EVALUATION OF TRAFFIC NOISE IN ARTERIAL ROAD WITH DIFFERENT ROAD ROUGHNESS

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Abstract

There are many sources of road traffic noise which affect the environment. Many engineers have already determined that there are two major sources of road traffic noise. The first is engine noise and the second is the interaction between vehicle tires and the road surface. An evaluation of different road surfaces (roughness) from flexible and rigid pavements was needed to determine the effect of these different surfaces on the propagation of road traffic noise levels, in terms of sound pressure levels of single vehicles.

The characteristic of the road surface are the most important factors in propagating this tire road noise when the vehicles are traveling at constant speeds exceeding about 40 km/h. The measurements of sound pressure levels of individual vehicles were carried out on the two types of pavement, with four different surface roughnesses each.

Overall, the results of the sound pressure levels in dB (A) of the individual vehicles showed that a vehicle that was running at a higher speed is noisier, and the road that had a higher IRI value, propagated higher values. Comparing rigid and flexible pavements, it was found that the rigid pavement which had a higher IRI value than the flexible pavement did not always produce higher sound pressure levels (dB(A)), so there were other variables that influenced the propagated of sound pressure levels. It was also found that there was no significant difference between the influence of roughness from flexible and rigid pavements on propagated sound pressure levels.

Keywords: noise, road roughness

1 INTRODUCTION

1.1 Background

Today in Indonesia traffic noise is becoming a serious problem. People start feeling disturbed by traffic noise. The main source of road traffic noise is individual vehicles that travel in a traffic stream. Road traffic noise is the summation of the noise which is generated by each vehicle in a traffic stream.

Noise from motor vehicles in motion comes from two major sources: the engine-exhaust system and the tire-roadway system. Major engine-exhaust noise sources consist of intake noise at the carburetor, cooling fans, valve filter, gearboxes, and exhaust noise. Exhaust noise, when properly muffled (as with factory-installed equipment), probably contributes no more than 10 or 15 percent to the overall noise signature of the vehicle (ITE, 1982).

Tire-roadway noise is present for all vehicles in motion and is the dominant source of noise under certain operating conditions. The tire-roadway interaction produces a sound signature primarily attributable to the pattern and depth of tire tread, roughness of the surface, wetness, tire stiffeners, tire loading, and the suspension system of the vehicle (ITE, 1982).

The engine-exhaust noise tends to be dominant at low operating speeds and tire-roadway interaction dominates at high operating speeds (ITE, 1982). At speeds ranging from moderate to high (70-150 km/h) the tire noise predominates. The tread design and the road texture are the major factors in the production of tire noise (Alexandre, et al, 1975).

It is obvious that the type of road surface is one factor which influences tire-road noise. Hence this study was carried out to find the effects of the roughness of surface on road traffic noise

1.2 The Scope of the Study

The scopes of the study are:

- International Roughness Index (IRI) was used to indicate the roughness properties of the road surface. The roughness that was measured on each site was assumed to represent every lane on that section.
- Three types of vehicles were evaluated, single passenger cars, trucks and motorcycles.
- Tire types and the depth of tread pattern were ignored.

2 LITERATURE REVIEW

2.1 Noise Pollution

Noise has often been described as unwanted sound. Generally noise has three sources: transportation noise, industrial noise, and community background noise. Because any noise is capable of producing both physical and psychological damage, all sources must be controlled.

2.2 Traffic Noise Sources

Traffic noise is one of the most prevailing sources of sound in the urban area. Much of the urban area background noise is composed of the aggregate sounds produced by the thousands of cars, trucks and other transportation modes in urban area sources.

2.2.1 Origins of Motor Vehicle Noise

The engine, the tire and the turbulence cause the noise of the vehicle. For urban traffic at low speeds engines are often the main sources of noise; tire and road interaction contribute to noise at higher speeds and air turbulence is generally unimportant.

Noise due to the engine is produced by radiation of vibrating surfaces and by various individual sources such as exhaust, inlet manifold, transmission and cooling fan.

2.2.2 Tire-Road Interaction Noise

At speeds ranging from moderate to high (70-150 km/h) the tire noise predominates. The tread design and the road texture are the major factors in the production of tire noise. For tires itself, tread wear, speed factors and carcass design all influence the noise emission.

2.3 Factors Affecting the Generation of Traffic Noise

The levels of noise generated by road traffic depend mainly upon the type of vehicle flow, the speed and the percentage of heavy vehicles, the road gradient, the distance from edge of near side carriageway, the propagation of and the type of road surface.

2.3.1 Type of traffic Flow

The pattern of traffic flowing on different roads is highly space and time dependent and clearly this time dependency has an effect on both the traffic noise time history and the resulting statistical levels of traffic noise. For this reason, it is usually convenient to refer to the traffic flow pattern as one of two broadly defined categories.

