Modelling the Group Size for Prediction of the Noise Level in Eating Establishments

David Svensson
Lloyd's Register Consulting, Strandvejen 104A, 2900 Hellerup, Denmark.

Cheol-Ho Jeong & Jonas Brunskog
Acoustic Technology, Technical University of Denmark, Ørsteds Plads, Building 352, 2800 Kgs. Lyngby, Denmark.

Summary
This paper is concerned with prediction of the noise level in large eating establishments. As part of a recent study of the subjective concept of acoustic comfort in eating establishments, an attempt was made at expanding the prediction model for the ambient noise level in eating establishments proposed by Rindel, by inserting a model for the group size parameter. In this project, the noise level and impulse response was measured in five different eating establishments in order to compute several different objective acoustic parameters for each room. The group size parameter was investigated in two different ways; as a single-number average parameter for each eating establishment and as a time-varying parameter. A linear regression analysis using several different objective parameters, including room dimensions and the acoustic room parameters from the IR measurements, resulted in models for both types of group size parameter. In the end, a prediction model for the average group size based on the average number of people, the ceiling height and the definition (D_{50}) as variables was developed to expand Rindel's model for the noise level in eating establishments.

PACS no. 43.50.Jh, 43.55.Br

1. Introduction

Acoustic conditions of rooms are commonly connected to theatres, music venues and other environments specialized for performance and musical use. But for other spaces, be that public or private, the advantages of acoustical treatment is often underrated. The understanding of the need for proper acoustical considerations in professional environments, such as large open-plan offices in big companies, is already booming. But slowly, the general public is opening their eyes to the importance of proper acoustic characteristics in spaces meant for enjoyment, such as restaurants and other eating establishments (EEs). A recent article in the Los Angeles Times [1] focuses on the high noise levels in many EEs, while the result of a recent survey regarding customer complaints from restaurants showed that noise had become the second largest area of complaints behind lousy service. This newly found public focus on acoustics in eating establishments has even resulted in popular restaurant-rating websites listing noise level atop their ratings. Rindel [2] suggested a model for predicting the average A-weighted sound pressure level in a room with multiple simultaneous speakers, taking the Lombard effect [3] into account and defining the parameter *group size*, a measure of the number of people pr. person talking – as the main uncertainty of the model. Rindel's model predicts a 6dB reduction of the noise level, when doubling the equivalent absorption area, which is different from a steady sound source. In this study, an attempt is made to expand Rindel's model by including a simple equation that determines the group size from a thorough assessment of the correlation between different simple objective parameters such as reverberation time, speech transmission index and noise level. In addition to these traditional measures, other objective parameters are studied in order to investigate whether there are better descriptors, which relate the group size to the acoustical characteristics or the room. This study is an extension of the work done in [4], where the acoustic comfort in EEs was investigated.

2. Method

Objective measurements were conducted in five different EEs, all considered large rooms with volumes greater than V = 1700 m3 and a minimum seating capacity of Ncap = 247. Table I presents the volume, V, ceiling height, h, floor area, S, reverberation time, T_{30}, and seating capacity, N_{cap}, for each eating establishment.

Table I - Room parameters for the five EEs.

	V *[m³]*	*h* *[m]*	*S* *[m²]*	*T₃₀* *[s]*	*N_cap*
DTU101	2500	2.98	780	1.05	294
DTU342	2420	5.91	600	1.08	247
DTU358	1800	3.63	560	1.06	332
KFDOWN	1715	2.88	600	0.57	377
KFURUP	2270	4.31	530	1.05	408

2.1 Impulse response measurements

The impulse response (IR) measurements were carried out in accordance with the precision method described in ISO 3382-2 [4], using an omnidirectional loudspeaker as the sound source and omnidirectional microphones (B&K Type 4192) as receivers. The DIRAC room acoustics software (B&K Type 7841) was used for forming decay record of level, following the integrated impulse response method. Calibration of the microphones and recording system was done using a sound level calibrator (B&K Type 4230). As required by [6], two source positions and six microphone positions were used, thus giving 12 independent source-receiver positions. All microphone positions were more than 2m apart while at least 1m in distance from any reflecting surface, and positioned 1.30m above the floor.

