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VALIDATION OF PREDICTIVE ALGORITHMS FOR THE ESTIMATION OF THE NUMBER OF PEOPLE IN A CANTEEN

Giulia Calia[1] **Giuseppina Emma Puglisi**[1] **Louena Shtrepi**[1]
Fabrizio Riente[2] **Pasquale Bottalico**[3] **Dario D'Orazio**[4]
Arianna Astolfi[1*]
[1] Department of Energy, Politecnico di Torino, Italy
[2] Department of Electronics and Telecommunication, Politecnico di Torino, Italy
[3] Department of Speech and Hearing Science, University of Illinois at Urbana-Champaign, USA
[4] Department of Industrial Engineering, University of Bologna, Italy

ABSTRACT

This study aims to estimate the number of people in a canteen from the babble noise level in the room. Noise levels were measured in the CIRCOOP canteen of the Politecnico di Torino across 4 days during the COVID pandemic, while three people counters, based on IR sensors, were located at the entrance and at the exit of the canteen. Reverberation time was also measured to calibrate the acoustic model in Odeon 16 and Grasshopper application of Rhinoceros 7 was used to calculate some parameters needed for the application of two prediction algorithms. The former assumes a diffuse field while the latter does not, and instead, it considers the rate of spatial decay per distance doubling and the interpersonal distance. Besides the acoustical parameters of the room, the models need as input the group size g and the Lombard slope c, which strongly depend on human context. In the case of this canteen, the best matching was obtained with g=8 and c=0.5 for both the models. Our results showed that the prediction of the number of people from the babble noise is possible only for noise levels lower than 70 dB(A).

Keywords: *Canteen, babble noise, Lombard slope, prediction algorithm, anthropic noise, number of people.*

[*] ***Corresponding author***: arianna.astolfi@polito.it

1. INTRODUCTION

According to Rindel [1] the number of persons N in a catering establishment can be obtained according to Eq. 1:

$$N = \frac{0.16V}{T_0\left\{10\left[\frac{69-45c-L_{N,A}(1-c)}{10}-log(g)\right]-A_p\right\}}\ [-] \quad (1)$$

Where:
V = Volume of the room in m^3;
c = Lombard slope in dB/dB;
g = group size, i.e., N/N_S;
N = number of people;
N_S = number of simultaneous speakers;
$L_{N,A}$ = anthropic noise level, dB(A);
T_0 = reverberation time of furnished but unoccupied room at middle frequencies of 0.5 kHz and 1 kHz;
A_p= absorption per capita, m^2.

This predictive model works good in catering environments with a diffuse acoustic field, where the $L_{N,A}$ exceeds the minimum value of 45 dB(A). The Lombard slope "c" is the ratio of the anthropic noise level generated in a closed environment, $L_{N,A}$, to the sound pressure level at 1 meter from the speaker's mouth, $L_{S,A,1m}$. According to Lazarus [2], "c" varies between 0.5 dB/dB and 0.7 dB/dB. The group size value "g" ranges between 3 and 4 in catering environments, while absorption per capita A_p ranges between 0.2 m^2 and 0.5 m^2. A_p strongly depends on diners' clothing type, whether it is summer or winter and from their position, if erected or seated.

A study by Pinho et al. [3] in a school cafeteria revealed that there is correspondence between measured and calculated noise levels $L_{N,A}$ by setting as input parameters an absorption per capita A_p equal to 0.25, a Lombard slope “c” equal to 0.4 dB/dB and a group size “g” equal to 2, or a Lombard slope “c” equal to 0.5 dB/dB and a group size “g” equal to 4.

D' Orazio et al. [4,5] developed a prediction model for the estimation of the number of persons in a room in which the ceiling height is far lower than the extension in plan. In this type of environment, the hypotheses of the diffusive Sabine field are not verified so it is advisable to introduce a new parameter, $D_{2,S}$, i.e., is the rate of spatial decay of an omnidirectional source, that replaces the reverberation time of the furnished but unoccupied environment. In this way, N can be estimated according to the following formula:

$$N = 10^{\left[\frac{L_{N,A(1-c)-55+45c+3.32D_{2,S}\log(r_{ij})}}{10}+\log(g)\right]}\ [-] \quad (2)$$

Where:

$D_{2,S}$ = rate of spatial decay of A-weighted sound pressure level (SPL) of speech per distance doubling in dB, as described in ISO 3382-3 [6];

r_{ij} = mutual distance between an i-th source and a j-th receiver in m.

