Introduction

This chapter introduces motivation and objectives of this research. The work highlights the challenges ahead in Indian scenario for modelling road traffic noise. The research objectives are defined and individual research goals are identified. The methodology is outlined to achieve the research objectives. Finally, the chapter highlights the contributions of this research and outlines the structure of the thesis.

1.1 Background

Transportation noise has emerged as a serious problem in Delhi city. The alarming increase in vehicular population and excessive use of horns has become havoc for the society causing serious annoyance amongst the community. Residents near the vicinity of roads and airports or dwellings under directly the funnel zone of aircraft are the major sufferers and thus proper measures have to be undertaken to prevent the exterior noise entering inside the dwellings. Noise pollution can cause annoyance and aggression, hypertension, high stress levels, hearing loss, sleep disturbances, and other harmful effects. With increasing vehicular population, the road traffic noise levels have caused a major concern amongst planners and pollution control bodies. The total vehicle population in Delhi city has amounted to more than three other metro cities, Mumbai, Kolkata and Chennai combined. The urban continuum comprising of rapidly growing towns in Haryana and Uttar Pradesh has added to flow and movement of traffic in Delhi. The imbalance between the growth of vehicles and road network has resulted in heavy traffic congestions and reduced vehicular speed. Delhi has the distinction of having 5 national highways passing through its territory: NH-1, NH-2, NH-8, NH-10, and NH-24 connecting the National capital region to the rest of the country. The road network has increased from 28,508 km in 2000-01 to 30,985 km in 2007-08, while number of vehicles has increased from
33.7 Lakh in 2000-01 to 64.25 Lakh in 2010 [1]. Thus, it is imperative to devise noise control strategies for abatement of road traffic noise for reducing annoyance and health effects caused. An ongoing socio-acoustic survey (Garg et al., 2012) was conducted amongst around 520 young individuals of age less than 30 years in Delhi city. The survey was a questionnaire designed to assess the feedback of respondents regarding their rating to noise annoyance attributed to traffic, metro trains, aircraft and horn noise in terms of slightly, moderately or extremely annoyed. The survey also investigated the reaction of community towards road traffic noise in conjunction with assessment of sleeping disorders and health effects suffered due to noise pollution [2]. The noise from metro train and industry is not so serious as compared to the response given for the road traffic noise as shown in Fig. 1.1. The operation of metro trains have been assessed to cause an increase in ambient noise level by 2 to 3 dB (A) in medium and high traffic density areas and thus causes a relatively less impact on community as compared to the road traffic noise [3].

![Image: Noise annoyance due to various noise sources reported in socio-acoustic survey in Delhi city [2].](image)

The survey results revealed that more than 50 % people are disturbed from road traffic and horn noise and 17 % are annoyed due to aircraft noise. The reaction towards road
traffic noise was also found to be serious as revealed from the survey results. 28 %
people felt stressed and 25 % felt mentally tired when exposed to traffic noise, while
21 % felt irritated and angry, 9 % have sleep disturbances induced, and 7 % feel
headache when exposed to long term traffic noise. The life style of people becoming
habitual towards noise pollution is reflected from the fact that around 9 % people have
no reaction. However, with economic expansion and infrastructural growth, the
concern towards health effects of noise has considerably increased and created an
inevitable need for devising strategic noise abatement plans for existing and future
roads.

The urgency and significance of such initiatives to be implemented is justified
from Tang et. al. 2003 [4] investigations on correlating the noise indices with
population density and traffic volume based on daily noise measurements at 12
independent sites in Hong Kong. The 24 hours ambient noise level, $L_{Aeq,24h}$ is
empirically expressed as [4]:

$$L_{Aeq,24h} = a \log_{10} Q + b \log_{10} P + c$$

(1.1)

where $Q$ is daily traffic volume and $P$ is local population density within each km$^2$ of
area and constants $a$, $b$ and $c$ for $L_{Aeq,24h}$ have been found to $a=2.59$, $b=2.33$ and
$c=47.7$. Substituting the value of $Q$ as 30,000 and $P$ as 9430 for Delhi city, the value
of $L_{Aeq,24h}$ comes out to be 69 dB(A), which is rather very high value when compared
to the ambient noise standards. There has been a lack of studies conducted in Delhi
(or NCR) region pertaining to road traffic noise modelling and abatement. The present
thesis work thus focuses on modelling transportation noise in conjunction with
investigating the passive noise control strategies with an objective of traffic noise
modelling and control. It is emphasized that a proper noise control at source,
propagation path and increased sound insulation of dwellings is very essential for accomplishing the desired objectives.

