SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V12I4P113

Volume 12 Issue 4, 128-133, April 2025

Original Article

Noise Emission Curves for Train in Arrival, In-front and Departure Mode

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Received: 10 February 2025 Revised: 12 March 2025 Accepted: 13 April 2025 Published: 30 April 2025

Abstract *- Rail transport has long been a cornerstone of societal development, contributing significantly to economic growth by facilitating the movement of goods and people. However, it also presents environmental challenges, one of the most prominent being noise pollution, affecting both urban and rural populations. This paper addresses the critical issue of railway noise emissions by identifying and analyzing the various noise sources produced during train operations. Noise emission curves were developed for trains in three distinct operational modes - arrival, in-front and departure. Analysis was done on a dataset of 180 noise measurements for trains traveling at different speeds using a Class 1 sound level meter, kept at the height of 1.2m from the ground, to simulate the location of human ears at a safe distance from the center of the track. The overall LAeq of trains passing a point, encompassing the arrival, in-front, and departure phases, ranged from 53.3 to 104.0 dB(A), with a mean value of 87.05 dB(A). Detailed analysis indicated that a logarithmic curve best fits the noise data across all modes and vehicle categories, supported by an R^2 value of about 0.85 during both the training and testing stages. This suggests the logarithmic model effectively represents the measured noise levels of concurrently moving noise sources loosely bound together. R^2 values indicate that the developed equations are reliable for predicting train noise emissions under various conditions. Notably, the mean actual and root mean square error for the arrival stage were both under 1 dB(A), which is lower than that for other stages. These predictive models can be helpful in noise mitigation efforts, offering a tool for railway planners and engineers to forecast noise levels and implement appropriate control measures.*

Keywords *- Rail noise, Environment, Rolling noise, Cruising noise.*

1. Introduction

The world is in constant motion, driven by the wheels of progress. A way in which rail transport has shaped society is through facilitating economic growth and cultural exchange. Rail lines make it easy to move cargo and passengers with minimal expenditure. Noise pollution, however, is a serious environmental hazard that comes with using this mode of transportation. The audible and sometimes disruptive sound generated by trains poses a challenge to both urban and rural communities located near railway corridors. The health of people and animals and the general quality of life are all at risk due to train noise. According to studies, those who live close to railway lines may experience cardiovascular issues, sleep disturbances, and irritation from continuous exposure to high levels of train noise. The constant and continuous rumble of passing trains may also affect flora and fauna, resulting in disturbances to biological diversity and ecological balance. Railways make a lot of noise even though efforts have been made to make them serene using new technology and methods. Challenges remain in achieving acceptable noise levels, particularly in crowded urban areas where railway infrastructure intercross residential neighbourhoods, intensifying concerns about noise pollution and its impact on community well-being. Understanding the sources, propagation and impact of railway noise is compulsory for developing strategies to manage and measure its effects on both humans and the environment. To influence this problem, it is necessary to identify and understand the various sources responsible for railway noise generation. Therefore, it is important to review a wide range of existing literature to make worthwhile multidisciplinary research.

2. Literature Review

Retrofitted braked trains, supported by the European Commission, were more pleasant than conventional ones. Retrofitting the wagon fleets of freight trains increases pleasantness (Weidenfeld et al., 2024). A social survey in Korea with 726 respondents found a positive correlation between railway noise and community annoyance, with annoyance levels similar to Japan but higher than Europe, based on residents living within 50m of railway lines at 18 locations (Lim et al., 2006). A study shows that aerodynamic pressure applied on noise barriers in high-speed corridors is significantly affected by train speed and track distance, with effects analyzed through field tests and simulations (Liu et al., 2023). At Bandar Khalipah Station, train noise exceeded permissible levels set by WHO and Indonesia's Ministry of Environment; using a sound level meter, noise from 14 arrivals and 14 departures was measured, with average levels of 98.4 dB for departures and 97.7 dB for arrivals. The noise was higher during departures and from cargo trains, with quieter periods in the mornings and evenings, reaching as low as 80.2 dB at 6:45 AM (Indrayani et al., 2021).

