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NOISE CONTROL FOR A BETTER ENVIRONMENT

Prediction of Statistical Noise Metrics for Road Traffic

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ABSTRACT

Objective: To improve current methods of prediction of road traffic noise impact levels.

Methods: A method of predicting road traffic noise using A-weighted statistical levels has been developed, primarily focussed on modelling individual source position and noise emission characteristics. The validity of the model has been verified by field studies involving concurrent vehicle flow and noise level surveying.

Results: Results using the model have been predicted under a range of traffic flow conditions for observation positions nominally 15 metres from the nearest carriageway. Statistical metrics and equivalent energy levels have been predicted for observation periods of 1 hour duration, with a very satisfactory level of accuracy better than 3dB(A) when compared against measurement observation.

Conclusion: The method produces a more informed prediction describing the potential impact on a community from a road project when compared with energy equivalent level predictions alone.

Implication: The methodology could be utilised for assessment of any stochastic and/or physically mobile noise generating system, such as a railway, an open-cut mine, construction site, industry or carpark. The method could be enhanced using narrow band prediction.

Keywords: Road, Modelling, Analysis
I-INCE Classification of Subject Number: 13,60,76

1. INTRODUCTION

This paper proposes a method of prediction of road traffic based on a sequence of instantaneous conditions, each representing a statistically defined random collection of discrete omnidirectional emission sources. The objectives for the paper are to establish a

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robust basis for road noise impact assessment, permitting greater insight into the factors contributing to community complaint. It is hoped that the superior findings able to be derived using the modelling will contribute to improved regulatory and design standards associated with road traffic noise.

The modelling procedures examined in this paper focus on modelling of the source emission characteristics. The paper does not focus on sound transmission parameters affecting the attenuation of sound from a source to a recipient – e.g. barriers – as the use of these parameters is both well documented and not controversial. An outcome of this paper could, however, be that a review of some of those attenuation parameters is contemplated.

2. ROAD NOISE MODELLING

2.1 Current Models

Following the publication by the UK Department of the Environment of a formal method of calculation, CoRTN [HMSO,1975] road traffic noise impact assessment in Australia has been calculated treating a roadway as a line source, attenuating at a nominal rate of 3dB per distance doubling perpendicular to the lane axis. The CoRTN assumptions predicting noise impact for a daytime (0700-2200) and night (2200-0700) have continued, with a relatively minor modification to amend the output assessment parameter to an L_{Aeq} in place of the CoRTN use of L_{A10}.

Internationally, more analytically complex models are in widespread use [Steele, 2001] and offer more flexible computation of both noise propagation and input source characteristics. However, assessment using these models continues to be based on the prediction of energy equivalent metrics, or variants thereof [Garg & Maji, 2014]. In one or two instances, an estimate of the maximum passby level may be derived. Overall, an expectation for prediction accuracy appears to be in the order of +/- 3dB(A) [Gulliver et al, 2015] based primarily on discussion of equivalent energy level predictions.

All current models examine noise from road traffic as a stationary noise generating system. In fact, road traffic noise is both a stochastic and, at times, chaotic noise generating system, for the impact assessment of which the use of a stationary noise model is likely to be inadequate [Fitzell,2019].

2.2. Modelling stochastic noise systems

At a recipient, stochastically varying incident noise may result from physically stationary sources with stochastically varying noise emission characteristics, sources with stationary noise emission but which are physically mobile, or a combination of both.

Modelling of incident noise from a stationary noise system requires knowledge of the source emission level, of the distance from the source to a point of observation, and of factors that affect the transmission of noise from the source to that point. A model of a stochastic noise system will examine the aggregate outcome conditions that arise from the constantly varying input states, by representing the numerous instantaneously stationary incident noise conditions that can be expected. Evaluation of these instantaneously incident conditions over a suitable time interval will allow inspection of the magnitude of change to an existing, often also stochastically variable, environment that will result from the introduction of the new stochastic system.

