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Modelling the effects of spectator distribution and capacity on speech intelligibility in a typical soccer stadium

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ABSTRACT

Public address system performance is frequently simulated using acoustic computer models to assess coverage and predict potential intelligibility. When the typical 0.5 speech transmission index (STI) criterion cannot be achieved in voice alarm systems under unoccupied conditions, justification must be made to allow contractual obligations to be met. An expected increase in STI with occupancy can be used as an explanation, though the associated increase in noise levels must also be considered. This work demonstrates typical changes in STI for different spectator distribution in a calibrated stadium computer model. The effects of ambient noise are also considered. The results can be used to approximate expected changes in STI caused by different spectator occupation rates.

1 Introduction

The performance of public address and voice alarm (PAVA) systems are validated with the use of measurements and acoustic computer models. However, these are most-often conducted under unoccupied conditions. Spectators can provide a significant amount of crowd noise alongside additional absorption altering reverberation times, both affecting intelligibility in opposing ways.

During the design of PAVA systems, speech transmission index (STI) values should meet a minimum 0.5 target [1] to ensure adequate intelligibility. For large and/or highly reverberant spaces such as soccer stadiums where it might not be possible to achieve 0.5 STI, justification must be made. The added absorption and consequent increase in intelligibility when the stadium is occupied by spectators can be used as an explanation. Little advice is available for the expected increase in STI due to spectators.

This work presents a case study of a typical soccer stadium, where an acoustic model is utilised to assess the STIPA differences between the unoccupied space and different occupation rates and spectator distribution. Expected crowd noise levels are also included within calculations. Although different methods exist to model spectators, previous work [2] found that using a floor plane spectator implementation, or using the pre-existing faces within the model, provides the least absorption. This technique is therefore used for this work to ensure STI results are not over-estimated.

2 Method

An acoustic model was created in EASE [3], of a real 30,000 capacity soccer stadium, as seen in Fig 1, 2 and 3, using architectural CAD drawings and photographs. The existing employed sound system consists of 60 distributed Community R2 400 Watt loudspeakers [4] delivering 103(+/-3) dB.

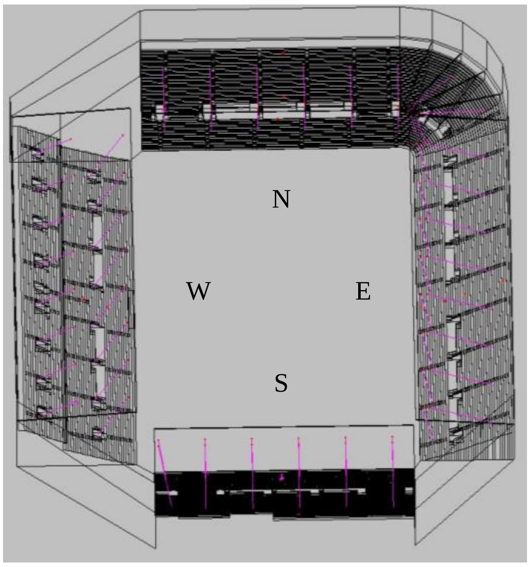

Figure 1. Soccer stadium model 1.

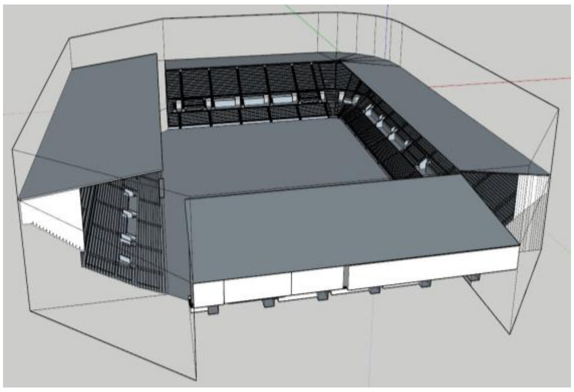

Figure 2. Soccer stadium model 2.

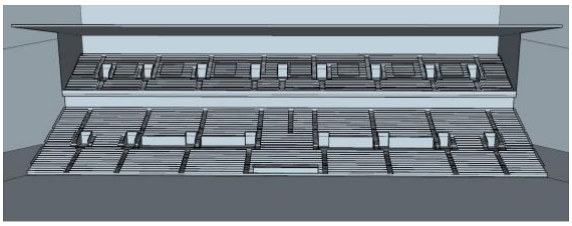

Figure 3. West stand.

T20 measurements were made mid-way along each stand at locations found in Table 1. The average for each stand was compared with average simulated listener positions in the same locations using the AURA module in EASE, to calibrate the model as closely as possible. STIPA measurements were also made at the positions in red font.

North	East	South	West
Row 12	Row 2	Row 20	Row 10
Row 20	Row 12	Row 36	Row 20
Row 36	Row 20		
	Row 36		

Table 2. Measurement positions.

