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Research Article

Measurement of Noise within Passenger Trains on a Costal Railway Line

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Abstract

The noise levels within passenger trains operating on a coastal railway line is presented. It was found that the engine noise is the main source of traction noise. Its contribution to the overall noise level within the passenger compartments was analyzed, and, the effect of engine noise on the passengers has been discussed. Noise enhancement due to external objects in close proximity to the railway line was carried out in order to assess the total noise exposure of the passengers in a train traveling on the costal railway line. In general passengers are exposed to average noise levels around 75 dB which can reach 85 dB in passenger compartments close to the engine of the train. A simple noise prediction model is proposed which was successful in predicting the average noise level within passenger compartments in trains running between two adjacent stations along the selected coastal railway line.

Keywords: Railway noise, Environment regulations, Passenger trains, Sri Lanka railways

1. INTRODUCTION

Many studies based on European countries have shown that railway noise is less annoying than road traffic noise [1-2]. However, social surveys conducted in Japan have shown different results [3-4]. The difference in these results could be due to variation in parameters including the frequency of disturbance, time of disturbance, the distance at which buildings are constructed from the railway/traffic line, the quality of material used to construct the building etc. Compared to road traffic noise which persists for most part of the day, there is a tendency for people to tolerate railway noise which exits for shorter periods of times. But the situation is entirely different for passengers traveling for long

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distances in rail compartments with open windows since they are exposed to a high level of noise for a long period of time. Unfortunately, measurements of noise within passenger compartments are scares possibly due to the high variability of operating conditions. Literature show that in general, the studies have been carried out in the open country on good quality rail tracks which is far from the conditions experienced by average passengers [5].

Railway noise is generated from various track and vehicle components, such as the rail, the wheel, the engine or traction motors and other components. There are three major sources of railway noise: traction/auxiliary noise, rolling noise and aerodynamic noise [6-7].

For trains with diesel locomotives the dominant traction noise is the diesel engine noise. Diesel traction may comprise of a number of sources including exhaust noise, inlet noise, noise due to the structure of the engine, noise from compressors and cooling fans etc. Traction noise is the dominant noise for speeds below 60 km/h. When electric locomotives are considered, noise from the cooling system will usually be the dominant traction noise. Electric power units are much quieter, though noise is emitted from the traction motor and extra cooling fans. Pantograph noise is significant at high speeds. Compressors, ventilation and brake systems cause auxiliary equipment noise.

The rolling noise is caused by structural vibrations of the wheel, rail and sleepers induced by the combined roughness of the wheel and rail running surfaces which are increased by poorly aligned track joints and the roughness of the wheel. This is often dominant between 100 and 250 km/h. Aerodynamic noise, often referred to as wind noise, is a major component of passenger compartment noise, which becomes dominant for speeds over 300 km/h.

The main objective of this work is to measure the noise levels within railway passenger compartments under actual running conditions. In order to evaluate the level of noise experienced by an average passenger traveling in a train, noise levels within the passenger compartments were recorded while traveling in trains under varying external conditions. Modeling the noise levels within the passenger trains was carried out by studying the noise level variation due to acceleration and deceleration between two consecutive stations.

2. RAILWAY TRANSPORT IN SRI LANKA

The Sri Lankan Railway Network was introduced to the country by the British in 1864. The main reason for building a railway system in Sri Lanka was to transport Tea and Coffee from the hill country to Colombo. Initially the railway service began with the construction of the Main Line of 54 km from Colombo to Ambepussa. The railway line extended to Kandy in 1867. From 1880 to 1928, many other railway lines were added in stages to the main line extending it to many parts of the country including the 161 km long coastal line (see Figure 1). Most of the railway network was built on broad gauge at 5'6" with now almost non-existence sections of narrow gauge at 2'6" (dual gauged since 1991). The railway network was known as the Ceylon Government Railway (CGR), which was later changed to Sri Lanka Railways [8].

The Sri Lanka Railways was founded in 1986 as a government department. Since then, the Sri Lanka Railways has been responsible for the operation of the railway network in the country. By 1927, Sri Lanka had an operational rail track network of 1530 km. Today it operates a rail network of 1449 km, connecting 172 stations and 162 sub-stations

[9]. Since the railway track standards have remained virtually unchanged, the speed of trains has been limited to an official 50 mph though many engine classes are capable of running at higher speeds.

Sri Lanka railways had various types of locomotives in operation. They can be categorized as follows: Steam Engines, Diesel Hydraulic Locomotives, Diesel Electric Locomotives, Diesel Multiple Units and Diesel Rail Cars and Rail Buses. Diesel traction was first introduced in 1984. Today almost all the trains are diesel locomotives. Sri Lanka Railways operates over 300 rains daily with 140 running on the main line and 104 on the coastal line [9].

