AN INVESTIGATION INTO THE ACOUSTIC ACCURACY OF NOISE MAPS: A GLASGOW CITY CASE STUDY

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1 INTRODUCTION

In 2002 the Environmental Noise Directive (END) 2002/49/EC (2002)[1] was enforced across Europe as a way of informing the public of potential exposure to noise within a particular 'agglomeration'. It is intended to be used in conjunction with existing EU legislation which sets the standards for noise emissions from road, rail, air traffic and industry. The END defines noise mapping in more specific terms as *'the presentation of data on an existing or predicted noise situation in terms of a noise indicator, indicating breaches of any relevant limit value in force, the number of people affected in a certain area, or the number of dwellings exposed to certain values of a noise indicator'.* Since its introduction, organisations such as Scottish Noise Mapping have produced maps to inform the public of the noise levels present within urban areas in Scotland. The noise maps are produced for use at a strategic level and are likely to give an acceptable level of accuracy for these purposes. These maps are based on equivalent continuous sound levels measured over a given time period (L_{eq}), and day, evening and night average sound levels measured over a 24 hour period (L_{den}). Such estimates are believed to be more cost effective than maps based on audio measurements which would have to be carried out over significant periods of time over a large area[2].

As part of the ongoing *Glasgow 3D Sound Map* project, this paper compares actual real world noise measurements taken at both head height (1.5m) and 4m with the estimated noise contours provided in the current round of noise maps produced by the Scottish Government in 2013. Measurements were taken at 20 locations around the city of Glasgow at various times of the day, evening and night. The results from this study shed light on the accuracy of the L_{den} estimates currently used to produce environmental noise maps.

2 BACKGROUND

A noise map is a geographical overlay which indicates estimated sound pressure levels using colour-coding and/or contour lines. As noise is often a transient phenomenon, it is often difficult to predict how noise will be perceived at any given instant[3]. To address this issue, the END requires member states to produce noise maps based on average noise levels for an average weekday in the year using noise mapping software based upon L_{den} and L_{eq} calculations. Noise maps represent average noise levels at a height of 4 meters above ground level, and are taken over a 24-hour period using L_{den} measurements. They are typically broken down into the following categories:

- 0700hrs to 1900hrs (L_{day})
- 1900hrs to 2200hrs ($L_{evening}$)
- 2200hrs to 0700hrs (L_{night})

These calculations are weighted in order to take into account the relative absence of sound sources when compared with daytime noise. This can, in effect, cause masking and thus reduce the perceptual impact of noise during the evening and at night. To account for this phenomenon the measured noise is increased by 5dB(A) and 10dB(A) respectively. The crux of the L_{den} formula lies with the L_{eq} measurements taken at a given location. The equivalent continuous noise level (L_{eq}), is the sound pressure level of a steady sound that has, over a given period of time, the same energy as the fluctuating sound in question. It is measured in dB(A), and 20μPa (the threshold of human hearing) is used as it as a reference. See Equation 1.

$$L_{eq} = 10log_{10}\left(\frac{1}{T_M}\int_{0}^{T_M}\left(\frac{P(t)}{P_0}\right)^2 dt\right)$$

Equation 1 *L_{eq} Formula*

Where:

- L_{eq} is the equivalent continuous linear weighted sound pressure level determined over a measured time interval T_M (seconds)
- $P_{(t)}$ is the instantaneous sound pressure of the sound signal
- P_0 is the reference sound pressure of 20μPa

According to ISO 1996-2: 1987 and the regulations stipulated in the END documentation, using L_{eq} and the noise descriptors outlined previously, L_{den} can be calculated using Equation 2.

$$L_{den} = 10lg\frac{1}{24}\left(12 * 10^{\frac{Lday}{10}} + 4 * 10^{\frac{Levening+5}{10}} + 8 * 10^{\frac{Lnight+10}{10}}\right)$$

Equation 2 *L_{den} Formula*

Where:

- L_{day} is the A-weighted long term average sound level determined over all day periods of a year
- $L_{evening}$ is the A-weighted long term average sound level determined over all evening periods of a year
- L_{night} is the A-weighted long term average sound level determined over all night periods of a year

