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A Review of Traffic Noise Standards and Noise Models

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Abstract
Traffic noise is one of the most irritating pollutions which affect human health in various forms, be it permanent hearing loss, shifting of hearing threshold, irritation/psychological problem, blood pressure, sleeping disorder, premature child birth, etc. The noise generated in the base year of any project may not be harmful, but it may be harmful by horizon year. Under this condition, noise mitigation measures need to be inbuilt in the project itself. In order to suggest right noise mitigation measure for future, noise prediction should be accurate as far as possible. Therefore, an attempt has been made in this paper to review most of the noise prediction models in the world. The paper also presents some basics of noise and comparison of noise standards in various countries including India.

Keywords: *Noise, noise standard, noise model*

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INTRODUCTION

Noise is defined as unwanted or excessive sound, which is an undesirable byproduct of our modern way of life. It can be annoying, can interfere with sleep, work, or recreation and in extremes it may cause physical and psychological damage. While noise emanates from many different sources, transportation noise is perhaps the most pervasive and difficult source to avoid in society today.

Urbanization is increasing at a very fast rate in our country; road length and its condition is also improving. Therefore, the number of vehicles is increasing at alarming rate of more than 7% per annum. During the period of 50 years from 1951 to 2001, the number of vehicles has increased from 3 to 430 lakh. This has led to traffic congestion on roads and noise pollution. Transportation sector is one of the major contributors to noise in an urban area. Road traffic noise is the most irritating pollution which has a major concern on communities living in the vicinity of highway corridors. Studies have shown that one of the most pervasive sources of noise in our environment today is the one associated with transportation. Traffic noise tends to be a dominant noise source in our urban as well as rural environment. In older days, vehicle growth was the blessing, but nowadays it is destroying the environment. Its effect can be seen not only in India but also all over the world. Various countries have evolved norms for traffic noise; in India very few efforts have been made in this field. In this research study, emphasis will be given to residential areas, as they are the most vulnerable to traffic noise.

COMPARISON OF NOISE STANDARDS FOR VARIOUS CATEGORIES OF ZONES IN INDIA (MOEF NOTIFICATION)

Ambient air quality standards with respect to noise for various categories of areas/zones in India (MoEF notification) are presented in Table 1.

Table 1: *Ambient Air Quality Standards w.r.t. Noise in India: MoEF Notification.*

Area code	Category of area/zone	Limits in dB(A)Leq.	
		Day time	Night time
(A)	Industrial area	75	70
(B)	Commercial area	65	55
(C)	Residential area	55	45
(D)	Silence zone	50	42

- Day Time – 6:00 a.m to 10:00 p.m.
- Night Time – 10:00 p.m. to 6:00 a.m.
- Silence zone is defined as area comprising not less than 100 m around hospitals, educational institutes and courts.
- dB(A) – time weighted average of the level of sound in decibels on scale A, which is relatable to human hearing.
- "A" in dB(A)Leq. denotes the frequency weighting in the measurement of noise and corresponds to frequency response characteristics of the human ear.
- Leq. – energy mean of the noise level over a specified period.

There are no different noise standards for existing and planned roads in India as in other countries. The variation of noise standard for residential and industrial zone is high, i.e., 20 dB(A). Though there is a broad classification for noise standards with respect to different types of land use as recommended by MoEF, noise standard with respect to different types of roads has never been prescribed by any agency so far. This is of paramount importance primarily because most of the people in urban areas do not like to be exposed near the high traffic arterial roads. On the contrary, this major section of people prefers to be located in residential areas other than the high-traffic arterial roads. This has necessitated having a relook on the perception on the effect of traffic noise in different categories of roads in urban areas.

INTERNATIONAL COMPARISON OF NOISE STANDARD

In general, noise standards are set too high but enforcement is weak. In three European countries (Switzerland, Netherlands and Germany), there is a huge gap between the admissible noise emission levels for existing transport infrastructure and sustainable level for health. Standards of noise level for existing transport infrastructure in all three courtiers is 70 dB(A), which is perceived to be at a higher level as presented in Table 2.

On the other hand, recent noise legislation in the countries has focused on construction of new transport infrastructure and residential areas. In these cases, stringent noise emission limits that meet the requirements of protecting human health and avoid annoyance to the population within their residential areas are brought into force. The new legislation is consistent with the recommendations of international organizations like OECD or WHO.

