ระดับเสียงอ้างอิงของรถยนต์ในประเทศไทย ในสภาพการไหลแบบไม่ต่อเนื่อง

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บทคัดย่อ

เอกสารงานวิจัยนี้เสนอวิธีการเก็บข้อมูลและการสร้างแบบจำลองระดับเสียงอ้างอิงของรถยนต์ในประเทศไทยในสภาพการไหลแบบไม่ต่อเนื่อง ซึ่งเป็นฐานข้อมูลที่สำคัญอย่างยิ่งในการทำนายเสียงจราจรที่บริเวณสี่แยก โดยระดับเสียงอ้างอิงแบ่งออกเป็น 8 ประเภทตามประเภทของรถยนต์ทั้ง 8 ชนิด ซึ่งได้แก่ รถยนต์ส่วนบุคคล รถกระบะ รถบรรทุกหกล้อ รถบรรทุกสิบล้อ รถพ่วง รถโดยสาร รถจักรยานยนต์ และรถสามล้อเครื่อง ข้อมูลสนามที่เก็บได้แก่ ระดับเสียงและความเร็วของรถยนต์ที่ตำแหน่ง 15, 30, 60, และ 120 เมตร จากตำแหน่งหยุด โดยติดตั้งเครื่องวัดเสียงจำนวน 4 เครื่องที่ตำแหน่งดังกล่าว และห่างจากกึ่งกลางช่องจราจรเป็นระยะ 15 เมตร ระดับเสียงและอัตราเร็วที่ได้จากทั้ง 4 จุดจะนำมาสร้างสมการความสัมพันธ์ โดยระดับเสียงจะเป็นตัวแปรตามและอัตราเร็วเป็นตัวแปรอิสระ โดยใช้สมการของกรมทางหลวงของสหรัฐอเมริกา

จากผลการศึกษาพบว่ารถยนต์แต่ละประเภทมีค่าระดับเสียงที่ความเร็วต่างๆ แตกต่างกันและลักษณะของเสียงรถยนต์ที่ใช้ในประเทศไทยแตกต่างกับลักษณะของเสียงรถยนต์ชนิดเดียวกันในประเทศสหรัฐอเมริกาอย่างมาก

คำสำคัญ : การไหลแบบไม่ต่อเนื่อง / ระดับเสียงอ้างอิง / เสียงจราจร / สี่แยก

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Interrupted Flow Noise Emission Levels for Vehicles in Thailand

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Abstract

The development of basic noise emission levels for vehicles in Thailand in the condition of interrupted traffic flow is presented in this paper. The basic noise emission levels are classified into 8 classes in accordance with the following vehicle types: passenger car, light truck, medium truck, heavy truck, tractor trailer, bus, motorcycle, and Tuk-tuk. The maximum A-weighted sound levels (L_{AFmx}) of accelerating vehicles and corresponding speeds were collected from several individual pass-by vehicles in Bangkok and other provinces. Four sound level meters were situated at the distances of 15, 30, 60 and 120 meters from the imaginary stop line with 15 meters setback from the centerline of the nearest travel lane for the measurement of maximum sound levels at the fronts of all instruments. The vehicular instantaneous speeds at the same locations with L_{AFmx} measurement were also measured. The L_{AFmx} of eight types of vehicles were then plotted against the corresponding speeds to determine their relationship. The results indicate that the eight vehicle types are significantly different in their acoustical features. Furthermore, the resulting basic noise emission levels are significantly different from those in the FHWA Traffic Noise Model (FHWA TNM) due to the country-to-country differences in vehicle characteristics.