2. MEASUREMENTS IN THE CIRCOOP CANTEEN AT THE POLITECNICO DI TORINO

Two NTI Class 1 Audio XL2 Sound Level Meter were installed in the CIRCOOP canteen at the Politecnico di Torino. Its sizes are 25.3 m length and 18.3 m width, with an average height of 2.80 m and a total volume of about 1115 m^3. The SLMs were installed at the 1.65 m height in the middle of the main eating area and close to the coffee room, respectively. To count the number of people in the environment during the monitoring campaign, three infrared sensors with single photocell were placed at entrance doors of the canteen and near to the two exit doors. Two measurement campaigns were carried out, the first the 25 and 26 of November 2020, and the second the 14 and 16 of April 2020, from 12 am to 2 pm. During the first campaign the arrangement of the tables respected the safety interpersonal distance imposed by the Italian Decree n. 265 for the COVID19 pandemic of 1.5 m. For each table there were only 3 seats available, for a total of 54 tables and 146 seats. In the first day of monitoring the flow of people reached a maximum peak of 117 persons while on the second day there was a peak of 151 persons. During the second campaign the third chair of each table was eliminated to reduce the distance between two consecutive tables. A total of 74 tables and 155 seats were available, with a maximum peak of 216 persons on the first day of measurements, and of 204 persons on the second day.

Reverberation time T20 was also measured in the empty canteen to calibrate the GA model in Odeon 16. The standard ISO 3382-2 [7] has been followed to perform the measurements by setting the sources and receivers positions.

3. GA SIMULATIONS

Geometrical acoustics simulations were carried out with Odeon 16 combined version software. Calibration of the model was based on reverberation time T20 in the empty but furnished canteen. $D_{2,S}$ was also simulated, assuming a source with a "Normal speech" vocal effort and with a standardized directivity pattern named "ISO3382-3_OMNI. SO8" available in Odeon 16. The source has been positioned at a height of +1.20 m to simulate a talking person in a sitting position. The receivers were also positioned at the same height in a linear position with respect to the source at a constant interpersonal distance of 2 meters. According to [6] 9 receivers were placed on a line on the longitudinal extension of the canteen. The receivers were placed 0.5 m from the furnishings and 1 m from the bounding surfaces of the room. Calculated $D_{2,S}$ was 3.6 dB.

4. SIMULATION IN GRASSHOPPER FOR RHINOCHEROS

The mutual distance r_{ij}, in meters, between a simulated i-th source within the canteen and the two SLMs in the CIRCOOP canteen was obtained using the Grasshopper application developed within the Rhinoceros 7 software. The canteen was imported in 2D on Rhinoceros and a series of points were placed at the seated positions. Two points representing the two SLMs were also added to the map. In the Rhinoceros model it has been simulated how seats are gradually randomly occupied with the increase in the number of people. The algorithm for simulating the random growth/decrease of occupied seats was implemented in Grasshopper as follows:

- A point cloud represents the total number of seats available within the canteen;
- By moving a slider "N" it is possible to increase or decrease the occupancy rate according to the room capacity;

- The third command indicated by a checkerboard icon is the "random reduce" and allows to fill/empty the space in random mode so as the number of people increases;
- The points in the space filled in randomly, change color from red, i.e., unoccupied, to green, i.e., occupied;
- The algorithm calculates for each occupied point the mutual distance the between point and the two SLMs;
- The algorithm calculates for each SLM the arithmetic mean of the r_{ij} distances.

5. RESULTS

5.1 Number of people vs babble noise level

Figure 1 shows the number of people in the canteen versus the babble noise level recorded by the two SLMs, overall in the canteen across the 4 days of monitoring.
Within the R software version 3.1.2 we applied the "segmented" or "broken-line" function which allows to create a regression model with two or more regression lines that better approximate the data. In the segmented model, data approximation lines must be constrained to one, or more points called break points, which correspond to the points where the relationships between the response variable and the predictor variable change. Applying the segmented function to the general linear regression model containing data from all the 4-day monitoring, one significant break-point was found at the L_n = 70.25 dB(A) where a change in slope of the two linear regression lines is clearly visible in Figure 1.
In the segmented function report, we found that up to the break-point, for 1 dB increase in the noise levels the number of people increase by 10, while beyond the break-point it decreases by about 2. It was therefore found that, beyond the break-point, the number of people estimated by the model tends to decrease despite the increase in noise level, perhaps due to the high background noise. The break-point at 70.25 dB(A) corresponds to a value of about 140 persons.

