Determination of exhaust sound pressure levels emitted by road vehicles in Sri Lanka

C.L. Perera [1]*, C.P. Abeyratne[1] and C.M.[2] Kalansuriya

[1] Department of Physics, Faculty of Applied Sciences, University of Sri Jayewardenepura, Sri Lanka.
[2] Noise and Vibration Section, Industrial Technology Institute, No 363, Bauddhaloka Mawatha, Colombo 07, Sri Lanka.
*****chathralochanie@gmail.com*

ABSTRACT

Vehicle noise is the most widespread source of noise pollution in Sri Lanka. Exhaust noise is a major component of total noise generated by a vehicle. There is no regulation enforced in Sri Lanka to control vehicle exhaust noise. Therefore, this study was done with the purpose of addressing this issue. Exhaust sound pressure levels (ESPLs) of a sample of stationary vehicles were measured in accordance with ISO 5130:2007 along with influencing factors of ESPL. The principle findings revealed that ESPLs of automatic transmission, hybrid and petrol engine vehicles are lower than those of other vehicles. ESPLs of several stationary road vehicles exceeded the maximum permissible noise limits specified in international regulations. Finally, baseline data were established using the results obtained from statistical analysis, to introduce regulations to Sri Lanka, so that the vehicle owners will have to take steps to maintain the ESPLs of their vehicles at appropriate levels.

1. INTRODUCTION

1.1 Background and Significance

Due to increasing urbanization and traffic levels (rate), Sri Lanka is facing the impact of noise pollution. International environmental guidelines such as WHO guidelines, 1999 **[1]** and researches done locally on road traffic **[2]** indicate that vehicle noise can be significant. International regulations such as ECE R41 (Table 1), ECE R51, etc., specify maximum permissible noise levels for different categories of vehicles. Although, there are regulations enforced in other countries to control vehicle exhaust noise, there is no such regulation enforced in Sri Lanka. There is also no evidence of any preliminary study conducted, on the noise generated by exhaust systems of vehicles in Sri Lanka. Therefore, this study was conducted with the main objective of establishing baseline data for ESPLs emitted by stationary road vehicles.

Table 1- ECE Regulation 41: Noise limits of Category L vehicles (motorcycles) [8]

Power- to -mass ratio index (PMR)	Limit value for L_{urban} in dB(A)
PMR<= 25	73
25<PMR<=50	74
PMR>50	77

1.2 Vehicle Noise

The noise generated by vehicles depends on the following factors.

- Type and class of vehicle (e.g. cars, trucks, buses, motorcycles etc.).
- Quantity and quality of noise control incorporated into the vehicle design.
- Mechanical condition of vehicles (e.g. wearing of components, condition of exhaust silencer, engine tuning, etc.).
- The mode of operation of the vehicle (e.g. steady speed, gear setting).
- The condition of the road surface.

Figure 1 shows the important sources of vehicle noise and this study mainly focuses on exhaust noise of vehicles.

