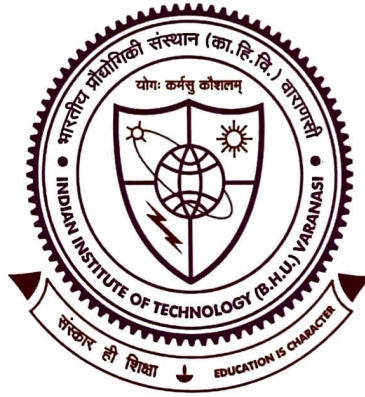


**Traffic Noise Modeling of National Highways and
Mid-Size Indian City Enviroscape Including
High-Rise Residential Buildings**

राष्ट्रीय राजमार्गों और मध्यम आकार के भारतीय शहर के परिवेश का यातायात
शोर मॉडलिंग जिसमें ऊंची आवासीय इमारतें शामिल हैं



Thesis submitted in partial fulfillment for the
Award of Degree

Doctor of Philosophy

By

Ashish Kumar Chouksey

आशीष कुमार चौकसे

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005
INDIA

Roll No. 18061514

Year 2025

*“This Work is
dedicated to my
beloved parents,
family and to the
service of humanity”*

**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005**



CERTIFICATE

It is certified that the work contained in the thesis titled "Traffic Noise Modeling of National Highways and Mid-Size Indian City Enviroscape Including High-Rise Residential Buildings" by Mr. Ashish Kumar Chouksey has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy, and SOTA for the award of Ph.D. Degree.

KB
14/05/2015

**Prof. Brind Kumar
(Supervisor)
Department of Civil Engineering
Indian Institute of Technology
(Banaras Hindu University)
Varanasi**

आचार्य/Professor
जानपद अभियांत्रिकी विभाग
Department of Civil Engineering
भारतीय प्रौद्योगिकी संस्थान (का.हि.वि.)
Indian Institute of Technology (BHU)
वाराणसी-221005/Varanasi-221005

MDL

**Prof. Manoranjan Parida
(Co - supervisor)
Director
CSIR – Central Road Research Institute**

**प्रो. मनोरंजन परिड़ा / Prof. Manoranjan Parida
निदेशक / Director
सी.एस.आई.आर.-केंद्रीय सड़क अनुसंधान संस्थान
CSIR-Central Road Research Institute
नई दिल्ली-110025 / New Delhi-110025**

DECLARATION BY THE CANDIDATE

I, "Ashish Kumar Chouksey", certify that the work embodied in this thesis is my own bonafide work and carried out under the supervision of Prof. Brind Kumar and Prof. Manoranjan Parida from January 2019 to December 2024 at the Department of Civil Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers, wherever their works have been cited in my work in this thesis. I further declare that, I have not willfully copied any others work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, thesis, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

Date: 14/05/2025

Place: Varanasi



Signature of the Student

(Ashish Kumar Chouksey)

CERTIFICATE BY THE SUPERVISOR

It is certified that the above statement made by the student is correct to the best of my knowledge.



Prof. Brind Kumar
(Supervisor)

Department of Civil Engineering
Indian Institute of Technology
(Banaras Hindu University)

Varanasi
आचार्य/Professor

जानपद अभियांत्रिकी विभाग

Department of Civil Engineering

भारतीय प्रौद्योगिकी संस्थान (का.हि.वि.)
Indian Institute of Technology (BHU)

वाराणसी-221005/Varanasi-221005



Prof. Manoranjan Parida
(Co - supervisor)

Director

CSIR – Central Road Research Institute

प्रो. मनोरंजन परिड़ा / Prof. Manoranjan Parida

निदेशक / Director

सी.एस.आई.आर.-केन्द्रीय सड़क अनुसंधान संस्थान

CSIR-Central Road Research Institute

नई दिल्ली-110025 / New Delhi-110025



Signature of Head of the Department

जानपद अभियांत्रिकी विभाग

ii Department of Civil Engineering

भारतीय प्रौद्योगिकी संस्थान (बी.एच.यू.)

