TANOISE:
A NEW NOISE ASSESSMENT TOOL FOR TRAFFIC NOISE EVALUATION

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1 INTRODUCTION

Accurate assessment of Road traffic noise is important, as it can guide the location of measures to help minimise any associated detrimental effects on health, wellbeing, and residential amenity. Traditional noise assessments use annual average daily traffic flow to estimate noise levels for day time and night time noise, but do not measure the change in noise levels over the peak periods. They do not measure the short peaks and troughs in noise levels due to congested traffic, yet these noise variations can be just as much a component of the noise nuisance as the constant sound level.

The 2002 EU directive on environmental noise (EU, 2002) quantifies noise as a set of average sound levels $L_{\text{Day}}, L_{\text{Evening}},$ and $L_{\text{Night}}$, summarised as $L_{\text{Den}}$, a day, evening and night composite. This metric has been be used in the first round of an EU wide strategic noise mapping exercise for all urban agglomerations with a population greater than 250,000. While use of the daily average noise is mandated for the wide area mapping, the EU directive also advocates the use of supplementary indicators for short term events such as a passing aircraft or train, or for impulsive noises, or in quiet areas.

The TANoise project takes the EU advice on supplementary indicators and applies it to the assessment of road traffic noise where that assessment now includes the detail of how noise varies during the day, hour by hour, minute by minute and down to the level of the individual noise peaks. It does not reduce the measure of noise levels to single values for the day-time and night-time hours, but provides a comprehensive picture of the rise and fall of road traffic noise and the short term peaks and troughs contained within the pattern of noise.

This level of detail has previously been unavailable using aggregate road transport models. For example, the Noise Pollution Level (NPL) measure of noise nuisance was defined in the 1960s to include both the average sound level and its variance, but it was never widely used due to the difficulty of estimating that variance either by observation or through modelling (Pronello and Camusso, 2012). A microsimulation transport model can now give the detail required to find the variance in noise, so a range of measures, more relevant to the perception of noise nuisance, may be estimated.

1.1 Application

Established methods of road traffic noise assessment address the issues of estimating the noise levels due to road traffic due to busy roads with high flows and speeds.
Where these are adjacent to dwellings there is an undoubted public amenity issue and efforts must be taken to reduce the noise levels with barriers and with landscape design. Noise levels due to road traffic are also keenly felt in urban environments where road traffic and people are in closest proximity and there is less scope for physical means of noise reduction such as acoustic barriers. Road traffic noise management is closely linked to the nature of the traffic flows the behaviour of queueing traffic and the duration of those queues. It is in these situations where traffic management plans can have significant impact on road traffic noise that the TANoise project is intended to assist planners in their assessment of the effect on noise emissions of road traffic management schemes.

Predicting noise levels at a particular point requires a complex set of calculations. The noise from each vehicle is reflected and diffracted by some surfaces, attenuated by others. It is refracted by air temperature gradients and it may take multiple paths from a source to a listener. Sophisticated models use a 3D representation of the acoustic surfaces (buildings, barriers, ground, etc.) in an area and model the track of sound waves as they propagate. It is easy to see how the budget for a noise assessment can soon match that of the initial road traffic assessment. The TANoise project simplifies these calculations foregoing accurate prediction of absolute values for low cost noise impact assessment based on the change in noise level attributed to different transport and demand management initiatives.

Measurement of noise annoyance has three components (Pronello and Camusso, 2012):

- **Level indicators**
  Measurements of sound levels

- **Exposure indicators**
  Measurements of the time and, the duration of the noise

- **Annoyance indicators**
  Subjective measures of sensitivity, attitude and awareness

Aggregate techniques address the first component only. TANoise adds the detail required by the second component. The third is the responsibility of the analyst undertaking the assessment. The TANoise Software will allow analysts to answer questions such as:

- What change in noise levels will be recorded at each listener point due to changes in road traffic demand?
- What change in noise levels will be recorded at each listener point due to changes in road traffic management?
- What is the effect of a change in road surface?
- What is the local effect of rumble strips?
- How does the noise level vary by time of day?
- How often are there excessive peaks in the noise level?
- How variable is the road traffic noise, from a constant background level to a set of peaks?

