UTILIZATION OF GEOGRAPHICAL INFORMATION SYSTEM FOR SIMULATION OF TRAFFIC NOISE

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Abstract: This research is aimed at the study of using Geographical Information System (GIS) for highway traffic noise forecasting and also for the presentation of traffic noise results in the form of noise contour lines. The US's FHWA traffic noise model together with the UK's CORTN model are used as basic models in this GIS platform for the analysis of the free flow traffic noise from the highway. The digital map is applied for providing data on physical conditions of the highway. Traffic characteristics on the highway section can be input through the tabulation. Information on the dimensions and alignment of line and block barriers along the side of highway can also be input for investigating the noise levels behind these barriers. The simulated traffic noise level from this system can be shown as a single or group of points around focused locations, or in noise contour line format overlay on digital base map. The validation test of this system performance shows the good estimated traffic noise results with errors less than 0.15%.

Key Words: geographical information system; GIS; highway traffic noise; simulation of highway noise; traffic noise forecasting.

1. INTRODUCTION

Noise from traffic creates increasingly greater environmental problems [Bugliarello, Alexandre, Barnes, Wakstein, 1976]. This is due to the increase in vehicle numbers on roads and highways. Traffic noise analysis and estimation, using traffic noise models, is one of the most important preventive measures in traffic noise control [Nelson, 1987, Pamanikabud, 1990]. The traffic noise levels along roads and highways can be forecast. Thus, noise mitigation measures can be applied to control traffic noise from roadway projects in the early stages of planning and design of roadways. This study views the use of geographical information system (GIS) for highway traffic noise simulation [Bennion, O'Neill, 1994, Anderson, Souleyrette, 1996, ESRI, 1996, Sutton, 1996] and also for the presentation of traffic noise results in the form of noise contour lines. In this study, the US's Federal Highway Administration (FHWA) traffic noise model [Barry, Reagan, 1978] together with the UK's Calculation of Road Traffic Noise (CORTN) model [Department of Transport, 1988] are used as basic models in this GIS platform so that they can be used for the analysis of uninterrupted flow or free flow traffic noise from the highways. The digital map can also be applied for providing basic data of physical conditions of the highway into the traffic noise analyses.

2. DEVELOPMENT OF GIS SYSTEM FOR HIGHWAY NOISE FORECASTING

This study utilizes the geographical information system (GIS) in the analysis and presentation of noise levels from traffic. Thus, the impact result of traffic noise from roadways can be easily understood. The GIS system in this study consists of two main parts of data, namely, spatial data and attribute data. These two databases are linked and can be worked together under the GIS platform, which makes this system very effective in analyzing traffic noise impact, since all the involved parameters in the analysis and different conditions of roadways can be easily changed and tested. Additionally, the analysis results can also be shown at any point of the study's location overlay on the digital base map. The ArcView 3.1 program [ESRI, 1996] is used in the development of GIS system for traffic noise forecasting under this project. Applications of the system's operation are fed into the system by writing script in the Avenue language [ESRI, 1996]. Several tools and dialog boxes are also used to simplify the operations of this system in forecasting roadway traffic noise. Each traffic noise model analysis consists of three operating sections, namely, input data, noise level analysis, and presentation.

In the first section of input data, there are two parts of development: The base map which is line type data that represents the center line of roadways. Secondly, the attribute data which reflects the physical conditions of roadways such as number of lane, lane width, roadway width, and traffic characteristics (i.e. traffic volume, combination of traffic, and traffic speed), together with other parameters being used in the analysis of traffic noise. The menu and several types of dialog boxes are applied to this section for data input. This is done by writing script to control the operation of this function. For the base map, this study develops system that can use the existing digital base map with the additional data given into the attribute of that map, or build its own new base map with the required data table. The data for both FHWA and CORTN models is stored in the same table that is linked to the spatial data of each particular roadway. Other than data on traffic and roadway conditions, the barrier data along the side of roadways can also be input in the form of a polygon due to the involvement of the barrier's thickness.

The second section, which contains the analysis for this GIS system, consists of calculation procedures of noise levels from traffic. Scripts are written into the GIS software with Avenue language [ESRI, 1996] in order to perform the analytical steps within the selected study area. After inputting the distance between each receiver point, the software creates an additional new layer, which consists of receiver points in the grid overlay on the selected area. Identification of each layer is then fed to the digital map such as line for road layer, point for observer layer, and polygon for barrier layer. The next step of the analysis is the selection of traffic noise forecasting models to be used in noise level calculations. This study utilizes two models, which applicable to the uninterrupted-flow traffic condition, namely, FHWA model of the USA, and CORTN model of the UK. These two models are based on two different sets of equations and calculation procedures, together with the difference in adjustment factors. Results of the noise level analysis from the selected models on all receiver points are stored in the attribute table of the receiver layer of traffic noise analysis procedures. The main calculation diagram is shown in **Figure 1**. If a noise barrier appears in the study area, receiver points inside the barrier boundary are taken out and the calculationis based on hard site condition for ground absorption and shielding adjustment. However, new receiver points on the angle of the barrier, as well as the center of each side of barrier, are added into the layer in order to increase analysis efficiency.