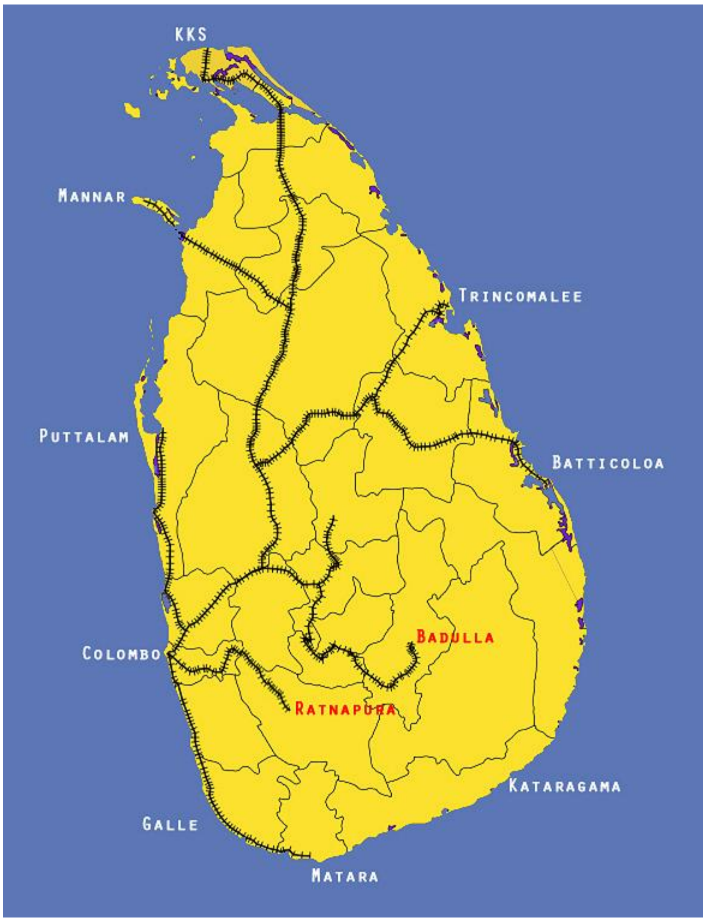


Figure 1: Sri Lanka Railway routes [10]

Although the railway network was initially built to transport Tea and Coffee from the hill country to Colombo, with population growth, passenger traffic increased and in the 1960's overtook freight as the main source of business. The Sri Lanka Railways is now primarily engaged in the transport of passengers, especially commuters to and from Colombo to different parts of the country [9]. However, since the railway network was not fully focused on population and service centers and the road network has expanded to cater to the growing demands, the contribution of railway services to the country's overall passenger and freight transportation is under 10%.

3. MEASUREMENTS

The section of the railway line selected for this work was the coastal railway line which stretches from Colombo to Bentota (roughly a 60 km stretch - halfway from Colombo to Galle). One side of the coastal line is directly open in many places to the sea. People live in shanties on either side of the railway tracks in a number of places. Shanties are common along the coastal line from Colombo to Panadura especially in areas such as Wellawatta, Korelawella, Egodauyana and Panadura. In some areas shanties are built very close to the railway track leaving less than a few meters of narrow space between the shanties and the railway track.

Noise measurements within passenger trains were taken from Colombo to Panadura traveling on trains that stop at every station from Colombo to Panadura. In addition, measurements were also taken from Colombo to Benthota traveling on express trains that stop at a limited number of stations. In all measurements, A-weighted equivalent continuous sound pressure level (L_{Aeq}) was measured for both 10-second and 1-minute integration.

Some measurements were taken within the passenger trains by moving from one passenger car to the next while the train was operating. The objective of taking measurements in different passenger cars was to find the contribution of traction noise to the overall noise level within the passenger trains. Since the passenger compartments are placed one behind the other with respect to the engine, higher noise levels are expected in passenger compartments closer to the engine. The study was carried out for class M (M7, M8, M9) diesel locomotive types and for class S (S8, S9) Diesel Multiple Unit (DMU) locomotives.

Figure 2: M7, M8 and M9 Diesel Locomotives (top) S8 and S9 DMU Locomotives (bottom) [11]

The sound level meters used in this work were RION NL - 04 and RION NL - 14. Both are basically identical in operation (approximately 25 to 130 dB with A weighting) and capable of measuring with an accuracy of ±0.1. Both sound level meters were calibrated using an electrical calibration method and an acoustical calibration method prior to the use.