2.2 Sound level measurements

The level of the noise during the lunch-hour in the different EEs was measured on seven different occasions, with two of the rooms measured twice (DTU101 and DTU342). A multichannel hard disk recorder (Sound Devices 744T) and four omnidirectional microphones (B&K Type 4192), pre-amplified with a conditioning amplifier (B&K Nexus Type 2692) were used for recording the sound. Calibration of the microphones was done before and after each measurement using a sound level calibrator (B&K Type 4230). The sound pressure level was measured at four different positions for each measurement, with the microphones suspended 0.40 cm from the ceiling.

3. Results

3.1 Impulse response measurements

The mean results from the IR measurements in each of the five rooms are presented in Table II, with the standard deviations noted in subscript. The Early Decay Time (EDT) ranges between 0.55s and 0.94s, while the reverberation time (T_{30}) ranges from 0.60s to 1.08s. The Clarity (C_{80}) goes from 3.8dB to 8.1dB, while the Definition (D_{50}) is 0.53 at the lowest and 0.74 at the highest. The Speech Transmission Index (STI), globally for the EEs, ranges from 0.62 to 0.74 [6].

Table II - Objective parameters from the IR measurements in the five eating establishments expressed as single value averages over the 500-2000Hz range. Subscript values are standard deviations.

	DTU 101	DTU 342	DTU 358	KF DOWN	KFUR UP
EDT [s]	$0.73_{0.25}$	$0.94_{0.15}$	$0.87_{0.09}$	$0.55_{0.08}$	$0.82_{0.12}$
T_{30} [s]	$1.07_{0.05}$	$1.08_{0.03}$	$1.03_{0.10}$	$0.60_{0.03}$	$1.04_{0.03}$
C_{80}[dB]	$7.7_{3.3}$	$3.8_{2.4}$	$5.1_{1.7}$	$8.1_{4.6}$	$5.9_{2.2}$
D_{50}	$0.74_{0.15}$	$0.53_{0.14}$	$0.62_{0.09}$	$0.67_{0.26}$	$0.64_{0.13}$
STI	$0.70_{0.08}$	$0.62_{0.05}$	$0.66_{0.03}$	$0.74_{0.05}$	$0.67_{0.05}$

3.2 Sound level measurements

The equivalent A-weighted sound pressure level, L_{Aeq} [dB(A)], was calculated in 15-minute intervals for the two-hour measurements and averaged over the four positions for each of the seven measurements. During the measurements, the number of people present in the EEs was counted every 15th minute in order to be able to compare the occupancy with the sound level. Figure 1 presents the number of people (blue/solid) and the measured sound pressure level (green/dashed) in the seven different measurements. Generally, the sound pressure level increases immediately with the occupancy of the EEs. When the number of people starts to decrease, there seems to be latency in the decrease of the sound pressure level. This could be explained by extra noise when people are beginning to leave, cleaning out tables, etc. This could be caused by people for some reason being slow to lower their voices after having increased their voice level, perhaps due to the Lombard effect. The trend is different for KFDOWN and KFURUP, where the number of people increases rapidly, which is caused by the people entering the room in one burst, coming from an auditoria next door, in contrast to DTU101, DTU342 and DTU 358, where the increase in occupancy happens at a slower pace.

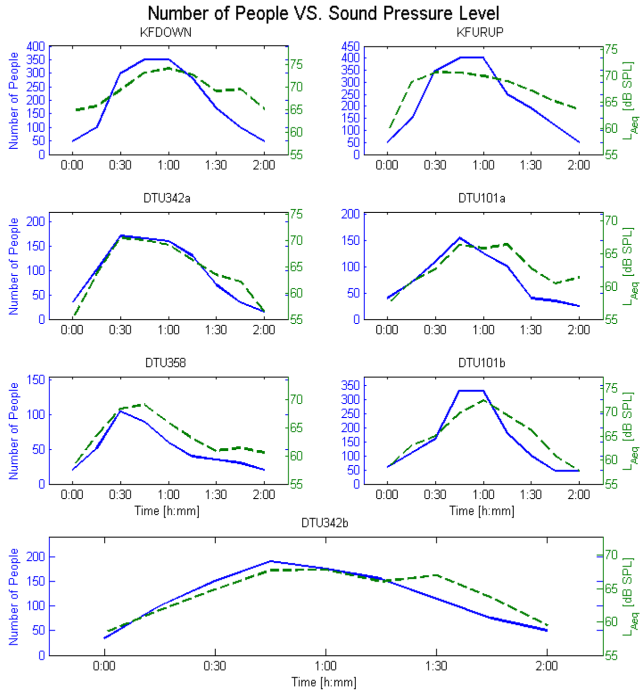

Figure 1 - Number of people (blue/solid lines) and sound pressure level (green/dashed lines) over time in the seven different measurements.

