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STUDY OF TRAFFIC NOISE MODELS IN THE EVALUATION OF TRAFFICE NOICE LEVELS : A REVIEW

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ABSTRACT

The noise generated from the vehicular traffic flow is a major source of environmental pollution. The forecast of traffic noise levels is generally carried out using analytical models, which relate noise levels to some non-acoustic parameters connected to traffic fluxes and road characteristics. The noise generated from the vehicular traffic flow is a major source of environmental pollution. The forecast of traffic noise levels is generally carried out using analytical models, which relate noise levels to some non-acoustic parameters connected to traffic fluxes and road characteristics. All the noise prediction models consist of evaluating basic noise levels and making series of adjustment to take into account geometric, traffic flow, barrier data etc. In this paper, noise prediction models i.e. Federal Highway Administration (FHWA), and calculation of Road Traffic Noise (CORTN), have been discussed. The traffic Studies included are individual vehicle noise level, traffic noise level, traffic volume and traffic speed. Analysis of individual vehicle noise levels, computation methodology, paired t-test for FHWA and CORTN and other models have been studied.

KEYWORDS: FHWA, CORTN

INTRODUCTION

Noise can be defined as simply “unwanted sound” or a sound with which civilization cannot reasonably put up. Any sound that is undesirable because it interferes with speech hearing is intense enough to damage hearing or is otherwise annoying. The definition of noise as unwanted sound implies that it has an adverse effect on human beings and their environment, including land, structures and domestic animals. Noise can also disturb natural wildlife and ecological systems. It creates interference in communication and health. While primary source of noise is the individual vehicle, the nuisance is caused by the accumulation of sound of individual vehicles of a traffic stream into traffic noise . Noise pollution has become a major concern of communities living in the vicinity of highways / road corridors, intersections [D.K. Parbat 1 , 2P.B. Nagarnaik and 3V.M. Mohitkar]

The major sources of noise are:

1. Industrial noise
2. Traffic noise
3. Community noise

Out of above three parameters, the sources that affects the most is traffic noise. In traffic noise, almost 70% of noise is contributing by vehicle noise. Vehicle noise, mainly, arises from two parameters i.e. engine noise and tyre noise. The major concern is to study and development of a road traffic noise model.

Highway noise is the sum of the total noise produced at the observser point by all the moving vehicles on the highway. Thus the fundamental component is the noise produced by the individual vehicles, which depend on the vehicle type and its mode of operation. The overall noise is also dependent on the characteristics of the vehicle and the relative proportions of the vehicle types included in the flow. Knowledge of these factors is thus necessary to define the characteristics of highway noise and to subsequently predict the associated noise level in the surrounding area. The amount of information required depends on the degree of accuracy desired in the predictions which in turn is a function of the method selected to characterize the temporal variation of the noise.[Study and Development of road traffic noise model A Thesis]

A great majority of the traffic noise prediction are stationary models. In most of the situations and given the precision of the same ones the stationary situation is in general enough. But situations exist in those that the traffic varies notably along the time. For these cases exist models of noise for pulsate traffic, or “stop and go” models of remarkable simplicity and sufficiently precision. However, it is interesting the use of the simulation of the traffic for the study of certain urban or intercity situations. The models “MACUS1” and “MACUS2” presented in this paper use the simulation of the even traffic to analyze the noise levels in certain situations like the urban intersections regulated by means of traffic lights or the study of the stabilisation times of the levels.[P. E. Solana Quirósa, M. A. Picard Lópeza and J. V. Arizo Serrullab, Traffic Flow Simulation for Road Noise Levels Prediction]

The traffic noise prediction models are commonly designed to assist in the conception of new roads or for taking into account changes in traffic noise conditions. The methods currently used model the traffic as a steady flow. Therefore, such models are only able to predict average noise levels generated at the roadside. A recent review of some traffic noise prediction models clearly displayed, that a model able to represent interrupted and complex flow is needed, e.g. to predict the effects of traffic light cycles, pedestrian crossing locations, and other scenarios generating short-time variations in traffic flow. This paper summarizes a feasibility study of a model with such qualities based on noise emission monograms associated with a dynamic traffic model. We also describe the experimental validation of this model in the basic scenario of a pedestrian crossing protected by light signals.[Ludovic Leclercqa, Joël Lelongb, Dynamic evaluation of urban traffic noise.]