4. RESULTS

4.1 Measurement of continuous noise levels

Figure 3 shows measured A-weighted sound pressure levels within passenger compartments of a M9 diesel locomotive traveling at an average speed of 40 km/h around 10.30 a.m. in the morning from Colombo Fort to Panadura. This locomotive stops at every station from Colombo to Panadura. The minima in the figure correspond to the noise levels within passenger compartments when the train is stopped at each of the stations. Acceleration and deceleration of the engine between consecutive stations generate the rising and trailing sections of the noise levels.

As seen from Figure 3, it is apparent that the noise level varies between 60 dB and 90 dB. This behavior is typical of diesel locomotive-hauled trains used in the selected coastal area. On average the background noise level in the selected coastal area is about 65 dB. The peak noise level increases by about 25 dB within the passenger compartments when the train is operating between stations. A typical passenger traveling by train in the coastal area is exposed to an average noise level of 75 dB which is 10 dB higher than the background noise levels.

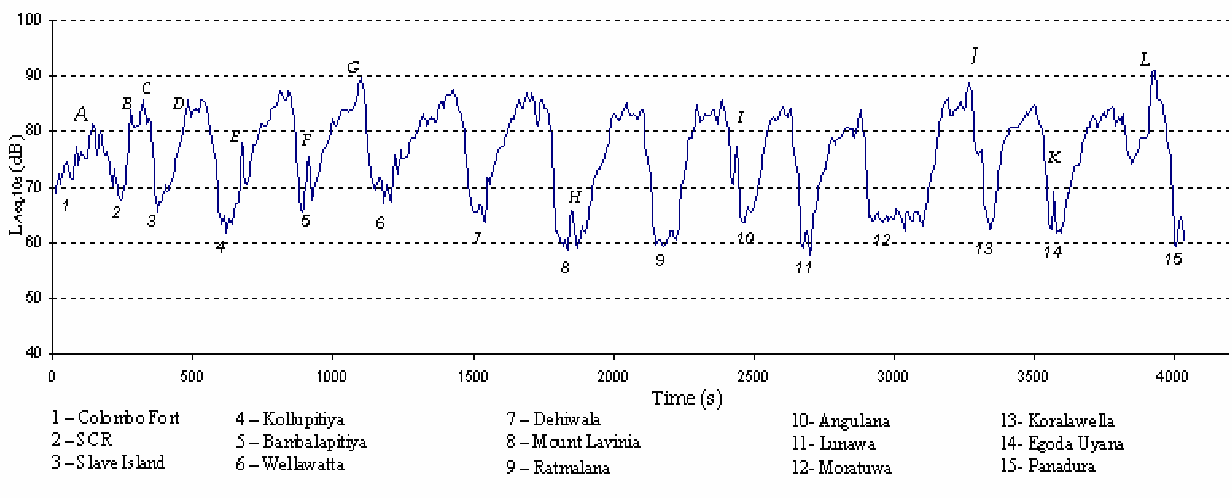


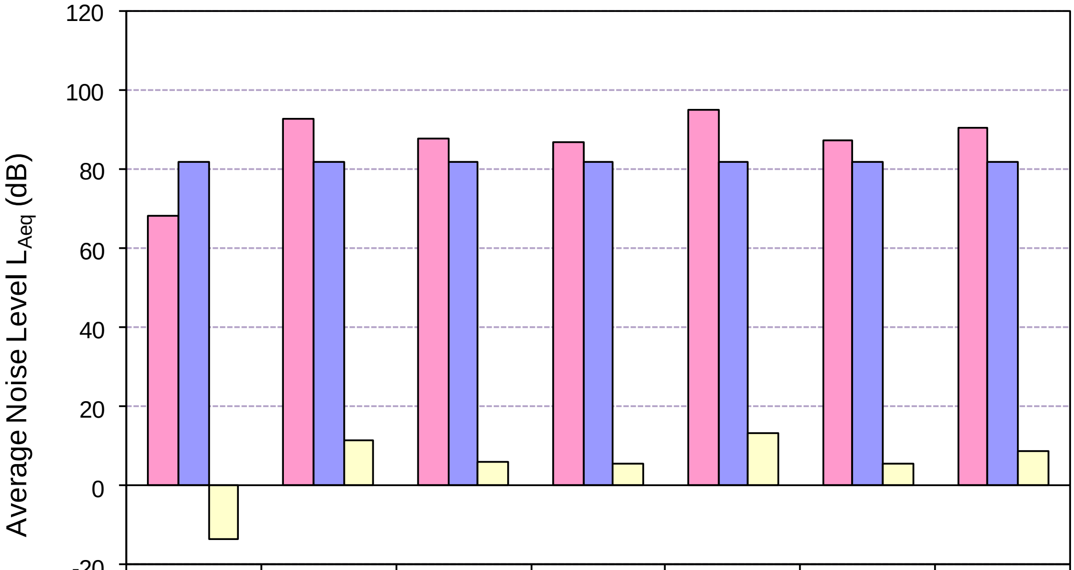
Figure 3: Noise levels for a M9 Diesel locomotive traveling from Colombo to Panadura. Minima in the figure correspond to the location of the stations.

