International Journal of Advancements in Mechanical and Aeronautical Engineering – IJAMAE
Volume 1 : Issue 3 *[ISSN 2372 –4153]*
Publication Date : 30 September, 2014

A multiple regression model for urban traffic noise in Delhi

N. Garg[1], S. Maji[2], S. K. Mangal[3] & P. Dhiman[4]

***Abstract* – This paper reviews the strategies so far recommended for modeling road traffic noise in India. An analytical model is developed to predict road traffic noise for busy roads of Delhi, India. Equivalent continuous sound pressure level, L_{AeqT} is analyzed at different busy road locations of Delhi. A multiple linear regression analysis is conducted to predict the noise metrics L_{Aeq}, *TNI* and *NPL* in terms of traffic flow rate, percentage of heavy vehicles, and average traffic speeds. The model so developed is validated with actual experimental data.**

Keywords:— ***Traffic noise, Equivalent continuous sound pressure level, L_{AeqT}, Traffic Noise Index, TNI.***

Introduction

In Indian scenario, the vehicular population is increasing at an enormous rate as compared to the road infrastructure. In National capital region, the vehicular population is increasing at a rate of 135.6% while the road network has increased by 16.5%. The number of vehicles both cars and two wheelers are rising at a rate of 8% per annum. For a city of 17 million, Delhi has close to 8 million registered vehicles more than Mumbai, Kolkata put together [1]. Although, the introduction of MRTS (Mass rapid transit system) and BTS (Bus transit system) has proven to be a convenient means of transport, yet the noise and vibration induced due to these sources has to be controlled for their betterment and mass use by community. Thus, it is imperative to conduct studies pertaining to the increased noise levels due to heavy vehicular density for planning suitable effective measures to control it. There has been an exhaustive study carried out in developed nations in this regard. Every nation has its own validated road traffic noise model for conducting EIA studies [2]. However, there are lot of uncertainties involved in modelling traffic noise. As a result, no model can be considered as an 'ideal model'. The source noise characteristics are also varying in different countries which thus create a need for developing a specific area based or country based model rather than a harmonized approach like that in *CNOSSOS* approach followed in EU [3]. The present work is an attempt to focus on this critical issue and tries to use multiple linear regression approach in modelling the sound levels generated by vehicular traffic correlating the parameters viz., vehicular flow, percentage heavies and average speed of vehicles. The accuracy of model so developed is ascertained by statistical tests.

[1]Corresponding author, Sr. Scientist, CSIR-National Physical Laboratory, New Delhi, India,
[2] Principal, G. B. Pant Engg. College, New Delhi – 110 020,
[3]Associate Professor, Deptt. of Mechanical Engineering, PEC University of Technology, Chandigarh, 160012,
[4]Graduate Student, Deptt. of Mechanical Engineering, PEC University of Technology, Chandigarh, 160012,

Studies done in India

The objective is to develop a regression based model for traffic noise prediction and its forecasting with definite accuracy so that it could be helpful in carrying out noise impact assessments in metropolitan cities like Delhi. It can also be helpful for planning and control especially for urban development bodies. Various models have been developed for different Indian cities in past few years. Rao *et al.* developed a regression equation for modeling L_{A10} as a function of traffic density [4]. In urban areas, most of the traffic flow is often interrupted by traffic signals and thus interrupted traffic flow conditions on urban roads create substantially different noise characteristics from highways to expressways [5 & 6]. Rajakumara *et al.* [6] developed a regression noise prediction model for both acceleration and deceleration lanes. Agarwal [7] introduced equivalent number of light and heavy vehicles for the calculation of L_{eq} values. Light motor vehicles have been analyzed to be the major culprit in noise pollution. The recent investigations of Kalaiselvi [8] introduces horn noise component into account. It has been observed that horn noise event with frequency of 16 per minute raises L_{eq} by 12 dB (A). There have been some studies that have reported a new factor *i.e.* tendency to blow horn in conventional Federal highway Administration (FHWA) model which could predict the equivalent noise level, L_{eq} to an accuracy of ± 3 dB(A) [9]. In Indian context, horn noise is an important issue that seriously affects the prediction accuracy of L_{AeqT}. There have been only a few studies reported on modelling the horn noise. Kalaiselvi study using the noise nomogram approach is one such example. A recent study by Paras *et al.* shows the application of ANN in modelling traffic noise for field noise monitoring data gathered in Patiala city [10]. Kumar *et al.* reported a road traffic noise prediction model using regression analysis based on Calixto model [11 & 12].

