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Effects of speed distributions on the Harmonoise model predictions

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Abstract [490] It is known that speed variation affects pass-by noise levels and the well developed speed level functions based on statistical and controlled pass-by methods have been produced for different road surfaces and categories of vehicle. Therefore the accurate prediction of vehicle noise from passing vehicles of known speed presents few difficulties. However, the pressing practical problem is how to assess the traffic noise produced by traffic streams over an extended period of time e.g. for the calculation of L_{den} . The problem is often more complicated in urban areas where the traffic flow is congested for a significant proportion of the day. It has been established that when traffic is freely moving the speed distribution of a given category of vehicle approximates to a normal distribution. It is possible from transport statistics to derive relationships between the width of the distribution (standard deviation) and the mean speed for different classes on different roads. However, under congested conditions the distribution is far from normally distributed. This paper examines the errors in noise prediction which would result if the mean speed was used for prediction purposes rather than the actual speed distribution. Examples are taken from real traffic data both for freely flowing and congested traffic.

1 THE HARMONOISE SOURCE MODEL

The source model [1] consists of two sources i.e.

- a source placed 0.01m above the road surface which in terms of sound power is 80% rolling noise and 20% propulsion noise and
- a source at 0.3m above the road surface for light vehicles and 0.75m for heavy vehicles which consists of 80% propulsion noise and the remainder rolling noise.

The sound power of the rolling noise is given by the well known relationship:

$$L_{WR}(f) = a_R(f) + b_R(f)\log\left[\frac{v}{v_{ref}}\right] \tag{1}$$

The sound power of propulsion noise is given by:

$$L_{WP}(f) = a_P(f) + b_P(f)\left[\frac{v - v_{ref}}{v_{ref}}\right] \tag{2}$$

A different set of coefficients in the above expressions are given for different categories of vehicles. Corrections are made for the different number of axles, road surface, temperature, acceleration/gradient etc. There is also a directivity correction which is ignored in the treatment outlined below.

In order to predict the equivalent continuous sound level L_{eq} at the roadside for different speed distributions on a long straight road it is necessary to calculate the sound exposure level (*SEL*) from the sound power level L_W of the different category of vehicles.

It can be shown that in a given frequency band:

$$SEL = L_W - 10\log v + 10\log(d) + 10\log\alpha - 10\log\left[4\pi(d^2 + (h_r - h_s)^2\right] - \Delta L \tag{3}$$

Where v is the vehicle speed in m/s, d is the distance of the microphone from the source, α is the angle subtended during the integration (assumed to be π radians) and h_r and h_s are the heights above ground level of the receiver and source respectively. ΔL is a term included to account for reflections effects. For a highly reflective road surface and the low source this is close to 6dB.

If the hourly flow on the road is n_c vehicles of category c then the L_{eq} over one hour is given by:

$$L_{eq} = 10\log\left[\frac{\sum_c n_c 10^{\frac{SEL_c}{10}}}{3600}\right] \tag{4}$$

For simplicity in the calculations below it is assumed that all vehicles pass the microphone at the same distance d from the receiver and that the broad band A-weighted level L_{Aeq} is employed.

2 FREELY MOVING TRAFFIC ON HIGH SPEED ROADS

Where vehicles are not impeded or freely moving it has been found that the speed distribution approximates to a normal or Gaussian distribution. Early work suggests that the standard deviation of the speed distribution of traffic (all types included) σ is approximate one-fifth of the mean [2] over wide range of road types.

The UK Department for Transport publishes annual speed data based on measurements of many thousands of vehicles. This is in the form of the average speed and the percentages P_l exceeding various speeds S_l at and above the posted speed limit [3].

Assuming a normal distribution of vehicle speeds as shown in Figure 1, for a given probability the standard deviation can be estimated if the average value S_0 is known.