2.3.2 Flow Rate

Whether considering hourly Leq as a function of mean hourly flow or longer term averages of these indices, it is generally accepted that over a wide range of traffic flows the variations of these indices with vehicle flow, Q, can be adequately represented by a logarithmic relation of the form.

$$L = C \log_{10} Q \tag{1}$$

Where:
L = sound level pressure
C = coefficient
Q = traffic flow (vph)

Theoretical model have suggested that the coefficient C should be take the value 10, where noise levels increase by about 3 db(A) for each doubling of traffic flow.

2.3.3 Vehicle Mean Speed and Percentage of Heavy Vehicles

Two speed regions can be identified: above 50-60 km/h where most traffic will be driven under fairly free flow conditions and below 50-60 km/h where interrupted flow conditions can be assumed to exist. Within the low speed region there is evidence that the average noise level is independent of traffic speed. In the free flow region most prediction schemes have adopted a logarithmic of the form $L = B \log_{10} V$, where B is a constant. The logarithmic form stems from the fact that nearly all the major sources of noise on a vehicle are logarithmically related to the linear or rotational speed of the engine, although in practice there is little to choose between linear or logarithmic forms to cover the rather narrow range of speeds observed.

For the purpose of noise prediction, traffic forecasts are generally limited to two vehicle classes, light and heavy vehicles. Based on multiple regression analysis of field data a linear relation between percentile noise level and composition, p%, has generally been adopted with a coefficient which varies from 0.1 on straight and level roads to nearly 0.2 on gradients. Nevertheless, the effect of varying the composition of traffic depends upon the mean traffic speed. For example, under free flow conditions and speed of 80 km/h the noise level may increase by 5-dB(A) for a 30% increase in commercial traffic. However, at the lower speed of

30 km/h a similar increase in noise would occur following an increase in commercial vehicles of only 15% of the total flow.

2.3.4 Gradient

It is generally accepted that traffic noise levels are affected by the gradient of road. Johnson and Saunders (1968) concluded that the effect of gradient depends upon the percentage of heavy vehicles and predicted increases of up to 12-dB(A) for a gradient of 1 in 8. However, a later analysis of these data suggested that the initial estimate was too high and that under normalized conditions the increase was only of the order of 4-dB(A). These later values are in fairly good agreement with the value obtained for motorways.

2.3.5 Road Surface

Road surface texture affects the noise level generated by traffic because it particularly controls the road-tire interaction noise. Broadly, the noise generated by vehicles traveling on concrete or surface dressed bituminous materials, can emit up to 3-dB(A) more noise than vehicles traveling on a well-worn concrete or asphalt surface.

2.4 Generation of Tire-Road Noise

The noise generated by the action of vehicle tires rolling on road surfaces of various textures can have a considerable effect on the total noise levels generated by moving vehicles. At speeds above 100 km/h on dry roads tire-road surface noise becomes the dominant source for all but the heaviest diesel-engined good vehicles. On wet roads, speeds can be much lower to give the same degree of tire noise.

2.4.1 Sources of Tire Noise

Source of tire noise include aerodynamic noise from the rotation of the wheel and tire, noise from vibration of the tire surface, and pressure fluctuation caused by pumping of air in the tread grooves in the contact patch.

2.4.2 Factors Affecting Tire-Road Noise

It has been mentioned previously that the type of road surface and tire design affect the generation of tire-road noise. Nelson (1987) proposed parameters affect tire-road noise, such as: speed of vehicle, weight of the vehicle (tire loading), tread pattern, tire structure, tread materials, tire wear, road surface texture, and surface water.

2.5 Measuring Road Roughness

Road roughness is the name given to the longitudinal unevenness of the road surface. It is measured on the scale that reflects the effect of the surface on any vehicle that travels over it. One of the most widely used roughness scales in developing countries is the International Roughness Index (IRI). The IRI is a standardized roughness measurement related to those obtained by Response-Type Road Roughness Measurement Systems, with recommended units: meters per kilometer (m/km).

