CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURES STUDIED

As an attempt to appreciate the research effort made in the area of traffic noise, various research studies such as annoyance, assessment of impact of traffic noise, noise barriers/abatement measures, traffic noise and valuation of property, application of fuzzy logic/fuzzy set theory, traffic noise modelling, rail noise, air traffic noise, urban forms to reduce traffic noise, noise measurement, policy issues, noise generation due to various types of pavements, noise emission characteristics of automobiles, noise levels in various parts of the world, etc. has been referred. In this regard, more than 200 research papers have been referred. As this research is primarily concerned with road traffic noise, the studies related to the annoyance due to traffic noise, assessment of impact of traffic noise, abatement measures, traffic noise and valuation of property, urban forms and noise measurements have been studied in detail as presented in following subsections as part of appreciation of road traffic noise.

2.1.1 Annoyance due to Traffic Noise

2.1.1.1 Phan Hai Yen Thi et al. (2010) established dose-response relationships between $L_{\text{den}}$ (day evening night noise levels) and the percentage of highly annoyed respondents of Hanoi and Ho Chi Minh city. It was observed that the Hanoi respondents seemed to be more annoyed by noise than Ho Chi Minh City respondents. Compared to annoyance responses of European
people, Vietnamese (Hanoi and Ho Chi Minh City) were less annoyed by road traffic noise by about 5 dB.

2.1.2 Jakovljevic Branko et al. (2009) determined principal factors for high noise annoyance in an adult urban population and to assess their predictive value. A cross-sectional study was performed on 3097 adult residents of a downtown municipality in Belgrade (1217 men and 1880 women), aged 18–96 years. Equivalent noise levels \( [L_{eq} \text{ (dBA)}] \) were measured during day, evening and night at all streets of the municipality. Noise annoyance was estimated using self-reported annoyance scale. Noise annoyance showed strong correlation with noise levels, personal characteristics and some housing conditions. Logistic regression model identified increased risk for a high level of noise annoyance with regard to orientation of living room/bedroom toward the street, duration of stay at apartment during the day, noise sensitivity and night time road-traffic noise level.

2.1.3 Lam Kin-Che et al. (2009) conducted a study in Hong Kong to appreciate mixed transportation noise annoyance response. The results of the study showed that annoyance was largely determined by noise disturbance and perceived noisiness. Personal noise sensitivity, attitudes towards different means of transport and perceived quality of the living environment were the secondary contributing factors.

2.1.4 Paunović Katarina et al. (2009) conducted a study to assess the predictive value of various factors on noise annoyance in noisy and quiet urban streets. Equivalent noise levels \( [L_{eq} \text{ (dBA)}] \) were measured during day, evening and night times at all of the streets of a central Belgrade municipality. Based on 24-hour noise levels, the streets were denoted as noisy (24-hour \( L_{eq} \) over 65 dBA), or quiet (24-hour \( L_{eq} \) under 55 dBA). A cross-sectional study was performed on 1954 adult residents (768 men and 1186 women), aged 18–80 years. Noise annoyance was estimated using a self-report five-graded scale. In noisy streets, the relevant predictors of high annoyance were the
orientation of living room/bedroom toward the street, noise annoyance at workplace, and noise sensitivity. Significant acoustical factors for high noise annoyance as reported were as under:

i. Night time noise level and night time heavy traffic.

ii. Day-evening-night noise level ($L_{den}$).

iii. In quiet streets, the significant predictors were noise sensitivity.

iv. The time spent at home daily.

v. Light vehicles at night time or heavy vehicles at daytime.

2.1.5 Ryu Jong Kwan et al. (2011) conducted laboratory experiments to investigate the influence of noise sensitivity on the annoyance caused by indoor residential noises and outdoor traffic noise. The results revealed that noise sensitivity significantly influenced the annoyance level caused by both indoor and outdoor noise.

2.1.6 Li H.N. et al. (2010) in his research work identified annoyance as the most important psychological impact arising from noise. Besides socioeconomic status, residing neighborhood characteristics such as greenery had been shown to be able to reduce noise annoyance. The results indicated that greenery perception exerts considerable influence on noise annoyance rated at home. Wetland parks and garden parks were shown to be able to reduce noise annoyance to a greater degree than grassy hills.

2.1.7 Aniansson G. et al. (1983) undertook a laboratory study to investigate annoyance caused by traffic noise among persons with normal hearing and impaired hearing. The groups with different hearing ability were exposed to 45 dB(A) and 55 dB(A) traffic noise during their engagements in four activities, in which noise did or did not interfere with speech. The results revealed that a higher sensitivity to noise in one of the noise-induced hearing loss groups compared with men with normal hearing.
2.1.1.8 Peterson Y. and Aniansson G. (1988) studied annoyance and changes in mood to the affected persons with impaired hearing caused by road traffic noise. The major finding in the study was a higher rating of annoyance among men with noise-induced hearing loss compared to men with normal hearing in the activities in which noise interfered with speech. Men with noise-induced hearing loss also showed a higher sensitivity to noise compared to men with normal hearing.

2.1.1.9 Vallet M. et al. (1978) revealed that annoyance was related to measured noise levels for the people living along the expressways. For the period 08:00-20:00 hours, the equivalent noise level (L\text{eq}) was proposed as a suitable unit and it was suggested that noise levels should not exceed 65 dB(A). Heavy lorries were found to constitute major sources of annoyance, particularly during the evening. For residents in bungalows, noise levels need to be somewhat lower. A second survey was carried out after an interval of two years. It was found that the level of annoyance had not declined during this period and it is concluded that no habituation to noise had taken place.

2.1.1.10 Ohrstrom E. et al. (1980) investigated the acute annoyance reaction to different noise sources (lorries, aircraft, mopeds and trains) in a laboratory experiment. The results demonstrated that L\text{eq} demonstrated the best correlation with noise annoyance. However, traffic noise due to lorry was found to be less disturbing than aircraft noise at the same L\text{eq} value.

2.1.1.11 Rasmusse K. B. (1979) investigated the relation between road traffic noise and annoyance with special reference to the number of noisy events in a laboratory study. Annoyance was found to be highly correlated with the noise level measured as L\text{eq}.

2.1.1.12 Gjestland T. (1987) suggested a simple model for assessment of annoyance from road traffic noise based on the noise index L_{Teq}. This index may be
either measured directly or estimated based on measured values for \( L_{eq} \) and \( L_{max} \). The percentage of heavy vehicles was also included in the model. By applying these values to two simple nomograms the annoyance caused by that particular traffic situation may be estimated.

2.1.1.13 *Izumi K. (1988)* validated the usefulness of the simulated environment method for the assessment of community responses, and also validated the noise annoyance models so far proposed for the evaluation of mixed source noise. The dose-response relations obtained both in the laboratory study and the field study were compared. A good similarity was discovered in the findings by the two approaches, which suggested the usefulness of the simulated environment method. With the findings obtained, seven annoyance models so far proposed for the evaluation of mixed source noise were examined.

2.1.1.14 *Takeshi Ishiyama et al. (2000)* described a laboratory study of the influence of sound quality on the annoyance caused by road traffic noise. Subjective evaluation test using a categorical scale of five steps for annoyance, and the other supported with listening interference test for matching the loudness of replayed classic music under the existence of road traffic noise of various loudness were carried out.

2.1.1.15 *Fields J. M. et al. (1982)* compared noise annoyance expressed in a railway noise survey with that of in two road traffic and three aircraft surveys in order to determine whether responses to various environmental noises were similar or were source-specific. It was found out that railway noise was less annoying than other noises at any given high noise level. Railway noise annoyance increases less rapidly with an increase in noise level.

2.1.1.16 *Matsumura Y. et al. (1991)* studied noise sensitivity in a random sample of the population of Gothenburg, Sweden. It was found out that sensitivity of noise was most common in older age groups. Noise-sensitive individuals
were more annoyed by road traffic noise, and also reported interference with daily activities to a higher extent than non-sensitive persons.

2.1.1.17 *Knall V. et al. (1983)* reported the results of a study on the relative annoyance by rail or road traffic noise in urban and rural areas. Fourteen areas with rail and road traffic noise with differing levels of loudness (L_{eq}) were investigated. The annoyance was assessed by means of a questionnaire. The analysis of the relationship between annoyance and L_{eq} (prepared separately for rail and road traffic noise) showed that the same amount of annoyance was reached for railway traffic noise at L_{eq} levels with 4-5 dB(A) higher than that of road traffic noise.

2.1.1.18 *Bangjun Zhang et al. (2003)* concluded in their study that when source of noise was visible, the annoyance was higher as compared to when source was not visible under the same acoustic environment.

2.1.1.19 *Mehdi Mohammed Raza et al. (2011)* studied the spatial and temporal patterns of noise exposure due to road traffic in Karachi City, Pakistan. It was found out that the average value of noise levels were over 66 dB, which could cause serious annoyance according to the World Health Organization (WHO) outdoor noise guidelines. Maximum peak noise was over 101 dB, which was close to 110 dB; the level that can cause possible hearing impairment according to the WHO guidelines.