At Bolpur and Prantik stations, sound pressure levels were measured at 10m and 20m from the tracks, with noise ranging from 70.2-88.0 dBA at 10m and 60.5-86.1 dBA at 20m, exceeding permissible limits (Yakub Ali & Chaudhury, 2016). A study of 194 trains at a level crossing found peak noise levels of 104 dBA due to honking when gates were closed. After the gate opening, noise from vehicles and pedestrians raised sound levels for nearby residents, and Artificial Neural Network (ANN) models predicted more accurately than multilinear regression (MLR) (Bhattacharya, 1994). Data of 194 trains had been taken at level crossing for diverse railway gate situations. The peak noise level due to the honking of trains passing through the level crossing when gates are closed is found to be 104 dBA. After the gate opening, noises emitted from accelerating vehicle engines and pedestrian presence raised the sound pressure level for people residing near the level crossing. ANN models predict more accuracy than MLR models (B. S. Kumar & Chowdary, 2023). (K. Kumar et al., 2024) compared the measured noise levels with those obtained from the Schall 03 model and found them to be very close in all 10 of the Delhi railway stations that were chosen. The percentage error among the measured and model-generated noise levels varied between 2% to 8%. So, we can say that the Schall 03 model is suitable for predicting railway noise in Indian conditions.

Noise pollution and its relationship with assets and services constitute the two-part analysis through which European railway environmental efficiency is demonstrated. While rail noise is a consistent burden in all countries, some deficiencies in data also prevent a full understanding of the impact of this noise (Michail et al., 2021). Jasim et al., 2022 reviewed noise pollution in Baghdad subway stations, wagons, and the train driver’s cabin. Three stages were considered: moving into stations, stopping at the station, and leaving stations. Station 3 had the highest Leq values, while Station 1 was very quiet. Wagons were noisier than expected, though the driver’s cabin remained within acceptable levels. Railway noise results from many sources: wheel-track interaction, mechanical components, aerodynamic forces, and auxiliary infrastructure. In addition, Track irregularities can thus amplify vibrations that originate when wheels encounter the track surface to an audible level. Diesel locomotives are the most common sound source due to their engines during acceleration, deceleration and negotiating gradients. Noise resulting from airflow around trains becomes more prominent as speed increases. Further, supporting infrastructures such as bridges, tunnels, and overhead electrification systems can increase noise transmission routes. Therefore, understanding these various railway noise generation mechanisms is critical for developing effective mitigation measures based on specific aspects of noise emission. The evaluation of railway noise for Indian conditions comprising permanent and rolling stock has not been evaluated so far. The current paper attempts to identify the overall noise.

3. Methodology

3.1. Geographical Location

This study is part of a research project aimed at analyzing railway noise annoyance in mid-sized cities like Varanasi (25°19'3.5184"N, 82°58'26.094"E), Chandauli (25°10'45.7068"N, 83°17'36.2796"E), and Mirzapur (25°8'1.3164"N, 82°33'51.948"E) in Uttar Pradesh, India. Over the past decade, rapid population growth has increased residential, commercial, and industrial development, with more human settlements along both sides of the railway tracks.

3.2. Site Selection

To ensure precise measurement of noise emissions from individual trains, we have carefully selected five research sites across three districts in Uttar Pradesh. The sites are strategically chosen to capture variations in velocity and location, allowing us to observe sound pressure levels affecting the largest number of residents from both passenger and freight trains along two of the busiest railway routes: Varanasi (BSB) to New Delhi (NDLS) and Deen Dayal Upadhayay (DDU) to New Delhi (NDLS). As shown in Figure 1, the data collection sites include Site 1 (Bhulanpur - railway crossing) and Site 2 (Lahartara - open track) on the BSB-NDLS route, as well as Site 3 (Avoiding cabin - wayside platform), Site 4 (Jeonathpur railway station - wayside platform), and Site 5 (Narayanpur Bazar railway station - wayside platform) on the DDU-NDLS railway line. Speed restrictions vary at all five locations.

3.3. Data Collection

Data was collected from November 8 to December 9, 2023, at five locations over five consecutive days, with a minimum of six trains measured each day during morning, forenoon, and evening hours to capture data variation. Instruments used included a Sound Level Meter (SLM), tripods, speed gun, and stopwatch to measure noise in dBA and train speed in km/h, as shown in Figure 2. Data collection involved three-time intervals: a) arrival time when the train was over 150 m from the SLM, b) in-front time when the train engine was at a 90-degree angle to the SLM, and c) departure time when the last bogie passed the SLM. The sound level meter (SLM) was set at a height of 1.2 meters and placed at a safe distance of 7.5 meters from the track's mid-point on the near side and 12.67 meters from the mid-point on the far side. The near side track and far side track are two separate tracks, positioned 3.5 meters apart from each other. Using a Type 1 Fusion Sound Level Meter, LAeq were recorded. Before data collection, the instruments were calibrated at 93.7 dB at 1 kHz using a class 1 acoustic calibrator. Stalker Lidar XLR speed gun was used to measure cruising speed in km/h.