Road roughness was conducted using static device Merlin. The Merlin is a machine for evaluating roughness using low-cost instrumentation. For all type roads the following equation gives the relationship between the Merlin scale and IRI (Cundill, 1991).

$$IRI = 0.593 + 0.0471\,D \quad (2)$$

Where:
IRI = International Roughness Index
D = the roughness on the Merlin scale uncorrected and it is measured in millimeter

Equation 2 assumes that D was derived using a mechanical amplification of 10. In practice this will be not true because of small errors in manufacturing. So before the equation is used, the D value must be adjusted (scaling factor)

$$Scf = (10*T)/S \tag{3}$$

$$D' = D * Scf \tag{4}$$

Where:
T = thickness of the block, that is inserted between probe and floor
S = Space between two marks on the chart
Scf = scaling factor
D' = roughness on the Merlin scale, corrected

3 METHODOLOGY OF DATA COLLECTION

3.1 Selection of Test Site

Consideration involved in selecting the location is the condition of the road at the location of the test measurements. The conditions should be such that:

- i). Adequate space is available for field measurements, so that the tests can be carried out safely and with minimum interference to other users.
- ii). Free from obstruction at the test site for at least 50 m before and after the Sound Level Meter (SLM) and Radar Speed Meter (RSM), so that the observer is free to observe the vehicle being measured as it passes the SLM and RSM.
- iii). No obstructions are located between the microphone and the test site.
- iv). The road is level.
- v). The test site is far from building or facades that will cause a reflection of noise intensity.
- vi). The traffic on the site test should have such a condition that average single vehicle speeds between 60 – 80 km/h are available.
- vii). The test sites should have different surface roughness. It was assume that other pavement conditions are ideal.
- viii). The test sites should has such a condition that no other variables can influence the propagation of SPL except roughness
- ix). The traffic on the site test should have such a condition that a single vehicle can be observed by LSM and RSM.

3.2 Field Data Observation

3.2.1 Roughness Measurement

A pilot survey was conducted to evaluate the roughness of the road surface on flexible pavements and rigid pavements. Four sections with different road roughness have been chosen for both flexible and rigid pavements. The IRI value for each section is shown in Table 1.

Table 1 IRI Values

Pavement Type	Section	D	D'	IRI (m/km)
Flexible	I	60.83	59.61	3.40
	II	65.71	64.40	3.63
	III	72.25	70.81	3.93
	IV	41.66	40.83	2.52
Rigid	I	115.13	112.83	5.91
	II	107.71	105.56	5.56
	III	103.00	100.94	5.35
	IV	102.14	100.10	5.31

3.2.2 Sound Pressure Level Measurement

Sound pressure level measurements were conducted at the site where the roughness of the roads was known. In this research data were collected using a Precision Integrating Sound Level Meter (SLM) type NL-15. The precision sound level meter was located approximately 7.5 m from the centerline of the vehicle path and 1.2 m above the ground level. Especially on flexible pavements the SLM was also located approximately 15 meters from the centerline. Sound pressure levels for individual vehicles were measured when each vehicle passed the SLM that has been set-up at the test site.

Test car was used in order to avoid the overlapping noise from other vehicle. But because of the limited time and fund, the test car was only run five times on each section for both rigid and flexible pavements.

3.2.3 Vehicle Speed Measurements

Vehicle speed data were collected in this study using a radar speed meter. The accuracy of radar units is affected by angle error. It occurs because the angle of incidence of the radar beam to the travel direction of the vehicle produces a reading on the unit is less than the actual speed. As shown in Table 2, the measurement is a function of the cosine of the incidence angle. Some radar units have a built-in correction for angle error based on preset of incidence. This type of radar units have been used in collecting speed data.

Table 2 Radar: True Speed and Cosine Error

Angle (deg)	Measured Speed at True Speed of:		
	30 mph	40 mph	50 mph
1	29.99	39.99	49.99
5	29.89	39.85	49.81
15	28.98	38.64	48.30
30	25.98	34.64	43.30
90	00.00	00.00	00.00

Source: Lunenfeld and McDade, 1983 as quoted in Robertson et.al., 1994

3.2.4 Traffic Flow Condition

Table 3 shows traffic flow at flexible pavement. Traffic flow was measured at the same time as the measurement of vehicle noise. Traffic flow was measured for 15-minute interval, and then it is converted into flow rate (vph). Flow rate is the maximum hourly rate at which vehicles reasonably can be expected to traverse a point of roadway.

Table 3 Traffic Flow at Flexible Pavements

Section	Flow (vehicle/15')			Flow Rate (vph)
	Cars	Trucks	Motorcycles	
I	188	62	96	1388
	181	59	102	
	194	73	91	
	189	54	98	
II & III	152	43	97	1168
	160	47	89	
	143	39	94	
	153	43	108	
IV	163	27	76	1064
	157	31	77	
	168	26	69	
	164	24	82	

4 DATA ANALYSIS

4.1 Summary of Data

Table 4 shows a summary of car, truck, and motorcycle data, running at various speeds at four different surface roughnesses on both flexible and rigid pavements. Then the data were grouped with two-interval classes of speed, 5 km/h interval class and 10 km/h interval class.