Indian Institute of Technology, (BHU)

वाराणसी-221005/Varanasi-221005

COPYRIGHT TRANSFER CERTIFICATE

Title of the Thesis: Traffic Noise Modeling on National Highways and Mid-Size Indian
City Enviroscapes Including High-Rise Residential Buildings

Name of the Student: Ashish Kumar Chouksey

Copyright Transfer

The undersigned hereby assigns to the Indian Institute of Technology (Banaras Hindu University), Varanasi all rights under copyright that may exist in and for the above thesis submitted for the award of the DOCTOR OF PHILOSOPHY.

Date: 14/05/2025

Place: Varanasi



Signature of the Student

(Mr. Ashish Kumar Chouksey)

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for author's personal use provided that the source and the Institute's copyright notice are indicated.

ACKNOWLEDGEMENTS

I extend my deepest gratitude to the individuals who have contributed to the completion of my research, whether directly or indirectly. Foremost, I am immensely thankful to my esteemed mentors, **Prof. Brind Kumar** and **Prof. Manoranjan Parida**, whose invaluable guidance and unwavering support have been instrumental throughout my PhD journey. Their wisdom and encouragement have enabled me to navigate this dissertation successfully, providing both freedoms to explore and guidance during moments of uncertainty. I am also indebted to my Doctoral Committee members, **Dr. Shishir Gaur** and **Dr. Tarun Verma**, for their insightful feedback and motivation. I also want to express my gratitude to the IMPRINT India sponsored research project funded by the **Ministry of Education** and the **Ministry of Urban Development (now Ministry of Housing & Urban Affairs), Government of India**. Because of their support, a plethora of data related to various aspect of urban road traffic noise were collected which may serve the cause of forming legislation and planning. A national facility called the 'Traffic Noise Research Laboratory' is established in the Department of Civil Engineering, IIT (BHU), Varanasi for coordinating and conducting research on aspects of traffic noise.

Lastly, I consider myself truly fortunate to have collaborated with my senior, **Dr. Gaurav Verma**. His unwavering commitment to teamwork, insightful guidance, and intellectually stimulating research discussions have been profoundly enriching and have significantly shaped my research journey.

I thank my co-research fellows, especially **Amar deep Pandey, Rohit Rodhia, Mrudul Sonar Md. Arif, Amarjit Himanshu, Amogh Pandey, Deepak Srivastava, Dhruv Bansal, Yuva Reddy, Deepak Meena and Bittu Kumar** for their constant moral support, thoughtful discussions, and the sense of camaraderie they brought into my research life. Their presence

not only enriched my academic experience but also offered emotional strength during challenging phases of the doctoral journey. I truly value the bond we shared and the encouragement that kept me going.

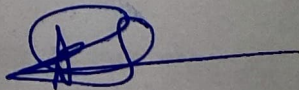
I also thank my dear friends **Mayank Sukhija, Mohit Chowdhary, Pawan Kumar Ojha, Amit Ram, Amit Singh, Uttam Kumar, Hari Prakash Yadav, Deepak Rathore, Manish Tiwari, Namit Pathak, Ranveer Singh, Saroj Kant Behera, Rupesh Kumar, Abhinav Kumar, Nirmal Prasad, Vivek wagh, Aakash Singh** for their unwavering help, encouragement, and support throughout my doctoral journey. Their presence made this demanding path more meaningful and memorable.

I also would like to take this opportunity to thank all seniors in the section of Transportation engineering section and other department **Dr. Jayvant Choudhary, Dr. Arunabh Pandey, Dr. Saurabh Sarkar, Dr sumit Kumar** for sharing their research experience and for their valuable companionship.

I am also thankful to **Mr. Amit Kumar Singh** and **Mr. Roshan Bhandari** for their consistent support in providing access to laboratory facilities.

