¨Noise control” in restaurants

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ABSTRACT:
It is a well-known phenomenon, that a (large) group of people in one room can (and often will) produce high sound levels. Even when asked to be quiet, after some time voices become louder and sound levels increase (again) to a certain rather constant value. Can this value be forecast? Can it be controlled to some extent? For this purpose a model was set up, based on the circumstance that people in a gathering tend to start conversations, and want to understand and be understood.
Speech intelligibility is the key word, in combination with the fact that people raise their voices in noisy circumstances, the Lombard effect. Of course much will depend on the characteristics of the gathering, the people, the type of occasion etc. The results of the model reflect this spread; nevertheless the results are useful in noise control. Measurements in practice support this.

Author Keywords
Group vocal output, noise control, feed back, speech intelligibility, sound absorption.

INTRODUCTION

It is a common experience that the noise level caused by the conversation of groups increases with the number of people; proportionally at first, when not many people are present yet, but even stronger if certain limits (noise level or number of people) are exceeded. At social events like cocktail parties, this phenomenon can often be regarded. This raises the question if the sound level caused by the people in a room can be predicted or estimated in some way. At least as important is the question to what extent the acoustical properties of the room determine the sound levels, and can be manipulated accordingly.[1]

The basic approach from acoustics theory, is that the resulting sound level in the room depends on the number of speakers (n), the vocal output (sound power, W_i) of each speaker, and the amount of sound absorption (A, m^2). The number of speakers is a certain fraction (f) of the number of attendees. This fraction however, and the vocal output are not constant, but depend on the level of the ambient sound, which is caused by the other speakers! This is shown in the diagram (figure 11), with two ways of feed back. The simulation model is based on this scheme.

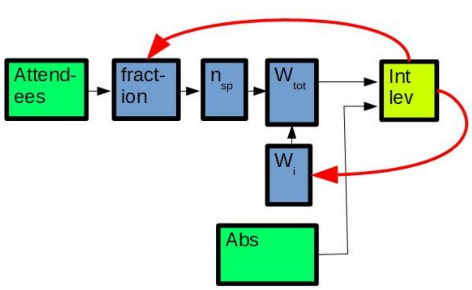

Figure 1: Schematic representation of feed back model

CONVERSATION.

Consider a room where a gathering is held. People arrive one by one; at first forming a circle with only one speaker at a time. The distance between neighbours in the circle will be constant, e.g. 1 m. As the number of attendees grows, the perimeter and consequently the diameter of the circle do, until conversation becomes less easy, because the distance between the speaker and some of the listeners hinders the speech intelligibility. Then the circle breaks up into two smaller ones. These new circles keep growing with new participants entering, until they break up again. In this way, the number of speakers increases, and so does the sound level in the room. This causes the speakers to raise their voices. The effects of the number of attendees, trying to maintain or start their conversation, and of the amount of sound absorption is implemented in the model, based on the extensive literature on speech intelligibility, preferred speech levels, etc.

While this description is probable for social events, where people can freely move around, the situation is different in restaurants. Nevertheless, people being seated at tables form groups: at first each table forms a group, but with an increasing number of people, the number of speakers increases, as does the ambient noise level. Basically this is not very much different from the behaviour of people in circles in a social event.

ELEMENTS OF THE MODEL

In the model a diffuse (*homogeneous, isotropic*) reverberant sound field is assumed. The direct field of the “other” speakers is negligible; compared to the reverberant field. Apart from basic acoustics, specific elements are necessary to describe the role of speech intelligibility, and the so called Lombard effect.

Interesting is the group size: how many listeners does each speaker have? Several opinions are found in literature. In our model the group size is not constant: in the contrary, it is dependent on the ambient noise level.

In practice the noise generated by various sources like traffic, kitchens, equipment can play a role. Here an appropriate background level of 35 dB(A) is assumed.

Speech intelligibility

Speech intelligibility can be measured in many different ways, like Articulation Loss of Consonants, AL_{cons} described by Peutz [2], or Speech Transmission Index (STI), described by Houtgast et al. [3]. In essence it is dependent on the signal to noise ratio (SNR), the signal being the voice of one speaker, the noise being the total of ambient noise, all other voices. For each of the speech intelligibility criteria, a corresponding satisfactory value of SNR can be defined.

The level of ambient noise is the same, everywhere in the reverberant field. The speech level is dependent on the vocal output of the speaker and the distance between speaker and listener. Therefore, for each pair of values of ambient noise level and vocal output, a *conversation radius* can be defined: the maximum distance with satisfactory value of SNR. If SNR becomes insufficient, the conversation circles rearrange.