Table 4 Summary of Data of Single Vehicles

Type of Vehicle	Parameter	Flexible Pavement				Rigid Pavement			
		IRI (m/km)				IRI (m/km)			
		2.52	3.40	3.63	3.93	5.31	5.35	5.56	5.91
Test Car	No. of samples	5	5	5	5	5	5	5	5
	Mean noise levels dB(A)	73.5	77.6	79.6	80.3	73.6	74.1	75.6	76.7
	Std. deviation of noise levels	3.2	3.3	4.1	4.1	3.8	3.8	3.7	3.5
	Mean speed (km/h)	69.3	68.3	67.3	65.7	59.7	59.4	60.1	60.1
	Std. deviation of speed	15.7	14.9	17.4	16.8	15.7	15.7	15.2	15.7
Cars	No. of samples	65	68	75	80	104	105	95	108
	Mean noise levels dB(A)	73.0	76.3	77.2	78.0	72.9	73.3	73.4	74.4
	Std. deviation of noise levels	1.4	1.4	1.9	2.1	3.0	2.8	2.4	2.5
	Mean speed (km/h)	57.3	56.4	68.3	63.5	59.3	56.8	51.8	50.9
	Std. deviation of speed	9.9	9.4	12.6	12.7	17.3	16.0	11.9	13.0
Trucks	No. of samples	42	41	33	34	6	6	7	9
	Mean noise levels dB(A)	74.1	79.5	80.1	81	82.5	82.1	78.6	79.0
	Std. deviation of noise levels	2.4	2.7	2.3	2.3	2.8	2.6	3.5	4.8
	Mean speed (km/h)	55.3	57.3	61.3	61.2	58.3	58.3	45.3	48.6
	Std. deviation of speed	8.1	8.8	7.0	7.3	11.4	10.7	12.9	10.8
Motorcycle	No. of samples	39	35	46	41	33	28	28	28
	Mean noise levels dB(A)	69.7	75.1	73.6	74.7	72.9	74.1	73.0	74.4
	Std. deviation of noise levels	2.6	2.5	2.3	2.3	2.0	2.0	2.1	3.0
	Mean speed (km/h)	46.7	50.1	51.4	50.4	40.2	44.2	43.8	42.2
	Std. deviation of speed	12.2	11.2	11.5	12.2	10.6	10.5	11.1	9.4

4.2 Presentation of Data Analysis

The following parts show the relationship between traffic noise (in term of sound pressure levels of single vehicles), road roughness and vehicle speed, especially the effect of road roughness on generated sound pressure levels.

4.2.1 Sound pressure levels on Flexible Pavement

There were four different roughness (as can be seen in Table 1), two distances, and three types of vehicles (car, trucks, and motorcycles) plus a test car that was investigated in this study. The data were plotted in sound pressure levels (SPL) against car speeds. From the statistical data, the statistical of R^2 maximum is 0.56 for distance 7.5 m and it is 0.51 for distance 15 m. Based on these results increased the distance was reducing the SPL of and car. It also can be concluded that the correlation between SPL and car speed is not quite good. This means that car speeds only have a limited influence on generated sound pressure levels.

Figure 1 shows a relationship between SPL and car speeds for at four different surface roughness of flexible pavement. This figure also shows the effect of roughness on generated sound pressure levels of single cars. It can be seen that road roughness has an influence on generated sound pressure levels cars. At the same speed, higher roughness will produce higher SPL.