4. Analysis

4.1 Correlation of acoustic parameters

For each of the five eating establishments, the room dimensions were measured. This includes the floor area (S), the ceiling height (h), the room volume (V), the seating capacity (N_{cap}), and seating distribution (dist). For the rooms with different ceiling heights, the highest point in the room was used. From the unoccupied impulse response measurements, the early decay time (EDT), the reverberation time (T_{30}), the centre time (TS), the clarity (C_{80}), the definition (D_{50}), the speech transmission index (STI) and the room acoustical speech transmission index (RASTI) were calculated. The Pearson correlation coefficients between all these objective parameters, acoustic and dimensional were computed, even though the small sample size skews the test of the significance, since it requires a quite high correlation coefficient in order to be statistically significant at the 5% level. The results show a high degree of correlation between the room acoustic energy parameters C_{80}, D_{50} and TS, as expected, with correlation coefficients near unity and significance at the 1% level. Likewise, the STI and RASTI have close to perfect correlation, meaning that including both parameters in further analysis would be redundant. The intelligibility parameters are also highly correlated with the energy parameters, especially the clarity, to which the correlation is significant at the 0.1% level, but also TS (negative correlation, significant at the 1% level) and the definition, to a certain extent. The reverberation time measures, EDT and T_{30}, are quite correlated, though not at a statistically significant level. Actually, T_{30} is not significantly correlated to any of the other measures, at least not with a sample size as small as this. EDT, on the other hand, is highly correlated to all of the other objective acoustic parameters, and significant at the 1% level, though negatively correlated with the clarity, definition and intelligibility, while positively correlated with the centre time. The same pattern is true for the ceiling height, which has a high correlation with the EDT, though not significantly, but is correlated with the energy and intelligibility parameters at the 1% significance level. No significant correlation at the 1% level or lower exists between the room dimension parameters. The floor area, though, is negatively correlated with the ceiling height and the seating distribution at the 5% level, even though h is almost totally uncorrelated to dist.

4.2 Expanding Rindel's model

As mentioned, Rindel has developed a prediction model for the A-weighted ambient sound pressure level in rooms with many simultaneous speakers. In this case eating establishments:

$$L_{N,A} = 93 - 20\log\left(\frac{A \cdot g}{N}\right) \quad [dB] \qquad (1)$$

with the equation for the equivalent absorption area, A, calculated from the room volume, V, the measured reverberation time, T_{30}, and the number of people, N, and using Rindels suggested value for absorption pr. person, A_p=0.5. The equivalent absorption area can be computed as follows.

$$A = \frac{0.16 \cdot V}{T_{30}} + A_p \cdot N \quad [m^2] \qquad (2)$$

4.2.1 Calculating the group size

By rearranging Rindel's model, an equation for calculating the group size, g, from a measured sound level, calculated absorption area and total number of people in the room, can be obtained.

$$g = \frac{N}{A} 10^{\frac{93 - L_{N,A}}{20}} \qquad (3)$$

Using the above equation and the measured A-weighted equivalent sound pressure level from the seven measurements, the counted number of people, the reverberation time and the calculated absorption area, the group size was calculated in two different ways. One was calculated as an average for each room, using the average number of people, N_{avg}, and the average sound pressure level, $L_{Aeq,avg}$. The other was calculated using the time-specific number of people, N_t, and corresponding time-specific sound pressure level, $L_{Aeq,t}$. The time range for the group size calculation was restricted to the four 15-minute time intervals within the official lunch-hour, starting at the 30-minute mark of the measurement and ending at the 90-minute mark. The reason for this restriction is that the occupancy varies significantly over time, during the early and late parts of the measurements. For the same reason, the shortest of the sound level averages, $L_{Aeq,45}$, together with a time-centred average of the occupancy, was used to calculate the average group size values. Since no individual time data for the subjects was collected in KFDOWN and KFURUP, only the average group size was calculated in these cases.
Figure 2 shows the calculated group size for each of the eating establishments. The full lines represent the time dependent group size values, while the dashed lines represent the average group sizes for each room. From the figure, it can be seen that the time-dependent group size is generally decreasing over time in the busy period of the measurements. This could be due to the Lombard effect, as the number of people and the noise level increased during this period of time. And even when the occupancy stops increasing, the noise level keeps increasing, probably due to the Lombard effect. The higher noise level results in lower group size values. The average group size values for the eating establishments range between 8.5 in KFURUP and 4.1 in DTU358.