Table 2: *Noise Emission Standards for Different Countries for Residential Zones.*

Leq, T (dB(A))	**Existing roads**		**B/N**	**Planned roads**		**B/N**
Country/Organization	**Day**	**Night**		**Day**	**Night**	
Germany	70	60	N	59	49	B
Netherlands	70	60	B 2010	50 (45)	40	B
Switzerland	70	65	B 2010	55	45	B
Japan	70	65	B 2009	60	55	B
OECD EST (until 2030)	55	45	N	55	45	N
WHO	55 (50)	45	N	55 (50)	45	N

Notes: *1. B – binding and year if binding in the future, N – not binding. 2. OECD EST – Organization for Economic Cooperation and Development (30 countries) project on environmentally sustainable transport.*

It can be seen from Table 2 that Netherlands, Switzerland and Japan have set their noise standard for residential zones which are binding up to 2010 and 2009 respectively, while OECD and WHO does not have any binding with respect to any specific year. It is worth mentioning that noise emission standards in the above countries on the planned roads for residential zones during night time ranges between 45 and 50 dBA.

NOISE PREDICTION MODELS

Various noise prediction models are applied internationally under different conditions. Few of them are discussed below. If L_{10} is estimated in the following models, then L_{eq} can be calculated as follows for road traffic noise.

$L_{eq} = L_{10} - 3$ dB(A)

FHWA Model

- Applied for free flow condition
- Nearside and far side concept is considered
- Vehicle categories – light, heavy, medium vehicles
- Road is divided into segments

The Federal Highway Administration (FHWA) has developed a FHWA traffic noise model (FHWA, TNM), a state-of-the-art computer program for predicting noise levels in the vicinity of highways [1]. It uses advances in acoustics and computer technology to improve the accuracy and ease of modeling highway traffic noise, including the design of efficient, cost-effective highway noise barriers.

Traffic noise levels in the vicinity of roadways can be predicted on the basis of individual vehicle noise levels, vehicle volume and speed, observer distance and other corrections. Traffic noise prediction algorithm is of the form given below:

$L_{eq} = L_0 + \Delta L_i$

L_0 = basic noise level for a stream of vehicles
L_i = adjustment applied

Basic noise level is the noise emitted by a particular class of a vehicle at a distance of 15 m from the center of the inner lane at a given speed and for a given road surface. FHWA model calculates noise level through a series of adjustments to the reference sound level. Reference sound level is measured through field measurements. Flow chart for highway noise prediction using FHWA model is presented in Figure 1.

The actual FHWA model is in the following form:

$Leq = L_0 + Avs + AD + AB + AF + AG + AS$

where,

Leq = Hourly equivalent sound level
L_0 = The reference energy mean emission level
Avs = Volume and speed correction
AD = Distance correction
AB = Barrier correction
AF = Flow correction
AG = Gradient correction
AS = Ground cover correction