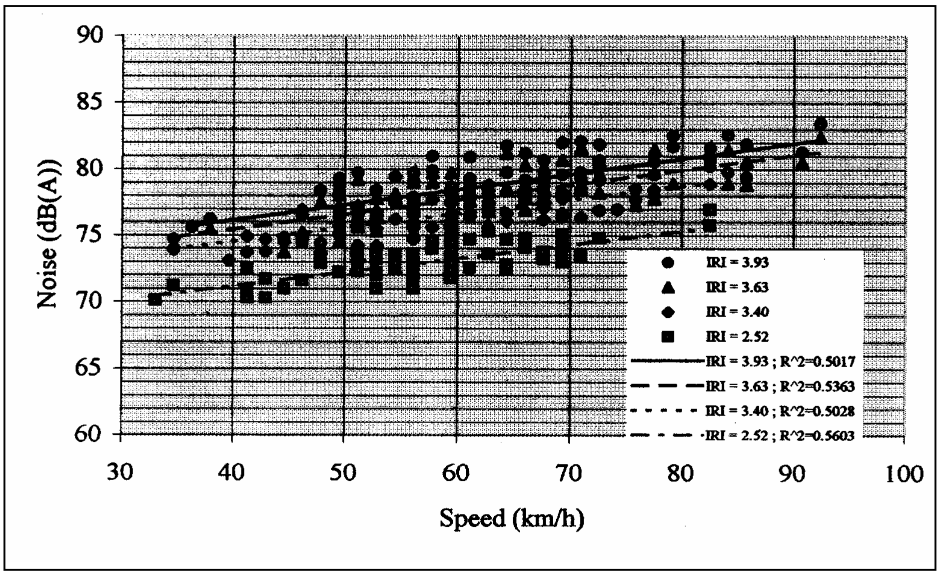

Figure 1 SPL of Cars on Flexible Pavements with Distance 7.5m

To evaluate the influence of road roughness on propagating sound pressure levels of single cars, the data were grouped with two interval class. Results were plotted in sound Pressure levels (SPL) against road roughness. Comparing the result from the 5-km/h and 10-km/h interval classes, the first one has better correlation between SPL level and road roughness. Figure 2 shows a relationship between SPL and roughness for single cars with interval class of 5-km/h.

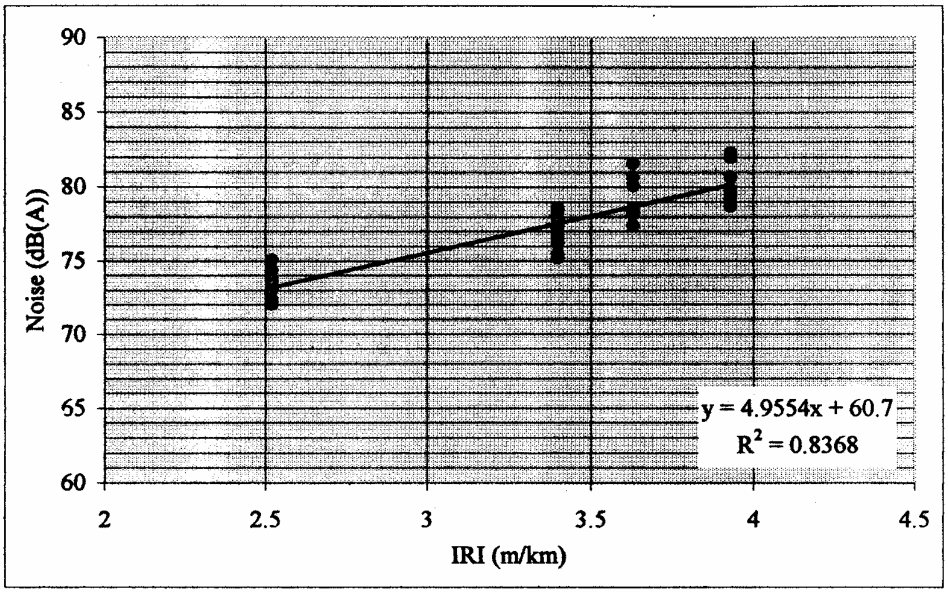

Figure 2 SPL of Cars on Flexible Pavements at V = 70 km/h
With Interval Class of 5 km/h

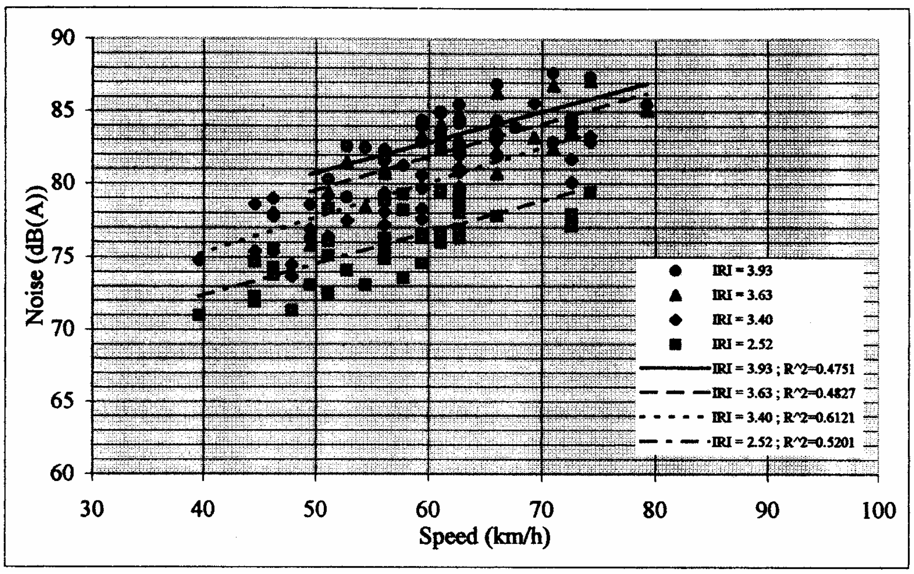

Figure 3 SPL of Trucks on Flexible Pavements with d = 7.5 m

As was with cars, trucks also do not have a quite good correlation between sound pressure levels and truck speeds. This means that for trucks, speeds also only have a limited effect on generated sound pressure levels. Figure 3 shows a relationship between SPL and speed for trucks at four different surface roughnesses. This figure also shows the effect of roughness on generated sound pressure levels of single trucks. As was the case with cars, for trucks the road roughness also has an influence on generated sound pressure levels.