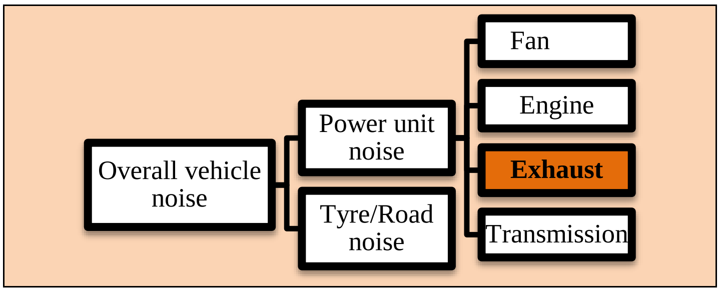

Figure 1- The sources of noise generated in a road vehicle

1.3 Exhaust system and Exhaust sound pressure level (ESPL) of a vehicle

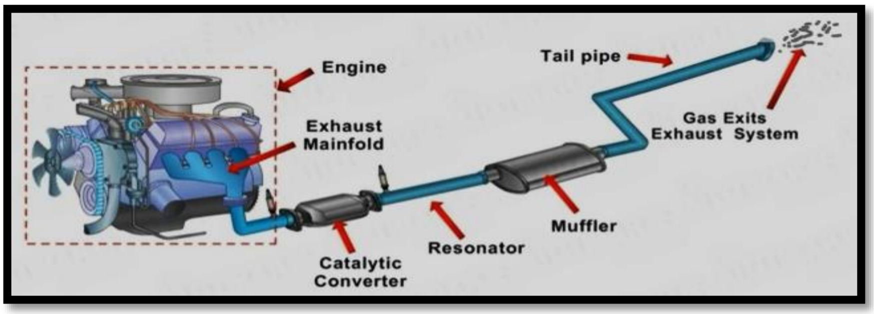

Figure 2- Exhaust system of a vehicle

The exhaust system (Figure 2) has a direct influence on engine efficiency and surroundings. It is located from the engine compartment to the back of the vehicle, generating the exhaust noise. The main purpose of it is to silence the levels of noise due to the high pressure hot and toxic gases leaving the engine.

The influence of damaged exhaust system of vehicles has observed an increase of ESPL and drastically reducing after the repair **[3]**. The contribution of exhaust noise to total vehicle noise has significant for all engine speeds. An increasing trend of ESPL with increasing engine speed has also identified **[4]**. The frequency distribution pattern for exhaust noise emitted by a gasoline engine has significantly increased with increasing engine speeds. Also it has identified that this higher noise will affect mostly the young people who can hear frequencies between 20 Hz to 20000 Hz and recommended implementing strategies to effectively reduce engine exhaust noise **[5]**. Exhaust systems often need to maintain (replace) to prevent corrosion. Very often, these defective exhaust systems are replaced with modified exhaust systems, which do not comply fully with specifications stated by the manufacturer of the vehicle. The reason for fitting non-standard exhaust systems is mainly to enhance engine power, but it will result in an increase in exhaust noise. The measurement of ESPL for a motorcycle has compared with the 'reference stationary noise level', which has specified by the manufacturer in the 'reference label' of the motorcycle and observed that the noise level of motorcycle has been exceeded the reference noise level. The reason for this case has identified as the changes done to the exhaust system of the motorcycle which have resulted in an increase of noise level **[6]**. The measurements of two vehicles of category M were compared with the ECE R51 noise limits and the limits were exceeded. As there were no defects in the engine and exhaust system operation, these results confirmed that ESPL is greater than the exterior noise of a moving vehicle. Further, it is inaccurate to compare ESPL with maximum permissible noise limits as prescribed in ECE R41 and ECE R51 **[6]**.

2. RESEARCH METHODOLOGY

2.1 Data Collection

This study was conducted at the premises of ITI, Colombo 07. An outdoor site with a dense asphalt surface within the ITI was chosen for the test site. A type 2250 sound level meter manufactured by Bruel & Kjaer, which meets the requirements of a Class 1 instrument was used to take the measurements (Figure 3) and a 'Class 1' acoustic calibrator, was used to calibrate the sound level meter.

Figure 3- Sound level Meter type 2250 produced by Bruel & Kjaer

Data related to a sample of 101 vehicles entered ITI premises for various purposes were collected on week days (Monday to Thursdays) from July to September 2017. The ESPLs of following vehicle categories as specified in ISO 5130:2007 were analyzed.

- <u>Vehicle category L</u>-Motor vehicles with less than four wheels (motorcycles)
- <u>Vehicle category M</u>-Power driven passenger vehicles (cars, SUVs and vans)
- <u>Vehicle category N</u>-Power driven commercial vehicles (lorries and double cabs)

A questionnaire survey was conducted among all the sample vehicle drivers to obtain influencing factors of ESPL. This was consisted of two parts as shown in Table 2. Relationships among these factors were obtained by using Microsoft Excel, considering ESPL as dependent variable and influencing factors as independent variables. Correlation and multiple regression analysis were done using data analysis tools used in Microsoft Excel.