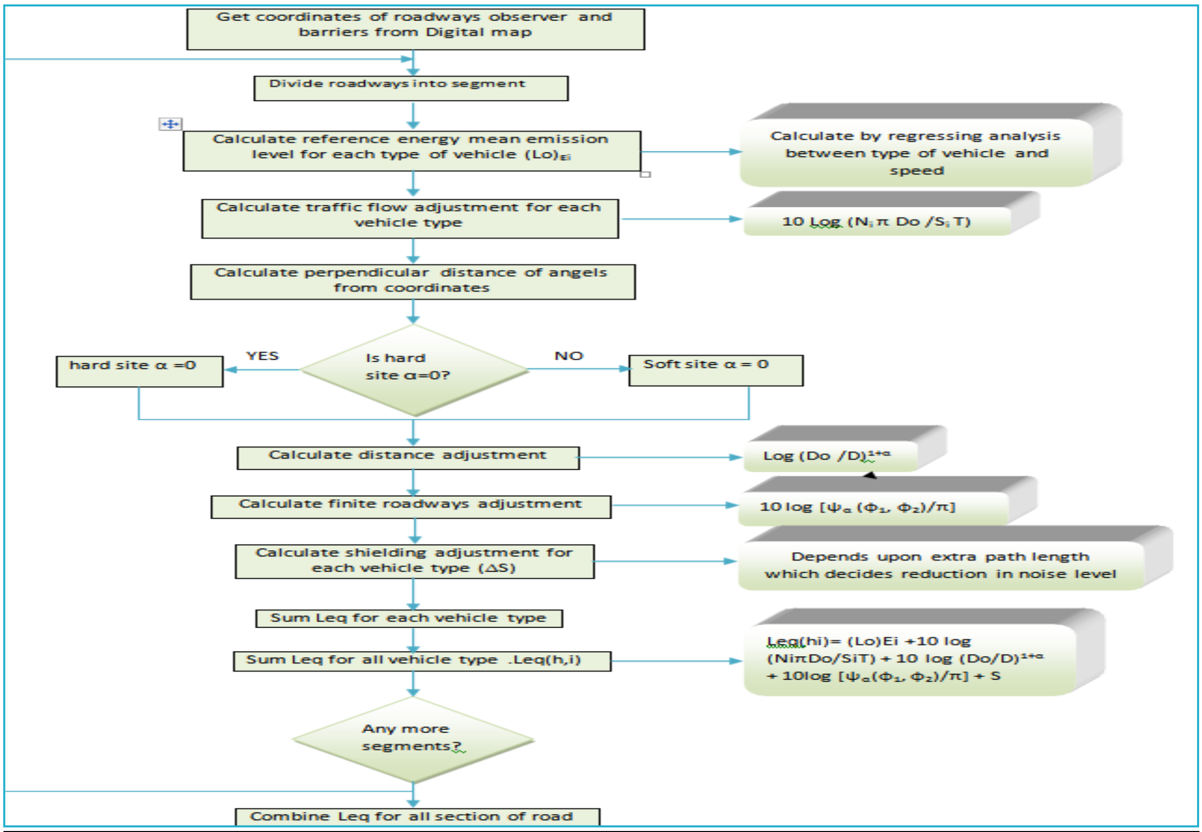

Fig. 1: *Flow Chart for FHWA Highway Noise Prediction Model.*

CORTN Model

- Applied for free flow traffic condition.
- Road is divided into segments; contribution from each segments are combined at receiver point.
- Vehicles categories – light and heavy vehicles
- Source position is near side carriageway edge.

The CORTN (Calculation of Road Traffic Noise) procedure was developed by the Transport and Road Research Laboratory and the Department of Transport of the United Kingdom in the 1975 and has been modified in 1988 [1]. It estimates the basic noise level L10 both on 1 h and 18 h reference time. This level is obtained at a reference distance of 10 m from the nearest carriageway edge of a highway.

For calculation of L_{eq} based on CORTN model, first of all the basis noise level is calculated at a reference distance of 10 m away from the nearside of the carriageway edge. This model does not take into account vehicle categories; therefore, basic noise level is obtained from traffic flow, traffic speed, traffic composition, gradient and road surface. This method is used for uninterrupted flow condition. The noise levels to be calculated are statistical description L_{10} for the loudest hour and an average L_{10} for 18 h period. Flow chart for the highway noise prediction using CORTN model is presented in Figure 2.

The CORTN procedure is divided in five steps:

1. Divide the road scheme into one or more segments, such that the variation of noise level within the segment is less than 2 dBA.
2. Calculate the basic noise level 10 m away from the nearside carriageway edge for each segment. It depends on the velocity, traffic flow and composition. Traffic is considered as a linear source positioned at 0.5 m from the road surface and at 3.5 m from the carriage edge.
3. Evaluate the noise level, for each segment, taking into account the attenuation due to the distance and screening of the source line.
4. Adjust the noise level taking into account:

a) Reflection due to buildings and facades on the other side of the road and reflective screen behind the reflection point.
b) Size of source segment (view angle).

5. Join the contributions from all segments to give the predicted noise level at the reception point for the whole road scheme.

Equations of the Standard

CORTN requires noise levels to be calculated one meter in front of the façade. Reflections of the own façade are not calculated. A façade correction of 2.5 dB is added to the final result of the calculation. The calculation consists of a source model and a propagation calculation. The reference distance of the source model is 10 m from the nearest edge of the carriageway. Unless the carriageways are separated by more than 5 m and when the outer edges of the carriageways are differing by less than 1 m, the road is assessed as one source line 3.5 m from the nearest curb. The source is 0.5 m above the road surface.

