Chapter 2

Literature Review

2.1 General

This section provides a comprehensive overview of the traffic noise model's development, from its inception to contemporary applications. It delves into the intricate variations of traffic noise across different heights in high-rise residential buildings, analyzes noise emissions from various vehicle types. By understanding the evolution of traffic noise models, readers will gain insights into the complexities of predicting and managing road traffic noise. The chapter also highlights how advancements in technology and data analysis have enhanced the accuracy and applicability of these models, enabling more effective urban planning and noise control measures.

2.2 Development of Traffic Noise Model

To mitigate traffic noise the first important step is to develop traffic noise predictive models. These kinds of models were initially developed in the 1950s, and a lot of further work has been done in this area ever since [33]. The traffic noise prediction model can help identify region with abnormally high noise level. Different traffic noise models have been developed as a result of variation in traffic circumstances throughout nations. Models for estimating traffic noise have been development for over 70 years. The first of these model was introduced in 1952 [30]. Some of the earlier models are given below in Table 2.1 below:

Table 2.1. Traffic noise model at early stages

S/N	Reference	Model
1	[34]	$L_{50} = 68 + 8.5 \log(V) - 20 \log D$
2	[35]	$L_{50} = C + 10 \log(V/D)$
3	[36]	$L_{50} = 3.5 + 10 \log(V * M^3/D)$
4	[37]	$L_{50} = 20 + 10 \log(V * M^2/D) + 0.4(T)$

Where V = Vehicles traffic volume per hour; D = Distance from the traffic lane, in feet; M = Vehicle mean speed in mph, and L_{50} is in dB(A).

Subsequent developments introduced additional variables and modifications, shifting from L_{50} to L_{10} and L_{eq} . Early efforts to predict traffic noise utilized straightforward empirical models that included fundamental traffic parameters like traffic volume and vehicle speed. Later in further approach of traffic noise prediction the various correction parameter for propagation were added to basic noise level of vehicles. Various established analytical models are commonly used for traffic noise prediction i.e. The Federal Highway Administration's (FHWA's) traffic noise model, Calculation of Road Traffic Noise (CoRTN), Richtlinien für den Lärmschutz an Straben (RLS90), Acoustical Society of Japan (ASJ) road traffic noise prediction model, Common Noise Assessment Method in Europe (CNOSSOS-EU), 01 dB Mithra, NMPB-Routes-96, Nord 2000, which stand as contemporary models [30] [31] [32].

2.3 Various Established Model Worldwide

2.3.1 FHWA approach

The Federal Highway Administration (FHWA) traffic noise model predicts noise level through a series of correction to a reference energy mean emission level (REMEL) [38] . The model assumes point sources moving at constant speed. The REMEL are the basic noise level and maximum noise level emitted by the vehicle measured at 15 meters from the mid-way of the nearby carriageway. Initially FHWA had considered three categories of vehicles i.e. automobiles, medium trucks, heavy trucks. The REMEL model for various vehicle category represented as Equation (2.1), (2.2) and (2.3).

$$Automobil: \overline{(L_0)}_E = 38.1\log V - 2.4 \tag{2.1}$$

$$Medium\ Truck: \overline{(L_0)}_E = 33.9\log V + 16.4 \tag{2.2}$$

$$Heavy\ Truck: \overline{(L_0)}_E = 24.6 logV + 38.5 \tag{2.3}$$

Where, V is speed in km/h

The L_{eq} is then calculated adding REMEL model with various adjustment for attenuation of sound as it travels from the source to the receiver. The Equation (2.4) representing L_{eq} is given below [38] :

$$L_{eq}(h) = \overline{(L_0)}_E + 10\log\left(\frac{N\pi D_0}{ST}\right) + 10\log\left(\frac{D_0}{D}\right)^{1+\alpha} + 10\ \log\left(\frac{\varphi_a\ (\emptyset_1, \emptyset_2)}{\pi}\right) + \Delta_s \tag{2.4}$$

L_{eq} stands for the equivalent continuous sound pressure level, $\overline{(L_0)}_E$ stands for the reference energy mean emission level, N represents the number of vehicle passing a specific point within a 1 hour period, D represents the perpendicular distance, in meters, from the centre line of the traffic lane to the receiver, D_0 is the reference distance, α represents the site parameter depends upon site conditions, S represents the average speed of vehicle, T represents the duration, usually 1 hour over which equivalent sound level is computed. $\emptyset_1 and\ \emptyset_2$ are the angles from the perpendicular that defines the limits of the observers view of a section of the roadway, Δ_s is the excess attenuation due to barriers, buildings, wood etc. Later in 1995 the FHWA has modified the REMEL equations using new data emission data sets of vehicles and two more category of vehicle were added i.e. motorcycle and bus. These emission levels were also calculated at the reference distance of 15m from the source as a function of speed, frequency, vehicle type, throttle condition and pavement type. The general REMEL equation is a function of speed and frequency is given below [39]:

$$\begin{aligned} L_{emis,i}(s_i, f) = {} & L_A(S_i) + (D_1 + 0.6214 D_2 S_i) \\ & + (E_1 + 0.6214 E_2 S_i)\,[\log_{10}(f)] + (F_1 + 0.6214 F_2 S_i)\,[\log_{10}(f)]^2 \\ & + (G_1 + 0.6214 G_2 S_i)\,[\log_{10}(f)]^3 \\ & + (H_1 + 0.6214 H_2 S_i)\,[\log_{10}(f)]^4 \\ & + (I_1 + 0.6214 I_2 S_i)\,[\log_{10}(f)]^5 + (J_1 + 0.6214\, J_2 S_i)\,[\log_{10}(f)]^6 \end{aligned} \tag{2.5}$$

The nominal frequency f of the one-third octave band depends on variable D_1 to J_2, which vary according to vehicle type, pavement type, and engine throttle.

2.3.2 CoRTN approach

Delany, Harland, Hood, and Scholes developed the Calculation of Road Traffic Noise (CoRTN) procedure for the United Kingdom Department of the Environment to assess road traffic noise. This model presumes a line source and assumes traffic moves at a constant speed that radiates cylindrical-shaped waves [30]. The noise level is expressed in terms of the index L_{10} hourly or L_{10} (18-hour). CoRTN estimates the basic noise level at a reference distance of 10m away from the nearside carriageway edge based on factors such as traffic flow, traffic speed, traffic composition, road gradient and the road surface. The algorithm for CoRTN procedure [30] is shown below in Equation (2.6).

$$L_{10} = 42.2 + 10\log_{10} q + \Delta_f + \Delta_g + \Delta_p + \Delta_d + \Delta_s + \Delta_a + \Delta_r \tag{2.6}$$

Where q represents the total hourly flow estimated at a reference distance of 10m from the edge of the nearside carriageway at a reference hourly mean traffic speed of 75km/h. Δ_f represents traffic flow adjustment, Δ_g represents gradient adjustment, Δ_p represents pavement type adjustment, Δ_d is distance adjustment, Δ_s is shielding adjustment, Δ_a is angle of view adjustment, Δ_r is the reflection adjustment. Correction for heavy vehicles is determined using Equation (2.7) given below :

$$\Delta_f = 33\log(v + 40 + \frac{500}{v}) + 10\log(1 + \frac{5p}{v}) - 68.8 \tag{2.7}$$

Where v denotes the average hourly traffic speed in km/h and p represents the percentage of heavy vehicle calculated as $p = 100 * f/q$ where f is hourly flow of heavy vehicles and q is total hourly flow.

2.3.3 RLS-90 approach

The German national standard, Richtlinien fur den Larmschutz an Straben (RLS 90) serves as a methodology for predicting road and parking lot noise emissions. This two -part model calculates the emission noise level $L_{m,E}$ at a reference distance of 25m from the centre of a road lane and 4 meters above ground. $L_{m,E}$ is determined incorporating several key factors into the calculations such as traffic characteristics i.e. vehicle speed , weight distribution, and the road characteristics (including grade) and the influence of sound reflection from adjacent building. The equation for $L_{m,E}$ [31] is shown in Equation (2.8).

$$L_{m,E} = L_{25} + R_{SL} + R_{RS} + R_{RF} + R_E \tag{2.8}$$

Where L_{25} is the standardize level assuming a speed 100km/h for cars and 80km/h for trucks, the road surface composed of non-grooved asphalt, a gradient less than 5% and free field propagation. The equation for L_{25} is given below:

$$L_{25} = 37.3 + 10\log\{Q.(1 + 0.082p)\} \tag{2.9}$$

Where Q is total number of vehicles per hour and P is % of heavy vehicles (over 2.8 tons) in traffic flow. Where R_{SL} is correction for speed limit, R_{RS} is correction for road surface, R_{RF} is a correction for rise and falls, R_E is correction for the absorption characteristics of building surface. The second part of the model represents the propagation stage, where the noise level at a specific location (the receiver) is determined by energetically summing all contributions from the sources. This calculation considers factors such as the road length, distance-related attenuation, air absorption, and the impact of temperature gradients on sound propagation [40].

2.3.4 ASJ approach

To address growing concerns about traffic noise, the Acoustical Society of Japan (ASJ) initiated a project in 1974 to develop a method for predicting road traffic noise levels. Later many modifications were developed. In current version of ASJ road traffic noise model 2018, the road vehicles are classified into three categories [41]. These three categories are light vehicles, heavy vehicles and motorcycles. This model calculates sound power level for different category of vehicles which is given below :

$$L_{WA} = a + b\log(V) + C$$

Where V represents vehicle speed in Km/h, a and b are regression coefficient, and C is the constant term. The correction term C in the traffic noise model accounts for how road conditions (surface, gradient) and vehicle design (directivity) affect sound propagation. Directivity refers to how a vehicle's shape and noise sources (engine, tires) influence sound direction. This term improves accuracy by considering real-world factors that can deviate from the reference noise level. To ponder these fluctuations in noise radiation, affect by these factors, the correction term C is

$$C = \Delta L_{grad} + \Delta L_{dir} + \Delta L_{etc}$$

Where ΔL_{grad} stands for road gradient correction (dB), ΔL_{dir} stands for sound radiation correction (dB) and ΔL_{etc} is corrections for other factors (dB). There are separate sets of values for these coefficients a and b depending on whether the traffic flow is considered steady or non-steady. The model considers various propagation correction [41] i.e. correction for diffraction, correction for ground effect, correction for atmospheric absorption, correction for reflection and meteorological effects . This model allows noise prediction at special road sections i.e. interchanges, junctions, signalized intersections, road tunnels, depressed and semi-underground roads, flat roads with an overhead viaduct, double - deck viaducts.