Keywords : Interrupted Flow / Basic Noise Emission Level / Traffic Noise / Intersection

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1. Introduction

The interrupted flow traffic noise, which can be generally encountered at intersections, causes the environmental impact to the nearby communities differently from uninterrupted flow situation. Modeling interrupted flow traffic noise needs the measurement of the individual vehicle pass-by sound levels as so-called basic noise emission levels or reference energy mean emission levels (REMELs). The US Federal Highway Administration (FHWA) has also developed the national data of the interrupted flow basic noise emission levels of vehicles for being applied to the FHWA Traffic Noise Model (FHWA TNM). However, those cannot be reliably applicable to traffic conditions in Thailand due to the differences in vehicle types and characteristics. This paper presents the results of an effort to develop the interrupted flow basic noise emission levels of vehicles in Thailand. The interrupted flow basic noise emission levels from this study can be used either in the existing models or for developing a new interrupted flow traffic noise model.

2. Classification of vehicles

According to the FHWA TNM, the vehicles are classified in five categories as: automobile, medium truck, heavy truck, bus, and motorcycle for both uninterrupted and interrupted flow traffic noise studies [1, 2]. Actually, bus and motorcycle are just additional vehicle types in FHWA TNM which were not studied in the previous FHWA traffic noise model [3]. In addition, there is the small number of data for buses and motorcycles collected in the condition of interrupted flow according to the Development of National REMELs for the FHWA TNM [1]. Also, the study of interrupted flow REMELs for the FHWA TNM by Bowlby et al., [4] omitted such two vehicle types.

Owning to the characteristics of vehicles and prevailing vehicle types in the US significantly different from those in Thailand, the traffic need to be classified dependent upon their own different acoustical features. As Table 1 shows, the vehicles in Thailand are classified in eight types as: passenger car, light truck, medium truck, heavy truck, tractor trailer, bus, motorcycle and Tuk-tuk.

In FHWA TNM, the noise characteristics of passenger cars and light trucks in the US are statistically similar and then grouped into the same type. In contrast, since the noise levels of light trucks are obviously higher than those of passenger cars, they are segregated to different categories in this study. Most heavy trucks in Thailand are single unit trucks with 10 wheels and the exhaust pipes are located at the height of about 0.5 m above the ground [5]. Therefore, they need to be classified in the different group from the tractor trailers of which the exhaust pipes are at the top of the drivers' chambers. The sizes of motorcycles in Thailand are mostly smaller than those in the US, especially the motorcycles from the Harley-Davidson Motor Company which are the representative of all the US motorcycles [1]. The highways and urban streets in many provinces in Thailand are plentiful of a local vehicle type so-called Tuk-tuk. In fact, the size of a Tuk-tuk is relatively smaller than a passenger car, but it unfortunately generates the noise levels so much louder.

Table 1 Classification of vehicle types and their descriptions

Vehicle types	Abbreviation	Descriptions
Passenger cars	PC	All vehicles with two axles and four wheels.
Light trucks	LT	All single unit cargo vehicles with two axles and four wheels including vans.
Medium trucks	MT	All single unit cargo vehicles with two axles and six wheels.
Heavy trucks	HT	All single unit cargo vehicles with three axles and ten wheels.
Tractor trailers	TL	All cargo vehicles with more than three axles and ten wheels including full-trailers and semi-trailers.
Buses	BS	All vehicles designed for carrying more than nine passengers.
Motorcycles	MC	All vehicles with two wheels and an open-air driver/passenger compartment.
Tuk-tuks	TT	Motorized tricycles with three wheels designed for carrying two or three passengers in a covered compartment.

3. Site selection

The physical criteria for each selected site include: a flat space, free of large acoustical obstructions, and good pavement conditions. Both asphaltic and concrete pavements are possible. In addition, the prevailing background noise levels should be low enough to uncontaminate the measured vehicle noise levels. The difference between maximum vehicle pass-by sound level and the background sound level has to be at least 6 dB with 10 dB being preferable [1, 4]. The selected roadways should have low traffic volumes enough to enable the convenient measurement and high enough to provide the reasonably desired number of samples. Accordingly, all of the study sites are two-lane highways far from the communities so as to meet the above requirements and enable the members of the team to conveniently block the vehicles as described hereafter. The measurement should not be conducted in case that wind speed exceeds a limit of approximately 20 km/h [1, 6, 7]. In addition, any other criteria necessary for site selection in the FHWA TNM can be also applied. The measurement sites are located in these provinces of Thailand, namely, Angthong, Bangkok, Chonburi, Kanchanaburi, Nakornpathom, and Suphanburi. Their descriptions are given in Table 2.

