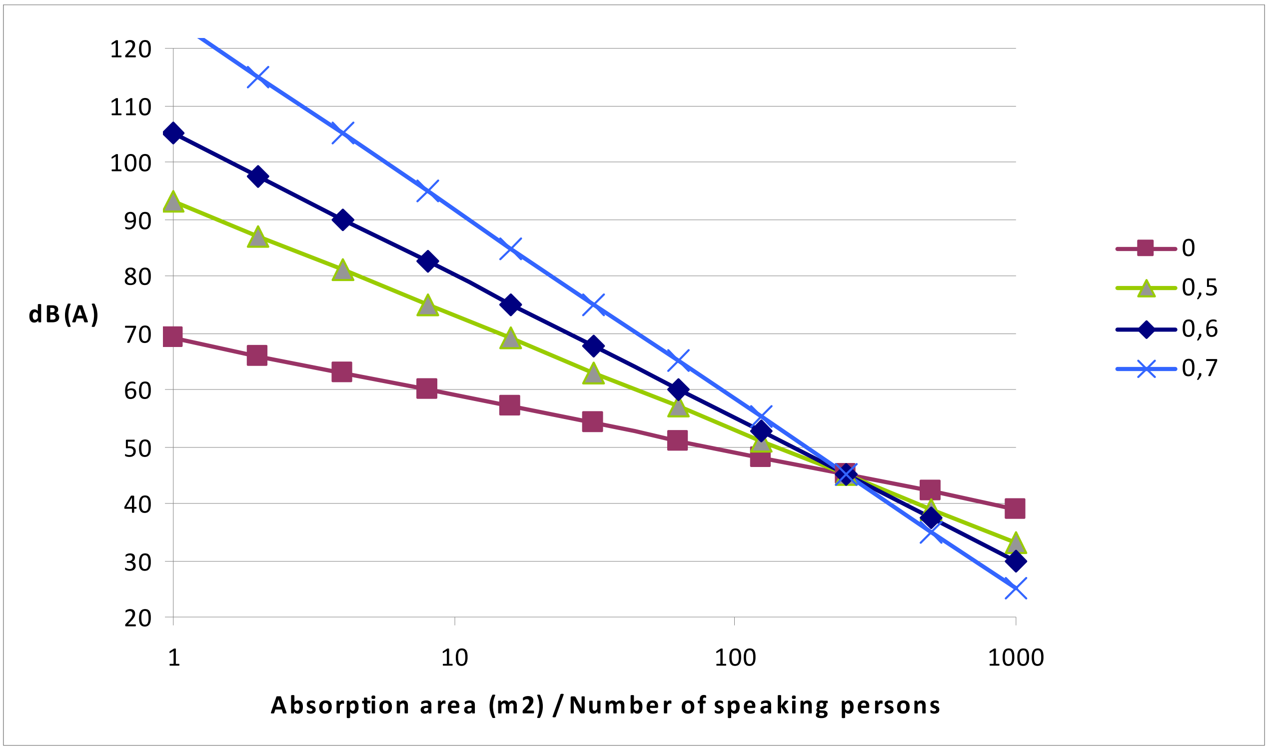

Figure 1. The noise level as a function of the equivalent absorption area per speaking person, eqn. (5), shown for different values of the rate c.

