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PREDICTION OF TRUE ROAD TRAFFIC LN

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ABSTRACT
L_N predictions are required for many building and verbal communication facilitation applications. As manual calculation is not feasible, a computer algorithm is presented. In this new algorithm, statistical analysis is done on the receiver sound pressure levels, whereas in earlier models, it was done on the raw source levels. The new algorithm also gives L_{max} and L_{eq}. The results are compared with such predictions as are available from earlier programs in common use.

1 - INTRODUCTION
The design of buildings for traffic noise exclusion requires either a measurement or a prediction of the sound pressure levels (L_N) exceeded for specified percentages (N) of the relevant exposure time. This paper treats prediction only. Certain problems with verbal communication also require such design data. Most predictive models in current use, such as FHWA [1], CoRTN [2], RLS-90 [3], MITHRA [4], STL-86 [5], and ASJ-93 B [6] give the expected equivalent continuous level (L_{eq}). Although valuable for an assessment of the overall noise pollution this is unsuitable for building and communication applications, since it takes no account of peaks. Similarly, the British CoRTN [2] model, which gives a pseudo-L_{10} derived from regressions on observed L_{10}, is not generally suitable. Such models do not take account of the pattern of traffic flow throughout the period considered.
In the development of the present model, spot data for numerous vehicles, taken from Fleming et al [7] and Bowlby et al. [8] and Samuels [9] were converted to piecewise continuous functions. These proved similar to Samuels' [9] observed continuous real-time levels. The outputs of the new model are predictions at chosen receivers of real-time sound pressure levels, L_{max}, L_{eq} and L_N for the required values of N.

1.1 - Calculation procedure
In this model, the user chooses a collection of (usually) dissimilar vehicles from a catalogue, and enters the environmental data. The required outputs are nominated and the program produces them. The procedure is as follows:

1. Select Traffic Pattern from Catalogue
2. Define Geodesic Path, Speeds & Traffic Interruptions
3. Deviations from Geodesic
4. Geographical, Building & Atmospheric Data
5. Calculate S.P.L. at Receivers in Time Order
6. Rank Elements & Determine L_{max}, L_N & L_{eq}

1.2 - Mathematical consequences
The principal consequences of calculating L_N, instead of L_{eq} are that the passage of all vehicles must be simulated separately, and that the statistical analysis be done separately at every receiver. These arise from the intrinsic properties of these levels, as follows:

- L_{eq} is a mapping of acoustical energy, which is a Lebesgue measure, that is; the energy can be added and subtracted. Lebesgue measures have the following property: $p(h_1) + p(h_2) = p(h_1 \bigcup h_2) + p(h_1 \bigcap h_2)$,
- L_N is a level set which has the inverse property: $f^{-1}(L_N) = \{\Sigma I_t = N/100 \mid f(t) > L_N\}$

Both this algorithm and its component algorithms must be severally suitable for every vehicle. This is a tighter constraint than is usually required for statistical means.

2 - KINEMATICS

2.1 - Elementary manœuvres

All vehicle manœuvres can be reduced to one of three. These are constant speed motion, acceleration or deceleration, and braking to rest at a predetermined point.

Constant Speed

The constant speed manœuvre is the simplest and is the only one considered in most existing models. This speed is usually the legal speed limit, a speed near it or the maximum safe speed for the stream segment considered.

$$s'[t] = v_j$$

where $s[t]$ is the distance reached at time t, and v_j is the constant speed.

Acceleration

A careful examination of Bowlby's [8] results for many vehicles of various types shows their acceleration to be a constant (initial acceleration) multiplied by a factor such that the acceleration approaches zero as the velocity approaches the final speed. This factor must be raised to an odd power, and a cubic was found to give a good fit for all vehicles. Figure 1 shows the distance vs time curve for one vehicle together with the experimental data. The resulting differential equation is:

$$s''[t] = a\left(1 - \frac{s'[t]}{v_j}\right)^3$$

where a is the initial acceleration.