Lombard effect

The Lombard effect is named after the French physician who in 1911 first described the phenomenon, that speakers raise their voices when ambient noise levels increase. Several relationships have been described in literature (Heusden, E. van, et al. [4](1979); ISO 9921 [5] (1996);Webster [6](1970)), some of them have been used in this study.

Conversation circles

The conversation groups form circles; the interpersonal distance between members of a circle is kept constant (1 m), for groups of five or more persons. For smaller groups – four members or less – the interpersonal distance d is decreased (0,5 to 1 m). The maximum distance D between two members of the group is the diameter of the circle. In formula:

$$D = n.d/\pi$$

n = number of members

d = interpersonal distance

This distance D is taken to determine the (worst case) speech intelligibility. In other words: the *conversation radius* must be greater than the diameter of the circle.

The members of the group are supposed to take part in the conversation. Therefore they strive for understanding the speech of all other members. Only one member speaks at a time. If speech intelligibility is unsatisfactory people will leave the circle, to join some other circle or to form a new one. This process is simulated by assuming first that all persons present form one circle. If speech intelligibility is unsatisfactory, the number of circles is increased by one, and people are spread equally over the circles. This process is repeated until speech intelligibility is satisfactory, or the conversation circles consist of only two persons. The ambient noise level at the end of each iteration process is called the Lombard level, a function of two variables: the number of people and the amount of sound absorption. This function is called a Lombard-2 function.

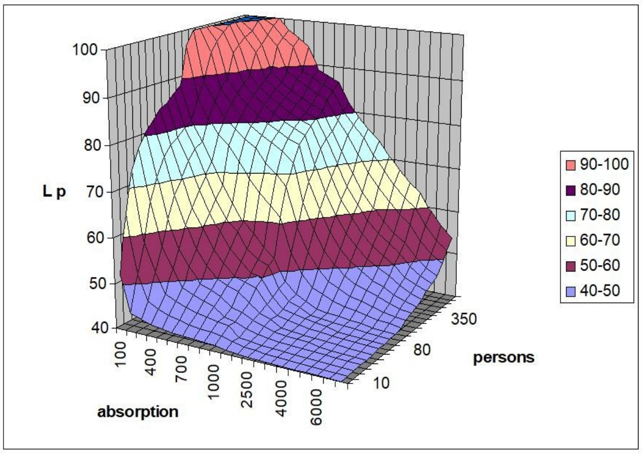

Figure 2: Lombard-2 function: equivalent sound level as a function of the amount of sound absorption and the number of attendees (ISO 9921).

MODEL OUTPUT

The personal vocal effort (as a function of the ambient sound level) and the criterion for speech intelligibility can differ. For each criterion the whole process can be repeated, yielding a new Lombard-2 function. The process described here was implemented in a number of spreadsheet programs, one for each criterion of speech intelligibility and the connected personal vocal output function. These criteria embrace: implicit criteria of Webster [6] (1970), from his figure 1; criterion of Van Heusden et al. [4] (1979), preferred listening level if conversation circles are large (5 or more persons), required listening level if conversation circles are smaller; international standard ISO 9921-1 [5](1996), Navarro et al. (2007)[7].

The assumed group size turns out to be rather variable: under optimal conditions (few people, much absorption) 8or more; in the worst conditions 2, which implies one-to-one conversations only.

ABSORPTION PER CAPITA

An important step in data reduction could be made, if the Lombard-2 functions were reduced to functions of one variable. Therefore a new independent variable is introduced: A/n, the amount of sound absorption per person. The calculated Lombard levels are plotted against this variable, as shown in Figure 43. Because each value of A/n can be the result of several combinations of A and n, many data points can occur with a single A/n-value. As the figure shows, the spread is not very large, and there is a clear trend. The trend line can be called a Lombard-1 function: the sound level in a room as a function of the absorption per person (A/n).