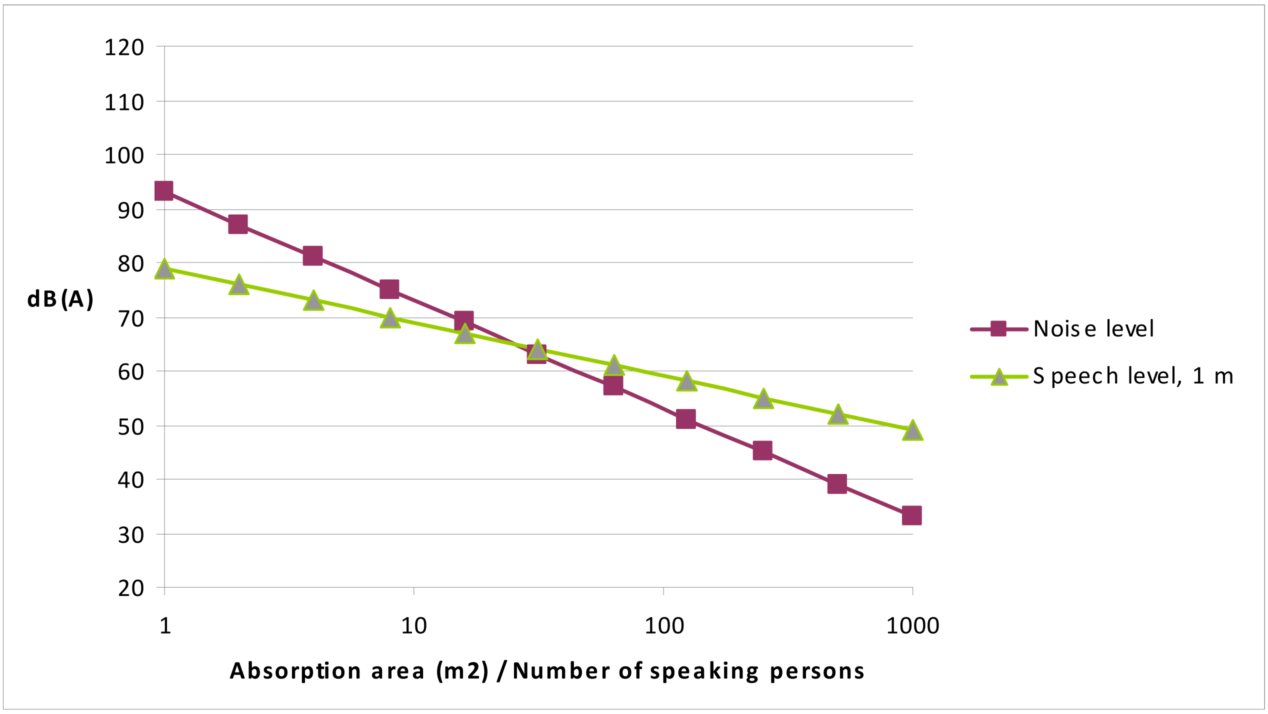

Figure 2. The noise level and speech level as functions of the equivalent absorption area per speaking person according to the suggested model, eqn. (5).

The suggested prediction model, eqn. (5) with c = 0,5 dB / dB is displayed as a function of the number of speaking people in Fig. 2. The corresponding speech levels are also shown. According to Lazarus (1986) the various speech levels can be characterised as stated in Table 1.

Table 1. Description of various speech levels, after Lazarus (1986).

Speech level, 1m, dB(A)	Description
54 – 59	Relaxed
60 – 65	Normal
66 – 71	Raised
72 – 77	Loud
78 – 83	Very loud
84 – 89	Shouting

Verification examples

Two examples of measured noise levels as a function of number of people in food courts are reported by Navarro & Pimentel (2007). In both cases measurements of the A-weighted sound pressure level were reported with different number of people present. However, it is not known how many people were actually speaking at the same time. In the Figures 3 and 4 the results are compared with the prediction model using different values of *g*, the number of people per speaking person (between 2 and 4). In both cases it is found that a group size of 3 gives the best overall agreement of the model with the measured results.