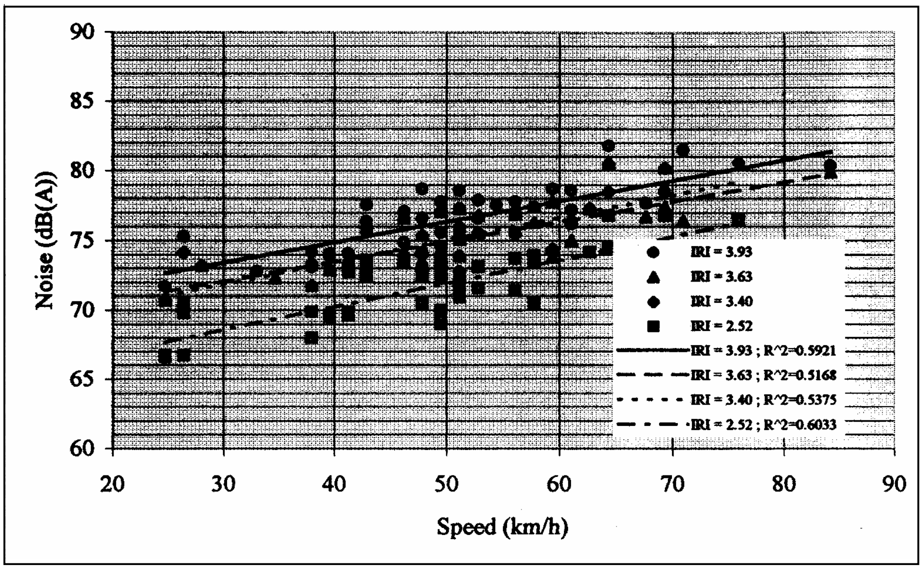

Figure 4 SPL of Motorcycles on Flexible Pavements with d = 7.5 m

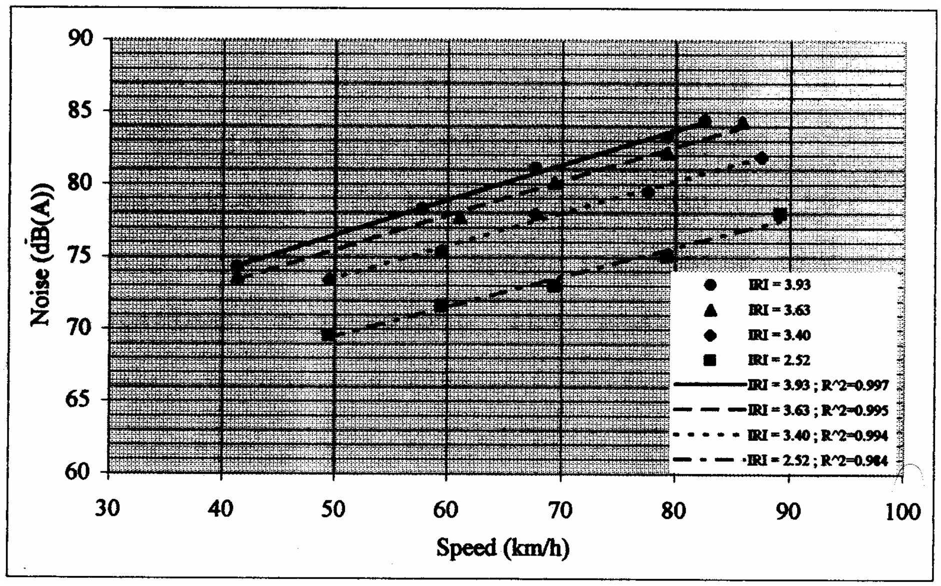

Figure 5 SPL of Test Car on Flexible Pavements

As was with cars and trucks, motorcycles also do not have a quite good correlation between sound pressure levels and motorcycle speeds. This means that for motorcycles, speeds also only have a limited effect on generated sound pressure levels. Figure 4 shows a relationship between SPL and speed for motorcycles at four different surface roughnesses. This figure also shows the effect of roughness on generated sound pressure levels of single motorcycles. It can be seen that, as with cars and trucks above, for motorcycles, there is an influence on generated sound pressure levels.

Figure 5 shows a relationship between SPL and speed of test car at four different surface roughness of flexible pavement. This figure shows the effect of roughness on generated sound pressure levels of single test car.