Assumptions and input constraints are involved in the modelling proposed by this paper. These require that:

- Individual noise-contributing sources are identifiable;
- Sources involved are frequency and phase-incoherent;
- Sources are operationally correlated only to the extent that the operation of one source may be associated with the operation of another source, but does not affect the emission level of that other source;
- The statistics (cumulative distribution function) describing the sound power emission characteristics for each source can be defined, either analytically or by measurement;
- The operating characteristics of each source – times of operation, movement, location, velocity of motion, can be defined, usually analytically;
- The modelled assessment period is longer than the operational cycle associated with any input source;
- The statistical parameters associated with each source apply to a stochastically variable source, but not a chaotically variable or chaotically operating source.

The modelling examined in this paper refers to noise generated by a road. However, noise incidence from many stochastically variable systems can be evaluated using similar techniques. Examples include vehicular carparks, aircraft, railways, large scale entertainment activities, mining activities, indoor occupancy noise, and, arguably, entire precincts. The modelling procedures could be expanded to assessment based on octave band data, subject to computing capacity.

2.3 Operational inputs and statistics

The inputs and the associated statistical variance required to model the operational noise from a roadway include:

1. Carriageway definition – a sequence of x, y and z coordinates defining each segment
2. A receiver location – z, y, z coordinates;
3. Posted speed limit – for each segment of the road carriageway;
4. Vehicle classes to be modelled – In Australia, 12 classifications are used following the AUSTROADS classification system, classes 1 and 2 combined identifying light vehicles, and classes 3 to 12 heavy vehicles [Austroads, 2006];
5. Average expected vehicle flow for each vehicle class – commonly estimated for design purposes as an average annual daily transit (AADT) but can refer to any appropriate interval of interest. Traffic flow data is used to calculate the expected vehicle flow for a period of interest (e.g. 1 hour). The number of vehicles arriving at a given location is a poisson variable, using which an instantaneous vehicle flow is calculated for each simulation calculation.
6. Vehicle passby speed – estimated empirically, based on observed vehicle passby speed. Modelled as an expected mean passby speed with an associated standard deviation. Using these parameters, an actual vehicle transit speed is calculated for each vehicle for each simulation calculation.
7. Individual vehicle noise generation – estimated by empirical formulae for each vehicle class, derived for this project by survey including an expected standard deviation. Using these parameters, an actual vehicle noise emission is calculated for each vehicle for each simulation calculation.

Modelling noise transmission from the source to receiver may also involve stochastic processes, such as wind or temperature gradients. These aspects are not examined in this paper, however, attenuation parameters could be each be modelled as an expected average statistical condition, with a relevant variance.

2.4 Source positioning

A fundamental input parameter is the number of vehicles likely to be situated within the road section of interest at any time. The arrival of a vehicle at a nominated observation point on a road can be considered a Poisson process. A process is said to be a Poisson Process [Law & Kelton, p405] if:

1. Each event arrives one at a time.
2. The number of arrivals (N) in the time interval (*t*,*t*+*s*) is independent of the number of arrivals in the preceding intervals (0,t).
3. The distribution of arrivals in each interval is independent of *t*.

Condition 1 requires that an independent poisson calculation be carried out for each lane and for each vehicle class. Conditions 2 and 3 may break down for periods of congested traffic flow while condition 3 may require a more sophisticated modelling assessment for roads on which traffic flows vary systematically during the day – e.g. distinct peak hour flows. A process for which only condition 3 is not satisfied is termed a ‘nonstationary poisson process’ [Law& Kelton, p406]

Expressed mathematically [Mendenhall et al, 1981] a poisson process is described as:

$$P(y) = \frac{\lambda^{y} e^{-\lambda}}{y!} \qquad (1)$$

where P is the probability of an event of magnitude y occurring in the interval
λ is the expected (average) number of events in the interval

It can also be shown [Law& Kelton, p406] that the inter-event time for a poisson process is an independent and identically distributed exponential random variable with mean value $1/\lambda$.

There are useful properties of a poisson function that relate to simulation application, one being that the mean value and the variance are equal. This has implications in selection of a suitable assessment interval over which simulation modelling should be carried out.

λ, obviously, may be simply calculated from the average expected traffic flow for the period of interest. Vehicle flow on each lane is, theoretically, an independent variable, as is the flow for each class of vehicle within each lane, so it is necessary to establish λ for each vehicle class flow, ideally, for each lane.