Similarly a recent study made by Sharma *et al.* (2014) models equivalent traffic noise in terms of four input variables *i.e.* equivalent volume, equivalent vehicle speed, distance and honking [13]. Various studies have been reported based on acoustic equivalence approach, wherein correlation have been developed based on acoustic equivalence of different vehicles with respect to light cars [14].

Table 1. Recommended empirical formulations in various Indian studies for modeling traffic noise [5-13]

Researcher	Area of study	Empirical formulation recommended
Paras *et al.* 2014	Patiala, Punjab	$L_{eq} = 67.6 + 5.8 \log Q + 0.27 P - 6.58 \log V$
Sharma *et al.*, 2014	Nagpur, Maharashtra	$L_{eq} = 59.44 + 4.461 \log Q_e + 0.1983 S_e - 0.3771 d + 0.582 h$ for $S_e > 30$ km/h & honking > 0, where Q_e is the equivalent traffic flow, S_e is equivalent vehicle speed, d is the distance and h is total honking per minute.
Kalaiselvi *et al.*, 2012	Chennai	$L_{eq,\ 15m} = 34.31 + 13.9 \log Q_i + 9.2 \log V$ where Q_i is the equivalent traffic flow
Kumar *et al.*, 2011	NH 58 Highway	$L_{eq} = 19.92224 \log [Q(1+0.1VP)] + 12.59764$ where VP is percentage of heavy vehicles
Agarwal *et al.*, 2010	Jaipur	L_{eq} (Lv) = 8.43 log (x) + 39.522 L_{eq} (Hv) = 12.67 log (x) + 27.579, where x is equivalent no of vehicles
Rajakumara *et al.*, 2009	Bangalore	Acceleration Lane Model: $L_{eq} = 59.21 + 0.043 S_E + 5.71 \log Q_E - 0.0197 R$ Deceleration Lane Model: $L_{eq} = 65.12 + 0.061 S_E + 2.14 \log Q_E + 0.923 \log L - 0.041 R$ where R is position of sound level meter & L is queue of waiting vehicles on deceleration lane
Nirjar *et al.*, 2003	Delhi	$L_{eq} = 81.715 + 0.361 S_n + 2.412 \log V_n - 0.189 S_f - 0.015 \log V_f - 1.532 D_g$ where S_n is mean speed of traffic on near side of observer, S_f is mean speed of traffic on far side of observer, V_n is volume of traffic for near side, V_f is volume of traffic on far side and D_g is geometric mean of road side section.

This factor denoted by E or $PCNE$ (in some studies) is calculated as $E = 10^{\left(\frac{SPL_T - SPL_C}{10}\right)}$ wherein SPL_T is sound pressure level of heavy vehicles and SPL_C is sound pressure level of a car.

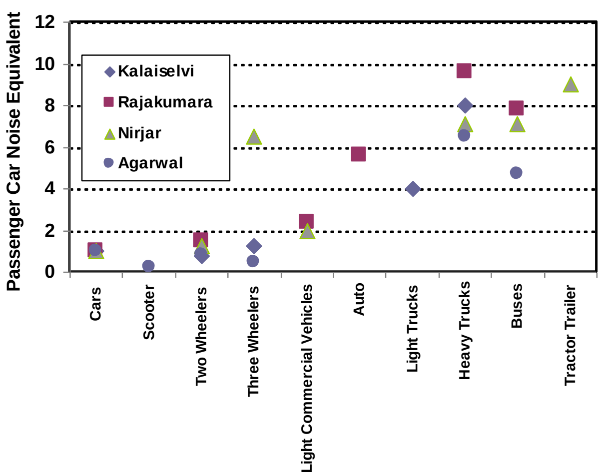

Fig 1. Passenger Car Noise Equivalent (*PCNE*) for different vehicles in various research studies carried out in India.