In Figure 3, the high noise level (81.5 dB) at point A is due to a tunnel located in between the stations of Colombo Fort and SCR. At point B, buildings on both sides of the rail track have increased the noise level to 83.9 dB. High noise at points C and D are due to walls on one side of the rail track. At point E a significant vibration has increased the noise level to 77.9 dB. The noise increase at points F, H and K is due to the sound of the horn. At point G which is situated in between the stations of Wellawatta and Bambalapitiya, the increase in noise is due to the train traveling on a bridge. At point I, the reason for the noise level of 77.2 dB is due to another train passing in the parallel track in the opposite direction. The noise level of 88.8 dB at point J is due to the train traveling at a high speed. Point L near the Panadura station is due to a bridge; here the noise level has increased to 91.0 dB.

From the measurements given in Figure 3 it is clear that high noise levels exist within passenger compartments in Sri Lankan trains. In addition to traction noise, the external parameters can contribute to the increase in the noise level. Since the M9 train has open windows, the aerodynamic noise component within the passenger compartments is high. The railway track in the selected coastal area in Sri Lanka is not a smooth track and therefore rolling noise could easily contribute to the overall noise level.

4.2 Noise level due to external parameters

In order to assess the effect due to external parameters, noise level measurements were made from Colombo to Benthota traveling on an express train; an S9 DMU power car running at approximately 70 km/h on a weekday. The measurements were taken when the train was running through various locations having different physical parameters including bridges, buildings, cross tracks etc.



	when stopped at a station	both sides high rise buildings	on a bridge	train passed by	crossed tracks inside the station	on crossed tracks when moving	high speed
Noise level	68	92.9	87.8	87	94.9	87.2	90.5
Noise when moving	81.7	81.7	81.7	81.7	81.7	81.7	81.7
Noise enhancement	-13.7	11.2	6.1	5.3	13.2	5.5	8.8

Figure 4: Noise enhancement due to external parameters

Figure 4 shows the noise enhancement caused by different physical parameters compared to the average noise level of the train while traveling (81.7 dB). The highest noise enhancement of 13.2 dB is seen when the train was moving on crossed tracks inside a railway station. There is a significant increase (11.2 dB) in the noise level when the train is moving between high rise buildings located on both sides of the railway track. When the train passes over a bridge, the noise enhancement is about 6 dB. There is a noise level increase of about 9 dB when the train runs at a high speed. When another train travels in the opposite direction along the adjacent rail track, the inside noise level increased by 5.3 dB. Compared to the average noise level when the train is stopped at a station (68 dB), there is an enhancement of about 14 dB when the train is moving at an average speed of 70 km/h.

4.3 Speed and Noise Level

To assess the relationship between the speed of the trains and the noise level within passenger compartments, the noise level was measured for trains traveling at different speeds between stations having approximately the same distance between them and similar surroundings (external parameters) alone the railway tracks. The locations of the stations selected for this work were, Kollupitiya, Bambalapitiya, Wellawatta, Dehiwala, Mount Lavinia and Ratmalana.