Traffic Noise Simulation Model:

Since 1950, traffic noise prediction models mostly were designed to predict a single vehicle sound pressure at roadside based upon constant speed experiments. The earlier road traffic noise model was given in the Handbook of acoustic Noise Control written by Anon (1952). The model is used for speeds between 56 km/hour (35 miles/hour) and 72 km/hour (45miles/hour) and the distances greater than 6 meter (20 feet) (Steele, 2001). The formulation for A weighted sound levels that exceed the 50 percentile of time interval is given as:

$$L50 = 68 + 8.5\log(V) - 20\log(D_F)\ \text{dBA} \quad (1)$$

where
V = traffic volume, vehicles/hour;
$D_{F=}$ the distance from traffic lane, in feet.

In 1965,Nickson (1965) and Lamure (1965) developed a model in the form of:

$$L_{50} = C_N = 10log(V/D_F)\ \text{dBA} \quad (2)$$

where
CN = a constant for individual noise levels.

Later, Johnson and Saunders (1968) introduced vehicle speed as a relevant factor and they proposed the following formulation:

$$L50= 3.5 = 10\log(VS^3/D_F)\ \text{dBA} \quad (3)$$

where
S = mean vehicle speed, miles/hour.

In 1966, Galloway (1969) introduced a further variable, PH, the percentage of heavy trucks. The equation becomes:

$$L_{50}= 20=10\log(VS^2/D_F)+0.4(P_H)\ \text{dBA} \quad (4)$$

Later developments introduced more variables and changes from $L50$ to $L10$ and equivalent continuous level (Leq) over a chosen period (Steele, 2001).

Recent models predict the equivalent continuous sound level (Leq) under interrupted and varying flow conditions. According to the reviews of Garcia (2001) and Steele (2001), traffic noise prediction models in different countries are designed to meet the requirements of government regulations. Those prediction models are enhanced with more accurate physics and more realistic computation in actual traffic flows. Detailed information for FHWA TNM (Menge et al., 1998), which is used in this thesis, will be discussed in Section 2.3.1. Section 2.3.2 is a review of others recent traffic noise models. [Hang see pheng,2007, Noise modeling in universiti sains malaysia and Offshore oil and gas platform”, universiti sains malaysia, page no.13-15.]

Equivalent noise levels (Leq)

Leq represents the equivalent energy sound level of a steady state and invariable sound. It includes both intensity and length of all sounds occurring during a given period. The noise levels of different squares in different time intervals were calculated along with their equivalent noise levels (Leq). The value of Leq in dB (A) unit was calculated by using the formula of Robinson, 1971, i.e.,

$$Leq = L50 + (L10-L90)2 / 56$$

where,
L10 : The level that were exceeded during 10% of the measuring time in dB(A).
L50 : The level that were exceeded during 50% of the measuring time in dB(A).
L90 : The level that were exceeded during 90% of the

measuring time in dB(A).

Noise Pollution Level (NPL)

As Leq is an insufficient descriptor of the annoyance caused by fluctuating noise (Robinson, 1971), noise pollution level (NPL) expressed in dB was calculated by using the following formula:

NPL = Leq + a (L10-L90)

Where,

a = 1.0 (constant in the equation).

NPL takes into account the variations in the sound signal and hence serves as better indicator of the pollution in the environment for physiological and psychological disturbance of the human system.

Traffic noise index (TNI)

Traffic noise index (TNI) is another parameter, which indicates the degree of variation in a traffic flow. This is also expressed in dB (A) and can be computed using the following relation:

TNI = 4 (L10-L90) + L90 – 30 dB (A)

Noise climate (NC)

Noise climate (NC) is the range over which the sound levels are fluctuating in an interval of time and was assessed using the following formula:

NC = (L10-L90)

Where, L90, the level exceeded for 90 % of the time of record, is very near to the background noise level in the absence of any motor vehicle traffic.

Traffic volume (Q)

The noise level near the highway depends on the number of vehicles. The noise level increases with an increase in traffic volume. Traffic volume is defined as the total number of vehicles flowing per hour. The number of vehicles passing through a fixed point on the road was counted.

Truck-traffic mix ratio (P)

Trucks and buses are contributing more noise to the environment, than compared to automobiles. It is evident that, besides the total noise level, the number of heavy vehicles will be an important parameter in the annoyance function. This is especially the case in the transition range between continuous noise and "just annoying noise events". The ratio of heavy trucks and buses to total traffic was called truck traffic mix ratio. This was computed in terms of percentage. An increase in this ratio will increase the noise level

Day, evening and night equivalent noise level (Lden):

Lden, an indicator that is a composite of long term Leq values for day, evening and night (termed Lday, Levening and Lnight). L stands for "level", d for "day", e for "evening", and n for "night". Lden noise value (day, evening and night) was calculated by using the following formula and compared withactual results.