2.3.5 Son Road approach

The Swiss road traffic noise model Son Road employs a two-part approach to predict traffic noise emissions. The source model accounts for the influence of various vehicle characteristics on sound power generation. These characteristics include vehicle type, speed, road grade, and surface type. In the Son Road model, vehicle noise source strength is defined by A-weighted maximum sound pressure levels recorded during a single vehicle pass-by at a reference distance of 7.5 meters and a height of 1.2 meters above the ground. Two vehicle categories are explicitly accounted for: passenger cars and trucks. The A-Weighted sound pressure level for passenger cars $L_{W,A,Passenger}$ and trucks $L_{W,A,Truck}$ [42] is given below in Equation (2.10) and (2.11).

$$L_{W,A,Passenger} = 28.5 + 10\log\left(10^{0.1(7.3+35logv)} + 10^{0.1\left(60.5+10\log\left(1+\left(\frac{v}{44}\right)^{3.5}\right)+\Delta_s\right)}\right) + \Delta_{BG} \quad (2.10)$$

$$L_{W,A,Truck} = 28.5 + 10\log\left(10^{0.1(16.3+35logv)} + 10^{0.1\left(74.7+10\log\left(1+\left(\frac{v}{56}\right)^{3.5}\right)+\Delta_s\right)}\right) + \Delta_{BG} \quad (2.11)$$

Where V represents vehicle speed in km/h, Δ_{BG} represents correction for road surface, Δ_s represents correction for uphill grade g (%) and $\Delta_s = 0.8g$. The Son Road propagation model employs a third-octave band framework for sound wave propagation calculations. This approach aligns primarily with the established methodologies outlined in ISO 9613 [41] . Son

Road takes a different approach to ground reflection compared to the ISO 9613 standard. Instead of relying on a simplified formula (empirical formula), Son Road uses a more precise method. This method involves a numerical calculation that approximates the sound field behaviour for a point source over a flat, uniform ground surface. This approach is then adapted to handle more complex terrain features (inhomogeneous and non-flat ground) using the Fresnel zone concept.

2.3.6 CNOSSOS-EU approach

Common Noise Assessment Methods in Europe (CNOSSOS- EU) considers the sound power of a vehicle to depend on both the traffic speed (V) and the frequency(f) divided into octave bands in the range of 63 Hz to 8 KHz. The equation of rolling and propulsion noise [43] are given below in Equations (2.12) and (2.13).

$$L_{WR}(f,v) = A_R(f) + B_R(f)\log\frac{V}{V_{ref}} \tag{2.12}$$

$$L_{WP}(f,v) = A_P(f) + B_P(f)\log\frac{V - V_{ref}}{V_{ref}} \tag{2.13}$$

:

Where L_{WR} and L_{WP} represents sound power level of rolling noise and propulsion noise respectively. (V) represents vehicle speed and V_{ref} represents vehicle reference speed (70 Km/h) A_R, B_R represents rolling noise coefficient and A_P and B_P represents propulsion noise coefficient. These equations have validity on certain reference condition i.e. a) constant vehicle speed (70Km/h), b) road surface having flat and dry condition consisting of a mixture of dense asphalt concrete and stone mastic asphalt between two and seven years old, c) 20℃

air temperature, d) no studded tires. Failing to meet these reference condition will require a correction for road surface type, gradient, accelerometer, deceleration. This model considered four categories of vehicles i.e. Light-Duty Vehicle (LDV), Medium-Duty Vehicle (MDV), High-Duty Vehicle (HDV), and two-wheelers (motorcycles and mopeds). Model also include an option of additional category vehicle for future needs. Each vehicle category is represented by a singular point source positioned at a height of 0.5 meters above the road surface.

CNOSSOS, based on the French NMBP-2008 standard, uses ray theory for sound propagation calculations, accounting for sound wave attenuation from source to receiver [44]. It considers two atmospheric scenarios: homogeneous conditions and downward refraction, as well as weather factors like temperature and wind direction to estimate traffic noise levels. Developed as a successor to the Harmonoise model, CNOSSOS aims to improve the consistency of traffic noise data across EU member states but requires thorough testing to ensure its accuracy.

2.3.7 NORD 2000 approach

The NORD 2000 prediction method estimates two key acoustic metrics: The A-weighted equivalent continuous sound pressure level, $L_{\mathrm{Aeq,24h}}$ and the A-weighted maximum sound pressure level with fast time weighting, $L_{AF,\mathrm{max}}$, using data on traffic flow and topography. It follows the CNOSSOS-EU model for calculating sound power levels for rolling and propulsion noise across a 1/3rd octave band from 25 Hz to 10 kHz. The model uses the same reference conditions as CNOSSOS-EU but includes corrections for gradient, road surface, acceleration, and temperature. Additionally, it adjusts for rolling noise from light duty vehicles (LDVs) on wet surfaces when temperatures differ from the standard 20°C. The NORD 2000 model categorizes vehicles similarly to CNOSSOS (LDV, MDV, HDV, two-wheelers/mopeds) with additional details based on axles and length. However, for noise prediction, it simplifies things to just LDV, MDV and HDV [45]. There are eight primary classifications for road surface conditions, with many of them having even more specific subcategories. Driving conditions, on the other hand, are typically grouped into six main categories. The sound pressure level at receiver [46] is predicted by Equation (2.14) is given below :

$$L_R = L_W + \Delta L_d + \Delta L_a + \Delta L_t + \Delta L_s + \Delta L_r \tag{2.14}$$

Where L_W stands for sound power level within the considered frequency band, ΔL_d stands for propagation effect of spherical divergence of sound energy, ΔL_a stands for propagation effect of air absorption, ΔL_t is the propagation effect of the terrain (grounds and barriers), ΔL_s stands for propagation effect of scattering zones and ΔL_r stands for propagation effect of obstacle dimensions and surface properties when calculating a contribution from sound reflected by an obstacle. NORD 2000's sound propagation module uses geometrical ray theory to predict sound attenuation across 1/3 octave bands (25 Hz to 10 kHz). It factors in terrain, ground type, and meteorological conditions like wind speed and temperature gradients, with refraction modelled by curved sound rays. The model also employs Fresnel zones, introduced by Hothersall and Harriott [47], to estimate the impact of different ground types on sound propagation over flat terrain [48].

2.3.8 NMPB-routes approach

The Nouvelle Méthode de Prévision du Bruit des routes (NMPB-Routes) method aligns with the established class of engineering models for outdoor sound propagation. This classification positions it alongside the well-regarded ISO 9613-2 standard [49]. Within the NMPB-Routes framework, the A-weighted sound pressure level generated by source S at a distance d from receiver R under propagation condition C is governed by a dedicated Equation (2.15) given below [49]:

$$L_{A,C} = L_W - (A_{div} + A_{atm} + A_{bnd,c}) \tag{2.15}$$

Where L_W is sound power level, A_{div} is geometrical spreading, A_{atm} is atmospheric absorption, $A_{bnd,c}$ is attenuation relating to sound speed profile and boundary characteristics. A_{atm} is computed as in the ISO 9618-1 standard for T = 15℃ and 70% relative humidity. Among the attenuation term, $A_{bnd,c}$ alone is propagation-condition-dependent. The class of meteorological conditions C can be either "homogeneous" or downward-refraction". The efficacy of this method hinges on the principle of propagation paths. Due to varied topography and obstacles, multiple sound paths exist between a source and receiver, each assigned a long-term sound level based on uniform and downward refraction conditions. NMPB uses a mean ground plan to represent ground influence on sound propagation. NMPB-Routes-2008 sets the source height at 0.05 meters, reflecting tire/road noise dominance and also to the fact that other noise source like the engine cannot be seen as pointy sources [31] . Vehicles are categorized into light (under 3.5 tonnes) and heavy (3.5 tonnes or more). The sound power level per meter for each category combines rolling and engine noise components, with the engine noise factoring in traffic flow, vehicle speed, and road gradient for heavy vehicles.

2.3.9 HARMONOISE approach

HARMONOISE project (Harmonised Accurate and Reliable Methods for the EU Directive on the Assessment and Management of Environmental Noise) was developed to provide

European Union member states with a consistent, accurate, and reliable method for creating strategic noise maps [50] [51]. The main vehicle category includes: a) light, b) medium heavy, and c) heavy vehicle. Apart from these vehicle category two more category i.e. other vehicles and 2-wheelers is also added. Each vehicle category is represented by two-point sources. The sound power contribution of vehicles is consisted of two parts : a) rolling noise which is result of road-tyre interaction b) propulsion noise. The equation for rolling and propulsion noise [52] is given below in Equation (2.16) and (2.17).

$$L_{WR}(f,v) = A_R(f) + B_R(f)\log\frac{V}{V_{ref}} \tag{2.16}$$

$$L_{WP}(f,v) = A_P(f) + B_P(f)\log\frac{V - V_{ref}}{V_{ref}} \tag{2.17}$$

Where L_{WR} and L_{WP} represents sound power level of rolling noise and propulsion noise respectively. V represents vehicle speed and V_{ref} represents vehicle reference speed (70Km/h) A_R, B_R represents rolling noise coefficient and A_P and B_P represents propulsion noise coefficient are given in 1/3rd octave bands in frequency range 25 to 10 kHz. The model accounts for both rolling and propulsion noise from light vehicles by using two sources: one at 0.01 meters above the ground and the other at 0.3 meters. For rolling noise, 80% is attributed to the lower source and 20% to the higher source. Conversely, for propulsion noise, 20% is attributed to the lower source and 80% to the higher source. Hamonoise considered the following effects during the calculation of excess attenuation in 1/3rd octave frequency bands: air absorption, ground effect, shielding by topography (which may include barriers or buildings), atmospheric refraction, and atmospheric scattering. The reference model utilizes a statistical description of the atmosphere, based on local meteorological data, and incorporates various impedance models for ground surfaces and other absorbing surfaces.