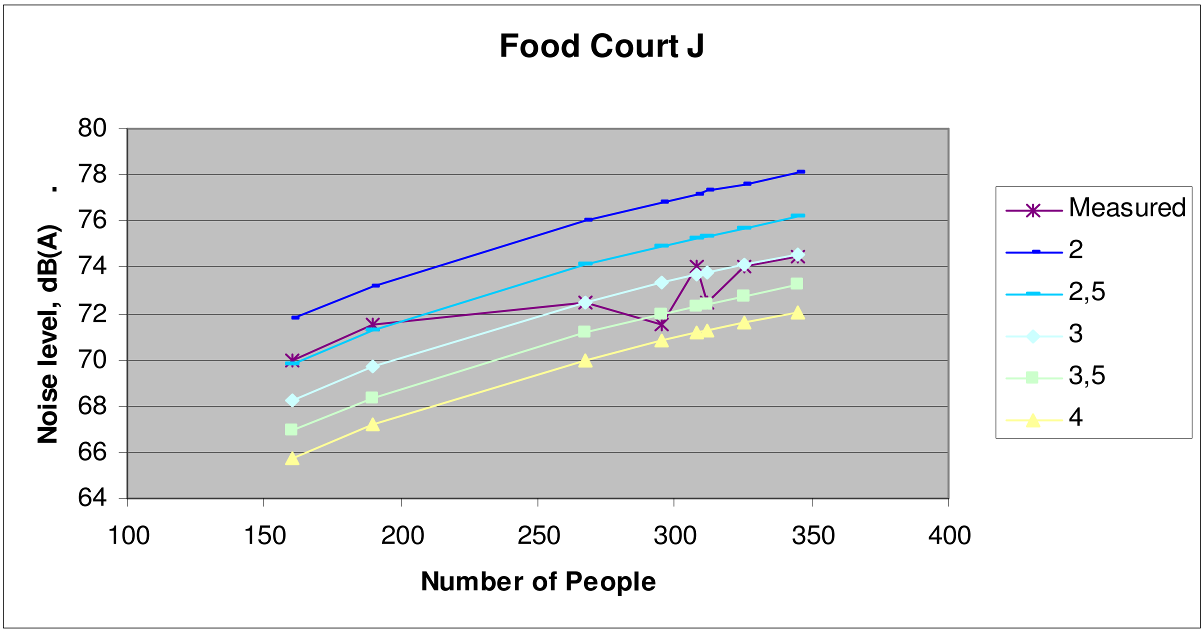

Figure 3. Measured and predicted noise level for Food Court J (7228 m^3, reverberation time 1,3 s). The parameter on the predicted curves is g, the number of people per speaking person.