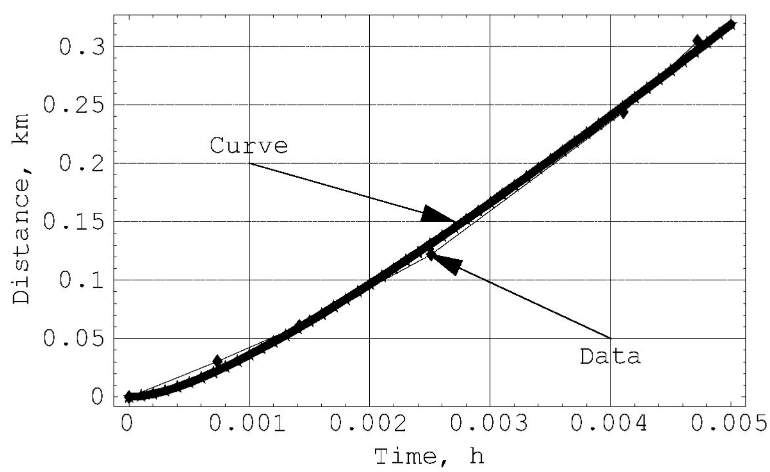

Figure 1: Typical acceleration of vehicles.

Braking to a Point

Braking to a point is different from mere braking in that the vehicle must come to rest at a preset point. Accordingly, the deceleration is not arbitrary. The resulting equation is:

$$s[t] = v_i t - \frac{v_i^2 t^2}{4d_i}$$

where v_i is the initial speed and $d_i$is the required distance.

2.2 - Logical conditions

The logical conditions determine the conditions under which the various manœuvres take place. There are four such conditions; these operate singly or in combinations. They are:

Position

This is self-evident.

$$cond1 \Rightarrow \{d_n \leq s\,[t] \leq d_{n+1}\}$$

Signalled intersections

The signal cycle has been represented as having a fixed time ratio for its different modes. Although some signal stations operate differently, the provision made here admits of examining the effects of various cycles.

$$cond2 \Rightarrow \{l_1 \leq l \leq l_2 \text{.......where } t \equiv l \bmod c\}$$

where l and c are cycle constants.

Unsignalled Intersections and Roundabouts

At these intersections, vehicles must give way to queues of various lengths. Such queues have a Poisson distribution.

$$cond3 \Rightarrow \left\{0 < l \leq Round\,[m.ranpi] \text{ ... where } t \equiv l \bmod Round\left[\frac{m.ranpi}{\sqrt{\mu}}\right]\right\}$$

where *Round* means to round off, *ranpi* is a random Poisson number for the ith position, and μ is the mean queue length.

Signalled Pedestrian Crossings

Signalled pedestrian crossing signals stop vehicles for a fixed time and are either on or off according to a Bernouli distribution.

$$cond4 \Rightarrow \{ranbp = 1\}$$

where *ranbp* is a random Bernouli number for the pth position.

3 - PARAMETRIC REPRESENTATION OF ACOUSTIC SOURCES

3.1 - Constant speed

The constant speed equation is taken from Fleming et al. [7], but with the constants adjusted to the performances of the individual vehicles in the selected pattern. Figure 2 shows the constant speed curve for a typical vehicle.

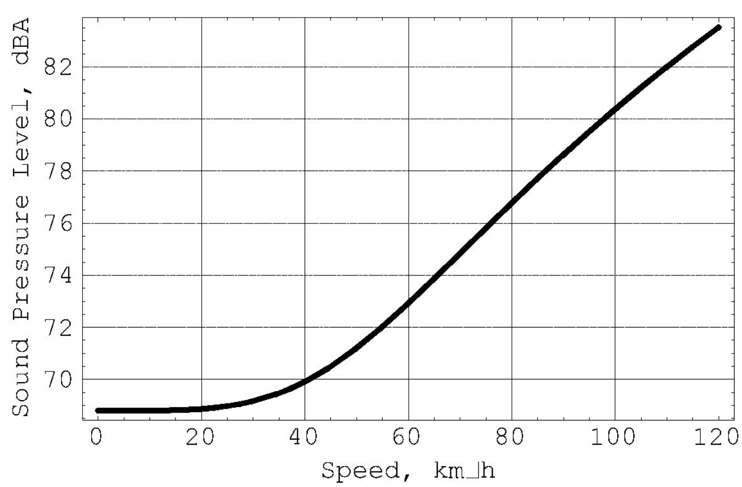

Figure 2: Typical sound pressure levels at constant speed.