Reference and Basic Noise Levels

The relationship between reference noise level and basic noise level given in CORTN noise model is as follows:
Reference Level = Basic Noise Levels + Speed Correction + Heavy Vehicle
Adjustments + Correction for Gradients

Basic Noise Level

The hourly L10 is calculated as:
L10 = 42.2 + 10Log 10 qdB(A)
For 18-h L10 it is:
L10 (18 h) = 29.1 + 10 Log 10 QdB(A)
where,
q = the number of hourly passenger cars
Q = the number of cars for 18-h period
Assumed speed is 75 kmph

RLS90 Model

- Applied for free flow condition.
- Vehicles categories – cars and trucks
- Depends on height of the buildings and distance between roads and buildings

Barriers are considered

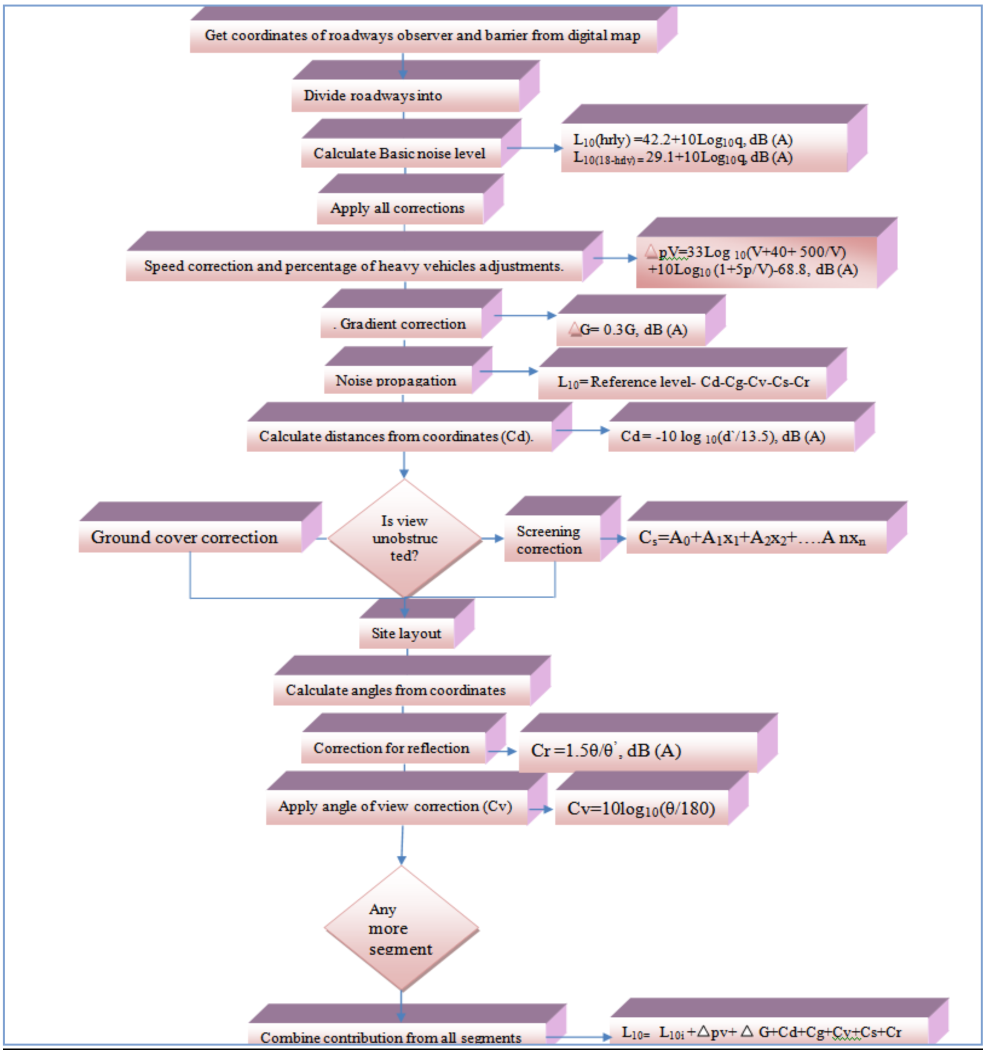

Fig. 2: *Flow Chart for CORTN Highway Noise Prediction Model.*

The RLS90 (Richtlinien für den Lärmschutz an Straben) traffic noise model has been defined as an improvement of oldest standard RLS81 [1]. RLS90 is an effective calculation model, able to determine the noise rating level of road traffic and, at current day, is the most relevant calculation method used in Germany. The model requires an input of data regarding the average hourly traffic flow, separated into motorcycles, heavy and light vehicles, the average speed for each group, the dimension, geometry and type of the road and of any natural and artificial obstacles. Flow chart for RLS 90 highway noise prediction model is presented in Figure 3.

