Validation of Environmental Noise Model (ENM Windows)

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1. INTRODUCTION

The Environmental Noise Model (ENM) simulates outdoor sound propagation and predicts noise levels from known noise sources for close and distant locations. The Model calculates attenuation due to noise source enclosures and other noise control measures, for distance from the source to the receiver, for the noise source size, type and directivity, for barriers and natural topographical features and for sound absorption in the air.

Excess attenuation from ground absorption effects such as those due to vegetation, bare ground or hard surfaces are derived using the most recently available scientific theories. Weather conditions such as wind speed and direction and the vertical temperature gradient of the atmosphere are also accounted for. Program ENM provides both a detailed quantitative output of each algorithm for each source or plots a noise contour map predicted for the area of concern. Other ENM Windows features include the following;

- ENM capacity allows for 1000 sources.
- Source directivity spectra at any selected angular point or 20 ISO points. Horizontal and vertical angle increments can also be specified.
- Both a plan and elevation view of barriers can be drawn to take account of finite width barriers.
- Individual points in Map contours can have their own Z co-ordinate so that ridge lines and sloping barriers can be incorporated.
- Automatic batching is available to enable faster runs with different meteorological conditions. Output is immediately available in a window. Contours are automatically coloured and labelled with dB(A) values (see Figure 1, for example).
- Full hardware support for any device capable of running under Windows 3.1 and Windows 95 including digitisers, plotters and printers.

ENM was developed by RTA Technology Pty Ltd of Sydney, Australia [1]. Since its first released in 1986, it has found international acceptance. The introduction of ENM Windows results in a simpler and uniform user interface and makes the program simpler to learn using the on-line help system. In this paper, the program's features are described together with a review of its accuracy reported in practical situations.

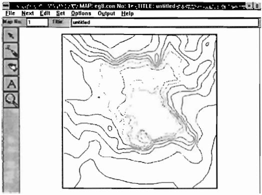

Figure 1. Example of Contour Output

2. ENM Calculation Algorithms

The basic format for the calculation in ENM is as follows;

$$L_p = 10\log_{10}\sum_n 10^{L_n/10} \qquad (1)$$

where the sound level from source n is

$Ln = Lw + D - A_1 - A_2 - A_3 - A_4 - A_5$

and Lw= sound power level dB re 10^{-12} watts, D = source directivity, A_1 = attenuation for geometric spreading, A_2= barrier attenuation, A_3 = attenuation for air absorption, A_4= attenuation for wind and temperature effects, and A_5 = ground attenuation.

Sound Power Level Lw

The ENM program allows the source sound power level to be input in spreadsheet format (see Figure 2). Sources may be enclosed or unenclosed. If the source is unenclosed then the sound power level is specified in the normal way. If the source (or a group of sources) is enclosed then one needs to specify both the sound power levels of the sources and the acoustic properties of the enclosure walls. Enclosures are defined as a collection of rectangular surfaces with an absorptive face on the side nearest the source and having a sound transmission loss. ENM works in both 1/3rd octave and 1/1 octave format from 25Hz to 20kHz.

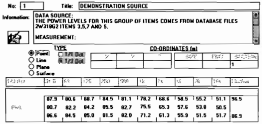

Figure 2. Noise Source Input Spreadsheet.

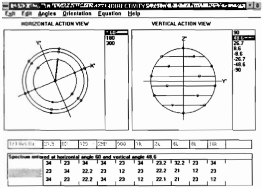

Figure 3. Directivity Correction Spreadsheet.

Directivity Correction

A frequency dependent directivity correction term is included in the ENM model and is based on either array co-ordinates recommended in ISO 3745 - 1977 or user selected angle increments (see Figure 3). These co-ordinates are points on the surface of a hypothetical sphere whose centre coincides with the acoustic centre of the source [2]. The program interpolates values for directions of source to receiver which do not coincide with these array co-ordinates.