Fig 1 shows the value of *PCNE* from various studies in India. A comprehensive study conducted by Rajakumara *et al.* [6] from 2.249 data sets reveals that the noise level produced by one truck is equivalent to noise emitted by 9.63 car/jeep/vans. Similarly, noise produced by one bus, auto, LCV/MB and two wheelers is equivalent to 7.80, 5.60, 2.39 and 1.48 car/jeep/van respectively. The *PCNE* values quantified by Nirjar *et al.* [5] for Delhi city is 1.2 for two wheelers, 2 for light commercial vehicles, 7.08 for Buses and Trucks, 6.5 for three-wheelers and 9 for tractor-trailor. The recent study reported by Sharma *et al.* [12] shows that one heavy vehicle produce 9.63 times the noise produced by medium vehicle, whereby the auto and light vehicles produce 5.60 times and 1.48 times the noise produced by a single medium vehicle (MV). It may be noted that generally the reference speed of measurement is chosen as 50 km/h. Consequently, an adjustment factor should be added to reference emission level as, $\Delta L_V = A(V_{eq}-50)$, where A is a constant and V_{eq} is number of equivalent vehicles [14 & 15]. There have been few more studies reported such as those by Kalaiselvi *et al.* [8] and Agarwal *et al.* [9]. In view of these approaches, it is imperative to conduct a revised survey for Delhi vehicles especially when noise and air pollution norms are strictly enforced and practised by Central Pollution Control Board (CPCB), India [16]. The exhaustive literature review shows that the majority of studies followed in India are based on multiple regression analysis of experimental data gathered from traffic noise measurements. This approach has been also followed in some countries. To [17] reported a multiple regression model for predicting L_{10} noise level due to road traffic. Statistical tests using the analysis of variance (*ANOVA*) and Tukey test reveals that the total traffic flow and the number of heavy vehicles are the most significant factors of urban traffic noise. Li *et al.* [15] developed an integrated noise-GIS system for China based on a similar approach. Givargis *et al.* [18] work on modifying the U.K CORTN model (Calculation of Road Traffic Noise) to a model capable of calculating $L_{Aeq,1h}$ for Tehran roads is an excellent illustration of calibration of road traffic noise models for country or area based usage.

Experimental Data Acquisition & Analysis

The precision digital sound level meter used for the study was kept at a distance of 0.4 m from the body and at a height of 1.4 m from the ground level and 3-4 m from the road for avoiding any reflections from road side barriers. The measurement of sound pressure in dB (A) was done along with the monitoring of the average speed of vehicles with the speed gun (Make: Bushnell) and numbers of vehicles were counted manually. Precision digital sound level meter helped in measuring L_{eq} and statistical parameters *e.g.* L_{10}, L_{50}, L_{90} etc. Short term, L_{AeqT} measurements ranging from 15 minutes to 60 minutes were undertaken at different busy road locations of Delhi. The measurements were conducted using a Norsonic, Nor 118 sound level analyzer and B&K 2250 sound level meter. While conducting the measurements, it was ensured that there is no reflection from the adjoining building facades or wall. It may be noted here that the recent studies conducted by Maruyama *et al*. shows that a minimum 170 number of vehicles is enough for obtaining a reliable L_{AeqT} during measurement time interval T [19].The equivalent traffic flow is calculated as:

$$Q_{eqv} = Q_{Car} + Q_{2W}\times E_{2W} + Q_{MCV}\times E_{MCV} + Q_{3W}\times E_{3W} + Q_{Bus}\times E_{Bus} + Q_{Truck}\times E_{Truck} \quad (1)$$

where Q_{Car}, Q_{2W}, Q_{MCV}, Q_{3W}, Q_{Bus} and Q_{Truck} are the total volume of car, two-wheelers, medium commercial vehicles, three-wheelers, bus and trucks respectively, while the values of E_{2W}, E_{MCV}, E_{3W}, E_{Bus} and E_{Truck} are measured as 1.13, 1.67, 2.36, 7.33 and 8.97 respectively as shown in Fig 1.