For roads on which free-flowing traffic cannot be assumed, simulation may need to be based on an empirical distribution based on physical observation at other similar road sites. This is likely to be the case, for example, for traffic flows within urban areas, at intersections, car parks and the like. While discussion of empirical distributions is beyond the scope of this paper, the use of an empirical or logical distribution function is a simple substitution for the poisson distribution in the simulation procedures discussed below.

3. A STOCHASTIC MODELLING PROJECT

The stochastic road noise model adopted for this project involves the iterative (N) application of the following algorithm and equation 2. From the array of N aggregate incident noise levels, it is possible to compute the incident road noise level statistics at the relevant receiver.

Table 1: Simplified model algorithm

```
For each simulation (N)
For each carriageway (e.g. North / South)
  For each lane of each carriageway
     Compute expected mean number of vehicles of each class at any instant
        Using poisson variable, define actual number of vehicles (n) for class
        Determine, randomly, the position for each of the n-vehicles
        For each vehicle (I=1:n)
           Compute actual transit speed for vehicle
           Compute actual sound power emission
           Compute incident noise level at recipient J
Compute aggregate incident noise level at J from all vehicles across all lanes
```

With incident sound pressure level at receiver (J) from vehicle (I):

$$Lp_J = \sum_{I=1,n} (Lw_{I,} + N_{DIVERG,J} + N_{EXTRA,J} + N_{GROUND,J} + N_{AIR,J} + N_{DIFF,J}) \quad (2)$$

where

Lw_I is the sound power level emitted by the I-th vehicle

$N_{DIVERG,J}$ = divergence attenuation $10*\log(Q/4\pi R^2)$ to the J-th receiver

$N_{EXTRA,J}$ = additional attenuation due to atmospheric effects to the J-th receiver

$N_{GROUND,J}$ = attenuation due to ground absorption, to the J-th receiver

$N_{AIR,J}$ = attenuation due to air absorption to the J-th receiver

$N_{DIFF,J}$= attenuation due to diffraction shielding to the J-th receiver

The inputs required for the model included the operational parameters discussed above in section 2.4 together with source noise generation parameters. Source noise generation parameters were obtained by noise survey, an important aspect of which was that the survey locations were unrelated to and not used for the either of the subsequent model verification studies. The collection of input data and the subsequent modelling studies were therefore independent.

3.1 Input Data Surveys

Vehicle surveys were carried out on sections of the Princes Highway and at one location on Bolong Road, NSW, between the townships of Berry and Nowra. Data was obtained at six locations, with measurement distances ranging from 6.5 metre to 15 metre from centreline of the nearest lane and at road sections with posted speed limits from 50 to 100 kph. Instrumentation was a Rion NA28 precision meter and pocket radar. Road sections involved single northbound and single southbound carriageways, with vehicle class, passby speed and maximum passby sound pressure level recorded. This data was used subsequently as model inputs:

Sources of potential error in the application of this data to other road situations can be noted:

1. Vehicle and driver composition limited to a limited region. The surveyed road sections service a mix of metropolitan, industrial and rural areas.
2. Uncertain road surface type. Surveying included areas for which recent sprayseal bitumen had been laid together with graded ashphalt of some years usage.
3. Pocket radar speed measurement error is unknown and may have included influence from unobserved sources – wildlife, concurrent vehicles etc.

3.2 Technical Assumptions used in stochastic model calculations

- Individual source energy divergence was calculated using the inverse square propagation rule
- Extra attenuation due to ground effects, forest vegetation scattering, shielding and the like was investigated as a single parameter ranging in value from 0-0.1dB(A) per 100 metre
- Ground absorption was otherwise set to zero throughout
- Air absorption was calculated at 0.001dB(A) per 100 metre propagation
- Barriers and shielding were set to zero
- Wind effects were set to zero
- Q for dispersion modelling was investigated at values between 1 and 1.5.
- Outcome verification examining potential effects due to ambient noise were calculated using inverse transformation sampling and summation.

3.3 Input Data

Important qualifications to this input data is the fact that road surface type is not considered, while each vehicle is treated as a single point source for which height was not a significant factor, the inclusion of source variance being orders of magnitude more important. For the primary objective of this project – accurately modelling the extended source emission characteristics – these parameters are not important. They could, however, be readily included.