2.3.10 Conventional models

CoRTN model was widely interpreted by researchers in the past in terms of local conditions. Abdur-Rouf and Shaaban [53] and Quiñones-Bolaños, Bustillo-Lecompte [54] developed the traffic noise prediction models by modifying CoRTN model. Ibili, Adanu [55] assessed the applicability of the CoRTN model and regression analysis for predicting noise levels in Nigeria. The noise values predicted using the CoRTN equation closely matched the recorded values. Mishra, Parida [56] in India made improvements to an existing model (FHWA) by developing REMEL to predict traffic noise near bus rapid transit systems. However, this method might not be reliable in other locations because traffic conditions and surroundings can differ significantly from place to place. Pamanikabud and Vivitjinda [57] developed a Modified FHWA traffic noise model in Thailand by replacing FHWA REMEL model with newly developed REMEL model for various vehicle type on real running condition in Thailand.

The original CORTN (developed by the Department of Transport in 1988) wasn't ideal for Tehran's roads, Givargis and Mahmoodi [58] adapted the UK's CORTN road traffic noise calculation system for Tehran by simplifying its algorithm to better estimate hourly noise levels $L_{\mathrm{Aeq,1h}}$ for the city's traffic using a trial-and-error approach. Researchers in Taichung City, Taiwan, modified the Nordic prediction model to account for high motorcycle traffic, achieving a strong correlation between predicted and measured noise levels (Pearson coefficient = 0.75). With 90.5% of predictions within ±3.5 dB(A) of actual values and a mean difference of 0.9 ± 2.1 dB(A), the model proved reliable for estimating noise exposure in similar urban settings [59]. Peng, Parnell [60] introduces a new method for predicting traffic noise on highways in New South Wales, Australia. Unlike traditional models that treat all heavy vehicles the same, this method categorizes them into six distinct groups. This allows for a more accurate and precise prediction of noise levels across the state's road network, especially considering the wide variety of heavy vehicles found on these roads. Murillo-Gómez, Gil-Carvajal [61] in Colombia assessed the effectiveness of the German standard RLS 90 in predicting noise generated by traffic flow in Colombian urban environments. The researcher compared RLS 90 with an alternative method based on interpolation. The evaluation revealed that RLS 90 offered greater precision in predicting noise levels, particularly in regions where traffic noise is the main concern. Compared to the interpolation method, RLS 90 provided more accurate results.

Prior to 2018, European Union countries relied on various methods for creating strategic noise maps. These included national calculation methods and a common interim approach called "NMPB-Routes-96 (SETRA-CERTU-LCPC-CSTB)" which originated from France [62]. However, since the end of 2018, a standardized system known as "CNOSSOS-EU" has become mandatory for all EU member states. This ensures consistent noise assessment across Europe [63]. Unlike some EU countries with their own noise calculation methods, Croatia never developed a national system. From the start, Croatian engineers relied on German standards for noise assessment. Initially, they used the general noise protection standard DIN 18005 [62]. Later, they adopted the more specific German noise calculation method, RLS-90, which remains popular in Croatian noise control practices . Using the in-built traffic noise propagation models i.e. CoRTN and RLS 90 in the software sound plan, Sonaviya and Tandel

[64] developed maps of traffic noise. Author research revealed that the CoRTN model and RLS-90 model is unsuitable for heterogeneous traffic condition. Honking significantly boosted the overall noise level by 2 to 13 dBA compared to just the measured ambient noise. Researcher have developed modified traffic noise prediction model using FHWA method. They have replaced FHWA REMEL with their own developed REMEL equation based on local condition using vehicle noise and spot speed [30, 65, 66].

Khan, Ketzel [43] analysed three traffic noise prediction models—CNOSSOS, Nord2000, and TRANEX. Their study revealed that CNOSSOS and TRANEX closely matched Nord2000's noise level predictions (within 3-5 dB(A)), with TRANEX showing slightly better agreement (94%) than CNOSSOS (87%). Discrepancies were attributed to CNOSSOS's handling of ground attenuation, multiple diffractions, and average ground level calculations, indicating a need for further development to enhance CNOSSOS's effectiveness for noise assessment in the EU. Afandizadeh and Gharehdaghli [67] developed a traffic noise prediction model based on Florida's REMEL and compared it with the CoRTN model. While both models predicted similar noise level patterns, the new model proved more accurate across various road types and traffic situations. Motylewicz and Gardziejczyk [68] developed a new traffic noise prediction model and compared it with the French NMPB-Routes-2008 and the German RLS-90. The new model demonstrated superior accuracy, predicting noise levels within 1.2 dB of actual values, significantly outperforming the French method (error range: -2.8 to +1.3 dB) and the German method (overestimation range: 0.8 to 5.2 dB).

2.3.11 Literature on machine learning approach

Machine learning, a branch of Artificial intelligence, is like giving computers the ability to learn on their own. Instead of needing specific instructions for every task, they use data and special algorithms to uncover hidden patterns. This lets them make predictions about new data, similar to how you might guess the weather [69] based on the clouds. Machine learning is also called predictive modeling or analytics because its main goal is to forecast future outcomes. There are four main categories of machine learning algorithms a) supervised learning which includes classification, regression b) Semi-supervised c) Unsupervised learning which includes clustering and dimensionality reduction and d) Reinforcement learning, each with its own approach to learning from data. AlKheder and Almutairi [70] used an Adaptive Neuro-Fuzzy Inference System model to predict traffic noise on a Kuwait ring road, incorporating traffic and environmental factors. The model achieved a low RMSE of 0.0022, indicating high accuracy. Sensitivity analysis showed that light vehicle count was the most influential factor, while heavy vehicle count had the least impact. In their study, Hamad, Khalil [71] developed an Artificial Neural Network (ANN) model to predict road traffic noise using field data from three locations. Their study highlighted the model's adaptability to different conditions and emphasized the importance of including road surface temperature in traffic noise analysis and future model development. In a 2012 study, Torija, Ruiz [72] used ANN to enhance traffic noise prediction, capturing both equivalent continuous sound level (L_{eq}) and temporal-spectral characteristics. Using data from 144 locations in Granada, Spain, and 821 data points, the ANN model outperformed multiple linear regression (MLR) models, achieving a mean percentage error of 1.27 and an R^2 of 0.67, compared to MLR's mean percentage error of 2.12 and R^2 of 0.62. This highlights the ANN model's superior performance in predicting complex traffic noise.

Ali Khalil, Hamad [73] explored various machine learning techniques for traffic noise prediction, including regression trees, support vector machines, ensembles, and ANNs. While all models achieved high accuracy (minimum $R^2$of 0.79), the ANN with 30 neurons in its hidden layer (ANN-30-neuron) outperformed the others, achieving the best performance with an R^2 of 0.995 and a MAE of 0.32 dB(A). Ahmed, Pradhan [74] improved traffic noise prediction using machine learning algorithms, focusing on an ensemble approach. Researcher compared ANN), Correlation-based Feature Selection with ANN (CFS-ANN), and Ensemble Random Forest with ANN (Ensemble RF-ANN). The Ensemble RF-ANN model outperformed others, with the lowest RMSE (training: 1.767, testing: 2.378) and highest R^2 (training: 0.923, testing: 0.835), indicating superior prediction accuracy. Kumar, Nigam [75] used an ANN model to predict highway traffic noise in India, incorporating traffic volume, truck proportion, and average vehicle speed as inputs. The model predicted L_{eq} and L_{10} noise levels, achieving mean squared errors of 0.501 for L_{10} and 0.404 for L_{eq}. These low errors suggest that ANN models can be effective tools for predicting highway traffic noise levels. Adulaimi, Pradhan [76] measured traffic noise along the Klang Valley expressway in Malaysia and applied a land use regression model combining machine learning, statistical regression, and geographic data. The study found that machine learning models, especially the random forest algorithm, outperformed statistical regression models.

Rahmani, Mousavi [77] developed two accurate mathematical models using genetic algorithms to predict L_{eq} for flat road noise. These models are incredibly precise, with predictions within a margin of error of plus or minus 1. Gündoğdu, Gökdağ [78] developed two traffic noise prediction models using genetic algorithms, incorporating vehicle types and legal noise limits. These models are designed for planning city traffic flow with noise reduction in mind. Their accuracy, tested against real-world noise measurements, showed good agreement with the measured data, outperforming existing methods.

Nourani, Gökçekuş [79] investigated the use of Emotional Artificial Neural Networks (EANN) for predicting traffic noise in Nicosia, Cyprus, marking its first application for this purpose. Compared to traditional Feedforward Neural Networks (FFNN), the EANN model significantly improved accuracy by up to 14% over FFNN, 35% over MLR, and 37% over traditional noise prediction models, using both vehicle details and traffic volume data. Torija and Ruiz [80] predicted urban noise levels using three machine learning methods: Multilayer Perceptron (MLP), Sequential Minimal Optimization (SMO), and Gaussian Processes for Regression (GPR). To identify key factors, they employed Correlation-based Feature Subset Selection (CFS), Wrapper for Feature Subset Selection (WFS), and Principal Component Analysis (PCA). The highest accuracy (94% with minimal error) was achieved by combining WFS with either SMO or GPR for prediction. Fallah-Shorshani, Yin [81] compared methods for predicting traffic noise on various streets, including a statistical land use regression model, Extreme Gradient Boosting, and three numerical/acoustic models: the US Noise Model (FHWA-TNM2.5), commercial model Computer Aided Noise Abatement (CadnaA), and the open-source European model Harmonoise. Extreme Gradient Boosting and CadnaA performed best, particularly for different road types, highlighting the value of machine learning and advanced software in urban traffic noise analysis. Yin, Fallah-Shorshani [82] created high-resolution noise maps for their city by collecting A-weighted equivalent noise data from hour-long walking surveys at 16 locations. They trained four machine learning models—linear regression, random forest, extreme gradient boosting, and a neural network—to predict noise levels every 20 meters along streets, using factors like traffic volume, road width, weather conditions, and land use. Extreme gradient boosting proved most accurate, achieving 71% accuracy (leave-one-route-out R^2 with a 4.54-decibel error, and 96% accuracy with a 1.8-decibel error in 5-fold cross-validation. The study found traffic volume to be the most influential factor, but also highlighted the roles of road design, nearby buildings, and weather conditions.