1.2 Objectives & Motivation

The objectives of the thesis work shall be developing of a road traffic noise model for predicting equivalent continuous sound pressure level, $L_{Aeq}$ and investigating the passive noise control methods for its abatement. A validated road traffic noise model is very essential for noise predictions, forecast and management. The work shall also focus on investigating the passive noise control measures for transportation noise abatement. Passive noise reduction works by physically blocking sound from reaching eardrum of receiver, while the Active noise cancellation reduces noise by sampling the outside sound and then producing an equal, but opposite sound.

The motivation behind this work is growing awareness amongst the society for clean and healthy environment and concern towards health effects of traffic noise. In recent years, there have been many public litigations filed in Delhi High Court pertaining to disturbance from metro trains; traffic noise and vibrations, and aircraft noise in areas near runway 29 in Delhi city. In Indian perspectives, there are not many studies reported which focus on these issues as compared to the European continent, wherein strict legislations and immense public awareness is there. Even the hedonic pricing models have been developed in Europe, wherein the cost of property near to noisy area is declining with respect to the increase in dB(A) levels. It is thus a need of hour to conduct such studies in Indian perspectives to safeguard ourselves from the noise pollution generated by rapidly expanding vehicular traffic on the roads. The
present study shall address these issues after an exhaustive literature survey and find out the best measures to be adopted in fighting against the ever-growing traffic noise.

1.3 Research Objectives

The thesis entitled ‘Investigations on modelling transportation noise and passive noise control measures for its abatement’ shall be a broad study focusing on various aspects of modelling traffic noise and its control. The thesis work is a comprehensive study with a broad objective of modelling traffic noise in conjunction with focussing on noise abatement and control. The objectives of this research work are stated as:

- Development of a validated road traffic noise model helpful in conducting EIA (Environmental Impact Assessment) studies in respect of noise.
- Development of a modelling technique for time-series prediction of traffic noise levels. The developed model can serve as alternate tool to the continuous long-term noise monitoring which is quite cumbersome and involves a lot of infrastructural and economic constraints.
- Investigations on the accuracy of short-term noise monitoring strategies with respect to the long-term noise monitoring.
- Investigations on passive noise control strategies for traffic noise abatement and control. The major objective of the work is to conduct experimental studies in Reverberation chambers in conjunction with analytical studies for investigating the sound insulation provided by building elements particularly the window glazing, which is considered to be the weakest part of building facades and development of best sandwich constructions that provides higher sound insulation.
• Recommendations pertaining to the ambient noise standards status in India based on analyzing the noise monitoring data of 35 sites spread across 7 major cities of India gathered in pilot National Ambient Noise Monitoring Network (NANMN) project.

• Recommendations pertaining to the amendment in sound regulation requirements in National Building Codes of India with inclusion of spectrum adaptation terms as per ISO 717-1 to effectively deal with the problem of traffic noise.

1.4 Summary and Limitations of Previous studies

Transportation noise has emerged as a major source of noise pollution. Control actions to decrease the effects of noise and vibration thus have a high priority in work so as to dilute their effect on environment and humans. A pre-requisite for this control function is that the exposure i.e. outdoor sound levels must be clearly defined and the control measures must give priority to the factors that are most important for the effect. The literature reports many studies done all over the world by various researchers pertaining to modelling the transportation noise, subjectively evaluating the annoyance due to perceived noise levels and combating with the noise pollution. In metro cities like Delhi, this problem has aggravated since last two decades due to alarming increase in the levels of vehicular traffic, traffic congestions, and annoyance due to horn noise. There’s a large vacuum in studies conducted particularly in India on these aspects summarized as:

• There is a stringent need of a validated road traffic noise model to forecast about traffic noise levels with a definite accuracy. The model that encompasses the
Indian traffic characteristics and prevailing environmental conditions shall be best suited for conducting environmental impact assessment studies in respect of noise. Thus, suitable effective mitigation measures can be adopted to control the high ambient noise levels in compliance with Central Pollution Control Board, CPCB standards.

