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REVIEW ARTICLE

Recent advancements in the challenges and strategies of globally used traffic noise prediction models

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Abstract

It is the need of an era to develop efficient traffic noise prediction models with optimum accuracy. In this context, the present work tries to comprehend the performance-related potential parameters based on earlier published articles worldwide that are responsible for deviation in noise values for different traffic noise prediction models and find out critical gaps. This study reviewed the process involved in source modeling and sound propagation algorithms, applicability, limitations, and recent modification in 9 principal traffic noise prediction models adapted by different countries all around the globe. The result of this review shows that many researchers had carried out comparative analysis among various traffic noise prediction models, but no emphasis was made on the recent modifications, limitations associated with those models, and strategies involved without ignoring the propagation and attenuation mechanism in the developing phase of these models. The findings of this study revealed that the major challenge for any traffic noise prediction model to be efficient enough is the inclusion of all the factors responsible for the generation and deviation of traffic noise before reaching the receiver. These responsible factors include a factor for source emission, sound propagation and attenuation, road characteristics, and other miscellaneous factors such as absorption characteristics of building facades, honking, and dynamic behavior of traffic. This study adds to the broader domain of research and will be used as reference material for future traffic noise modeling strategies.

Keywords L_{eq} · CRTN · FHWA · MITHRA · RLS90 · Principal traffic noise models · Sound propagation

Introduction

Acoustics has played an important role in vehicle design since the 1970s. Interior vehicle noise, in particular, has decreased dramatically over the past few decades as a result of user demand for quieter interiors. Exterior noise levels, on the other hand, have not improved in the same way, owing to the fact that everlasting noise from traffic is an environmental externality that vehicle occupants are not aware of (Guarinoni et al. 2012). Road traffic noise acts as a major disturbance to the community residing in the vicinity of any highway corridor. This causes more people to be disturbed than any additional factor. However, such a threat to people's health and standard of life has been growing at an alarming rate in recent years for a variety of reasons (Suksaard et al. 1999; Nirjar et al. 2003). The proportion of humans exposed to road traffic noise greatly outnumbers those exposed to locomotive and aircraft noise combined. The noise produced by a vehicle's propulsion system (engine noise) and the noise made by the vehicle's tires contacting the roadways (tire/road noise or rolling noise) is referred to as road traffic noise. The amount of noise produced by a vehicle is mostly influenced by its speed, and the proportion of each generating component is determined by speed: Engine noise dominates at a slower velocity, while a tire/road noise prevails at greater velocity. Previously, there were no separate estimation approaches for the various source mechanisms of a vehicle; rolling noise and engine noise were measured together, and it was thought that a vehicle could be interpreted as a simple moving point sound source (Chevallier et al. 2009). By integrating over time, this single moving point source could be interpreted by a line source (Li et al. 2002). A strategy to evaluate the degree of noise at the source (called the source model) and a procedure to

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explain how noise will transmit outward from the origin are the two segments of most noise detection approaches (called the propagation model) (De Coensel et al. 2005). As a result, these models (source and propagation models) rely on cutting-edge technology and competent labor to reach their end aim. As a result, it is critical to conduct scientific analysis and comparison of various models in order to identify their relevance and the best approach for modeling traffic noise among them. Steele (2001) conducted a comprehensive analysis of some of the most important traffic noise prediction approaches. Nevertheless, most of such approaches have been updated in recent years, making it necessary to amend assessments based on modifying scientific characteristics. The FHWA (Federal Highway Administration) model of the USA, MITHRA model of Belgium, ASJ 1993 (Acoustical Society of Japan) model of Japan, CRTN (Calculation of Road Traffic Noise) model of the United Kingdom, RLS-90 (Richtlinien für den Lärmschutz an Straben) model of Germany, STL-86 model of Switzerland, ERTC (Environmental Research and Training Centre) model of Thailand, Nord 2000 (New Nordic Prediction Method for Traffic Noise) model of Scandinavian countries, and CNOSSOS-EU (Common Noise Assessment Methods in Europe) approach of European countries are among the models addressed in this article. The main objective of this review study is to scientifically examine and compare the above-mentioned traffic noise prediction models based on various technical attributes (traffic conditions, types of vehicles, meteorological effects, propagation types, attenuation factors, etc.) in order to find their applicability as well as to determine the best strategy among them for traffic noise modeling, identifying challenges faced in their development process along with all the possible factors responsible for deviation in the value of traffic noise and limitations associated with all these traffic noise prediction models, recommending future considerations for further modification in the models to enhance the traffic noise prediction accuracy.

The present study will be valuable to facilitate the planning and design of roads as well as to assess current and anticipated variations in traffic noise conditions. It helps highway engineers to assess whether there is a requirement for barriers or additional space between the road and adjacent buildings. These traffic noise prediction models will be helpful when sometimes, in addition to the value of L_{eq} (continuous equivalent noise level), prediction of other important noise descriptors such as L_{peak} (peak value of the whole set of intervals), L_5 (noise level exceeding 5% of the time), and L_{10} (noise level exceeding 10% of the time) are required. The present study will also be beneficial to environmental engineers in preparation for the environmental noise pollution section under environmental impact statements of any government project. Moreover, noise prediction models are also helpful in noise forecasting and the development of noise contour maps to identify the noise-prone and vulnerable zone of any study area.

Methodology

The methodology of the present study involves various steps. Firstly, a broad research topic was chosen as traffic noise prediction models; then, several relevant articles were collected using different keywords related to the topic such as noise modeling, prediction models, traffic noise modeling, traffic noise, traffic noise models, and traffic noise prediction models. For collecting relevant articles, different scientific databases were employed, such as Scopus, Google Scholar, Web of Science, ScienceDirect, ProQuest, ResearchGate, and Research Reports. Moreover, the concept of snowball was used to collect more articles by finding citations from various publications. Subsequently, an in-depth analysis was done for each article, and various traffic noise prediction models were identified and analyzed, out of which 9 globally used models were selected for this study. The basis on which comparison among all selected models can be done was studied. Basis of comparison includes applications, traffic conditions, data needed in the modeling process, model type, mapping type, noise descriptor, source, type of vehicles, directivity, etc. Furthermore, noise propagation and attenuation mechanism were analyzed separately. Finally, after comprehension of the whole analysis, various limitations associated with particular models and future considerations were also recommended.

Fundamental noise model

All the noise predictive models that were developed from different emission sources, i.e., road, rail, air, or industrial. (Murphy and King 2014), have applied some form of the basic expressions (Eq. (1)).

$$L_p = E - A_{tot} \tag{1}$$

The sound pressure level at the receiver end is denoted by the letter "L_p." Different measuring approaches can utilize different indicators to define this number, such as L_{10}, 18 h, L_{Aeq}, L_{den}, and EPNL. The letter "E" represents the source's emission. This is a representation of the sound power level of the source, L_w. Because the source description differs from one standard to the next, use E instead of L_w. It can be stated as the sound power level of a single point source, the sound power per unit length of a single line source, or even the sound pressure level at a particular distance from the source (which could then be further considered to derive the sound level if needed). The term "A_{tot}" refers to the entire amount of sound attenuation that occurs between the source and the receiver, which includes ground absorption, air dissipation, geometrical divergence dissipation, and diffraction dissipation around noise barriers. Here, "C" represents a collection of different correction factors that may be caused by facade reflection, different road surfaces or types of trains, or detailed emission term correction (e.g., which may have been introduced before the attenuation). The flow chart for predicting noise levels from road schemes is illustrated in Fig. 1.

Early traffic noise models

The oldest roadway noise exposure model was published in the literature (Bolt et al. 1952). It was designed for speeds of 35 to 45 miles per hour and spans of more than 20 feet. The expression for the 50th percentile was as follows (Eq. (2)).