4.2.2 Sound Pressure Levels on Rigid Pavements

There were four different roughness (IRI = 5.31, 5.35, 5.56, and 5.91) and three types of vehicles (car, trucks, and motorcycles) plus a test car that was investigated in this study. The SPL were measured at 7.5 m from centerline. But there is very limited data of trucks that had been collected in the field; hence, there is no analysis for trucks on rigid pavement. The data were plotted in sound pressure levels against speed.

Data from rigid pavement were also analyzed similar to data from flexible pavement, then the relationship between SPL and vehicle speed (car, motorcycle, and test car) were plotted. It can be concluded that road roughness has an influence on generated sound pressure levels for car, motorcycle, and test car.

4.2.3 Comparison of SPL on Three Types of Vehicles

Based on the result those explained in previous section, the SPL of single vehicle were compared between three types of vehicle. Figure 6 shows a comparison between SPL of cars, trucks, and motorcycles on flexible pavement. It can be seen from Figure 6 that trucks produced higher SPL than cars and motorcycle. And there was no significant difference in SPL of cars and motorcycles.

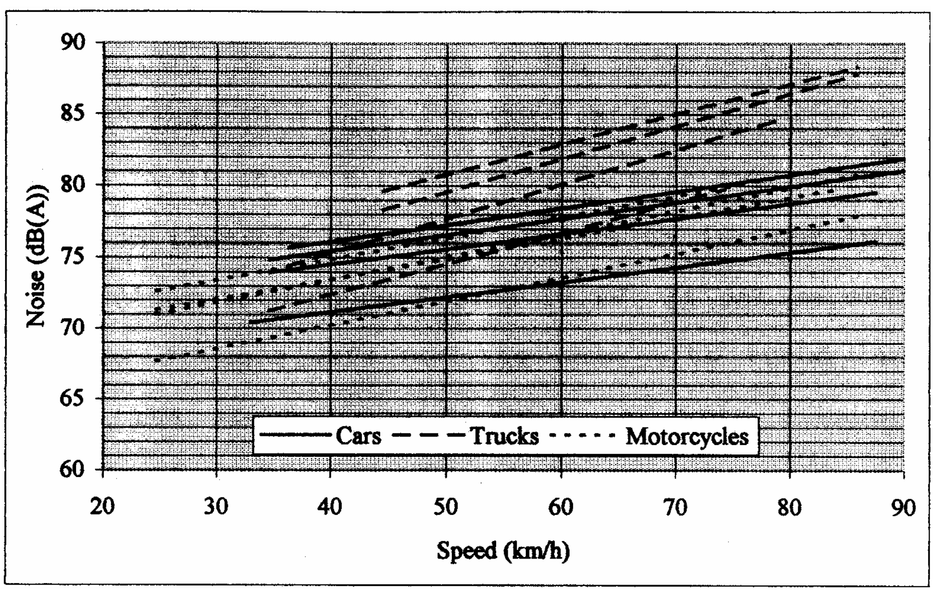

Figure 6 Comparisons SPL of Cars, Trucks, and Motorcycle
On Flexible Pavements

On a rigid pavement, trucks produced higher SPL than cars and motorcycles. Increase in speed caused higher SPL for each individual vehicle, but truck had the highest rate of increase. These can be seen in Figure 7.