- The earlier investigations in Indian context have been concentrated on regression based approach on modelling traffic noise as function of vehicular density, speed and distance from the road. The models so developed have been based on multiple regression of real-time data gathered from noise monitoring at various sites. In Indian context, no such study focusing on characterizing the noise radiated by different vehicles in terms of fundamental unit of sound power level has been reported so far. The work reported in the thesis is inline with the methodology adapted by developed nations for developing a Road Traffic Noise model.

- The various noise control programmes in conjunction with a noise abatement goal has been an initiative taken in Europe. In Indian conditions, no such studies are reported which aims at controlling the traffic noise by passive methods.

- The studies pertaining to the low frequency sound insulation have not been undertaken so far in Indian perspectives. As the frequency spectrum characterizing the traffic and aircraft noise is dominated by low frequency, it is imperative to adopt ISO 717-1 [5] in laboratory measurements. The sound regulation requirements followed in National Building Codes have to be further revised to include the low frequency insulation to effective deal with controlling the transportation noise.
• Long-term noise monitoring data has not been reported so far in Indian scenario. These investigations are very much required for planning for noise abatement measures for controlling the noise pollution in India.

1.5 Research Methodology

The thesis work is an attempt to focus all these issues comprehensively with an objective of noise modelling and control. The control strategies focus on strengthening the receiver i.e. dwellings so as to reduce the noise exposure and provide acoustic comfort to the residents. As windows and doors are usually the weakest part of facades and partition systems, their acoustic performance often determines the acoustic performance of the whole facade. Thus, the focus on work is on experimental and analytical studies for design and development of highly sound insulative window glazing for traffic noise abatement. The research methodology employed for the dissertation work is shown in Fig. 1.2.

The research work employs a traceable sound level analyzer, Norsonic Nor 118 and B&K 2250 sound level analyzer for the field measurements. The sound pressure level measurements are traceable to the national standards of sound pressure realized at Acoustics and Vibration Laboratory located at Room No. 122, Main Building, CSIR-National Physical Laboratory (NPL), India [6]. The sound transmission loss measurements are conducted in Reverberation chamber facility of Acoustics and Vibration Laboratory of NPL, India [7]. As the experimental results are practically cumbersome and expensive to perform, so a validated software ‘Insul SW’ version 7.0.4 was used to analytically predict the sound transmission and single number rating associated with various material combinations. The thesis work also utilizes soft computing skills like Artificial Neural Networks (ANN), Genetic
Algorithms (GA) etc. for traffic noise modelling and predictions and the well known Taguchi method in optimizing the sound transmission through double glazing in order to investigate the relative influence of the various parameters affecting the sound insulation characteristics for design of highly insulative facade constructions and windows for traffic noise abatement.

![Fig. 1.2. Flowchart of the Research Methodology.](image-url)
1.6 Contributions of the thesis

The thesis work is a comprehensive study with broad objectives carried out for the first time in Indian scenario. The outcomes of the research work have been presented all over India in many national and international conferences held in various parts of the country and abroad. A major part of the work has been published in several reputed peer-reviewed journals enlisted in Appendix. The thesis work has been an outcome of many sponsored and consultancy projects financially supported by government bodies and private industries in India.

The thesis work demonstrates the development of a validated road traffic noise model helpful in conducting Environmental impact assessment (EIA) studies in respect of noise and explores the suitability of various modeling techniques for traffic noise modeling and predictions. The work analyzes and interprets the noise monitoring data gathered under the pilot NANMN project established by CPCB, India. The work also provides recommendations pertaining to the random short-term noise monitoring strategies, anomalies related to use of Sound Transmission Class (STC) rating in laboratory sound transmission loss testing and revision of sound regulation requirements that shall be helpful for Central Pollution Control Board (CPCB), India, Bureau of Indian Standards (BIS) and Delhi Development Authority (DDA). The work provides a source model for development of an integrated GIS road traffic noise model best suited for Indian conditions for noise mapping of the larger parts of the Delhi city.