For result presentation in the third section of this GIS system, the traffic noise forecast system is developed to be able to present traffic noise levels at any particular point, or set of points in the study area. It can also be presented in the form of a grid network uniformly distributed over the study area. Further development also given by this study to present traffic noise results in the form of a contour line of noise levels by utilizing the Spatial Analysis [ESRI, 1996] that is an extension part of ArcView software. This contour line can also be applied in the different intervals of noise level in the analysis. In the event of attention given to any particular location, the distance spacing between receiver points can also be identified in order to analyze for the smaller and more detailed grid network of receiver points. Thus, the efficiency of displaying traffic noise contour lines can be increased. The application of different color and grayscale shades into the contour of different noise levels can also be shown in this system, so that the noise impact level can be easily seen and understood.

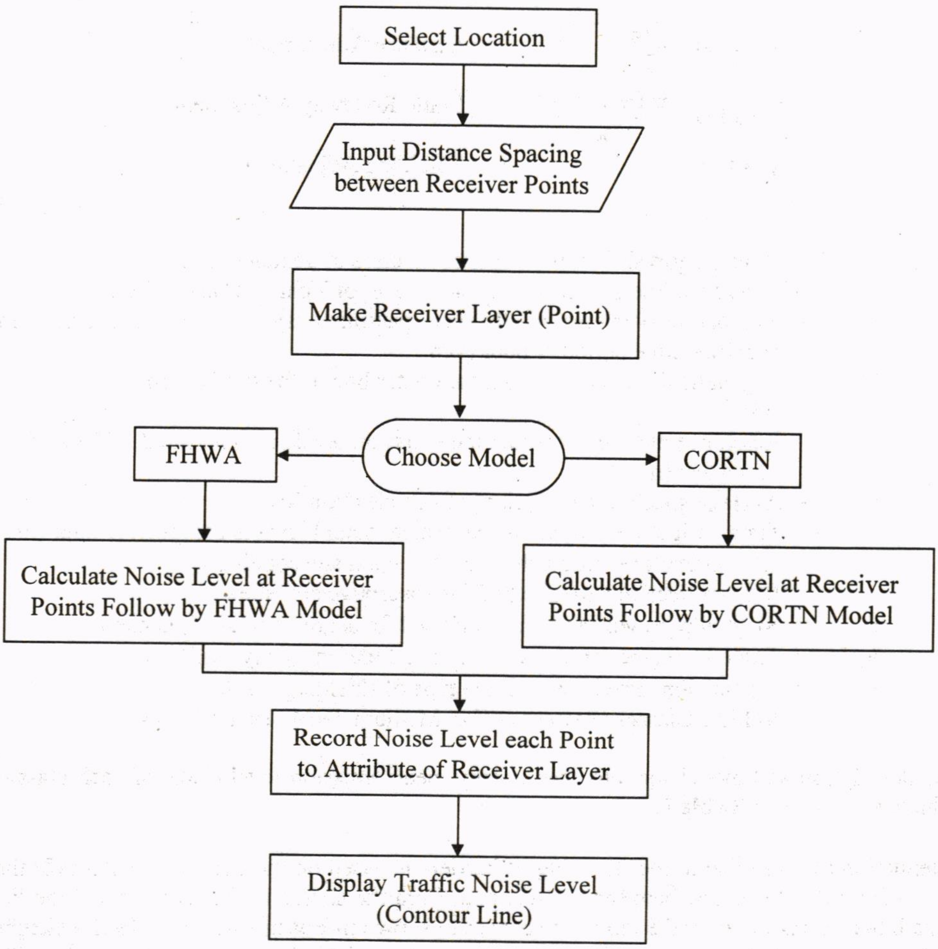


Figure 1. Main Calculation Diagram of Traffic Noise Level Analysis

3. OPERATIONAL PROGRAMING FOR ANALYSIS OF FHWA MODEL

Operational programs for the analysis and calculation of traffic noise, based on FHWA models, are developed by using attributes and linkages between the respective model's equations and input data. FHWA is the mathematical simulation model that has been developed in USA for analysis and forecasting of highway noise in the uninterrupted traffic flow condition [Barry, Reagan, 1978]. The estimated noise level from this model is in L_{eq} or Equivalent Noise Level index in the unit of dBA. This model separates traffic vehicles into three classes, specifically, passenger cars (<4,500 kg.), medium trucks (4,500-12,000 kg.) and heavy trucks (>12,000 kg.). The model can be mathematically described as follows.

$L_{eq}(h)_i = (L_0)_{Ei}$	Reference Energy Mean Emission Level
$+ 10 \log \dfrac{N_i \pi D_0}{S_i T}$	Traffic Flow Adjustment
$+ 10 \log \left(\dfrac{D_0}{D}\right)^{1+\alpha}$	Distance Adjustment
$+ 10 \log \dfrac{\psi(\varphi_1, \varphi_2)}{\pi}$	Finite Roadway Adjustment
$+ \Delta S$	Shielding Adjustment

.........(1)

where: $L_{eq}(h)_i$ = Hourly equivalent sound level of *i*th class of vehicles (dBA)
$(L_0)_{Ei}$ = Reference Energy Mean Emission Level of Vehicle Class i (dBA)
N_i = Number of vehicles in *i*th class passing a specified point during some specified time period, 1 hour (veh.)
D = Perpendicular distance, from the center line of the traffic lane to the observer (m)
D_0 = Reference distance at which the emission levels are measured. FHWA, D_0 is 15 meters (m)
S_i = Average speed to the *i*th class of vehicles (km/hr)
T = Time period over which the equivalent sound level is computed,1 hour (hr)
α = Site parameter whose values depend upon site conditions (0 for reflective hard site, 0.5 for absorptive soft site)
ψ = Symbol representing a function used for segment road adjustments
ϕ_1,ϕ_2 = Angle in degree for highway section under the analysis (°)
ΔS = Attenuation, provided by some type of shielding (dBA)
i = Vehicle Classes (Passenger Car, Medium Truck, Heavy Truck)

The description and model for reference energy mean emission level $(L_0)_{Ei}$ of each class of vehicle are shown in **Table 1**.