In accordance with the guidelines produced by the Glasgow Agglomeration Working Group[4], predictions are calculated on the basis of a 10 meter grid at a height of 4m from ground level (± 0.2m). The value of the grid is determined at the centre point although it is important to concede that fluctuations may occur within that grid. The computational method of noise mapping has benefits, where time and cost factors determine the level of detail the map produces. However noise which is generated over a given period of time cannot be broken down into the types of noise prevalent in that area[5]. For example, although one may imagine what type of noise is prevalent in an urban environment, noise maps do not explicitly state if the noise present is from vehicle or human sources therefore datasets from road, railway, airport, and industry are used as a basis for calculating noise figures in the current noise mapping system. The data required for the calculations of noise levels have been determined by consultation with various organisations including Transport Scotland, SEPA, Network Rail, British Airports Authority, Local Authorities, and others. In computer models which implement the formulae outlined above, noise levels are calculated using a series of *'virtual microphones'* or observation points[2]. Within the noise mapping software, a virtual microphone is specified with x, y, and z coordinates and predicts what the noise level would be at a given location under certain circumstances. Each point represents three areas of key information:

1. The noise source i.e. road, rail, industry etc., the surface type, average speed of travelling vehicle (where applicable);

2. The influence of the physical surroundings on noise propagation i.e. buildings, noise barriers and noise absorption from open areas such as grass etc. This information also covers the height of buildings and other topography taken from Geographic Information System (GIS) data which has been acquired for a given agglomeration;

3. The 3D distance and direction of the data points with respect to the noise source.

There are approximately 10,000 observation points every $1km^2$, or approximately 25,900 observation points every square mile[6]. In most cases, these grid points are not evenly distributed. At each location point, the datasets can then be associated with the relative GIS data points in order to produce 2D noise maps.

As previously stated, the END stipulates that noise predictions be calculated at a height of 4m above ground. This is due to the fact that the strategy assumes that residential dwellings are 4m above ground level[7]. In accordance with ANNEX I of the directive, for the purpose of strategic noise mapping In relation to noise exposure in and near buildings, other heights may be chosen but must never be less that 1.5m above the ground. This study looks at measurements both at 4m and head height (1.5m) to ascertain of there is any real difference in each set of measurements as the current noise maps do not take into account of smaller walls and fences which may have an effect on the amount of noise exposure at head height at any particular location.

The aim of this study is to examine real world L_{eq} measurements (and subsequent L_{den} calculations) with those estimated measurements provided by round two of the Scottish Noise Map (www.scottishnoisemapping.org) at given locations. The measurements taken provide a snapshot of noise data over a short period of time and are compared against those produced for the noise maps which represent noise levels averaged over a one year period.

3 METHODOLOGY

In order to comprehensively compare the current noise map estimations within Glasgow City Centre, field measurements were taken at 20 pre-selected locations where the L_{eq} was measured at both 1.5 meters and 4 meters (in accordance with END). The locations were chosen based on the existing noise maps to ensure there was a spread of consolidated L_{eq} contours represented during the study (see figure 1). The locations provided a mixture of quiet spaces, busy roads, industry, business/office, and residential areas. Each measurement was taken at day, evening, and night times to allow for direct comparison with the maps produced by the Scottish Government. The L_{eq} for each location was recorded using Faber Acoustical's SoundMeter application for the iPhone and due the frequency response limitations of the in-built microphone on Apple devices, MicW's i436 calibrated omni-directional microphone (which complies with IEC61672 Class 2 Sound Level Meter standard for instrumentation quality measurements) was used instead. The SoundMeter app delivers high accuracy readings for general purpose A-weighted noise measurements[8]. The duration of each measurement was approximately 15 minutes per height and manually recorded on a spreadsheet at the time of measurement. It should be noted that two measurements were taken during the day (morning and afternoon) which were then logarithmically averaged to create an L_{day} measurement. Capturing two measurements during the day allowed for a greater accuracy in the exposed noise levels throughout the daytime period of 12 hours.

The L_{den} for each location was then derived from the formula outlined in section 2 using Mathworks Matlab software where a pre-written script was used to collate the data and produce a spreadsheet for analysis. The L_{night} measurements were also extracted in order to further provide comparisons with the current noise maps as they present noise into a consolidated day, evening and night estimation as well as, nighttime exposure on its own.