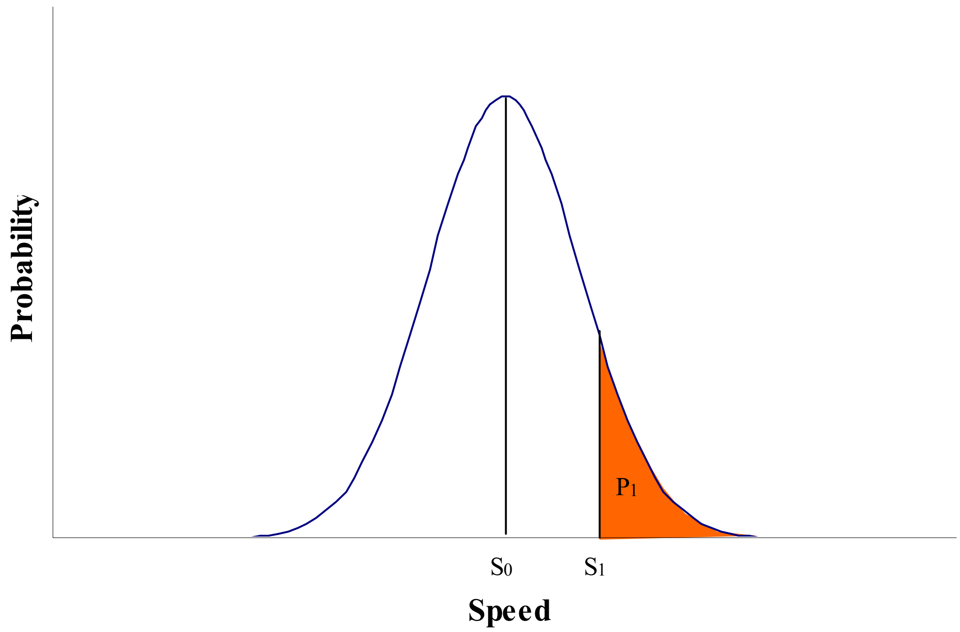

Figure 1: *Normal distribution assumed for analysis of speed effects*

The standard deviation σ can be obtained from:

$$S_1 - S_0 = F\sigma \tag{5}$$

where F is the fraction of a standard deviation which leads to the observed percentage at speed S_1. The value of F was obtained from statistical tables by entering the percentage expressed as a probability P_1. For each vehicle type shown in Table 1 the value of σ was estimated at two speeds and then averaged.

Vehicle class	Number observed (thousands)	Average speed (m) (km/h)	Estimated standard deviation (σ)	σ/m
Motorcycles	2,468	114.3	27.97	0.245
Cars	409,120	112.7	18.56	0.165
Light goods	45,846	111.0	18.19	0.164
Buses and coaches	3,388	96.6	8.75	0.091
2 axle trucks*	23,556	96.6	15.44	0.160
>2 axle trucks*	47,316	86.5	5.88	0.068

*Over 3.5 tonne gross weight

Table 1: *Vehicle speeds on UK motorways subject to 113km/h (70mile/h) speed limit (based on 27 sites)*

It can be seen that generally the heavier the vehicle the smaller is the σ/m ratio. In the UK the speed limit for heaviest trucks is 96km/h (60 mile/h) and in practice many trucks are driven close to this speed resulting in the relatively small ratio. In contrast car drivers and especially motorcycle riders are often driving in excess of the posted speed limit and the speed variation is consequently significantly wider.

Equations (1), (2) and (3) were used in the assessment of the importance of speed distribution rather than average speed for determine L_{Aeq} levels. As an illustration three vehicle categories were examined i.e. cars, 2-axle trucks (with weights over 3.5 tonne) and heavy trucks with more than 2-axles. The parameter values for the equations were obtained from the source model report of WP1.1 [3]. The values of m and σ were obtained from Table 1. The hourly flow was assumed to be 3600 vehicles. The percentages of vehicles falling in bands of width 0.5 σ in the range $\pm$ 3.25 σ were calculated from normal statistics.

Vehicle type	L_{Aeq} [dB(A)]			Increase in speed to achieve equality (km/h)
	Based on average	Based on distn	Difference	
Cars	82.25	82.45	0.20	2.3
2-axle trucks	84.62	84.90	0.28	2.8
>2-axle trucks	87.78	87.83	0.05	0.5

Table 2: *Hourly L_{Aeq} based on speed distribution and on the average speed*

It can be seen that there is a small increase in L_{Aeq} if the speed distribution is used in the calculation rather than the average speed. The right-hand column lists the increase in average speed that would be needed to obtain the same result as the value based on the speed distribution.