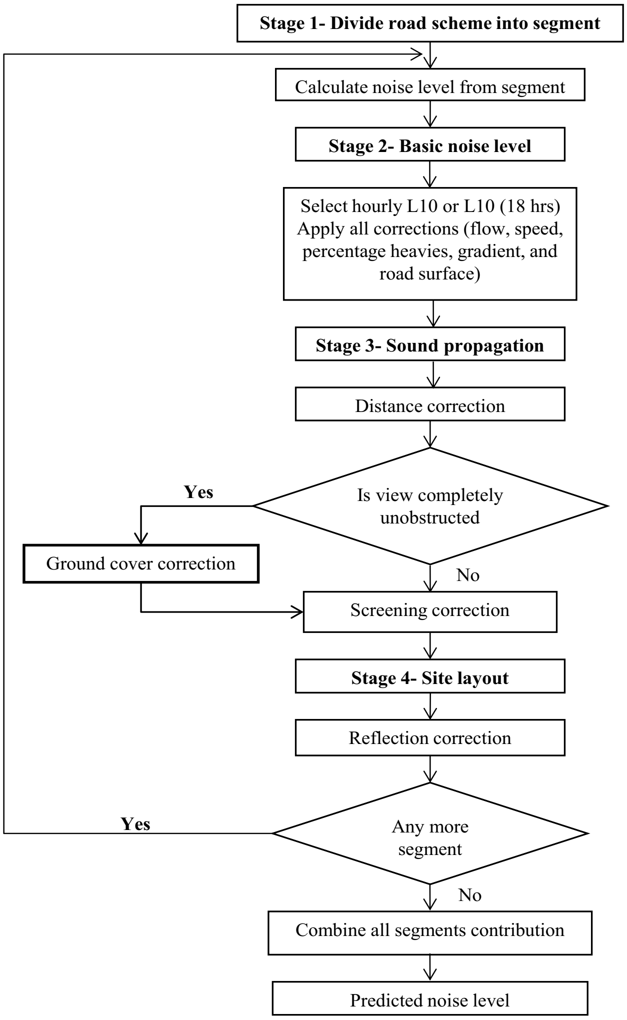


Fig. 1 Flow chart of prediction of sound pressure level caused by roadways

$$L_{50} = 68 + 8.5\log(V) - 20\log(D) \tag{2}$$

where the number of vehicles (in vehicles/hour) is represented by "V," and the length from the driving lane is represented by "D" (in feet). Nickson (1965) and Lamure (1965) separately combined and altered the models as per Eq. (3).

$$L_{50} = 3.5 + 10\log\left(V.S^3/D\right) \tag{3}$$

where "S" represents the mean speed of the vehicle in miles per hour and L_{50} is in dB(A).

This was claimed to pertain to 20% of commercial vehicles, and their data was said to be within 1 dB for commercial vehicles ranging from 0 to 40%. There were also remedies for excessive ground attenuation and slopes.

In the coming year, the new variable "T" of heavy-duty trucks was introduced by Galloway et al. (1969). The expression is given in Eq. (4).

$$L_{50} = 20 + 10\log\left(V.S^3/D\right) + 0.4(T) \tag{4}$$

where L_{50} is in dB(A)

New variables were added to the current models, as well as adjustments from L50 to L10 and Leq. Inconsistent units are used in prediction expressions that include velocity and commercial vehicle modifications. The tendency of employing logarithms of physical parameters is at best, as Gündoğdu et al. (2005) pointed out. To get around this issue, noise researchers have traditionally employed relative to a reference value.

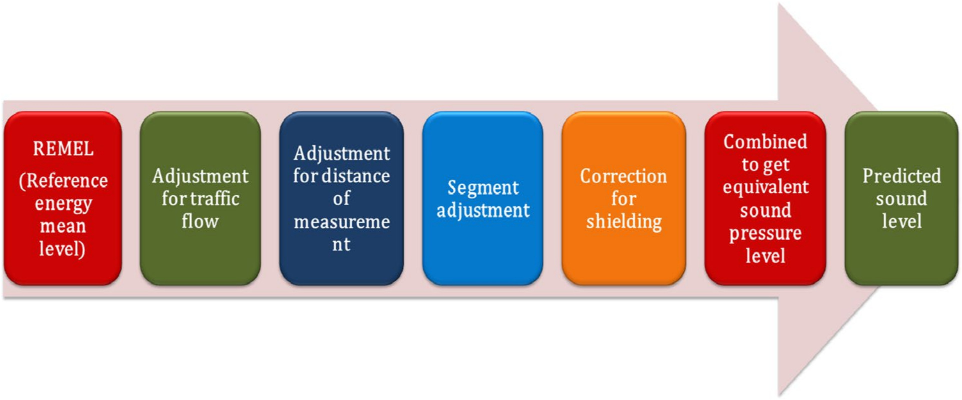
Global road traffic noise estimation approaches

FHWA approach

This traffic noise prediction model was developed by the Federal Highway Administration which is one of the divisions of the United States Department of Transportation by Barry and Reagan in the year 1978. The noise level resulting from a single lane of a single class of traffic was calculated first in the model. (i.e., category of the vehicle) at the receiver. This calculation is repeated for all combinations of lanes and traffic types. Several alterations to the reference sound level, known as the reference energy mean emission level (REMEL) in the TNM, are used to determine the sound pressure level at the receiving side. At a distance of 15 m, these reference levels define the vehicle's maximum sound level. The flow diagram of the FHWA model is illustrated in Fig. 2.

The REMEL database is a database of noise emission levels derived from measurements of more than 6000 vehicle passes made across nine states in the USA, covering both constant traffic flow and interrupted traffic flow and including sub-source height data (Anderson et al. 1998). Reference

Fig. 2 Flow diagram of FHWA model



emission levels are included in the TNM database for many different types of vehicles, road surfaces, and driving conditions (cruising, accelerating, and idling). Data are available in 1/3 octave bands for five standard vehicle categories:

- automobiles (including light vehicles) – vehicles with a gross weight of less than 4500 kg;
- moderate trucks – vehicles with a gross weight of between 4500 and 12,000 kg;
- commercial vehicles – vehicles with a gross weight of more than 12,000 kg;
- busses – vehicles with a capacity of more than 9 occupants; and
- motorcycles – vehicles with two or three tires and an open-air motorist cupboard.

In order to calculate the noise at the receiver, a few adjustments are introduced to the reference level for each vehicle class, taking into account the various acoustic effects associated with traffic flow, distance, and shielding given by FHWA (Barry and Reagan 1978) (Eq. (5)).

$$\mathrm{L}_{\mathrm{Aeq,1h}} = \mathrm{EL}_{\mathrm{i}} + \mathrm{A}_{\mathrm{traffic}} + \mathrm{A}_{\mathrm{d}} + \mathrm{A}_{\mathrm{s}} \tag{5}$$

where EL_i is the noise emission by the vehicle of each category I, $\mathrm{A}_{\mathrm{traffic}}$ is an adjustment for the quantity and speed of each vehicle type I, A_d and A_s are propagation model changes that account for the distance between the road and the receiver, as well as shielding and ground impact. Adjusting the flow of traffic depends on the number of vehicles in the flow, v, and their speed, s, and is presented in Eq. (6). The adjustment is made separately for each vehicle type, and it is done in third-octave bands.

$$A_{traffic,i} = 10\log_{10}\left(\frac{V_i}{S_i}\right) - 13.2 \tag{6}$$

In most cases, the FHWA TNM relies on the user's feedback for vehicle speeds. TNM, on the other hand, computes the vehicle speed separately in two situations: (1) when traffic speeds are reduced by enhancements and (2) when traffic speeds are reduced by vehicle dynamics.