A large data scatter is observed. This suggests, potentially, a large error contribution. However, survey observation was that chaotic operational parameters commonly affect noise generation in otherwise similar situations - driver behaviour, vehicular speed grouping, slower vehicle flow impediment, unstructured changes to engine operating load, road wear and surface imperfections. Some aspects of road noise variation show stochastic variance, while others are chaotic and unpredictable. Modelling based on variance determined from field surveys, rather than under controlled or laboratory conditions, is therefore strongly recommended.

In recognition of convention, log-linear data models for noise generation were used based on the logarithm of vehicle speed, despite log-linear relationships not being the best fit. Relatively poor R-squared model variance was obtained from all model regression analyses.

Vehicle speed variation was observed to conform, reasonably, to a normal distribution, though a secondary factor of vehicle spacing and grouping tendency was also observed, itself a function of speed and volume flow. Other speed related effects were observed to occur in the subsequent verification model analyses.

3.3.1 Expected Passby Speed

Dependent on the algorithm adopted for a model, vehicle speed could be either the posted speed limit on the chosen section of road, or the expected individual vehicle speeds making up the traffic flow. The modelling for this project used the latter. When surveying, it is desirable to record both the vehicle passby speed and the posted speed limit, as either may be appropriate for future modelling.

Using the field survey observations, average and standard deviation vehicle speed for light and heavy vehicles is summarised in equations 3 and 4:

$$\text{EPS(light)} = 0.963\text{PSL} \qquad \text{with a standard deviation of } 0.104\text{PSL} \tag{3}$$

And

$$\text{EPS(hv)} = 0.932\text{PSL} \qquad \text{with a standard deviation of } 0.118\text{PSL} \tag{4}$$

where

EPS(cars) is the expected average passby speed for cars, kph

EPS(hv) is the expected average passby speed for heavy vehicles, kph

PSL is posted speed limit for the road section in kilometres per hour

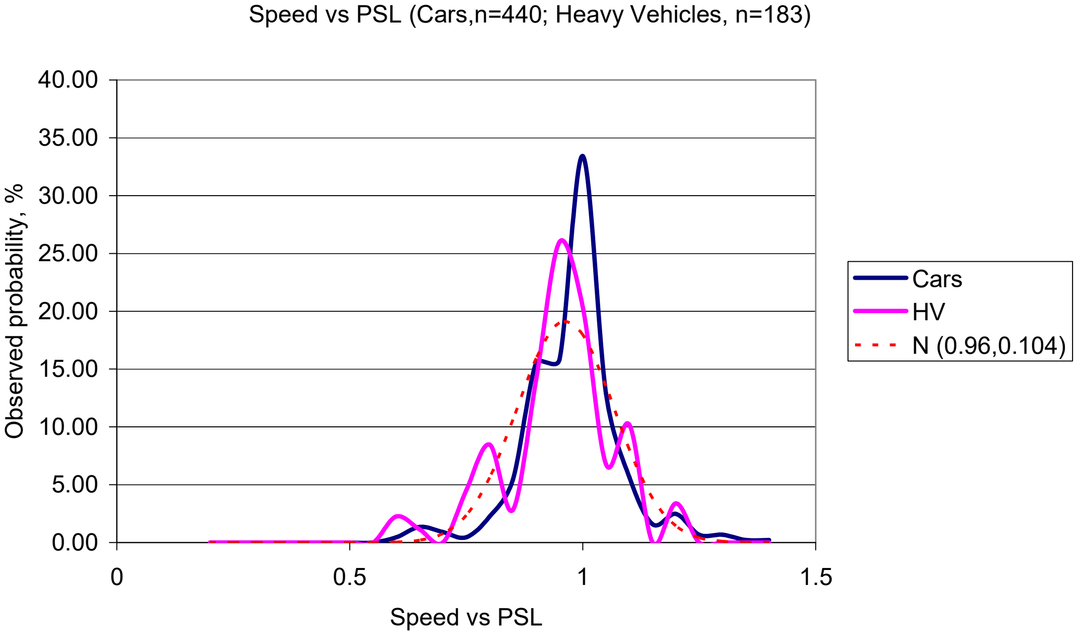


Figure 1: Speed Variation vs Posted Speed Limit

Figure 1 shows the summary of vehicle speed compared with posted speed limit for both cars and heavy vehicles, together with a normal distribution for the parameters determined from survey analysis for cars. The relatively high probability values coinciding with the average observed transit speed, compared with a statistically normal distribution, demonstrates that a degree of flow saturation affected the survey data due to vehicles tending to move in groups at a group speed. Notwithstanding, the use of a normal distribution is considered satisfactory, predicting comparable individual vehicle variance from the expected mean speed within a bound of +/- 1 standard deviation as observed by survey.