I am incredibly fortunate to have amazing parents whose unwavering support and encouragement, along with their numerous sacrifices, have been instrumental in enabling me to reach this significant milestone in my life. I acknowledge my brothers **Ankit, Rupesh, Rahul, Jittu Bhaiya, Abhishek, Allu Bhaiya, Nitesh and Prakhar** for their invaluable support and love. At the end I owe it all to the Almighty for being all in all and enabling me to complete the doctoral work.

Date: 14/05/2025
Place: Varanasi


Ashish Kumar Chouksey

LIST OF FIGURES

Figure 3.1. MERLIN apparatus with tally box	72
Figure 3.2. Geographical location of the study area	76
Figure 3.3. Flowchart illustrating the complete process of developing the computer-based	80
Figure 3.4. Flowchart for modified traffic noise model.....	84
Figure 3.5. Selection of corrected noise signal	87
Figure 3.6. Data collection site of traffic noise study for high-rise residential building	96
Figure 3.7. Pictorial representation of data collection site.....	97
Figure 4.1. Traffic volume plot for different zones	104
Figure 4.2. Frequency plot for traffic volume of different category of vehicles at different	110
Figure 4.3. Noise level range for different zones.....	111
Figure 4.4. Traffic speed range for different zones	114
Figure 4.5. PCU/hour vs LA_{eq} for different locations	115
Figure 4.6. Speed vs LA_{eq} , for different locations	115
Figure 4.7. Correlation matrix for morning peak dataset.....	119
Figure 4.8. Correlation matrix for off peak dataset	120
Figure 4.9. Correlation matrix for evening peak dataset	121
Figure 4.10. Scatter plot for Leq model in the TR and TS dataset of MP, OP and EP	124
Figure 4.11. Error frequency plot for Leq model in the TR and TS dataset of MP, OP and EP	125
Figure 4.12. Scatter plot for L_{10} model in the TR and TS dataset of MP, OP and EP	126

Figure 4.13. Error frequency plot for *L10* model in the TR and TS dataset of MP, OP and EP 127

Figure 4.14. Software for predicting *Leq* and *L10* of MP, OP and EP 129

Figure 5.1. Emission curve for various vehicle category 137

Figure 5.2. Emission curve comparison of various vehicle category 139

Figure 5.3. Comparison of FHWA vs present study automobile emission curve 140

Figure 5.4. Comparison of FHWA vs present study buses emission curve 140

Figure 5.5. Comparison of FHWA vs present study motorcycle emission curve 141

Figure 5.6. Comparison of FHWA vs present study truck emission curve 141

Figure 5.7. Vehicle % composition for highway traffic 147

Figure 5.8. Vehicle % composition for mid-size city traffic 147

Figure 5.9. Speed comparison of highway and mid-size city traffic 148

Figure 5.10. Comparison of noise level from highway traffic vs mid-size city traffic 148

Figure 5.11. Scatter plot for developed *Leq* model 150

Figure 5.12. Scatter plot of the *Leq* model used for validation 150

Figure 6.1. Classified traffic volume at data collection site 155

Figure 6.2. Noise level variation for Building 1 157

Figure 6.3. Noise level variation for Building 2 158

Figure 6.4. Analysis of noise level 158

Figure 6.5. Frequency spectrum curve 161

Figure 6.6. Floor wise location of dominating frequency 162

Figure 6.7. ANN architecture.....	167
Figure 6.8. Training performance of <i>Leq</i> model for experimental data	173
Figure 6.9. Testing performance of <i>Leq</i> model for experimental data	173
Figure 6.10. Training performance of <i>L10</i> model for experimental data	174
Figure 6.11. Testing performance of <i>L10</i> model for experimental data.....	174
Figure 6.12. Relative importance of input variables.....	176