Assessment based on an aggregate traffic model is limited to answer only the first three questions and only in the context of an average flow at a constant speed on a
single road link. Further calculations are required to aggregate the sound from many links. TANoise is able to address all questions and also in the context of complex traffic situations, such as at junctions where queues build up and dissipate and accelerating traffic adds to the overall noise levels.

1.2 Project history

The TANoise project was initiated in 2008 to research into the feasibility of using microsimulation data to evaluate road traffic noise. It identified an EC project “IMAGINE” as a base for subsequent developments and, in particular, the HARMONOISE module within the IMAGINE project. HARMONOISE was funded by the EC under the sixth framework policy oriented research environmental assessment goal. Its output was a set of algorithms to model the noise emissions of individual vehicles given the behaviour of the vehicle, its speed and acceleration, and the road surface it traverses (EU, 2007). The HARMONOISE algorithms were adopted for use in the TANoise project and included in subsequent software development.

In 2010 – 2011, software was developed to take the output of a microsimulation model as a set of vehicle positions and behaviour written at one second intervals and process these into an LAeq sound pressure level at a specified listener point evaluated over a specified period of time.

1.3 Assessment Example

A comparison of a noise assessment using both TANoise and CRTN (Calculation of Road Traffic Noise) illustrates the difference between the two methods. This example is derived from early validation of TANoise comparing its output with that from CRTN.

The proposal to be tested includes significant changes to the junction at the Thainstone Roundabout on the A96 to the South of Inverurie. Figure 1 and Figure 2 show the Base and the Design models for the roundabout. The position to be evaluated, marked with a diamond in, is adjacent to the A96 150m north of the existing roundabout. In the Base model and in the Do-minimum model the queue from this roundabout extends past the evaluation position. In the Design model with the new roundabout, the queue is relocated approximately 1km south.
Figure 1: Thainstone Roundabout Developments, Base model

Figure 2: Thainstone Roundabout Developments, Design model

Figure 3 shows a typical comparison between the sound levels found by TANoise and by CRTN at the side of the A96. The CRTN value was derived using the average speed and flow on the link over the 3 hour period for a point 3.5m from the kerbside with no barriers and no surface absorption. The TANoise value was found for a
listener point at the same location with the same sound propagation characteristics. The TANoise value was found at 1 minute intervals during the 3 hour period.

Figure 3: Sound Level adjacent to the A96

Figure 4: Sound Level at evaluation point, base model
Figure 5: Sound Level at evaluation point, scheme model

Figure 4 and Figure 5 show the sound levels predicted by CRTN and TANoise at the evaluation point for the current base situation and for the design scheme. As the traffic is queueing in the base model and is slower than in free flow, the overall sound level predicted by CRTN has dropped, however, the sound level predicted by TANoise has risen and the time profile has flattened. This is attributed to the acceleration of the vehicles in the queue as they stop and start and that this factor in the noise level is dependent on adjacent individuals rather than overall flow. In this case we have a systematic difference between the predictions from TANoise and CRTN. In the design model the comparison of average sound level between the two methods is restored. The relocation of the queue means traffic is once again free flowing and both methods give similar overall results. The variance and the profile of the sound levels are once again modelled by TANoise and omitted by CRTN.

2 TANOISE SOFTWARE

A common theme of contemporary software development is the use of re-usable components, software libraries developed once and used in multiple applications. The current TANoise software is a library of routines which undertake the HARMONOISE calculations to generate a sound power output for each vehicle then propagate that sound to a set of listener points where the sound from each vehicle will be aggregated over the number of vehicles and over the assessment interval.

The use of a library separates the calculation from the user interface. Once audited and approved the library can be included in many applications without need for re-approval at every re-use. At present the library is primarily used as a plug-in to an Excel spreadsheet with the TANoise software undertaking the calculations while the spreadsheet is used to process and display the results as well as handle the input of the control variables.
The inputs to the process are:

*Microsimulation Input*
A file of vehicle positions output every second from a run of a microsimulation model.