2.1.1.20 *Sandrock Stephan et al. (2007)* conducted two studies; the first study reveals that the noise of a tram was judged to be equally annoying as the noise of a bus with lower level than a 3 dB(A), which corresponds to the calculated loudness difference. In the second study, noises of a tram and of a bus were superimposed onto a 2-h realistic road traffic scenario. Performance data did not differentiate between the noise conditions, but the participants were again less annoyed by the scenario with the tram, suggesting a possible bonus for the tram.
2.1.1.21 *Martin M.A. et al. (2006)* conducted a social survey aiming at identifying the main sound sources, evaluating the annoyance as well as analyzing the main effects of noise on people. It was found that the spatial distribution of “people highly annoyed by noise” and points with $L_{dn}$ (day night) above 65 dB (A) was very similar (both plots present a high degree of coincidence). $L_{dn}$ related very well to the annoyance. The relation was better when considering people highly annoyed than when considering average annoyance.

2.1.1.22 *Sommerhoff Jorge et al. (2006)* presented residents perception of road traffic noise loudness in relation to the measured noise indices close to their dwellings. Percentile distributions of five loudness categories as a function of the day-night noise index $L_{dn}$ were obtained. It was concluded that hearing sensitivity for noise was one of the variables that explains the loudness classification difference in different $L_{dn}$ index ranges and that the percentages of people “Highly Annoyed” by noise were slightly higher than the percentages obtained in the “Extremely Loud” category of loudness perception.

2.1.1.23 *Klaeboe R. et al. (2004)* estimated exposure–effect relationships between the level of road traffic noise at the most exposed side of a dwelling’s facade and the residents’ reactions to road traffic noise. Exposure-effect relationships for all degrees of annoyance were estimated simultaneously from ordinal logit models. This predicted road traffic noise annoyance for right outside the apartment and indoors, as a function of the road traffic noise level which was the outside the most exposed facade.

2.1.1.24 *Ali S.A. et al. (2003)* conducted a study on road traffic noise in Greater Cairo, the capital and the largest city in Egypt and the eleventh biggest city in the world. Extensive measurements were carried out in 21 sites in Greater Cairo. Restrictions were introduced to improve environmental conditions including (i) a ban on horns, (ii) a ban on horns and trucks (iii) a
ban on horns, trucks and noisy buses. Equivalent noise levels (L_{Aeq}) were measured before and after these restrictions. The equivalent noise level was considerably reduced by the bans. This shows that various strategies can be used to change the traffic composition in order to achieve quieter city environments. The degree of annoyance was measured by means of questionnaire. The results showed that there was a strong relationship between road traffic noise levels and the percentage of highly annoyed respondents.

2.1.1.25 Roberts M.J. et al. (2003) had detected unexplained peaks of annoyance in quieter places, or a plateau of annoyance in high noise. Such anomalies may especially affect those sensitive to noise. The pattern of alternation of passby noise and background traffic noise explains the positioning in soundspace of anomalies variously reported at 60 dB (A) L_{eq}; 4000 NV (daily traffic volume) and 1800 NHV (daily heavy traffic volume). Such anomalies occur where there were regular or rapidly alternating patterns of passby noise.

2.1.1.26 Koushki Parviz A. et al. (1993) found out that the degree of awareness of the health impact of traffic noise increased with an increase in the respondents' income and level of education. The extent and degree of annoyance with traffic noise varied with the change in the functional classification of urban roadway. People living and working along major arterials and freeways were considerably more annoyed than those residing along local or collector streets.

2.1.1.27 The Investigations by Koushki P.A. et al. (1999) mainly focus on likely relationships between exposed residents’ annoyance and measured traffic noise levels. Results indicate that exposure to higher traffic noise levels was naturally associated with increasing annoyance. Residents were most annoyed with noise from traffic at collector streets.
2.1.1.28 *Piccolo, et al. (2005)* presented the results of a study on the environmental noise pollution of the city of Messina (Italy). Results indicated that main roads of Messina were overloaded by traffic flow during day-time period and at all the examined sites where daily average sound levels due to road traffic exceed environmental standards by about 10 dB(A); environmental noise exhibits a certain degree of spatial variance resulting primarily from the peculiar geo-morphological structure of the town and from the transport infrastructure; and more than 25% of residents should be highly disturbed by road traffic noise.

2.1.1.29 *Klaeboe R. et al. (2000)* adopted an integrated alternative approach in the Oslo traffic study to allow people's environmental annoyances to be studied relative to the indicators of air pollution, road traffic noise and residential traffic. The results indicated that people were exposed to the higher air pollution levels more likely they were to be annoyed by road traffic noise at a specified noise level.

2.1.1.30 *Thancanamootoo S. (1987)* studied the concerns about the noise nuisance resulted from the operation of urban railways (Metro) in Wallsend and Walkergate. UK. The following Noise Annoyance Model (NAM) had been developed in the study:

\[
\text{LOGNAI} = -0.14 + 0.01(\text{LEQMI8H}) + 0.05(\text{METROVI}) + 0.04(\text{BGNOISE}) - 0.003(\text{AGE}) - 0.05(\text{TENURE})
\]

- **LOGNAI** = log of noise annoyance index
- **LEQMI8H** = noise level
- **METROVI** = degree of annoyance with vibration from Metro
- **BGNOISE** = degree of dissatisfaction with noise from road traffic and aircraft
- **AGE** = Age of the respondent
- **TENURE** = whether or not the respondent was an owner occupier

The finding of the study were:

i. Metro was the biggest source of noise nuisance for people living in the houses bordering the rail tracks
ii. $L_{eq}$ dB(A) appears to be the most practical noise index for measuring railway noise annoyance (NAI) when compared to Noise and Number Index (NNI)

iii. People were more annoyed with vibration and more dissatisfied with other transportation noise

iv. Older people were less annoyed than younger ones

v. Regular maintenance of rolling stock and track was the most effective way of keeping noise under control at source

2.1.1.31 Mohammed Ahmed Ali (2001) investigated the road traffic noise, the bus transit noise and the noise perception in urban areas in Kuwait, Hyderabad and Warangal. The following models were developed to predict annoyance factor for road traffic noise, bus transit noise and noise prediction:

- **Perception of road traffic noise model**
  \[ Y_c = 0.2008X_2 + 0.1895X_4 + 0.2097X_6 + 0.1885X_7 + 1.2115X_8 \]
  \[ Y_c = \text{annoyance factor} \]
  \[ X_2 = \text{annoyance variable (resting)} \]
  \[ X_4 = \text{annoyance variable (phone)} \]
  \[ X_6 = \text{annoyance variable (reading)} \]
  \[ X_7 = \text{annoyance variable (watching TV)} \]
  \[ X_8 = \text{annoyance variable (sleeping)} \]
  \[ X_1, X_3 \text{ (working, conversation) and } X_5 \text{ (eating) demonstrated weak correlation with } L_{eq} \]

- **Rider’s perception of bus transit noise model:**
  \[ Y_c = 0.295X_1 + 0.304X_2 + 0.221X_3 + 0.257X_4 \]
  \[ Y_c = \text{annoyance factor} \]
  \[ X_1 = \text{annoyance variable (headache)} \]
  \[ X_2 = \text{annoyance variable (nervousness)} \]
  \[ X_3 = \text{annoyance variable (hearing impairment)} \]
  \[ X_4 = \text{annoyance variable (fatigue)} \]

- **Traffic noise prediction model for medium size urban area in India:**
  \[ L_{10} = 79.101 - 1.458 \times \log_{10}(D) + 0.0517 \times (VHV) + 0.0015 \times (VTW) \]
  \[ (F=25.792, p<0.001, R=0.815, R^2=0.664) \]
  \[ L_{eq} = 77.796 - 1.54 \times \log_{10}(D) + 0.08 \times (VHV) \]
  \[ (F=21.383, p<0.001, R=0.774, R^2=0.6) \]
D = Distance
VHV = volume of heavy vehicle
VTW = volume on 2 and 3 wheeler

Following mitigation measures were suggested in the study:

i. Source emission control,
ii. Landuse control (zoning)
iii. Demand and supply management of traffic
iv. Promotion of transit and non-motorised modes
v. Public education and awareness programs

2.1.2 Assessment of Impact of Traffic Noise

2.1.2.1 *Brink Mark (2011)* investigated the associations between residential traffic noise exposure from the noise sources i.e. road, rail and aircraft and self-reported indicators of health and well-being in a representative sample of the Swiss population. A range of noise exposure effect relationships between noise and other parameters had been studied. These includes health and well-being such as self-reported health status, satisfaction with health, sleep disturbances, the intensity of the wish to move from the current residence as well as the awareness of "noise problems" at the place of living were investigated. It was found that the contribution of residential noise exposure as regards to the subjective estimates of health cannot been ruled out, but must be put into perspective as the effects of exposure measures were of rather small magnitude, especially compared to well established determinants of health.