Attenuation of noise due to the shielding of barriers is based on the extra path length (δ) that occurs from the difference between a direct path from the source to the receiver and the line of path that is passing over the top of the barrier as shown in **Figure 4**. The effective heights of the source are applied to each class of vehicle in the calculation of extra noise paths. The Fresnel number is estimated from this extra noise path, and the final shielding adjustment is then obtained.

Table 1. Reference Energy Mean Emission Level $(L_0)_{Ei}$, FHWA model

Vehicle Type	Weight of Vehicle	Formula for Reference Mean Emission	Height of source
Passenger Car	< 4,500 kg	38.1 * log (S) – 2.4	0.00 m.
Medium Truck	4,500-12,000 kg	33.9 * log (S) + 16.4	0.70 m.
Heavy Truck	> 12,000 kg	24.6 * log (S) + 38.5	2.44 m.

Where: S = Speed of vehicle (km/hr)

3.1 Data Input for FHWA Model

Data for all of the necessity and essential parameters in the analysis of traffic noise based on FHWA model can be put into the system through the designed menus and dialog boxes. The data consists of physical conditions of highway (i.e. lane width, number of lane, roadway width, etc.), and the traffic characteristics (i.e. volume, combination, and average speed of each vehicle class). They can be separately put in two directions of highway for two-way highway or in one direction for a one-way highway. In general, all sections of one roadway line utilize the same road and traffic information. In case of roadway with multi sections that have different road and traffic characteristics, these different data sets can be input in the different dialog boxes that linked to each particular section of roadway. The example of data input into FHWA model is shown in **Figure 2**.

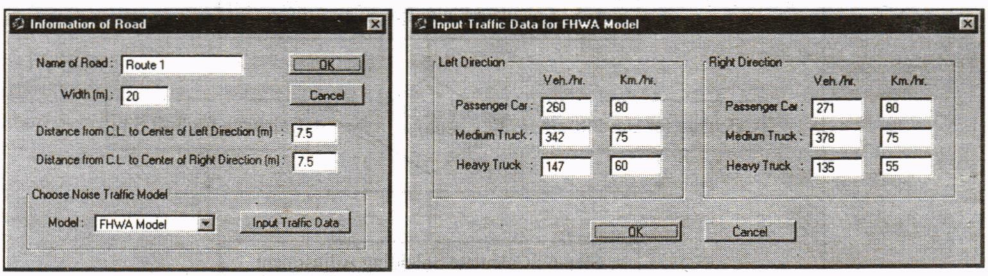


Figure 2. Dialog Boxes for Input of Data into FHWA Model

3.2 Analysis of Noise by FHWA Model

In the analysis of traffic noise using the FHWA model, noise level estimation is separated into three parts according to three classes of vehicles, specifically, passenger car, medium truck, and heavy truck. Within each part, there are three main calculations that require different set of models and equations, namely, reference energy mean emission level, traffic flow adjustment, and shielding or barrier adjustment. This is due to the different characteristics of the three classes of vehicles. The other calculations of distance adjustment, and finite road adjustment are the same for all classes of vehicles. After the noise levels from each class of vehicle are calculated, the final traffic noise of this roadway section can be obtained by a summary of noise levels from these three classes of vehicles together under a logarithmic scale. Since the coordination data is already installed in the GIS platform, it is not necessary to input data of certain parameters into the attribute tabulation such as distances, and angles.

Since this information can be estimated from the coordination of digital base map. The development is also given to the estimation processes of shielding adjustments from barriers in order to increase the analysis efficiency, especially in the case of block barriers with abnormal shape and angle. This is done by projecting the largest angle of barrier into the right angle perpendicular to the roadway centerline. The noise path difference being used in the calculation of shielding adjustment is then estimated along this perpendicular line. **Figure 3** shows the calculation procedures under the FHWA model.