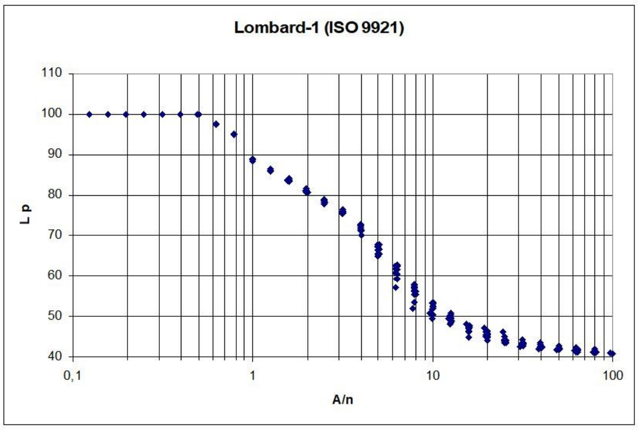

Figure 3: Lombard-1 function, equivalent sound level as a function of the amount of sound absorption per capita (ISO 9921).

The Lombard-1 curves all have the same trend, as was expected. As long as there is ample sound absorption per capita, and the sound levels are still low, the agreement between the Lombard-1 functions is large.

The differences might be attributed for an important part to differences in the social context, type of occasion, local (drinking) habits etc. Different definitions of the speech level, especially the way of determining an equivalent speech sound level may be involved as well, for example ISO 8253-3 [8](1996).

From basic acoustic theory a slope of –10 dB/decade is expected. For values of A/n < 10 m^2 the curve is steeper, about – 30 dB/decade. The transition point can be estimated at roughly A/n = 5 - 10 m^2.

More or less arbitrarily a sound level of 60 dB(A) can be

regarded as the start of noisiness in public spaces. The different Lombard functions lead to different A/n-values for which this limit is reached: Webster: A/n ≈ 10 m^2; Van Heusden: A/n ≈ 3 m^2; ISO 9921: A/n ≈ 7 m^2.

A value of 5- 10 m^2 therefore seems a reasonable compromise, as a guideline for the minimum amount of sound absorption per capita in (large) spaces.

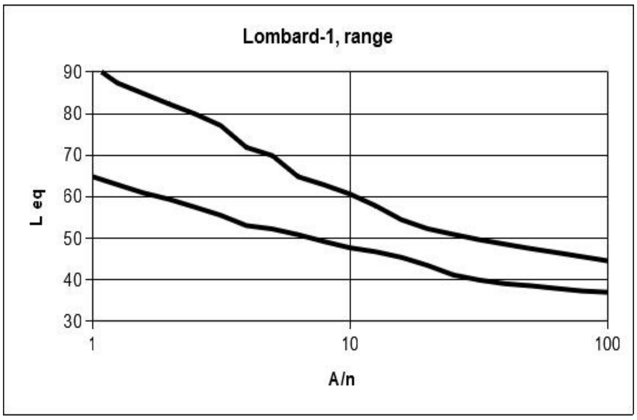

Figure 4: Range of Lombard-1 functions for various criteria of speech intelligibility

EXAMPLES GROUP VOCAL OUTPUT

For a number of occasions data regarding number of people, amount of sound absorption and resulting, measured equivalent sound level have been compiled; partly from literature i.c. Gardner [9](1971), Zelem et al. [10], (Oestergaard) Nielsen [11], others from Peutz' archives. The data points are plotted in Figure 5, where also the average of the values as calculated with the model of conversation circles is drawn. Included too is the expected sound level based on a formula by Rindel [12]. The data points fit well in the range of the model; the spread is rather large as can be expected for such a complex phenomenon.

ARCHITECTURAL GUIDELINE

In many textbooks guidelines are given for the desired room acoustics of spaces, usually expressed in values of reverberation times. In general for non-musical rooms, but certainly for large spaces, the amount of sound absorption is much more relevant than the reverberation time. From the results of this model an amount of sound absorption per person of around 5-10 m^2 can be adopted as a guideline. Sometimes the (maximum) number of people to be expected is known, and can be used directly. In other cases a density of roughly one person per 5-10 m^2 floor area can be assumed; this means an amount of sound absorption roughly equal to the floor area. If this condition is met, one may expect that the sound levels caused by the attendees will not rise to extreme values, but remain below 60-65 dB(A). Of course, no guarantee can be given: noisy behaviour or higher density of occupants is ruled out.

