# Study of Vehicle Noise under Different Operating Conditions

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## Abstract

The noise emission level from a vehicle is significantly influenced by different driving conditions and drivers' behaviour. Almost all the in practice road traffic noise estimation models do not differentiate between different operating conditions. In this study, noise measurements are performed (on a small sample of one heavy and two light vehicles) to study the influence of different driving conditions on vehicle noise. Both pass-by and coast-by measurements are performed along with noise measurements for idle vehicles. Different operating conditions are considered so as to reproduce the vehicle noise in urban and freeway network. For pass-by measurements, the parameters measured are vehicle operating gear; harsh/smooth driving condition; speed profile of the vehicle motion and corresponding peak value of the noise level (at 7.5 meter from the test track and 1.2 meter above the ground). Each of these parameters are transformed and aligned for the data analysis. Pass-by measurements provide the information for total sound power level (PWL) of the vehicle, whereas coast-by and idle vehicle measurements provide the rolling sound power level (R-PWL).

It is observed that the PWL difference between harsh and smooth acceleration is noticeable and it can be around 5 dB(A). Accelerating vehicle has more noise than cruising under the same speed and the difference between them can be around 10 to 15 dB(A) for smooth and harsh acceleration, respectively. R-PWL for heavy vehicle is more than that of light vehicle and the difference between them is of the order of 9 dB(A). Based on the measurements, further research direction is provided.

## Keywords

Noise estimation, Noise measurement, Vehicle noise, Operating conditions, Sound power level

# 1. Introduction

It has been estimated that approximately 80 million people in the European Union (excluding the new member states) are exposed to unacceptable noise levels i.e., noise levels which cause sleep disturbance and/or other adverse health effects [7]. Around 170 million people live in so called “grey areas” where noise levels can cause serious annoyance during day time. The external social economic cost of environmental noise (mainly transportation noise) is estimated around 0.2 to 2 per cent of Gross Domestic Product [3]. Hence, by considering the lower estimate, the financial loss to society is more than 12 billion Euros annually [2]. The modes of transportation are one of the basic necessities and are also one of the major sources of noise. Of the three main transportation sources (road, rail and air), road traffic is the most widespread and dominant noise source for over 90% of the exposed population [8].

In order to address the problem of noise, we need to evaluate the noise and its impacts. The basic step for noise evaluation is to have a model which can estimate noise level based on different scenarios. Most of the countries have developed their own road traffic noise estimation model (such as ASJ Model for Japan [9], SonRoad Model for Switzerland [4] etc.) based on the countries vehicles standard. The development of a noise estimation model is an ongoing research and there is a need for a noise estimation model which can estimate noise levels under different operating conditions.

It has been shown that the integration of a noise estimation model with traffic simulation model can be applied effectively and efficiently for the evaluation of urban road traffic noise abatement policies [1]. Now a days microscopic traffic simulation models can provide detailed traffic inputs, such as vehicle performance characteristics (acceleration, deceleration and cruising) based on different levels of drivers’ behaviour (ranging from aggressive to cautions). The availability of detailed traffic input is the strength to evaluate dynamic traffic noise in urban area where generally, during peak conditions the system is performing above its capacity, leading to vehicle operation in transient running conditions. However, if the noise model can incorporate different operating conditions then the noise estimation can be more accurate. This paper presents a study of vehicle noise based on the different operating conditions and need for the up gradation of the noise estimation model to incorporate different operating conditions is also stressed.

Remaining of the paper is structured as follows: first a short background for the road traffic noise estimation is presented (section 2). In section 3, the framework of the study is discussed followed by information for noise measurements (section 4) and practical issues (section 5). The procedure for data transformation and alignment is discussed in section 6 followed by data analysis in section 7.

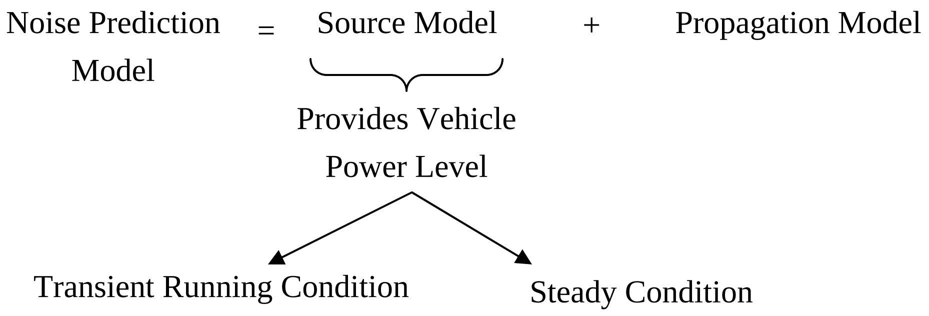
# 2. Background

The noise from a road vehicle can be classified as the noise due to tyre-road interaction (rolling noise); the noise from engine-exhaust (motor noise) and the noise due to interaction of the air with the vehicle body (aerodynamic noise). Under steady operating conditions rolling noise dominates, whereas under transient running conditions motor noise dominates. In this study, the aerodynamic noise affect is incorporated in the total noise from the vehicle.

All algorithms for traffic noise estimation are generally of the same form (Figure 1). The model is divided into two sub models, source model and propagation model. The source model provides the vehicle power level based on the vehicle running conditions. The propagation model is based on the basic principles of sound propagation, which are applied on the power level, obtained from the source model. The propagation model also considers the effect of different geometrical and environmental conditions between and around the source and receiver.

Most of the in practice noise models (source models) have limited applications in transient running conditions. For the estimation of noise level in urban areas (where the vehicles are mainly in transient running conditions), the changes in sound power level at transient running conditions, especially at intersections, is a serious problem. There is a need to improve the existing model(s) so as to explicitly take into account the transient running conditions.

Figure 1 Basic algorithm for noise estimation models.



In Switzerland, StL-86 model [6] is used for road traffic noise estimation and evaluation; and this is to be replaced by a new model, the SonRoad Model [4]. In StL-86 model, the vehicle sound level is defined as a single formula which is the function of the average speed of all the vehicles, percentage of heavy vehicles and traffic flow. This model does not use separate formulas for different categories of vehicles (light and heavy) thus, different vehicle categories cannot be assigned their own speed (the assigned speed is the average speed for all the vehicles).

Recently, the model is updated and the new model is SonRoad model, which considers different vehicles types independently, distinguishing between the components of motor noise and rolling noise (Equation 1). The vehicle sound power level is determined as a function of vehicle type, speed, grade of the road and surface type. The components of motor noise and rolling noise are distinguished, which permits more realistic accounting for factors, such as uphill grades (influences mainly motor noise) and road surface (influences mainly rolling noise). In fact, the correction for road surface type is still based on the total noise. However, the noise from the motor of the vehicle depends on the operating condition of the vehicle (transitional or cruise), which is not considered in this latest model.

$$L_{W,A,passenger} = 28.5 + 10\log(10^{0.1(7.3+35\log V)} + 10^{0.1(60.5+10\log(1+(V/44)^{3.5}+\Delta s))}) + \Delta_{BG}$$

$$\begin{array}{cc} \Downarrow & \Downarrow \\ \textit{Rolling Noise} & \textit{Motor Noise} \\ (7.3 + 35\log V) & (60.5 + 10\log(1 + (V/44)^{3.5} + \Delta s) \end{array}$$

$$L_{W,A,truck} = 28.5 + 10\log(10^{0.1(16.3+35\log V)} + 10^{0.1(74.7+10\log(1+(V/56)^{3.5}+\Delta s))}) + \Delta_{BG}$$

$$\begin{array}{cc} \Downarrow & \Downarrow \\ \textit{Rolling Noise} & \textit{Motor Noise} \\ (16.3 + 35\log V) & (74.7 + 10\log(1 + (V/56)^{3.5} + \Delta s) \end{array}$$