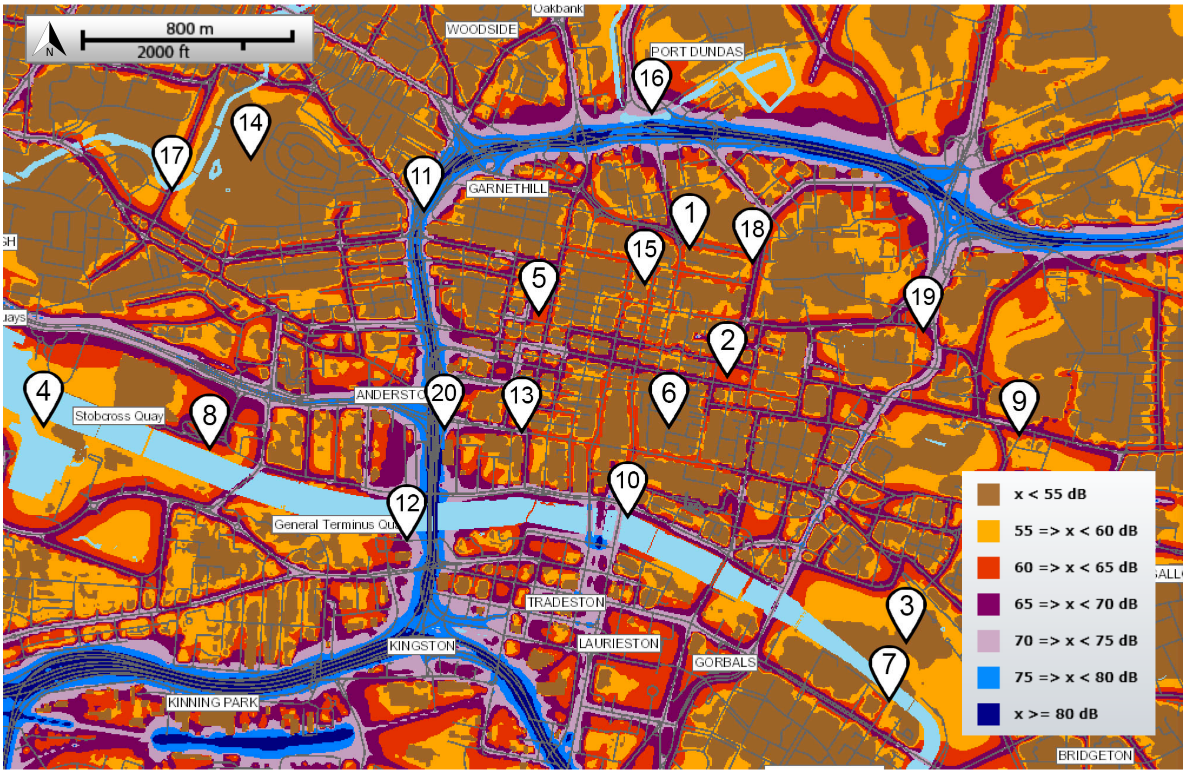

Figure 1 *Map of measurement location points within Glasgow City Centre – colour bars represent the predicted noise contours*

4 RESULTS

The results show a relatively large disparity between estimated noise levels produced for the noise maps and the measurements taken for this study. For L_{den} rmeasurements, only 40% of readings at 1.5m and 45% of readings at 4m lay within the corresponding calculated noise map contour. Examination of the readings for L_{night} shows only 30% of measurements at 1.5m and 35% of readings at 4m lay within the calculated noise contour. The greatest difference between measurement and map was -18dB(A) which was taken at location 16 during the night and the smallest difference was +0.1 dB(A) take at location 4 as part of the consolidated day, evening, and night average. Location 16 for example, was located next to a major road and close to residential and industrial buildings but was unusually quiet when the measurement was taken. Location 4 was near quiet, pedestrian space where the level of noise was fairly consistent for each of the measurements taken that day.

An overview of each location point and its respective measurements is given in table 1 below.

Point No.	Lden (Head)	Noise Contour	Within Limit?	Lnight (Head)	Noise Contour	Within Limit?
1	67.7	60-65	NO	48.1	50-55	NO
2	63.6	60-65	YES	46.7	50-55	NO
3	68	55-60	NO	60.2	<50	NO
4	59	55-60	YES	35.7	<50	YES
5	60.1	65-70	NO	44.6	55-60	NO
6	61.8	<55	NO	43.3	<50	YES
7	70.7	55-60	NO	64.6	50-55	NO
8	56.9	60-65	NO	33.9	50-55	NO
9	74.7	70-75	YES	65.7	60-65	NO
10	79.8	70-75	NO	73.4	60-65	NO
11	76.2	75-80	YES	61.1	65-70	NO
12	71	70-75	YES	63.7	60-65	YES
13	68.4	65-70	YES	60	55-60	YES
14	60.4	<55	NO	51.7	<50	NO
15	74	60-65	NO	66.9	50-55	NO
16	65	70-75	NO	46.8	65-70	NO
17	71.2	65-70	NO	64.8	55-60	NO
18	70.4	65-70	NO	56	55-60	YES
19	68	65-70	YES	55.2	55-60	YES
20	86.6	>80	YES	79.1	70-75	NO