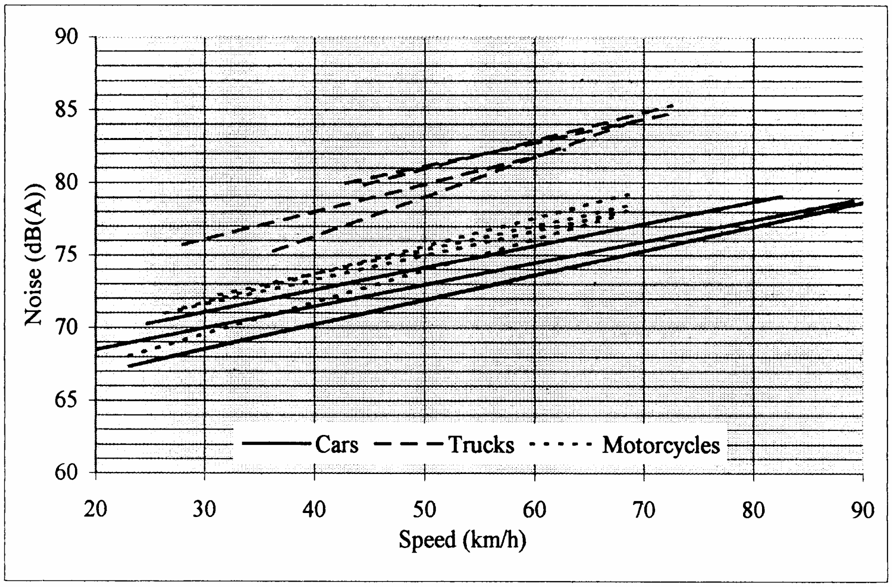

Figure 7 Comparisons SPL of Cars, Trucks, and Motorcycle
On Rigid Pavements

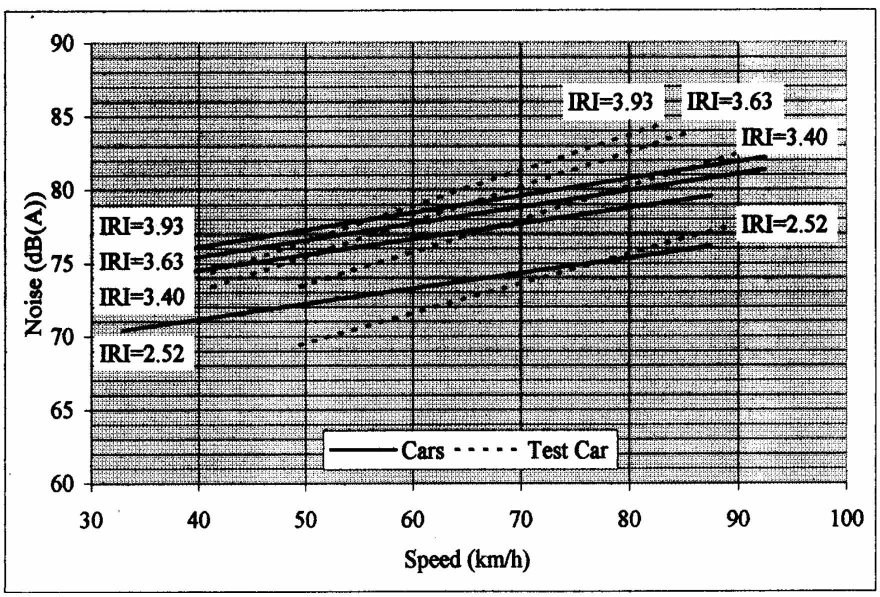

Figure 8 Comparisons SPL of Cars, and Test Car on
Flexible Pavements

Figure 8 shows a comparison between SPL of cars and test cars on flexible pavement. It can be seen that trend lines of car were not the same with trend lines of test car. The trend lines of test car were steeper than trend lines of cars. As was the case with flexible pavements, on rigid pavements also the trend lines of test car were steeper than trend lines of cars.

4.2.4 Comparison of SPL on Two Types of Pavement

From comparison between SPL of test car on flexible and rigid pavements can be seen that at IRI=3.93 and 3.63 flexible pavement had sound pressure levels exceeding sound pressure levels at IRI=5.91, 5.56, 5.35, and 5.31 on rigid pavements. And the IRI=3.40 on flexible pavements produce sound pressure levels exceeding sound pressure levels at IRI=5.35 and 5.31 on rigid pavements.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

The following conclusions can be drawn based on the analysis of the data results of sound pressure levels for single vehicles.

1. Based on a statistical regression for correlation between sound pressure levels and vehicle speeds, the statistical of R^2 for cars, trucks, and motorcycles are about 0.50 – 0.75. Moreover the statistical of R^2 for the test car is about 0.97 – 0.99. This means that there is a good correlation between sound pressure levels and vehicle speeds.

2. Double distance of SPL measurements reduced the values by around 4.5 dB(A) for cars and motorcycles and 5 dB(A) for truck.

3. Based on statistical regression for correlation between sound pressure levels and vehicle speeds, the trend lines of cars were not the same with trend lines on test cars. This means that characteristic of test car was different with cars on the field.

4. Over all results on flexible pavements, trucks produced higher SPL than cars and motorcycles. And there was no significant difference in SPL of cars and motorcycles.

5. As was the case with results on flexible pavements on rigid pavements trucks also produced higher SPL than cars and motorcycles. But here motorcycles produced slightly higher SPL than cars.

6. The effect of roughness on SPL for rigid pavement and for flexible pavement is different. Even though rigid pavement had a higher IRI value than flexible pavement, the rigid pavement did not always produce higher SPL.

7. Based on the correlation result road roughness is one of many variables that should be considered in measuring traffic noise (in terms of sound pressure levels of single vehicles).

5.2. Recommendation

1. Limited number of single test car data on the field causes a difficulty in analysis. For further research a larger number of data is recommended. Using other test vehicles like truck, motorcycle is also very useful.

2. There are other variables such as type of pavement, road surface micro texture which should be considered for further research of sound pressure levels for individual vehicle.

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