ACOUSTIC DIRECTIONS

WHEN SOUND MATTERS

PREDICTING PATRON NOISE LEVELS IN RESTAURANTS AND BARS

AN EXTENSION TO J.H RINDEL’S METHOD

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Introduction

- J.H. Rindel proposed a method to predict the increase in noise level and required vocal effort in social situations.
- Based on the involuntary response of human talkers when speaking in the presence of noise known as the Lombard effect.
- Rindel states that the Lombard effect:
    - starts at an ambient noise level around 45 dBA, and
    - a speech level of 55 dBA.
- Assuming a linear relationship for noise levels above 45 dB, the speech level is:

$$L_{SA\ 1m} = 55 + C(L_{NA} - 45)$$

C is the Lombard ratio in dB/dB

$L_{SA\ 1m}$ is the A-weighted talker level at 1 m on axis.

- Rindel recommends a Lombard ratio of 0.5.
- Equates to 0.5 dB increase in talker level per 1 dB increase in the ambient level.

Statistical Method - Equations

- Based on a Lombard ratio of 0.5, Rindel develops the following equation.

$$L_{NA} = 93 + 20\log(N_s/A)$$

A is the average absorption area (S.alpha) N_s is the number of people speaking

- 6 dB increase in sound level for every doubling of the number of people talking simultaneously
- Contrasts with the usually accepted rule of 3 dB increase per doubling of talkers
- 6 dB decrease in sound level for every doubling of the sound absorption area (A)
- Unpacking the equation with DI = 3 and Power to Intensity conversion of -6 dB yields:

$$L_{NA} = 1/(1 - C)\{69 - 45C + 10\log(N_s/A)\}$$

C is Lombard ratio

Statistical Method - Weaknesses

$$L_{NA} = 93 + 20\log(N_s/A)$$

- Does not include contribution of talkers' direct field and early-arriving reflections to the overall level.

- Does not include the effect of talker directivity that varies with frequency.

- The Lombard ratio is not explicitly stated in the calculation –
  - may be helpful to allow the ratio to be input into the model.

- Total absorption term A may underestimate the amount of sound absorption in the space and room constant R may provide a better estimate.

- Breaks down in situations in which the reflected sound field in the space is not constant.

  e.g. when groups of talkers are spaced apart in semi-enclosed areas and hotel beer-gardens.

Simulation Method

- Extension to the method which allows 3D acoustic simulation software to compute the total sound field in a patron area relative to a nominal talker level.
- Simulation method addresses the weaknesses in the statistical method.
- The relationship between talker level and overall noise level is re-formulated:

$$L_{NA\,nom} = L_{SA\,1m} + K$$

where:

$L_{SA\,1m}$ is the nominal talker level at 1 m on axis of a talker

L_{NAnom} is the modelled nominal sound field immersing the talkers

K is the A-weighted difference between nominal talker level at 1m and modelled total sound field, with *N* talkers

- Using K, the relationship between talker level and overall noise level can be re-formulated:

$$L_{NA} = (55 - 45C + K)/(1 - C)$$ and $$L_{N_j} = (55 - 45C + K_j)/(1 - C)$$

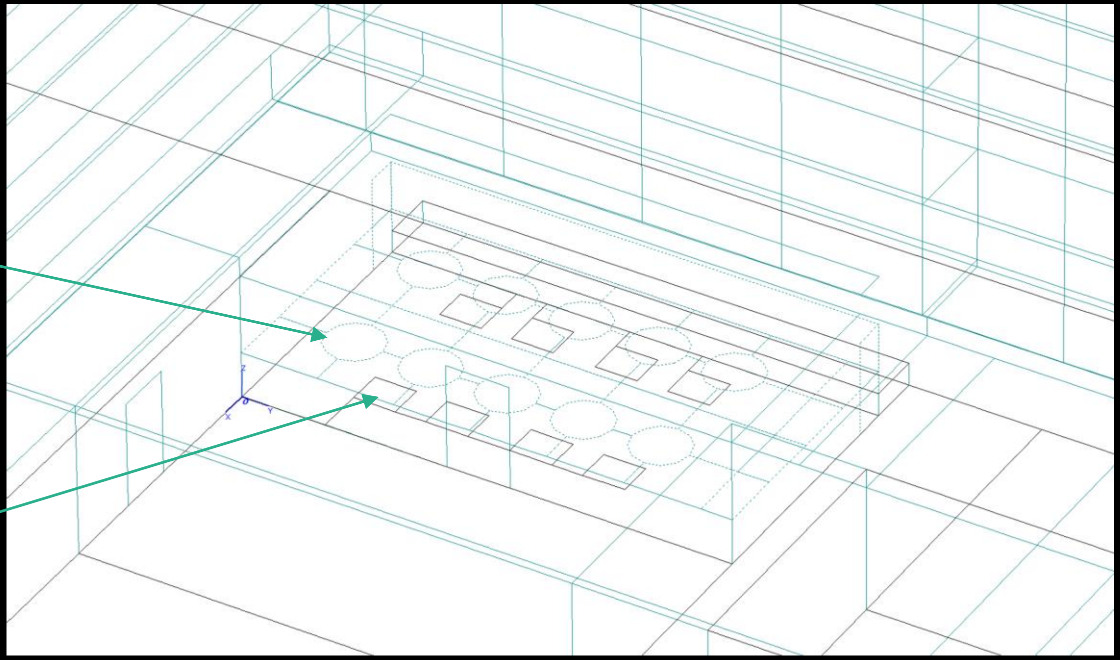
$L_{NAj} = L_{SA\,1mj} + K_j$ where j is the jth octave or one-third octave band

Simulation Method (cont)

- Ensure that the direct field component of the calculation is not dominated by a small distance between talker and the calculation point.
- Create an exclusion zone around each talker for calculations.

exclusion zone

talker



wire-frame model

Hybrid Method

- The hybrid method estimates the room-gain parameter *K* in $L_{NA\,nom} = L_{SA\,1m} + K$
- Combines the statistical reverberant level with an estimate of the average direct field permeating the patron area.
- Not as accurate as the simulation method but does include several factors that the statistical method ignores.
- The method calculates levels in octave-wide frequency bands, with the spectrum of a raised voice being initially used.
- As before, using *K*, the relationship between talker level and overall noise level is:
- $L_{NAj} = L_{SA\,1mj} + K(j)$ where *j* is the *j*th octave

$$L_{NA} = (55 - 45C + K)/(1 - C)$$

- Reverberant component: $L_{p\,Reverb} = L_{Snom\,1m} + 11 - DI + 10\log\left(\frac{4}{R}\right) + 10\log N_s$
- Talker directivity:

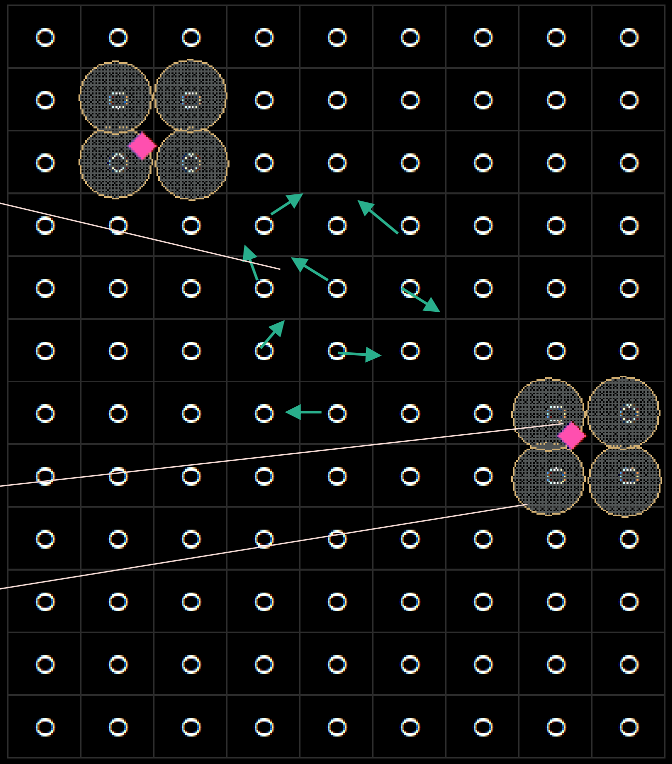
Frequency	125	250	500	1000	2000	4000	8000
DI dB	0.6	2.6	1.6	1.9	4.4	4.4	5.5