Data extraction was performed with dB Trait, which provides metrics such as Leq, Lmin, Lmax, and Std. Dev, L10, L50, and L90. Time stamps were recorded for trains' arrival, in-front, and departure events. Any event of horn blowing during the passage of the train was marked separately.

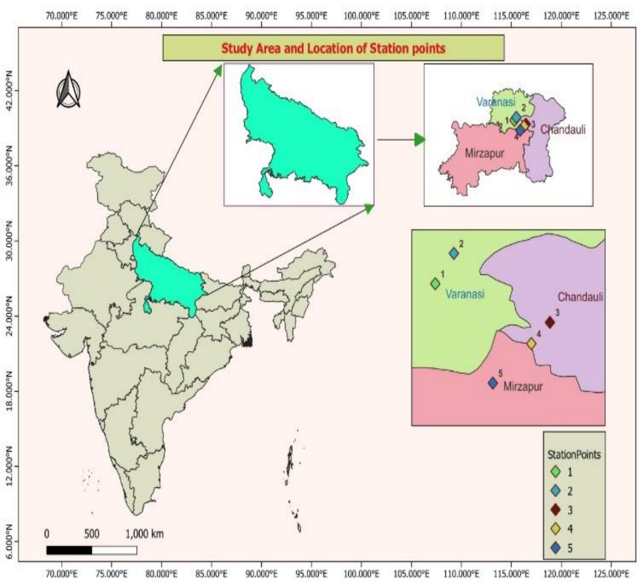


Fig. 1 Location of data collection sites in the study area

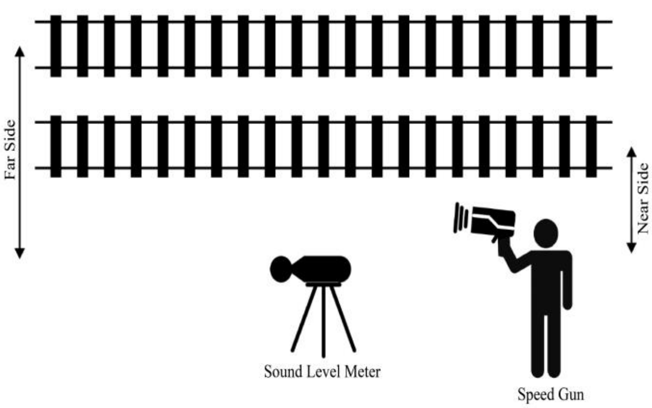


Fig. 2 Pictorial view of data collection and instrument placing

3.4. Modelling

The dataset was split into two parts: 70% was used for training the model, while the remaining 30% served as the testing data set to evaluate the model's performance. The approach is given below:

3.4.1. Data Categorization and Pre-Processing

- The collected data was categorized into 5 km/h speed bands. For example, Train traveling at speeds between 20 and 25 km/h were grouped together in a single speed band.
- This banding approach allows for a more granular analysis of how noise emissions change with speed, capturing subtle variations within the data that might be overlooked if broader categories were used.
- Within each speed band, two key statistical measures were calculated:
    - 50th Percentile Noise Level (Median Value)**:** This value represents the middle point of the noise emission data within each speed band, providing a robust measure that is less affected by outliers compared to the mean.
    - Mean train speed**:** The average speed of the train within each speed band was calculated to represent the central tendency of speed for that group.

3.4.2. Regression Analysis and Model Development

- The median noise levels (50th percentile values) were plotted against each speed band's corresponding mean train speeds.
- A regression model was developed for each mode to describe the relationship between noise emissions and vehicle speed. This involved fitting a mathematical equation to the data points, typically in the form of a linear or logarithmic regression model, depending on the characteristics of the data.
- The resulting regression equations represent the noise emission curve for each mode of running the train, allowing for predictions of noise levels at different speeds.

4. Results and Discussion

The descriptive analysis of data is shown in Table 1. From the data collected, it was observed that the LAeq for cruising trains has three modes, i.e. arrival, in-front and departure. Arrival LAeq varied from 53.3 – 94 dB(A) with a mean noise level of 69.3 dB(A). In-front noise level varied from 62.7 – 104 dB(A) with a mean value of 86.8 dB(A), and departure noise level varied from 54.8 dB(A) to 99.1 dB(A) with a mean value of 74.8 dB(A).