MITHRA approach

MITHRA was created by 01 dB, L' acoustique numerique, a French company, in the year 1987, and it is extensively used as a commercial software package. It includes a detailed ray-tracing kit that accounts for atmospheric and ground impact, as well as local topography, structures, and windows, as well as reflection and diffraction caused by cuttings. The premise is that traffic is a producer of lines. There are five main types of roads, each with six different types of driving surfaces to evaluate. Mithra also includes a noise estimate for railways. The sound intensity level per unit length is stated in Eq. (7) (Anon 1982):

$$LW = LW_{\mathrm{VL}} + 10.\log\left[\frac{flow + flow\%\mathrm{PL}.(EQ - 1)/100}{V_{50}}\right] - 30 \tag{7}$$

where "$\mathrm{LW}_{\mathrm{VL}}$" stands for light vehicle acoustic power, "Flow" stands for the number of vehicles per hour per lane, and the % PL denotes the percentage of large trucks on the road. The equivalency value of a light vehicle to a heavy vehicle is represented by the letter "EQ." The speed of the entire vehicle stream is represented by "V_{50}." A light vehicle's acoustic power is calculated as follows (Eq. (8)).

$$LW_{\mathrm{VL}} = 46 + 30.\log V_{50} + C \tag{8}$$

Whenever V50 is lower than 30 km/h, 30 is substituted by V50, and "C" is determined by the nature of traffic. C=0 indicates the smooth flow of traffic, 2 indicates the irregular flow of traffic, and 3 indicates the escalating flow of traffic. The speed and gradient are used to calculate EQ.

CRTN approach

The CRTN approach to traffic noise prediction was developed by the Department of the Environment and Welsh Office in the United Kingdom in 1975. This approach assumes traffic as a line source with constant speed and is commonly used in Ireland, Australia, New Zealand, and Hong Kong, among some other places. The previously developed version in 1975 was replaced and modified in 1988 by the Transport and Road Research Laboratory and the Department of Transport in the United Kingdom. Although separate emission and propagation models are included in this modified version, researchers reported that the CRTN model underestimated high observed noise levels and overestimated low observed noise levels. In a study conducted on Australian road conditions, a huge difference was reported in predicted noise values (Samuels and Saunders 1982). CRTN was noted in a 2001 analysis of some of the most popular traffic noise prediction models for its substantial implications for curve fitting connecting empirical results, even though it was understood that this approach did not conform to theory (Steele 2001). The analysis concludes that the CRTN L_{10} index is a pseudo-L_{10}, which significantly simplifies calculations while also resulting in a lack of validity, with the study's author concluding that the CRTN model is now obsolete (Steele 2001). However, the approach is still widely used in practice and was used for noise mapping in the United Kingdom and Ireland (Murphy and King 2014).

The model works by dividing a road into several different parts, each with a noise variance of less than 2 dB(A). After that, each section is viewed as a distinct noise source, with calculations carried out separately for each. The approach produces a fundamental noise level that is basically a reflection of the source emission.

The accompanying equation is applied to determine the fundamental noise exposure (Eqs. (9) and (10)).

$$L_{10,1h} = 42.2 + 10\log_{10}(q) \tag{9}$$

or

$$L_{10,18h} = 29.1 + 10\log_{10}(Q) \tag{10}$$

where "q" and "Q" are hourly and 18 h flows, respectively, of all types of vehicles (both heavy and light). This basic noise level is then modified as Eq. (11) to account for different aspects of the traffic flow such as the average speed of traffic, V, and the proportion of freight trucks, p:

$$\text{Correction}_{V\mathcal{F}p} = 33\log_{10}\left(V + 40 + \frac{500}{V}\right) + 10\log_{10}\left(1 + \frac{5p}{V}\right) - 68.8 \tag{11}$$

A correction for road gradient, G, expressed as a percentage, is calculated as follows (Eq. (12)):

$$\text{Correction}_{\text{G}} = 0.3\text{G} \tag{12}$$

Correction for the nature of road surface is also incorporated. For impervious road surfaces, there are two equations: one for concrete surfaces and the other for bituminous surfaces. The texture depth (TD) of the road surface, expressed in millimeters, is the input variable in both cases. A sandpatch test may be used to assess the TD. These formulas hold valid when the speed of traffic is more than or equivalent to 75 km per hour. If the traffic speed is lower, a fixed adjustment of – 1 dB(A) should be used.

Correction for concrete (Eq. (13)).

$$\text{Correction}_{\text{TD}} = 10\log_{10}(90\text{TD} + 30) - 20 \tag{13}$$

Correction for bituminous surface (Eq. (14)).

$$\text{Correction}_{\text{TD}} = 10\log_{10}(20\text{TD} + 60) - 20 \tag{14}$$

RLS 90 approach

The RLS-90 is a German approach to noise prediction developed by the German Federal Ministry of Transport in the year 1990 replacing its older version which was published in 1981. The model determines the environmental noise level $L_{m,E}$ at a range of 25 m from a traffic lane's centreline (Eq. (15)). The parameter $L_{m,E}$ is a measure of the magnitude of automobiles per hour Q and the % of large vehicles P (size N 2.8 tonnes) estimated theoretically assuming hypothetical situations, such as a velocity of 100 km per hour, a highway slope of less than 5%, and a specific road quality (Quartieri et al. 2009).

$$L_{\text{m,E}} = 37.3 + 10\log\{\text{Q}\cdot(1 + 0.082p)\} \tag{15}$$

where "L_m" denotes the A-weighted average, Q is the standard vehicle circulation regardless of whether the highway is a Federal, state, district, or municipal roadway, and "p" indicates one percent (over 2.8 t). The subsequent stage is to quantify the many variations from such hypothetical scenarios in terms of real-world pace, roadway slope, and surface type, among other variables. The mean value L_m is evaluated as per the following expression (Eq. (16)).

$$L_{\text{m}} = L_{\text{m,E}} + R_{\text{SL}} + R_{\text{RS}} + R_{\text{RF}} + R_{\text{E}} + R_{\text{DA}} + R_{\text{CA}} + R_{\text{TB}} \tag{16}$$

where "R_{SL}" represents a speed limit correction, "R_{RS}" represents a road surfaces correction, "R_{RF}" represents a modification for moving up and down across the streets, "R_E" represents a modification for attenuation property of construction interfaces, "R_{DA}" represents the quotient of attenuation which considers the spacing from the receiver and air permeation, "R_{GA}" represents the quotient of attenuation from the floor and ambient situations, and "R_{TB}" represents the quotient of attenuation due to topography and building size.

"$L_{m,E}$" for the individual lane is expressed as per the following expression (Eq. (17)).

$$L_{\mathrm{m,E}} = 10\log\left[10^{0.1L}\mathrm{m}_1 + 10^{0.1L}\mathrm{m}_1 f\right] \tag{17}$$

where "n" and "f" denote the near lane and the farther lane, respectively.

In the study done by Calixto et al. (2003), the RLS-90 model was validated in an urban setting and the results seem to be satisfactory, corresponding to the actual measured value. Later, a software system developed in accordance with the German regulation RLS-90 made noise level calculation and prediction easier.

STL 86 approach

The Swiss Federal Ministry for Environmental Conservation, Switzerland, developed STL-86 Version 1.0 1987. Architects and urban administrators (Balzari and Grolimund 1988) proposed Modele de Bruit du Traffic Routier dans les Zones Habitees, which was also recognized by the Swiss Federal Service for Environmental Conservation. Both traffic and an acoustic concept are included in this design. The usual road traffic source in the case of STL-86 and many other traffic noise prediction models is the outcome of this road noise model. The noise modeling, like other designs, is split into two phases: generation and transmission.

The above approach considers traffic as a single route rather than discrete flows. As a result, the overall slope is required to maintain traffic to move in both ways, calculated by Eq. (18).

$$I = \frac{i}{2}\left[1 + \frac{N_{\mathrm{mont.}} - N_{\mathrm{desc.}}}{N_{\mathrm{mont.}} + N_{\mathrm{desc.}}}\right] \tag{18}$$

where "I" represents the overall slope in percentage, "i" represents the slope of the road, N_{mont}. represents traffic stream in uphill, and N_{desc}. represents the traffic stream in downhill.