*Assessment Criteria*
A set of listener points, the positions where the road traffic noise is to be evaluated is required. The range of audibility is specified by the analyst (up to 1km) as is the evaluation interval. Bounds such as the area of the simulation model and the start and end times of the assessment are also required.

*Noise Parameters*
A default road surface may be used with specific links adjusted for a different surface or areas of specific links identified as rumble strip with new coefficients. The road may also be marked as “wet”. A set of coefficients for different vehicle types and road surfaces derived from the HARMONOISE project are used by default. If required these can be overridden or new sets added by the analyst. Finally, a conversion from vehicle types in the simulation model to HARMONOISE types is required.

*Variance*
TANoise also includes the ability to add an induced variance to the noise emission from each vehicle to model the variation of noise characteristics in individual vehicles, an aspect of noise emission not included in the HARMONOISE model.

Three validation exercises have been carried out in Perth to verify the outputs of the TANoise software. All noise measures use the “A” filter which takes the sound spectrum of a source and adjusts it to a sound level as perceived by a human ear. The available outputs are:

*LAeq*
This is the basic noise level measurement from which the other measurements are derived. It is defined as the equivalent continuous sound over a period of time that would contain the same sound energy as the varying sound source over the same period. In road traffic noise assessment this is normally expressed over a period of 1 hour or 18 hours and written as LA_{eq,1hr} or LA_{eq,18hr}. In TANoise the time interval may be specified from 1 second to the entire duration of the assessment.

*LA_{xx}*
This refers to a family of statistical noise measures and is defined as the sound level which is exceeded xx% of the time. Typically LA_{10} is used to describe the peaks in noise, while LA_{90} is used to describe the background noise and LA_{50} describes the mean. TANoise outputs both an LA_{high} and an LA_{low} measure with the values of high and low selectable by the user.

*LA_{max} and LA_{min}*
These are the maximum and minimum values of LAeq in an assessment period. There is an implicit evaluation period for the value of these measures – A
typical noise meter would have options to sample for periods of 10 to 1,000msec to determine LA_max or LA_min. TANoise uses 1,000msec (1 second).

$L_{eq}$
The standard deviation of the sound level in the assessment period. This is used in the Noise Pollution Level indicator, but has normally been hard to evaluate using aggregate models.

3 VALIDATION

Two validation exercises have been carried out in Perth to verify the outputs of the TANoise software. The focus of the validation was on examining the variance in the recorded noise levels where that variance has two components: A systematic variance with the rise and fall of flows over a peak period measured over durations of hours and an aleatory variance due to individual vehicles measured over durations of seconds.

Matching the systematic variance would validate the software’s ability to predict sound levels for differing traffic flows while matching the individual peaks and troughs would validate the software’s ability to predict the variance in sound levels and the maxima and minima in the received sound.

3.1 Perth South Inch

In February 2012, a listening device was installed at the South Inch in Perth to measure noise levels in the morning peak; LAeq measurements were provided at 10 second intervals for a 3 hour period. Video of the road traffic was also recorded and was used to calibrate a microsimulation model of the area. Of the five weekdays in the data, one suffered equipment problems and one was wet with standing water on the road. Three days were used in subsequent comparison. The surveyor also commented that at the monitoring point adjacent to the A912, the sound from vehicles on Marshall Place was audible which was intended in selection of the location and that on some days, other activity such as grass cutting was audible.

The South Inch was chosen as it has an open aspect, reducing the sound propagation uncertainties, the recording location was adjacent to a bus stop which implies there will be the sound of accelerating heavy vehicles present, the queue leading up to the adjacent signals extended to the recording location and flow from those signals was broken by the signal stages. Finally traffic on Marshall Place would also be audible at the listener point and, as it is controlled by a different signal stage its time profile would be different. The short term variance in sound levels was expected to be high while at the same time there would be a rise and fall in flow rates over the period.