For overall noise (combining arrival, in-front and departure), LAeq noise varied from 62.9 – 101.8 dB(A) with a mean value of 87 dB(A). While speed varied between 12-110 km/h. The railway noise sources comprised rolling noise, aerodynamic noise, engine noise, braking noise, curve squeal and track noise.

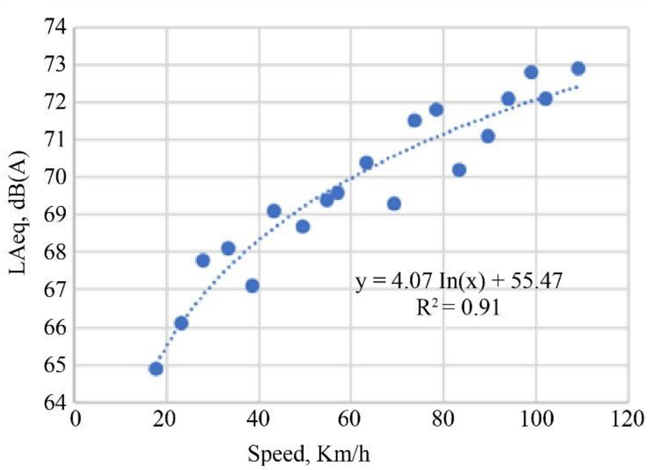
Each source contributes to the noise pollution experienced near railway lines, with the intensity varying depending on train speed, type, and environmental conditions.

Figure 3 to 6 show emission curves for testing and training for different modes. Based on the analysis, it was observed that the logarithmic curve provides a better representation of the measured noise levels across modes, as evidenced by a high coefficient of determination. The performance metrics indicate a strong fit of the model to the data, particularly for the arrival and in-front stages, which both have high R^2 values of 0.91, suggesting reliable explanations of variability in noise emissions. The correlation coefficients (R) further support this, ranging from 0.90 to 0.94, indicating a strong positive correlation between predicted and actual values.

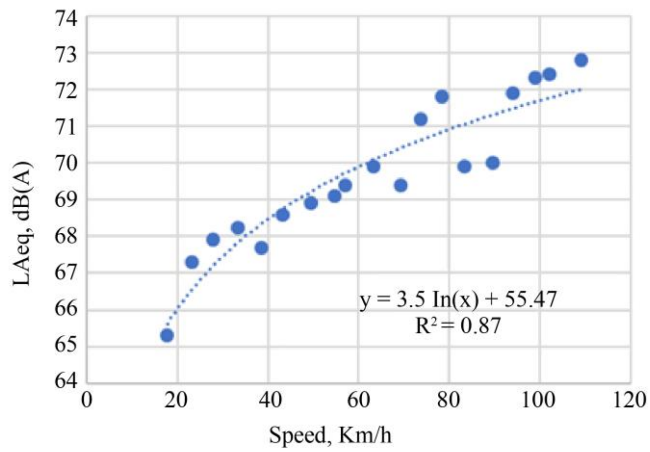
Mean Absolute Error (MAE) values are low for the arrival (0.62 dB(A)) and in-front (0.53 dB(A)) stages, demonstrating high precision in predictions; however, the departure stage shows a higher MAE of 1.62 dB(A), indicating less precision. Root Mean Square Error (RMSE) follows a similar trend, with the lowest values observed during the arrival (0.70 dB(A)) and in-front (0.65 dB(A)) stages, while the departure stage has a higher RMSE of 1.73 dB(A). Overall, the performance metrics confirm the model's effectiveness in predicting train noise emissions, particularly in the arrival and in-front phases, with the departure stage identified as a potential area for further refinement. The results of performance measurement are given in Table 2.

Table 1. Descriptive statistics of collected data

Particulars	N	Min.	Max.	Mean	Std. Dev.
Speed (kmph)	180	12	110	52.2	28.1
Arrival LAeq,dB(A)	180	53.3	94.0	69.3	8.1
In-front LAeq,dB(A)	180	62.7	104.0	86.8	11
Departure LAeq,dB(A)	180	54.8	99.1	74.8	8.6
Overall LAeq,dB(A)	180	53.3	104.0	87.05	9.02