3.2 - Deceleration

Tentatively, it is assumed that the levels arising from deceleration are the same as the constant speed levels. Figure 3 shows the curve for a typical vehicle decelerating to rest. It generally accords with curves shown by Samuels [9], but detailed data are not readily available elsewhere.

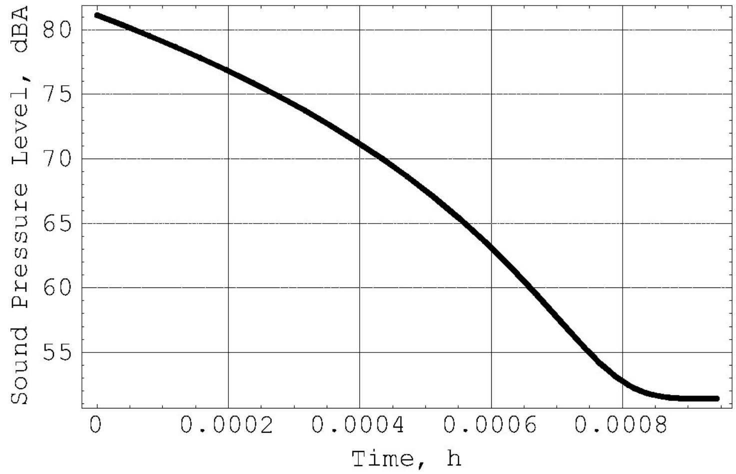

Figure 3: Tentative deceleration sound pressure levels.

3.3 - Acceleration

The sound pressure level curves are more complicated for acceleration than for the other manœuvres. Firstly, there is a discontinuity in the curve, which appears to comprise enriched mixture acceleration followed by an adjustment to the constant speed regime.

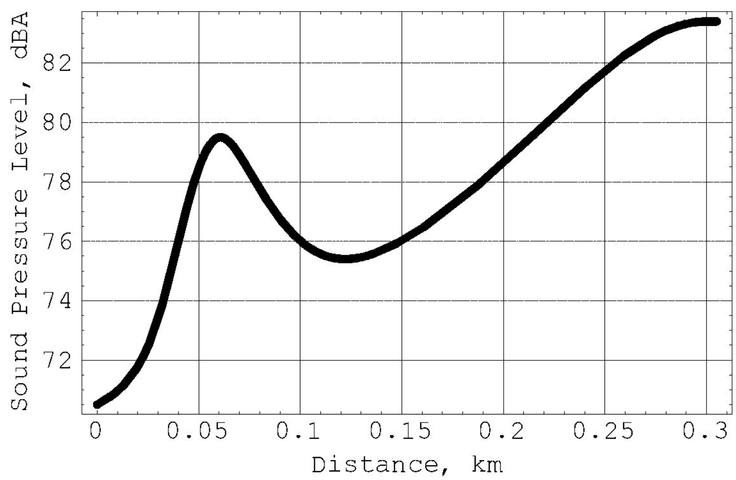

Figure 4: Typical first section of acceleration sound pressure levels.

Secondly, within each section, no simple function fits the data for any vehicle. However, by fitting successions of cubic splines to Bowlby's [8] data quite good curves resulted, similar to Samuels' [9]. It seems that whereas adjacent levels were simply related, more distant ones were not. Figure 4 shows the first section of a typical acceleration curve.

3.4 - Deviations from geodesics

Existing programs have corrections for gradient. In this program a correction is also introduced for curves in roadways and roundabouts.