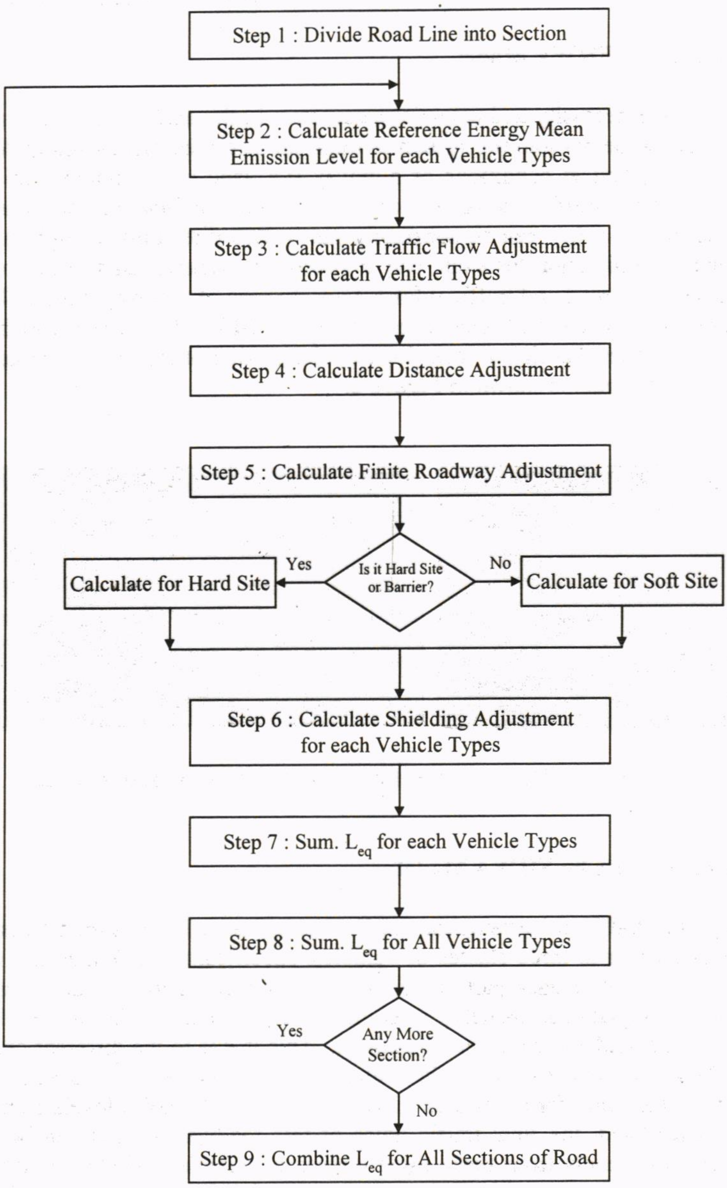
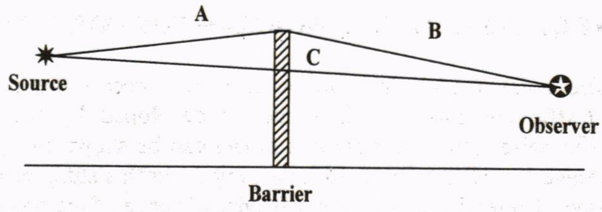


Figure 3. Calculation Procedures of FHWA Model in GIS Platform

In Step 1, if a roadway line is created by more than one straight line section (more than 2 coordination points), this line is divided into several small sections so that each section will have only 2 coordination points for calculation. The GIS system has coordinate data of every points in roadway base map, so it will choose only 2 points for one section of roadway and continue to next section by using next coordination point according to the roadway data in GIS. **Figure 4** shows the calculation of pathlength difference for the FHWA model. **Figure 5** shows the height of sources, barrier, and observers of the FHWA model for calculating of pathlenght difference for each vehicle type.



$$\delta = A + B - C$$

Figure 4. Pathlength Difference (δ) Calculation of FHWA model

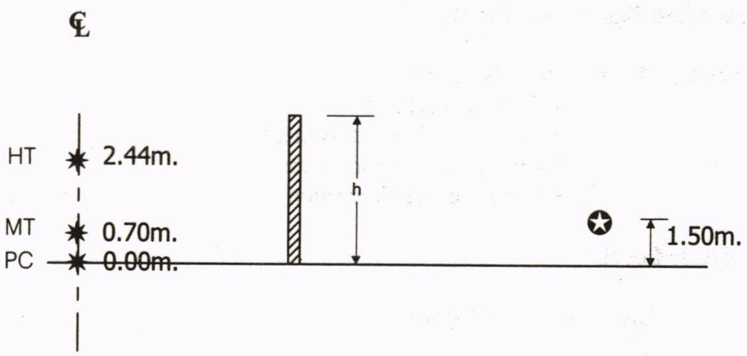


Figure 5. Height of Source from Different type of vehicles and Observer of FHWA model

The validation of this GIS system of FHWA model for traffic noise is then checked againt the spread sheet calculation using Microsoft Excel. These results are shown in **Table 2**.

The validation results of FHWA model are calculated on the following conditions: A two-lane roadway with the lane width of 3.5 meters, and operating speed of 75 km/hr. Given passenger car = 317 veh/hr, medium truck = 24 veh/hr, and heavy truck = 22 veh/hr for near lane and passenger car = 281 veh/hr, medium truck = 12 veh/hr, and heavy truck = 25 veh/hr for far lane. An observer is located 60 meters from centerline of near lane. The perpendicular distance between centerline of near lane and observer is 60 meters. The barrier is 4 meters high and distance from curb of road is 10 meters.