Table 2- Questionnaire

Part A	Part B
• Class of vehicle: Motorcycle/Car/Van/ Double cab/SUV/Lorry • Make and Model: • Year of manufacture: • Condition at the time of registration: Brand new/Pre-owned (Reconditioned/ Second hand)	• Type of gear box: Manual/Automatic • Hybrid vehicle: Yes/No • Fuel type: Petrol/Diesel • Exhaust system type: Original/Modified • Mileage: • Rated engine power: • Displacement:

2.2 Test Procedure in measurement of ESPLs

i. Positioning and preparation of the vehicle-The vehicle transmission was set in neutral position for manual transmission or in parking position for automatic transmission.

ii. Microphone position-The microphone was located approximately at a distance of 0.5 m from the exhaust pipe and approximately at an angle of 45^0 (Figure 4). The microphone was kept at a height of approximately 0.2 m from the ground surface.

iii. ESPL measurements-Taken while accelerating up to the relevant Target Engine Speeds, as specified in ISO 5130:2007.

(a) (b)

Figure 4- Position of cars at the test site and the microphone position

3. RESULTS AND DISCUSSION

According to Figure 5, ESPL measurements of motorcycles are below the limits specified in India, ECE R41, and Central Motor Vehicle noise. The reason for this behavior is these maximum permissible limits are enforced to moving vehicles and as indicated in the literature review, ESPL is greater than the exterior noise of a moving vehicle **[6]**. Several motorcycles have exceeded noise limits specified in Japan and Australia. Similarly, ESPL measurements for other two categories were compared with limits specified in international regulations.

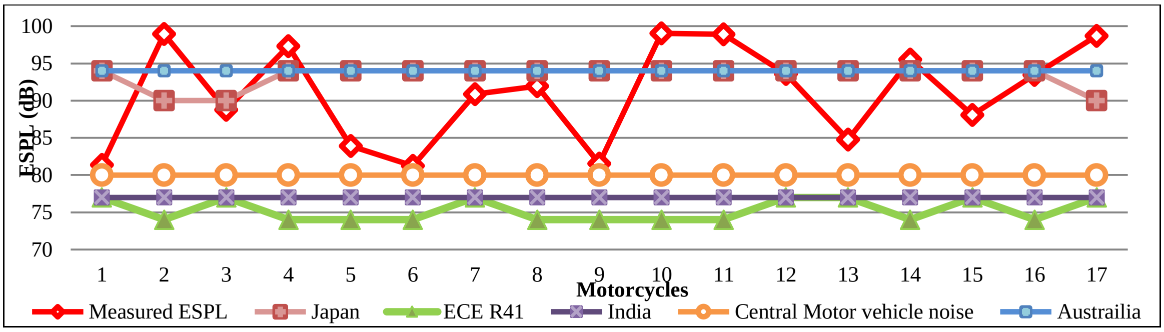

Figure 5- Comparison of ESPLs of motorcycles with noise limits specified in international regulations

Linear regression analysis was performed to determine coefficient of determination (R^2) between ESPL and influencing factors. According to Figure 6, weak negative and positive relationships are obtained between ESPL with year of manufacture and mileage, respectively for passenger vehicles. Similarly, due to poor maintenance or repairs in the exhaust systems of vehicles, these patterns were observed for other two categories as well. Then, a statistical analysis was conducted to determine the cumulative percentages of vehicles that lie above (or below) a particular ESPL.

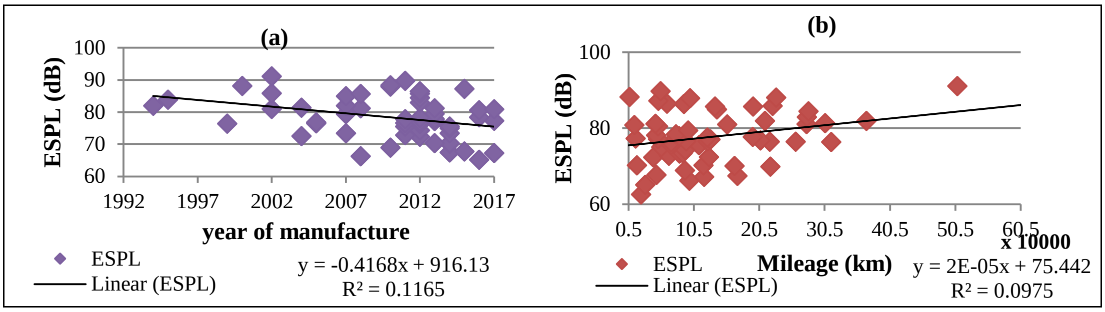

Figure 6- Relationship between ESPL with (a) year of manufacture (b) mileage for passenger vehicles