LIST OF TABLES

Table 1.1. WHO guidelines for noise	4
Table 2.1. Traffic noise model at early stages	16
Table 2.2. Traffic noise model for heterogeneous traffic flow	38
Table 2.3. Influential attribute used for modeling in previous researches.....	48
Table 2.4. Modeling of traffic noise on vertical scale	56
Table 2.5. Vehicular source emission model.....	61
Table 3.1. Study area	77
Table 3.2. Optimal combination of K-NN algorithm hyperparameters for different peak of <i>Leq</i> and <i>L10</i>	82
Table 3.3. Building details.....	97
Table 4.1. Traffic volume details of individual locations.....	108
Table 4.2. Design service volume for roads	109
Table 4.3. Speed range for different locations.....	112
Table 4.4. Descriptive statistic values of parameters.....	117
Table 4.5. Descriptive statistics of PCs obtained for MP, OP and EP hourly duration.....	122
Table 4.6. Statistical performance of <i>Leq</i> model in TR and TS dataset of MP, OP and EP.	124
Table 4.7. Statistical performance of <i>L10</i> model in TR and TS dataset of MP, OP and EP	127
Table 5.1. Descriptive statistics of noise level, dB(A) data.....	133

Table 5.2. Correlation coefficient between datasets	135
Table 5.3. Descriptive statistics of speed, Km/h data	135
Table 5.4. Emission curve equation of various vehicle category.....	138
Table 5.5. Descriptive statistics of highway data.....	146
Table 6.1. TNI and NC indices level at different floor of buildings	159
Table 6.2. Noise level corresponding to dominating frequency	163
Table 6.3. Descriptive statistics	164
Table 6.4. Model results.....	175

LIST OF ABBREVIATIONS

2-w	2-wheeler
3-w	3- wheeler
ABHOS	Average Building Height Opposite Side
ABHSS	Average Building Height Same Side
ANN	Artificial Neural Network
ANFIS	Adaptive Network Based Inference System
B1-C1	Building 1-Cycle 1
B1-C2	Building 1- Cycle 2
B2-C1	Building 2- Cycle 1
B2-C2	Building 2- Cycle 2
CadnaA	Computer Aided Noise Abatement
CDoT	California Department of Transportation
CNOSSOS-EU	Common Noise Assessment in Europe
CoRTN	Calculation of Road Traffic Noise Model
CPCB	Central Pollution Control Board
DF	Dominating Frequency
EP	Evening Peak
EU	European Union
FHWA	Federal Highway Administration
FOS	Façade Opposite Side
FSS	Façade Same Side

GPS	Global Positioning System
HCV	Honking Contributor Vehicle
HE	Honking Event
IEC	International Electrotechnical Commission
IRI	International Roughness Index
ISO	International Organization for Standardization
K-NN	K-Nearest Neighbor
L_{10}	10 th Percentile time exceeding noise level
L_{90}	90 th Percentile time exceeding noise Level
L_{eq}	Equivalent Sound Pressure Level
$L_{Aeq,1h}$	A-Weighted L_{eq} , measured over a 1-hour period
$L_{AF,max}$	Maximum A Weighted Sound Pressure Level with fast response time weighting
LCV	Light Commercial Vehicle
MAE	Mean Absolute Error
MERLIN	Machine for Evaluating Roughness Utilizing Low-Cost Instrumentation
ML	Machine Learning
MLR	Multiple Linear Regression
MP	Morning Peak
NC	Noise Climate
NH	National Highway
NMPB-Routes	Nouvelle Méthode De Prévision Du Bruit Des Routes

OD	Observer Distance
OP	Off Peak
PCA	Principal Component Analysis
PCU	Passenger Car Unit
Q	Traffic Volume
R	Coefficient of Correlation
R ²	Coefficient of Determination
REMEL	Reference Energy Mean Emission Model
RLS 90	Richtlinien Für Den Lärmschutz An Straben
RMSE	Root Mean Square Error
SLM	Sound Level Meter
TNI	Traffic Noise Index
TNM	Traffic Noise Model
TRANEX	Traffic Noise Exposure
V	Speed
WHO	World Health Organisation