Table 2 Measurement sites and descriptions

Site No.	Provinces	Main vehicle types studied	Pavement type	Site surface	Grade
1	Angthong	TL, BS, and MC	Asphaltic	Hard	0
2	Bangkok	TT	Concrete	Hard	0
3	Chonburi	HT, LT, and PC	Asphaltic	Soft	0
4	Nakornpathom	HT, MT, MC, and TL	Asphaltic	Hard	0
5	Suphanburi	PC, LT, and MT	Asphaltic	Hard	0
6	Kanchanaburi	HT, TL, and BS	Asphaltic	Hard	0

4. Vehicle noise and speed measurements

Owning to the difficulties of data collection at real signalized intersections, straight sections of two-lane highways are applied instead as previously described. As Fig. 1 shows, an imaginary stop line (Point 0) is established in order to make the measurement site like an intersection. Four sound level meters at a height of 1.2 m above the roadway elevation are placed at the distances of 15, 30, 60 and 120 m from the stop line with 15 m setback from the centerline of the nearest travel lane. It should be noted that the height of sound level meters of 1.2 m is different from the US studies which utilize 1.5 m. However, the results of emission noise levels in both cases are comparable because the effects of such an insignificant difference can be ignored [7]. The locations of time pulse recording are at the same places with the sound level meters.

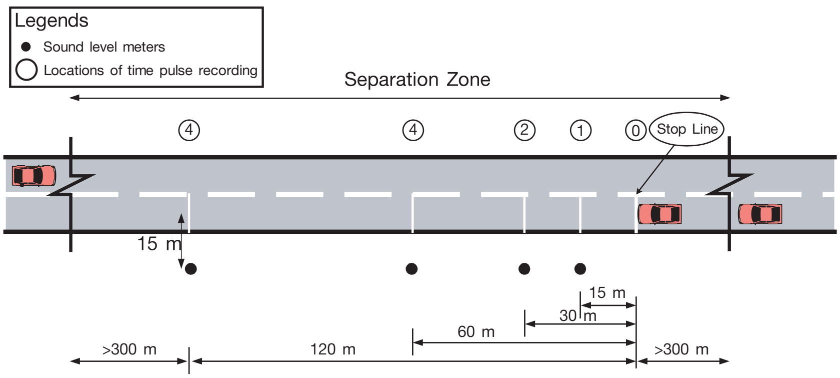

Fig. 1 Typical layout of a measurement site

The separation zone as illustrated in Fig. 1 is established at the distance of more than 300 m from the stop line (Point 0) and the last sound level meter (Point 4) to ensure that the measured noise levels are not interfered by other vehicles. To measure interrupted noise levels of a vehicle, a selected subject was called to completely stop at the stop line and the others were blocked at both ends of the separation zone to enable the measurement of uncontaminated vehicle pass-by noise levels. As a selected vehicle was in front of each sound level meter, a measurer would record A-weighted maximum sound levels (L_{AFmx}). Simultaneously, other members of the team at Points 0 through 4 would raise and lower signal flags for time pulse recording as the front axle of the vehicle passed over the marker lines painted on the pavement. The vehicle spot speed at the front of each sound level meter will be determined by subsequent analysis.

5. Data analysis

5.1 Number of samples

With reference to FHWA TNM, the number of sample size of each vehicle type is arbitrary which depends highly upon the budgetary constraints. The more the number of samples collected, the higher accuracy of the basic noise emission model will be obtained [8]. In this study, the number of vehicles in each type collected is shown in Fig. 2. The number of passenger cars and especially light trucks are much more than other vehicle types because both of them are dominating vehicles for highways and streets in Thailand. Due to the scarce events of buses in the study sites in which two-lane highways are applied, 105 vehicle samples are used to represent the bus population in Thailand. In case of Tuk-tuks, a number of data of 196 are resulted from fair to good fifteen vehicles which are hired for measuring pass-by noise levels.