3.3.2 Vehicle Sound Power Emission

For the road inclinations at sites chosen for field survey work, none of which exceeded 2 degrees, no effect of gradient on vehicle noise emission could be identified. The standard error of the estimated sound power emission level vs speed was found to be lowest for regression models in which road inclination effect was set to zero.

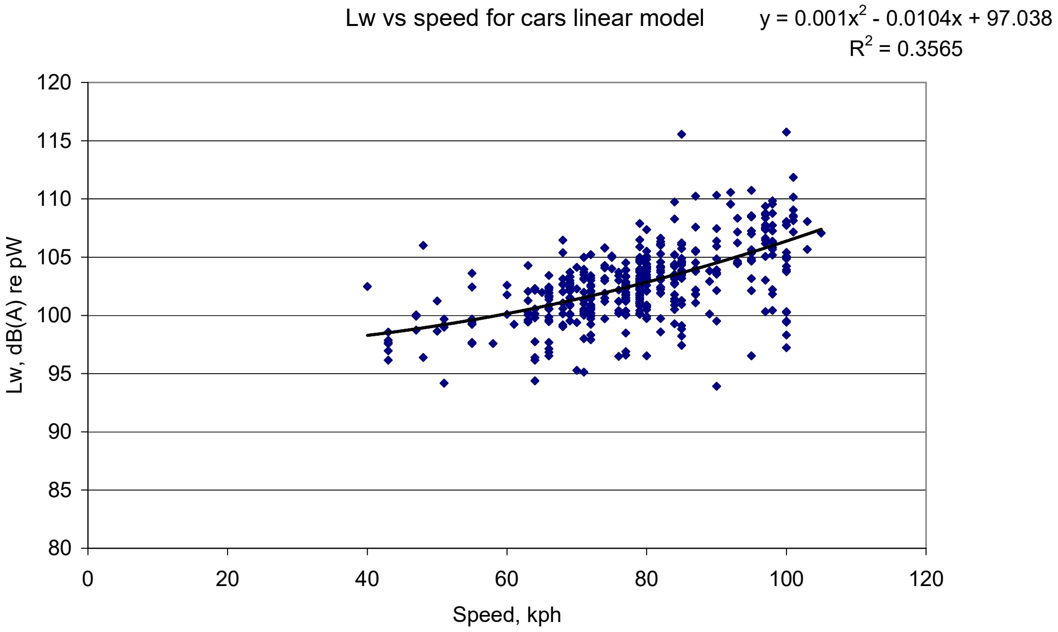


Figure 2: Sound Power Level vs Speed for Cars

More unexpectedly, the highest correlation between sound power level and passby speed (R^2=0.36) was found to occur for a polynomial model shown in figure 2. The correlation for sound power level vs Log(speed) was found to be almost equal (R^2=0.33) and was adopted for reasons of industry convention.

$$Lw_{i,j} = M*\log(V) + K_0 + VAR \quad dB(A) \text{ re } 1pW \qquad (5)$$

where

$Lw_{i,j}$ is the sound power level of the j'th vehicle, class i, dB(A) re 1pW

V is the vehicle transit speed in km/hr and

Input parameters M and K_0 are listed in table 2 for the class

And VAR is the variance in sound power emission for the class.

The parameters used in Equation 5 and summarised in Table 2 have been derived from surveyed maximum passby sound pressure level, converted to sound power level based on Q=2, for a theoretical source and microphone height of 1.1m and a source to microphone distance measured perpendicularly from lane centre to microphone position.