Figure 6 shows the modelled area and the location of the listener point adjacent the A912 to coincide with the position of the recording device. Flow data from 14 February was used as input to the model as a representative weekday.
Figure 6: Perth South Inch modelled area and listener point

Figure 7 and Figure 8 show the raw data from a single day of recording and a single run of the simulation model. In both cases, the systematic variance is obscured by the much larger aleatory variance and sophisticated smoothing is required to separate the two.

Figure 7: Raw data, Recorded data 14 February
Smoothing

Data smoothing is used to measure the value of a variable that is both slowly varying and corrupted by random noise. There are many different methods to smooth data, i.e. Moving window filter, Polynomial filter, Low pass filter.

Moving Window

The moving window average filter is the simplest and takes the average of N data points before and after the point under consideration. Where the variance from the smoothed value is high compared to the variance of the smoothed value, N must be large to accommodate sufficient samples to ensure the underlying mean can be reliably estimated which presents difficulties in determining the finding the local minima or maxima. An exponential filter which finds a weighted average of the historical and current value has the same problem (Press et al., 2007).

Polynomial Filter

The polynomial filter method approximates the data in a local region with a polynomial expression rather than an exponential expression or the linear expression of the moving average method. Despite these filters providing a better estimate of an individual peak, they still operate on a restricted localised window into the data and do not take into account any systematic structure to the variation in the data over the long and short term variations.

Low Pass Filter

A low pass filter cuts off any varying component in a sample data set with rate of variance higher than a specified rate. The cut off rate can be set to filter out the variance induced by platoons formed by signals, by selecting a rate slower than the cycle time or it can be set to only keep the variance expected in the rise and fall over the peak by selecting a rate faster than the peak to trough rate.

The approximate structure of the road traffic noise can be qualitatively described. There is a slowly changing systematic variation in noise based on the rise and fall of flow in a peak period and a rapidly changing variation in that pattern of noise due to the effects of individual vehicles, the platoon formations with in the flow and the
changes in queues at signals. The requirement of a smoothing algorithm is that it recognises both of these components and does not systematically over or under estimate the width or height of the slowly changing component as it removes the rapidly changing component.

The low pass filter has the advantage that it is designed to take the entire dataset into account in the smoothing operation on the premise that there is a frequency based structure in the time series. After experimentation with the recorded data, the low pass filter was chosen with a rate set to filter out changes with a peak to trough rate faster than 10 minutes. Figure 9 shows the comparison between the raw and smoothed data.

Figure 9: Smoothed and raw data

**Induced variance**

The HARMONOISE algorithms provide a set of coefficients to generate the sound emission for vehicles in five different classes: car, light goods, heavy goods, motorcycle and illegal exhaust motorcycle. The sound power generated by each vehicle is computed from its speed then modified to take into account the acceleration of the vehicle and road surface, gradient and temperature. Within each class, every vehicle is treated the same - two cars travelling at the same speed will both be predicted to emit identical sounds with no provision to differentiate between them.

While this is adequate for calculation of noise levels over extended periods of time or where the sound from many vehicles is aggregated with none particularly dominant, it is not adequate for modelling the rise and fall of noise levels in detail over short periods where one individual may contribute most of the received sound. In this situation the variability in the sound power for each individual must also be modelled.

This variability in output is briefly mentioned in the final report on the HARMONOISE project, but is not well quantified (EU, 2007). While there are insufficient measurement available to make accurate estimates of the variability, Figure 10, taken from that report, gives the best estimate of the variation in emission – aggregated over many vehicles and how it varies with speed. The solid line is the estimate, the lighter lines the range in which the true value may fall.
This variation with road speed was taken as a guide to including variance for individual vehicles and implemented within the TANoise algorithms. Variance in noise emission is specified for each individual vehicle type and each vehicle is given a fixed (and repeatable) variance taken from a random distribution.

Note: It is considered necessary to keep a constant value per vehicle for consistency in a single vehicle drive past measurement.