The emissions caused from 3 distinct categories of transportation are estimated using the following expressions (Eqs. (19)–(21)).

$$L_{\mathrm{E1}} = \max.\left\{12.8 + 19.5 \cdot \log V_1, 45 + 0.8(I - 2)\right\} + 10 \cdot \log N_1 + A \tag{19}$$

$$L_{\mathrm{E2}} = \max.\left\{34 + 13.3 \cdot \log V_2, 56. + 0.6.(I - 1.5)\right\} + 10\log N_2 + A \tag{20}$$

$$L_{\mathrm{Eb}} = E_{\mathrm{b}} + 10 \cdot \log N_{\mathrm{b}} \tag{21}$$

where L_{E1}, L_{E2}, and L_b represent noise production from 3 different segments in dB(A), "V" represents the speed of the vehicle, "N" represents the flow of traffic, and "E_b" indicates the emission from individual trams. E_b can be assumed as 56 dB(A) if trams are less than or equal to 10%; otherwise, it should be measured. "A" represents a constant which depends on the nature of the road surface.

Modifications for reflection through buildings via highways, attenuations because of houses and other barriers in between highway and recipient, proximity impact, and the elevation of highway viewed by the recipient are all included in this approach.

The following expression (Eq. (22)) is used to estimate the mathematical values for trams and motors individually:

$$L_i = L_{\mathrm{r},ei} + \Delta R_i + \Delta O_i + \Delta D_i \Delta \Phi_i \tag{22}$$

At last, all these values are added logarithmically to get the final result.

ASJ 1993 approach

The Acoustical Association of Japan devised an approach to forecasting a pseudo-L_{50} in open traffic in 1975. It was first documented by Koyasu (1978); then, it was amended by Takagi (1994), Yamamoto (2010), and Sakamoto (2018). The change entails using a direct approach to determine L_{eq} and then estimating the pseudo-L_{50} from the finding, which must meet the former condition. This is referred to as the A-Approach. ASJ also provided the B-Approach, which is an empirical approach. Only if you are a long way from the line source is this true. For two and three classes of vehicles, the sound power level of the traffic stream is represented as Eqs. (23) and (24).

$$L_{\mathrm{w}} = 65.1 + 20\log V + 10\log\left(a_1 + 4.4a_2\right) \tag{23}$$

The magnitudes of small and large automobiles are a_1 and a_2, respectively, and the sum of a_1 and a_2 equals to 1.

$$L_{\mathrm{w}} = 64.7 + 20\log V + 10\log\left(b_1 + 1.5\mathrm{b}_2 + 4.9\mathrm{b}_3\right) \tag{24}$$

The letters b_3 stand for small, moderate, and large automobiles, respectively.

The A-approach and the empirical B-approach are two types of ASJ approaches. The A-approach includes calculating octave band spectra. According to the equation: $L(f) = -10\log\{1 + (f/2000)\} \pm 2.5\log(\mathrm{f}/1000)$, these are derived from the band center frequencies of 63 Hz to 4 kHz, as long as v is higher or less than 80 km/h. L_{eq} can be calculated from Eq. (25).

$$L_{\mathrm{eq}} = 10\log\left[\sum_{i=1}^{k} 10^{U_i/10} \Delta t N/T\right] \tag{25}$$

where U_i is the ith subinterval of $U(f)$, the range of the propagation function at the receiver, N is the traffic volume, and $T = 3600$ s.

A model comparable to this one has been proposed by $\Delta t = \Delta d/v$ (Anderson et al. 1996). For each vehicle, $U(f)$ is added at discrete places, which should be in a straight line and separated at distance Δd. This method is limited to uniform separations.

Recently, a newly developed prediction model named ASJ RTN-Model 2018 of sound propagation is suggested by Fukushima et al. (2019). This is the practical calculation model rely on geometrical acoustic. The equations developed in this model are defined according to numerical analysis or experimental data. The amount of L_{eq} in dB(A) from the vehicle is evaluated directly by taking into account the frequency characteristics of vehicle noise. Calculation in this model considers different affecting factors such as impacts of several categories of restrictions, ground surface attenuation, atmospheric absorption, sound reflection, and meteorological effects.

ERTC approach

This methodology of environmental impact assessment was established by Thailand's Environmental Research and Training Centre (ERTC) in the year 1999. In this model, automobiles were divided into two groups, and the mean static sound intensity of every category was assessed over a huge number of automobiles. The sound intensity rating of every vehicle type was calculated using the noise intensity of operating automobiles.

The equivalent sound intensity "L_{eq}" is calculated from Eq. (26).

$$L_{eq} = \mathrm{PWL} - 10\log 2ld + L_d + L_g \tag{26}$$

PWL is the vehicle's A-weighted energy mean power output in dB(A), l is the separation from the traffic line to the receiver antenna in meters, L_g and L_d are the diffraction and distance attenuation adjustments in dB(A), and d is the mean spacing between the fronts of two automobiles in meters (Eq. (27)).

$$\mathrm{d} = 100.\mathrm{V}/\mathrm{Q} \tag{27}$$

where "V" represents the mean velocity in kilometers per hour and "Q" denotes the volume of traffic in vehicles per hour. The following formula is used to calculate the energy power rating of vehicles:

In the case of heavy vehicles (Eq. (28)),

$$\mathrm{PWL} = 75.1 + 20.4\log\mathrm{V} \tag{28}$$

For light vehicles (Eq. (29)),

$$\mathrm{PWL} = 67.8 + 20.4\log\mathrm{V} \tag{29}$$

The mean noise intensity of heavy automobiles is approximately 7.3 dB(A) which is larger than light automobiles, and for a group of mixed-type automobiles is expressed as Eq. (30).

$$\mathrm{PWL} = 67.8 + 20.4\log V + 10\log[(1-a) + 5.37a] - 10\log 2ld + L_d + L_g \tag{30}$$

The proportion of large automobiles to total automobiles is denoted by the letter "a." According to the report, the results' performance is adequate for practical application, and they will be employed in Thailand for environmental impact assessment. The model has been shown to work for 2, 4, 6, 8, and 10 lane roads with speeds ranging from 30 to 140 km per hour. The model's accuracy has been demonstrated to be 92.3% of the time within a 3 dB(A) range, and it can estimate highway traffic noise levels at lengths of 1–80 m and elevations of 1–12 m above ground level (Ohrstrom et al. 2006).

NORD 2000 approach

NORD 2000 approach for traffic noise prediction was introduced by a joint Nordic project group by revising the existing older version of the model developed in 1996. The group consists of a collaboration of several organizations including the Swedish Environmental Protection Agency, Danish Road Directorate, Finnish Road Administration, Norwegian State Pollution Authority, and The Swedish Road Administration. The noise pressure intensity at the receiver is calculated by the following expressions (Kragh; Jonasson and Storeheier 2001) (Eq. (31)).

$$L_k = L_w + \Delta L_d + \Delta L_a + \Delta L_t + \Delta L_s + \Delta L_r \tag{31}$$

where "L_w" represents the noise power rating under the regarded frequency range, "ΔL_d" represents the impact of propagation of divergence of noise in a spherical way, "ΔL_a" is the transmission impact of absorption of air, "ΔL_t" represents the impact of the flow of the terrain, "ΔL_s" represent the propagation effect of zones of scattering, and "ΔLr" represents the transmission effect of barrier size and surface characteristics while evaluating an involvement from noise reflected by a barrier.

Vehicles are grouped into five categories in the road traffic noise model, light vehicles such as cars, double-axle large automobiles, multi-axle large automobiles, motorcycles, and mopeds. Types of highway textures are categorized into eight major types, the majority of which have further subtypes, and the situation of driving is divided into six ways. L_{AE} is used to convey the source data at a length of 10 m away from the highway (Kragh 2001). From 25 Hz to 10 kHz, the approach produces 1/3rd octave frequency band results. The model can be used to calculate weather conditions such as rapid atmospheric turbulent motions. The vertical noise velocity graph is developed with the help of meteorological data like wind and temperature gradient. The refraction is expressed by curved sound rays, whose curvature is calculated using a semi-analytical approach and is based on the vertical noise velocity graph.