Spectator absorption coefficients were applied to the surface planes used for the plastic seating. This was conducted at full capacity, half capacity (bottom half of each stand) and half capacity (even rows omitted). Absorption coefficient data was derived from measured audiences [5] using the method originally proposed by Bradley [6].

Crowd noise levels were included in the calculation of occupied STIPA results to mimic realistic conditions. Noise levels (Fig 4) were based on a survey of average crowd noise of similar UK soccer stadiums [7]. 3dB was deducted for half capacity, representing half the number of incoherent sources.

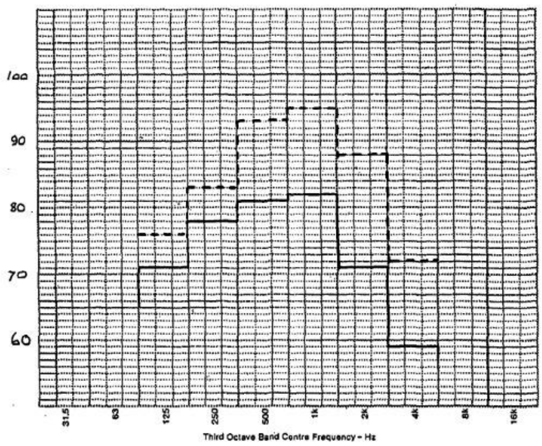

Figure 4. Crowd noise levels [7].

3 Model calibration

The average measured and simulated T20 results for each stand are displayed in Fig 5 and 6. There are some tolerable differences as importantly, material absorption coefficients were kept consistent between stands and STIPA results for each position were very close with differences of 0.01 or 0.02 STI, displayed in Table 2. Despite the differences between measured and predicted T20 results, the little differences between STI values demonstrates how STI is not super sensitive to reverberation times.

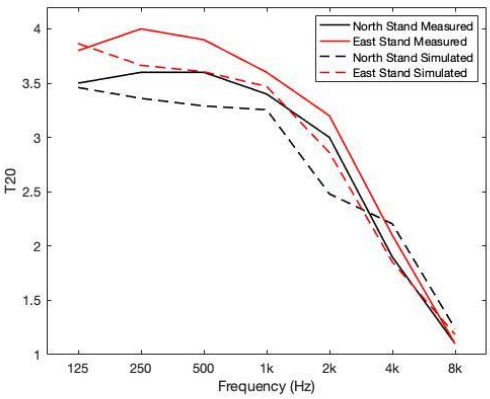

Figure 5. Average measured and simulated T20 results for the North and East stands.

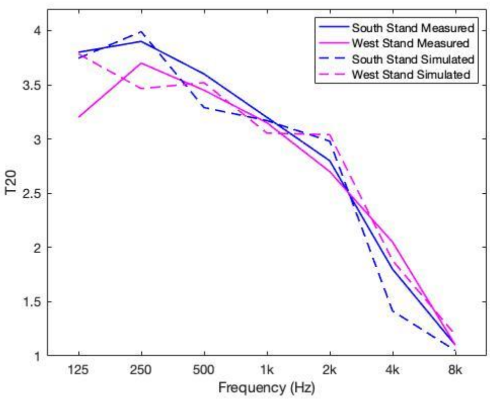

Figure 6. Average measured and simulated T20 results for the South and West stands.

	Measured	Simulated
North (36)	0.50	0.51
East (36)	0.52	0.50
South (36)	0.53	0.51
West (10)	0.54	0.53

Table 2. Measured and simulated STI.

4 Results

Fig 7 shows the averaged T20 values for different spectator distribution for the North stand. As the listener positions are located on rows at the front, middle and back of the stand, differences are expected between positions. This is due to the surrounding spectator absorption. For example, when the lower 50% of the stand is occupied, row 36 at the back of the stand will be further away from spectators compared with row 12.

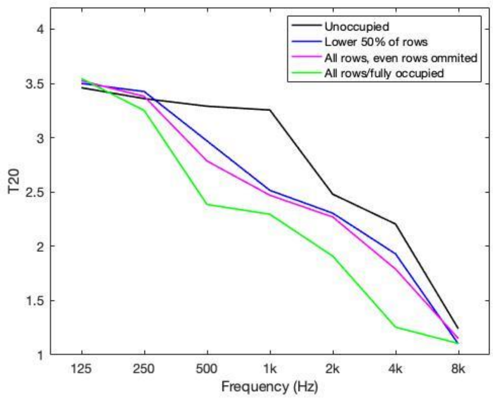

Figure 7. Average T20 results for the North stand.

The STIPA results for each row in each stand are found in Fig 8 to 11. The distribution of spectators affects intelligibility as different STIPA results are observed for the same amount of absorption. For example, row 12 at the front of the North stand (Fig 8) has a higher STIPA result for the front half of the stand occupied compared to spectators evenly distributed. Row 20, in the middle of the North stand, has a higher STIPA result for evenly distributed spectators compared with the front half occupied. This may be because of the reduced absorption behind this position.