The base variance is selected from a normal distribution and the analyst is able to control the standard deviation of that distribution by vehicle type. As the graph from the HARMONOISE project shows little change in variance above the reference speed but up to three times greater at slow speeds, the variance is computed using the following formula:

$$Variance = \begin{cases} 
\text{BaseVariance} \times (1+ 2 * (V_{ref} - V)/V_{ref}) & \text{for } V < V_{ref} \\
\text{BaseVariance} & \text{for } V \geq V_{ref} \end{cases}$$

Where: $V = \text{vehicle speed}$  
$V_{ref} = \text{HARMONOISE reference speed (70 km/h)}$  
$\text{BaseVariance} = \text{Variance derived from distribution specified by user}$

The effect on the sound level received at a listener point is shown in Figure 11 for a short period of time with the noise level evaluated at 5second intervals and a standard deviation of 0dB (i.e. no induced variance), 3dB and 6dB.
Figure 11: Effect of induced variance

The pattern of emissions over time is observed to be similar but the peaks and troughs are more pronounced.

Note: Due to the nature of the logarithmic summation of sound where louder sounds have a predominant effect, the increase in variability has the secondary effect of increasing the overall mean.

**Calibration**

The calibration methodology was:

1) Smooth the raw recorded and modelled data using the low pass filter
2) Find the RMS variance between the raw and smoothed data
3) Find the range of the smoothed data
4) Adjust the induced variance for individual vehicles such that the RMS variance and the smoothed data ranges match for modelled and recorded data

Table 1, an extract from the validation exercise in Perth South Inch (Sykes, 2012), shows the effect of the induced variation on the raw and smoothed data. Increasing variation increases the range of both datasets and a value of ~1.5dB induced variation allows the variation in modelled and recorded data.
Table 1: Effect of induced variation on raw and smoothed data

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The RMS error, (the difference between smoothed and raw data) was not matched by the induced variation. The error was 5.6 in the recorded data and 3.7 in the modelled data. Figure 12 and Figure 13 show the error for the recorded data on three days and the average modelled error. While the skew to the low positive values is present in both, i.e. the most regularly occurring error is -2dB to +4 dB, the tail in the negative values is not repeated. While the overall range and the mean is similar, the shape of the distribution has differences which leads to the difference in RMS error.
The root of the difference occurs in the quiet periods when the recorded noise is lower than the systematic noise. The difference is unlikely to be due to the modelled vehicle noise as the differences in profile when the noise is high, i.e. when there is a vehicle adjacent to the recording device, is less marked. It may be hypothesised that the difference is due to un-modelled effects, i.e. background noise, pedestrian noise, vehicles out of range of this model, grass cutting operations as noted by the surveyor, etc. There is insufficient data to test any of these hypotheses.

**Comparison**

Finally to validate the process, and to validate the TANoise software the correlation between modelled and recorded smoothed data was found and is shown in Figure 14, Figure 15 and Figure 16. The correlation between the time-series on the three days is 0.37, 0.61, and 0.62.
Figure 14 Comparison of modelled and recorded data, 13 February

Figure 15 Comparison of modelled and recorded data, 14 February

Figure 16 Comparison of modelled and recorded data, 15 February
3.2 Perth Bridgend

In 2013, a similar validation exercise was undertaken using data recorded from a set of Motes installed in Perth in 2012 (Sykes 2013).

Motes are low cost environmental data collection devices. Powered by solar cells and communicating wirelessly they are cheap to install and designed to be used in a dense, pervasive network to give a comprehensive view of the current air-quality level (NO, CO, NO2) and the current sound level at 1 minute intervals (Bell and Galatioto, 2013). Eight Motes are installed at Bridgend in Perth to monitor air quality and the noise level data was made available from these Motes to compare with the predictions from TANoise derived from a large simulation model of the whole of Perth Town.