Point No.	Lden (4m)	Noise Contour	Within Limit?	Lnight (4m)	Noise Contour	Within Limit?
1	68	60-65	NO	52.7	50-55	YES
2	65	60-65	YES	45.6	50-55	NO
3	67.6	55-60	NO	59.1	<50	NO
4	60.1	55-60	NO	36.2	<50	YES
5	57.9	65-70	NO	46	55-60	NO
6	62.9	<55	NO	42.1	<50	YES
7	70.9	55-60	NO	64.7	50-55	NO
8	60.6	60-65	YES	33.9	50-55	NO
9	73.8	70-75	YES	66.1	60-65	NO
10	80	70-75	NO	73.2	60-65	NO
11	77	75-80	YES	59.5	65-70	NO
12	71.3	70-75	YES	64.4	60-65	YES
13	68.4	65-70	YES	59.6	55-60	YES
14	62.3	<55	NO	54.3	<50	NO
15	74.4	60-65	NO	68.2	50-55	NO
16	64.5	70-75	NO	46.6	65-70	NO
17	69.7	65-70	YES	62.5	55-60	NO
18	73	65-70	NO	58	55-60	YES
19	67.7	65-70	YES	56.3	55-60	YES
20	86.8	>80	YES	80.3	70-75	NO

Table 1 *L_{den} and L_{night} observations at both head height (1.5m) and 4m*

A paired-samples t-test was conducted to compare the measurements taken at head height (1.5m) and the measurements taken at 4m. The data shows there was an average 0.2dB difference between each height (the logarithmic mean calculated was 75.65dB for 1.5m and 75.86dB for 4m with a standard deviation of 8.71) with no significant difference between the two datasets (p>0.05). Table 2 provides a summary of each of the dataset means compared to that of the noise map means.

	Lden		**Lnight**	
	1.5m	**4m**	**1.5m**	**4m**
Measured mean	75.65297	75.86982	67.93965	68.76457
Noise map mean	71.25855	71.25855	62.83936	62.83936

Table 2 *Measured mean values in dB at each height compared to noise maps*

The results demonstrate that for L_{den} measurements there was around a 4dB increase in noise level across all 20 locations when compared to the median values of all related noise bands at both 1.5m and 4m (75.65dB and 75.86dB respectively compared to 71.25dB of noise contour medians). It is important to note that where a median were not possible for the lowest noise contour i.e. <55dB for example, the boundary figure was used instead (54.9dB). A paired sample t-test showed that there was a significant difference between the measured values and the median of noise contours for both 1.5m and 4m (p <0.05).

For L_{night} measurements, the mean at the 4m level is around 0.8dB greater than 1.5m (68.76dB and 67.93dB respectively) compared to that of the mean from the noise map contours (62.83dB for both heights). Again, by using the median and boundary values of the noise contours, there was an average of 5.1dB increase in the observed noise level across all locations when compared to the median values of the related noise bands at 1.5m. At 4m, there was an average of 6.5dB increase in the observed noise level across all locations when compared to the median values of the related noise bands. T-tests show that there is no significant difference between measured values and the median of the noise map contours *(p* >0.05) at either of the measured heights. Figure 2 shows the standard deviation for each of the measured locations (L_{den}) and the errors bars associated with each at both 1.5m and 4m.