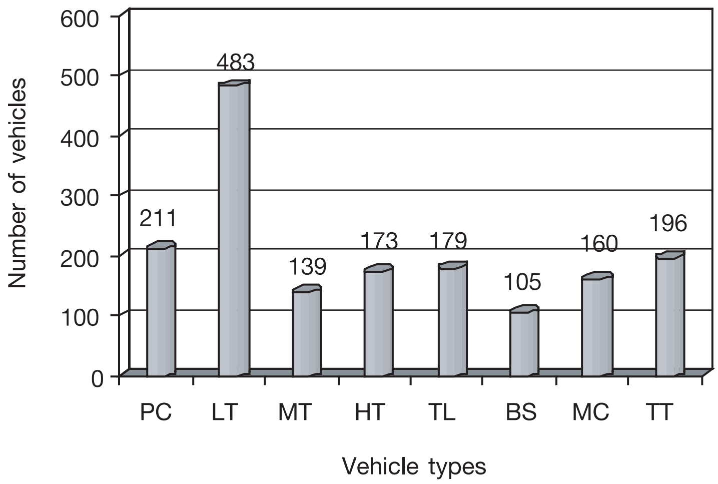

Fig. 2 Number of vehicles sampled

Since a passage of a vehicle generally results in four data points for vehicle noise emission levels, the number of data points at each location of measurement in the regression as in Figs. 4-12 are presented in the Table 3.

Table 3 Number of data points for each type of vehicles in the regression

Vehicle types	Number of data points at each location				Total
	15 m	30 m	60 m	120 m	
Passenger car (PC)	211	211	211	211	844
Light truck (LT)	483	483	483	483	1,932
Medium truck (MT)	139	139	139	139	556
Heavy truck (HT)	173	173	173	173	692
Tractor trailer (TL)	179	179	179	179	716
Bus (BS)	105	105	105	105	420
Motorcycle (MC)	160	160	160	160	640
Tuk-tuk (TT)	196	196	196	196	784

5.2 Determination of vehicle speeds

A critical part for the formulation of vehicular basic noise emission models is to determine vehicle speeds. The formulas of a vehicle's motion are applied to compute the vehicle spot speeds at every location of sound level meters. According to Eqs. (1)-(3), the acceleration rate of a vehicle is assumed to be constant over two adjacent sound level meters, but not for the entire length of measurement site. That is, the acceleration rates of a vehicle from Points 1 to 2, Points 2 to 3, Points 3 to 4, and Points 4 to 5 in Fig. 1 are presumably constant but not equivalent among each other. The computed acceleration rates varying from section to section will represent the actual driving behavior better than assuming constant acceleration rate for the entire length.

$$S_f = S_i + at \quad \textbf{(1)}$$

and;

$$a = \frac{2\left(D - S_i t\right)}{t^2} \quad \textbf{(2)}$$

Substituting (2) to (1);

$$S_f = S_i + \frac{2\left(D - S_i t\right)}{t^2} \quad \textbf{(3)}$$

The vehicle spot speeds at each location of sound level meters are calculated by using Eq. (3) as the following:

$$S_{0m} = 0 \tag{4}$$

$$S_{15m} = \frac{30}{t_{0m\text{-}15m}} \tag{5}$$

$$S_{30m} = S_{15m} + \frac{2(15 - S_{15m} \times t_{15m\text{-}30m})}{t_{15m\text{-}30m}} \tag{6}$$

$$S_{60m} = S_{30m} + \frac{2(30 - S_{30m} \times t_{30m\text{-}60m})}{t_{15m\text{-}30m}} \tag{7}$$

$$S_{120m} = S_{60m} + \frac{2(60 - S_{60m} \times t_{60m\text{-}120m})}{t_{60m\text{-}120m}} \tag{8}$$

where S_f is final spot speed of each section (m/s); S_i is initial spot speed of each section (m/s); a is acceleration/deceleration rate (m/s) of a section; D is the distance of a section; t is the measured time period for each section (s).