Equation 1

Where,

$L_{W,A,passenger}$, $L_{W,A,truck}$ is the sound power level for passenger car and truck, respectively in dB(A)

$V$ is the speed of the corresponding vehicle [km/h]

$\Delta s$ is the correction for uphill grade $g[\%]$ where, $\Delta s = 0\ 0.8g$

$\Delta_{BG}$ is the correction for road surface in dB(A)

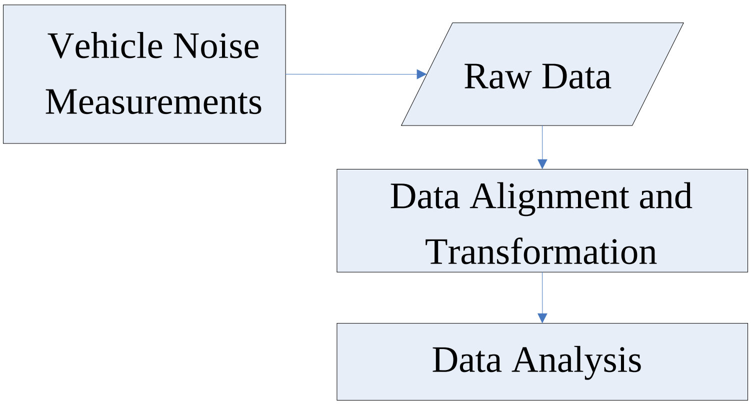
The present application of the Swiss noise estimation model, at intersections, does not consider stop and go conditions. The increase in noise level at intersections due to stop and go condition is known to the practitioners, which is accounted by overestimating the average speed of the vehicle at intersection. At intersections, there is increase in motor noise level and decrease in the rolling noise contribution due to transient running condition. This method can be acceptable when we are looking for the noise level averaged over larger periods, such as day (LAeq(day)) and night (LAeq(night)). But for shorter periods, such as LAeq(15 minutes) and LAeq(hourly) there can be a significant amount of deviation.

# 3. Framework

In this study, operational exterior vehicle noises (rolling and total vehicle noise) are measured for different (heavy and light) vehicles, considering international standards (ISO 362:1998, [5]). In urban network, especially at signalized intersections, vehicles are in stop and go conditions (e.g., they decelerate, stop and accelerate at the signalized intersections). In order, to study the effect on traffic noise, it is necessary to reproduce the vehicle motion by considering different operating conditions. So, different operational conditions are considered to reproduce typical noise levels that occur during urban driving.

The raw data obtained from the above measurements (i.e. kinematics, acoustic and mechanical data); are transformed and aligned into vehicle power levels for corresponding vehicle operating conditions (i.e., average speed, cruise/accelerating/deceleration, harsh/smooth driving and operating gear). The transformed and aligned data is then analyzed to study the vehicle noise for different operating conditions (Figure 2).

Figure 2 Study framework



The following section provides information for the measurement details, such as experimental site, weather conditions, type of vehicles used and raw data obtained.

# 4. Experimental Program

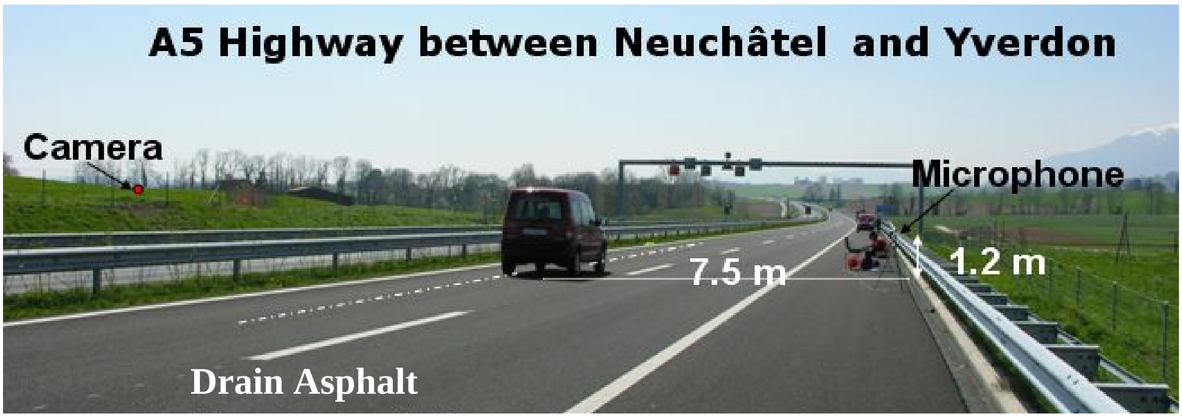
## 4.1 Measurement Site

The data was collected on a newly constructed highway (A5) between cities of Neuchâtel and Yverdon in Switzerland, on a sunny day. The measurements were performed before the opening of this new highway section. The test track site is fairly levelled and the pavement is drain asphalt (drain asphalt DRA-10) particularly, in the portion of the area between the vehicle path and the microphone location (Figure 3). The test track and the surface of the site were dry.

It is to be noted that drain asphalt (porous asphalt) has noise absorbing characteristics. The large size aggregates increase lightly the noise due to tyre road contact; whereas the noise absorbing characteristics (due to porosity and tortuosity) of the drain asphalt decrease largely the noise. This paper does not deal with such issues as the objective of the paper is to study the effect of different operating conditions on the vehicle noise (by analyzing accelerating and cruising conditions on the same pavement).

Microphones, located at a height of 1.2 meters and 7.5 meters away from the centre line of the running track, were used to record the noise level during the study period. Digital video cameras were also mounted (in front of the microphone) on the other side of the test track. They were used to video record the vehicle motion during the measurement period (Figure 3).

Figure 3 Measurement site



The wind speed at the height of microphone did not exceed 5 m/s during the sound measurement intervals. The ambient air temperature, test track surface temperature and relative humidity were well within the recommendations of ISO 362:1998(E) [5].

It is observed that the A-weighted background noise was around 42 dB(A) which was more than 15 dB(A) below the emissions produced by the vehicle under test. As the background noise was much below the noise emissions from the vehicle, we can say that the noise recording from the microphone when the vehicle was in the test region is due to the noise from the vehicle only. Note, noise levels calculations in decibels (dB) are energy based i.e., 57 dB + 57 dB = 60 dB, similarly, 57 dB + 42 dB = 57.13 dB.

## 4.2 Number and Types of Vehicle

In order to reduce the cost of the experiment it was decided to perform the noise measurements on a small sample of one heavy and two light vehicles. Diesel truck is used as a heavy vehicle and the light vehicles used are Renault Kangoo (2004 Model) and BMW 320i (1998 Model). The gross vehicle weight for truck, Kangoo and BMW are 8200 kg, 1840 kg and 1850 kg, respectively.