This model takes also into account the main features which influence the propagation of noise, such as obstacles, vegetation, air absorption, reflections and diffraction. In particular, it makes possible to verify the noise reduction produced by barriers and takes into account also the reflections produced by the opposite screens. In addition, it is one of the few models present in literature that are able to evaluate the sound emission of a parking lot. The starting point of calculation is an average level LmE measurable at a distance of 25 m from the center of the road lane. This $LmE^{(25)}$ is a function of the amount of vehicles per hour Q, and of the percentage of heavy trucks P (weight > 2.8 ton), under ideal conditions (i.e., a speed of 100 km/h, a road gradient below 5% and a special road surface). Analytically, $LmE^{(25)}$ is given by:

$$LmE^{(25)} = 37.3 + 10\ \mathrm{Log}[Q(1 + 0.082P)]$$

The next step is to quantify various deviations from these idealized conditions by means of corrections for "real speed," actual road gradient or actual surface, etc. In particular, these corrections depend upon whether day (6:00–22:00 h) or night (22:00–6:00 h) is considered. So for each lane, the mean level in dBA Lm is calculated as:

$Lm = Lm,E^{(25)} + R_{SL} + R_{RS} + R_{RF} + R_E + R_{DA} + R_{GA} + R_{TB}$

where,

R_{SL} is correction for speed limit

R_{RS} is a correction for road surfaces. It depends upon kind of surface and vehicle speed. It ranges from 0 to 6 dB.

R_{RF} is a correction for rises and falls along the streets.

R_E is a correction for absorption characteristics of building surfaces.

R_{DA} is attenuation's coefficient that takes into account the distance from the receiver and air absorption