Table 2 : Vehicle Noise Emission Parameters

Vehicle class i	M	K0	N	Std Error, dB
Cars	26	53	443	2.62
Heavy Vehicles	25	62	177	4.03

4. MODELLED ROAD STUDY

Two independent surveys were carried out, each involving a road section with single carriageway in each direction and a posted speed limit of 100 kilometres per hour. The survey locations were:

- Survey 1: Bolong Road, Seven Mile Beach, approximately 1 kilometre south of Beach Rd. This is a secondary road with a load restriction and carries primarily light vehicle flows.
- Survey 2: Picton Road, Cordeaux, approximately 9.5 kilometres south of Wilton. This is a major thoroughfare carrying a large proportion of heavy vehicles. Survey was carried out at one of a small number of remaining sections of undivided single carriageway.

Each survey gathered the following data:

1. Statistical noise levels determined over consecutive periods of 15 minutes and 1 hour duration, over a period of nominally five days each, for two microphone positions at one site and a single position for the second. Data was obtained using an ARL Ngara noise level logger, and a Rion NA28 sound level meter.
2. Concurrent classified vehicle counts, using the MetroCount logging system to record vehicle classification and passby speed for each carriageway. Data was then analysed to provide aggregate flow for each class, mean vehicle speed against class and mean vehicle speed against flow rate, for each observation period.

The data obtained for traffic flow was consolidated to aggregate light and heavy vehicle flow for each 15 minute and/or 1-hour period. These data were then used as input to the numerical model described in section 3 above, with incident noise modelled at the microphone positions used for each survey. The input parameters used for each predictive model were:

1. Vehicular flow for each class (light and heavy) and each direction for each sequential period, modelled to an expected flow for each iteration based on section 2.4 and randomly located along each carriageway
2. Passby speed for each individual vehicle modelled according to section 3.3.1.
3. Noise emission for each individual vehicle modelled according to section 3.3.2.

4.1 Modelled Outcomes

For model 1 (Bolong Rd), co-ordinates for a section of road 7km in length were used, or a transit duration of less than 5 minutes. This limits the accuracy of levels predicted for percentiles below approximately L_{A10}. For model 2 (Picton Rd), co-ordinates for a section of road 12.5km length and a transit duration of approximately 9 minutes. This limits the accuracy of levels predicted for percentiles below approximately L_{A20}. In practice, these lower percentile levels tend to be masked by ambient noise. For very quiet areas, however, modelling noise emission and potential noise impact based on a short road section only is likely to lead to erroneous conclusions.

Notwithstanding the qualifications above, the outcomes for Survey 1 showed that the modelled $L_{Aeq,1hr}$ levels, for Q=1, zero extra attenuation, N=10000 iterations for a sample of 144 sequential 1-hour periods, were approximately 3dB lower than the measured results. Error inspection showed that error increased at low vehicle flows, but was within a bound of +/-3dB for flows greater than 16 vehicles per hour. Adjustment to model input conditions, using Q=2, extra attenuation of 0.2dB(A) per 100m, and a restriction on the computation of Lmax gave an improved average error but, in fact, slightly larger error bounds.

Survey 1 data comparison showed that modelling of the stochastic physical properties of the source alone gave extremely good results and suggested that modelling based on Q=2, with a constraint on Lmax=99.95%-th value would be appropriate. This is demonstrated in the results from Survey 2 at Picton Rd.

Table 3: Survey 1 Bolong Rd, Predicted statistics N=10000, n=144,Q=1,Nextra=0

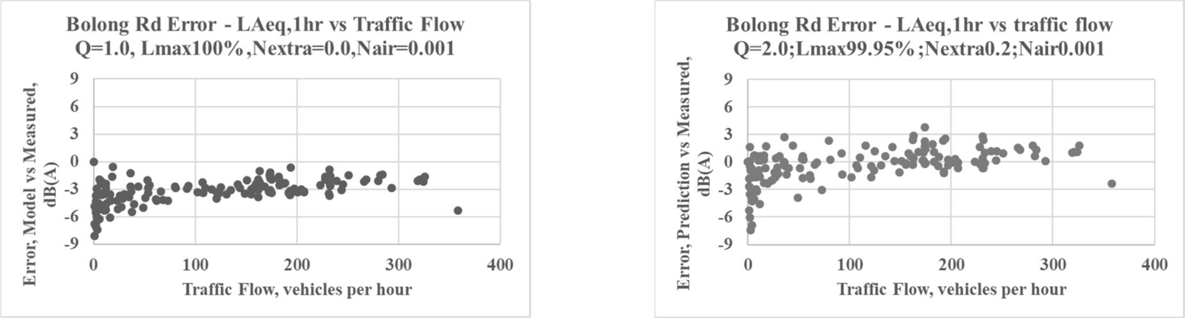
	L_{Amax}	L_{A1}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Aeq}
Mean Measured	81.9	71.3	58.2	43.7	38.1	34.5	60.2
Mean predicted	82.7	68.2	56.2	45.5	39.6	30.4	56.7
Prediction Error	0.8	-3.1	-1.9	1.8	1.6	-4.1	-3.5
Stdev Measured	3.4	9.8	13.0	7.0	5.2	5.1	6.8
Stdev Predicted	4.7	9.4	12.6	9.8	7.2	4.9	8.6