2.1.2.2 *Babisch W. et al. (2001)* studied the nocturnal excretion of cateholamines in urine in 30-45 year old women whose bedroom and/ or living room were facing streets of varying traffic volume. The traffic volume of the streets was used as an indicator of noise exposure; adrenaline and noradrenaline concentrations were assessed as indicators of the outcome of the physiological stress. Significant associations between traffic volume and
noradrenaline concentrations in urine were found with regard to the exposure of the bedroom (not the living room), indicating a higher chronic physiological arousal in noise-exposed subjects as compared to less exposed.

2.1.2.3 *Pirrera Sandra et al. (2010)* studied the impact of nocturnal road traffic noise on sleep and the consequences on daytime functioning demonstrates detrimental effects that cannot be ignored. The physiological reactions due to continuing noise processing during night time lead to primary sleep disturbances, which in turn impair daytime functioning.

2.1.2.4 *Jamie M.A. Graham et al. (2009)* developed relationships between road and rail traffic noise with pre-ejection period (PEP) and with respiratory sinus arrhythmia (RSA) during sleep, as indices of cardiac sympathetic and parasympathetic nervous system tone, were investigated in the field. The results indicate that higher indoor traffic noise exposure levels may lead to cardiac parasympathetic withdrawal during sleep, specifically during the second half of the sleep period. It was obtained that mean indoor traffic noise exposure was negatively related to mean RSA during the sleep period, specifically during the second half of the sleep period.

2.1.2.5 *Fyhri Aslak et al. (2009)* investigated the relationships between noise complaints, noise sensitivity and subjectively reported hypertension and heart problems. There were 1842 respondents in Oslo, Norway who were interviewed about their experience of the local environment and their subjective health complaints. The data were analysed using Structural Equation Models. It was found out that sensitivity to noise was related to hypertension and chest pain and noise being the causal agent leading to health problems.

2.1.2.6 *Zaheeruddin et al. (2006)* found out that the middle-aged people had more probability of sleep disruption than the young people at the same noise
levels. However, very little difference was found with sleep disturbance due to noise between young and old people. In addition, the duration of occurrence of noise was an important factor in determining the sleep disturbance over the limited range from few seconds to few minutes.

2.1.2.7 Ouis D. (2001) reviewed negative effects on people's well-being resulted from exposure to road traffic noise. It was found from this research that the continuous exposure of people to road traffic noise leads to suffering from various kinds of discomfort. The findings were important at both the society and the individual level as much as they may help in regulating in a more efficient way the planning of road traffic activity.

2.1.2.8 Mohan Surender et al. (2008) identified six different occupations in their study and the effort had been made to assess the risk of health due to noise on the workers involved in various types of occupations. Noise exposure standards and the damage risk criteria to hearing impairment had been discussed in this study on the basis of physical sound pressure level and duration of exposure to noise for Indian Community. Various options for controlling noise had also been recommended for the group of workers working at different work places.

2.1.2.9 Belojevic Goran et al. (2007) observed that heart rate was significantly higher (2 beats/min on average) in children from noisy residences, compared to children from quiet residences (p<0.05). Multiple regression, after allowing for possible confounders, showed a significant correlation between noise exposure and children’s systolic pressure (B=1.056; p=0.009).

2.1.2.10 Pathak Vinita et al. (2007) presented their result of the study which indicated the fact that eighty five percent of the people were disturbed by traffic noise out of which, about ninety percent of the people reported that
traffic noise was the main cause of headache, high BP problem, dizziness and fatigue.

2.1.2.11 *Muzet Alain* (2007) revealed in his study that continuous high level exposure could lead to aggression in a hostile, angry, and helpless population. It often happens, the population with the least income that suffers the most from noise in general.

2.1.2.12 *Reinhard B. Raggam et al.* (2007) combined the subjective ratings within objective psychoacoustic parameters by multiple regression analysis. It was found that heart rate increased during all noise exposure phases compared to neutral phases while respiratory rate remained unaffected.

2.1.2.13 *Ohrstrom E. et al.* (2006) carried out Socio–acoustic surveys to assess the health effects of various soundscapes in residential areas. The results demonstrated that access to quiet indoor and outdoor sections of one’s dwelling supports health; it produces a lower degree of annoyance and improves sleep and contributes to physiological and psychological wellbeing. Having access to a quiet side of one’s dwelling reduced disturbances by an average of 30-50% for the various critical effects, and corresponds to a reduction in sound levels of ($L_{Aeq,24h}$) 5dB at the most-exposed side. To protect most people (80%) from annoyance and other adverse effects, sound levels from road traffic should not exceed ($L_{Aeq,24h}$) 60 dB at the most-exposed side, even if there is access to a quiet side of one’s dwelling ($L_{Aeq,24h} \leq 45$ dB).

2.1.2.14 *Barbara Griefahn et al.* (2006) compared the effects of road, rail, and aircraft noise and tested the applicability of the equivalent noise level for the evaluation of sleep disturbances. Study finally concluded that the rail traffic noise was more harmful with respect to physiological sleep parameters as compared to air and road traffic noise.
2.1.2.15 In the first part of this study, a neighbourhood soundscape adjusted exposure indicator, NAL\textsubscript{den}, was derived by Klaeboe R. et al. (2006). NAL\textsubscript{den} values were designed to be used as input to traditional exposure-effect relationships to improve annoyance impact estimates. In the second part, generic spatial procedures were developed and implemented. This produces map presentations in the form of contiguous neighbourhood quality areas. The quality of each neighbourhood was determined from the predicted annoyance impacts for residents.

2.1.2.16 The objective of the study conducted by Ohrstrom Evy et al. (2006) was to evaluate exposure-effect relationships between road traffic noise and sleep quality and to compare sleep assessed by sleep logs and wrist-actigraphy for children and parents. The results from the in-depth study showed that children had better perceived sleep quality and fewer awakenings than parents, although sleep assessed by wrist-actigraphy indicated a better sleep for parents.

2.1.2.17 The relationship between noise exposure, income and noise annoyance was investigated in this paper by Fyhri A. et al. (2006). Structural equation models incorporating both direct and indirect pathways had been estimated using data from six socio-acoustic surveys combining individual noise exposure measures with questions on noise perception and background characteristics. The hypothesis was that high-income groups prefer to buy dwellings, free from noisy area. It seems to hold true for residents of a small-to-medium size city, but not for residents of a larger city.

2.1.2.18 The aim of this study by Skanberg A. et al. (2006) was to investigate whether there were any differences in the effects of noise on sleep between studies performed in the laboratory and in field settings with equal road traffic noise exposure. No significant differences in sleep quality were found between home and laboratory conditions on variables assessed either by questionnaires or wrist-actigraphy.
2.1.2.19 Sergei A. Schapkin et al. (2006) focused on possible after effects of noise-induced sleep disturbances on inhibitory brain processes reflecting in performance changes. The results suggest that physiological costs to maintain performance were increased after noisy nights. Decisional processes underlying overt responses were less vulnerable to noise-disturbed sleep than those related to inhibition. Inhibition-related ERPs may be more sensitive indicators of moderate sleep disturbances caused by noise than performance measures.

2.1.2.20 Stansfeld S. A. et al. (2005) found out that exposure to road traffic noise was linearly associated with increases in episodic memory. Neither aircraft noise nor traffic noise affected sustained attention, self-reported health, or overall mental health.

2.1.2.21 The main objective of this study conducted by Qudais Saad Abo et al. (2005) was to evaluate the impact of traffic noise on exposed owners and employees of businesses near to road edge. At the same equivalent noise level, single individuals was reported to be more annoyed than married individuals. Single females were found to be more annoyed by traffic noise than single males. While for married individuals, female were found to be less annoyed than males.

2.1.2.22 This study by Sergio Antonio Melo Barbosa et al. (2005) was aimed at assessing hearing status among workers exposed to urban noise during activities related to the co-ordination of vehicle traffic in the city of Sao Paulo, Brazil. Prevalence was higher among those working in the noisier areas than among those working in areas with lower noise levels (38.8% versus 24.2%) suggests that occupational exposure to urban noise plays an important role. The high prevalence of suspected NIHL (noise-induced hearing loss) indicated the existence of a significant health problem among these workers.
2.1.2.23 Ingle S.T. et al. (2005) found that traffic police had a high risk of hearing loss due to road traffic noise exposure. In this study, data on self-reported health status was collected by questionnaire. An audiometry was used to determine hearing threshold at high and low frequencies. Eighty-four percent of the sample reported hearing loss and defined at least some difficulty in hearing by one or both ears.

2.1.2.24 Sayed Abas Ali (2004) in his study indicated that traffic noise levels were higher than those set by Egyptian noise standards and policy to protect public health and welfare in residential areas: equivalent continuous A-weighted sound pressure levels (L_{Aeq})=80 dB and higher were recorded, while maximum permissible level was 65 dB. There was a strong relationship between road traffic noise levels and percentage of highly annoyed respondents.