Table 2. Validate Results of Traffic Noise (dBA) between GIS System and Spread Sheet Calculation of FHWA Model

Condition	Spread Sheet	GIS system	% Error
No barrier	65.14	65.07	- 0.11
Infinite Barrier	55.68	55.61	- 0.13
Finite Barrier (150 m)	62.53	62.48	- 0.08

Units: dBA

4. DEVELOPMENT OF OPERATIONAL PROGRAM FOR CORTN MODEL

CORTN is the traffic noise model that can be used to forecast the noise level from uninterrupted flow traffic condition. This model is developed by the Department of Transport, UK. Traffic noise estimated from this model can be shown in L_{10} (dBA) for the loudest hour, and average L_{10} (dBA) for an 18 hour period. In this study project, the L_{10} for the loudest hour is used. Under this model, the reference distance of the point for calculating reference noise level is 10 meters from the nearest edge of the carriageway. Unless the carriageways are separated by more than 5 meters and when the level of outer edges of the carriageways differ by less than one meter, the road is assessed as one source line 3.5 meters from the nearest curb. The source is 0.5 meters above the road surface. [Department of Transport, 1988] This model can be mathematically described as follows.

The Reference and Basic Noise Levels

Reference Level = Basic Noise Level
+ Speed Correction
+ Heavy Vehicle Adjustment
+ Corrections for Gradients
+ Road Surface Correction ....(2)

- Basic Noise Level:

$$L_{10} = 42.2 + 10 \log_{10} q \qquad \text{.........(3)}$$

where: L_{10} = The basic noise level for hourly L_{10} (dBA)
q = The number of passenger cars for the hourly (veh/hr) (Assumed speed is 75 km/h and no trucks)

- Speed Correction & Percentage of Heavy Vehicle Adjustment:

$$C_{sp} = 33 * \log_{10}(V + 40 + 500/V) + 10 * \log_{10}(1 + 5*p/V) - 68.8 \qquad \text{.........(4)}$$

$$p = 100 * f / q \qquad \text{.........(5)}$$

where: C_{sp} = Speed Correction (dBA)
V = Mean Traffic Speed (km/h)
p = Percentage of Heavy Vehicles (%)
f = The number of heavy vehicles for the hourly (veh/hr)
G = Gradient (%)

- Corrections for Gradients:

$$C_{gr} = 0.3 * G \quad ....(6)$$

where: C_{gr} = Gradients Correction (dBA)
G = Gradient (%)

- Road Surface Correction:

Correction is given to different types of road surface as shown in **Table 3**.

Table 3. Show Surface Correction, CORTN model

Road Surface Type	Valid for Speed	Surface Correction
Concrete	>= 75 km/h	10 * log(90*TD+30) – 20 dBA
Asphalt	>= 75 km/h	10 * log(20*TD+60) – 20 dBA
Impervious road surface	< 75 km/h	-1
Pervious road surface	All Speed	-3.5

TD : Texture Depth of the road

This Reference noise level is then corrected for the noise propagation path from the reference point to the point of the receiver. The mathematical formulas for this propagation correction are as follows.

The Propagation

L_{10} = Reference Level
- Distance Correction (C_d)
- Ground Attenuation (C_g)
- View Angle Correction (C_v)
- Screening (C_s)
+ Reflection Correction (C_r) ....(7)

- Distance Correction:

$$C_d = 10 * \log(d' / 13.5) \quad ....(8)$$

where: C_d = Distance Correction (dBA)
d' = shortest slant distance from effective source position. (Taken in the perpendicular position) valid for d > 4 meters. (m)

- Ground Attenuation:

For $0.75 < H < (d+5)/6$; $C_g = 5.2 * I * \log((6*H-1.5)/(d+3.5))$ ....(9)
For $H < 0.75$; $C_g = 5.2 * I * \log(3/(d+3.5))$ ....(10)
For $H > (d+5)/6$; $C_g = 0$ ....(11)

where: C_g = Ground Attenuation (dBA)
H = Average Height of propagation (m)

d = Distance from edge of near side carriage way (m)
I = Coefficients based on different % of absorbent ground

- View angle Correction:

$$C_v = 10 * \log(\theta / 180) \qquad ....(12)$$

where: C_v = View angle Correction (dBA)
θ = View angle (°)

- Correction for Screening:

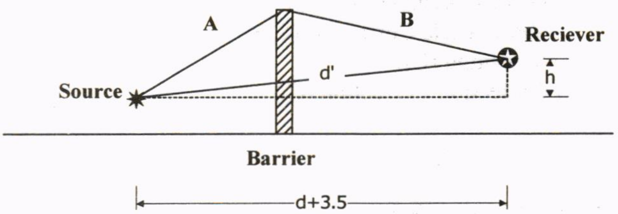
$$C_s = A_0 + A_1 * X + A_2 * X^2 + \ldots + A_n * X^n \qquad ....(13)$$
$$X = \log_{10}(\delta) \qquad ....(14)$$

where: C_s = Correction for Screening (dBA)
δ = The path difference (m) as shown in **Figure 6**
A_n = Coefficient of screen correction at any n of shadow or illuminated zones
n = 0-7 for shadow zone, and 0-5 for illuminated zone
h = Height difference between receiver and source (m) (in this study, h=1 m.)

- Reflection Correction:

$$C_r = 1.5 * (Ai / A) \qquad ....(15)$$

where: C_r = Reflection Correction (dBA)
Ai = sum of reflected angles (°)
A = sum of total angle (°)



$$\delta = A + B - d'$$

Figure 6. Pathlength Difference (δ) Calculation of CORTN Model

4.1 Data Input for CORTN Model

Several parameters being used in the traffic noise analysis of the CORTN model are different from those of the FHWA model. The menus and dialog boxes are developed especially for the input of data into the analysis of traffic noise from this model. The example of dialog boxes for data input into the CORTN model is shown in **Figure 7**. The system for road and traffic data input of either a single straight line section or multi lines sections of roadway is the same as that of the previously described FHWA model.