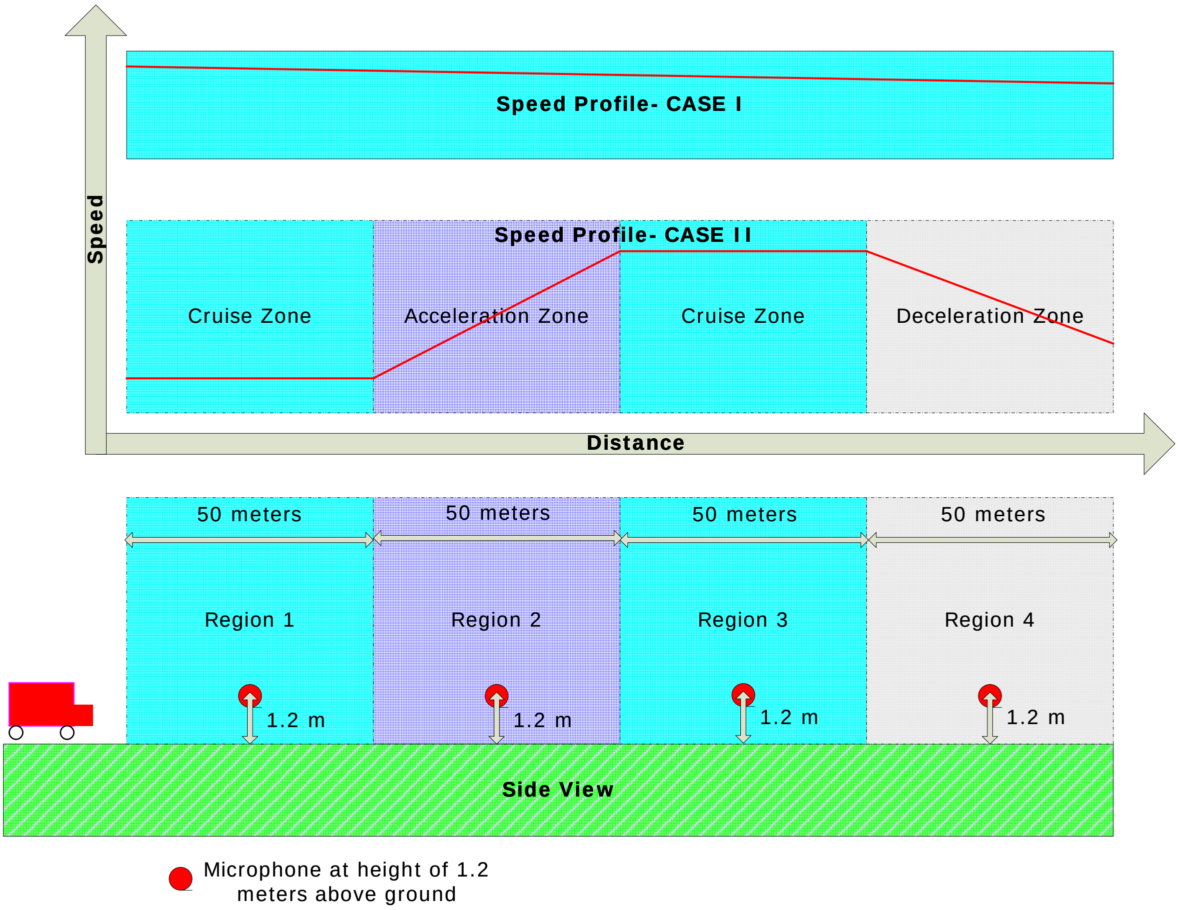
## 4.3 Measurement Procedure and Setup

The whole test is divided into two different cases. CASE I, in which rolling noise from the vehicle is measured and the CASE II, in which total noise is measured. The following section describes the ideal desired procedure for CASE I followed by CASE II.

For noise measurements, we had one dual channel real time acquisition unit and two sound level meters. The maximum practical distance between the channels can be 50 meters. In effect, we can have four places of simultaneous measurements with the maximum 50 meters distance between the microphones. In order to maximize the number of data points and to reduce the cost of the experiment it was decided to have four regions with length of 50 meters each.

The cross section of the study area is represented in the lower part of Figure 4 and the upper part represents the illustrated speed profile of the vehicle in each region for the two cases, under study (CASE I and CASE II). For CASE I, the speed profile indicates that there is actually some deceleration due to friction. For CASE II different regions correspond to acceleration, cruising and deceleration zones. Practically, the actual speed profile in each zone is not linear.

Figure 4 Side view of the test site and speed profile of the running vehicle for CASE I and CASE II.



## CASE I

Coast-by measurements were performed under constant speed to evaluate rolling noise. The vehicle entered Region 1 (Figure 4) with a predefined initial speed and neutral transmission (Table 1). The gear of the vehicle was released (with the help of clutch), so the vehicle transmitted under almost constant speed in each region. Note that due to friction there is actually a slight deceleration of the vehicle but within each region the average speed of the vehicle can be considered as constant. Due to the larger affect of the friction during low initial speeds (less than 50 km/h), only the measurements of the microphone at Region 1 can be considered. However, for higher speeds (more than 50 km/h), the microphone readings in the other regions were also considered for analysis.

Noise measurements were also performed for idle vehicle with different engine revolution speed (1000, 2000, 3000, 4000 and 5000 rpm). It is assumed that the noise from vehicle transmitting in neutral have major noise contribution from tyre-road contact and the engine contribution is same as that of the noise from an idle vehicle (with engine revolution speed of 1000 rpm). Based on the assumptions, rolling noise is obtained from Equation 2.

$$L_{Rolling\ Noise}(A) = 10 * \log(10^{L_{Coast-by\ Observation}/10} - 10^{L_{idle}/10})$$

Equation 2

Where,

$L_{Rolling\ Noise}$(A) is the A-weighted rolling noise in dB(A)

$L_{Coast\text{-}by\ Observation}$ is the A-weighted coast-by observation in dB(A)

$L_{idle}$ is the A-weighted noise from an idle vehicle with engine speed at 1000 rpm in dB(A)

**CASE II**

Pass-by measurements were performed to obtain the total noise (combined engine and tyre-road noise) under different predefined running conditions (Figure 4) and drivers were instructed to act accordingly. They were instructed to enter Region 1 with a predefined initial speed and operating condition (gear) where they were required to cruise. In Region 2 they have to accelerate and again cruise in Region 3. Finally in Region 4 they were required to decelerate. It is to be noted that the gear of the vehicle was to be held constant during each running condition and each run was repeated for harsh and smooth driving behaviour. The initial speed of the light vehicles in Region 1 was from 10 km/h to 120 km/h (at interval of 10 km/h) and the operating gears considered were 1 to 5. The maximum practical speed for the heavy vehicles was 90 km/h and the initial speed was in the range of 10 km/h to 90 km/h (at interval of 10km/h) with gear 3, 4, 6 and 8 (Table 1).

Table 1 Types of measurements and corresponding operating conditions.

| **Case** | **Type of Measurement** | **Drivers Behaviour** | **Light Vehicle** | | **Heavy Vehicle** | |
|---|---|---|---|---|---|---|
| | | | **Speed range (km/h)** | **Gear** | **Speed range (km/h)** | **Gear** |
| CASE I | Coast-by | - | 10 to 120 | - | 10 to 90 | - |
| CASE II | Pass-by | Harsh and Smooth | 10 to 120 | 1to5 | 10 to 90 | 3,4,6,8 |

# 5. Some Practical Issues to Address

## 5.1 Drivers' Behaviour

Different drivers have different driving behaviour; harsh driving for one can be smooth for other. In this study, there is no technical definition for harsh and smooth driving and the drivers were instructed to fully (maximum power) and partly (calmly) engage the accelerator control for harsh and smooth driving, respectively. We have three different drivers for three different vehicles, so the results for harsh and smooth driving are as per drivers' behaviour.