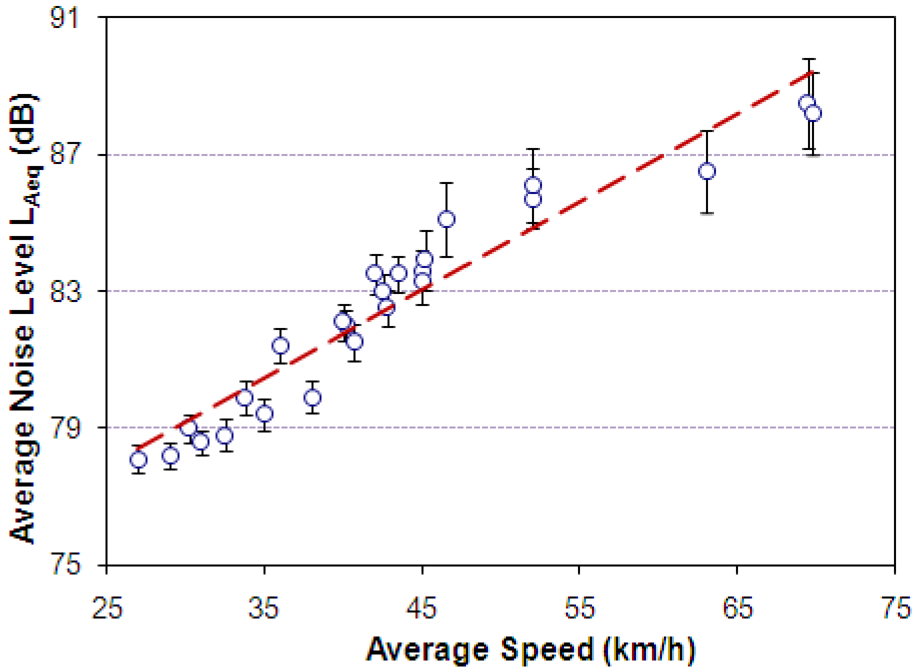


Figure 5: The average noise level within rail compartments as a function of train speed

Figure 5 shows the relationship between the average noise levels within the passenger compartments and the speed of the train. There is a linear relationship between the noise levels and the speed of the train with a correlation coefficient of 0.96. Equation 1 shows the relationship between the average noise level $\overline{N}$ and the average speed of the train $\overline{S}$.

$$\overline{N} = 0.26 \times \overline{S} + 71.4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Although the combination of traction noise, rolling noise and aerodynamic noise tends to produce an exponential relationship with the total measured noise levels with the speed of the train, within the limited speed range considered in this work (25 km/h to 75 km/h), both exponential and linear fits agree with the data set. An exponential fit to the same data produced;

$$\overline{N} = 72.18 \times \exp\left[0.003 \times \overline{S}\right] \quad \ldots\ldots\ldots\ldots\ldots(2)$$

with a correlation coefficient of 0.95. The data show that speed is an important parameter in the noise emission. Approximately, an increase of 10 km/h in the speed increases the noise level by 2.5 dB.

4.4 Contribution of Engine noise

For a class M9 locomotive, at the engine there is a noise level of 100 dB when it is stationary. In order to assess the situation while in service, noise measurements were taken in the guardroom (i.e. next compartment to the engine) as well as in different passenger compartments while the train was traveling from Colombo to Panadura. The average speed of the train was 35 km/h. The sound levels were recorded with 1 minute integrated A-weighted continuous sound pressure levels.

In Figure 6 the closed circles represent the noise levels measured in the guardroom (compartment adjacent to the engine) and the open circles represent the noise levels measured in the 5th passenger compartment. The thick lines in the figure show the variation when a 5-point moving average filter is applied to the noise measurements.

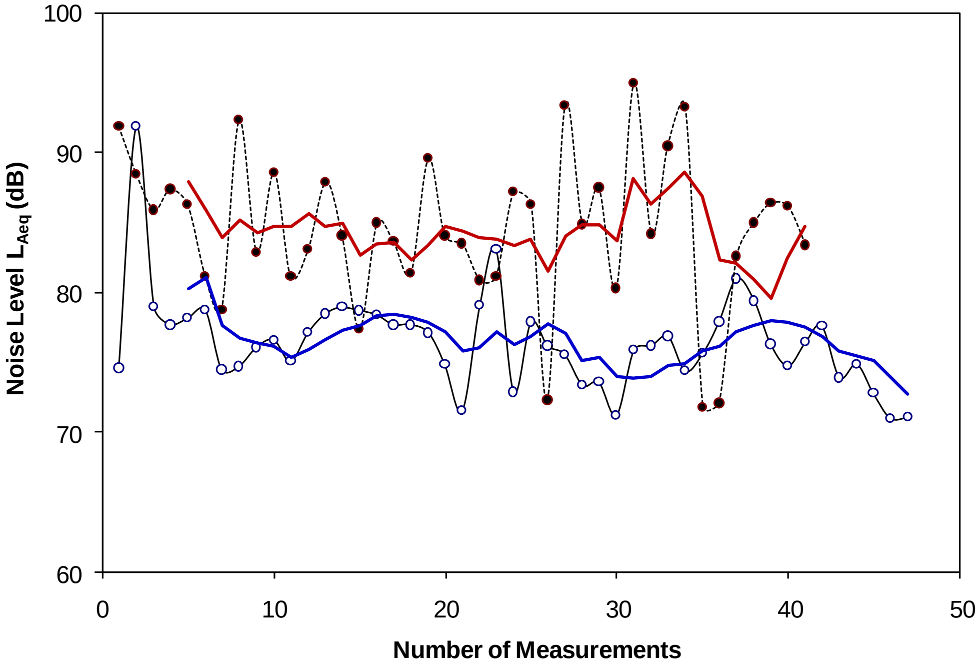


Figure 6: Comparing the noise level in the guardroom with the noise level in the 5th passenger compartment of a M9 locomotive running at an average speed of 35 km/h.