$$L_{den=}10.^{10}\log\frac{12.10\frac{Lday}{10}+4.10\frac{Levening+5}{10}+8.10\ Lnight+\frac{10}{10}}{24}$$

Burgess traffic noise model:

The prediction of equivalent noise level (Leq) was computed by using the following formula of Burgess (1977):

Leq = 55.5 + 10.2 log (Q) + 0.3P – 19.3 log (d)

where, 'Q' is the vehicles flow, 'P' is the percentage of heavy vehicles and 'd' is the distance of source receiver. [Akula Chandra Pradhan, 2012,"Measurements and model calibration of traffic noise Pollution of an industrial and intermediate city of india",The Ecoscan: Vol.1,Page No. 379.]

FHWA Traffic Noise Model

The Traffic Noise Model (TNM) is developed by the Federal Highway Administration (FHWA) for predicting noise levels in the vicinity of highways and to design highway noise barriers (Menge, 1998). This model is known as a state-of-the-art computer program and developed by advance acoustics and computer technology in modeling highway traffic noise (FHWA, 2002). In year 1998, the FHWA TNM, version 1.0 was released by FHWA to replace the highway noise analysis program, Standard Method In Noise Analysis (STAMINA 2.0) (Anderson et al., 1998; Harris et al., 2000). The FHWA TNM is derived from the STAMINA 2.0 program (Bowlby et al., 1982) and has several substantial improvements. The improvements include provision for acceleration, stop signs, toll booths, input of user-defined vehicles using their reference energy mean emission level (REMEL) data, etc (Steele, 2001).

$$-(K1+K2s_i)+D1+D2s_i+(E1+E2s_i)\log f$$
$$+(F1+F2s_i)(\log f)^2$$
$$+(G1+G2s_i)(\log f)^3$$
dBA ()
$$+(H1+H2s_i)(\log f)^4$$
$$+(I1+I2s_i)(\log f)^5$$
$$+(J1+J2s_i)(\log f)^6$$

Five classes of vehicle are used in this FHWA model; they are automobiles, medium trucks, heavy trucks, buses and motorcycles. To calculate sound levels for entire traffic streams, FHWA TNM incorporates energy averaged vehicle noise emissions for each vehicle type (Menge et al., 1998). Based on FHWA TNM technical manual (Menge et al., 1998), TNM needs three constants to compute A-weighted noise-level emissions: *A*, *B* and *C*. It also needs fourteen additional constants to convert these A-weighted noise-level emissions to 1/3rd-otave-band spectra: *D1, D2, E1, E2, F1, F2, G1, G2, H1, H2, I1, I2, J1 and J2*. Each vehicle type's total measured noise emissions take into account the whole frequency spectrum. The general REMEL equation is function of speed and frequency for each type of vehicles (*i*) as follows:

$$L_E(s_i,f) = 10\log[10^{(C+\Delta E)/10} + (0.6214 s_i^{A/10})(10^{(B+\Delta E)/10})]$$

Where,

f = nominal 1/3rd-octave-band center frequency, in Hetz;

si = vehicle speed, in kilometer/hour;

A = the slope of tire/pavement noise portion of regression curve;

$B+\Delta E_b$= the height of the tire/pavement noise portion of the regression curve;

$C+\Delta E_c$ = the height of the engine/exhaust noise portion of the regression

equation, which is independent of vehicle speed;

D to 2 J = constants of the sixth-order polynomial fit curve for the 1/3rd spectra;

K1 and *K2* = the calibration of the resulting A-weighted levels from the sixthorde polynomial fit.

Several adjustments are made to the emission level to account for traffic flow, distance and shielding in FHWA TNM (Menge et al., 1998). The following equation is the equivalent sound level over one hour time period, (1 h) *Aeq L* which involved those adjustments for different vehicle types:

$$L_{Aeq}(1h)= EL_i+A_{traff} + A_d+A_s \quad dBA$$

Where,

ELi = the vehicle noise emission;

Atraff(i) = the adjustment for traffic flow, the vehicle volume and speed;

Ad = the adjustment for distance between the roadway and receiver and for

the length of the roadway;

As = the adjustments for all shielding and ground effects between the roadway and the receiver TNM has been updated several times and the latest version is TNM Version 2.5 (Lau et al., 2004; Ning, 2005). TNM Version 2.5 has the improved implementation to the vehicle emission level database. More comprehensive methodologies are applied in correcting the measured emission back to the source (Lau et al., 2004). The diffraction algorithm parameters are also improved in the latest version. Table 2.1 shows the FHWA TNM release versions since year 1998 until 2004.[Hang see pheng,Noise modeling in universiti sains malaysia and offshore oil and gas platform,2007, pg no.15-17]

Noise Regulatios

Noise Impacts: The 23 of the Code of Federal Regulations (CFR), Part 722 (23 CFR 722), Procedures for Abtaement of Highway Traffic Noise and Construction Noise, contains FHWA's criteria for evaluating noise impacts. Table 1 contains the FHWA noise abatement criteria (NAC).