2.1.2.25 Takashi Morihara et al. (2004) conducted a study which showed that the annoyance in areas close to railways was greater than that in distant areas, while there was no difference in dose–response relationships for road traffic noise between both areas. Considering the situation of houses in Europe and Japan, it was expected that the annoyance caused by railway noise was more severe in Japan than in Europe. The distance from noise source to houses may be one of the causes of the difference in community responses between Europe and Japan.

2.1.2.26 The results of studies conducted by Ohrstrom E. et al. (2004) showed a higher prevalence of sleep disturbances and poorer sleep quality in the exposed areas as compared to the control area. It was concluded from the two year investigation (1997-1999) that exposure to high levels of road traffic noise induced adverse effects on sleep and that sleep quality was significantly improved after an extensive noise reduction.
2.1.2.27 *Sommerhoff Jorge (2004)* created a noise map of the city of Valdivia, Chile to evaluate the noise of the city. In conclusion, the noise pollution in the city was widespread throughout most of its streets area, where measured noise values were similar to those commonly observed in cities that do not had mitigation programs and whose road traffic was their principal noise generation source.

2.1.2.28 *Ohrstrom E. et al. (2004-A)* assessed the effects on sleep due to different types of noise exposures (road traffic, ventilation and combination of noise from road traffic and ventilation) and compared the effects on sleep both in laboratory and in field settings. Noise from ventilation caused a decrease in judged sleep quality by 12%, while sleep assessed by actigraph indicated better sleep as compared with the quiet reference night. When comparing sleep with traffic noise exposure in the laboratory and in the home the results showed no differences on sleep effects.

2.1.2.29 *Wenk Ruedi Müller (2004)* proposed a new computational procedure for the determination of health impairment resulting from noise emissions of road vehicles. The magnitude of health impairment due to noise was determined separately for each vehicle class (cars, trucks, etc.) and was calculated per vehicle-kilometre driven during the day or at nighttime on the Swiss road network. This health impairment was expressed in cases of sleep disturbance or communication disturbance, and furthermore aggregated in DALY (Disability Adjusted Life Years) units representing the number, duration and severity of the health cases.

2.1.2.30 *Ouis D. (1999)* in his study reviewed the disturbances to sleep caused by exposure of road traffic noise in the light of the latest published findings. Several studies had confirmed the fact that mood, too, was strongly affected after being exposed continuously during the night time with significant noise exposure. Other psychological and physiological functions affected
by night time exposure to road traffic noise, such as performance the following day and cardiovascular reactivity were also reviewed.

2.1.2.31 Stephen A Stansfeld et al. (2003) studied occupational and environmental noise exposure and suggested an association with hypertension, whereas community studies showed only weak relationships between noise and cardiovascular disease. Aircraft and road traffic noise exposure were associated with psychological symptoms but not with clinically defined psychiatric disorder. In both industrial studies and community studies, noise exposure was related to raised catecholamine secretion. In children, chronic aircraft noise exposure impairs reading comprehension and long-term memory and may be associated with raised blood pressure.

2.1.2.32 Long-term exposure to air pollution was generally accepted to be a health hazard. Additionally, exposure to noise facilitates diseases, which were caused by stress as a co-factor. The study by Hartmut Ising et al. (2004) revealed that long-term exposure of children to the combination of traffic noise and air pollution might result in more adverse health effects than exposure to air pollution alone.

2.1.3 Noise Barriers/Abatement Measures

2.1.3.1 Parida M. et al. (2004) developed an analytical model for designing a noise barrier at flyover locations in Delhi. Mitigation measures at the studied flyovers were suggested as (i) Cantilever barrier of vertical height 3.11 m with 0.52 m canopy at 150 with horizontal should be erected on both sides of the carriageway on Ashram flyover, Delhi; (ii) Cantilever barrier of vertical height 3.02 m with 0.39 m canopy at 150 with horizontal should be erected on both sides of the carriageway on Moolchand flyover, Delhi.

2.1.3.2 Mohan Surinder et al. (2005) had emphasised that by installing traffic calming measure such as mini roundabout with cushions, magnitude of
noise energy per 24-hour day resulted in the decrease of by 857 Kw-hours (~5dBA), alongside cushions by 864 Kw-hours (~7dBA), near the raised junction by 821 Kw-hours (~4dBA) and between cushions by 857 Kw-hours (~5dBA) approximately. The study recommended implementing of specific traffic calming measures at different traffic situations prevailing at Indian roads.

2.1.3.3 *Nadaf A.M. (2000)* suggested few measures to minimise the noise pollution generated by the movement of vehicles inBanglore City. These measures were change in design of vehicles, change in tyre, treads and road surface, elimination of noise of vehicles, modification in traffic operation, designing streets building areas for producing less noise, depressing or elevating the roadways, protect built environment by constructing buffer zones, equipping heavy vehicles with noise control equipments, synchronization of traffic signals to avoid delays at intersection, blowing horn without reason and dense planting of trees.

2.1.3.4 *Mina H.L. et al. (2004)* in their study suggested traffic noise control by noise reduction at source, streamlining traffic flow, landuse control, improving road structure viz. noise barriers, buffer zones, porous asphalt pavement, designing building with sound insulation.

2.1.3.5 The study conducted by *Cianfrini Claudia et al. (2007)* mentioned the development of a radiosity-based theoretical model for the evaluation of the sound field behind pairs of diffusive noise barriers and validated its ability to predict the extra Sound Pressure Level (SPL) attenuation deriving from the replacement of geometrically reflecting barriers with diffusely reflecting barriers.

2.1.3.6 *Lee Pyoung Jik et al. (2007)* found that parapets of the balcony were more effective in reducing exterior noise than lintels. Based on the measurements of the parapet used for this study and the absorptive materials in the scale
model, a maximum noise reduction of 23 dB was obtained. The method of exterior noise reduction can be useful in high-rise buildings where tall barriers cannot be built.

2.1.3.7 A Study by Okubo Tomonao et al. (2006) describes the noise shielding efficiency of barriers with an acoustic device mounted on their top edge for reducing sound diffraction. Diffraction behind the edge-modified barrier was investigated by scale model experiments in which the positions of a source and a receiver were aligned along a circular arc around the barrier top. The result indicated that the acoustic efficiency of the edge device was a function of the angles of the source and receiver and independent of their radii.

2.1.3.8 The study carried out by Bhaskar Ashish et al. (2007) discussed the area-wide Dynamic Road traffic Noise (DRONE) simulator, and its implementation as a tool for noise abatement policy evaluation. DRONE involves integrating a road traffic noise estimation model with a traffic simulator to estimate road traffic noise in urban networks. The output from DRONE was linked with a geographical information system for visual representation of noise levels in the form of noise contour maps.

2.1.3.9 Kokowski Piotr et al. (2006) found out that a speed bump reduced traffic noise levels during the deceleration phase and increased them during the acceleration phase. The net effect of a speed bump on noise from a light vehicle was assessed by means of the concept of noise energy density, S. This was a function of the instantaneous distance between the vehicle and the bump, S(x). It was assumed that the noise from each vehicle was generated by a single non-directional point source and propagates without vertical-surface reflections.

2.1.3.10 The study by Tyagi Vikrant et al. (2006) found out that noise attenuation generally increases with frequency. The results indicated that vegetation
belts could be used as effective barriers for traffic noise control along the roadsides.

2.1.3.11 Monazzam M.R. et al. (2005) described an investigation about the acoustic performance of noise barriers with quadratic residue diffuser (QRD) tops, designed with T-shape, Arrow-shape, Cylindrical and Y-shape profiles. It was found that reduction in the design frequency of QRD shifts the performance improvement towards lower frequency. Therefore the most efficient model for traffic noise was a barrier covered with a QRD tuned to around 400 Hz.

2.1.3.12 Kaku Jiro et al. (2004) investigated the effect of noise on sleep in subjects’ own houses using recorded traffic noises. A railway noise and two kinds of road traffic noise differing in level-fluctuations were used as stimuli. Subjects were exposed all night to the artificially controlled stimuli for 10 days through a portable compact disc (CD) player. The results of the analysis of the actigraphy data showed a rapid increase in the incidence of mid-sleep awakening at sound pressure levels higher than 50 dB, L_{Aeq,1 m} for railway noise. However, road traffic noises had not showed such a tendency, as long as the sound pressure level was less than 55 dB, L_{Aeq,1 m}.

2.1.3.13 Skanberg Annbritt (2004) conducted a study to assess the effects of road traffic noise exposure on sleep in laboratory and in field settings. The eighteen respondents participated were exposed to noise from road traffic in the laboratory and exposed to the same recorded traffic noise exposure in their own homes. Their sleep was evaluated with wrist actigraphs and questionnaires on sleep. No significant increase in effects of noise on sleep in the laboratory was found. The results indicate that laboratory experiments did not exaggerate the effect of noise on sleep.