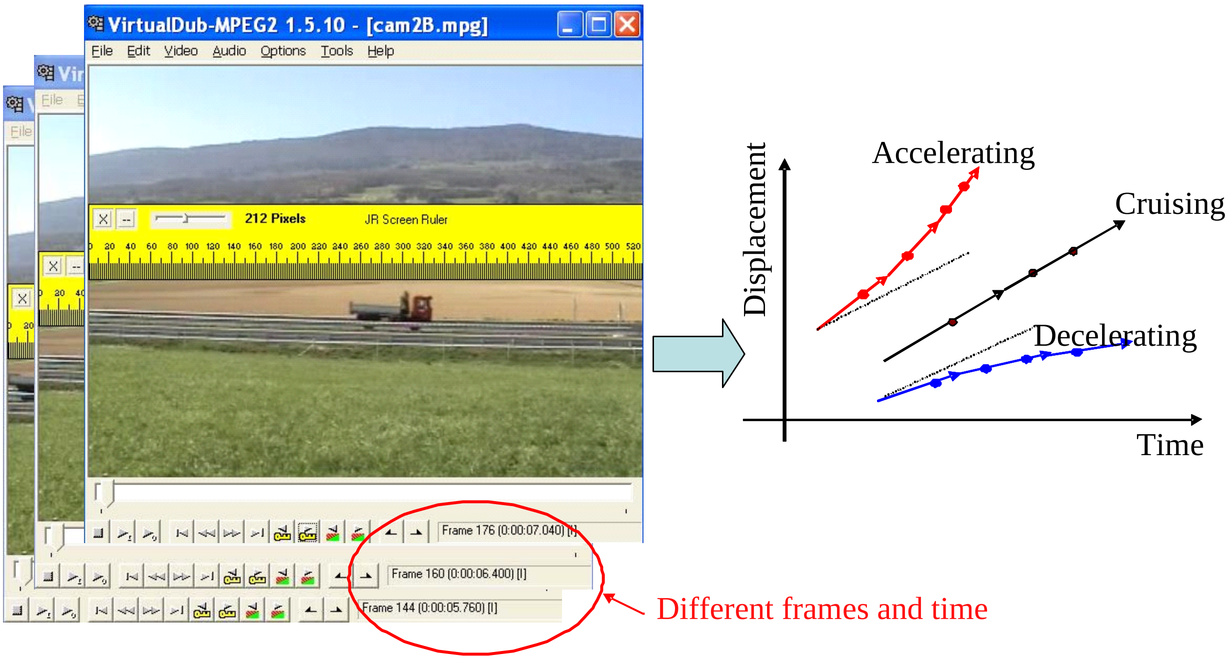
The rate of acceleration is directly related to the drivers' behaviour and is an important parameter affecting the noise generated. Unfortunately, in the present measurements, we were unable to obtain the accurate values for the rate of the acceleration to be used for the analysis. This issue is discussed in the following sub section.

## 5.2 Kinematics Data from Video Recording

The kinematics data for each vehicle run is obtained by the raw digital video data. Each frame of a digital video provides the information for time and position of the vehicle. So, frame by frame transformation is done to obtain displacement time curves (Figure 5). This further provides information for the instantaneous vehicle operating conditions in each region of microphone.

The quality of the video recording of the vehicle motions is not good enough to be used for automatic generation of the speed profile by the use of image processing software. So, manual processing is done. However, for manual processing the error in speed estimation is in the range of ±5 km/h which makes it difficult to obtain the acceleration values. Hence, the average speed of the vehicles in each region was considered and the corresponding running condition (acceleration/deceleration/cruising) was decided, based on the predefined running conditions in each region. This is based on the assumption that the drivers follow the instructions of running condition in each region. As it was difficult to obtain the true acceleration/deceleration values, it is recommended that for further measurements more advance techniques (such as pulses from automatic braking system and GPS) should be used to obtain the rate of acceleration.

Figure 5 Digital video data transmission into kinematics data for each vehicle run.



Different frames and time

Digital Video Data

Kinematics Data

# 6. Data Transformation and Alignment

We have the following three different types of data:

- Kinematics data: is the data of average speed and running condition (cruising, accelerating and decelerating) for each vehicle in different regions and different run. For each run and for each vehicle the average speed of a vehicle in each region is obtained from the transformed video data. And different regions correspond to different running conditions.

- Mechanical data: is the information for drivers' behaviour (harsh/smooth) and engaged gear for different runs and for each test vehicle. Both the drivers' behaviour and engaged gear are predefined for each run which is obtained from the measurement schedule.

- Acoustic data: is the continuously recorded sound pressure level on each of the four microphones i.e., a time history of the sound pressure level for whole test period. When the vehicle is in the test region then the noise level increases and the peak value corresponds to the time when the vehicle is just in front of the microphone. During other periods, when there is no vehicle then the recording represents the background noise levels.

To obtain the sound power levels of a running vehicle from observed acoustic data, a simple method called "peak method" is used. In this method the observed peak values of A-weighted sound pressure level determined are used to calculate the sound power level considering the amplification as a consequence of the ground reflection (ground effect) of 2.2 dB(A) (Equation 3). The vehicles are assumed to be non-directional point source.

$$\begin{aligned} PWL &= Lp(A) + 10\log(4\pi r^2) - ground\ \ effect \\ &= Lp(A) + 10\log(4\pi 7.5^2) - 2.2 \\ &= Lp(A) + 26.3 \end{aligned}$$

Equation 3

Where:

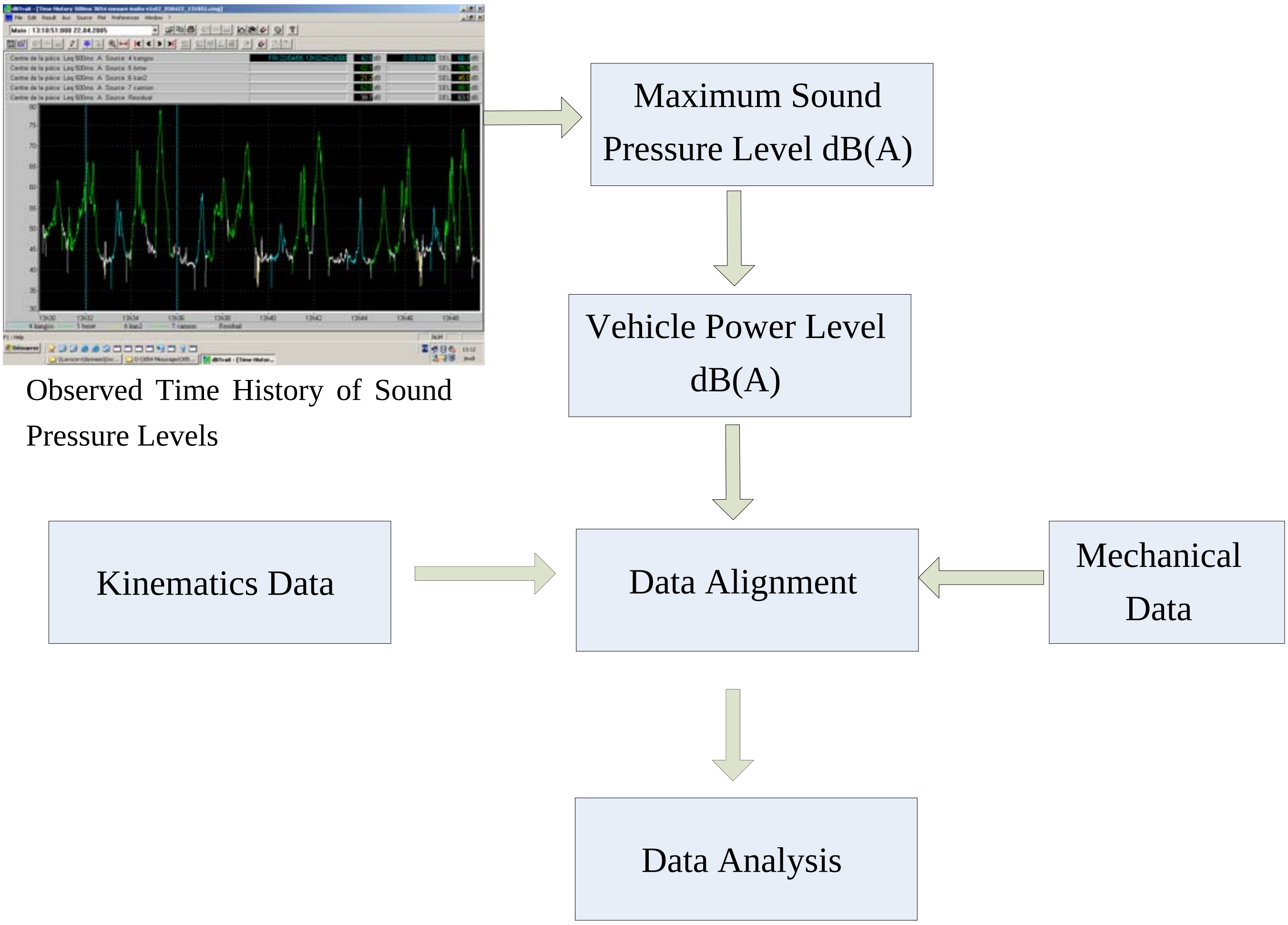
$PWL$ is the sound power level of the vehicle in dB(A),

$Lp$(A) is the peak value of the pass-by noise in dB(A)) and,

$r$ is the distance between running plane and microphone (r =7.5 m).

The transformed acoustic and kinematics data are aligned with the corresponding vehicle mechanical data, which are further used for data analysis (Figure 6).

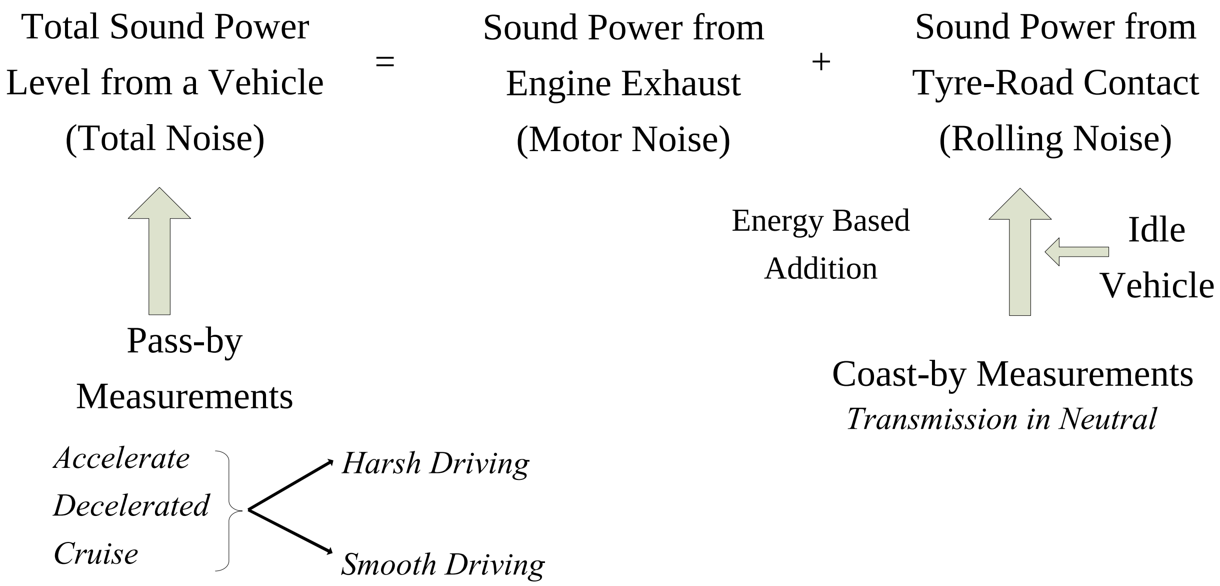
Figure 6 Data transformation and alignment to be used for data analysis.



# 7. Data Analysis

Total sound power level of a vehicle can be classified into the sound power level due to engine-exhaust (motor noise) and the sound power level due to tyre-road contact (rolling noise) (Figure 7). Pass-by measurements provide total sound power level of a vehicle and different operating conditions are also considered in these types of measurements (CASE II). Rolling noise is obtained by the energy based subtraction of the idle vehicle measurement from the coast-by measurement (Equation 2) (CASE I). For coast-by measurements the vehicle are transmitting in neutral, and in idle vehicle measurements the measurements are on the idle vehicle at 1000 rpm. Motor sound power level (M-PWL) can be obtained from the energy based subtraction of rolling sound power level (R-PWL) from total sound power level of a vehicle (PWL).

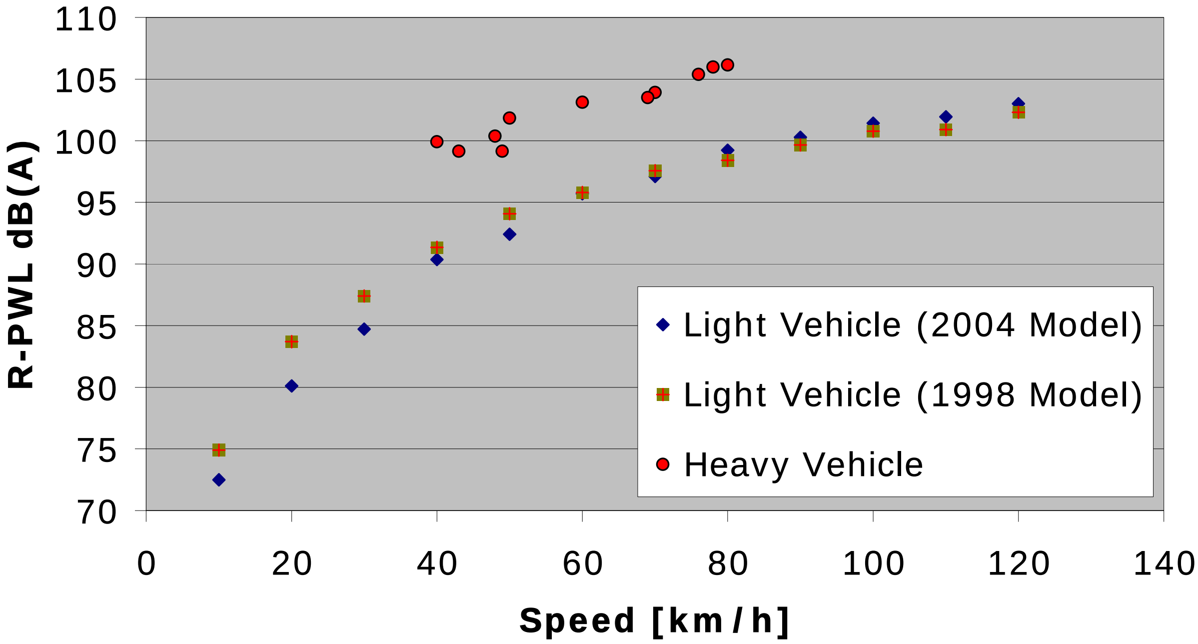
Figure 7 Types of measurements.