The noise transmission system uses a geographical ray concept and includes techniques for evaluating 1/3rd octave spectrum noise attenuation along the way from origin to the recipient while considering topography structure and floor form.

CNOSSOS-EU approach

The European Commission in the year 2009 initiated to establish CNOSSOS-EU approach (Common Noise Assessment Methods in Europe) for noise contour mapping of roadways, railways, aircraft, and occupational noise, with the goal of creating a standardized conceptual approach for noise measurement (JRC Report 2010). The model of emission for road traffic was released in preliminary form in 2012 (Kephalopoulos et al. 2012). It is unlikely to change substantially in upcoming model revisions. It divides vehicles into five groups (*m*):

- light vehicles with $m = 1$,
- medium-heavy vehicle with $m = 2$,
- heavy vehicles with $m = 3$,
- powered two-wheelers (e.g., motorcycles) [$m = 4$a for 2 wheelers ≤ 50 cc and $m = 4$b for 2-wheelers > 50 cc], and
- an open category to be defined accounting for future needs (e.g., electric vehicles) [$m = 5$].

In terms of its noise intensity, the CNOSSOS-EU system describes the sound generation of an EU road car. A single point source representing each vehicle type is located at an elevation of 0.05 m above the road surface. A source line representing traffic noise emission is defined by its directional intensity of noise per meter per cycle. CNOSSOS-EU divides noise and engine (propulsion) calculations for rolling sound.

For rolling sound, the noise intensity range is defined in Eq. (32) for each vehicle category, *m*, and frequency band, *i*:

$$L_{WR,i,m} = A_{R,i,m} + B_{R,i,m}\log_{10}\left(\frac{v_m}{v_{ref}}\right) + \Delta L_{WR,i,m}\left(v_m\right) \tag{32}$$

where "v_m" represents the mean velocity of the stream of traffic and values for "A_R" and "B_R" is the standard across octave ranges for every type of vehicle and a predefined velocity of 70 km/h. For propulsion noise, the noise intensity range is defined by Eq. (33).

$$L_{WP,i,m} = A_{P,i,m} + B_{P,i,m}\left(\frac{v_m - v_{ref}}{v_{ref}}\right) + \Delta L_{WP,i,m} \tag{33}$$

Now, the overall noise intensity for that vehicle, $L_{W,i,m}$, is the energetic average of the rolling and propulsion noise as indicated in Eq. (34).

$$L_{W,i,m} = 10\log_{10}\left(10^{\frac{L_{WR,i,m}}{10}} + 10^{\frac{L_{WPP,m}}{10}}\right) \tag{34}$$

Comparison of models

It is clear that all the newly introduced major traffic noise prediction models in developed countries serve entirely all the purposes of road traffic noise modeling, starting with source identification in terms of sound power level to sound propagation through various meteorological conditions, including reflections, diffraction, and absorption occurrence. Simpler engineering models, such as RLS-90, generate an empirical formulation based on increasing level with reflecting floor surface or dissipation with attenuating nature of ground relying on sound wave height, whereas latest approaches, such as ERTC and Nord 2000, design the coherent superposition of direct wave and ground reflection, as well as phase connections depending on various wavebands (Probst and Huber 2010; Probst 2010). To account for the extent of the reflecting surface characteristic, the Fresnel zone definition is applied. (Hothersall and Harriott 1995). There are several intrinsic differences between CNOSSOS and Nord 2000. In general, both of these models consider diffraction and refraction distinctly including effects of attenuation due to meteorological conditions (Khan et al. 2021). Discussion of the source model has already been done, and Table 1 shows a systematic comparison of all of the major models produced in past years based on a thorough literature review.

Noise propagation and attenuation mechanism

Sound propagation and the random nature of traffic flow in a dynamic environment is a crucial research subject for enhancing traffic noise model accuracy. Numerical propagation methodologies such as the boundary element approach (BEM), parabolic equation (PE), and straight-ray approach are used to calculate the effects of the atmosphere, ground surface, and barriers on sound waves (RAY). The set of numerical codes enables practical roadway and railway designs with range-based sound speed profiles to be handled, with a "reference" L_{den} value as the end result (Defrance et al. 2007). Among the candidate models in harmonize are the parabolic equation (PE) model, fast field program (FFP), boundary element approach (BEM), Meteo-BEM, RAY

Table 1 Comparison of global traffic noise calculation approach

S. no	Particulars	FHWA TNM version 1.0	MITHRA	CRTN	RLS-90	STL-86	ASJ 1993	ERTC	NORD 2000	CNOSSOS-EU
1	Country users	USA, Canada, Japan	Belgium, France	UK, New Zealand, Australia	Germany	Switzerland	Japan	Thailand	Norway, Denmark, Sweden, and Finland	European countries
2	Proposed year	1978	1987	1975	1990	1986	1993	1999	2000	2009
3	Application	Highway (L_{eq})	Highway and railway (L_{eq})	Highway (L_{10})	Highway and car parks (L_{eq})	Highway, Light rail (L_{eq})	Barriers (highway)	Highway (L_{eq})	Highway and railway	Road, rail, aircraft, and industrial
4	Traffic conditions	Constant speed, acceleration, and grades	Constant speed, grades	Constant speed, grades	Constant speed, grades, intersections	Constant speed, grades	Constant speed	Constant speed	Motorway, urban motorway, main road, urban road, residential road	Constant speed, grades, intersections, and varying driving conditions
5	Predicts traffic volumes	No	No	No	Yes	No	No	No	No	No
6	Data needed	Traffic type, flow, road, and environs data; local characteristics	Traffic type, flow, road, and environs data	Heavy/light ratio, flow, speed, road, and environs data	Traffic type, flow, park or road data, and environs data	Traffic type, flow, road, and environs data	Traffic type, flow, road, and environs data	Traffic type, flow, speed, and barrier	Traffic intensity, speed and composition, vehicle per lane, road surface, and temperature	Traffic type, flow, road surface, temperature
7	Model type	Mathematical/hybrid	Hybrid consistent	Hybrid inconsistent	Hybrid consistent	Hybrid inconsistent	Mathematical	Hybrid inconsistent	Mathematical	Mathematical/hybrid
8	Mapping type	Multiple dual points to grid	Line to grid	Line to point	Line to point	Line to point	Multiple points to point	Line to point	Line to point	
9	Noise descriptor	L_{eq}	L_{eq} (8–20 h)	Quasi L_{10} (18 h)	L_{eq}	L_{eq}	L_{eq}, quasi L_{50}	L_{eq}	L_{eq}, L_{den}, L_{night}	L_{eq}, L_{day}, L_{night}, $L_{evening}$, L_{den}
10	Source	Simple stream	Simple stream	Simple stream	Simple stream	Simple stream	Simple straight stream	Simple stream	Simple stream	Simple stream
11	Type of vehicle	Automobile/medium trucks/heavy trucks/busses/motorcycles	Light vehicles, heavy vehicles, and train	Light vehicles/heavy vehicles	Light vehicles/heavy vehicles/car parks	Light vehicles/heavy vehicles/trams and suburban trains on roadways	Light vehicles/medium vehicles/heavy vehicle	Small and large groups	Light vehicles/medium vehicles/heavy vehicle	Light vehicles/medium vehicles/heavy vehicles

Table 1 (continued)