Geometric Spreading - A_1

All sources are considered firstly in the absence of the ground, that is, as if they were suspended in a free field. Sources are of three types: point, line and plane. Traffic can be modelled by defining a series of point sources along the route, the spacing between them being set to a value no greater than three times the distance of the nearest residential receiver to the road. Other noise sources which can be modelled include trains, helicopters and aircraft.

Barrier Attenuation - A_2

The Maekawa theory for predicting noise reduction from barriers is commonly used today. New developments in this field [3,4,5], however, include the influence of the ground on both sides of the barrier. At certain frequencies, the ground effect can become more important than the barrier attenuation and hence the results based on an ideal half infinite barrier can be substantially in error. Other complications arise when

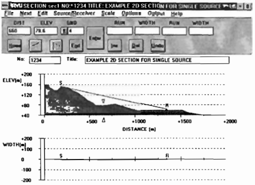

Figure 4. Ground Cross-section.

the barrier is not infinitely wide, as is assumed by Maekawa's theory. ENM Windows incorporates the usual method of calculating the noise contribution around the sides of the barriers by Maekawa's algorithm.

Ground contours are digitised in the ENM program as a sequence of co- ordinates (see Figure 4). The topography of the ground in a straight line between the source and the receiver is determined by scanning co-ordinate pairs A hypothetical thick barrier is then constructed according to the maximum angle subtended to the topographical feature as viewed alternatively from the source and receiver.

Air Absorption - A_3

The algorithm for the calculation of air absorption is based on American National Standard ANSI S1.26 [6]. The ENM program calculates the value of air absorption in third octaves and logarithmically sums the result to one-third octaves or octaves as required.

Wind And Temperature Effects - A_4

The effects of refraction of sound in the atmosphere can best be thought of in terms of sound ray propagation. Curvature of sound ray paths is a result of variations in the speed of sound with height. Sound speed variations can either be caused by changes in air density due to temperature or simply by the movement of the air medium itself. Intuitively, one would expect that sound speed variations caused by a combination of these two effects would be additive. Examination of measurements conducted by Parkin and Scholes shows there is some evidence to support this theory [7].

In the case of open terrain, data from Parkin and Scholes [8] as summarised by Piercy [7] for observed excess attenuation of ground-borne aircraft noise measured under a variety of weather conditions was classified in terms of the total vertical sound speed gradient. Values of A_4 are interpolated for other distances except that saturation is assumed to occur farther than 616 metres and for values of total sound speed gradient greater than 0.15. Wind and temperature effects on barriers are treated in a similar manner to DeJong [9]. In essence, the height of source and receiver are modified to take into account the ray curvature.

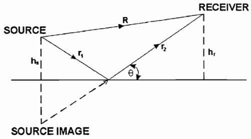

Figure 5. Geometry for ground absorption algorithm.

Ground Attenuation - A_5

Propagation of sound from a source placed above a semi-infinite ground plane has been extensively reviewed. Reference to Figure 5 shows that specular reflection may be considered simply by creating an image of the sound in the ground. The expression of the plane wave reflection coefficient R_p may be written as [10];

$$R_p = \left[\frac{\sin\theta - (\rho c / Z_g)}{\sin\theta + (\rho c / Z_g)}\right] \quad (2)$$

where θ is the angle between the ground and the incident or specularly reflected wave, ρc is the characteristic impedance of air, 407 SI rayls, and Z_g is the impedance of the ground surface and is given by [10]

$$Z_g = \rho c\left[1 + .0571\left(\frac{\rho f}{\varphi}\right)^{-0.754} - i0.087\left(\frac{\rho f}{\varphi}\right)^{-0.732}\right] \quad (3)$$

where f is the frequency and φ is the ground surface flow resistivity, SI rayls/m. The surface flow resistivity is defined to be the pressure gradient required to induce unit flow velocity in the bulk material. Eleven values of flow resistivity for various ground surfaces are incorporated in the model ranging from snow to grass, exposed earth to asphalt [11].