Hybrid Method (cont)

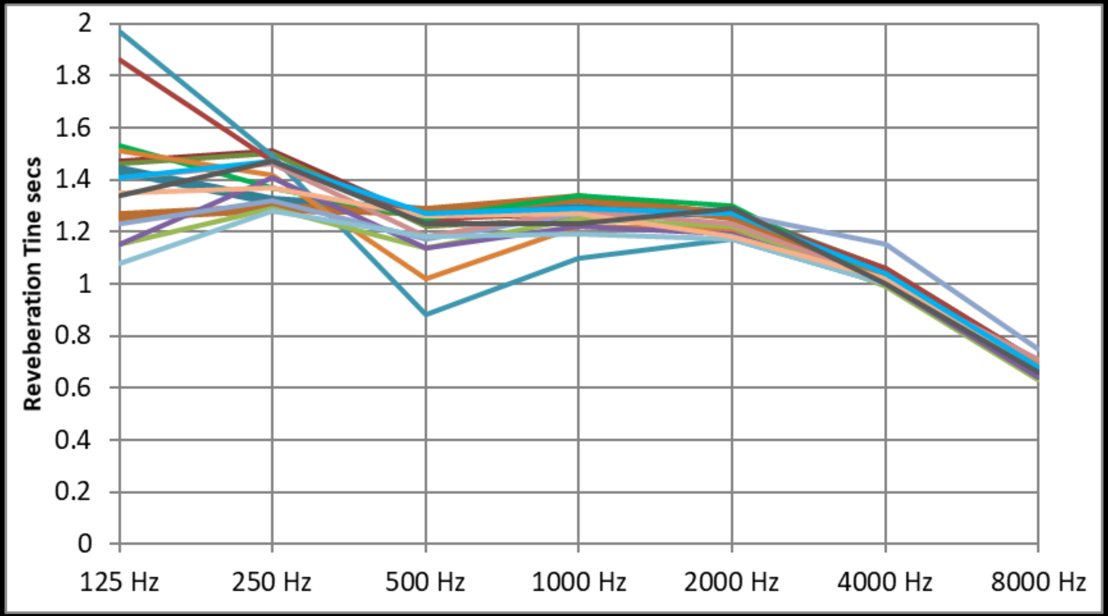
- Direct field component:
  - N_s talkers assumed to be evenly distributed over the venue floor plan.
  - Talkers assumed to face in every direction, with an average directional loss over 360 º.

Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Average directional loss	-1.2	-1.9	-1.6	-1.8	-3.5	-4.3	-4.9

  - Ten calculation points randomly located in the in the patron area.
  - Minimum distance of 1.2 m between a talker and calculation point.
  - Energy sum of the direct-field level of every talker at each calculation point is computed.
  - Energy average of the ten calculation points is computed to yield the estimate of the total direct field with N_s talkers .