## 7.1 CASE I: Coast-by Measurements for Rolling Sound Power Level (R-PWL)

Figure 8 represents the observed R-PWL (dB(A)) (i.e., R-PWL obtained by Equation 2) for light and heavy vehicles for different running speeds. As expected, for the same speed R-PWL for heavy vehicles is more than that of light vehicles. One of the reasons for this is that heavy vehicles are heavier and have more number of tyres than light vehicles which accounts for increase in tyre road contact area and hence, more contribution of noise from tyre road interaction. The difference between the R-PWL for heavy and light vehicles is around 9 dB(A). Observed values of R-PWL for both types of vehicles follow logarithm function of speed.

Figure 8 Observed rolling sound power level dB(A) for light and heavy vehicles.



## 7.2 CASE II: Pass-by Measurements for Total Sound Power Level (PWL)

As expected, the sound power level depends on the type of the vehicle. Under similar driving conditions, heavy vehicles have greater sound power level than light vehicles. The power level is high if the vehicle accelerates which further depends on drivers' behaviour. Harsh acceleration generates more noise than smooth. Cruising or decelerating vehicles have lower sound power level than that of the accelerating vehicles.

The observed sound power level of different vehicles (light/heavy) for different driving conditions (harsh/smooth) is represented from Figure 9 to Figure 14. Each driving condition has a predefined initial speed and operating gear before entering the test regions. The graphs in these figures have X-axis, as the initial speed and Y-axis, as the observed power levels for each condition in accelerating, cruising and decelerating regions (Refer to Figure 4 for different regions). It is to be noted that for each speed we have two or more different values for acceleration, cruising and deceleration, this is because of different operating gears. For same speed, higher noise level corresponds to lower gear. The maximum difference between the noise level for different gears at the same speed is around 6 dB(A).

Under urban driving conditions (speed < 60 km/h) the difference between harsh and smooth acceleration is noticeable and it can be around 5 dB(A). The difference between the cruising (or decelerating) vehicle from those of accelerating (for same speed) can be around 10 to 15 dB(A) from smooth to harsh acceleration, respectively. The sound power levels for deceleration are close to the cruising because the deceleration does not produce any extra engine load.

For higher speed (>60 km/h), the gap between the values for accelerating and cruising vehicles reduces which depends on the type of the vehicle and engaged gear. For light vehicle –Kangoo, 2004 Model, the difference is of the order of 1dB(A) (Figure 11 and Figure 12), whereas for the BMW 320i, 1998 Model, the difference is of order of 5 dB(A) (Figure 9 and Figure 10).

Moreover, for vehicle speed, greater than 60 km/h, it is difficult to differentiate between harsh and smooth acceleration. This is because the rate of acceleration is relatively low for slow speeds than for high speeds. At higher speeds (> 80 km/h), rolling noise dominates the motor noise and total noise is controlled by the rolling noise.

As discussed in the section 2, the development of the noise estimation models is an ongoing research, and almost all the in practice models do not differentiate between different operating conditions, such as accelerating, cruising with different drivers' behaviour (harsh/smooth). The noise estimation provided by these models has limited application for urban network. However, as per present observations, the influence of the different operating conditions on the vehicle noise is significant. For noise estimation in an urban network, where the vehicles are generally in the transient running conditions, the need for more advance noise estimation model is required so as to efficiently and effectively evaluate the urban road traffic noise abatement policies.

It is to be kept in mind that the present observations are on a small sample of one heavy and two light vehicles and for upgrading the noise estimation model much more work and measurements on large sample of vehicles is needed to be carried out, which is beyond the scope of this study.

Figure 9 Observed PWL for light vehicle (BMW 320i, 1998 Model) under smooth driving condition.

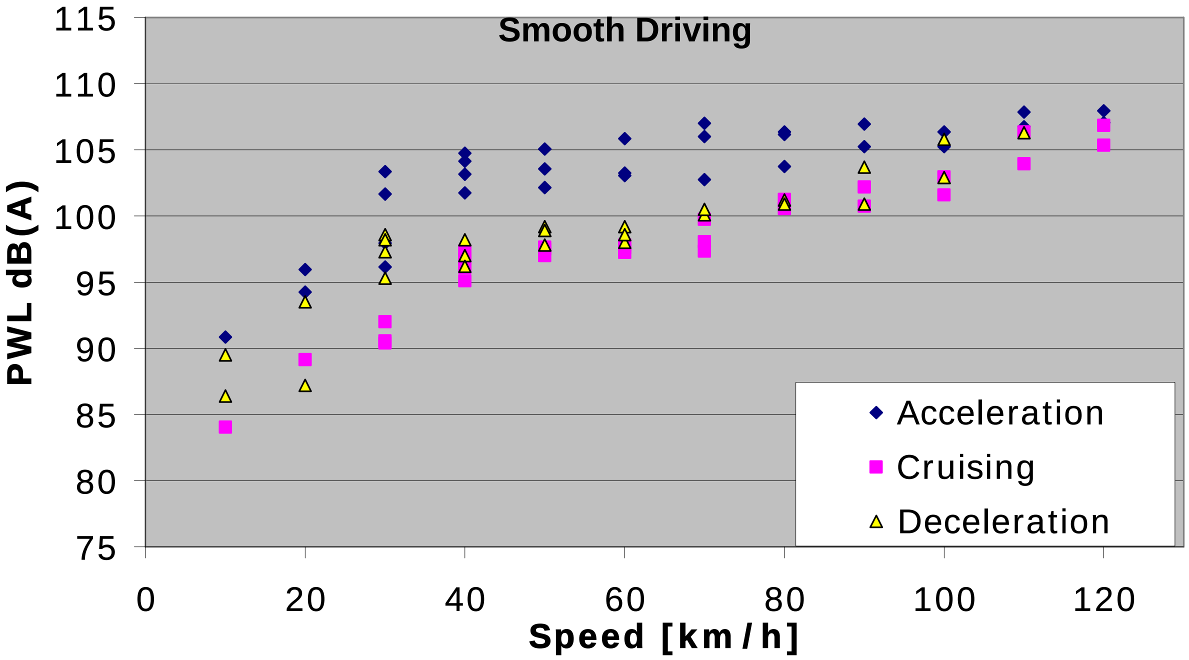


Figure 10 Observed PWL for light vehicle (BMW 320i, 1998 Model) under harsh driving condition.