2.1.3.14 In a laboratory experiment, the disturbance caused by two types of noise (railway and road traffic noises) at three noise levels (55, 65 and 75 dB_{L_{Aeq}})
in two kinds of stimulation conditions (listening and calculation) was investigated by *Ma Hui et al. Yano* (2004). There was a significant difference between the effects of two noises on listening performance when noise level was 75 dB, but no difference was found between railway and road traffic noises on experiment performance. The results suggest that the disturbance evaluation was determined by several factors and that the interaction among the factors increases with the increase of noise level.

2.1.3.15 *Sasazawa Y. et al. (2004)* conducted a survey and measured the actual sound level of noise in an urban area to clarify the relationship between traffic noise and insomnia. Average values of sound level at distances of 20, 50, and 100m from the major road were $L_{eq}$ 64.7, 57.1, and 51.8 dBA, respectively. Overall, there were no significant differences among the three zones in the prevalence of insomnia and no association between distance from the road and insomnia.

2.1.3.16 *Takashi Ishizuka et al. (2004)* tested performances of barriers having different shapes and surface conditions using the boundary element method in a well-controlled environment. It was shown that absorbing and soft edges significantly improve the efficiency of the barrier, but configuration modifications provide only a slight improvement. The soft T-shaped barrier produces the highest performance. A three m high T-shaped barrier provides the same performance as a ten m high plain barrier.

2.1.3.17 The study by *Defrance J. et al. (2003)* deals with the characterization of real performance of a T-shaped absorbing cap with road traffic noise conditions.

2.1.3.18 *Li K.M. et al. (2003)* explores the noise reducing effect of a balcony and described the development of a simple theory pertaining to the propagation of traffic noise from a road into a balcony. A new methodology was proposed based on the well-known prediction scheme i.e. “Calculation of
Road Traffic Noise” (CRTN)-developed in the UK. A geometrical ray
theory was developed for the prediction of noise levels inside a balcony due
to road traffic. The source level of road traffic noise was obtained as per the
standard CRTN methodology. It was found that a properly designed
balcony can provide considerable screening effects in protecting dwellings
against road traffic noise.

2.1.3.19 Porous road surfaces reduce road traffic noise. Subjective assessments by
Golebiewski R. et al. (2003) of drive-by noise suggest that the sound
exposure and the road surface coefficient can be used as the acoustical
characteristics of a road surface. Their average values, with the average
number of vehicles passing the receiver during a day or night, makes it
possible to predict the equivalent continuous A-weighted sound pressure
level for the new road surface.

2.1.3.20 Nijland H.A. et al. (2003) described a cost-benefit analysis of a number of
(possible) noise abatement measures in the Netherlands. Benefits were
calculated according to consumer’s preferences for dwellings, and values
applied were derived from two different methodologies (hedonic pricing
and contingent valuation). Costs were shown to be surpassed by benefits.
Some weaknesses were also demonstrated in valuing noise, particularly
where issues of equity, benefit transfer and embedding were concerned.

2.1.3.21 A portion of I-76 roadway near Akron, Ohio, was reconstructed by the
Ohio Department of Transportation with concrete pavement to replace the
previous asphalt surface. It was found out by Lloyd Herman et al. (2006)
that the average reduction in the A-frequency-weighted broadband noise
levels at 7.5 m (24.6 ft) was 3.5 dB, while the average reduction at 15m
(49.2 ft) was 3.1 dB.

2.1.3.22 Elsafi Osman Hag et al. (1999) proposed noise barriers made of recycled
plastic. The proposed material was recycled-plastic lumber, a material
extruded into standard lumber sizes used by the timber industry. It was durable and requires little maintenance, can be cut and fastened like wood, provides several aesthetic alternatives in both color and texture, was highly resistant to insects and graffiti, was readily available, and was thus inexpensive compared to custom-made plastic shapes. Being denser, it would block noise more effectively than wood sheathing of similar thickness. The proposed systems were competitive with current barriers with respect to initial cost and may had long-term economic benefits because of greater durability, minimal maintenance, and low life-cycle cost.

2.1.3.23 Ronald K. Faller et al. (2006) developed a new transparent noise barrier system for use on rigid bridge railings and other rigid structures. The safety performance of the transparent noise barrier system was determined to be acceptable according to Test Level 4 evaluation criteria specified in National Cooperative Highway Research Programme (NCHRP) Report No. 350.

2.1.3.24 Takayuki Tokairin et al. (2005) evaluated performance of porous fence as a tool for control of both air pollution and noise pollution. Evaluation showed that the fence of 60% porosity leads to reduction of air pollution by 20% compared with solid fence case, and reduction of noise pollution by 4-6% in dB compared with no fence case, at 1 m high and 10 m from the road.

2.1.4 Traffic Noise and Valuation of Property

2.1.4.1 Brons Martijn et al. (2003) presented a casual chain model in which railroad traffic density, noise emission; noise emission and noise annoyance were carefully related. Noise level, habituation and railroad usage were determinant factors. Noise annoyance causes social and economic costs were incorporated in various stages of the casual model. Economic feasibility of policy measures was usually analysed by means of a cost-
benefit case study. Cost Benefit Index (CBI) could be interpreted as the cost per dB(A) reduction per person.

\[
CBI = \frac{\text{yearly costs}}{N[\text{dB(old)} - \text{dB(new)}]}
\]

2.1.4.2 The study by *Kim Kwang Sik et al. (2007)* evaluated the monetary effect of traffic noise on property values in Seoul, Korea. Hedonic price models were estimated using the zone-based data that included traffic noise levels, official land price, land use classification, distance to roadways, type of nearby roadway facilities, and traffic characteristics. It was found that a 1% increase in traffic noise associated with a 1.3% decline in land price.

2.1.4.3 *Arsenio Elisabete et al. (2006)* in their study presented application of the stated choice method to the valuation of road traffic noise. The innovative context used was that of choice between apartments with different levels of traffic noise, view, sunlight and cost with which respondents would be familiar. Stated choice models were developed on both perceived and objective measures of traffic noise, with the former statistically superior.

2.1.4.4 *Wilhelmsson Mats (2005)* analyzed the economic consequences of an investment in traffic-noise abatement. The benefits had been estimated by analyzing prices of houses that had been sold more than once; that was the repeated-sales method (RSM). The total benefit to the stock of houses had been estimated and compared with the total cost. It was concluded in this case that public investment in a traffic-noise barrier could be clearly justified.

2.1.4.5 *Marcel A.J. Theebe (2004)* estimated the non-linear impact of traffic noise on property prices. The used data set was very extensive; over 100,000 sales transactions were studied. In a rising market, Marcel A.J. Theebe found that the impact of traffic noise ranged to a maximum of 12%, with an
average of about 5%. The discount varies across sub-markets, and was a non-linear function of the noise level.

2.1.4.6 Objective of the study conducted by Wilhelmsson Mats (2000) was to provide an empirical analysis of the impact of traffic noise with the values of single-family houses. Noise pollution was found to had a substantial negative effect on housing values. A single-family house of SEK975 000 would sell for SEK650 000 (SEK is Sweden currency referred as ‘krona’) if located near a road where noise was loud, equivalent to a total discount of 30%.

2.1.5 Urban Forms and Building Designs to Reduce Traffic Noise

2.1.5.1 Barbara Lebiedowska (2005) analysed the interaction between noise and transport noise in urban space. A new classification of city soundscape was proposed. This relative classification was based on two principal sources of noise in urbanised areas; background and transport noise. Following five types of urban soundscape were proposed from very quiet area to very loud area:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Very quiet area</td>
<td>Transport noise level very low in comparison to background level (influence of transport noise on total noise level equals 0 dB)</td>
</tr>
<tr>
<td>ii. Quite area</td>
<td>Transport noise level not high in comparison to background level (influence of transport noise between 0 and +1dB)</td>
</tr>
<tr>
<td>iii. Elevated loudness in the area</td>
<td>Transport noise level elevated (influence of transport noise between +1 and +2dB)</td>
</tr>
<tr>
<td>iv. Loud area</td>
<td>High transport noise level (influence of transport noise between +2 and +3dB)</td>
</tr>
<tr>
<td>v. Very loud area</td>
<td>Very high transport noise level (influence of transport noise equals +3dB)</td>
</tr>
</tbody>
</table>

2.1.5.2 Sharma Umesh et al. (2008) presented status of noise pollution in commercial areas of Chandigarh due to road traffic. The study indicated that noise levels in commercial areas exceeded permissible levels. A correlation model of noise level with traffic characteristics had been
proposed. The model could be used as an effective tool in traffic management, land use planning and pollution control.

2.1.5.3 The study conducted by Tang U.W. et al. (2007) shows that the urban forms in historical areas with narrower roads, complex road networks and a higher density of intersections lead to lower traffic volumes and thus lower noise pollution. However, the greater street canyons with 15.1 meter height effects in these historical urban areas lead to higher carbon monoxide (CO) concentrations.