The equivalent vehicle speed is calculated as:

$$S_{eqv} = (Q_{Car}V_{Car} + Q_{2W}\times E_{2W}\times V_{2W} + Q_{MCV}\times E_{MCV}\times V_{MCV} + Q_{3W}\times E_{3W}\times V_{3W} + Q_{Bus}\times E_{Bus}\times V_{Bus} + Q_{Truck}\times E_{Truck}\times V_{Truck})/ Q_{eqv} \quad (2)$$

where V_{Car}, V_{2W}, V_{MCV}, V_{3W}, V_{Bus} and V_{Truck} are average speed of car, two-wheelers, medium commercial vehicles, three-wheelers, bus and trucks respectively.

The objective function based upon the three parameters is thus defined as:

$$L_{eq} = A + B\times\log Q_{eqv} + C\times\log V_{eqv} + D\times(V_{eqv}-50) \quad (3)$$

where L_{eq} is the predicted equivalent continuous sound pressure level and Q_{eqv}, V_{eqv} are equivalent traffic volume and equivalent traffic speed. A, B, C and D are the constants whose value is to be computed.

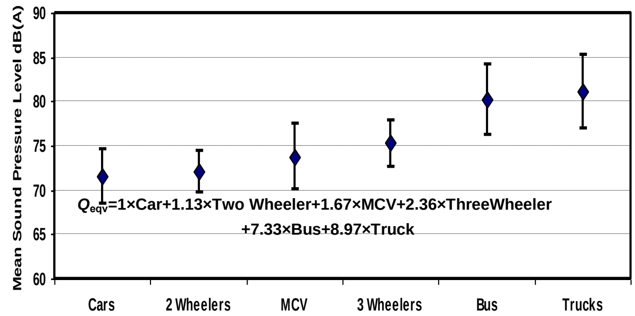

Fig. 2. Mean sound pressure level emitted by various vehicles in Delhi roads for acoustic equivalence of various vehicles in terms of Passenger Car Noise Equivalent, *PCNE* (or *E*).

Multiple Regression Analysis

Multiple linear regression analysis is an extension of simple linear regression. It is used to predict the value of a variable based on the value of two or more other variables. The variable desired to be predicted is called the dependent variable. Additionally, multiple linear regression approach also facilitates the determination of the overall fit of the model and the relative contribution of each of the predictors to the total variance explained. Standardized regression coefficients (constants) are a measure of how strongly each predictor variable influences the criterion variable. It can be generalized as:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \varepsilon \quad (4)$$

where β is coefficient of each term, k is number of independent variables and ε is error. The coefficient of multiple determination is calculated as:

$$R^2 = 1 - \frac{SS_e}{SS_T} \quad (5)$$

where SS_e is Sum squared error and SS_T is sum squared total error. R^2 indicates the proportion of the variability in the observed responses that can be attributed to changes in the predictor variables [20].