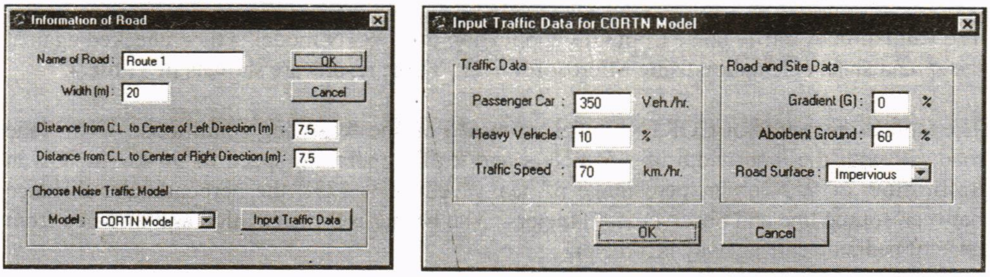


Figure 7. Dialog Boxes for Data Input into CORTN model

4.2 Analysis of Noise by CORTN Model

The main noise analysis of the CORTN model is the reference noise level calculation, which is based on noise analysis from traffic volume and speed, and the physical conditions of the highway in terms of gradient and road surface. This reference level consists of four parts: (1) basic noise level (L_{10}), which is based on passenger car hourly volume at a speed of 75 km/hr without any truck; (2) speed and percentage of heavy vehicles adjustment; (3) gradient correction; and (4) road surface correction which is based on the texture depth of the road [Department of Transport, 1988]. This reference level is then corrected for noise propagation from the reference point to receiver that is based on the physical and environmental conditions of the surrounding area of the roadway. These corrections consist of distance correction, ground attenuation, view angle correction, and screening and reflection corrections.

Most of these data sets are input into the system through dialog boxes, except in the case of distances and angles, which require additional scripts to determine the values of these two parameters. The scripts written into the software of this GIS system control all of the operations, which include calculations and corrections for the different conditions of roadway and traffic characteristics.

Furthermore, the conversion of L_{10} to L_{eq} is also given into this system in order to let this system be able to present the traffic noise level in the Equivalent Noise Level (L_{eq}) which is the noise index utilized by ISO Standard. The conversion model can be mathematically described as follows [Bolt, Beranek and Newman, 1976].

$$L_{10} - L_{eq} \doteq 5.57\sqrt{\ln\left(1 + \frac{0.371 \times 5280}{A}\right)} - 2.18 \ln\left(1 + \frac{0.371 \times 5280}{A}\right) \qquad \text{.......(16)}$$

where:
- A = ND/S
- N = Traffic Volume (veh)
- S = Traffic Speed (km/hr)
- $D = \sqrt{d(d+a)}$
- d = Distance from receiver to the nearer edge of the carriageway (m)
- a = Width of the carriageway (m)

The calculation procedures for the analysis of traffic noise level by using CORTN model is shown in **Figure 8**.

The validation of traffic noise from GIS application of CORTN model is then checked against the spread sheet calculation using Microsoft Excel. These results are showns in **Table 4**.

The validation results of CORTN model are based on the following conditions: A two-lane roadway with the lane width of 3.5 meters and traffic operating speed of 90 km/hr. Given traffic flow of 500 veh/hr, percentage of heavy vehicle is 12%, the perpendicular distance between source line and observer is 40 meters. The barrier is 3 meters high and distance from edge of nearside carriageway is 5 meters.

Table 4. Validate Results of Traffic Noise (dBA) between GIS system and Spread Sheet Calculation of CORTN model

Condition	Microsoft Excel	GIS system	% Error
No barrier	70.29	70.22	- 0.09
Infinite Barrier	59.08	59.01	- 0.07
Finite Barrier (75 m)	63.92	63.87	- 0.08

Units: dBA

5. DISPLAY OF ANALYSIS RESULTS

Traffic noise levels from the analysis results of FHWA and CORTN models can be displayed by this system in two formats. First, in the form of digital noise level at the single or set of points of analysis, and second, in the contour lines format in the interested area.

For the digital noise levels, the display shows analysis results of traffic noise levels in digital numbers of dBA on the specific location of analysis of the digital base map. This can be done in a singular point display of traffic noise on certain point of interest or in the form of uniform grid points of traffic noise overlays on the specified study area. **Figure 9** shows traffic noise levels in the uniform grid points on the base map.

In the display of the contour lines format, the noise contour pattern is applied onto the digital base map based on the values of traffic noise levels from the uniform grid points, as given in the previous case. This contour application utilizes the Spatial Analysis extension of ArcView software [ESRI, 1996]. The analysis of contour lines are done by interpolation method. The contour lines in this system can be displayed in the different spacing of noise levels i.e. 1 dBA, 2 dBA, 5 dBA etc. Furthermore, the grayscale shades and colors can also be applied onto this contour in order to enhance the different traffic noise levels in the display, so that the impact of traffic noises in study area can easily be seen and investigated. **Figure 10** and **Figure 11** shows the traffic noise levels in noise contour lines and shaded contour lines under FHWA and CORTN models respectively. In the analysis of line and block barriers along the side of highway, the graphic display of traffic noise contour can also be presented as in **Figure 12** and **Figure 13** for FHWA and CORTN models respectively.