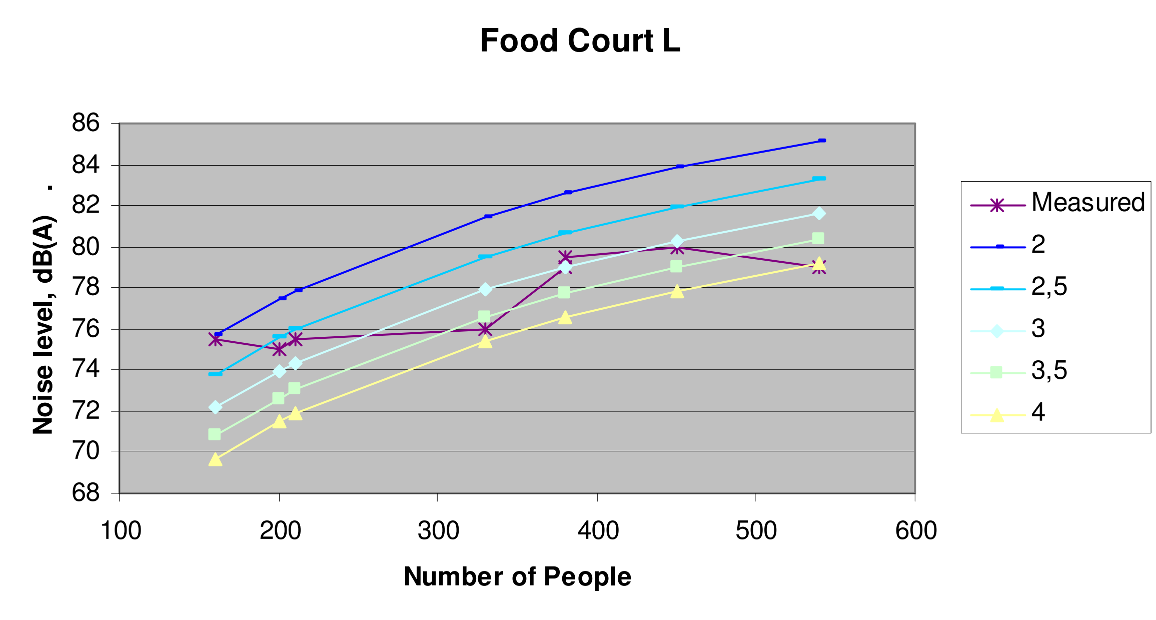

Figure 4. Measured and predicted noise level for Food Court L (3133 m^3, reverberation time 0,9 s). The parameter on the predicted curves is g, the number of people per speaking person.

Another set of measured data was found in a paper by Tang et al. (1997). The noise level was measured continuously in a canteen for 2,5 hours during lunch time, where the number of people increased in the first hour from nil to around 250 (Measurement A in Fig. 5). In the later 1½ hour the number of people gradually decreased, but to some extent the noise level didn't decrease as much as could be expected, and at the end of the measurements only 60 people were left, but the noise level was much higher than with 50 people at the beginning.

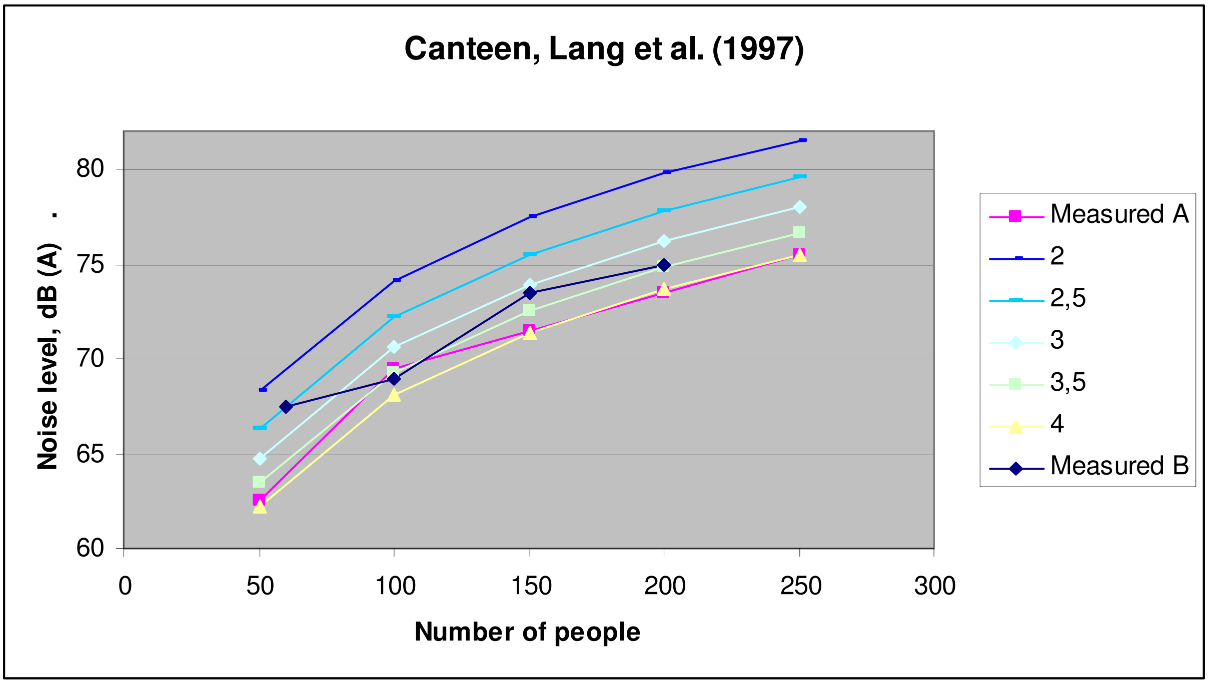

Figure 5. Measured and predicted noise level for a canteen (1235 m^3, reverberation time 0,47 s). The parameter on the predicted curves is g, the number of people per speaking person.