The sound pressure at the receiver is determined from;

$$p = \frac{e^{-ikR}}{kR} + R_p\frac{e^{-ik(r_1+r_2)}}{k(r_1+r_2)} + \left[1 - R_p F(\omega)\frac{e^{-ik(r_1+r_2)}}{k(r_1+r_2)}\right] \quad (4)$$

The ENM algorithm calculates values of A_5 at one-ninth octaves and combines these to third-octaves or octaves as required.

In the ENM program, a ground type code is input along with other contour information. A vertical cross-section of the ground is taken from each source to receiver point in order to calculate barrier effects. In the ENM model, a choice is made to average the ground types in cases where there is not a single ground type. There is no physical justification for this decision, rather, it is a temporary measure to be replaced when more is known about the effects of changes in ground types.

Whenever a barrier is interposed between source and receiver, the reflection angle θ is calculated for two cases; first the receiver is placed at the top of the barrier and θ_s is calculated on the source side. Secondly, the source is placed at the top of the barrier and θ_r is calculated for the receiver side. The value of θ is then taken to be the average of θ_s and θ_r. Again, this methodology is taken to be a temporary measure until more is known about the performance of barriers in the presence of the ground.

3. Validation and Accuracy

a) Impulse Noise

Work on verification of the Environmental Noise Model began immediately after its release. Mitzia [12] set up an impulsive point source of sound and measured noise levels at various distances and for a number of meteorological conditions. The results are shown in Table 1.

Table I. ENM modelling accuracy reported by Mitzia [11].

Distance from source (m)	25	50	100	200	400	800
MET1 Lc-Lm std dev in measured Lm	0.7	3.0	0.1			
MET6 Lc-Lm std dev in measured Lm		4.8	4.4	2.8		
MET7 Lc-Lm std dev in measured Lm			3.7	1.4	5.1	
MET9 Lc-Lm std dev in measured Lm				2.7	8.5	3.4

Lc=Calculated dB(A) noise level, Lm=Measured dB(A) noise level, MET=Specific meteorological conditions encompassing wind speed, direction, temperature, humidity and vertical temperature gradient.

At most points, the difference between measured and calculated noise levels is less than 5dB(A) except for one point at 400m from the source. This point corresponds to a location just behind the apex of a hill where air is subjected to considerable local turbulence. The meteorological conditions at this point were different to that measured 400m from the source in another direction along the slope of the hill.

b) Industrial Noise

Validation of ENM at a steel works in an industrial area of a town in the North of Italy was reported by Cerrato etal [13]. The subject area is traversed by a railway and is close to the slope of a mountain. Sound pressure levels were measured at various locations both day and night.

The principal noise sources included the smelting furnace, smoke extraction system, the rolling mill and the pickling fans. In the first instance, sound power levels were determined using sound pressure level measurements close to the sources of noise. The paper shows good correlation between the measured and calculated third-octave band spectra at two of the locations chosen for checking the calibration of the model. The program was subsequently used to model noise contours around the steel plant for the purpose of determining best methods of noise control.

An intense long-term noise study was reported by Moller and Brown [14]. Boyne Smelters Ltd operates a modern aluminium smelter in Queensland, Australia. The smelter is located some 1000m from the nearby Boyne Island/Tannum sands community (5,000 people). ENM was used to calculate noise levels in the community - the modelling established the area of the community predicted to be "routinely affected" by noise from the smelter. In addition it allowed quantification of the few identified dominant noise source contributions to be made as well as the extent of practical attenuation that could be applied to each source.

Source sound power levels were first measured using directional microphone techniques. The features noted during the measurement process included plant layout, external elevations of buildings, cladding types, wall/roof ventilators, specific noise source locations and operation times of plant equipment.

A total of 104 noise sources were quantified but subsequent analysis showed that only 18 were significant. Modelling input data included topographical data at 5 metre contour intervals, vegetation density estimates and locations of natural and man made features. Noise contours were produced to determine the extent of the community exposed to excessive noise levels for various meteorological conditions.