4 - RECEIVER PREDICTION FOR A SIMPLE EXAMPLE

4.1 - L_p, L_{max}, L_N, L_{eq}

The existing models predict constant speed noise, some predict interrupted flow noise, and Mithra predicts acceleration. The present model predicts noise for all feasible conditions, but to compare results with the other models, it is necessary to restrict our predictions to constant speed or free flowing traffic.

Given:

Given a traffic pattern based on the 316 vehicles with complete data for Fleming's [7] Site 30, near Wrentham, Massachusetts, USA. The vehicles have random spacing and pass a receiver, 15 m from the road, in about one hour.

Aim:
The aim is to determine the real-time sound pressure level for the given pattern and spacing, the L_{eq}, and, say, L_{max}, L_1, L_{10}, L_{50} and L_{90}.
Method:
The vehicles are assumed to maintain the given sound pressure levels and the given speeds. For equal time spacing, but with the random distance spacing, the sound pressure levels at the receiver are calculated for the transit of all 316 vehicles. The concurrent levels are then added logarithmically. This is a table of real-time sound pressure levels for the given receiver. The result is plotted in Figure 5. In this example, the calculations were arranged for most of the vehicles to pass the receiver within approximately one-hour period (500 time units in Fig. 5). Because of the random spacing, some fell outside this period.

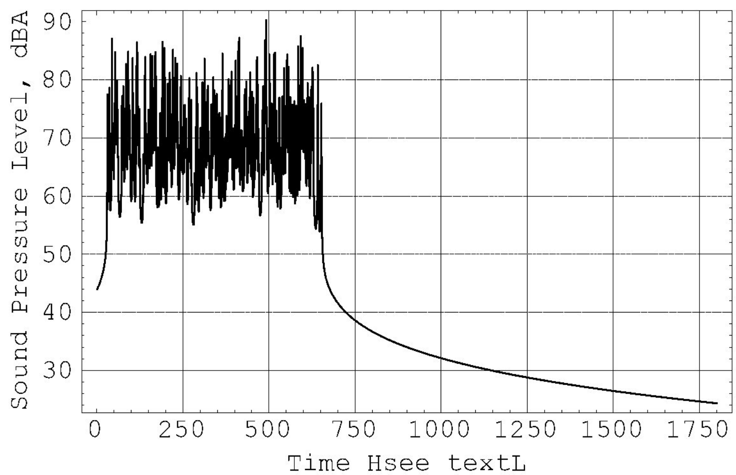

Figure 5: Predicted roadside sound pressure level for 316 vehicles.

The levels, which were plotted in Figure 5 are ranked in order and the values of L_{max}, L_1, L_{10}, L_{50} and L_{90} extracted. These are listed below and compared with such predictions as are available from other programs using the same data.

Model	Actual Levels	This Model *	FHWA	CORTN	RLS-90	MITHRA	STL-86	ASJ-93 B
L_{max}	90.3	89.7	—	—	—	—	—	—
L_1		86.5	—	—	—	—	—	—
L_{10}		79.0	75.4	77.6	—	—	—	—
L_{50}		65.8	—	—	—	—	—	55.4
L_{90}		57.0	—	—	—	—	—	—
L_{eq}		75.3	77.0	—	76.3	74.1	74.2	77.5

Table 1: Example (* these results depend on vehicle spacing, with a range of about ±1 dB).

5 - CONCLUSIONS AND DISCUSSION

None of the earlier models considered in this paper predicted a true L_N, thus errors were introduced by their mathematical procedures. FHWA, CoRTN, and ASJ gave pseudo-L_{10}, pseudo-L_{10} and pseudo-L_{50} respectively. None took account of traffic pattern. Five of the earlier models predicted L_{eq}, with a range of 3.4 dB and the new model gives an L_{eq} about the average of the others. These variations are partly due to imprecise and different corrections for road surface texture. The value of L_{eq} also depends on whether given vehicles transit within the selected time period or not.
The range in L_{eq} predictions suggest a need for more quantitative research on the requisite corrections for road surface texture. More research on the acoustics of deceleration is also indicated.

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