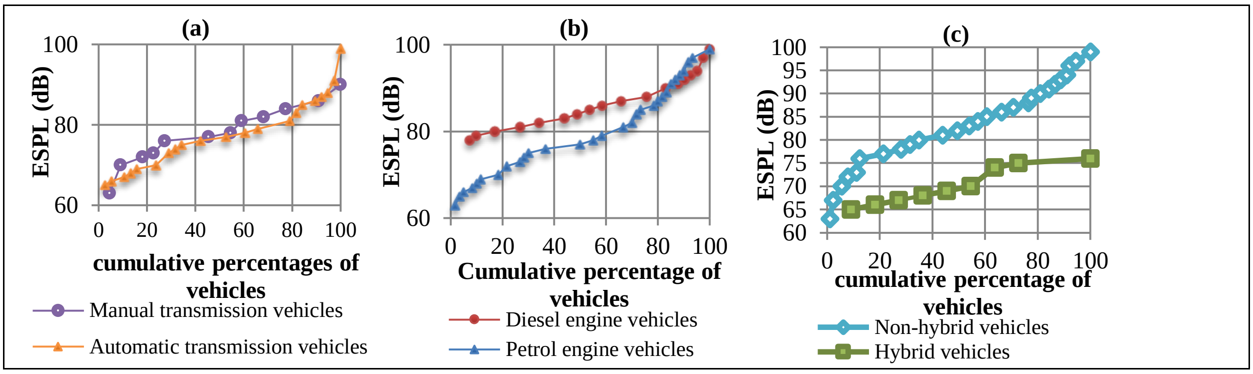

Figure 7- ESPL vs. Cumulative percentages of vehicles with (a) manual and automatic transmissions (b) Petrol and Diesel engines (c) hybrid and non-hybrid vehicles.

For the ESPLs in the range 65 dB to 87 dB, the cumulative percentages of automatic transmission vehicles are lower than those of manual transmission vehicles (Figure 7(a)). This may be due to catalytic converters and torque converters provided in those vehicles. As seen in Figure 7(b), for a given ESPL up to 90 dB, the cumulative percentages of diesel engine vehicles are higher than those of petrol engine vehicles. This may be due to the difference in the way energy is released during fuel combustion. Because of the higher compression ratio of diesel engines (20:1) as compared to petrol engines (8:1), the higher vibrations produced during fuel combustion and hence emit more noise. The cumulative percentages of hybrid vehicles for a given ESPLs are lower than non-hybrid vehicles, as indicated in Figure 7(c), probably due to absence of engine noise in them when running on battery mode.

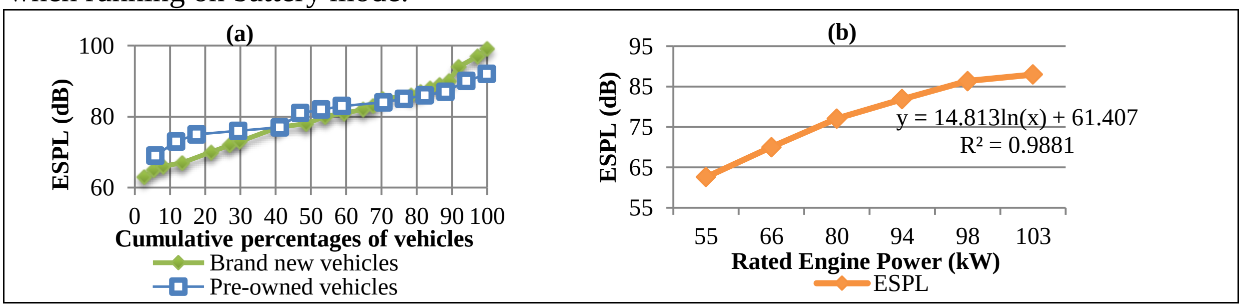

Figure 8- ESPL Vs (a) Cumulative percentages of brand new and pre-owned vehicles (b) Rated Engine Power of vehicles with modified exhaust systems.