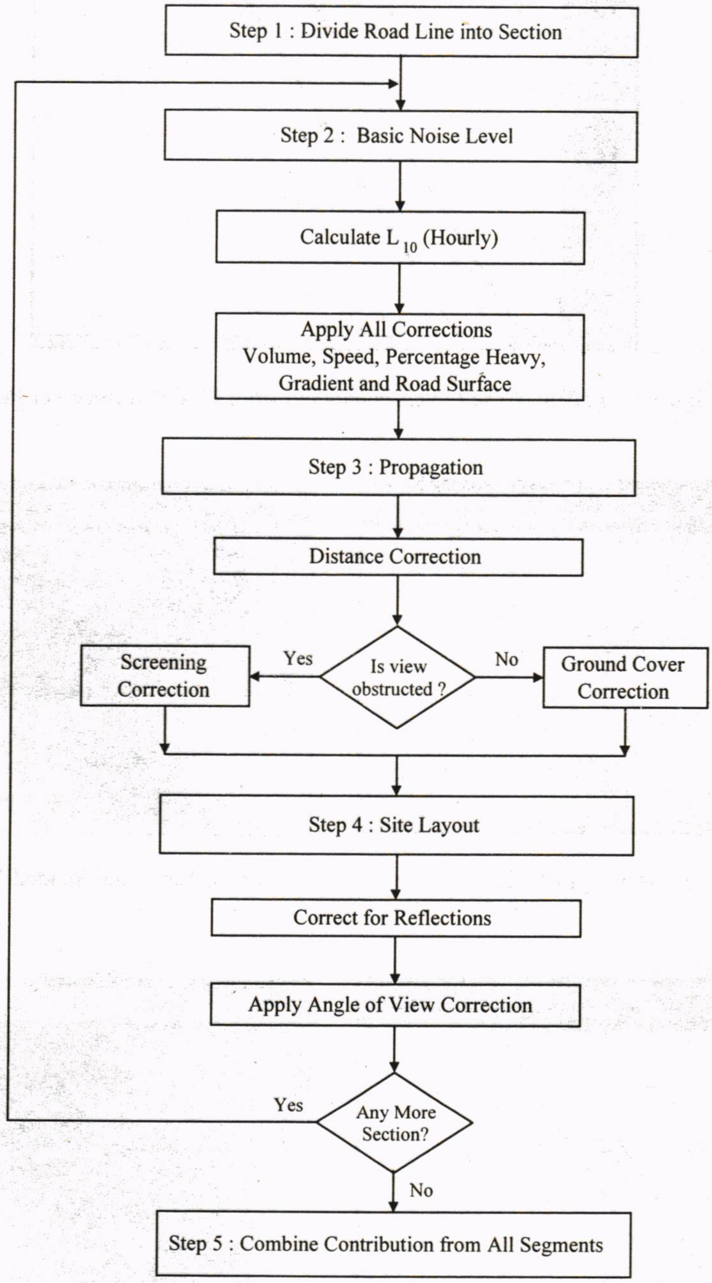


Figure 8. Calculation Procedures of CORTN Model in GIS Platform

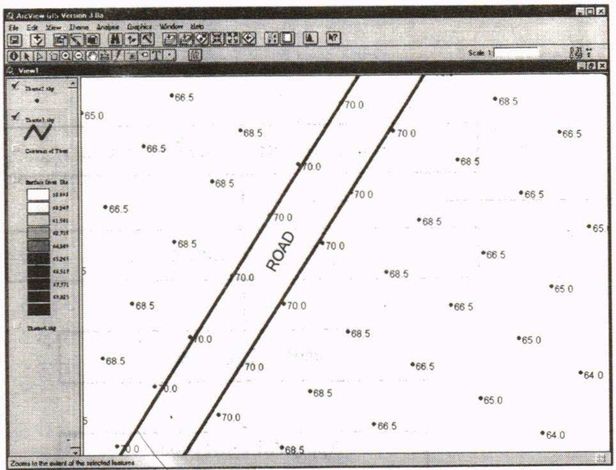


Figure 9. Traffic Noise Levels calculated from Model at Receiver Points

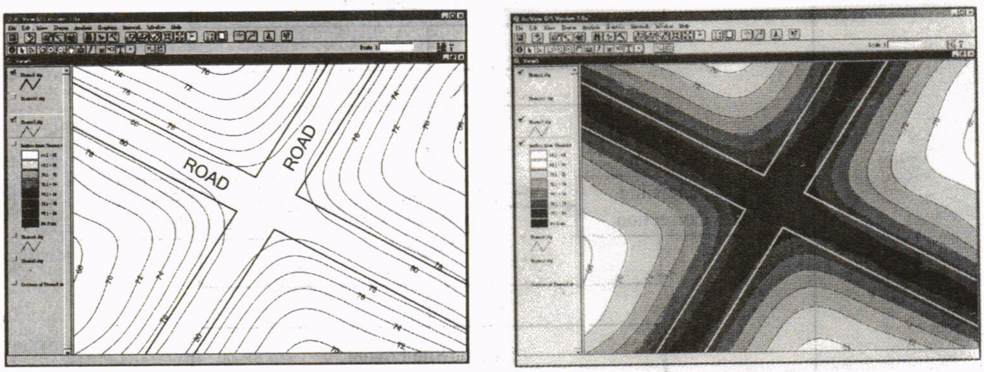


Figure 10. FHWA's Traffic Noise Level in Noise Contour Lines and Shaded Contour Lines