The predicted noise levels were verified by taking a total of 287 measurements at 95 locations between the hours 2115 and 0515 every day. It was concluded that 75% of all predicted values were within ±3dB(A) of the measured value and 90% of all predicted values fell within ±4.9dB(A) of the measured value.

c) Traffic Noise

ENM has been used to predict traffic noise on most motorways and freeways in Sydney including the M2, M4, M5, M5 East and many other secondary transport corridors. The modelling method most commonly used [15] is to simulate traffic as a discrete series of point sources of sound power level L_{wi} spaced a distance b apart where;

$$L_{wi} = L_{po} + 10\log(r_o b) + 3 \quad (5)$$

where, L_{po} is the sound pressure level at a distance r_o metres from an infinitely long line source of traffic noise. The value of L_{po} is taken from either CORTN [16] or FHWA [17] algorithms as required by the user. In most cases, the distance b in metres is selected to be between 20m and 50m and in any case is less than or equal to three times the minimum distance between any receptor point and the road.

Noise contours were produced for the M5 west of King Georges Road using ENM. The road surface and the adjacent landforms were digitised and input into ENM. For this section of the motorway, an 80km/hr design speed was used to generate vehicle sound power emission levels using the CORTN algorithms as described above.

Table II shows the accuracy of the model at multiple locations between Fairford Road and the King Georges Road intersection. It is clear from the table that the ENM/CORTN noise model is generally conservative.

Table II. Comparison of measured and predicted traffic noise levels.

POSITION	PREDICTED		MEASURED	
	Leq(24hr)	Leq(8hr)	Leq(24hr)	Leq(8hr)
15 Windarra St	54	44	52	46
56 Parry Ave	53	43	48	<41
28 Grove Ave	54	44	48	44
22 Iris Ave	56	46	53	45

The accuracy of the ENM model in predicting source-to-receiver attenuation was tested by comparing actual and predicted noise levels from a truck pass-by. Figure 6 shows a comparison of the measured and predicted noise level from a single truck pass-by on the M4 motorway at Sapphire Street, Pendle Hill in Sydney.

The measured truck sound power level was input into ENM and the sound pressure levels predicted at a receiver point for the case of the truck located at various chainage points along the road. By way of explanation, the metric distance measured along the centre line of the road referenced to the start of the road is called the "chainage". As the truck travels along the road, it passes each chainage point. The receiver point is located directly opposite chainage point 28025 (approximately) so that the sound level of the truck is at a maximum here. In most cases, the difference between the measured and calculated sound pressure levels at the receiver location is within measurement error.

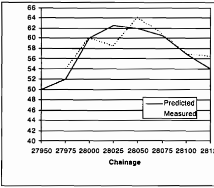

Figure 6. Comparison of Predicted and Measured Noise Levels of Truck Passby.

d) Train Noise

ENM was used to predict train noise on the East Hills railway line in the southern suburbs of Sydney. Measurements were conducted at three points on flat land on an imaginary line orthogonal to the rail track but at different distances from the railway line. The sound power level of the train was determined from the sound pressure level at the nearest point. The attenuated sound pressure levels at the other two locations was predicted using ENM and are shown in Table III.

Table III: Comparison of Measured and Predicted Train Noise Levels

Distance From Track	Measured Noise Level Lavmax	Calculated Noise Level Lavmax
15	89	-
65	80	81
148	75	74

CONCLUSION

ENM has proven to be a popular and useful acoustic tool to provide accurate prediction for a wide range of environmental noise sources. Improvements are being made to the algorithms as more information becomes available. Improvements are also being made to interfaces with other programs, such as Windows and graphic packages. Thus the program has become even simple to use, without any decrease in the accuracy of the predictions, and noise level contours can be clearly presented, see Figure 7 and front cover.

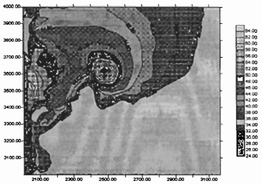

Figure 7. Example Contour Output.

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