2.3.12 Empirical modeling approach

In an empirical approach to noise modeling, predictions of noise levels are based on observed data instead of relying on theoretical calculations or physical models. This method is particularly advantageous as it is grounded in real-world measurements, allowing it to reflect a wide array of actual conditions. However, the effectiveness of such models is closely tied to the quality and breadth of the data used in their creation. Using the gathered data, statistical models, such as regression analysis, are developed to establish these predictions. Numerous regression models [83], [84], [75], [85], [29], [86], [87], [88], [89], [68] have been created worldwide to predict traffic noise specific to different countries. Empirical models often provide a practical approach when theoretical understanding is limited. Their reliance on real-world data makes them adaptable to complex systems, simplifying development and application compared to models based on theoretical assumptions.

2.3.13 Mathematical approach

Mathematical noise modeling employs a theoretical approach to predict noise levels based on the physics of sound propagation. This methodology involves identifying noise sources, applying sound propagation equations i.e. inverse square low, line source model that incorporate environmental factors, and subsequently superposing the calculated sound levels. A common application of mathematical noise modeling is calculating road traffic noise using the CoRTN model. Various researchers [90], [91], [92], [93], [94], [95], [96] developed prediction model based on mathematical approach. Mathematical noise models offer broad applicability and predictive power, enabling noise estimation even without real-world data.

However, they demand comprehensive knowledge of environmental and source characteristics, and their complexity can escalate in multifaceted scenarios.

2.4 Traffic Noise Study for Indian Scenario

Since gaining independence, India’s journey of rapid development has brought with it an unwelcome companion — a dramatic and exponential surge in traffic noise, echoing through its bustling cities and growing road networks. Rao, Rao [97] developed the first traffic noise prediction model tailored to Indian conditions, aiming to estimate L_{eq} based on traffic density and L_{10}, considering traffic volume as the input parameter for Vishakhapatnam city. Several Indian researchers, concerned about the growing issue of traffic noise, have explored the suitability and effectiveness of global traffic noise models within the unique context of Indian conditions. The suitability of Various conventional model were checked for Indian road traffic condition i.e. FHWA by author Pathak, Lokhande [98], Shukla, Jain [99], Patel, Singh [100], Pandey, Dubey [101] and CoRTN model by [102], Alam, Ahmad [103], Sonaviya and Tandel [104], Manojkumar, Basha [105].

Various authors have also modified various conventional model i.e. Mishra, Parida [56] have considered 7 categories (motorcycle, car, bus, LCV, truck, three wheeler and tractor trailer) of vehicle instead of the three broad categories (light, medium and heavy vehicle) used in the original FHWA model. A study by Debnath and Singh [102] investigated traffic noise Modeling in Dhanbad township. They developed a noise prediction model using CoRTN equations. Interestingly, the model resulted in separate equations for different times of day. They found the model's accuracy varied depending on the time interval. Garg, Mangal [106] introduced the ANN model for predicting traffic noise in Delhi city. They compared its performance to a traditional statistical method called MLR. The ANN model clearly outperformed the MLR models, achieving significantly lower MSE for both L_{eq} and L_{10} noise levels. This confirms ANNs as a more effective method for traffic noise prediction. Authors i.e. Banerjee, Chakraborty [107], Rajakumara and Mahalinge Gowda [65] were also used regression technique to model traffic noise. Kumar, Nigam [75] used an ANN model to predict highway traffic noise in India, incorporating traffic volume, truck proportion, and average vehicle speed as inputs. The model predicted L_{eq} and L_{10} noise levels, achieving mean squared errors of 0.501 for L_{10} and 0.404 for L_{eq}. These low errors suggest that ANN models can be effective tools for predicting highway traffic noise levels. Chauhan, Garg [108] compared classical analytical models with machine learning models for predicting traffic noise in Delhi-NCR, using data from over 200 locations. They found that machine learning models, such as decision trees, random forests, and neural networks, outperformed classical models like multiple linear regressions, achieving accuracy within ±3 dB(A) for predicting hourly average noise ($L_{\mathrm{Aeq,1h}}$) and noise levels exceeded for 10% of the time (L_{10}). Singh, Nigam [109] proposed a novel traffic noise prediction approach for Patiala, India, using generalized linear models, decision trees, random forests, and neural networks. The Random Forest model outperformed the others, achieving an R^2 of 0.94 during training and 0.85 with unseen data, demonstrating high accuracy and effectiveness in predicting noise levels. Yadav, Mandhani [110] proposed an integrated model utilising Bayesian Network and Partial Least Square- Structural Equation Modeling to examine the interrelationship among various variables and their connection with traffic noise level. Singh, Prakash [111] explored the influence of meteorological parameters on ambient noise levels in Delhi. The analysis reveals that wind velocity plays a positive role in reducing noise levels, while temperature tends to increase ambient noise levels.

In developing countries such as India, traffic is characterized by its heterogeneous nature. This means that the traffic flow includes vehicles with varying sizes, speeds, spacing, and operational characteristics [66]. However, the traffic situation in Indian mid-sized cities is vastly different from that of the western world due to the significant proportion of non-motorized vehicles in the traffic flow. These vehicles often contribute to congestion, leading to increased honking and, in turn, higher noise levels [26]. Researcher Thakre, Laxmi [112], Kalaiselvi and Ramachandraiah [66] emphasis on honking noise within the context of heterogeneous traffic conditions in India. Noise levels can be increased to 0.5 to 13 dB due to horn usage, varying with the traffic flow conditions [66]. Honking contributed an extra 2 to 5 dB(A) of noise on top of the existing traffic noise levels [113]. The operation of heterogeneous traffic on narrow carriageways is known to reduce the traffic speed and, consequently, higher road traffic noise level. Literature to this effect are available for cities of developing economies like Asansol [114], Jaipur [115], Delhi [106], Nagpur [98] [112], Varanasi [116], Kolhapur [117], Visakhapatnam city, [118], Lucknow [99], Dhanbad [102] [119] [120], Surat [121], Thailand [57], Colombo [122], Patiala [75] [123], state of Andhra Pradesh and Telangana [102], Jammu and Kashmir [124], Vijayawada [125], Further description of these studies is provided on Table 2.2.

Table 2.2. Traffic noise model for heterogeneous traffic flow

Authors	**Influencing Attribute**	**Method Used**	**Noise Sampling interval**	**No. of data sets**	**Road type**	**Finding**
Banerjee, Chakraborty [114]	Various Land use selected in Asansol city	Field Noise Measurement (L_{Aeq}, L_{dn}, L_{max}& Lmin)	1 hour	NA	UR& INT.	a. Noise maps were developed for impact analysis and Noise Risk Zones. b. Noise Level Ranges i. $L_{dn:}$ 55.1-87.3 dB(A) ii. $L_{eq:}$ 51.2 – 89.0 dB(A) during day and 43.5-81.9 dB(A) during night.
Agarwal and Swami [115]	Equivalent number of vehicles per hour of a particular category corresponding to the mixed traffic density	Empirical Noise prediction model to predict L_{eq} in terms of traffic density number.	10 minutes	NA	UR	a) R^2 = 0.535 (in term of light vehicles/hr.) b) R^2 = 0.5125 (in term of heavy vehicles/hr.)

Garg, Mangal [106]	a. Equivalent traffic volume b. Equivalent traffic speed c. Total traffic volume d. Average speed e. Percentage of heavy vehicle f. Average speed of heavy and light vehicle	a. Field Noise Measurement (L_{eq} & L_{10}) b. MLR &ANN Model	15-60minute	51 L_{eq}	UR	a) Neural Network outperformed the MLR model. b) ANN Model Prediction: L_{eq} Training: R=0.95 Testing: R =0.93 L_{10} Training: R=0.95 Testing: R=0.83
Pathak, Lokhande [98]	a) REMEL b) Volume and speed of each category of vehicle c) Distance between source and receiver	a) Field Noise Measurement (L_{eq}) b) FHWA Model	1 hour	NA	INT.	Model performance: a) $R^2 = 0.455$ b) Error Margin = ± 2.1dB(A) for peak hour and ± 1.6 dB(A) for off-peak hour

Pathak, Tripathi [116]	a) Various Land use selected in Varanasi city. b) Community survey regarding traffic noise exposure.	a) Field Noise Measurement (L_{eq}, L_{10}, L_{90}) b) Personal interviewed	1 hour	NA	UR	a) Most of the sample site had exceeded central pollution control board (CPCB)noise guidelines. b) 90% of participants said traffic noise causes headaches, high blood pressure, dizziness, and fatigue.
Hunashal and Patil [117]	Various Land use selected in Kolhapur city	Field Noise Measurement (L_{eq}, L_{10}, L_{90})	Day-1 hour& Night -2 minute	NA	UR	Highest L_{eq} of 72.25 dB(A) was observed in industrial-cum-residential zone followed by 64.47 dB(A) in commercial-cum-residential zone, 63.71 dB(A) in educational zone, 53.26 dB(A) in recreational zone and 42.84 dB(A)in silence zone.
Sagar and Rao [118]	Various Land use selected in Visakhapatnam city	Field Noise Measurement (L_{avg}, L_{10}, L_{peak})	NA	NA	UR	Remedial measures were suggested to reduce the impact of noise for each zone.
Shukla, Jain [99]	a) REMEL b) Traffic volume and speed of each category of vehicle c) Distance between source and receiver	a) Field Noise Measurement (L_{eq}) b) FHWA Model	15 second	240/hour	UR	$R^2 = 0.90$