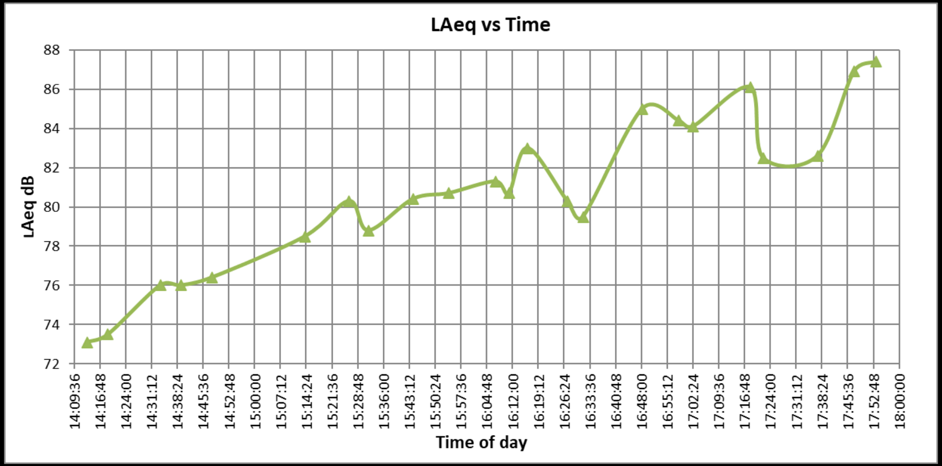


Case Study 1 - Large Bistro

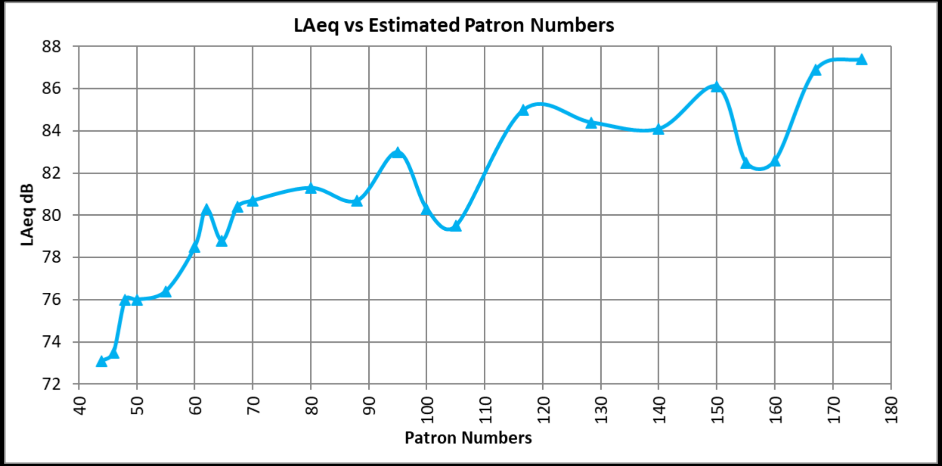


Reverberation times (empty)

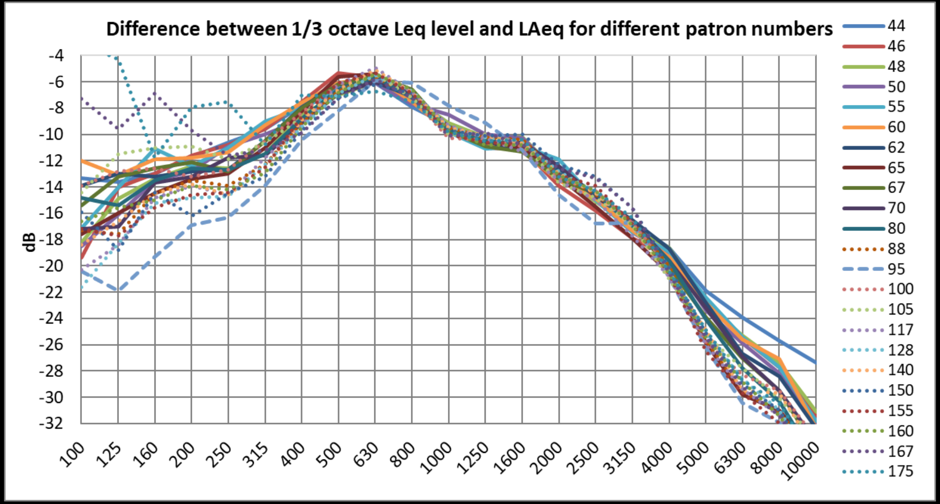
Case Study 1 - Large Bistro: Levels & Spectra