R_{GA} is attenuation's coefficient due to ground and atmospheric conditions

R_{TB} is attenuation's coefficient due to topography and buildings dimensions

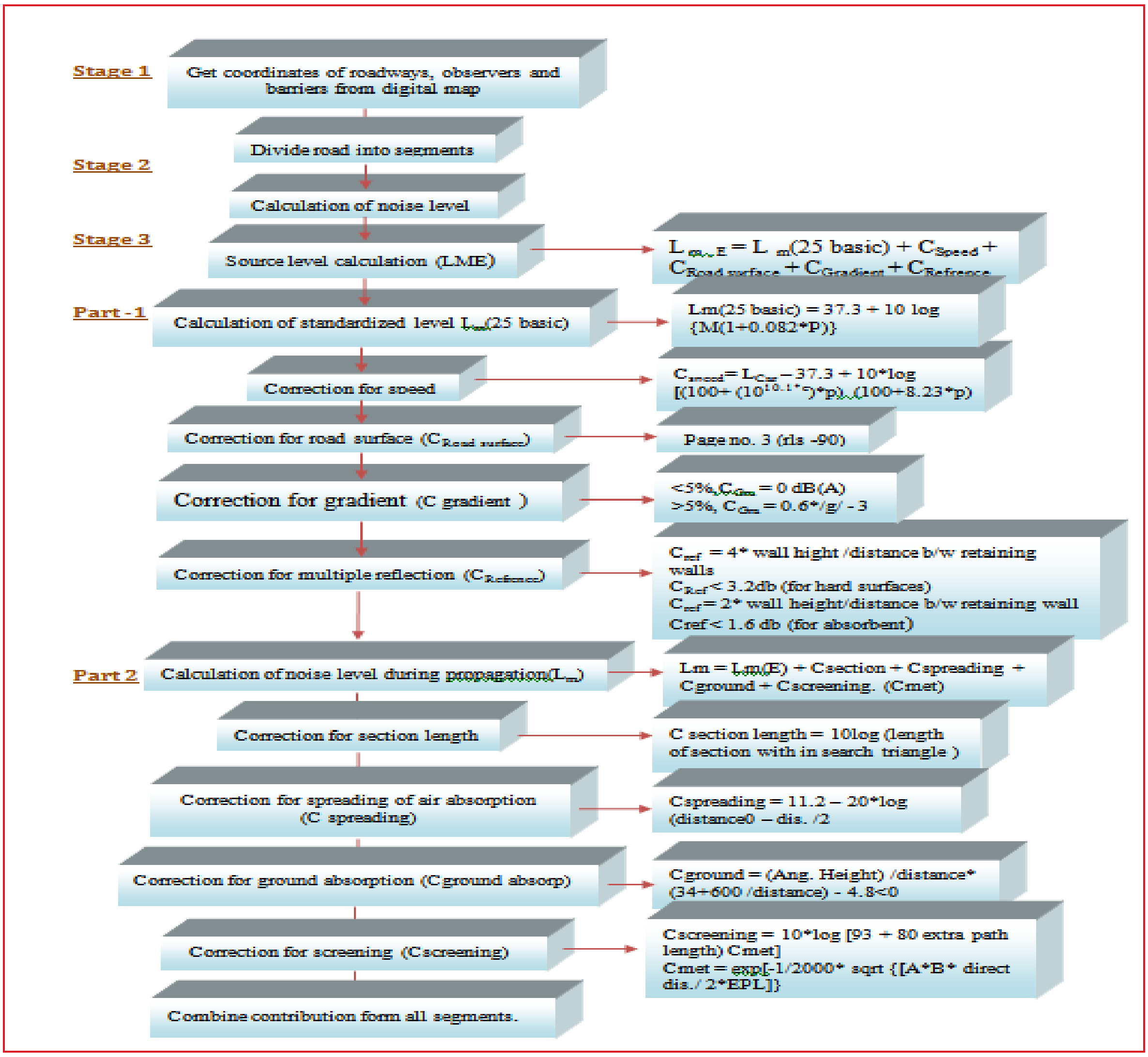

Fig. 3: *Flow Chart for RLS 90 Highway Noise Prediction Model.*

Stop-and-Go Model

- Applied for interrupted traffic conditions
- Has separate lane concept (deceleration and acceleration)
- Vehicle categories – car, jeep, van, TW, LCV/MB, auto, truck, bus
- Consideration of near-side and far-side concept

The urban road network in the Central Park of Bangkok, surrounded by the cordon line of Rajchadapisek Ring Road, is used as the study area [1]. Data collection includes measurement of traffic characteristics, traffic noise levels, and geometrical dimensions of road cross-section, which were used at 60 uniformly distributed locations within the study area.

Traffic Characteristics

Traffic characteristics data consists of traffic volume, traffic composition and spot speed of vehicles using the roadway during measurement periods. Traffic composition includes automobiles, trucks (light, medium and heavy) and two other non-conventional but popular vehicle types found in Bangkok, namely, motorcycle and motorized tricycle taxis.

Analysis of Modeling

There are two analytical approaches for uninterrupted traffic flow noise.

1) Single model analysis
2) Separated model or dual model analysis

Traffic Volume Computation

Traffic volume is computed using following equation:

Volume = (AU) + 1.04(LT) + 1.12(MT + TT) + 1.14(HT) + 1.09(MC + BU + MB)

where,

AU = Automobile, HT = Heavy Truck, LT = Light Truck, MC = Motorcycle, MT = Medium Truck, BU = Bus, MB = Minibus

Single Model Analysis

The single-model approach analysis was first applied to build a single Stop-and-Go traffic flow noise model. This model can be applied to both sides of an urban roadway. All parameters, which have a potential effect on traffic noise, were tested to check their linear relationship with the measured traffic noise levels. The model developed in this study is given below:

Leq = 71.05 + 0.10Sn + 0.95logVn + 0.04Sf + 0.015logVf−0.111Dg

where,

Leq = equivalent traffic noise level in 1 hour (dB(A))

Sn = mean speed of traffic on near-side of observer (both sides of road), kmph

Sf = mean speed of traffic on far-side of observer (both sides of road), kmph

Vn = volume of traffic for near-side of traffic (both sides of road), veh/h

Vf = volume of traffic for far side of traffic (both side of road), veh/h

Dg = geometric mean of road side section, m

Dg = $\sqrt{(Df \times Dn)}$

Df = Distance from the observer to center line of far-side roadway, m

Dn = Distance from the observer to center line of near-side roadway, m

Comparison of FHWA, Stop-and-Go, CORTN and RLS 90 models is presented in Table 3.

CNR Model

Italians use the model developed by their technicians is "Consiglio Nazionale delle Ricerche" (CNR) and then improved by Cocchi *et al.* [2]. This model represents a modification of the German standard RLS 90, adapted to the Italian framework; a relation between traffic parameters and the mean sound energy level is supposed and the traffic flow is modeled as a linear source placed in the center of the road. So the equivalent sound level in dBA is given by:

$$L_{eq} = \alpha + 10\log(Q_L + \beta Q_P) - 10\log(d/d_0) + \Delta L_V + \Delta L_F + \Delta L_B + \Delta L_S + \Delta L_G + \Delta L_{VB}$$

where,

QL and QP are the traffic flow in 1 h, related to light and heavy vehicles respectively, d_0 is a reference distance of 25 m and d the distance between the lane center and observation point on the road's edge. Then:

ΔLV is the correction due to mean flux velocity defined in Table 4.