The thesis work also recommends the revision in ambient noise standards, which shall be helpful in execution of noise abatement action plans for controlling the noise pollution in India. These recommendations shall be helpful for Central Pollution
Control Board (CPCB), India; Panel for Acoustics, Sound Insulation and Noise Control, CED 46:P15 of Bureau of Indian Standards (BIS); Delhi Development Authority (DDA) and National Committee for Noise Pollution Control (NCNPC), India for reviewing the National Building Codes and National ambient standards of India and considering the recommended amendments.

1.7 Outline of the thesis

The thesis consists of nine chapters and is organized as follows:

First Chapter discusses the traffic noise scenario in India in brief. The motivation and research objectives are discussed in the chapter. The summary of previous studies and limitations in previous work are highlighted.

Second Chapter presents the literature review spanning the research contributions in modeling traffic noise and passive control measures for its abatement. The chapter summarizes the various regression models developed in India in past years in various parts of the country. The exhaustive review of literature pertaining to traffic noise abatement has been summarized. The literature review has been instrumental in identifying the state-of-art pertaining to the accomplishment of the research objectives.

Third Chapter deals with a critical review of principal traffic noise models developed and implemented recently in developed nations. The source model and propagation algorithms followed have been clearly identified and compared w.r.t each of these models. The implications of these models, sources of uncertainty have been discussed.
**Fourth Chapter** discusses the development of a validated road traffic noise model using the multiple regression approach and soft computing skills e.g. Artificial Neural Networks, Genetic Algorithms. The chapter also discusses the development of a traffic noise model based on sound power level of vehicles. Finally, the validation of model and its implications are highlighted.

**Fifth Chapter** discusses the comparison of long-term versus short-term noise monitoring strategies and their implications in Indian scenario. The statistical analysis pertaining to random noise monitoring strategy is highlighted considering a case study of noise monitoring data gathered from 35 sites of seven major cities in India under pilot National Ambient Noise Monitoring Network (NANMN) project established by CPCB, India.

**Sixth Chapter** presents the application of *ANN* and *ARIMA* approach in time-series prediction of traffic noise levels. The application of *ANN* and *ARIMA* approach in long-term time series prediction and forecasting of ambient noise levels for one sample site in Delhi city is demonstrated.

**Seventh Chapter** deals with passive noise control measures for transportation noise abatement. The chapter highlights the sound insulation properties of various window glazing developed and tested in reverberation chambers. The design considerations involved in development of highly insulative sandwich window glazing is discussed based on application of Taguchi method and experimental investigations conducted in reverberation chambers. Finally, the parametric sensitivity analysis of various factors affecting the sound insulation of sandwich constructions utilizing the gypsum boards for enhancing their sound insulation is discussed.
Eight Chapter discusses the significance and implications of airborne sound insulation criteria in building elements for traffic noise abatement. The chapter highlights the modification of spectrum adaptation term for traffic noise in Indian conditions. Sound regulations in terms of prescriptive and verification criteria are proposed and practical implications of these regulations particularly related to material aspects with respect to minimum and comfort class is also discussed.

Ninth Chapter summarizes the present research. The chapter concludes the research findings. The individual contributions of each chapter are discussed with respect to the overall research objective. It also highlights the recommendations which can be pursued further to achieve the underlined research objectives.

The last section of the thesis report includes References and Appendices. It contains the experimental database of field traffic noise monitoring of 8 various sites of Delhi city used for developing and validation of Multiple Linear Regression (MLR); Genetic Algorithm (GA); Artificial Neural Network (ANN) model and RTN model based on sound power level of vehicles. A CD-ROM is appended along with the thesis showing the TNM Simulator developed for various principal models. A database of dry wall constructions having high sound insulation manufactured in India (18 manufacturers) and tested in Reverberation Chambers at CSIR-National Physical Laboratory, New Delhi, India is also included.

The soft copy of all the papers published in reputed Journals and Proceedings of Conferences, and thesis is also appended in the CD-ROM.