Table 1: Federal Highway Administration Noise Abatement Criteria

Activity Category	Leq	Description of Activity Category
A	57 (Exterior)	Lands on which serenity and quiet are of extraordinary significance and serve and important publicneed and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals
C	72 (Exterior)	Developed lands, properties, or activities not included in Categories A or B above.
D	n/a	Undeveloped lands.
E	52 (interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

CORTN MODEL

Basic hourly L_{10} Valve: for the calculation based on corton model, first of all , the basic noise level is calculated at a reference distance of 10m away from the nearside carriageway edge.the basic noise level is obtained from traffic flow speed of the traffic , composition of the traffic gradient of the road and the road surface.

The basic noise level equation for hourly L_{10} is given as

$$L_{10}=42.2+10\log_{10} q$$

Where q=total flow in vehicle/hourly

- **Calculation of hourly percentage of heavy vehicle:**

Hourly percentage of heavy vehicles is calculated using the following:

$P=100f/q$

Where,

P=percentage of heavy vehicles
F= hourly flow of heavy vehicles
q=hourly flow all vehicles

Adjustment applied for the calculation of final L_{10} value:

The various adjustment applied to the basic noise level so as to calculate the final L_{10}value arefollowing:

1. mean traffic speed and percentage of heavy vehicle
2. distance
3. grade
4. ground cover
5. angle of view
6. barrier

Mean traffic speed and percentage of heavy vehicles:
The correction for mean traffic speed V and percentage of heavy vehicles P is given as

$$\text{Correction}=33\log_{10}(V+40+500/V)+10\log_{10}(1+5P/V)-68.8$$

The value of traffic speed(V) used in the calculation depend upon the road classification as specified by the CORTN model.

Distance:
For reception points located at distance greater than or equal to 4 meters from the edge of the nearside carriageway, the distance correction is equal to be applied to the basic noise level. The distance correction is calculated along the shortest slant distance (d') from the source line to the reception point. This value is determined from the shortest horizontal distance (d) from the edge of the nearside carriage way to the reception point and the height (h) of the reception point relative to the source line at the point where the slant line intersects the source line at the effective source position, S . The correction for distance is given as:

$$\text{Correction} = -10\ \text{Log}_{10}\ (d'/13.5)$$

Where,

d' = Shortest slant distance from the effective source position in metres.

$$= [(d+3.5)^2+h^2]^{1/2}$$

Grade:
For roads with a gradient traffic speeds will be reduced from the values given for level roads. The reduction in traffic speed (ΔV) depends upon the percentage gradient (G) and the percentage of heavy vehicles (p). The value of traffic speed to be used for roads with a gradient is obtained determining the appropriate traffic speed from the road classification table provided by CORTN and reducing this value by the amount (ΔV). In the case where the carriageways are treated separately or for one way traffic schemes the speed correction should not be applied to the downword flow.

The change in mean traffic speed ΔV in terms of the percentage of heavy vehicles P and gradient G is given as

$$\Delta V = [0.73+(2.3-\frac{1.15P}{100})\frac{P}{100}]\times G$$

Where, G is the gradient in present.

Ground Cover:
If the surface between the edge of the near side carriage way of the road or the road segment and the reception point is totally or partially of an absorbent nature, (eg. Grassland, cultivated field or plantations) an additional correction for ground cover often referred to as ground absorption ia applied to the basic noise level. The correction is progressive with distance and particularly affects reception points close to the ground. The correction for ground absorption is given in terms of the mean height of propagation (H) the distance (d) and the proportion of absorbing ground (I) between the edge of the nearside carriageway and the segment boundaries leading to the reception point R. The correction for ground absorption in CORTN assumes the intervening ground cover to be 90% absorbent for which the value of I=1. Hence, out of the identified fourteen locations, ground absorption s applied only for three locations.