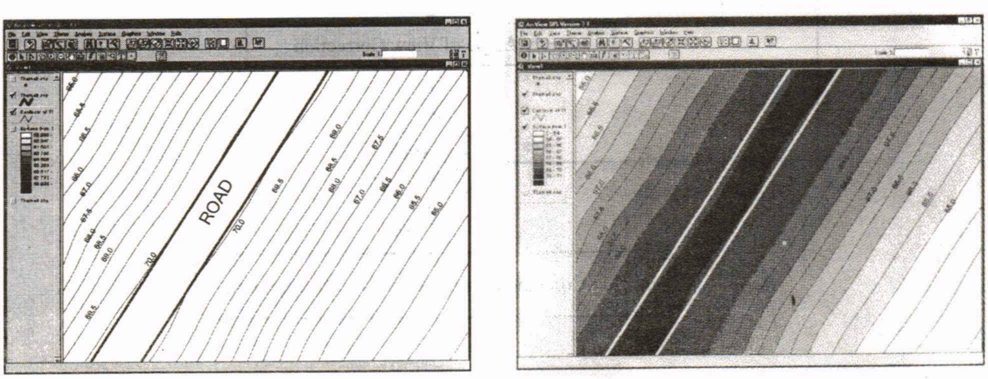


Figure 11. CORTN's Traffic Noise Level in Noise Contour Lines and Shaded Contour Lines

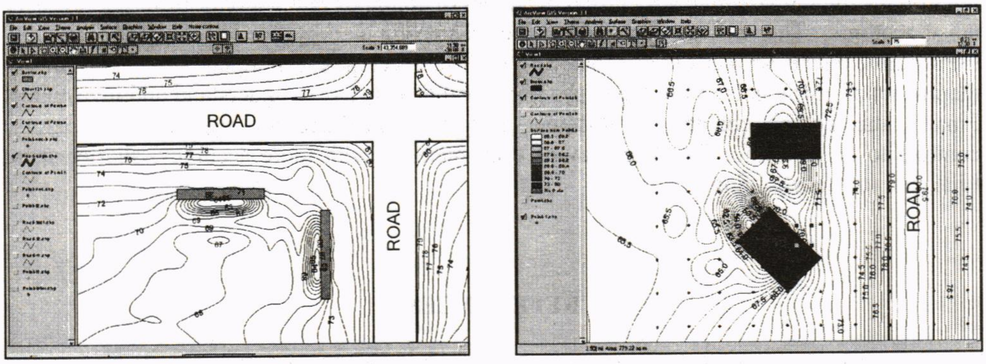


Figure 12. FHWA's Traffic Noise Contour line Around Different Types of Barrier

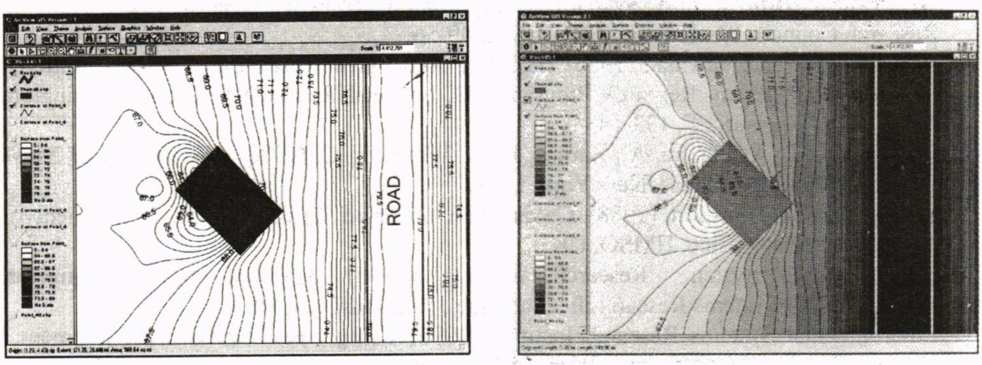


Figure 13. CORTN's Traffic Noise Contour line Around Different Types of Barrier

6. CONCLUSION

From this study of the development of the geographical information system (GIS) for analysis and simulation of highway traffic noise, the results show that the GIS system developed by this study can be applied effectively to analyze traffic noise levels generated by uninterrupted or free flow traffic conditions based on the two popular traffic noise models: US's FHWA, and UK's CORTN. The application of menus and dialog boxes enables this system to easily receive the input data for the required analysis parameters. The development of linkages and attributes allows for more efficiency in the analytical part of the system that requires effective links between data and the digital base map on different layers of the GIS platform. The display section of this system can provide graphic displays in the format of digital numbers at any particular location point, or groups of numbers on the grid points overlay on the base map. This traffic noise result can also be displayed in the form of an overlay of noise contour lines on the digital base map with different shades of colors or grayscale for different levels of noise contours. The validation tests of traffic noise estimated by this GIS system also show the accurate results with errors less than 0.15%. The developed technique in this study allows the impact of traffic noise from highways to be visible and easy to understand and investigate. Finally, this system enables the different mitigation measures for highway traffic noise controls to be tested for the efficiency of each measure with more accuracy, shorter spent time, and total cost saving.

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