S. no	Particulars	FHWA TNM version 1.0	MITHRA	CRTN	RLS-90	STL-86	ASJ 1993	ERTC	NORD 2000	CNOSSOS-EU
12	Meteorological effects	TNM does not account for atmospheric effects such as varying wind speeds or directions or temperature gradients. TNM assumes neutral atmospheric conditions	Not mentioned	Negligible in CRTN approach	DBM is attenuation due to ground and atmospheric effect	Meteorological effects on sound propagation are ignored	Change in L_{Aeq} due to effect of wind defined $\Delta L_{m,line}$	Two classes of meteorological conditions: homogenous and downward propagation defined	Wind and temperature the gradient used to approx the vertical effective sound speed profile by lin–log relationship	Inputs of temperature and wind conditions. The approach can manage temperature gradients, wind gradients, and statistical data on meteorological conditions
13	Directivity	Sub-source-split ratio for vehicle emission, r_i defined in terms of five constants	Not mentioned	Angle of view adjustment defined	Not mentioned	Not mentioned	Directivity function defined	Not mentioned	Directivity function defined	Directivity functions defined for rolling and propulsion noise
14	Propagation type	Energy type	Ray tracing	Energy type	Energy type	Energy type	Mathematical (velocity potential)	Energy by type	Energy type	Energy type
15	Atmospheric absorption and refraction	Atmospheric absorption defined in terms of ambient air temperature, reference air temperature 20 ℃ and oxygen relaxation frequency	Not mentioned	Not mentioned	$D_{s,i}$, attenuation due to distance and air absorption defined	Not readily available	Correction term ΔL_{air} is calculated considering the standard state of the atmosphere (20 ℃, 60% R.H, and 101.325 kPa) as a function of distance from source to prediction point	Not mentioned	Refraction modeled by using curved sound rays. The curvature depends upon the vertical sound speed profile and is determined by a semi-analytical approach	Refraction is generated by vertical or nearly vertical surfaces and considered as separate sound paths

Table 1 (continued)

S. no	Particulars	FHWA TNM version 1.0	MITHRA	CRTN	RLS-90	STL-86	ASJ 1993	ERTC	NORD 2000	CNOSSOS-EU
16	Validation	Not readily available	Not readily available	+ 1.4 @ 50–54.9 dBA (Delany): − 1.2 @ 80–84.9 dBA. + 1.7 @ facades (Saunders)	Not readily available	Not readily available	Not readily available	± 3dBA range about 92.3% of the time	Not readily available	Not readily available
17	Author opinion	L_{eq} only; allows local vehicle types; accurate	Use for complex buildings and unknown traffic flows	Obsolete	Use for car parks and unknown traffic flows	Use for trams and light rail and unknown traffic flows	Use for free-flowing traffic with long roadside barriers	Use for free-flowing traffic	Use for rail and road traffic	Use for road, rail, aircraft, and industrial noise

model with straight rays (neutral weather), and RAY model with curved rays (refractive atmosphere). BEM can handle complex terrain shapes; however, weather impacts are not taken into account. PE may involve weather factors as well as the impact of uneven ground conditions, and FFP is ideal for flat land. In Meteo-BEM, BEM and PE/FFP are merged. NMPB-Routes-2008 is a collection of routes created by the National Park Service (Dutilleux et al. 2008). The French model distinguishes between homogeneous and downward refraction meteorological circumstances. The sound level in a homogeneous atmosphere is merely a simple approximation of the sound level in upward-refraction conditions because homogeneous environments are just a transient state of the atmosphere on the scale of the day-night cycle. Under downward refraction conditions, NMPB-Routes-2008 exhibits a relatively modest pattern of noise level overestimation. The likelihood of occurrence (p_i) of downward refraction conditions based on location and orientation can be used to calculate long-term sound levels, as demonstrated by Eq. (35).

$$L_{Ai,LT} = 10\log\left\{p_i 10^{0.1L}A_{A,F} + \left(1 - p_i\right)10^{0.1L}_{Ai,H}\right\} \tag{35}$$

(ISO 9613–2: 1996) also defines an engineering framework to measure the attenuation of sound while propagating outdoors in order to calculate the levels of ambient noise at a distance from various types of sources. The method calculates the attenuation of sound output by a single point source or a group of moving or stationary point sources using octave band algorithms (with nominal mid-band frequencies ranging from 63 Hz to 8 kHz). The continuous downwind octave band sound pressure level at a receiver position L_{ft} (DW) can be measured as (ISO 9613–2: 1996) (Eq. (36)).

$$L_{\mathrm{ft}}(\mathrm{DW}) = L_W + D_C - A \tag{36}$$

L_w denotes the octave band sound power level in dB(A) radiated by a sound source in comparison to a sound power of 1 pW, D_c denotes the directivity correction in dB(A) in the direction from the source's center to the receiver, and A denotes the sum of attenuation due to geometrical divergence (A_{div}), ambient absorption (A_{atm}), ground effect (A_{gr}), diffraction ($A_{diffraction}$), and miscellaneous effects (A_{misc}). The attenuation word A is written in Eq. (37).

$$A = A_{div} + A_{atm} + A_{gr} + A_{diffraction} + A_{misc} \tag{37}$$

Geometric divergence

Sound's energy is conserved as it moves away from its source, but it should be spread over a greater region. The energy of a simple point source that propagates noise uniformly in every direction is spread over a sphere having a surface area of 4πr^2. This geometric divergence's attenuation, A_{div}, is estimated from Eq. (38).

$$A_{\mathrm{div}} = 10\log_{10}\left(4\pi r^2\right)[\mathrm{dB}] \tag{38}$$

where 'r' denotes the distance from the source to a receiver.

Atmospheric absorption

When sound travels all the way through the atmosphere, its energy is eventually converted to heat by a variety of molecular processes, causing a reduction in sound level at a receiving point located far away from the source. Attenuation due to atmospheric absorption is negligible at near distances from the source and only becomes significant at great distances. Atmospheric absorption is influenced by four factors: sound frequency, ambient temperature, humidity, and air pressure. ISO 9613–1: 1993 contains a collection of tables for calculating the attenuation coefficient based on humidity, air pressure, temperature, and sound frequency (ISO 9613–2: 1996). Higher frequencies are usually attenuated at a faster rate due to atmospheric absorption.

The attenuation can be calculated from Eq. (39).

$$A_{\mathrm{atm}} = \frac{\alpha d}{1000}[\mathrm{dB}] \tag{39}$$

where "α" represents the quotient of attenuation and *d* is the span length from the source to a recipient.

Ground effect

Ground effect attenuation is primarily estimated using characteristics of the ground on which propagation occurs (i.e., whether the ground surface is acoustically absorbent or not) and the current atmospheric situation, as certain conditions may develop a curvature in the propagating sound waves.

The porosity of a ground surface has a direct relationship with its acoustic absorbent properties. Compact ground types are reflective in nature, whereas porous ground is absorptive. The acoustic properties of various ground surfaces are given using a ground factor *G*, which has a value between 0 and 1 and is used to describe two types of ground surfaces. A reflective ground surface, or hard surface, has a value of 0, whereas an absorbent ground surface, or soft surface, has a value of 1.

Diffraction

The effect of diffraction is calculated as (ISO 9613–2: 1996) (Eq. (40))

$$D_z = 10\log\left[3 + \frac{C_2}{\lambda}C_3 z k_{\mathrm{met}}\right]\mathrm{Db} \tag{40}$$

where the value of C_2 is 20 which consists of the impact of ground reflection, the value of C_3 is 1 for single diffraction, and for double diffraction C_3 is $\left[\frac{1+\left(\frac{5\lambda}{e}\right)^2}{\frac{1}{3}+\left(\frac{5\lambda}{e}\right)^2}\right]$; here, λ represent the wavelength of sound corresponding to nominal mid-band frequency, "z" represents variation in the path lengths of direct and diffracted sound, "k_{met}" represents meteorological correction factor, and "e" shows the span of two diffraction edges in double diffraction. The variation in path length "z" for single diffraction is expressed as (Eq. (41))

$$z = \sqrt{\left(d_{ss} + d_{sr}\right)^2 + a^2} - d \tag{41}$$

where "d_{ss}" represents the distance from the first diffraction edge to the source in meters, "d_{sr}" is the span length from the diffraction edge in meters, and "a" is the part span length parallel to the barrier edge between the source and the receiver in meters. The path length difference z is determined for double diffraction using Eq. (42).

$$z = \sqrt{\left(d_{ss} + d_{sr} + e\right)^2 + a^2} - d \tag{42}$$

The expression for correction factor "k_{met}" for the meteorological condition is (ISO 9613–2: 1996) (Eq. (43))

$$\mathrm{k}_{\mathrm{met}} = \exp\left(\frac{-1}{2000}\sqrt{\frac{\mathrm{d}_{\mathrm{Ss}}\mathrm{d}_{\mathrm{sr}}\mathrm{d}}{2\mathrm{z}}}\right)\mathrm{elsek}_{\mathrm{met}} = 1\mathrm{forz} \le 0 \tag{43}$$

Other miscellaneous effects

Temperature inversion

As the temperature of air increases, the speed of sound also increases. Generally, with an increase in altitude, the temperature of air decreases and this affects the way in which noise propagates through the air due to which sound waves are liable to be refracted away from the ground surface. In some special cases, such as during a storm, temperature inversion may take place due to which temperature of the air rises with the elevation and sound waves tends to refract toward the earth's surface (Fig. 3).