According to the data, the noise level in the guardroom is about 10 dB higher than the noise level in the 5th passenger compartment when the train is moving at an average speed of 35 km/h. Therefore the guard in the train is always exposed to a higher level of noise than the average passenger traveling in the train. Although the situation of the driver is not known, it can be concluded that the driver is exposed to a much higher noise level than the guard of the train. As far as passengers are concerned, they are better off occupying a passenger compartment at the tail end of the train a minimum amount of noise is present than in the front end, especially when the journey is long. However, if the train is equipped with air conditioned passenger compartments with sealed windows, the position within the train may not make any difference to the noise levels within the passenger compartments.

5. MODELLING NOISE LEVELS

Apart from the shift in the noise levels caused by external objects in close proximity to the railway track, the data also shows that there is a steady increase in noise during the acceleration phase and decrease in noise during the deceleration phase. This feature was exploited to model the average noise level as a function of time, in-between two adjacent stations along the coastal railway line for a class M or S train, which travels at an average speed of 40 km/h.

The general behavior of the noise level between two adjacent stations is common to most of the locations. Therefore to develop the model, the noise level distribution in between Slave Island and Mount Lavinia was selected. There are five stations in the selected section of the railway line. The distance in between these five stations is nearly equal and it was assumed that the physical parameters in the five locations are also the same. The data set was divided into two parts representing acceleration and deceleration. Due to the close proximity of the stations in the selected section, on average about 75% of the total time required for the train to travel from one station to the other is spent in the acceleration phase and the remaining 25% is spent in the deceleration phase.

5.1 Modeling the Acceleration

The data collected for the acceleration phase for the five locations in between Slave Island and Mount Lavinia are shown on Figure 7. The time axis was normalized to represent 0 (start time) and 1 (end acceleration) in order to combine the data extracted from the different parts of the journey (i.e., when the train traveled between different pairs of stations).

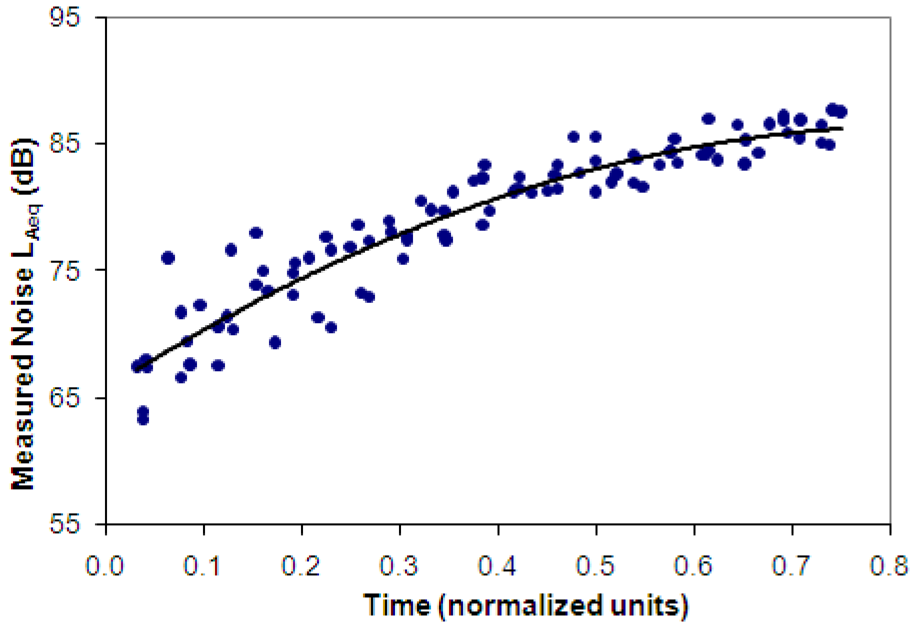


Figure 7: Noise levels during the acceleration phase as a function of time

The average noise level during the acceleration phase can be modeled by a 2nd degree polynomial

$$\overline{N}_A = -29.42 \times T^2 + 49.46 \times T + 65.69 \quad \text{.........................(3)}$$

with a correlation coefficient of 0.89 and a standard deviation of 2.0 dB.

To check the reliability of the proposed model for acceleration, the measured noise levels and the noise levels predicted by the model were compared using an unused data set taken in the same journey. The data that was not used for predicting the model are the measured noise levels of three stations situated further down the railway line (.i.e., between Mount Lavinia and Lunawa). This part of the railway line is also similar to the first part selected for the model development.