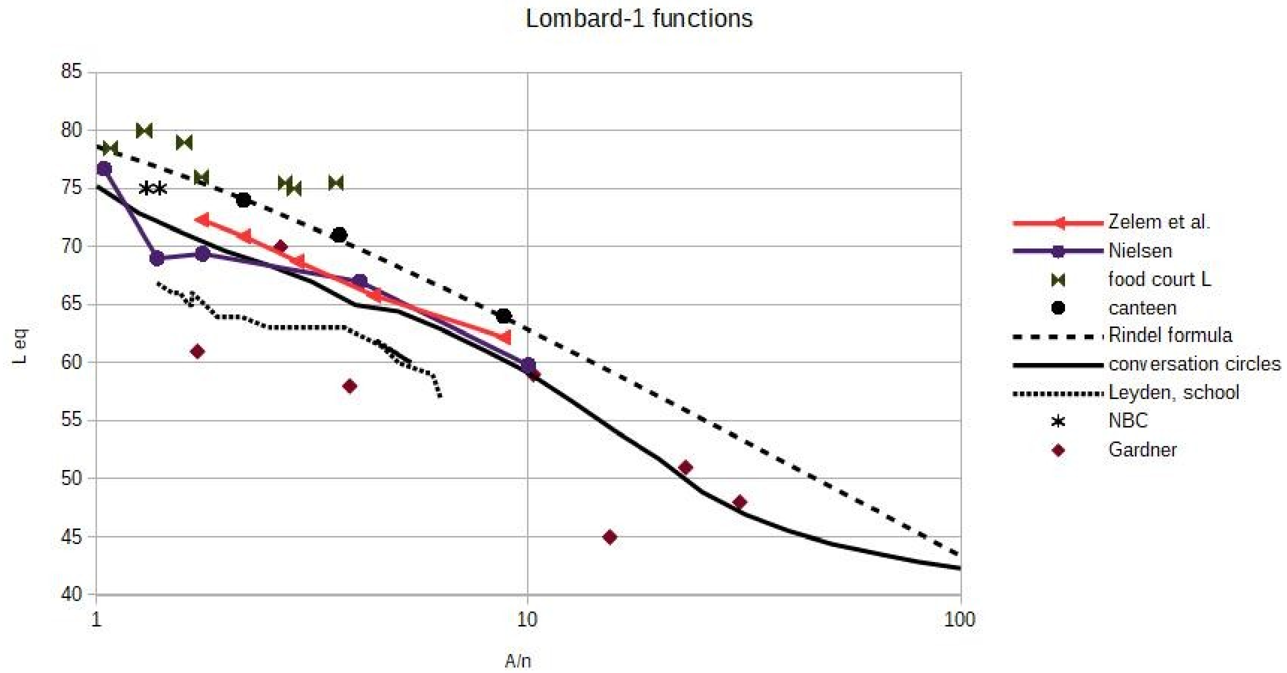

Figure 5: Equivalent sound level (group vocal output) as a function of the sound absorption per capita.

Where higher densities of people are to be expected, for example at the entrance of a hotel or shops, sound absorbing surfaces or elements near these areas may be necessary, and feasible.

Bonus: Group size

The group size as resulting from the model turns out to depend on the amount of sound absorption per capita, as shown in Figure 6. The average, and the spread (average ± standard deviation) are drawn.

A small amount of sound absorption allows only small conversation groups.

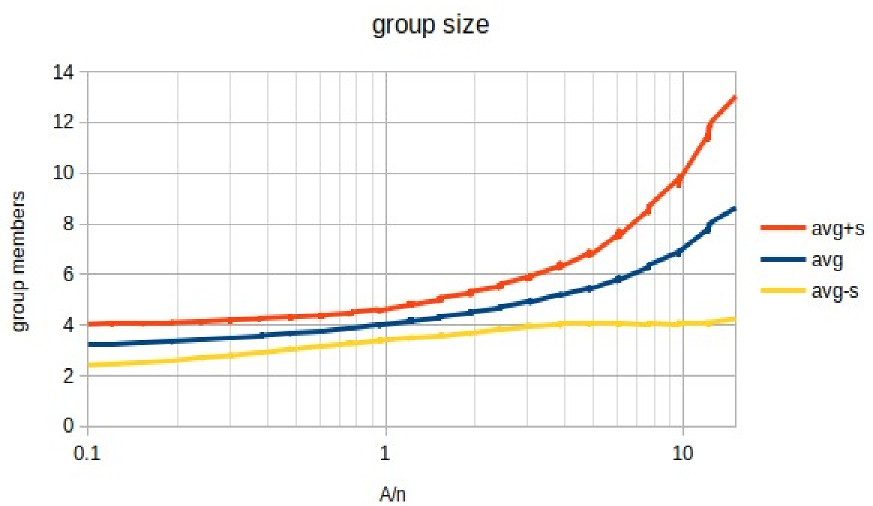

Figure 6: Group size as a function of sound absorption per capita (A/n), from model.

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