Table 3: *Comparison of FHWA, Stop-and-Go, CORTN and RLS 90 Models.*

S.N	PARTICULARS	FHWA(TNM)	STOP AND GO	CORNT	RLS90
1	Country	USA	Bangkok	U.K	Germany
2	General condition	Fee flow	Interrupted	Free flow	Free flow
3	Calculation approach	Road is divided into segment. Separate L_{eq} values are combined.	No segments	Road is divided into segments. contribution from each segment are combined at receiver position	Road is divided into segments, separate $L_{A,eq}$ values are combined.
4	Time period	Hourly measurement of L_{eq}	Hourly (1hr)	One hr 6:00-24:00	Day -6:00-22:00 Night -22:00-6:00
5	Vehicles categories	Three (light , heavy, medium)	Six - (Car, jeep, van, TW, LCV/MB, auto, bus, trucks)	Two- (light and heavy vehicles)	Two –(car, truck)
6	Traffic volume	calculated in terms of (vehicles /hr)	Is converted into PCME then calculated	Calculated in terms of vehicles /hr	Calculated in terms of vehicles /hr
7	Traffic volume	calculated in terms of (vehicles /hr)	Is converted into PCME then calculated	Calculated in terms of vehicles /hr	Calculated in terms of vehicles /hr
8	Speed	Spot speed of each vehicle was measured. (range - 48-125kmph)	Mean speed of traffic considered Sn=nearside of observer Sf = far side of observer then S_E (equivalent speed is calculated)	Mean traffic speed is taken range – (50- 108 km/h)	Parametric L_w= f(V) V= Road Speed Limit
9	Ground absorption	Yes (in terms of ground absorption coefficient) Value-0 to 0.75	No	Yes (in terms of ground coefficient)-value - 0.75 to 1	Yes (depends on the average height and distance)
10	Barriers	Yes	No	Yes	Yes
11	Façade Reflection	No	No	Yes	Multiple Reflection
12	Metrological effect	No	No	No	Yes
13	Angel of view	Φ(angle of highway section)	Not utilized	In terms of θ & θ΄(reflected are taken)	Not utilized
	Reference distance	Do =15m from centre of nearside lane and actual distance measured	Geometric mean of cross section is utilized	Do=10m from nearside carriage way edge	D_O =25m reference distance for calculation of noise level
14	Geometric mean of cross section	Not utilized	Is utilized and given as: D_g=D_f x D_n	Not utilized	Not utilized
15	Nearside and far side concept	Considered	Considered	Not considered	Not considered

Table 4: *ΔLV Correction due to Mean Flux Velocity.*

Flux mean speed (km/h)	ΔLV (dBA)
30–50	+ 0
60	+ 1
70	+ 2
80	+ 3
100	+ 4

- ΔLF and ΔLB are the correction for the presence of reflective façade near the observation point (+ 2.5 dBA) or in opposite direction (+ 1.5 dBA) respectively.
- ΔLS is the correction for the road pavement defined in Table 5.

Table 5: *ΔLS Correction for Road Pavement.*

Road pavement	ΔLS (dBA)
Smooth asphalt	−0.5
Rough asphalt	0
Cement	+ 1.5
Rough pavement	+ 4

NMPB-Routes

The European directive suggested using the official interim French standard model "Nouvelle Methode de Prevision de Bruit" or simply NMPB-Routes-96 [2]. This method has been developed by different French institutes of Ministère de l'Equipement (CSTB, SETRA, LCPC, LRPC) and represents an improvement of the oldest one defined in the "Guide de Bruit" of 1980, that takes into account the meteorological conditions and long distance (d > 250 m) prevision, as suggested in ISO 9613. Nowadays, it represents one of the most used TNM, being also integrated in some commercial software such as CadnaATM by 01 dB.

In the year 2000, under request of SETRA, a revision of NMPB-Routes-96 started, bringing to the NMPBRoutes-2008. The method is based on the concept of propagation path. Several paths between a source and a receiver can exist, depending on topography and obstacles and, at each of them, a long-term sound level LAi,LT may be associated. Despite previous models, NMPB takes into account the standard meteorological conditions, as suggested by ISO 9613, to adjust the prevision for long period. They are classified into two types: meteorological conditions "favorable to the propagation" (as defined in ISO 9613) and "homogeneous acoustical conditions" (corresponding to the conditions used in the oldest French model).