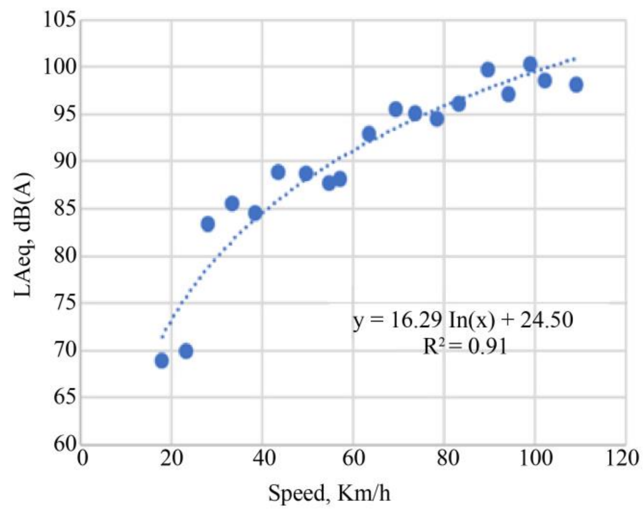


a) Testing data set

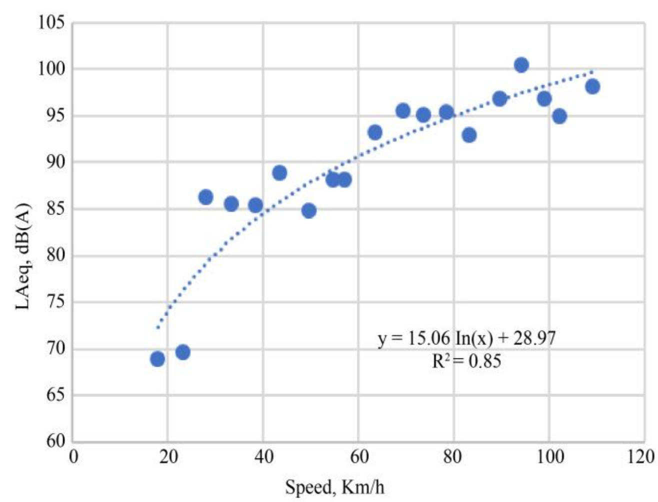


b) Training data set

Fig. 3 Emission curve for arrival stage

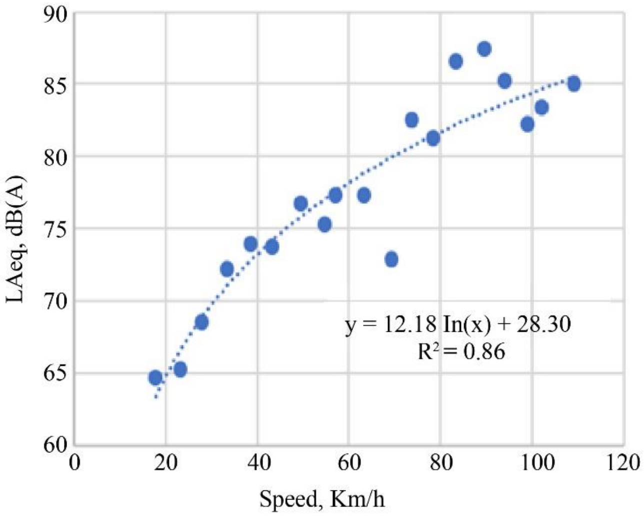


a) Testing data set

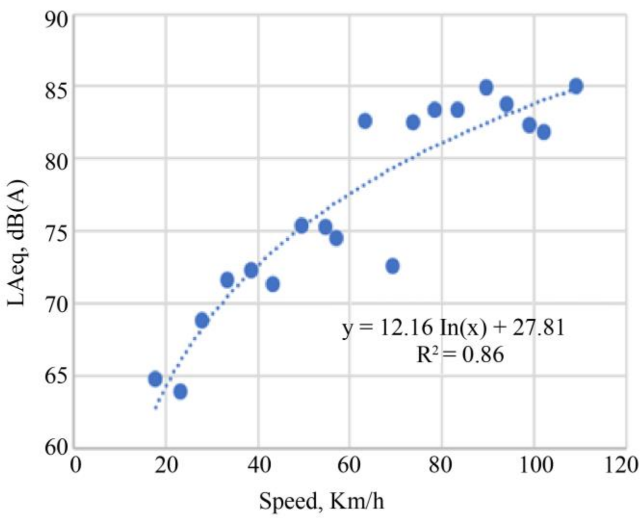


b) Training data set

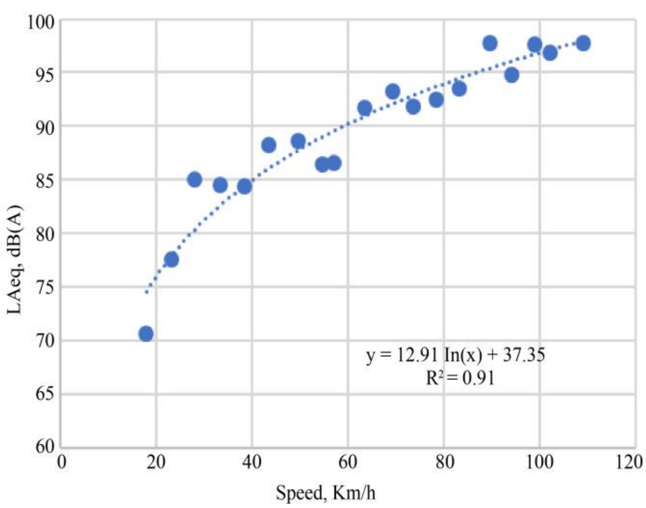
Fig. 4 Emission curve for in-front stage



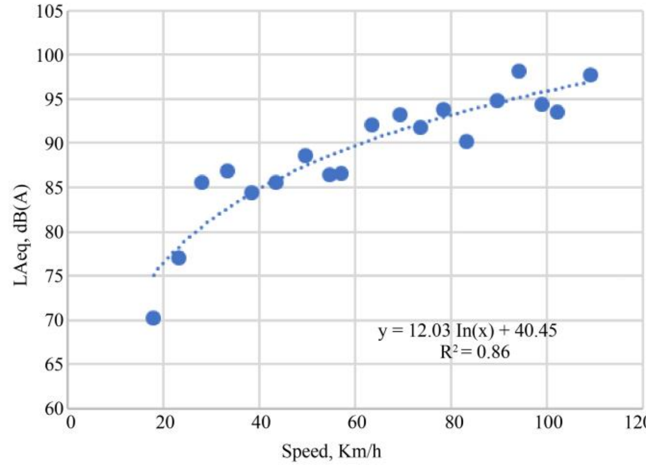
a) Testing data set



b) Training data set
Fig. 5 Emission curve for departure stage



a) Testing data set



b) Training data set
Fig. 6 Emission curve for overall LAeq

Table 2. Performance measurement parameter

PMP	Arrival		In front		Departure		Overall	
	TR	TS	TR	TS	TR	TS	TR	TS
R^2	0.91	0.87	0.91	0.85	0.86	0.86	0.91	0.86
R	0.94	0.93	0.94	0.90	0.91	0.91	0.91	0.90
MAE	0.62	0.53	1.71	1.91	1.62	1.84	1.67	2.15
RMSE	0.70	0.65	1.93	2.11	1.73	2.01	1.78	2.29

5. 5. Conclusion

The train noise emission curves were developed for arrival, in-front and departure stages. The coefficient of determination (R^2) indicates that the developed equations were reliable for predicting train noise emissions across various speeds. MAE values of 0.62 dB(A) for the arrival stage reflect high prediction accuracy, while 1.71 dB(A) for the in-front and 1.62 dB(A) for the departure stage exhibit a higher MAE but in a reasonable range (< 2 dB(A)) indicating a need for further refinement. Overall, these results affirm the model's reliability in predicting noise emissions, which is crucial for developing effective noise management strategies and minimizing the impact of train operations on surrounding communities. These predictive models are not only crucial for understanding current noise levels but also for proactively addressing noise pollution in future rail projects. By providing railway planners and engineers with precise forecasts of noise levels, these models enable the design and implementation of effective noise reduction strategies, such as sound barriers, improved track designs, or modified operational practices. Moreover, these equations can form the basis for more comprehensive noise propagation models considering varying environmental and operational factors. Such models would be invaluable in assessing the long-term environmental impacts of rail transport, aiding in developing policies and infrastructure that minimize noise pollution. Ultimately, this research contributes to enhancing the quality of life for communities located near railway lines by supporting more informed decision-making in urban planning and transportation management, helping to strike a balance between rail transport efficiency and environmental protection.

Acknowledgement

The authors would like to acknowledge and sincerely thank the organizing committee of the International Conference on Computer-Aided Modeling for the Sustainable Development of Smart Cities (CAMSSC), sponsored by the Anusandhan National Research Foundation (ANRF), held at the Department of Civil Engineering, North Eastern Regional Institute of Science and Technology (NERIST), Nirjuli, Arunachal Pradesh, India, during November 27–30, 2024, for allowing us to present the paper and sponsoring the paper for publication.

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