3 TRAFFIC IN URBAN AREAS

Traffic in urban areas is often not freely moving however at certain off-peak hours especially at night the speed variation is likely to approach the Gaussian distribution. UK Department for transport statistics were used to compile the data in Table 3 using the approach adopted in the previous section.

Vehicle class	Number observed (thousands)	Average speed (m) (km/h)	Estimated standard deviation (σ)	σ/m
Motorcycles	741	46.7	14.39	0.308
Cars	54,117	49.9	9.70	0.195
Light goods	4,337	51.5	8.37	0.163
Buses and coaches	505	45.1	8.91	0.198
2 axle trucks*	1,319	49.9	9.25	0.185
>2 axle trucks*	462	49.1	7.71	0.157

*Over 3.5 tonnes gross weight

Table 3: *Roads subject to a 52km/h (30mile/h) speed limit (based on 30 sites)*

It can be seen that the σ/m is generally significantly larger than is the case for motorway traffic indicating a greater relative variation in speed. It is also noticeably that the average speeds and standard deviations do not differ so widely between vehicle classes as is the case for motorway traffic. This is because individual vehicles are constrained to travel at relatively low speeds by the low speed limit, congested traffic and frequent junctions. The exception is motorcycles which is not surprising since they are more able to weave between stationary or slow moving traffic. It is likely that the assumptions concerning a normal distribution are not so robust in such cases due to periods of congested traffic so that the estimates of standard deviation could be misleading. Information concerning detailed speed profiles of traffic on an hourly basis is difficult to find but useful information was provided by the traffic authorities in Paris.

Figure 2 gives the counts of vehicles falling in the following speed bands for selected hours throughout the day and night: 0-10, 10-15, 15-20, 20-25, 30-35, 35-40, 40-45, 50-55, 55-100 and >100 km/h.

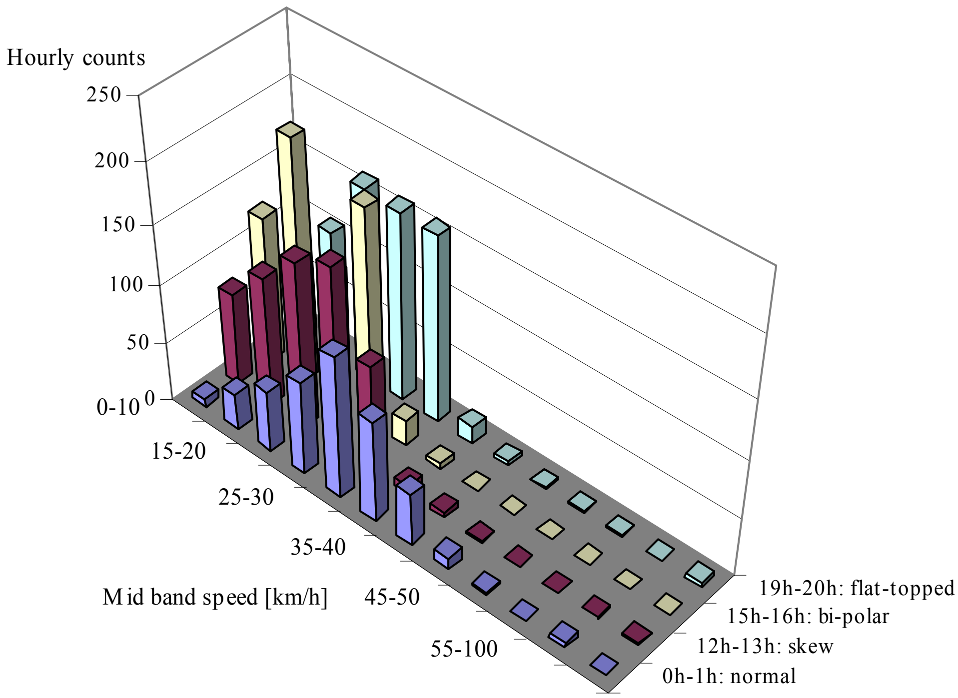

Figure 2: *Speed distributions at selected hours during the day and night*

It can be seen that the speed distribution changes from a normal distribution during low flow conditions to flat-topped, skew and bi-polar distributions during congested periods.