So, the long-period prediction level for each path LAi,LT is evaluated adding the terms corresponding to these two conditions:

LAi,LT = 10Log [pi10(0.1 LAi,F) + (1–pi)10 (0.1 LAi,H)]

where, LAi,F and LAi,H are the global levels evaluated respectively for favorable and homogeneous conditions and pi represents the probability of occurrence of favorable conditions. These levels are calculated for each octave band and for each path from the source, according to the following formulas:

LAi,F = LA,W−Adiv−Aatm−Agrd,F−Adiff,F

LAi,H = LA,W−Adiv−Aatm−Agrd,H−Adiff,H

For each path the algorithm computes three different attenuations: the geometrical spreading Adiv and the atmospheric absorption Aatm that are the same in both formulas, and the boundary attenuations Abnd, which depends on the propagation conditions and are determined by ground effect (Agrd) and diffraction (Adiff).

The sound power level, LA,W, is evaluated considering the hourly flux Q, and directly obtaining the equivalent hourly level in dB(A), E, associated to a single light or heavy vehicle. By this procedure, the point-like source acoustical power representing the road is given by:

LAwi = [(EL + 10Log QL) + (EP + 10Log QP)] + 20 + 10Log (Ii) + R(j)

where, EL and EP are the emission levels obtained for light and heavy vehicles, Ii the length in meters of considered road and R(j) is the value of normalized noise spectra from CEN 1793-3(1995) that take into account the frequency behavior of propagation.

The predictions of NMPB-Routes-96 have been validated on a great number of experimental campaigns with various topography and meteorological conditions, founding a very good agreement with the noise data but generally an overestimate level is found in downward propagation conditions. That is why SETRA required the revision of the model. The NMPBRoutes-2008 presents a better estimation of noise level in downward condition, takes into account reflections on embankments, is able to evaluate the correction due to diffraction by low barriers and has implemented other minor corrections.

Edinburg Model

This model is built to predict interrupted flow traffic noise in the United Kingdom used in the early stage of investigation [3]. In the initial stage, field survey data were obtained from a wide range of urban streets. Some 300 sites were surveyed. Traffic volume recorded at the sites ranged between about 100 and 2000 vehicles per hour, and traffic flow was generally interrupted in character. The analysis of L10 were based on meter readings (at 4 s intervals) taken from the time-lapse films. The vehicles flow was divided into vehicles group, light – up to 1.5 ton, and heavy at over 1.5 ton. Vehicles speeds were also measured at the monitoring point. The mathematical formula of the model is as below:

$$L_{10} = 55.2 + 9.18\log Q(1 + 0.09PH) - 4.2\log Vy + 2.3T$$

where, L_{10} = traffic noise level in dB(A) that exceeds 10% of the measuring time (1 h)

Q = traffic volume, veh/h

PH = proportion of vehicles exceeding 1.5 ton
T = Index of dispersal (ratio of variance to the mean on number of the vehicle arriving in each 10-s interval)
V = Mean speed of traffic, kmph
y = carriageway width, m

Sheffield Model

The mathematical formula of the model is given below [3]:

$$L10 = 51.51 + 10.5\log Q(1 + 0.04PH) - 5.7\log (dk + 0.5y) + 2.38\log G$$

where,
L10 = traffic noise level in dB(A) that exceeds 10% of the measuring time (1 h)
Q = traffic volume, veh/h
PH = proportion of vehicles exceeding 1.5 ton
T = index of dispersal (ratio of variance to the mean on number of the vehicle arriving in each 10-s interval)
V = mean speed of traffic, kmph
y = carriageway width, m
dk = distance from noise meter to edge of kerb, m
G = 1, or percentage gradient whichever is larger

Gilbert Model

The mathematical formula of the Gilbert model is given below [3]:

$$L10 = 43.3 + 11.2\log (L + 9M + 13H) - 0.43y + (2.42/df)$$

where,
df = distance from the near side façade, m and df > 1; L = number of light vehicles (< 1525 kg), veh/h; M = number of medium goods vehicles (< 1525–4500 kg), veh/h
H = number of heavy goods vehicles (> 4500 kg), veh/h

CONCLUSIONS

The paper presents a review of most of the traffic noise prediction models used in the world, viz., FHWA (USA), RLS-90 (Germany), Calculation of Road Traffic Noise (CORTN) (UK), NMPB-Routes-96 (France), STOP-and-GO model (Bangkok), CNR model (Italy) and Edinburg model (UK). Main description of the model is presented in the paper. Few studies suggest that CORTN model, FHWA model and RLS-90 model will give better results for Indian conditions in comparison to other models due to different types of traffic scenarios while some studies highlight the importance of the CORTN model which appears to be better than FHWA model in Indian conditions. The Stop-and-Go and Edinburg models can predict traffic noise for interrupted flow conditions.

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