Figure 17 shows the location of the Motes in the Bridgend area and Figure 18 shows the Northernmost mote, mounted on an existing pole.
Figure 18: Northernmost Motes, Bridgend

Figure 19: Perth Microsimulation model
The microsimulation model of Perth (Figure 19) is approximately 10km square with 142km of road 128 origin-destination zones. It models 39,000 trips and 54,000 trips in the AM and PM peak. It was one of the first city area microsimulation models, originally created in 1996 and has been regularly updated since. It is in frequent use in a range of applications from testing city centre traffic management proposals to examining the effect of demand management on the Western bypass. The model was unaltered for this validation exercise save for the collection of vehicle position data in the relevant areas.

Comparison
Data from the Motes was incomplete. The wireless communications are line of sight and are interrupted by passing tall vehicles. All Motes had some missing data. In the Bridgend area, this ranged from a single record to 25% of the data missing over a week with the Motes furthest north suffering higher drop-out rates. In the periods to be assessed, the worst case Mote had an average of 34 gaps per period with a maximum length of 6 minutes in the AM peak and 9 minutes in the PM. An average of 1/3 of the data was missing in each period for this device compared with just one record for the most reliable device.

Rather than compare time series with missing data, the gaps were in-filled with data sampled from times selected randomly from records within adjacent 10 minutes of the missing record. This makes the assumption that the underlying base level of noise would not change significantly during the gap and the adjacent few minutes and that the random variation from that base level was similarly unchanged.

Smoothing with a low pass filter presented some issues, the sample size of 150 data points, 1 per minute, coupled with the 10 minute peak to trough time and the requirements for the low pass filter that the data be extended to be a power of 2 in length (here extended to 256) meant the low pass filter was at the limit of its capabilities and the smoothed data tended to distortion at the start and end times. In this case, a moving window smoothing algorithm was used with a 30 minute window. The jagged nature of the underlying systematic data – after such a wide smoothing filter was applied is clear.

The validation using the Motes first examined the effect of induced variance to verify the value of 1.5dB used in the exercise in the South Inch. Comparison of the RMS error between smoothed and raw data at each of the Motes for the AM and PM peak period gave a range of required induced variance from -0.8dB to +1.6dB with an average of 0.75dB. The error in the RMS value was typically > 2dB indicating that these values should not be used too precisely.

The conclusion is that the induced variance of 1.5dB found in the initial validation exercise at the South Inch is at the higher end of the range but is commensurate with the values found using the Mote data.

Figure 20 shows a sample comparison between the recorded sound levels for nine dry days in December 2012 and the predicted sound levels from six microsimulation runs for the Mote shown in Figure 17.
Across the eight Motes and for the first part of the AM period and the entire PM period, the times series correlation between the Mote recorded data and the TANoise prediction ranges from 0.53 to 0.99.

4 FUTURE DEVELOPMENTS

When validation of the TANoise library is confirmed, it is intended that it be used with a user interface to enable analysts to readily input microsimulation data, the associated control data and the position of the listener points in the model. Output will consist of graphs comparing different road traffic management, demand, and infrastructure proposals to enable the analyst to make statements about the change of noise levels and the change in the noise nuisance indices at the chosen locations.

A study in Belgrade (Paunović et al., 2009) found that the characteristics of the emitted noise measured in terms of $L_{A_{Den}}$ were less significant predictors of noise annoyance than personal, social and housing characteristics. This does not imply the measures predicted by TANoise are unimportant, but it does imply that the characteristics of the listener point are highly relevant in determining the noise nuisance level. To put it another way, “If a Ferrari revs on the motorway and no one is around to hear it, does it make a sound?” and if someone is around to hear it, will they be offended?

A more thorough assessment requires more evaluation of exposure in terms of level, time and location and inclusion of subjective factors such as social and economic environment. Integration of the TANoise calculations into a GIS tool with the ability to draw in demographic data would make for an interesting noise assessment tool.

For the future, Transport Scotland are considering the application of microsimulation post processing tools such as TANoise and AIRE to the real-time measurement of environmental emissions. Application of these tools will play a part in the
development of any Environmental Incident monitoring system. A significant part of this application will include completion of the validation and calibration of the tools using further independent monitoring and review. A collaborative approach to these next steps is being developed.

5 REFERENCES