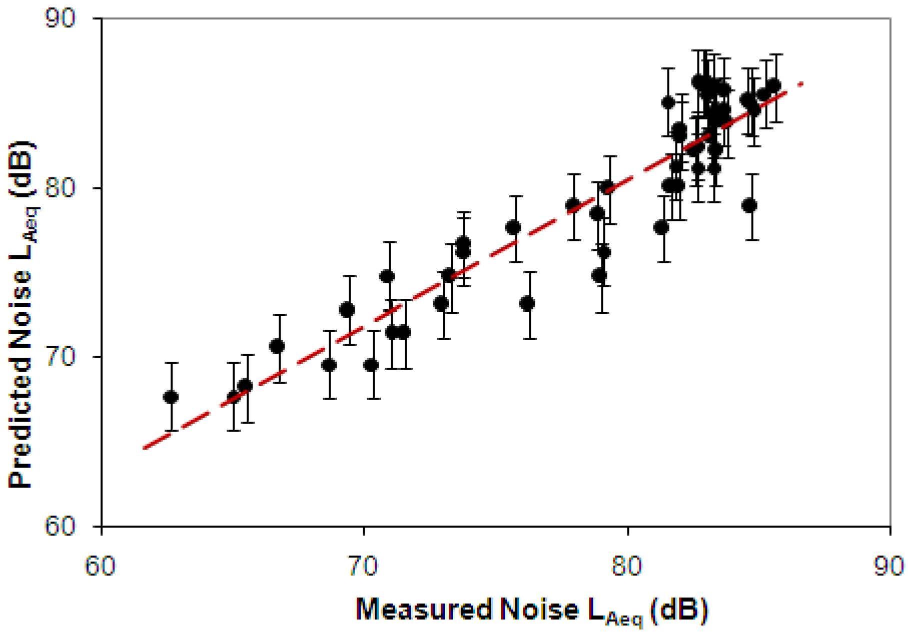


Figure 8: Measured and predicted noise levels for the acceleration phase. The three symbols represent three different sections of the journey. The error bars indicate the 2.0 dB uncertainty in the predicted values.

Figures 8 shows the measured noise levels and the predicted noise levels during acceleration phase for trains traveling from Mt. Lavinia to Ratmalana, Ratmalana to Angulana and Angulana to Lunawa respectively. The relationship between the measured and predicted noise levels is linear with a gradient of 0.86 and a correlation coefficient of 0.93. The error bars indicate the ±2.0 dB error expected for each of the predictions. Although there is a variation in acceleration between each of the sections as well as changes in the external parameters, in general, it can be concluded that the overall noise levels within passenger trains during the acceleration phase can be reasonably modeled by a 2nd degree polynomial with the parameters given in equation 3.

5.2 Modeling the Deceleration

The average noise levels measured for the same five locations in between Slave Island and Mount Lavinia for the deceleration phase are shown on Figure 9. Since a normalized time axis was used, valid data exists between 0.75 s and 1.0 s. In general, this part of the journey shows higher scatter in data compared to the acceleration part.

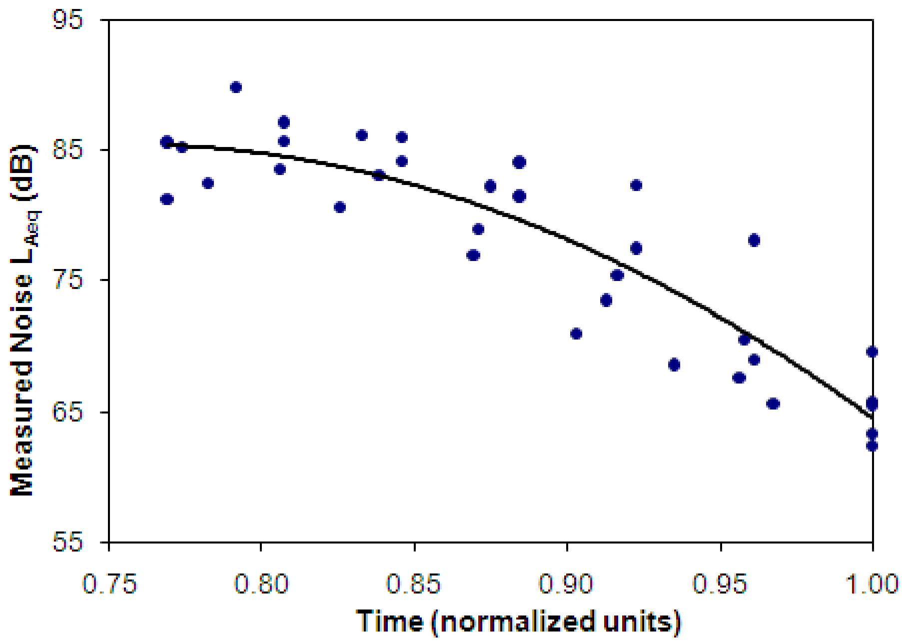


Figure 9: Average noise levels during the deceleration phase as a function of time

The average noise at the deceleration phase can also be modeled by a 2nd degree polynomial fitted to the data

$$\overline{N}_D = 349.1 \times T^2 + 527.6 \times T - 113.8 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

with a correlation coefficient of 0.81 and a standard deviation of 3.5 dB.