For the example in Fig. 5 the best overall agreement with the present prediction model is obtained with a group size of 3,5. However, in Measurement A between 150 and 250 people, a very good agreement is obtained with a group size of 4, indicating that people are not talking so much in the beginning of the lunch, whereas the later part of the lunch represented by Measurement B matches better with a group size of 3, i.e. more people talking.

The average deviations between measured and predicted noise level are listed in the Tables 2-5 for each of the cases, the Canteen example being split into two (early or late part of lunch). The results obtained with values of the two constants *c* and *g* are listed.

Table 2. Deviation between predicted and measured noise level in Food Court J, using different values of the calculation constants.

	Group size, *g*			
c-factor	2,5	3	3,5	4
0,5	2	**0**	-1	-3
0,6	9	7	5	4
0,7	21	18	16	14

Table 3. Deviation between predicted and measured noise level in Food Court L, using different values of the calculation constants.

	Group size, *g*			
c-factor	2,5	3	3,5	4
0,5	1	**0**	-2	-3
0,6	10	8	6	5
0,7	24	21	19	17

Table 4. Deviation between predicted and measured noise level in the canteen, measurement A, using different values of the calculation constants.

	Group size, *g*			
c-factor	2,5	3	3,5	4
0,5	4	2	1	**0**
0,6	11	9	7	6
0,7	23	21	18	17

Table 5. Deviation between predicted and measured noise level in the canteen, measurement B, using different values of the calculation constants.

	Group size, *g*			
c-factor	2,5	3	3,5	4
0,5	2	**1**	-1	-2
0,6	9	7	6	4
0,7	21	18	16	14

It is clear from the Tables 2-5 that c = 0,5 dB / dB should be used; the other possible values yield much bigger deviations from the measured data. It appears that within a range of ± 2 dB the suggested prediction model seems to give the best results with the following values of the constants:

- c = 0,5 dB / dB
- a = 0,2 m^2 (for people seated at tables; a = 0,44 m^2 for standing persons)
- $g = N / N_S = 3$ (may vary between 2 and 4, depending on the arousal level)

All the verification examples are with people seated at tables; the model has not been tested against examples with standing people.

The parameter that remains for the user to estimate is the average group size g, which can also be looked at as a measure of the arousal level of the people gathered. A higher number (e.g. 4) indicates a relatively quiet party, whereas a low number (e.g. 2) suggests a very lively party. If the party is like a reception and the people are drinking alcohol, it is very likely that the arousal level will increase with time, meaning a decreasing group size.

Conclusion

Using the relationship between speech level and background noise found in the literature, a new simple prediction model has been derived for the average A-weighted noise level due to many people speaking in a room with assumed diffuse sound field. It is precondition that the noise level is at least 45 dB(A).

The prediction model has been verified by comparison to results measured in two food courts and a canteen, the number of people ranging from 50 to 550. As it is obvious that a gathering of people can be more or less lively, it is necessary to estimate the average group size, defined as the number of people per speaking person. This group size parameter was found to be around 3 - 4 in the cases considered here, but in a more lively party or a very dead gathering it is likely that the parameter can take on values outside this range.

It is found that with a fixed number of speaking persons in a room, the change of the equivalent absorption area of the room can be expected to lead to a much stronger change of the noise level than for a constant level noise source. Due to the feed-back influence of noise on the speech level (the Lombard effect), the speech level increases in noisy environments, and the suggested prediction model gives a 6 dB reduction of the noise level by doubling the equivalent absorption area of the room. This is in contrast to the lowering by 3 dB by doubling of the absorption area for a constant power sound source.

References

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