Where the intervening ground cover is non-absorbent eg. Paved areas, rolled asphalt surface, the value of I is zero, no ground cover correction ia applied.

$$\text{Correction}= 5.2I\ \text{Log}_{10}\left(\frac{6H-1.5}{d+3.5}\right) \qquad \text{For } 0.75 \leq H < \frac{d+5}{6}$$

$$\text{Correction} = 0 \qquad \text{for } H \geq \frac{d+5}{6}$$

$$\text{Correction} = 5.2I\ \log_{10}\left(\frac{3}{d+3.5}\right) \qquad \text{for } H < 0.75$$

Angle of View:
The correction for angle of view is given as

$$\text{Correction}= 10\ \text{Log}_{10}\left(\frac{\theta}{180}\right)$$

Barrier:
The potential barrier correction is calculated as a function of path difference (δ) CORTN model gives a polymial expression for potential barrier correction as

$$A = A_0 + A_1x + A_2x^2 + \ldots\ldots\ldots\ldots\ldots\ldots A_nx^n$$

Where,

$X = \text{Log}_{10}\,S$

S = Path length difference in metres between the direct and diffracted rays.

The values of coefficients for both the zones are provided by the CORTN model and are accordinguly used for both calculation of barrier correction.[C.C.Bhattacharya, Dr.S.S.Jain, S.P.Singh,Dr.M.Parida, Ms. Namita Mittal,2001,Development of cophrensive highway noise model for Indian Conditions, Page No.471-475.]

OTHER TRAFFIC NOISE MODELS

There are some other noise models such as CORTN, *RLS-90*, *MITHRA*, *StL-86* version 1 and *ASJ Method 1993* that are used by different countries. Calculation of Road Traffic Noise (CORTN) is developed for the prediction of traffic noise in the United Kingdom Department of the Environment (Bies and Hansen, 2003). This model assumes a line source and constant speed traffic. The adjustments that apply in the model include percentage of heavy vehicle, traffic speed, gradient, road surface and propagation. The acceleration is not taken into account in CORTN (Steele, 2001). *Richtlinien fur den Larmschutz an StraBen* (*RLS-90*) (Guidelines for Noise Propagation on Streets) is a noise prediction model used in Germany (Steele, 2001). The attenuation in the noise propagation is calculated with usual ray tracing methods in *RLS-90* model. *MITHRA*, developed by a French firm, contains an extensive ray-tracing procedure. This commercial software package takes into account ground effects, diffraction, reflection, topography, building and barrier (Steele, 2001). *StL-86* version 1 is developed by the Swiss Federal Office of Environmental Protection. The model includes corrections for the reflection from building, attenuations of building and obstacles, usual distance effects and angle of road open to receiver. The Acoustic Society of Japan has developed *ASJ Method 1993* to predict a pseudo – *L50* from free-flowing road traffic. This software contains 2 types of methods; they are A-Method and B-Method. A-Method is a direct method of calculating the equivalent sound level (*Leq*), and deriving the pseudo- *L50* from the results. B-Method is an empirical method which is only valid for distances that are far from the line source. Table 2.2 provides the comparison of fhwa stamina, fhwa tnm version 1.0, *mithra*, cortn, *rls90*, *stl-86* and *asj-1993* by steele (2001). hang see pheng,noise modeling in universiti sains malaysia and offshore oil and gas platform,2007, pg no.18-19]

A comprehensive model of driver behaviour which can handle both longitudinal and lateral interactions and also simple enough to be used to simulate large traffic streams. CUTSiM (Comprehensive Unidirectional Traffic Simulation Model) developed by Maurya (2007), find its use as a suitable program package to simulate heterogeneous, uninterrupted traffic streams with or without lane discipline i.e. similar to Indian traffic streams. Like any microscopic models, the description of traffic stream behaviour presented in this model is also a discussion on drivers and their behaviour. The model concentrates on studying and modeling unidirectional and uninterrupted traffic streams and also, the program code was written in C language.[M.Sreekumar,A. K. Maurya.2012, " Need for the Comhrensive traffic simulation model in Indian context", International journal of computer application, page no.15]

CONSLUSION

Most of the countries, keeping in view the alarming increase in environmental noise pollution, have developed the permissible noise standards. In order to meet the permissible noise standards and to control the highway traffic noise, various noise prediction models are highlighted like Federal Highway Administration (FHWA), Calculation of Road Traffic Noise (CORTN), Acoustical Society Of Japan (ASJ) etc. It is always essential that the predicted noise through a model should always be lower than the target value, then a noise barrier of appropriate height is recommended to attenuate noise. A part from the height of the barrier, its material and location should also be taken into account because they also effect noise attenuation. It show that CUTSiM is able to simulate Indian traffic streams with and without lane discipline on various kinds of roads with different vehicle mixes reasonably realistically. It has been seen that CUTSiM can simulate large streams very realistically with limited computation power.

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