2.1.5.4 Gunnarsson Anita Gidl¨of et al. (2007) found out that in the process of planning health-promoting urban environment, it was essential to provide easy access to nearby green areas that can offer relief from environmental stress and opportunities for rest and relaxation, to strive for lower sound levels from road traffic, as well as to design “noise-free” sections indoors and outdoors.

2.1.5.5 Nicol F. et al. (2004) conducted a study to examine the vertical variation in noise in the canyons in order to give advice on natural ventilation potential. The developed simple regression model could be used to predict the fall-off (attenuation) of the noise level with height above street level. The attenuation was found to be a function of street width and height above the street, but the maximum level of attenuation (at the top of the canyon) was almost entirely a function of the ratio of height to the width of the building in narrow streets.

2.1.5.6 The study by Li Bengang et al. (2004) reveals that expanding ring roads mitigate heavy traffic flow in the central part of Beijing City, but spread high traffic noise outwards at the same time.

2.1.5.7 Sharma V.P. (1978) conducted a study with the objectives of the study to evaluate noise in Indian cities and assessment of traffic noise in relation to hierarchy of roads, layout of residential areas (conventional &
neighbourhood type) and height of building to give guidelines in network planning to minimise the traffic noise problem. He finally concluded that noise level in grid iron type layouts were considerably high and were unacceptable.

2.1.6 Noise Measurement and Perception

2.1.6.1 William H.K. Lam et al. (1998) examined the reliability of traffic noise measurement techniques and the noise estimates in Hong Kong. Traffic flow, traffic speed and traffic composition were identified as the key factor influenced the generation of traffic noise. The reliability of traffic noise estimated was obtained from the combined probability distribution of the key factors.

2.1.6.2 Ohrstrom E. et al. (2004) found out that there were several significant relationships between sleep parameters measured with the two methods viz. wrist actigraphs type AMI mini-motion-logger and questionnaires. If the choice were between studying fewer and solely subjective sleep parameters in a larger group, then questionnaires method should had been chosen to study noise-induced sleep disturbances.

2.1.6.3 Tang S.K. et al. (2004) developed or re-calibrated formulae for the prediction of the $L_{A10}$, $L_{A50}$, $L_{A90}$ and $L_{Aeq}$ by regression analysis and simple physical consideration of the traffic noise production mechanisms. Results suggested tyre noise had the major contribution to the overall noise environment when the source was an inclined trunk road. Also, the road gradient was found to had a higher contribution to the traffic noise than assumed in the existing models, but becomes unimportant when the background noise level $L_{A90}$ was concerned.

2.1.6.4 Dae Seung Cho et al. (2006) presented a new and efficient method to determine sound power levels (PWLs). The statistical pass-by (SPB) of ISO
11819-1 was used for SPL measurements; however, numerous SPBs must be carried out to reduce measurement of uncertainty as well as to satisfy requirements related to meteorological conditions and background noise.

2.1.6.5 *Gaja E. et al. (2003)* summarized 5 years of continuous noise measurements carried out at one of the most important squares in Valencia (Spain). The aim of this study was to determine the appropriate measuring time in order to obtain a 24-h noise level suitable to represent the annual equivalent level. A random day strategy for sampling was found to give a more accurate representation than a consecutive day strategy. If the sampling strategy involved measurements on randomly-chosen days, then at least 6 days should had been used.

### 2.1.7 Other Aspects Related to Traffic Noise

2.1.7.1 *Fung Y.W. et al. (2011)* did regression analysis on the measurement results indicates that both the traffic-induced noise and the PM10 concentrations at the case study units exhibit a linear correlation with the logarithm of their corresponding distance from road (log R). The result confirms that “log R” can be adopted as a common parameter for evaluating the combined impact of road traffic on the noise and air pollutions of a residential unit.

2.1.7.2 *Bhattacharya C.C. (2002)* presented noise standards in few countries, Federal Highway Administration (FHWA) standards and Ambient Noise standards in India for different landuses and residential areas. Factors affecting generation of highway traffic noise, noise prediction methodology, strategies for noise control (at source, transmission path and noise abatement measures through barriers) were also discussed in this study.

2.1.7.3 The study by *Yuichi Kato et al. (2006)* presented a practical detection method of extraneous interfering sounds by horns, sirens, animals,
construction sites, and the like, was proposed by deriving a necessary condition that road traffic sound levels must satisfy. The necessary condition provided an easy method of identifying sound levels not satisfying the condition, and distinguished them as extraneous abnormal sounds, even in a large volume of observed data. The validity and usefulness of this method were confirmed by application to actually observed data.

2.1.7.4 Janczur R. et al. (2006) presented predictions of relative sound level distribution on building facades in city-centres obtained by using the simulation PROP11. The simulation involves the geometry of surrounding buildings, road geometry (number of lanes and their positions) and traffic structure (vehicle flow rates and their average speeds). The agreement between measurement and simulation results was tested for different directivity characteristics of an equivalent point source representing the vehicles.

2.1.7.5 Nese Yugruk Akdag (2004) presented a graphic method to determine the required minimum sound reduction index ($R_{tr}$) of building envelope components, depending on road traffic noise, room function and transparency ratio of the facade.

2.1.7.6 Jaime Ramis et al. (2003) made a comparative of the noise levels before and after the opening of the motorway that goes through Motilla de Palancar, Spain. The reduction obtained was considerable, since it was between 3.0 and 7.5 dB (A). In general, the decrease had been smaller in $L_{Aeq,T}$ and $L_{A10,T}$ than in $L_{A90,T}$ and $L_{A50,T}$. The acoustic pollution had been notably reduced along the road that goes through town, reaching the 65 dB (A) recommended by the World Health Organization.

2.1.7.7 Paulo H.T. Zannin et al. (2003) described the reaction to environmental noise of the population of Curitiba (~1.6 million inhabitants). The survey
showed that in the subjective evaluation performed in the city of Curitiba, the perception of the population was that the urban noise had increased. On the other hand, another study conducted in the same city, where only the noise emission levels were evaluated, had showed a decrease on the urban noise.

2.1.7.8 Bernhard Robert J. et al. (2005) in their study defined sound and noise, illustrated the public’s growing awareness of noise issues, explained the units of measurement and measurement techniques, outlined some of the mechanisms of noise generation at the tyre-pavement interface, and briefly discusses how pavements could help to mitigate noise problems. Significant progress had been made to reduce tyre-pavement noise, and, with more applications and an increased understanding of noise generation and propagation, economical pavements were possible that control noise while maintaining safety and durability.

2.1.7.9 Blumenfeld Dennis E. et al. (1977) applied the Pearson curve methodology to determine the full pdf (probability density function) and find that the best fit was given by a beta distribution. This was true with and without excess attenuation due to atmospheric or ground absorption and when a mixture of vehicle types was present. The exact and approximate distributions were compared indirectly by comparing higher moments not used to fix parameters.

2.1.7.10 Blumenfeld Dennis E. et al. (1994) consider the effects of nongeometric attenuation, represented as a negative exponential absorption factor, on the calculation of cumulants of the noise intensity. This absorption would arise from sound propagation through tree zones or shrubbery.

2.1.7.11 Hoel David G. et al. (1976) considered the second order statistical properties (variance, autocorrelation function, and spectral density) of the acoustic noise generated by traffic streams. Calculations were given for a
model in which the headway distribution within a queue differs from that between successive queues. It was showed that changes in flow rate were more important for determining second order properties than were details of the within queues headway distribution. Particular results were given for queue length distributions of the form $p_n = \theta^{n-1}(1 - \theta)$ where $\theta$ was the probability of having more than one car in the queue.

2.1.7.12 Kuemmel David A. et al. (1996) observed a dependency between the pavement textures and their noise characteristics. Noise measurements indicated that uniformly transverse tined portland cement concrete pavement (PCCP) created dominant noise frequencies that were audible adjacent to the road and inside the test vehicles. Careful design and construction of transversely tined PCCP can reduce tire-road noise. No significant acoustical advantages of open-graded asphalts over the standard dense asphalt were found.

2.1.7.13 Jaeckel John R. et al. (2000) found in the study that both uniform and random transverse tining provide higher interior and exterior noise levels than skewed or longitudinal tining. Transverse tining, even in some random-spaced textures, can cause a discrete frequency or whine. The study recommendations include the need for better quality control over tining and a wet-pavement-accident study of longitudinal tining. If noise considerations were paramount, longitudinal tining was recommended. If texture was paramount, skewed tinning was recommended. If a skew was not possible, then carefully constructed random transverse was recommended.

2.1.7.14 Calixto Alfredo et al. (2002) studied the problem of traffic noise on roads which had been transformed into big avenues in the city of Curitiba. The measured sound pressure levels had been compared with the calculated ones obtained from the mathematical model and the German Standard RLS-90 as well. The mean traffic noise levels around those roads and the noise
limits of the municipal law 8583/1995 were examined and it was confirmed that people living or working in these areas were exposed to noise levels beyond the legislated norms.