Debnath, Singh [119]	a) Traffic volume b) Vehicle speed c) %Heavy vehicles. d) Pavement, gradient and distance adjustment	a) Field Noise Measurement (L_{eq}) b) ANN Model	1 hour	NA	UR	Observed and predicticted noise level deviation up to ± 0.6 d B(A) and $R^2>0.9$ for all five-noise hour.
Ranpise, Tandel [121]	a) Traffic Volume b) Traffic speed c) Road width d) Average building height	a) Field Noise Measurement (L_{eq}) b) ANN Model	1 minute	NA	UR	R^2 Value for training data sets > 0.9 for all the roads and MSE values < 0.2 for all roads
Pamanikabud and Vivitjinda [57]	a) REMEL b) Volume and speed of each category of vehicle c) Distance between source and receiver d) Ground surface between highway and receiver	a) Field Noise Measurement (L_{eq}) b) FHWA model	1 hour	360 $L_{eq,1hr}$	Highway	Initial model did not fit well with field measured data and later adjustment factor was applied for prediction accuracy.
Chowdhury, Razzaque [126]	Various Land use selected in Dhaka city.	Field Noise Measurement (L_{eq}, L_{50}, L_{10}, L_{90})	5 minutes	NA	UR	a) Assessment of the level of noise pollution for city. b) Average L_{eq} for Roadside crossed 80(dBA)

Haq, Islam [127]	Various Land use selected in Dhaka city.	Field Noise Measurement (highest average value and lowest average value)	3 specific intervals:2 ,4 and 3 hours	NA	UR	a) Noise level contour line were made. b) Banglamotor have highest average noise level than other places. c) Average highest noise level of many places crosses 85 dB(A).
Kalansuriya, Pannila [122]	a) Heavy vehicle/hour b) Light Vehicle/hr.	a) Field noise measurement (L_{eq}, L_{10}, L_{50} L_{90}, Lmax and L_{min}) b) Linear regression	10 minutes	NA	MR, SR&LR	a) R^2 for prediction of Leq, L_{10}, L_{50} $L_{90} \geq 0.85$ b) Contribution of light vehicles on the overall noise level is small for Leq, L_{10}, L_{50}. c) For Leq, L_{10}, L_{50} heavy vehicle are the main source of noise.
Kumar, Nigam [75]	a. Traffic volume, b. truck-traffic mix ratio c. vehicle speed	ANN	1 hour	NA	Highway	$R^2 = 0.97$ and 0.94 during testing and training for L_{10} and $R^2 = 0.81$ and 0.85 during testing and training for L_{eq}

Thakre, Laxmi [112]	a. Classified traffic volume b. Number of light and heavy vehicles c. Honking d. Speed	Regression	1 minute	NA	UR	Prediction range were 1.7 to + 1.4 dB (Leq) with 84% of observations in the range of − 1 to + 1 dB (Leq) and having R^2 = 0.65
Gilani and Mir [124]	a. Traffic Volume b. Average traffic speed c. Carriageway width d. Number of heavy vehicles Honking	Graph theory approach	1 hour	NA	UR	R^2 = 0.71,0.67,0.71 for L_{eq}, L_{90} and L_{10} respectively
Singh, Upadhyay [123]	a. Traffic Volume b. Percentage of heavy vehicle, c. Average speed of vehicle	Various Machine learning model i.e. Linear model, decision model, neural networks, Random forest and ANFIS	1 hour	303	highway	ANFIS performed better than other ML model with R2 value of 0.96

Ramakrishna, Saigiri [125]	a. Traffic volume b. Heavy vehicle %	Regression & ANN	2 minutes	NA	UR	a. ANN model is more reliable than Regression approach. b. R^2 value for commercial zone using regression method i.e. 0.687 were better than other zones.
Kumar [128]	a. Total vehicle volume b. % Heavy vehicles c. Average vehicle speed	Hybrid modelling approach using ANN & Response surface method	1 hour	NA	Highway	a. Full quadratic model performed better than linear, square and interaction model b. The residual values for model (4) lies in the range of + 0.9/ − 0.5 dB (A) for L_{10} and + 0.8/ − 0.5 dB(A) for L_{eq}
Debnath and Singh [102]	a. Traffic Volume b. Traffic speed c. % heavy vehicle	Modified CoRTN	1 hour	NA	UR	R^2 = 0.819 and a mean difference of +0.8 dB(A) for morning (9–12 Pm) datasets

Current study	a) Classified traffic volume b) Average speed of each category of vehicle c) Non-motorized vehicle d) Percentage of honking contribute vehicles e) Façade distance f) Average building height g) International roughness index h) Road width i) Observer Distance	a) Field noise measurement ($L_{eq,}$ L_{10},) b) PCA &K-NN	1 hour	776, $L_{eq,1hr}$	UR	a) R^2=0.81(MP),0.78 (OP)&0.77(EP) for L_{eq} b) R^2=0.86(MP),0.80 (OP),0.84(EP) for L_{10}

UR – Urban road; INT. – Intersection ; OR – Other roads (outside city i.e. main and secondary road); NA – Not available

2.5 Influential Attribute Affecting Traffic Noise

To forecast traffic noise, models are created that consider various influencing attributes. Studies have shown that many elements play a role in how loud traffic noise becomes. These elements can be grouped into broader categories, like road characteristics, traffic characteristics, the surrounding weather, and even the presence or absence of buildings. All these factors together significantly affect the noise pollution caused by traffic [124]. When it comes to road characteristics that impact traffic noise, several key elements come into play. These include the carriageway width, road surface, the space separating opposing traffic lanes (median width), road gradient. All of these features play a significant role in how much noise traffic generates [99, 129]. Traffic itself plays a major role in how loud it gets. Traffic characteristics such as traffic volume, traffic speed, the use of horns, and the proportion of large trucks and buses (heavy vehicle percentage) all significantly influence traffic noise levels [112, 130]. Climate conditions consider relative humidity, temperature and wind velocity [71] [111]. Traffic noise models also consider the built environment, including building height, how close buildings are together (density),unauthorized street parking, and land use [131, 132]. The three primary factors that have the greatest impact on traffic noise are traffic volume, road geometry, and speed [53, 133]. In a noisy environment, the acoustic performance of the façade significantly amplifies the ambient noise level [134]. Research has demonstrated that the height of a façade affects the acoustic environment, with numerous studies concluding that taller façades result in higher sound pressure levels [135-139] and increased reverberation time, primarily due to sound reflection, diffusion, and scattering on façades [136, 140]. The impact of the façade increases as the receiver gets closer to the building, but becomes negligible at distances greater than 20 meters [135]. To explore potential areas for future research on factors that influence traffic noise, it's helpful to examine the key attributes that have been identified in past studies. Several influential attributes have been highlighted in previous research, which could provide a foundation for further investigation into the variables that affect traffic noise Table 2.2 and Table 2.3 summarize some of the most important attributes used in these studies. By analysing these factors, researchers can gain valuable insights into how traffic noise may be influenced by a variety of conditions and can determine which attributes warrant further exploration.

Table 2.3. Influential attribute used for modeling in previous researches

Reference ID	Study Location	Inputs to the model	Model
[141]	Delhi	Traffic flow, average speed of vehicle, heavy vehicle percentage and number of honks	Regression and Machine Learning
[142]	Nicosia, North Cyprus	Volumes of cars, medium vehicles, buses, heavy vehicles, and average speed	Hybrid model (combination of regression and machine learning)
[87]	Ondo, Nigeria	% Heavy vehicles, traffic volume, speed	CoRTN and regression model
[81]	Long beach, California	Vehicles per hour, % heavy vehicles, vehicle speed, road gradient, road surface, multiple reflection of building, different speed between passenger car and heavy vehicles	CadnaA using RLS-90 emissions
[143]	Guangdong, china	Distance and traffic volume	Monte Carlo simulation
[83]	Kuala Lumpur, Malaysia	Classified traffic volume, Density of road, gradient, humidity, temperature, time, digital surface model	Machine learning method
[76]	Shah Alam, Malaysia	Traffic volume, wind speed, distance, digital surface model, traffic jams, road intersection, traffic lights, road tall gats, gas station, public transport	Land use regression model
[79]	Nicosia, North Cyprus	Total traffic volume, Classified volume, heavy vehicle %, average traffic speed	Machine learning model
[33]	Nicosia, North Cyprus	Classified traffic volume, number of horns and average speed	Machine learning model
[144]	Shah Alam, Malaysia	Volume of car, motorcycle, heavy vehicle, sum of vehicles, car ratio, motorcycle ratio, heavy vehicle ratio,	Machine learning model

		highway density, digital elevation model, wind speed	
[71]	Sharjah, UAE	Classified traffic volume, Receiver distance, average speed and roadway temperature	Machine Learning model
[29]	Serbia	Classified traffic volume and average speed	Machine learning model
[59]	Taichung, Taiwan	Traffic volume data, road data, round and barrier data, geometry data, façade	Modified Nordic prediction model
[77]	Mashhad, Iran	Equivalent traffic flow and equivalent traffic speed	Genetic algorithm
		Total traffic volume, classified traffic volume, percentage of heavy vehicle	Computational model
[145]	Thailand	Basic noise emission of vehicle, reference distance, distance between source and receiver, ground condition	Mathematical model
[145]	Thailand	Basic noise emission of vehicle, reference distance, distance between source and receiver, ground condition	Mathematical model

2.6 Traffic Noise Study on High Rise Residential Buildings

Huang, Pan [146] conducted a noise evaluation on various floors of high-rise buildings. The results showed that the noise level increased with building height, starting at the lowest level on the first floor and increasing to its highest level on the eleventh floor (or 34 metres in the air), and after that, it decreased with height. Results also revealed that the acoustic amenity is between 12 and 24 metres (4-8 floors) and above 54 metres (18th floor) compared to other heights. Sotiropoulou, Karagiannis [147] measured the traffic noise levels on nine different floors of the 23-floor building, which had a height of 80.5m. The findings reveal that traffic noise level increased with altitude up to 31.5 meters (8th floor) and then decreased. Through surveys and noise measurements, Wu, Zou [148] analysed the vertical noise gradient and assessed the impact of traffic noise on nearby homes. Sixty per cent of respondents said the noise was somewhat or extremely disturbing to their physical comfort. The finding also revealed that noise levels rise sharply on the lower floors and drop marginally on the upper floors. The noisiest floors in the buildings A, B, and C were the sixth, sixth and ninth, respectively. Zou, Zhu [149] measured the amount of noise emanating from a 31-story residential structure with 270 households due to a nearby construction, subway operation, road traffic, and possible human activity. Results showed a minor increase in noise levels from the lowest to the middle floors, followed by a progressive decrease as one moved higher in the building. Brown, Lam [150] conducted questionnaire surveys on a random sample of 10,077 homes to evaluate their exposure to road traffic noise and measure aggravation and self-reported sleep response. Rental units from the public sector, subsidised apartments, private homes, other types of permanent housing, and short-term accommodations were all selected. Those experiencing annoyance and sleeplessness were polled with a questionnaire. Daytime annoyance levels ranged from severely annoyed (7.9%) to bothered (24.6%) to little annoyed (47.2%). High sleep disturbance was selected by 4.1%, moderate by 11.3%, and low by 27.3%.