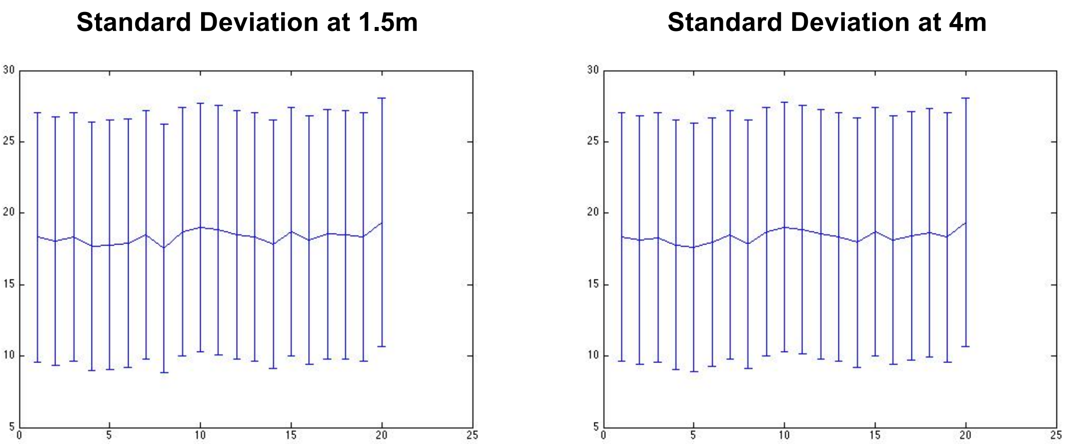

Figure 2 *Standard Deviation for both 1.5m and 4m taken across each location*

5 DISCUSSION

Overall the recordings made in this study demonstrate some marked differences between recordings of environmental noise at 20 locations in Glasgow city centre and the corresponding noise map estimations for these locations. For L_{den}, 40% of measurements taken at 1.5m were within the predicted noise contours whereas 45% were correctly predicted at 4m. There is a similar pattern for L_{night} measurements also. 30% of those taken at 1.5m were correct whereby 35% were within the noise contours at 4m. Mean values for the L_{den} measurements at both head height and 4m over the 20 locations are significantly higher than those estimated in the noise maps, at around +4dB. L_{night} measurements are again significantly higher than those estimated in the noise maps, at +5.1dB at 1.5m and +6.5dB at 4m. In summary, the measurements show a pattern of real world noise measurements exceeding the estimates produced in noise maps, and between 55%-70% of measurements lying outside the estimated noise contours.

No significant differences are found between measurements taken at head height and 4m, suggesting that, within this dataset, there is no significant interaction with smaller objects such as walls and fences at the measurement point.

6 CONCLUSION

This study compares recordings of environmental noise, representing a 'snapshot' in time, with long term estimates produced for environmental noise maps. Although the direct comparison of data for these different timescales is problematic, some broad patterns are observed in the dataset. The findings suggest a large percentage of measurements disagree with noise map estimates, and are in general louder than those same estimates. This merits further investigation, and future work may benefit from long-term acoustic monitoring of the locations sampled in this study to observe whether these patterns are upheld[9]. Noise maps are produced at a strategic level in order to inform the authorities of noise planning decisions and highlight the population exposed to excess noise levels. The maps do however, allow the public to view potential noise levels in a particular area. Testing the veracity of these estimations may provide insight to the accuracy of noise map estimations, and ultimately improve the information communicated to the general public[10].

This study forms part of the *Glasgow 3D Sound Map* project which aims to investigate how the use of advanced audio technology can be used to create more meaningful sound maps for dissemination to the public. Further information can be found project website:

http://www.glasgow3dsoundmap.co.uk.

7 REFERENCES

1. *Environmental Noise Directive (END) 2002/49/EC*. **7,** (2002).

2. Stoter, J., de Kluijver, H. & Kurakula, V. 3D noise mapping in urban areas. *Int. J. Geogr. Inf. Sci.* **22,** 907–924 (2008).

3. Klæboe, R., Engelien, E. & Steinnes, M. Context sensitive noise impact mapping. *Appl. Acoust.* **67,** 620–642 (2006).

4. Glasgow Agglomeration Working Group, NOISE ACTION PLAN FOR THE GLASGOW AGGLOMERATION, 1-67, (2013).

5. Cho, D. S., Kim, J. H. & Manvell, D. Noise mapping using measured noise and GPS data. *Appl. Acoust.* **68,** 1054–1061 (2007).

6. Castle, J. Guidance Note for Strategic Noise Mapping Environmental Noise Regulations 2006 Version 2. (2011).

7. Ministry for the Environment, Government of Gibraltar, NOISE ACTION PLAN, 1-17, (2012).

8. Kardous, C. a. & Shaw, P. B. Evaluation of smartphone sound measurement applications. *J. Acoust. Soc. Am.* **135,** EL186–EL192 (2014).

9. Mioduszewski, P., Ejsmont, J. a., Grabowski, J. & Karpiński, D. Noise map validation by continuous noise monitoring. *Appl. Acoust.* **72,** 582–589 (2011).

10. Manvell, D. & Hartog van Banda, E. Good practice in the use of noise mapping software. *Appl. Acoust.* **72,** 527–533 (2011).