2.1.7.15 Ahmad Jamrah et al. (2006) investigated traffic noise pollution in Amman. Road traffic noise index $L_{10}$ (1 h) was measured at 28 locations that cover most of the City of Amman. The results of the investigation showed that the minimum and the maximum noise levels were 46 dB (A) and 81 dB (A) during day-time and 58 dB (A) and 71 dB (A) during night-time. The measured noise level exceeded the 62 dB (A) acceptable limit at most of the locations.

2.1.7.16 Guoxia Ma, et al. (2006) analysed continuous traffic noise monitoring data at 142 sites distributed in 52 roads from 1989 to 2003 in Lanzhou City. The characteristics of traffic noise and effect factors were analyzed through traffic noise indices, such as $L_{10}$, $L_{50}$, $L_{90}$, TNI, etc. It was found that traffic noise made a distinction between trunk lines and secondary lines, west-east direction roads and north-south direction roads. Traffic volume, traffic composition, road condition, and traffic management were identified as the key factors influencing traffic noise in this city.

2.1.7.17 Rohatgi Rajesh (1994) assessed traffic noise characteristics and develop relationship between traffic noise and stream flow variables. Vikas Minar-Barakhamba Road corridor in Delhi was selected as case study area. Passenger Car Noise Equivalences (PCNE) had been established as follows:

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Car/Jeep/Van</th>
<th>Two-wheeler</th>
<th>Auto</th>
<th>Bus/Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCNES</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

- Relationship between Traffic Volume and Traffic Noise had been prepared for:
  i) 4-lane undivided carriageway (two-way traffic)
    
    \[
    L_{10} = 13.98 + 16.04 \log_{10} V \\
    L_{10} = 27.58 + 2.76 \log V_c + 3.26 \log V_{tw} + 3.74 \log V_a + 9.05 \log V_b
    \]
\((V_c = \text{no. of cars/hr.}, V_{tw} = \text{no. of TW/hr.}, V_a = \text{no. of auto/hr.}, V_b = \text{no. of bus/truck/hr.})\)

ii) 4-lane undivided carriageway (one-way traffic)
\[ L_{10} = 18.08 + 14.53 \log_{10} V \]

iii) 6-lane divided carriageway (Two-way)
\[ L_{10} = 8.05 + 17.23 \log_{10} V \]
\[ L_{10} = 24.58 + 2.25\log V_c + 3.5\log V_{tw} + 4.01\log V_a + 10.24\log V_b \]

- Relationship between Traffic Noise and Speed had been prepared for:
  i) 4-lane undivided carriageway
  \[ L_{10} = 87.46 - 4.545 \log S \]
  \((S = \text{average stream speed in kmph})\)
  ii) 6-lane divided carriageway (Two-way)
  \[ L_{10} = 88.21 - 5.613 \log S \]
  \[ L_{10} = 24.58 + 2.25\log V_c + 3.5\log V_{tw} + 4.01\log V_a + 10.24\log V_b \]

2.1.8 Inferences of Literature Review

The above studies carried out has been very comprehensive in nature and discussed ways and means to evaluate noise levels. It is also noteworthy to mention that these studies identified many parameters with a view to find out the annoyance due to traffic noise, impact due to traffic noise, abatement measures and valuation of property under prevailing traffic situations. Though these studies are interesting and a step forward to evaluate and account of various traffic noise parameters. But these studies are silent with respect to evolving the acceptability of noise levels for different types of residential areas under various categories of urban roads. The details of conducting an analysis of traffic noise as discussed in the above studies are extremely useful for conducting the present research study.

2.2 COMPARISON OF NOISE STANDARDS FOR VARIOUS CATEGORIES OF ZONES IN INDIA (M.O.E.F. NOTIFICATION)

Noise standards with respect to various categories of areas/zones in India as per Ministry of Environment and Forest (MoEF) Notification (2000) are presented in Table 2.1.
Table 2.1: Noise Standards in India: MoEF Notification

<table>
<thead>
<tr>
<th>Area Code</th>
<th>Category of Area/Zone</th>
<th>Limits in dB(A) $L_{eq}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Day Time</td>
</tr>
<tr>
<td>(A)</td>
<td>Industrial Area</td>
<td>75</td>
</tr>
<tr>
<td>(B)</td>
<td>Commercial Area</td>
<td>65</td>
</tr>
<tr>
<td>(C)</td>
<td>Residential Area</td>
<td>55</td>
</tr>
<tr>
<td>(D)</td>
<td>Silence Zone</td>
<td>50</td>
</tr>
</tbody>
</table>

- Day Time- 6:00 a.m. to 10:00 p.m.
- Night Time- 10:00 p.m. to 6:00 a.m.
- Silence zone is defined as area comprising not less than 100 meters around hospitals, educational institutes and courts
- dB(A) - time weighted average of the level of sound in decibels on scale A, which is relatable to human hearing
- “A” in dB(A) $L_{eq}$. Denotes the frequency weighting in the measurement of noise and corresponds to frequency response characteristics of the human ear
- $L_{eq}$ – Energy mean of the noise level over a specified period

The variation of noise standard for residential and industrial zone is high i.e. 20 dB(A). Though there is a broad classification for noise standards with respect to different types of landuse as recommended by MoEF, noise standard with respect to different types of roads has never been prescribed by any agency in India so far. This is of paramount importance primarily because most of the people in urban areas do not like to be exposed near the high traffic arterial roads. In the contrary, this major section of people prefers to be lactated in residential area other than high trafficked arterial roads. This has necessitated having a re-look on the perception on the effect of traffic noise in different categories of road in urban areas.

2.3 INTERNATIONAL COMPARISON OF NOISE STANDARD

Noise emission standards for different countries for residential areas are presented in Table 2.2. In general, noise standards are set too high coupled with poor enforcement. Most of the countries follow World Bank guidelines of 55 dB(A) for day time and 45 dB(A) for night time; these countries are Switzerland, Sweden, Denmark, Spain (Madrid), Japan, Brazil and India. Japan also describes different standards for residential areas facing roads with two or more lanes as 60 dB and 55 dB for day and night time respectively. In case of Ireland (Dublin) the day standards are same as 55 dB(A) but a range of 35-45 dB(A) is mentioned for night time. Night time standards in Australia are 45 dB(A) as per the above mentioned countries but day time standard are 3 dB(A) less than above countries as 52 dB(A). The standards in Los Angeles, California (USA) and Netherland are same as 50 dB(A) and 40 dB(A) for day time and 40 dB(A) and 30 dB(A) for night time respectively.
dB(A) for day and night time respectively. Israel recommends only one value for 24 hours as 50 dB(A). The standards in Germany are 4 dB(A) high in comparison to World Bank as 59 dB(A) and 49 dB(A) for day and night time respectively. The Malaysia prescribed two types of standards for low density residential area and high density residential areas/mix use. The standards for low density residential areas are same as prescribed in Los Angeles and Netherland as 50 dB(A) and 40 dB(A) for day and night time respectively, but the standards for high density residential areas/mix use are high as 60 dB(A) and 50 dB(A) for day and night time respectively.

### Table 2.2: Noise Emission Standards of Different Countries for Residential Areas, $L_{eq}$ [dB(A)]

<table>
<thead>
<tr>
<th>Country/Organisation</th>
<th>Day</th>
<th>Night</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switzerland</td>
<td>55</td>
<td>45</td>
<td><em>Urban Transport and Environment, An International Perspective, 2004</em></td>
</tr>
<tr>
<td>Sweden</td>
<td>55</td>
<td>45</td>
<td><em>Bhattacharya C.C., 2002</em></td>
</tr>
<tr>
<td>Japan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>55</td>
<td>45</td>
<td><em>Ministry of the Environment, Government of Japan</em></td>
</tr>
<tr>
<td>Residential areas facing roads with two or more lanes</td>
<td>60</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Curitiba, Brazil</td>
<td>55</td>
<td>45</td>
<td><em>Diniz, Fabiano B. et al., Urban Noise Pollution in Residential Areas of the City of Curitiba, Brazil, Américas CEP: 81531-990, Curitiba</em></td>
</tr>
<tr>
<td>Denmark</td>
<td>55</td>
<td>45</td>
<td><em>Neighbour and Neighbourhood Noise - A Review of European Legislation and Practices: Research Contract EPG 1/2/36, March 2002</em></td>
</tr>
<tr>
<td>Ireland (Dublin)</td>
<td>55</td>
<td>35-45</td>
<td></td>
</tr>
<tr>
<td>Madrid (Spain)</td>
<td>55</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>52</td>
<td>45</td>
<td><em>The Environment Protection (Noise) Policy 2007 and its impact on existing and proposed developments, June 2009</em></td>
</tr>
<tr>
<td>Country/Organisation</td>
<td>Day</td>
<td>Night</td>
<td>Reference</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----</td>
<td>-------</td>
<td>-----------</td>
</tr>
<tr>
<td>Netherlands</td>
<td>50</td>
<td>40</td>
<td><em>Urban Transport and Environment, An International Perspective, 2004</em></td>
</tr>
<tr>
<td>Malaysia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Density Area</td>
<td>50</td>
<td>40</td>
<td><em>Department of Environment, Ministry of Natural Resource and Environment, Malaysia</em></td>
</tr>
<tr>
<td>High Density, Mix use</td>
<td>60</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Los Angeles, California</td>
<td>50</td>
<td>40</td>
<td><em>Noise Regulation, California (Ord. No. 144,331, Eff. 3/2/73)</em></td>
</tr>
<tr>
<td>Israel</td>
<td>50</td>
<td>50</td>
<td><em>Prevention of Unreasonable Air and Odor Pollution from Solid Waste Disposal Sites, Regulation, 1990</em></td>
</tr>
<tr>
<td>Germany</td>
<td>59</td>
<td>49</td>
<td><em>Federal Immission Control Act (16th BImSchV), Germany</em></td>
</tr>
<tr>
<td>India</td>
<td>55</td>
<td>45</td>
<td><em>Ministry of Environment and Forest, Government of India</em></td>
</tr>
<tr>
<td>WHO</td>
<td>55</td>
<td>45</td>
<td><em>Urban Transport and Environment, an International Perspective, 2004</em></td>
</tr>
</tbody>
</table>