Build-up of level over time

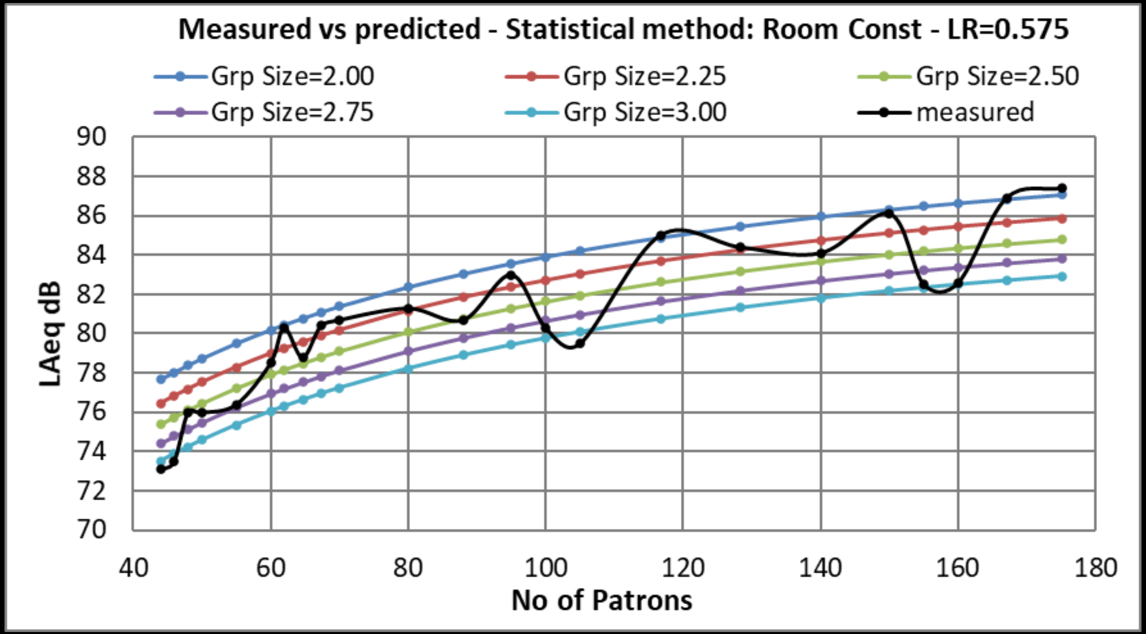


Build-up of level with patron numbers

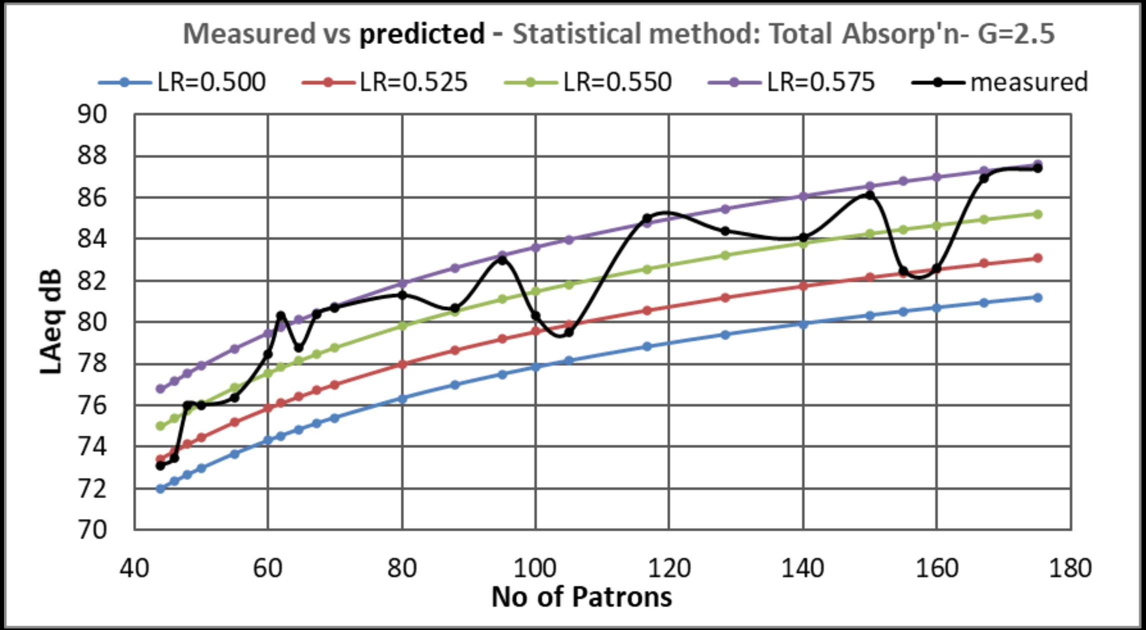


Normalised spectra with patron numbers