Effect of wind

Wind also has the property to bend the sound waves. The speed of the wind near the earth's surface is liable to be slower than the speed of wind at height. The wind will bend the sound waves back toward the ground if the

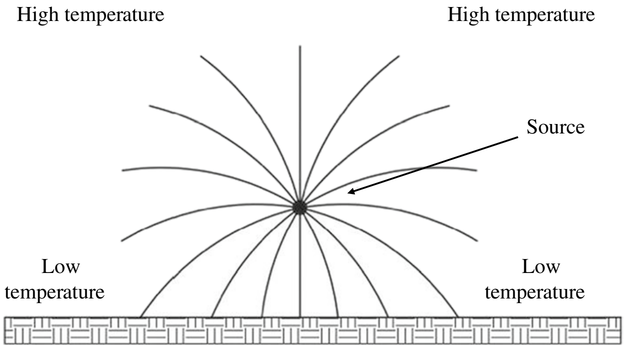


Fig. 3 Sound wave propagation systems in case of thermal inversion (Long 2006)

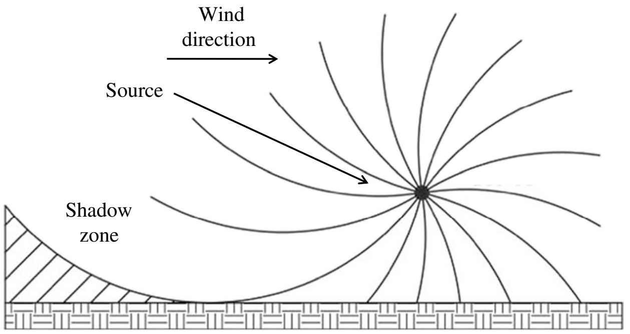


Fig. 4 Sound wave propagation systems in case of wind gradient (Long 2006)

recipient is facing downwind. Whereas when a receiver is situated upwind from the source, the condition reverses and the sound waves get refracted upward (Fig. 4).

Foliage effect

The plantation of trees and bushes act as very poor noise barriers. Sound waves can easily move through this plantation with very low attenuation. But when the foliage is quite denser, it blocks the line of sight totally; in that case, a little bit of attenuation occurs when sound waves propagate through the foliage. However, several years are needed for the foliage to become dense and effective enough to encounter an attenuation effect. ISO 9613–2 suggested different values of noise attenuation due to sound propagation through foliage (Table 2).

Discussion

According to the findings of this review article, traffic noise models are designed to analyze and estimate traffic noise in order to reduce the environmental impacts it has on residents. It is crucial to investigate the causes and implications of noise in terms of its indicators (L_{eq}, L_{10}, and so on) by assessing the determinants that affect traffic noise levels (Ibili et al. 2021). For categorizing any traffic noise prediction models to be an ideal model based on their prediction accuracy, it needs to deliberate all the factors responsible for traffic noise emission including their propagation path. In addition to this actual traffic, flow conditions should also be considered in the developing phase of any traffic noise prediction models. In terms of traffic conditions considered, all discussed models except CNOSSOS-EU have not included factors for intersection and varying driving conditions. In the absence of additional traffic and traffic dynamics caused by vehicle interactions and queue length expansion, single-vehicle dynamics significantly affect vehicle kinematics at intersections (Chevallier et al. 2009). Among all the models included in the present study, FHWA, MITHRA, CRTN, and STL-86 approaches do not deliberate for atmospheric effects such as variation in wind speed, direction, and temperature. Models like MITHRA, CRTN, and ERTC lack the inclusion of absorption and refraction criteria. Free-flowing traffic is a major assumption in most of the approaches such as FHWA, CRTN, ASJ 1993, and ERTC. Since actual traffic flow can never always be free-flowing, so this needs to be addressed and rectified in upcoming newer versions of all these models. Various corrections related to the nature of road surface are also varied among different prediction models (Descornet and Goubert, 2006). Because most of these modeling approaches have been validated in their originating countries, it is extremely difficult to assess the advantages and disadvantages of all of them. Furthermore, an ideal model, as presented by Steele in 2001, is compensated by newer models that focus entirely on technical improvements. None

Table 2 Sound attenuation values suggested in ISO 9613–2

Nominal mid-band frequency [Hz]						
Propagation distance, d	125	250	500	1000	2000	4000
$10 \le d \le 20$	Attenuation in dB					
	0	1	1	1	1	2
$20 \le d \le 200$	Attenuation in dB/m					
	0.03	0.04	0.05	0.06	0.08	0.09

of the discussed models consider interrupted traffic flow situations; each of them assumes a vehicle is always moving with constant speed though few of the models account for ground attenuation. For improving the efficiency of all these models, the potential is especially needed for interrupted, complex flow including temporal and spatial evaluation of vehicle speeds. It is obvious that these models developed globally account for traffic noise situations from the point of sound propagation to the receiver in accordance with traffic conditions, weather factors, diffraction, and adsorption. The propagation of indoor-outdoor sound in a dynamic context has been a key research issue for boosting the performance of traffic noise prediction approaches.

Limitations and future considerations

Current noise prediction techniques for road traffic are out of date and are being used in cases where they were never intended. In this respect, CNOSSOS-EU is a big move forward. Many elements of today's best practices in noise emission and sound propagation modeling will be included. In terms of frequency analyses, CNOSSOS-EU is expected to run calculations across octave bands**.** This is compatible with the recommended interim approach for road traffic (although CNOSSOS-EU considers two extra octave bands beyond the reach of the recommended interim approach, at central frequencies of 63 Hz and 8000 Hz) and is unquestionably better than approaches that only estimate an overall A-weighted noise intensity level. The way highway traffic sound is divided into vehicle groups is one feature that CNOSSOS-EU will boost. CNOSSOS-EU divides vehicles into five groups in compliance with Directive 2007/46/EC definitions, while the existing default estimation assumes only two categories (light and heavy). The treatment of low-noise road surfaces is a region needed for further investigations. There is a lot of variance in the acoustic properties of road surfaces, and there is no specific approach for measuring those (Kephalopoulos et al., 2012). Since emission amounts were originally obtained from single microphone pass-by measurements, most current road traffic noise prediction approaches combine engine noise and rolling noise. Separating rolling noise and propulsion noise using the CNOSSOS-EU approach is a welcome advancement that is now considered a standard solution worldwide. Corrections for vehicle acceleration and deceleration are also included in CNOSSOS-EU (Gilani and Mir 2021). Since the acoustic characteristics of irregular traffic flow vary significantly from free-flowing traffic in free-field environments, these corrections are critical. However, the impacts of acceleration and deceleration can be a disregard for noise maps development (Kephalopoulos et al. 2012) because, in general, the average sound pressure level for accelerating and decelerating traffic does not differ substantially from the intensity supposed for a steady pace through a joining point (Dittrich and Zhang 2006). Some expectations go beyond what would usually be considered a prediction model's reach. For example, the German RLS-90 approach provides an approach for measuring the noise level of parking areas that are not included in most of the estimation approaches (Steele 2001). As further research is done in the field, it may be necessary for future versions of CNOSSOS-EU to consider aspects beyond the reach of the current.