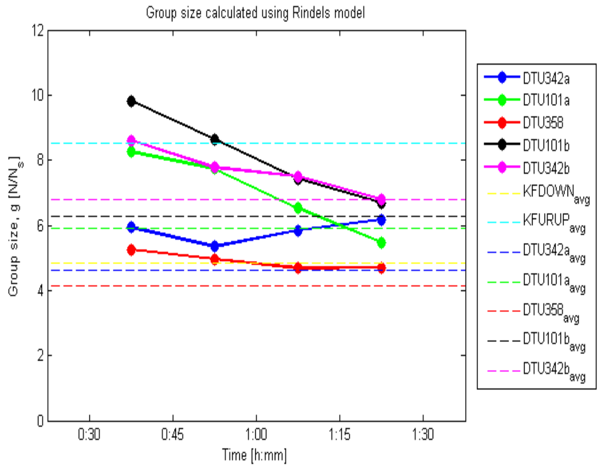

Figure 2 - Estimated group size, g, calculated using Rindels model. Full lines represents the time dependant group size. The dashed lines represent the group size from average L_Aeq.

4.2.2 Regression models

The purpose of this analysis is to find a model for estimating the average group size for an eating establishment, using only simple objective parameters. A linear regression for the average group size was performed on 13 different objective parameters. In addition, the logarithm of those parameters as well as the square of the parameters were used in the regression analysis, yielding a total of 39 different parameters. In order to find the best combination of parameters for the regression, all combinations of the parameters were tried, starting with combinations of two different parameters at a time, then combinations of three parameters and so on, until a combination of the parameters gave a satisfactory result.

Table III shows the best models from the linear regression for the average group size for 2, 3 and 4 variables. The best model using two variables is comprised of the centre time, TS, and the logarithm of the ceiling height as variables with R^2_{adj}=0.75. The best 3-variable model uses the average number of people, the logarithm of the definition and the logarithm of the ceiling height as variables, and the goodness of fit for the model is $R^2_{adj} = 0.79$. Finally, a model with 4 variables is computed. The variables are STI, $\log(N_{avg})$, $\log(D_{50})$ and N^2_{avg}, with R^2_{adj}=0.98. In this case, with a small sample size of n=7, the jump in goodness of fit going from 3 to 4 variables seems indicate over fitting, since the model becomes almost perfect.

Table III – Best combination of parameters for linear combinations in model for the average group size, with the R^2 and R^2_{adj}.

$N_{parameters}$	R^2	R^2_{adj}	*Constant term,* c_0	*Regression coefficients*	*parameters*
2	0.7498	0.7474	3.1815	-0.4116 43.4603	TS $log(h)$
3	0.7895	0.7875	-1.4035	0.0080 39.1618 23.4854	N_{avg} $\log(D_{50})$ $log(h)$
4	0.9800	0.9798	-355.7282	167.7449 245.7527 -329.8917 -0.0021	STI $log(N_{avg})$ $log(D_{50})$ N_{avg}^2

Table IV – Best combination of parameters for linear combinations in model for the time dependent group size, with the R^2 and R^2_{adj}.

$N_{parameters}$	R^2	R^2_{adj}	*Constant term,* c_0	*Regression coefficients*	*parameters*
2	0.5672	0.5656	-8.86	4.167 6.222	$\log(N_{avg})$ T_{30}^2
3	0.6677	0.6659	-19.91	0.016 0.183 -0.0003	N_{avg} N_{cap} N_{cap}^2
4	0.7215	0.7195	-205.3	-259.9 -191.6 302.4 -0.003	D_{50} STI $log(N_{avg})$ N_{avg}^2

Another regression model is computed, this time for the time-dependent group size. Again, 2-4 variables were used, yielding better goodness of fit every time the number of variables increased. The best models for the different number of variables are listed in Table IV. The best model was with the following 4 variables: D_{50}, STI, $\log(N_{avg})$ and N_{avg}^2. The model had a goodness of fit of $R^2_{adj} = 0.7195$), and the equation for the time-dependent group size is:

$$g = -205.3 - 259.9 \cdot D_{50} - 191.6 \cdot \mathrm{STI} + 302.4 \cdot \log(N_{avg}) - 0.003 \cdot N_{avg}^2 \quad (4)$$

The model for the time-dependent group size is not quite as good as the model for the average group size, even though 4 variables were used for the regression. It still makes good sense though, that the group size depends on the number of people in the room.