The analysis of experimental data shows that sound pressure level L_{AeqT} varied from 72 to 81 dB (A) at various locations. Predicted values were computed by the empirical formula using software tool (SPSS Downloaded version v 20). No constraints were considered for estimating parameters A, B, C and D and iteration rate is taken as 500. The non-linear regression parameters estimation is run. Table 2 represents the results of non-linear parameters estimates in L_{Aeq} determination in terms of Q_{eqv}. The final empirical formulations are derived as equations (6) to (9) in terms of equivalent traffic flow, Q_{eqv}.

$$L_{Aeq} = 67.969 + 4.165\log Q_{eqv} - 3.857\log V_{eq} + 0.077(V_{eq}-50) \quad (6)$$

$$L_{10} = 71.639 + 3.627\log Q_{eqv} - 4.176\log V_{eq} + 0.024\,(V_{eq}-50) \quad (7)$$

$$NPL = 73.454 + 5.532\log Q_{eqv} - 6.881\log V_{eq} + 0.069(V_{eq}-50) \quad (8)$$

$$TNI = 55.382 + 6.785\log Q_{eqv} - 8.971\log V_{eq} + 0.047(V_{eq}-50) \quad (9)$$

Table 2. Results of non-linear parameter estimation in L_{Aeq} determination in terms of Q_{eqv}

Parameter	Estimate	Std. Error	95 % Confidence Interval	
			Lower Bound	Upper Bound
A	67.969	14.320	39.640	96.299
B	4.165	0.398	3.377	4.953
C	-3.857	8.707	-21.083	13.369
D	.077	0.093	-0.107	0.261

The model goodness of fit is ascertained by paired *t*-test [10, 21, 22]. The test statistic (*t*-stat) value is compared with the *t*-critical and in case the *t*-stat value is within ± *t*-critical value for the two tailed test, then there is no significant difference between the two samples (accept the null hypothesis).

It can be observed from table 3 that the *t*-stat value is less than and far away from the critical value and is within the non-rejection region, which shows that the predicted traffic noise level fits well with the experimental data at 5 % significance level. Fig 3 shows the comparison of measured and predicted noise levels for the multiple regression model in terms of Q_{eqv}. The predicted sound pressure levels are within ± 2 dB(A) as compared to the measured values for the model.

Table 3. Paired *t*-Test for Measured & Predicted $L_{Aeq,T}$

Parameters	*Measured Values*	*Predicted Values*
Mean	76.46	76.46
Variance	1.76	1.07
Observations	134	134
Pearson Correlation		0.74
Hypothesized Mean Difference		0
Df		133
t Stat		0.002
P(T<=*t*) one-tail		0.499
t Critical one-tail		1.656
P(T<=*t*) two-tail		0.998
t Critical two-tail		1.98

The analysis of predicted data in comparison to the measured sound pressure level shows that the difference from measured value is within ± 2 % with average difference of 0.26 % for 40 samples. It may be noted here that the coefficient of determination, R^2 for the predicted model is 0.54 owing to the uncertainties induced due to honking noise, ground reflections, reflection from building facades, meteorological parameters, road surface corrections etc. Also the concept of acoustic equivalence may induce some uncertainties due to variable vehicular speed owing to the intermittent or free-flowing characteristics. It may be noted here that average vehicular flow calculated with E=1 for each vehicle also has some limitations as it is observed that the percentage heavies ranges from 1.5 % to 12.4 %. Consequently, the average speed is more influenced by light vehicles as the light vehicles are the major contributor of traffic flow, which has been also reported in previous studies [7]. However, the present model in conjunction with the sound propagation part as followed in ISO 9613-2 [23] can be used to predict the traffic noise levels with an accuracy of ± 2 dB(A).

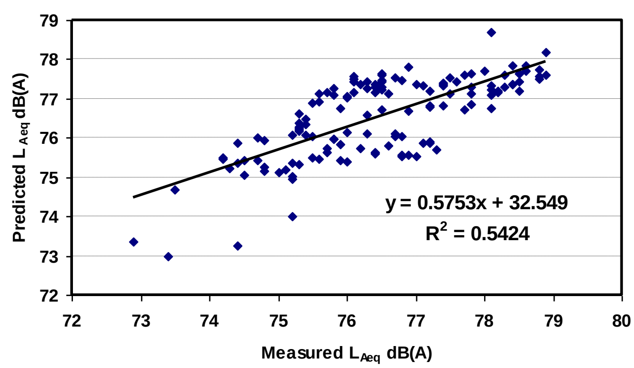

Fig 3. Predicted versus Measured $L_{Aeq,T}$ for multiple regression model in terms of Q_{eqv}.