Approximately 60,000 years of potential life expectancy are cut short in Western Europe because of ischemic heart disease caused by exposure to environmental noise [151]. Noise level data at different floors due to community noise i.e. food courts, designated playgrounds, schools, and garbage trucks have been considered. Researchers found that noise levels dropped as height increased [152]. Benocci, Bisceglie [153] investigated noise transmission through field measurement and a three-dimensional acoustic simulation model Computer

Noise Assessment Method (CADNAA) at various heights within the framework of a moderately sized road network. Results showed an anticipated average decay of 4 dB(A) in the first 30 m (the difference in height between the 1st and 10th floors) and about 3.4 dB(A) in heights exceeding 30 m up to 70 m (the difference in height between the 10th and 23rd floors). Noise levels measured in L_{eq} (dB(A)) due to a higher concentration of heavy vehicle traffic were higher on lower floors than on upper floors [154]. Traffic noise levels were measured on each floor of five residential structures with sixteen stories. According to the research findings, traffic noise increased between 3.5 dB(A) and 4.1 dB(A) at 10.0 m to 15.5 m above the ground as building height increased [155]. A simulation model was created to explore vertical noise propagation. Real-world measurements of noise levels were used to confirm the simulation's conclusions. It revealed a maximum decay of 4 dB(A) at heights exceeding 50 m up to 140 m and a 6 dB(A) decay throughout the first 50 m of height [156]. Comparing the simulated and measured noise levels demonstrated that noise level climbs to a peak value, with height starting from the first floor and then beginning to decline [157]. On floor 3, the full effect of neighbourhood traffic was felt with louder excursions in noise level. The intermediate floors, 14 and 26, showed a relatively lesser impact of nearby traffic noise. [158]. Lee, Kim [159] conducted noise measurement on different floors of high rise residential building and reported that the noise level on the upper floors was marginally greater compared to that on the lower floor. Qin, Li [160] conducted an analysis of noise fluctuations at varying heights in different scenarios, such as under various heights of vertical noise barriers, facing both street and non-street building facades, and with different balcony orientations. According to his findings, the noise levels on building facades initially increase and then gradually stabilize as the floors rise. In addition, the noise level on building facades that face away from the street is higher than on facades that face the street; this is because the building in the front row reflects sound waves. The rise in the height of the floor results in a decrease in the sound pressure level of the indoor noise level [161]. Noise levels in a neighbourhood can vary greatly from one flat to the next, depending on factors including floor plan, orientation, and density [147]. Built factors such as roads, traffic, buildings, and topography can significantly alter the amount of road traffic noise that a family is exposed to, particularly in densely populated urban areas [162].

The severity of noise pollution in the high-rise buildings has been previously demonstrated in research [28, 146, 148, 156, 163]. Many research efforts have utilized aggregated noise levels that are computed for a building, neighborhood, or district [164-166]. Therefore, it is of the utmost importance to take measures to effectively manage noise pollution in high-rise structures. The three main categories of commonly used strategies for reducing traffic noise are - regulating the noise power source, enhancing attenuation during propagation, and noise reduction at the receiver end [167]. The first categories comprise the utilization of low-noise pavement [168] [169] , advancements in vehicle tire technology [170], the promotion of electric vehicle adoption[171], enhancing road infrastructure [172], urban planning initiatives such as road network optimization, traffic flow management [173, 174], traffic signal coordination [175, 176], speed restriction enforcement [174, 177] , and reduction of heavy traffic congestion [60, 173, 178] . The second set of categories involve noise barriers, natural greenery [27] , structures, and various urban obstacles that notably contribute to reducing sound levels. Acoustic data such the noise absorption coefficient (NAC), noise reduction coefficient (NRC), transmission loss coefficient (TLC), and sound transmission class (STC) are considered to determine the acoustic efficacy of noise barriers. This ensures a comprehensive assessment of the barriers [179]. The acoustic effectiveness of the barrier relies on both its shape and the materials used in its construction. In addition to geometry, the efficiency of the noise barrier is also influenced by any top-mounted elements [179]. The third categories involve design of buildings. Building acoustics are largely shaped by the architectural design i.e. room geometry, building materials and the positioning of sound-absorbing components used in construction. These factors affect both the interior auditory experience and the attenuation of outside sounds [180]. A room's acoustic performance is affected by these factors, which are crucial in deciding the reverberation time and the characteristics of sound transmission within the room. The influence of the interior structure on the noise distribution is strong. The indoor noise environment is affected by the interior structures and floors. The strip-type house performs the worst in terms of indoor traffic noise levels, as they exhibit the highest noise levels across all floors, with particularly elevated levels on the middle and lower floors. Following closely behind are the foursquare-type and narrow-type houses in terms of noise levels, but the narrow-type house may be limited in terms of daylight and ventilation, the foursquare -type house is recommended in practice [161].

The acoustic performance of a room in high rise residential building can also influenced by the outdoor spaces surrounding it. These outdoor areas can play a crucial role in determining the reverberation time and the characteristics of sound transmission within the room. Urban environments are shaped by complex acoustic phenomena, including multiple reflections, diffraction, and diffusion. These factors can significantly impact the acoustic environment within high-rise buildings. It is crucial to manage the outdoor space's sound field by utilising acoustic materials with a high absorption coefficient, including soil and green walls, which can lower the reverberation time (RT) and elevated sound pressure level (SPL) caused by multiple reflections between building facades[181-184]. Reflected sound energy contributes to heightened SPL and longer RT. The pattern of reflection is influenced by various design factors, including building height, layout, shape, spacing between buildings, facade configuration, and the acoustic properties of surfaces [185].

Double glazing windows can greatly reduce outside noise; however, this is at the detriment of allowing for adequate natural ventilation [186]. A type of ventilation-enabling façade noise control device, a plenum window can reduce 15–20 dB in closed mode compared to acoustic and by-pass modes [187]. Windows with external protrusions i.e. Lintels, fins, eaves, louvres, and solar shading are solutions can block road noise and provide ventilation. The road view angle viewed by the opening and the presence of absorption material limit its usefulness [188]. Yu, Lu [189] designed a ventilation window utilising resonant-chamber unit cells, made up of acrylic panels to generate an acoustic metasurface. The partition with the window prototype has a transmission loss above 20 dB at 800–315 Hz frequency range [190]. Biler, Unlu Tavil [191] researched the performance of trickle vents and reported that their acoustic insulation can reach value of around 40 dB.

The efficacy of a balcony can significantly influence its role as a barrier against noise. Balconies are regarded as a component of the building's exterior that can effectively reduce environmental noise levels due to their design and the usage of sound-absorbing materials that can be applied to their surfaces. Various treatment i.e. ceiling-mounted reflectors, lintel, balcony depth, parapet, inclined ceiling, absorbing material, effect of incidence angle were investigated on balcony by the researchers [28, 159, 192-196]. Lee, Kim [159] conducted a study on six different treatments to determine their effectiveness in reducing traffic noise. These treatments included: a) using a lintel of either 50 or 100cm, b) installing a parapet, c) using an inclined ceiling, d) applying an absorber to the inclined ceiling. e) parapet plus treatment (d) and f) Placement of an absorber on the inner side of the plus treatment (e). The treatment (f) yields the most significant decrease in noise, reaching a maximum value of 23 dB on the second level. It is unrealistic to expect a single product to meet all of the necessary acoustic quality standards, and there is no silver bullet when it comes to acoustic design [197]

The initial stage in mitigating traffic noise is to construct models for its prediction. Models of this nature were first developed in the 1950s, and since then, many subsequent efforts have been undertaken in this field [33]. The traffic noise prediction model can assist in pinpointing hotspots where noise levels are exceptionally high. As a result of differences in traffic conditions between different countries, various traffic noise models have been developed. Some of the traffic noise models used are FHWA's, CoRTN, RLS90, ASJ, CNOSSOS-EU, 01dB Mithra, NMPB-Routes-96, NORD 2000, which stands as contemporary models [30-32]. Despite the prevalence of horizontal traffic noise propagation models, vertical traffic noise propagation models are still in their infancy. The vertical noise propagation model may help urban planners plan mitigation strategies, real estate players to determine the cost of apartments at individual floors and the customers to make judgements about the best choice for them. The field of noise simulation in high-rise buildings needs to be more researched; and some researchers have attempted this in the past [146-148, 152, 153, 160, 163]. Their salient findings are shown below in Table 2.4. They have used various inputs for the development of model based on their local condition, like light vehicle, medium vehicle, heavy vehicle, % heavy vehicle, road data, traffic data, vehicle speed data, distance etc., while few of them modelled through software.