Case Study 1 - Predicted Levels: Statistical method



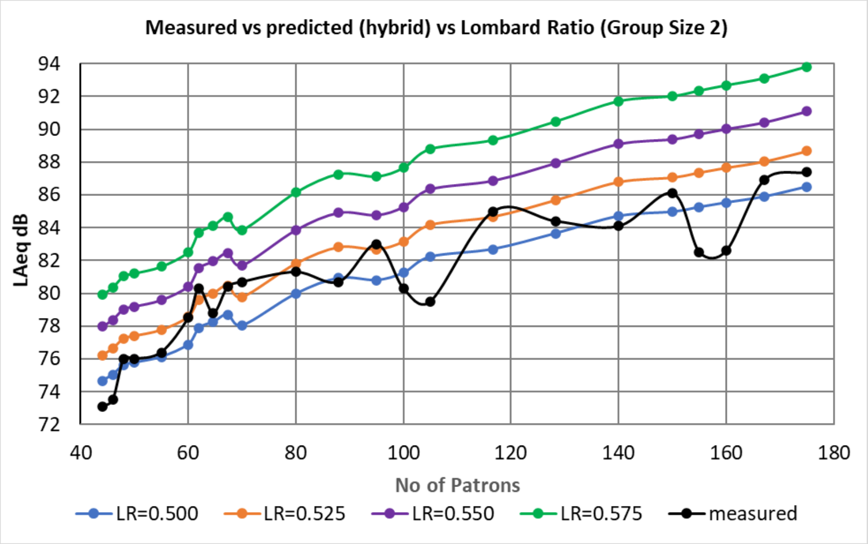
Measured vs predicted with Lombard ratio=0.575 vs group size