4.2.3 Expansion of Rindel's model

With two different models for the group size computed, a choice of which of the equations to include in Rindel's model for the ambient noise level has to be made. The model for the average group size is the simplest, depending on three variables only. It also has the highest R^2 value, even with fewer variables. This could also be because of the small sample size. In reality, the group size is unlikely to be a constant value for an entire eating establishment, since it is highly dependent on the number of people, the occupancy would have to be constant, which often will not be the case. Besides these arguments, the assumptions of Rindel's model should also be taken into account. The model was developed with no mention of fluctuations in the occupancy of the eating establishments, and using noise levels averaged over long periods of time. Due to these considerations, the optimal model for the group size to be included in Rindel's model must be the model for the average group size. Finally, the model for the average group size can be inserted into Rindel's model for the ambient sound pressure level.

$$L_{A,N} = 93 - 20\log\left(\frac{A \cdot g_{avg}}{N}\right) \;\Leftrightarrow$$

$$L_{A,N} = 93 - 20\log\left(\frac{A}{N}\right) - 20\log\left(g_{avg}\right) \;\Leftrightarrow$$

$$L_{A,N} = 93 - 20\log\left(\frac{A}{N}\right) - 20\log\left[-1.40 + 0.008N_{avg} + 39.2\log(D_{50}) + 23.5\log(h)\right] \quad (5)$$

With this equation, the ambient sound pressure level in a room with multiple simultaneous speakers can be predicted, from the equivalent absorption area (which depends on the reverberation time and volume of the room), the average number of people during its most occupied state, the ceiling height and the definition, calculated from the impulse response measurements.

5. Conclusions

By rearranging Rindel's model, the group size was calculated in two different ways. One way was an average group size for each of the seven measurements, using the average number of people and the average equivalent continuous A-weighted sound pressure level. The other way, was a time-dependent group size value that changes over time, depending on the time-specific measured sound pressure level and the counted number of people at those certain points in time. The more realistic of the two group size values, is probably the time-dependent group size, as it seems unrealistic that the number of people pr. speaking person does not vary over time, especially in a canteen type eating establishment, where people come and go. Using linear regression, a model for each of the two group size variables was developed. For the average group size, a model with three variables was chosen. The equation for the average group size depends on the average number of people, the logarithm of the Definition and the logarithm of the ceiling height with R^2_{adj}=0.79. For the time-dependent group size, a model with 4 variables was chosen, depending on the Definition, the speech transmission index and the logarithm and squared value of the average number of people with R^2_{adj} =0.72. Even despite the above reasoning for the time-dependent group size as the most realistic version, the average group size was chosen to be included in the expansion of Rindel's model, because of the better match with the underlying assumptions for the model. Insertion in the model yielded the new version of the predictive model for the ambient sound pressure level in an eating establishment.

The main goal of this study was to expand Rindel's model for the ambient sound pressure level in an eating establishment was accomplished. Rindel's model was successfully expanded by modelling the average group size for an eating establishment, from different objective parameters, such as number of people, definition and ceiling height. The main uncertainty of Rindel's model, has been replaced by a linear combination of the simple objective parameters from the model for the average group size.

References

[1] Tiffany Hsu: Noisy restaurants: Taking the din out of dinner. Los Angeles Times (2012).
http://articles.latimes.com/2012/jun/08/business/la-fi-restaurant-noise-20120504

[2] Jens Holger Rindel: Verbal communication and noise in eating establishments. Applied Acoustics 71, p. 1156-1161. 2012.

[3] H. Lazarus: Prediction of Verbal Communicartion in Noise – A Review: Part 1. Applioed Acoustics 19, p. 439-464. 1986

[4] Svensson, Jeong & Brunskog: Acoustic Comfort in Eating Establishments. Forum Acusticum. 2014.

[5] ISO 3382-2: Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms. Dansk Standard, 2. Edition. 2008.

[6] ISO 60268-16: Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index. Dansk Standard, 2. Edition. 2003.