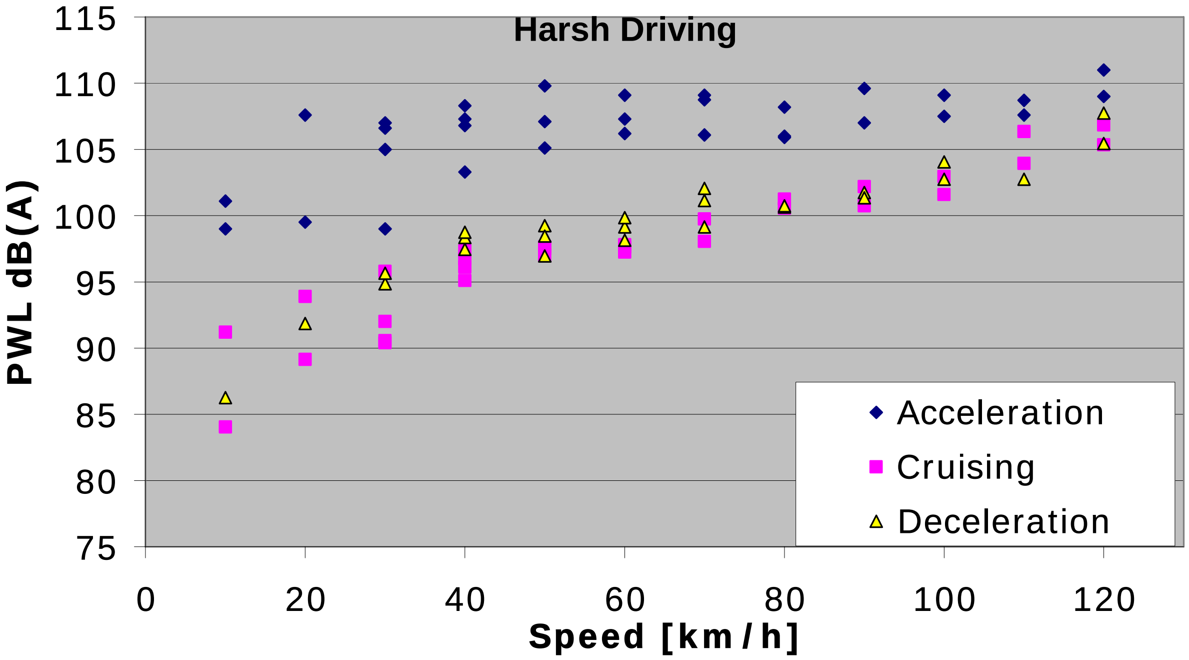


Figure 11 Observed PWL for light vehicle (Kangoo, 2004 Model) under smooth driving condition.

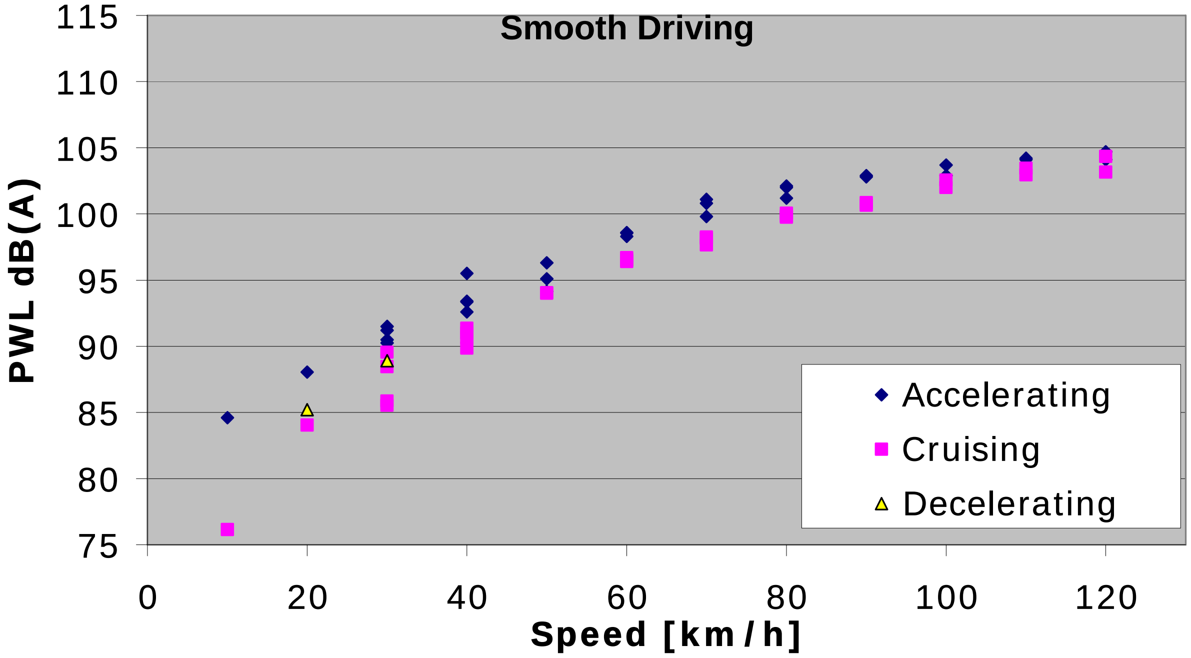


Figure 12 Observed PWL for light vehicle (Kangoo, 2004 Model) under harsh driving condition.

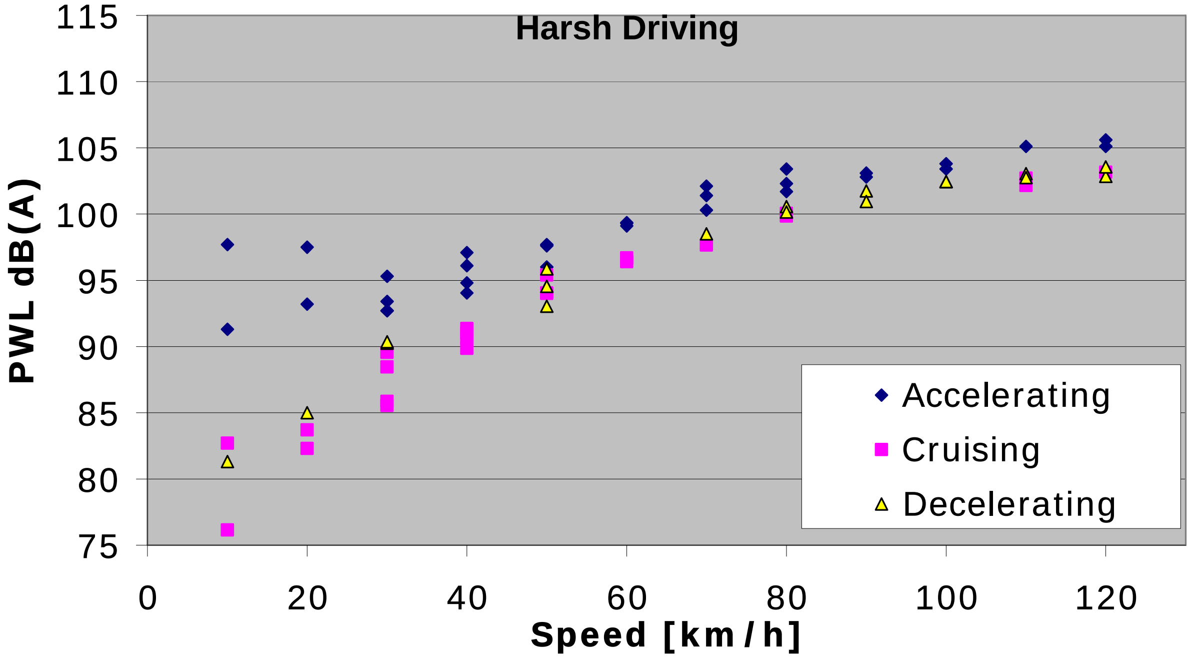


Figure 13 Observed PWL for Heavy vehicle under smooth driving condition.