As shown in Figure 8(a), cumulative percentages of brand new vehicles which have ESPLs below 85 dB are lower than those of pre-owned vehicles. But for ESPLs beyond 85 dB, cumulative percentages of brand new vehicles are higher than those of pre-owned vehicles. The reason for this behavior was identified as the modifications done to the exhaust systems of brand new vehicles. Figure 8(b) shows an increase of ESPL with the Rated Engine power of vehicles which have modified exhaust systems. The reason for fitting non-standard exhaust systems is mainly to enhance engine power, but it will result in an increase in exhaust noise.

Then a correlation analysis was performed to indicate both the direction and strength of relationship between ESPL and the influencing parameters. Correlation coefficients between 0.5 and 1 were considered to be reasonable. According to Table 3, it is found that, ESPLs of passenger and commercial vehicles are having good correlations with gross vehicle weight (GVW) & Rated Engine Power (P) and of motorcycles with displacement.

Table 3- Correlation coefficients for the three vehicle categories

Factors affecting ESPL	**Correlation coefficients with ESPL**		
	Motorcycles	**Passenger vehicles**	**Commercial vehicles**
Year of manufacture	0.2	-0.3	0.0
Target Engine Speed	0.6	0.0	-0.1
Mileage	-0.2	0.3	0.3
GVW	0.2	**0.7**	**0.5**
Rated engine power (P)	-0.3	**0.5**	**-0.5**
displacement	**-0.5**	0.5	-0.1

Multiple regression analysis was carried out to identify a functional relationship between ESPL and its influencing factors. As given in Table 4, the most significant factors ($p<0.05$) that were identified are the condition of vehicle when registered, type of gear box, fuel type, GVW and target engine speed, rated engine power and displacement.

Table 4 - Results of the multiple regression analysis

Variables	**Coefficients**	**P-value**
Intercept	56.19	0.01
Year of Manufacture	-0.19	0.24
Condition of vehicle when registered	3.67	**0.04**
Type of Gear box	4.29	**0.03**
Hybrid vehicle or not	-2.78	0.25
Fuel Type	-6.09	**0.04**
Type of exhaust system	0.10	0.97
Target Engine Speed	5.31	**0.00**
Mileage	0.03	0.68
GVW	6.08	**0.04**
Rated Engine Power (P)	7.13	**0.02**
displacement	4.02	**0.04**

Therefore, the same factors were taken for establishment of baseline data. In order to finalize the noise limits, normal distribution curves with frequency histograms were drawn for each category (Figure 9). The criteria followed in deciding on the baseline data are indicated below;

a. When the highest ESPL is within the highest frequency interval, then the highest ESPL is selected as the baseline data for that particular category (Figure 9(a)).
b. When the mean ESPL is lower than the highest frequency interval (s), then the higher value in that interval is considered as the baseline data for that particular category (Figure 9(b)).
c. When the mean ESPL is higher than the highest frequency interval (s), then the mean ESPL is considered as the baseline data for that particular category (Figure 9(c)).