Singh et al. (2016) recently introduced the concept of soft computing for the development of new approaches for vehicular traffic noise prediction models, in which four soft computing approaches, namely, random forest, generalized linear model, decision tree, and neural network, are used for calculation of equivalent sound pressure level. In addition, a few studies used the concepts of machine learning, evolutionary algorithms, and graph-theoretical approaches to construct traffic noise prediction models. A new theoretical approach based on probability models has also been proposed to estimate traffic noise with great accuracy on free flow and controlled flow roadways (Li et al. 2016; Thakre et al. 2020). This method also eliminates the difficulties seen in the dynamic traffic noise simulation method (Cai et al. 2011). The study reveals that many advanced tools for noise modeling may be used other than the statistical approach, particularly focusing on complex road conditions, such as intersections, jamming conditions, and interrupted traffic flow. The major idea is to consider dynamic perspectives in traffic noise prediction like the speed of vehicles, position, and acceleration. For both indoor and outdoor environments, a dynamic traffic noise model has been proposed using the ray-tracing approach. Figure 5 illustrates an overall idea of the dynamic traffic noise model for both indoor and outdoor surroundings both.

Moreover, for the development of any kind of traffic noise model across the world, all the factors illustrated in Fig. 6 should always be considered since these are responsible for the deviation and fluctuation in values of noise levels induced due to traffic.

Conclusion

In this paper, we have investigated and rigorously reviewed 9 principal traffic noise prediction models used all around the globe. The main conclusions derived from this study are summarized as follows.

- The source model for all the discussed models might be different, but in general, there must be a consistent approach for sound propagation modeling. While using numerical approaches to solve wave equations for defining meteorological factors improves prediction accuracy, it also introduces a slew of computational complexities and solutions that may necessitate specialized skills that

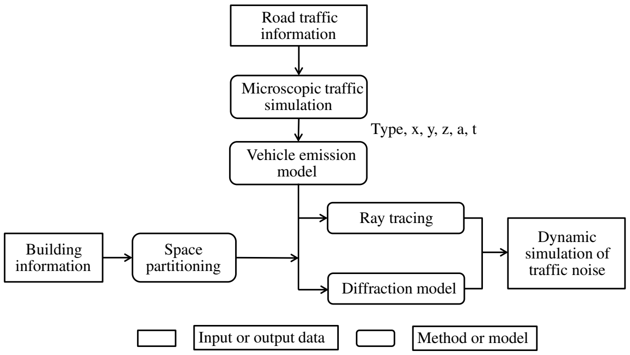


Fig. 5 Outline of a dynamic traffic noise model for indoor and outdoor environments (modified from Hou et al. 2017)

are not always practical for town planners and urban development governing bodies.

- Unfortunately, traffic noise prediction models sometimes fail because all of the factors responsible for the generation of noise are not taken into account. Researchers should always try to consider all the influencing factors of traffic noise such as speed, traffic volume, average noise level, type of pavement, road gradient, acceleration and deceleration, the effect of the noise barrier, vehicle and tire age, and traffic congestion when there is need to develop an efficient traffic noise prediction model.
- All other road vehicles, in addition to trucks and cars, are permitted in some models, and one of the models even includes car parks. In all of the models discussed here, the acoustic energy representations are commonly specified as L_{eq} and, in two cases, as pseudo-L_{10}.
- Among all the models included in the present study, some of the approaches do not account for atmospheric effects such as variation in wind speed, direction, and temperature. Few of them also lack the inclusion of absorption

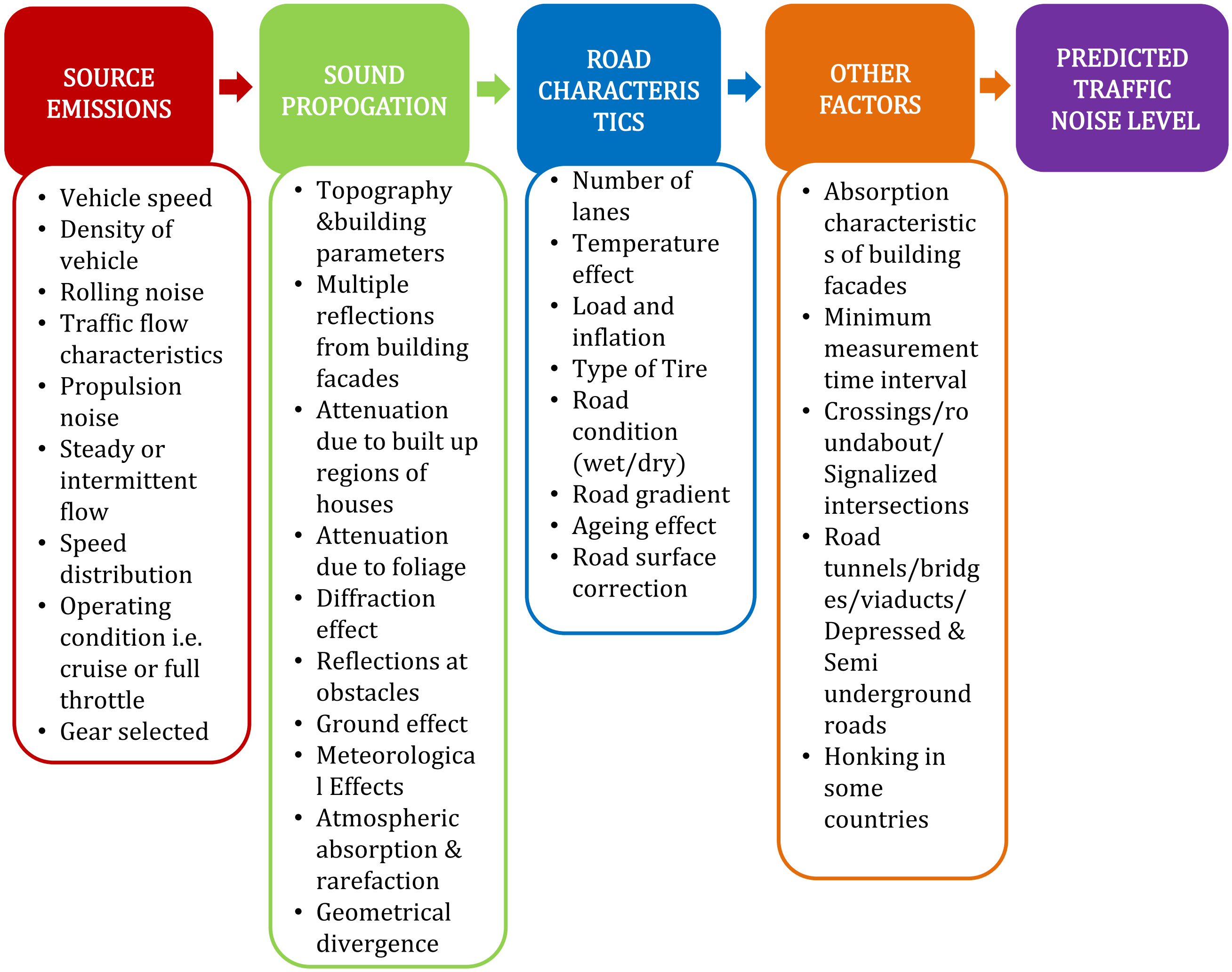


Fig. 6 Factors affecting deviation of predicted traffic noise level (modified from Garg and Maji 2014)

and refraction criteria. Free-flowing traffic is a major assumption in most of the approaches since actual traffic flow can never always be free-flowing, so this needs to be addressed and rectified in upcoming newer versions of all these models. Various corrections related to the nature of road surface are also varied among different prediction models

- Most of the current road traffic noise prediction approaches combine engine noise and rolling noise. Separating rolling noise and propulsion noise using the CNOSSOS-EU approach is a welcome advancement that is now considered a standard solution worldwide. This approach is an example of the trends toward more accurate physics in models and toward more realistic representations of the actual traffic flows.

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Data availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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