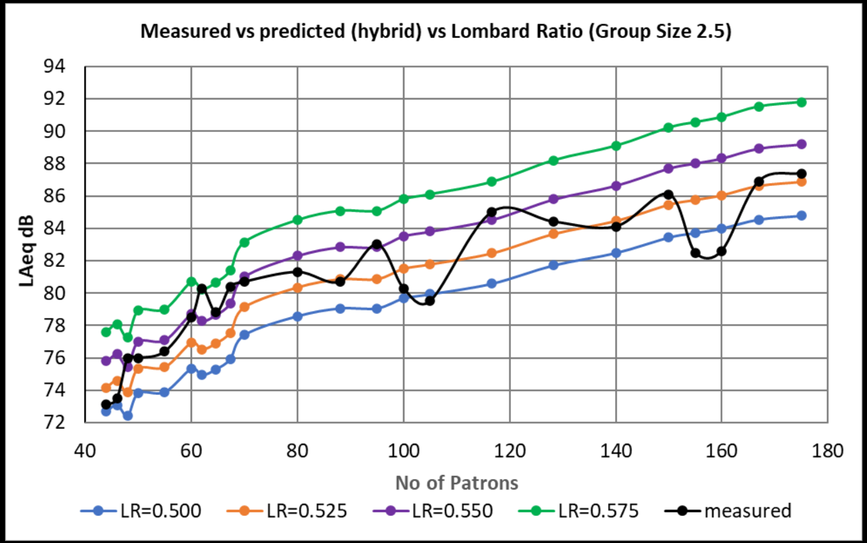


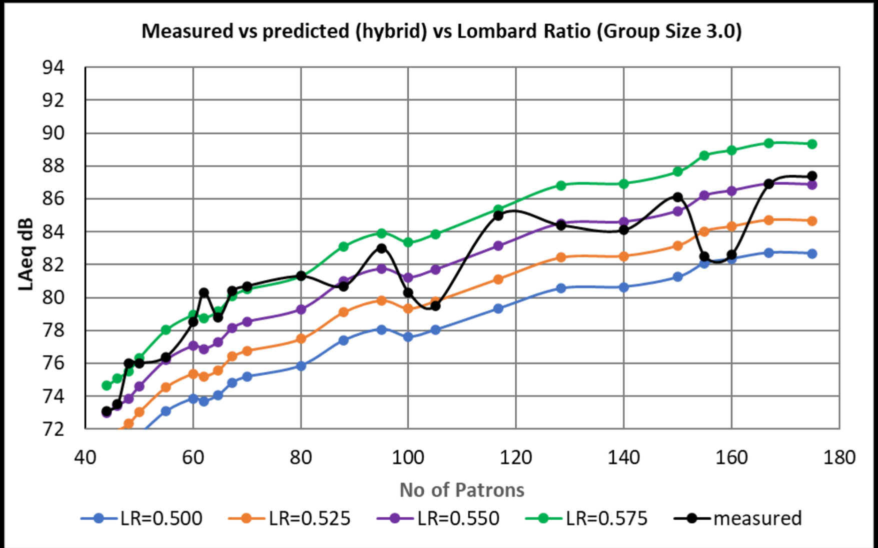
Measured vs predicted with group size =2.5 vs Lombard ratio

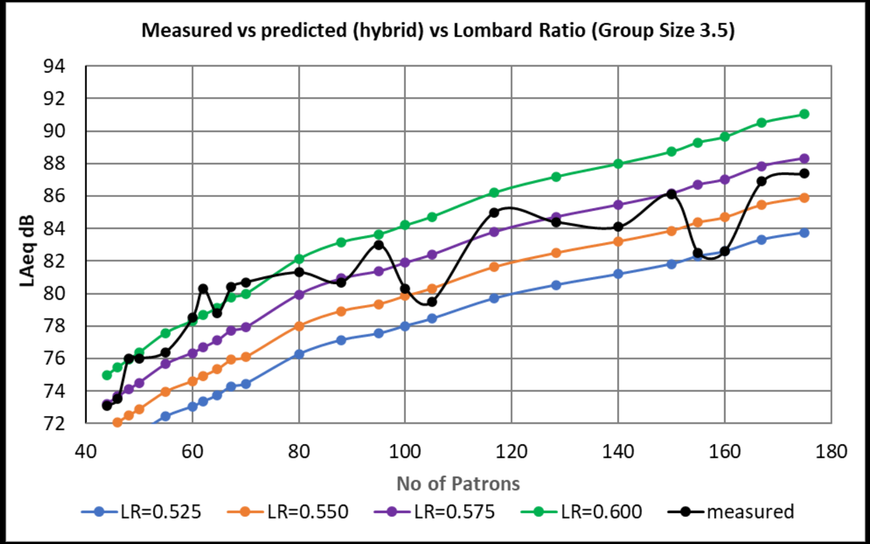
Group Size = number patrons/number talking patrons