The data was not detailed enough to allow individual vehicle speeds to be logged so for the purposes of this analysis it was assumed that two types of vehicle were present i.e. cars and two-axle delivery trucks. The heavier vehicles making up 15% of the total count in any one hour. It was also assumed that the speed distributions of the two vehicle classes were similar. Using the analysis outlined in the previous section the L_{Aeq} in each hour was computed based on the average speed and the distribution.

Table 3 summarises the results:

Speed distribution	L_{Aeq} [dB(A)]			Increase in speed to achieve equality (km/h)
	Based on average	Based on distn	Difference	
Normal (theoretical)	64.19	64.43	0.24	2.20
Normal (measured)	64.13	64.53	0.40	3.60
Flat-topped	65.57	66.18	0.61	9.66
Skew	64.93	65.71	0.78	11.02
Bi-polar	65.41	66.27	0.87	15.29

Table 4: *Hourly L_{Aeq} based on speed distribution and on the average speed*

It can be seen that generally the greater the departure from a Gaussian distribution the larger is the difference between L_{Aeq} based on the average speed and on the actual distribution. The largest difference is for the bi-modal distribution where the average speed was lowest (15.4 km/h). This probably results from a mixture of heavily congested and more freely moving conditions. Larger speed increases are required to achieve equality due to the fact that at relatively low speeds above 10km/h the SEL does not change very quickly with increasing speed. To illustrate this point Figure 3 shows the speed variation of SEL for category 1, 2 and 3 vehicles. Note the minimum near the average speed.

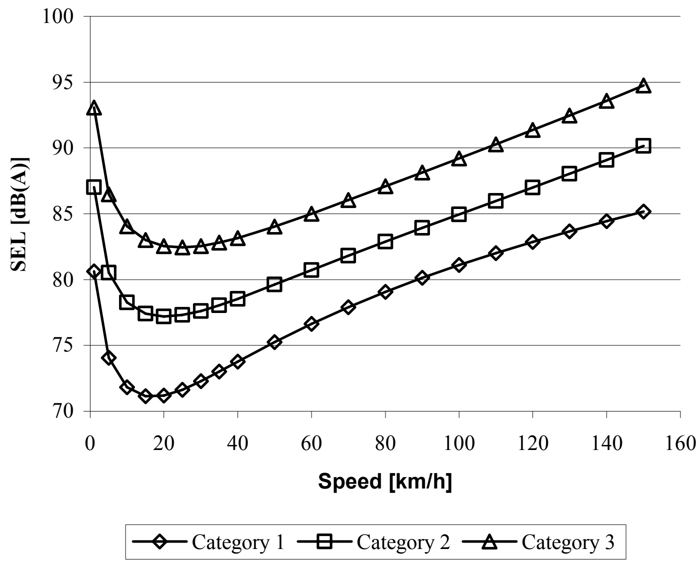

Figure 3: *Variation of SEL with vehicle speed*

4 CONCLUSIONS

The following conclusions can be made for the calculation of L_{Aeq} based on the average speed and the actually measured speed distribution.

- For freely moving traffic the speed distribution approximates to a normal or Gaussian distribution. Under these conditions the L_{Aeq} based on the average speed underestimates the L_{Aeq} based on a speed distribution from between 0.05 to 0.28 dB(A). The smallest difference occurs for the heaviest vehicles where the standard deviation is smallest.
- Data collected in urban areas suggests that speed variation expressed as a ratio of average speed is relatively large compared with the situation under free flow conditions on high speed roads.
- These urban data indicate a complex pattern of changes in speed variation over 24 hours. Under low flow conditions vehicles are freely moving and the speed variation approximates to a Gaussian distribution. Under more congested conditions the distribution becomes flat-topped or skewed. Finally, under heavily congested conditions a bi-modal distribution can be observed.
- For these urban conditions it was found that the L_{Aeq} based on average speed was up to 0.9 dB(A) lower than that based on the distribution of speeds obtained from the local highway authority.

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