Table 4: Survey 2 Picton Rd, Predicted statistics N=1000, n=144,Q=2,Nextra=0.2

	L_{Amax}	L_{A1}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Aeq}
Mean Measured	91.4	84.5	77.2	65.2	51.4	36.5	73.9
Mean predicted	91.0	84.6	76.0	65.3	56.8	47.5	73.5
Prediction Error	-0.4	0.1	-1.1	0.0	5.4	11.0	-0.4
Stdev Measured	2.4	2.0	4.7	10.6	11.6	9.1	3.5
Stdev Predicted	2.9	3.2	5.4	8.4	9.6	12.2	4.1

It is evident that the standard deviation (variance) of predicted statistical levels is uniformly larger than those observed by measurement. It is relevant to note that the measured data includes ambient noise, so the relatively large values, particularly at night, observed in L50-Lmin in predicted data can be generally ignored.

Figures 3A and 3B: LAeq,1hr prediction error



Considering day, evening and night metrics, analysis of the measured and predicted data for these time periods produced the following:

Table 5: Picton Rd Survey: Error in predicted mean daytime 0700-2200, evening 1800-2200 and night 2200-0700 levels compared with measurement results

	Lmax	L01	L10	L50	L90	Lmin	Leq
Mean Day	-0.4	0.64	-1.0	-2.74			-0.5
Mean Eve	-1.1	-0.8	-1.7	-2.8			-1.1
Mean Night	-0.3	-1.3	-3.1	-2.9			-1.4

4.2 Survey observations

1. Vehicle speed of transit is a complex parameter and should include a congestion function. For the freely flowing traffic involved in this project, predicted noise levels were lower than measured levels at lower traffic flow volumes, when the analysis of surveyed passby speed showed that vehicles tended to travel faster.
2. The length of roadway necessary for a reliable study is important and is affected by both the statistics of interest and by the relative magnitude of traffic noise against the ambient noise.
3. The presence of, and influence on measurement due to, ambient noise needs to be considered in the analysis of survey observations.

5. CONCLUSIONS AND RECOMMENDATIONS

The studies carried out and reported in this paper demonstrate the accuracy achievable using statistically based noise modelling for a stochastically variable source, examined in this paper for the complex example of a roadway. The procedures used in this paper ignore road surface type, vehicle height and operating conditions of the vehicles. Notwithstanding, it is shown that the predictive accuracy of modelling based on independently obtained input data, to receiver locations in close proximity to roads, is at least equal to, and generally superior to, models in widespread use.

More significantly, the procedures described enable the modelling of statistical noise level parameters generated by a stochastic source. These parameters are not readily available from other modelling procedures, all of which incorporate assumptions regarding the arrangement and propagation characteristics of the sources, together with a fundamental constraint in providing an evaluation valid only for a stationary model. The modelling procedures and the input data described above focus on the incorporation of statistical source position and emission properties applied to otherwise simple, classical and uncontroversial noise dispersion models.

When used in conjunction with inverse transformation sampling, to examine the potential impact on an existing locality, this modelling technique will facilitate substantial insight into factors leading to adverse noise impact from stochastically variable noise systems such as roads. It is considered that these modelling procedures will address the issues of variance, source distribution, multiplicity of sources, source dynamics and source uncertainty, all of which have been noted by Lercher & Schulte-Fortkamp [Lercher et al, 2003] and which impede an informed assessment of factors affecting noise annoyance.

The work described in this paper forms a part of a continuing research project being undertaken by the author.

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