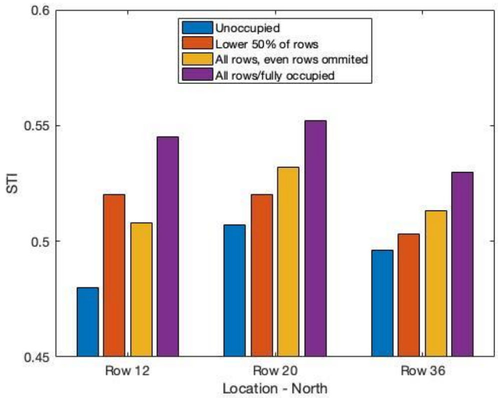

Figure 8. STIPA results for the North stand.

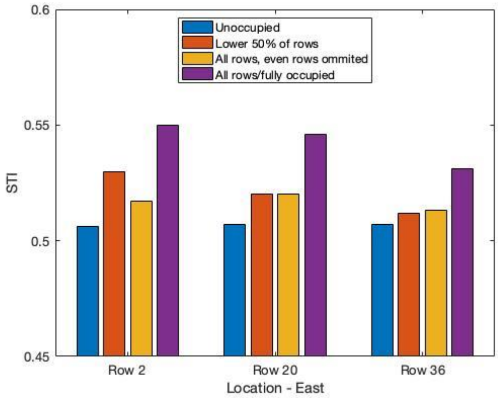

Figure 9. STIPA results for the East stand.

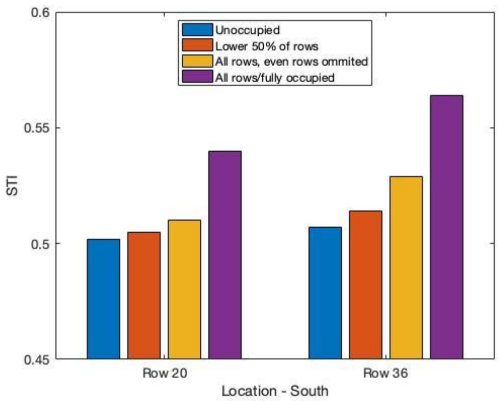

Figure 10. STIPA results for the South stand.

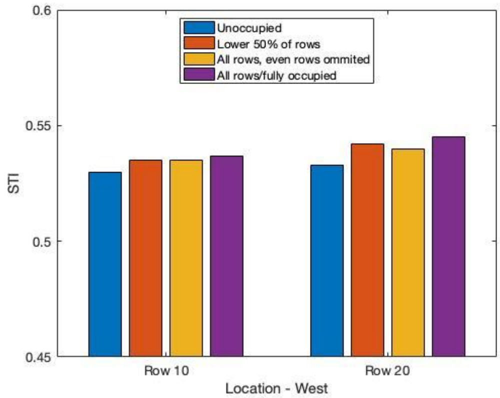

Figure 11. STIPA results for the West stand.

The average STIPA differences between the unoccupied and fully occupied stadium are found in Table 3. This includes the average for each stand which is as high as 0.048 and the total average of 0.035. There is less increase for the West stand as the initial STIPA score is higher. For half capacity, evenly distributed throughout, 0.013 is the average difference in STIPA compared to the unoccupied stadium. Positions outside of the spectator area are, in practice, unlikely to be important for intelligibility. Therefore, 0.018 is the average increase in STIPA for half capacity in the front part of each stand, excluding positions outside of the area.

North	East	South	West	Total
0.0480	0.0357	0.0475	0.0100	0.0350

Table 3. Average STIPA difference between unoccupied and fully occupied.

5 Conclusions

The STIPA differences between spectator distribution in a typical soccer stadium have been presented. Expected crowd noise levels have been included in calculations. The reduction of intelligibility caused by the additional noise is counteracted by the additional absorption from the spectators. Occupants make a significant change to reverberation times but this is not linear. For example, from unoccupied to 50% capacity has a greater impact than from 50% to 100% capacity.

The average increase in STIPA results for an original unoccupied ~0.5 level is approximately 0.035. The limited number of data points may affect results but full mapping of the entire audience area will be explored in future work. It is also observed that higher unoccupied STIPA values will result in less increase when spectators are introduced. It is predicted that for lower STIPA values, there will be a greater increase. As the system used in this case meets the 0.5 STI criterion before occupation, system designs with a lower STI may expect a greater increase after spectators are included. This is highlighted by row 12 in the North stand (Fig 8), the only position with a STIPA result less than 0.5, which increased by the greatest amount after the stand is populated. This also demonstrates how a STIPA result of under 0.5 in an unoccupied stadium can exceed this target when fully occupied, despite the introduction of crowd noise. The placement of the measurement/simulation position is also important in relation to the placement of spectators. Evenly distributed spectators will have less impact compared with a densely packed crowd, if positioned within the area.

References

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