Table 2.4. Modeling of traffic noise on vertical scale

Reference ID	Model	Influential attribute	Data information	Key aspects
[146]	ANN	a) Light, medium and heavy vehicles volume and their respective speed b) Distance D c) Angle Ø d) Distance D_o e) Angle $Ø_2$	a) Data sets: 327 b) STI: 10 minutes	a) No. of building: 4 b) No. of floors: 22 (Information of only 1 building were mentioned) c) Distance from expressway: 60.0 meters d) Light vehicle volume ratio: 96-98% e) Mid-size vehicle ratio: 1.06-1.35% f) Heavy vehicle %: 1.4-2.2%
[147]	CoRTN	a) % Heavy vehicles b) Traffic flow volume c) Traffic speed d) Road data e) Road gradient	a) Data sets: 9 b) STI: 5 minutes	a) No. of building: 2 b) No. of floors: 23 and 24 c) Building height: 80.5 and 88 d) Building distance: 46.0 and 10.0 meters from the Road kerb
[148]	Polynomial fit curve of noise level transfer function	Floor height	a) Data sets: 42 b) STI: 10 minutes	a) No. of buildings: 3 b) No. of floors: 12,12 and 18 c) Building distance: 21.0 meters (each building) from the bridge

[152]	Community noise Modeling using CADNAA software.	a) Noise emission level b) point source c) Directivity factor of the noise source	a) Data set: 6 b) STI: 10minutes	a) No of buildings: 5 b) No. of floors: 16 (each building) c) Building distance from community noise source: 15.0 meters
[153]	Tri- dimensional acoustic simulation model using CADNAA	a) Traffic flow information b) Origin/ destination matrix, c) Time value	a) Data sets: 445 b) STI: 1 hour	a) Analysis over the entire urban area of Milan. b) Receptors were assumed to be located at residential buildings higher than 50.0 meters
[160]	Using software Sound PLAN 8.2	a) Building height b) Initial elevation c) Receiver point position d) Geographical environment	a) Data sets: NA b) STI: 20 minutes	a) No. of building:8 b) No. of floors: 29, 17, 12, 13, 25, 12, 13, 18 c) Building distance from road:125.0, 106.0, 92.0, 64.0, 95.0, 65.5, 83.0, 81.0 meters
[163]	CoRTN	a) % Heavy vehicles b) Traffic flow volume c) Traffic speed d) Road data e) Road gradient	a) Data sets:19 b) STI:1 hour	a) No. of building: 1 b) No. of floors: 20 c) Building height: 59.0 meters d) Heavy vehicle %: 28-51% e) Building distance: 8.0 meters from the road kerb
Present Study	ANN	a) Classified traffic volume b) Classified traffic speed c) Hypotenuse distance d) Honking event	a) Data sets:258 b) STI:15 minutes	a) No. of building:2 b) No. of floors: 15 c) Two – wheeler %: 53 -75% d) Heavy vehicle %: 0-3.8%

				e) Building distance: 18.4 and 33.3 meters from the edge of the nearby carriage-way.

STI : Sampling time interval; NA : Not available

2.7 Vehicular Source Emission Model

The basic approach for various road traffic noise prediction models like the FHWA Traffic Noise Model (TNM) , ASJ, Son Road Model, NORD 2000 model, is the same as they achieve their prediction aim by combining two models, i.e. vehicular source emission model and sound propagation model [30, 31]. The traffic noise prediction model relies on two key components: vehicular source emission model, which estimates the sound pressure level generated by a single vehicle passing by at the roadside, and the sound propagation model, which calculates the attenuation of sound as it travels from the source to the receiver [198]. The FHWA TNM has been widely used for detailed noise impact and forecasting, utilizing input from various vehicle types', called Reference Energy Mean Emission Levels (REMEL). FHWA has identified REMEL as a function of speed and vehicle category [199]. FHWA provides a predicted noise level through a series of adjustments to a reference sound level. These REMEL model is called as vehicular source emission model. The FHWA and the Volpe National Transportation Systems Centre (TSC) collaborated on a paper in 1995 that detailed the findings of a national REMEL analysis for the USA [39]. More than 6000 individual pass-by events of vehicles were gathered to compile new REMEL datasets, which were subsequently utilized as input for the development of the FHWA TNM [39]. ASJ has released an updated edition of the road traffic noise prediction model, titled "ASJ RTN-Model 2018." Over the past decades, the ASJ research committee conducted pass-by-noise measurements on real roads to improve the model's accuracy. They amassed approximately 5800 data points for dense asphalt pavement during this process. Subsequently, they revised numerous values associated with the sound power level [137]. The California Department of Transportation

(CDoT) realized the necessity of developing California vehicle noise emission levels, and over 3000 noise measurements of Cars, medium trucks, and heavy trucks were taken [200]. The CDoT has used the reference energy mean emission values as a speed function since 1978. It is logical to infer that vehicle noise emissions have changed since 1975. Following the first energy crisis in 1973-1974, there have been alterations in truck noise emission regulations, and there has been a growing popularity of compact and energy-efficient Cars. Consequently, recognizing the shifts in the 3-wheelermotive landscape, a need for a California vehicle noise emission study arose [200]. Florida-specific REMELs were formulated in response to several factors. These include the elevation of the interstate highway speed limit from 55 to 65 mph, advancements in Car technology, and disparities in pollution levels between Florida and the national averages [201]. The outcomes of the REMEL study conducted in Riyadh revealed a notable discrepancy. The traffic noise emission statistics suggested by FHWA models did not align with those recorded from Cars in Riyadh. It was observed that traffic noise levels in Riyadh were often underestimated when using the FHWA emission curves [202]. When utilizing California emission levels, the noise predictions are expected to be approximately 2 dB(A) lower than predictions made using the FHWA curve. This difference is anticipated for both average traffic mixes and grades on highways [200]. Georgia decided to develop its emission level curves for highway traffic due to uncertainty regarding the validity of the emission curves established by the Federal Highway Administration (FHWA) for the state's specific conditions [203].

The noise prediction models are used to develop mitigation strategies, and the Vehicular source emission model for various vehicle types is at the heart of these models [203, 204]. These emission levels are the model's foundation, indicating the highest, energy-averaged, A-weighted sound level of a specific vehicle type passing through a given site [201]. Emission levels are affected by various elements, including vehicle type, engine size, speed, tire type, etc. It is necessary to test the emissions of many vehicles at multiple speeds to get the REMELs [205]. The summary of various vehicular source emission model is given in Table 2.5.

Table 2.5. Vehicular source emission model

S/N	Reference ID	Emission model	Vehicle sample size	Pavement surface
1	Barry and Reagan [38]	$Automobil: \overline{(L_0)}_E = 38.1\text{logV} - 2.4$ $Medium\ Truck: \overline{(L_0)}_E = 33.9\text{logV} + 16.4$ $Heavy\ Truck: \overline{(L_0)}_E = 24.6logV + 38.5$ (V in kph)	NA	NA
2	Hendriks, Benson [200]	$Automobile: \overline{(L_0)}_E = 38.8\text{logV} + 5.2$ $Medium\ Truck: \overline{(L_0)}_E = 25.6\text{logV} + 35.3$ $Heavy\ Truck: \overline{(L_0)}_E = 19.2\text{logV} + 50.4$ (V in mph)	2,734	NA
3	Harris [203], Georgia	$Automobile: \overline{(L_0)}_E = 28.19\text{logV} + 21.91$ $Medium\ Truck: \overline{(L_0)}_E = 16.36\text{logV} + 50.4$ $Heavy\ Truck: \overline{(L_0)}_E = 81.1\ dBA$ (V in mph)	880	Asphalt
4	Wayson, Ogle [201], Florida	$Automobile: \overline{(L_0)}_E = 31.13\text{logV} + 12.777$ $Medium\ Truck: \overline{(L_0)}_E = 18.765\text{logV} + 43.697$ $Heavy\ Truck: \overline{(L_0)}_E = 12.831\text{logV} + 58.270$ (V in kph)	Not clearly mentioned except medium truck data- 67	Asphalt Surface
5	Cohn [206], Colardo	$Automobile: \overline{(L_0)}_E = 28.68\text{logV} + 19.78$ $Medium\ Truck: \overline{(L_0)}_E = 28.74\text{logV} + 27.18$ $Heavy\ Truck: \overline{(L_0)}_E = 28.77\text{logV} + 31.01$ (V in mph)	1495	DGAC, OGAC PCC
6	Agent [207], Kentucky	$Automobile: \overline{(L_0)}_E = 30.32\text{logV} + 14.18$ $Light\ Truck: \overline{(L_0)}_E = 31.08\text{logV} + 15.45$ $Medium\ Truck: \overline{(L_0)}_E = 31.37\text{logV} + 20.50$	10,128	NA

		$Heavy\ Truck: \overline{(L_0)}_E$ $= 28.20\text{logV} + 30.70$ (V is in kph)		
7	REMEL FHWA 1995 Fleming, Rapoza [39]	$L_E(S) = 10\log_{10}[10^{(C+\Delta E)/10} + (S^{\frac{A}{10}})(10^{\frac{B+\Delta E}{10}}]$ *Constant have different values for different category of vehicle (S is in mph)	Over 6000 vehicles	DGAC, PCC and OGAC
8	Cai, Zhong [198]	$Light\ Vehicle = 16.19\text{logV} + 55.12$ $Middle - Size\ vehicle$ $= 22.94\text{logV} + 43.97$ $Heavy\ Vehicle = 21.80\text{logV} + 50.00$ (V is in kph)	480	Wet stone mastic asphalt
9	JTG B03-2006 (the industry standard for traffic noise studies in China) recommended model [198]	$Light\ vehicle = 34.73\text{logV} + 12.6$ $Middle - Size\ vehicle = 40.48\text{logV} + 8.8$ $Heavy\ vehicle = 36.32\text{logV} + 22$ (V is in kph)	NA	Asphalt
10	Wayson, Ogle [201]	$Automobile: \overline{(L_0)}_E$ $= 32.283\text{logV} + 10.803$ $Medium\ Truck: \overline{(L_0)}_E$ $= 23.221\text{logV} + 36.129$ $Heavy\ Truck: \overline{(L_0)}_E$ $= 14.058\text{logV} + 56.234$ (V is in kph)	NA	NA
11	Pamanikabud and Vivitjinda [57], Thailand	$Automobile: L_{Aeq} = 63.07 + 0.07V$ $Light\ Truck: L_{Aeq} = 63.78 + 0.12V$ $Medium\ Truck: L_{Aeq} = 72.57 - 0.01V$ $Heavy\ Truck: L_{Aeq} = 72.35 + 0.07V$ $Motorcycle: L_{Aeq} = 65.93 + 0.12V$ $Bus: L_{Aeq} = 68.18 + 0.10V$ $Semi\ and\ Full\ Trailer: L_{Aeq}$ $= 67.09 + 0.14SV$ (V is in kph)	130-230 for each type of vehicle category	NA