Conclusions

A traffic noise survey is conducted on various sites in Delhi and a multiple linear regression approach is used to fit the data for development of a model. The experimental data was collected from various locations at various times during the day. The traffic density, average speed of vehicles and percentage heavies were simultaneously monitored along with the traffic noise. A multiple linear regression approach was utilized to develop a model using software tool SPSS (Downloaded free version v-20). The present model follows a generalized approach of modelling traffic noise without considering the geometrical propagation of sound waves and receiver locations, which may induce uncertainty in predictions. This model in conjunction with distance correction, road surface gradient correction, noise barrier correction, road surface condition correction, ground absorption correction can be thus a good substitute for modelling traffic noise and reliable predictions within an accuracy of ± 2 dB(A). It is imperative to further extend these studies for developing a validated model which can be very helpful in predicting the noise levels rampant at various locations and identification of hot spots so as to devise and plan suitable measures to control the traffic noise in Delhi city.

Acknowledgments

Author thanks M. Tech scholars of NIT Kurukshetra, Mr. Manish, Mr. Manoj, and Mr. Rahul for helping in noise monitoring around various sites. Authors also thank Mr. Anil Kumar, Head, Mass Standards, CSIR-NPL for his constant support and guidance. The financial grant allocation by CSIR-NPL under project *NWP*-45 & *OLP* 071132 for procurement of noise monitoring facility and softwares is acknowledged.

References

[1] Hindustan Times, New Delhi, Where all roads lead to chaos, May 07, 2013.

[2] Garg N and Maji S, A crticial review of principal traffic noise models:Strategies and implications, Environmental Impact Assessment Review, 46 (2014) 68-81.

[3] Kephalopoulos S., Paviotti M., F Anfosso-Lèdèe F., 2012. Common noise assessment methods in Europe (CNOSSOS-EU), 1-180.

[4] Rao P and Rao S., Prediction of L_{AT} Traffic Noise Levels in the City of Visakhapatnam, India, Applied Acoustics, (1991) 101-110.

[5] Nirjar R. S., Jain S. S., Parida M., Katiyar V. S. and Mittal N., A study of transport related noise pollution in Delhi, Journal of the Institute of Engineers (I)- Environment, 84, 6-15.

[6] Rajakumara H. N. and Gowda R. M. M., Road traffic noise pollution model under interrupted traffic flow condition, Environmental Monitoring Assessments, 14, 2009, 251-257.

[7] Agarwal S. and Swami S. L., Comprehensive approach for the development of traffic noise prediction model for Jaipur City, Environmental Monitoring Assessment, 2011, 113-120.

[8] Kalaiselvi R. and Ramachandraiah A., A model for traffic noise prediction in heterogeneous traffic conditions, International Journal of Current Research, 4, 2012, 180-184.

[9] Agarwal S., Swami B. L. & Gupta A. B., Development of a noise prediction model under interrupted traffic flow conditions: A case study for Jaipur city, Noise and Health, 11, (2009) 189-93.

[10] Kumar P., Nigam S. P. and Kumar N., Vehicular traffic noise modelling using artificial neural network approach, Transportation Research Part C, 40 (2014) 111-122.

[11] Kumar K, Katiyar V K, Parida M and Rawat K, Mathematical modeling of road traffic noise prediction, International Journal of Applied Maths and Mech, 7 (2011) 21-28.

[12] Calixto A, Diniz F B and P H T Zannin, The statistical modelling of road traffic noise in an urban setting, Cities, 20 (2003) 23-29.

[13] Sharma A, Bodhe G L and Schimak G, Development of a traffic noise prediction model for an urban environment,Noise Health, 16 (2014) 63-67.

[14] Rahmani S, Mousavi S M and Kamali M J, Modeling of road-traffic noise with the use of genetic algorithm, Applied Soft Computing, 11 (2011) 1008-1013.