### 2.4 BASICS OF NOISE

#### 2.4.1 Definitions

**Sound**

Sound is created when an object moves, the movement cause vibrations of the molecules in air to move in waves like ripples on water; when the vibration reach our ears, we hear what we call sound.

Sound is produced by the vibration of sound pressure waves in the air. Sound pressure levels are used to measure the intensity of sound and are described in terms of decibels.
Decibels (dB)

Generally, the pressure is measured in Pascal, but it is customary to specify sound level in decibels (after Graham Bell). The decibels (dB) is a logarithmic unit which expresses the ratio of sound pressure level being measured to a standard reference pressure level of 20 micropascals (zero dBA). In order to provide a convenient scale, the actual RMS acoustic pressure is divided by reference pressure of $2 \times 10^{-5}$ Pa before the logarithm is taken. Zero dB corresponds to threshold of hearing and the scale extends upward typically to 130 dB before the sound become so loud that it starts to pain. The 130 dB is called threshold of pain. Comparison of frequency and noise level is presented Figure 2.1.

Noise Frequency Weightings

The most commonly used Frequency Weightings on a modern sound level meter are ‘A’, ‘C’ and ‘Z’. These are discussed briefly below [website (1)]:

(i) ‘A’ Weighting

Sound is composed of various frequencies, but human ear does not respond to all frequencies. Frequencies to which human ear does not respond are filtered by sound level meters with weighted circuits. Human ear can detect sound from 20Hz to 20,000Hz. Within this range, ear is particularly more sensitive to sound at frequencies between 500 to 6000 Hz.

The ‘A’ weighting filter covers the full frequency range of 20 Hz to 20 kHz. So, the A-weighted value of a noise source is an approximation to how the human ear perceives the noise.
Measurements made using ‘A’ weighting are usually shown with dB(A) to show that the information is ‘A’ weighted decibels or, for example, as $L_{Aeq}$, $L_{AF_{max}}$, $L_{AE}$ etc. where the A shows the use of ‘A’ Weighting.

(ii) ‘C’ Weighting

‘C’ Weighting is a standard weighting of the audible frequencies commonly used for the measurement of Peak Sound Pressure level.

Measurements made using ‘C’ weighting are usually shown with dB(C) to show that the information is ‘C’ weighted decibels or, for example, as $L_{C_{eq}}$, $L_{C_{Peak}}$, $L_{CE}$ etc. where the C shows the use of ‘C’ Weighting.

(iii) ‘Z’ Weighting

‘Z’ weighting is a flat frequency response between 10Hz and 20kHz ±1.5dB excluding microphone response.

Measurements made using ‘Z’ weighting are usually shown with dB(Z) to show that the information is ‘Z’ weighted decibels or, for example, as $L_{Z_{eq}}$, $L_{Z_{F_{max}}}$, $L_{ZE}$ etc. where the Z shows the use of ‘Z’ Weighting. ‘A’, ‘C’ & ‘Z’ Frequency Weighting Curves is presented in Figure 2.2.

Infrasound and Ultrasound

Sound with frequencies below 20-Hz is called infrasound, and sound with more than 20,000Hz is called ultrasound as presented in Figure 2.3. There is some evidence that these
sounds which cannot be heard can under certain conditions be hazardous to workers’ health.

**Sound pressure level**

A quantity related to the magnitude of the pressure fluctuations in the sound measured in dB.

$L_{eq}$

A representation of equivalent continuous sound level containing the same amount of sound energy as the measured varying noise, over the measurement period. It can be considered as the “average” noise level.

$L_{10}$

The actual sound pressure level exceeded for 10% of total observation time. It is an indication of peak level of intruding noise.

$L_{max}$ (Maximum Energy Level)

The greatest root-mean-square noise value obtained over the measurement period. The maximum (A-weighted) sound level during a given time, measured on a slow time response setting.

$L_{day}$

The long term A-weighted average sound level over the day period.

$L_{evening}$

The long term A-weighted average sound level over the evening period.

$L_{night}$

The long term A-weighted average sound level over the night period.

**Day Time**

This is generally taken to be the 12 hour period from 07:00 to 19:00 hours.

**Evening Time**

This is generally taken to be the 4 hour period from 19:00 to 23:00 hours.

**Night Time**

This is generally taken to be the 8 hour period from 23:00 to 07:00 hours.
2.4.2 Sound Transmission Loss

In line sources when the distance is double then the noise will reduces upto 3 dB(A). Traffic is considered as line source. A vehicle create 70 dB(A) noise when it is monitored at 50 feet but when the noise is monitored at same time on 100 feet (double distance) the noise becomes 67 dB(A). The noise level is reduced by 6 dB(A) at a distance ‘2d’ from a point source. If a point sound source produces a sound level of 95 dB(A) at a distance of ‘d’ meter, the sound level at a ‘2d’ meter distance is 89 dB(A), at ‘4d’ meter 83 dB(A), etc. [website (2)]. Distance Attenuation of Noise Levels is presented in Figure 2.4.

![Figure 2.4: Distance Attenuation of Noise Levels](image)

The reduction of noise from a line source can be expressed as follows [book by Kumares C. Sinha et al. (2007)]:

\[ \Delta \text{SPL (dB)} = 10 \log_{10} \left( \frac{d_1}{d_2} \right) \]

\( \Delta \text{SPL} = \) reduction in Sound Pressure level

\( d_1 \) & \( d_2 \) = distance of line source from point 1 and 2 respectively

2.5 SUMMARY

The literatures studied related to the present research work identifies many parameters with a view to determining annoyance due to traffic noise, impact due to traffic noise, abatement measures and valuation of property under prevailing traffic situations. These studies are silent with respect to evolving the acceptability of noise levels for different types of residential areas under various categories of urban roads.
The noise standards adopted by the Government of India are in tune with the norms suggested by World Health Organisation (WHO). Various countries in the world have also adopted similar norms but few Asian countries like Japan & Malaysia and one European country like Germany have adopted higher standards of traffic noise for residential areas. Israel has adopted higher noise standards for night time i.e. 50 dB(A). Japan and Malaysia have adopted two standards. In case of Japan, noise standards for general residential areas are 55 dB(A) and 45 dB(A) for day and night time, but separate standards are adopted for residential areas facing roads with two or more lanes as 60 dB(A) and 55 dB(A) for day and night time respectively. The noise standards for low density areas in Malaysia are 50 dB(A) and 40 dB(A), but for high density mix use areas, the noise standards are higher as 60 dB(A) and 50 dB(A) for day time and night time respectively. Germany has adopted higher standards of traffic noise for residential areas as 59 dB(A) and 49 dB(A) for day and night time respectively.
REFERENCES


55. Lam Kin-Che, Chan Pak-Kin, Chan Tin-Cheung, Au Wai-Hong and Hui Wing-Chi (2009), “Annoyance response to mixed transportation noise in Hong Kong”, Applied Acoustics 70; 1–10


89. Phan Hai Yen Thi, Takashi Yano, Phan Hai Anh Thi, Tsuyoshi Nishimura, Tetsumi Satoa and Yoritaka Hashimoto (2010), “Community responses to road traffic noise in Hanoi and Ho Chi Minh City”, Applied Acoustics 71; 107-114
92. Qudais Saad Abo and Qdais Hani Abu (2005), “Perceptions and attitudes of individuals exposed to traffic noise in working places”, Building and Environment 40; 778–787
93. Rasmusse K. B., “Annoyance from simulated road traffic noise” (1979), Journal of Sound and Vibration 65(2); 203-214
96. Rohatgi Rajesh (1994), Traffic Noise Characteristics in a Metropolitan City, Case Study-Delhi, M. Planning Thesis, School of Planning and Architecture; 69-86


20. Website(1)-http://www.cirrusresearch.co.uk/blog/2011/08/what-are-a-c-z-frequency-weightings