5.2 Validation of the two algorithms for the prediction of the number of people in a canteen

The regression line that represents the relationship between the number of people and the measured babble noise levels was approximated with a Poisson generalized model up to the noise level of 70 dB(A), where a significant break-point was found in the experimental values. The data distribution is exponential, and it successfully merges the trend of the two algorithms by Rindel [1] and D'Orazio et al. [4,5].

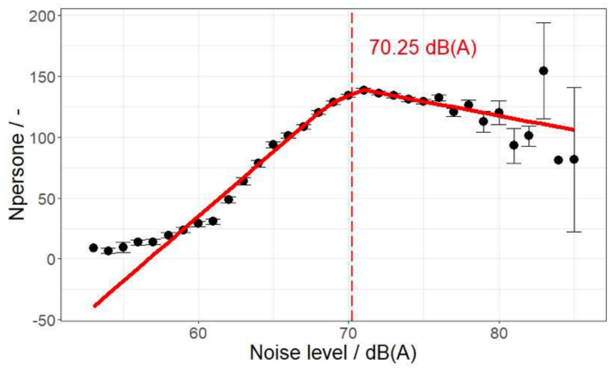

Figure 1. Number of people versus chatting noise level, L_n, overall, across the 4 days of monitoring, in the CIRCOOP canteen. Segmented function applied to the general linear regression model with data from all the 4-days monitoring of babble noise in the CIRCOOP canteen, and the significant break-point found at noise level equal to about 70 dB(A).

Figure 2 shows the regression lines from experimental data and from the two models in which the best matching was obtained with g=8 and c=0.5. The Lombard slope "c" falls within the range of values found by Rindel for the application of his model in school cafeterias, where a c=0.4-0.5 dB/dB was adopted. Group size "g" ranges between 3 and 4 in catering environments, and g=8 is a very high value. It can be assumed that such a high value of group size is a direct consequence of the restrictions imposed from the D.P.C.M. 26 October 2020, n. 265 " Urgent measures to contain contagion throughout the national territory". A group size equal to 8 implies fewer people speaking simultaneously within the environment, that is the number of speakers is a small number compared to the conditions before the COVID-19 pandemic. This was the consequence of the impossibility of sitting with more than 2-3 people per table.

6. CONCLUSIONS

In this study we estimated the number of people from the babble noise level recorded in a canteen across 4 days during the COVID-19 pandemic. Two prediction algorithms were also compared with the measured data, in which the former is based on a diffuse field hypothesis while the latter does not, and instead it considers the rate of spatial decay per distance doubling and the interpersonal distance. The best matching was obtained including in the models a group size, i.e., the ratio between the number of people and the number of people speaking simultaneously, equal to 8, and a Lombard slope equal to about 0.5, for both the models. The group size is double compared to the condition pre COVID-19 pandemic. Our results showed that the prediction of the number of people from the babble noise is possible only for noise levels lower than 70 dB(A).

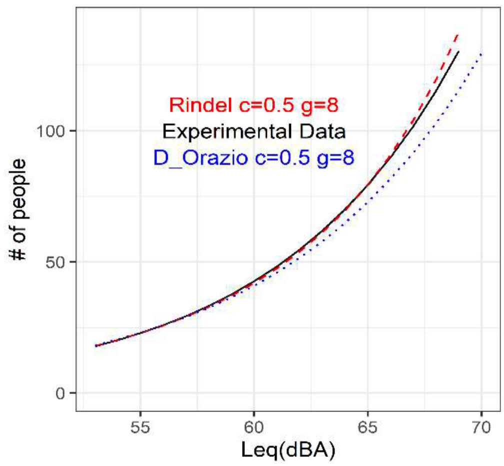

Figure 2. Number of people vs babble noise levels in the CIRCOOP canteen: regression lines from experimental data and from Rindel [1] and D'Orazio et al. [4,5] models with c = 0.5 and g =8.

7. ACKNOWLEDGMENTS

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