[15] Bengang Li, Shu T, Dawson R W, Cao J and Lam K, A GIS based road traffic noise prediction model, Applied Acoustics 63 (2002) 679-691.

[16] Central Pollution Control Board (CPCB), Noise limits for vehicles applicable at manufacturing stage, April, 2005. *http://cpcb.nic.in/divisions of head office/pci2/Moise-vehcile.pdf*.

[17] To W M, Ip R C W, Lam G C K and Yau C T H, A multiple regression model for urban traffic noise in Hong Kong, Journal of Acoustical Society of America, 112 (2002) 551-556.

[18] Givargis Sh and Mahmoodi M, Converting the UK calculation of road traffic Noise (CORTN) to a model capable of calculating L_{Aeq}, 1h for the Tehran's roads, Applied Acoustics, 69 (2008) 1108–1113.

[19] Maruyama M, Kuno K and Sone T, The minimum measurement time for estimating L_{AeqT} of road traffic noise from the number of vehicle pass-bys, Applied Acoustics, 74, 2013, 317-324.

[20] *http://www.public.iastate.edu/~maitra/stat501/lectures/MultivariateRegression.pdf.*

[21] Pamanikabud P, Vivitjinda P, Noise prediction for highways in Thailand, Transportation Res. Part D, 7 (2002) 441-449.

[22] Montgomery D C, Runger G C, Applied Statistics and Probability for Engineers, J. Wiley and Sons Inc., USA, Fifth Edition, 2011, Chapter 10, 351-394.

[23] ISO 9613-2:Acoustics-Attenuation of sound during propagation outdoors-Part 2: General method of calculation, 1996.

Mr. Naveen Garg is working as a Senior scientist in CSIR-National Physical Laboratory, New Delhi, India. He has been working in CSIR-NPL since year 2004 in the field of maintenance of primary standards of sound pressure and vibration amplitude, sound transmission loss and absorption characteristics of acoustical materials and noise and vibration abatement and control and played a leading role in getting the NPL,India Calibration and Measurement capabilities (CMCs) for parameters 'sound' and 'vibration' published in Key comparison data base (BIPM) website. He has been involved in various consultancy projects pertaining to noise and vibration abatement and control. He has also spent some time in PTB, Germany, NIMT, Thailand, KIM-LIPI, Indonesia for getting training in acoustic and vibration metrology and has published many papers in national and international journals.

Prof Dr. Sagar Maji is Principal of G. B. Pant Engg. College, New Delhi. He is B. Tech, M.E and PhD is Mechanical Engg. Earlier he had been working as a Professor in Mechanical Engg, Deptt. in Delhi Technological University (DTU), Delhi and also served as Dean, IRD in DTU. He is an eminent academician and researcher and has published many papers in national and international journals and also guided several PhDs. He is active member of many academic bodies in India and has provided consultancies in field of performance and emission characteristics of IC engines.

Sanjay Kumar Mangal is working as Associate Professor in Mechanical Engg. Department, PEC University of Technology Chandigarh. He has received his B.E. degree in Production Engg. from Punjab Engineering College, Chandigarh in 1988 and M. E. in Mechanical Engg. from IIT, Roorkee in 1990. He has obtained his Doctoral of Philosophy in Mech. Engg. from I.I.T. Kanpur in 2000. His field of interest is FEM and vibration control. He has 22 years of teaching and research experience and published various papers in international and national journals. He has guided more than 15 M. Tech thesis. He is a life member of Indian society for technical education (I.S.T.E.), India and Associate member of Institution of Engineers (A.M.I.E) Kolkata, India.

Puneet Dhiman is currently pursuing his ME in Mechanical Engineering from PEC Univesity of Technology,Chandigarh. He has received his B. Tech degree in Mechanical Engineering from NIT Hamirpur in 2012. His academic interest areas includes Mathematical Modelling and Optimization, Manufacturing Processes and Artificial Neural Networks.