To check the reliability of the proposed model for deceleration, the measured noise levels and predicted noise levels were compared using the unused data set taken for the next 3 stations (Ratmalana, Agulana and Lunawa).

Figure 10 show the correlation between the measured noise levels and the predicted noise levels. Similar to the acceleration phase, the deceleration phase also show a linear correlation with a gradient of 0.94 and a correlation coefficient of 0.90. The error bars indicate a ±3.5 dB error in the predictions. Since only 25% of the available data were used to model the deceleration phase, a limited number of data points were available to test the model. However, the results indicate that the model (equation 4) is able to predict the deceleration phase with a reasonable accuracy.

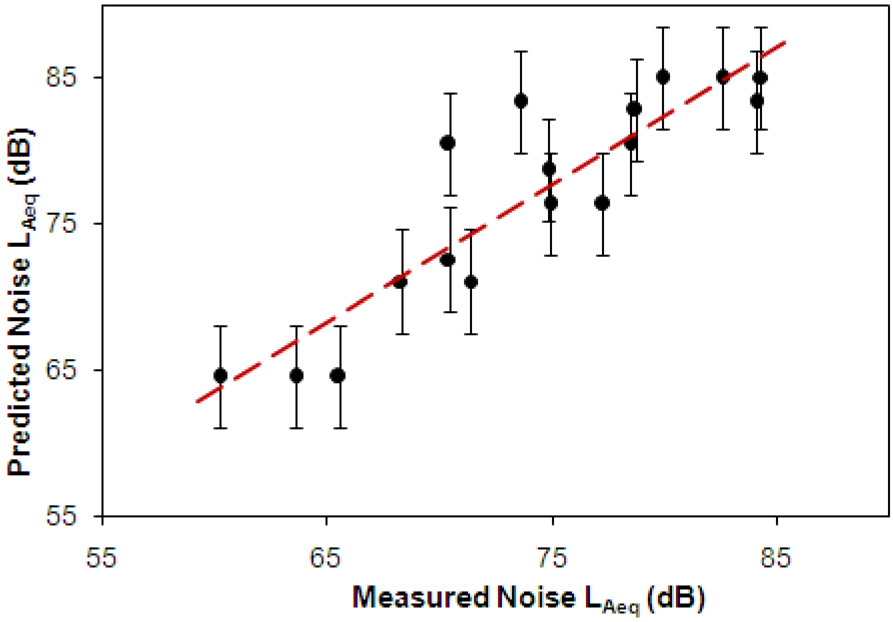


Figure 10: Measured and predicted noise levels for the deceleration phase. The three symbols represent three different sections of the journey. The error bars indicate the 3.5 dB uncertainty in the predicted values.

7. CONCLUSIONS

According to the National Environmental (Noise Control) Regulations [12] the maximum permissible noise level in an urban area is in-between 60 dB and 70 dB. Measurements taken within the passenger compartments of trains operating on the coastal railway line indicate that passengers are exposed to noise levels of around 75 dB on average. The passengers traveling in passenger compartments close to the engines are exposed to higher noise levels; around 85 dB on average. The situation is aggravated by the external objects in close proximity to the railway track which cause the noise levels to increase beyond 90 dB for short durations.

The following conclusions can be arrived at from the results presented in this study.

- The average noise levels within the passenger compartments of trains traveling on the coastal railway line are high.
- There is a significant noise enhancement due to various external parameters.
- The engine noise is the main source of traction noise.
- The guard and the driver of the train are exposed to very high noise levels.
- Average noise levels within passenger compartments can be reasonably modeled by considering the acceleration (within ±2.0 dB error) and deceleration (within ±3.5 dB error) phase of the journey between two given stations.

The study indicates a clear need for further studies in estimating the noise passengers traveling within passenger compartments in trains of Sri Lanka Railways are subjected to, assess and implement noise reduction strategies. The measurements show that for trains traveling at slow speeds, the acceleration/deceleration condition is important and can be used to model the noise levels within passenger compartments. The presence of high rising buildings along a railway line can increase noise levels substantially and strategies are required to prevent passengers as well as residents from unnecessary noise exposure.

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