Case Study 1 - Predicted Levels – Hybrid Method









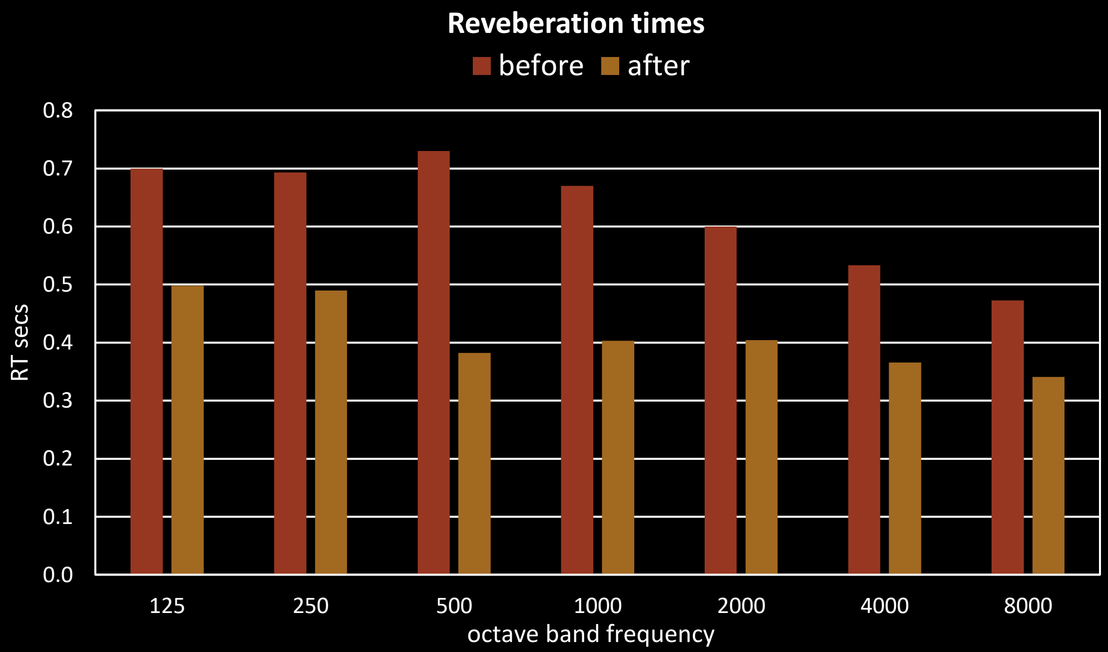
Group size	Lombard ratio giving best match
2	0.5
2.5	0.525
2.75	0.535
3	0.55
3.5	0.575

Measured vs predicted with various group sizes and Lombard ratios

Case Study 2 - Medium-small size restaurant

Fifty patrons in space 8 m x 4.7 m x 3.6 m

acoustic treatment area = 46 m^2



Case Study 2 - Medium-small size restaurant

Scenario	Statistical Method				Hybrid Method	Measured
	Absorption Area (64)		Room Const (94)			
	DI=3	DI=2.6	DI=3	DI=2.6		
G= 2.5 | LR =0.55	87.1	87.9	83.4	84.1	86.2	87.6
G= 2.5 | LR =0.565	88.5	89.3	84.7	85.5	87.6	
G= 3.0 | LR =0.575	87.7	88.5	83.8	84.6	86.7	
G= 3.0 | LR =0.6	90.4	91.2	86.2	87.1	89.3	

Levels before acoustic treatment

Scenario	Statistical Method				Hybrid Method	Measured
	Absorption Area (86)		Room Const (141)			
	DI=3	DI=2.6	DI=3	DI=2.6		
G= 2.5 | LR =0.55	84.3	85.1	79.5	80.3	82.9	82.6
G= 2.5 | LR =0.525	82.2	82.9	77.7	78.4	80.9	
G= 3 | LR =0.55	82.5	83.3	77.8	78.5	81.2	
G= 3.0 | LR =0.575	84.7	85.5	79.7	80.5	83.4	

Levels after acoustic treatment (46 m^2)

Conclusions

a) When using the statistical method in a large venue such as the bistro,predictions using either the total absorption area or the room constant can be made to fit the measured levels using small changes in the Lombard ratio or larger changes to the group size. It can be argued that an increase in Lombard ratio is required to compensate for the lack of the direct field component.

b) In the smaller restaurant situation, the statistical method using the room constant underpredicts the measured levels, due to the absence of the direct field component.

c) With the hybrid method, the contribution of the direct field to the calculation allows a slightly lower Lombard ratio and/or larger group size. As the hybrid method can account for many more acoustical factors, it appears to be more accurate.

d) With the hybrid method and a group size of 3.5 or less, it was not possible to obtain a good match between measured and predicted levels using Lombard ratio of 0.6 or greater. The predicted levels are very sensitive to small changes in Lombard ratio (e.g, 0.025). In contrast, changes in group size of 20% are required to substantially affect predicted levels.

e) The statistical method using the total absorption area can be used to provide a quick estimate of the noise levels.

f) The most accurate prediction method is the simulation method, and it is the only method that can accommodate a sparse distribution of patrons or spatially-varying sound absorption in a room.

THANK YOU