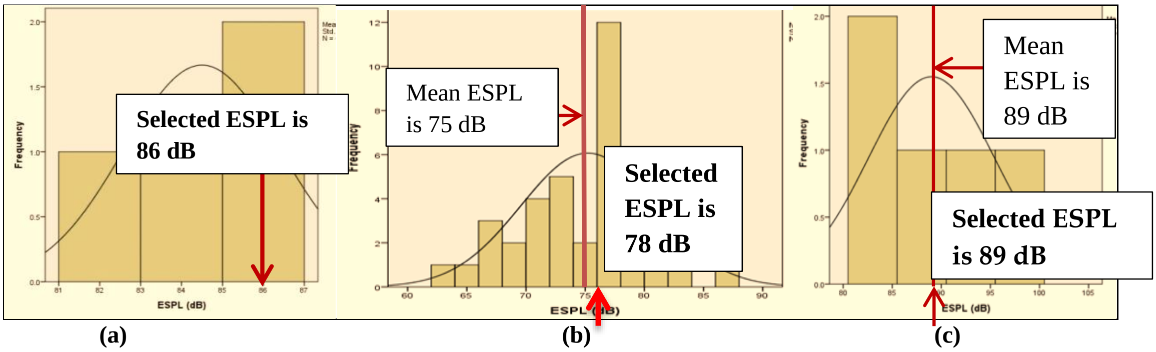

Figure 9- Normal distribution curve with frequency histograms

The limits for ESPLs of stationery vehicles have been indicated only in the Regulations of Japan and Australia. Therefore, established baseline data of ESPL were compared only with the limits specified in these Regulations as shown in Table 5. Established limits for motorcycles and one category of Commercial vehicles are higher than limits specified in those two countries.

Table 5- Comparison of established baseline data with limits specified in Regulations of Japan and Australia

Vehicle type	Description of the vehicle	Proposed limits (dB)	Limits specified in Japan (dB)	Limits specified in Australia (dB)
Motorcycles	50 cc<displacement≤125 cc	**99**	90	94
	125 cc<displacement≤250 cc	**99**	94	94
Passenger cars		78	96	90
Passenger vehicles	GVW≤3000 kg P≤ 100 kW	86	97	90
	GVW≤3000 kg P> 100 kW	89	97	90
	GVW>3000 kg P≤100 kW	90	97	90
	GVW>3000 kg P>100 kW	86	97	90
Commercial vehicles	GVW≤2000 kg	83	97	95
	2000 kg <GVW≤3000 kg P≤ 100 kW	94	97	95
	2000 kg <GVW≤3000 kg P> 100 kW	89	97	95
	3000 kg <GVW≤4500 kg P≤ 100 kW	88	98	95
	3000 kg <GVW≤4500 kg P> 100 kW	**97**	99	95

The main limitation of the study was the duration of the study limited to six months and hence data collection had to be completed within three months. Also, readings could be taken only from vehicles entering the ITI premises, therefore, readings could not be taken from buses as they did not enter the ITI premises although they produce more exhaust noise. Since, all the vehicles that entered the ITI did not have RPM meters, such data had to be disregarded and the sample size of these categories became low which also posed a limitation. Reliability of the sample is dependent on the information provided by the drivers and some of them were not aware of the exact details which can be stated as a third limitation. Some drivers were fear of accelerating up to the Target Engine Speed and the difficulty faced by them in accelerating up to the target engine speed & maintaining the acceleration at the target engine speed during measurements, was also a limitation.

4. CONCLUSIONS AND RECOMMENDATIONS

Vehicle noise is one of the main causes of environmental pollution experienced by people of many cities in Sri Lanka. ESPLs of some vehicles measured in this study were higher than the limits specified in international regulations. The ESPLs of automatic transmission vehicles are lower than those of manual transmission vehicles and ESPLs of diesel engine vehicles are higher than those of petrol engine vehicles. Modifications done to exhaust systems of vehicles, mainly to enhance power output will also increase its ESPL. ESPLs of hybrid vehicles on battery mode were found to be lower than those of non-hybrid vehicles. Therefore, it is recommended that the use of more environmentally friendly vehicles such as hybrid and electric vehicles be promoted. Baseline data that can be used to control noise pollution were identified using the measurements taken during the study.

It is recommended that annual measurement of ESPLs of vehicles be made mandatory along with their exhaust emission tests and both tests be carried out probably at the same test centers for the convenience of vehicle owners. It is recommended that when the readings exceed the baseline data, the vehicles be declared as defective, requiring effective repairs to reduce their exhaust noise. Also, it is recommended a regulation pertaining to ESPLs of road vehicles be introduced and strategies be implemented to control noise pollution in Sri Lanka. Finally, it is recommended that a regulation be drawn up, to ensure that its specifications related to ESPLs are available for verification whenever a new model of vehicle is to be imported to Sri Lanka.

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