12	Koushki, Felimban [202], Riyadh, Saudi Arabia	$Automobile\ :\ \overline{(L_0)}_E = 33.2\log V + 9.84$ $Medium\ Truck: \overline{(L_0)}_E = 35.68\log V + 15.54$ $Heavy\ Vehicle: \overline{(L_0)}_E = 22.46\log V + 44.39$ (V is in kph)	277	NA
13	ASJ-RTN 2018 model Sakamoto [41]	$Light\ Vehicle; L_{WA} = 30\log V + 45.8$ $Medium - size\ vehicle; L_{WA} = 30\log V + 51.4$ $Larg - size\ vehicle; L_{WA} = 30\log V + 54.4$ $Heavy\ Vehicles; L_{WA} = 30\log V + 53.2$ $Motorcycle; L_{WA} = 30\log V + 49.6$ (L_{WA} *is sound power level,* V is in kph)	5,800	Asphalt Pavement
14	Tansatcha, Pamanikabud [96]	$Light\ truck; L_{Aeq}(10sec) = 12.488\log V + 45.20$ $Medium\ truck; L_{Aeq}(10sec) = 6.60\log V + 61.75$ $Heavy\ truck; L_{Aeq}(10sec) = 7.08\log V + 61.37$ $Full\ trailor; L_{Aeq}(10sec) = 4.69\log V + 66.63$ $Semi\ trailor; L_{Aeq}(10sec) = 7.66\log V + 60.255$ $Bus; L_{Aeq}(10sec) = 11.585\log V + 52.128$ $Motorcycle; L_{Aeq}(10sec) = 7.11\log V + 61.22$ (V is in kph)	2267	Asphaltic concrete
15	Danilevičius, Karpenko [208] .	$Motorcycle\ ; L_{Aeq} = 9.50\ln(V) + 35.79$ $Passanger\ cars\ ; L_{Aeq} = 11.11ln(V) + 27.92$ $Vans\ ; L_{Aeq} = 8.8ln(V) + 38.07$ $Buses\ ; L_{Aeq} = 9.08ln(V) + 38.30$ $Light\ trucks\ ; L_{Aeq} = 11.85ln(V) + 27.55$ $Heavy\ trucks\ ; L_{Aeq} = 10.45ln(V) + 36.821$ (V is in kph)	813	Asphalt Pavement
16	REMEL equations by [209]	$Bus\ :\ (L_O)_E = 12.25\log V + 58.58$ $Truck\ :\ (L_O)_E = 8.88\log V + 67.86$ $Tractor\ :\ (L_O)_E = 9.66\log V + 69.12$ $LCV\ :\ (L_O)_E = 2.82\log V + 71.26$ $Car\ :\ (L_O)_E = 13.63\log V + 49.13$ $Auto: (L_O)_E = 15.33\log V + 50.72$	10,700	Bituminous pavement

		$Motorcycle: (L_O)_E = 18.63\text{ogV} + 41.46$ $E-rickshaw: (L_O)_E = 16.94\text{logV} + 45.53$ $Bi-cycle: (L_O)_E = 6.67\text{logV} + 46.19$ $Cycle-Rickshaw: (L_O)_E = 19.61\text{logV} + 34.63$ $Horse\ Driven\ Vehicle: (L_O)_E = 75.25\text{logV} - 23.16$ (V is in kph)		
17	REMEL equation by [210]	$Bus: (L_O)_E = 20.84\text{logV} + 48.205$ $Truck: (L_O)_E = 6.05\text{logV} + 73.184$ $Tractor: (L_O)_E = 17.77\text{logV} + 60.14$ $LCV: (L_O)_E = 8.61\text{logV} + 64.31$ $Car: (L_O)_E = 17.92\text{logV} + 46.95$ $Auto: (L_O)_E = 5.85\text{logV} + 65.68$ $Motorcycle: (L_O)_E = 19.49\text{ogV} + 42.82$ $E-rickshaw: (L_O)_E = 16.87\text{logV} + 47.79$ $Bi-cycle: (L_O)_E = 3.29\text{logV} + 51.30$ $Horse\ Driven\ Vehicle: (L_O)_E = 101.46\text{logV} - 43.85$ (V is in kph)	4,390	Concrete Pavement

2.8 Research Gap

2.8.1 For noise prediction model

a) Most traffic noise models were developed for segregated traffic prevalent in the Western economies. Developing economies like India cater to heterogeneous or mixed traffic on their road network in mid-sized cities, which often have narrow carriageways. In general, each country with different geographical location has its own unique set of environmental factors and traffic patterns, therefore, no generalized solutions are available that can be applied throughout the world in any environmental situations [211]. Therefore, traffic noise Modeling for heterogeneous road traffic needs to be considered separately.

b) Most of the previously developed models for western world traffic were based on motorized vehicles [30, 42, 49, 51, 52, 58, 151, 212-220]. However, the Indian mid-sized city's traffic scenario is completely different from the western world as the presence of sizable share of non-motorized vehicles in the traffic stream which are many a time responsible for causing congestion, consequently rise to honking, and subsequently higher levels of noise. The consideration of a non-motorized vehicle as an input to the traffic noise model is also lacking in many research studies. In mid-sized Indian cities, motorcycles and auto-rickshaws (3-wheelers) make up a larger share of traffic volume compared to other vehicle categories. However, many empirical models worldwide have not accounted for these categories. Due to vastly differing traffic circumstances and characteristics, models developed in the West cannot reliably anticipate the traffic noise on the roadways of mid-sized Indian cities. This calls for more research to quantify the traffic noise environment having heterogeneous traffic on narrow carriageways in mid-sized cities considering the effect of façade, non-motorized vehicles and road surface condition. The present study is a step in this direction. Consequently, there is a need for a traffic model that considers the vehicle categories prevalent on mid-size Indian city roads. The success of any model for foreseeing traffic noise relies heavily on the input parameter choice [53, 133].

c) The selection of input parameters in the previously attempted studies were only based on correlation analysis which sometimes may responsible for overfitting the model as of having the multi-collinearity problems. Furthermore, the proportioning of dataset into training and testing subsets were carried out on an arbitrary basis. Sometimes, an improperly proportioned dataset may be accountable for vanishing some of the significant features of the training dataset, which may lead to under-fitting and over-fitting of the model and subsequently the accuracy of any predictive models. The K-Nearest Neighbor (K-NN) algorithm was adopted for Modeling purposes and Principal Component Analysis (PCA) technique was espoused to overcome the problem of multi-collinearity and dimensionality reduction. The collected was proportioned into training (80%) and testing (20%) set through K-Fold cross validation approach. Lastly, a computer-based traffic noise monitoring system has also been developed for the easiness to the policy planner.

2.8.2 For traffic noise study on vertical scale

a) The aforementioned literature suggests that the floor peak noise level and variations in traffic noise along vertical profile within the high residential buildings differ depending on the type of urban canyon they are situated in. This underscores the significant impact of the geometry and shape of the urban canyon on the distribution of noise variation along the vertical profile. This acknowledges that the geometry and shape of these urban canyons are distinct from one city to another, emphasizing the uniqueness of each urban environment. So, this study attempts to contribute valuable insight about noise variation along vertical profile in high -rise building located in mid-size Indian city. In the context of a mid-sized Indian city, urban canyons typically consist of streets bordered by buildings of moderate height, distinguishing them from the towering skyscrapers of larger cities or the lower-rise structures of smaller towns.

b) Many traffic noise models were originally designed for the segregated traffic commonly found in Western economies. In mid-sized cities of developing economies like India have the challenge of accommodating heterogeneous or mixed traffic on their road networks, which frequently have narrow carriageways. In Indian mid-sized cities, non-motorized vehicles play a significant role in traffic flow, contributing to congestion and, consequently, increased honking and noise levels. These factors were not studied in various traffic noise models discussed in this paper. Given the significant disparities in traffic circumstances and characteristics, it's clear that models devised in Western contexts are inadequate for predicting traffic noise in mid-sized Indian cities. This underscores the need for further research aimed at quantifying the noise environment in such cities. Also, each country possesses a distinct array of environmental factors and traffic patterns due to its geographical location. Consequently, there are no universal solutions applicable worldwide across all environmental contexts [211]. Therefore, the modeling of traffic noise for heterogeneous road traffic needs to be approached separately and tailored to the specific conditions of each location.

c) In the previous studies, the researchers have developed prediction model using some machine learning technique, and those models were limited to have shown the hyper parameter value of their respective used algorithm, these hyper parameter values are not understood to the traffic design engineers and city planners. In that case a mathematical equation or computer software is required which can solve the problem. Thus, this study developed scientific equations using the ANN technique for the prediction of vertical traffic noise which is quite important for formulating the mitigation strategies.

2.8.3 For vehicular source emission model

Previously, the FHWA provided REMEL (Reference Energy Mean Emission Levels) for various categories of vehicles based on data collected in 1995. These REMEL values were subsequently used as inputs for the development of the FHWA TNM. However, since then, vehicle technology has undergone significant changes. Additionally, road surfaces and noise emission regulations vary from country to country. Therefore, it is necessary to develop a new vehicular source emission model that reflects current vehicle technology, road surfaces, and noise emission regulations based on Indian standards. The FHWA considered only five categories of vehicles: automobiles, medium trucks, heavy trucks, buses, and motorcycles. These categories do not adequately represent Indian highway traffic, which also includes other significant vehicle types such as 3-wheelers, tractors, and e-rickshaws. Therefore, a more comprehensive classification is needed to accurately reflect the diversity of Indian highway traffic. Thus, in this research we have included 8 categories of vehicles. We have collected 13,684 data of single vehicle pass-by events to develop a vehicular source emission model for future traffic noise modeling under Indian road traffic conditions. These models may serve as basic input for future traffic noise modeling.