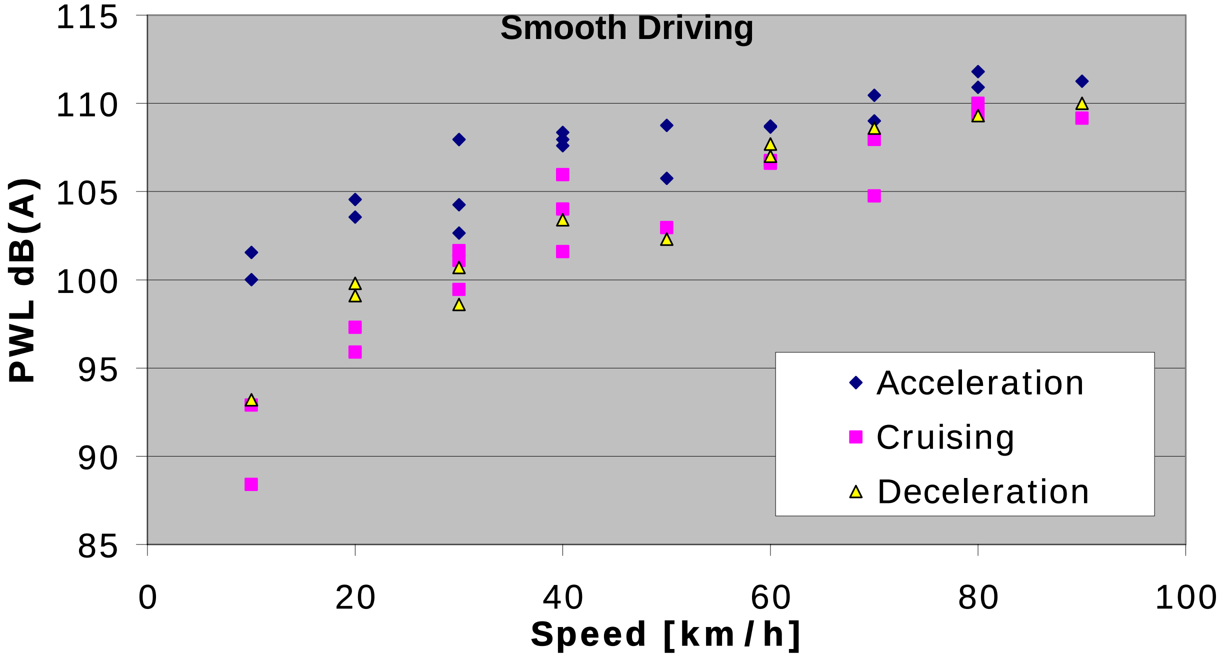
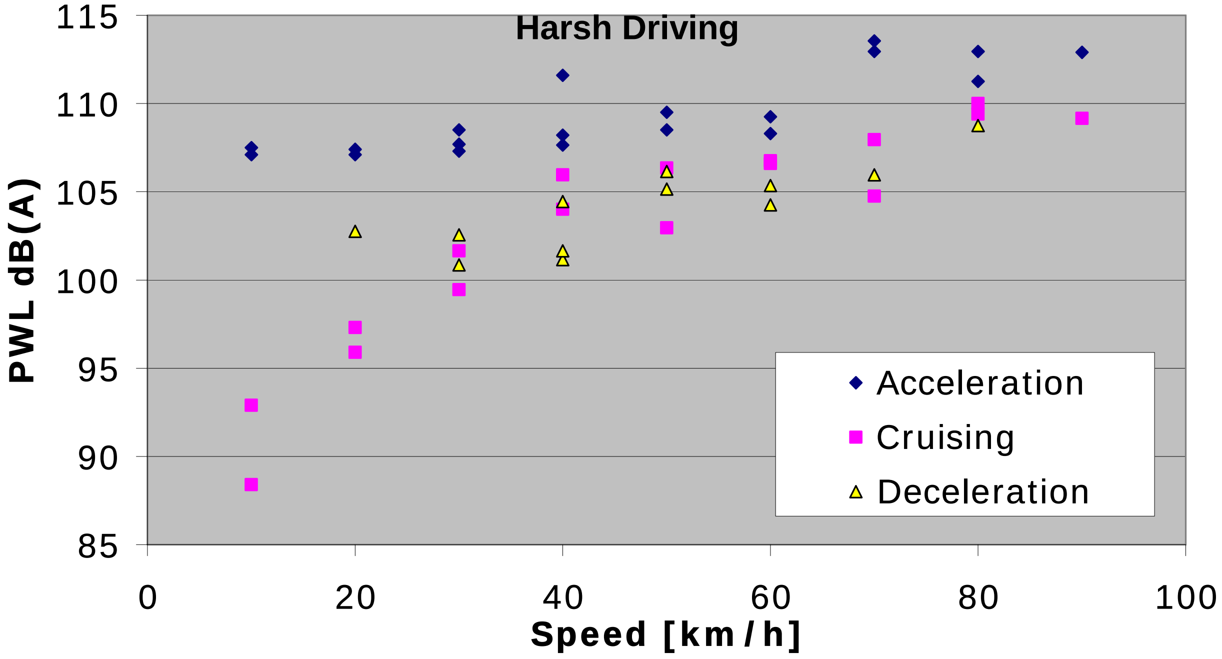


Figure 14 Observed PWL for heavy vehicle under harsh driving condition.



# 8. Conclusions and Further Research

It is observed that rolling sound power level (R-PWL) for heavy vehicle is around 9 dB(A) more than that of light vehicle. The noise difference (PWL) between harsh and smooth acceleration is noticeable and it can be around 5 dB(A). Accelerating vehicle has more noise than cruising under the same speed. The difference between them is significant and can be around 10 to 15 dB(A) for smooth and harsh acceleration, respectively. Subjectively, these increments in noise level can double the perceived increment in the loudness or noisiness of traffic. Note that sound wall can reduced traffic noise from 5 to 10 dB(A) along the road side area.

Some noise estimation models, such as ASJ-model [9] consider transient running conditions. However, the acceleration and deceleration effects are not explicitly considered in the model. That is to say that the model can provide acceptable estimate of noise levels under steady conditions but in congested urban network, the stop and go conditions can result in significant amount of deviation. For effective and cost efficient road traffic noise abatement transportation policy evaluation it is necessary to estimate the noise level under real operating scenarios. As none of the in practice noise estimation model consider different operating conditions, there is a need for more advanced noise estimation model.

In this study, different operating conditions are considered so as to reproduce the typical noise that occur during urban and freeway driving conditions. The considerations of different operating conditions provide us flexibility to compare the results of this study with noise measurements on different types of pavement. Hence, the comparative overview of the performance of different pavements with respect to noise can be provided.

The test site is a newly constructed highway with drain asphalt (DRA-10) pavement. Therefore, the noise measurements of the study can also be used to evaluate the performance of the drain asphalt pavement with time (one year, five years) i.e., the performed measurements will act as a reference noise level for longitude study of the drain asphalt deterioration on road traffic noise.

# 9. References

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