5.3 Analysis of interrupted noise emission levels

In determining basic noise emission models, the measured noise levels of each vehicle type in the condition of interrupted flow are plotted against the corresponding spot speeds. Bendtsen [9] as well as Lee and Fleming [8] demonstrated that, in the low speed range of approximately 0-50 kph, the noise emission level is influenced by vehicle engine and exhaust pipe, which is independent on speed; however, it obviously shows the linear relationship of the tire/pavement interaction noise with higher speed range. The functional form of the basic noise model is defined as [1, 2, 4, 8].

$$\begin{aligned} L(s) &= 10 \log [10^{C/10} + 10^{(A\log(s)+B)/10}] \\ &= 10 \log [10^{C/10} + (S^{A10}10^{B/10})] \end{aligned} \tag{9}$$

where $L(s)$ is the maximum pass-by sound level; C is the coefficient of engine/exhaust noise, that is independent of vehicle speed; and the term $A \log(s) + B$ is the tire/pavement term, which is speed dependent.

The graph of the basic noise emission model in Eq. (9) is illustrated in the following figure.

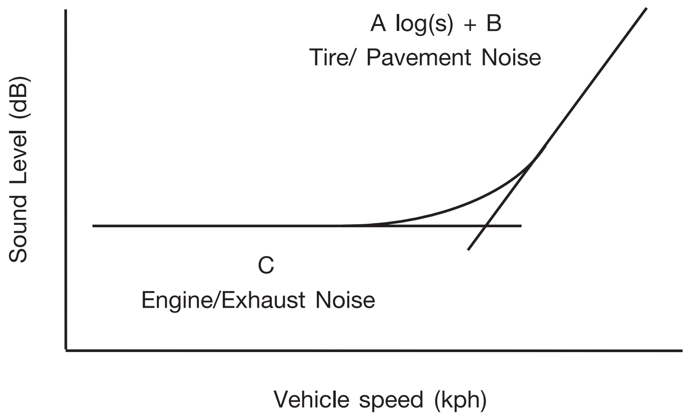

Fig. 3 Graphical form of the regression equation

To adjust from level mean to energy mean, the methodology in the FHWA REMELs report is applied. Eq. (10) is the adjustment term for adjusting the level mean noise data to energy mean in the condition that traffic data are not normally distributed [1].

$$\Delta E \quad = \quad 10 \log \left(\frac{1}{n} \sum RE_i \right) - \frac{1}{n} \sum RL_i \qquad \textbf{(10)}$$

where ΔE is an adjustment term for converting the level mean regression to an energy mean regression; RL_i is the difference between the measured L_{AFmx} and the predicted values at the same speed from the regression equation; RL_i is the energy residuals equivalent to $10^{(RLi/10)}$.

The adjustment term in Eq. (10) is then added to Eq. (9) as follows:

$$L_E(s) \quad = \quad 10 \log \left[10^{(C+\Delta E)/10} + (S^{A/10}\, 10^{(B+\Delta E)/10)})\right] \qquad \textbf{(11)}$$

where $L_E(s)$ is energy-mean sound level.

To construct the basic noise emission models, the coefficients A, B, and C including statistical values will be determined from nonlinear regression analysis using SPSS for Windows 10.0. However, it should be noted that the coefficients A and B in the FHWA TNM interrupted flow REMELs report conducted by Bowlby et al., [4] were not directly achieved from the interrupted flow noise emission data. Both of them were obtained from the uninterrupted flow data by pre-specifying the values of A and B in the regression. In the other word, only the coefficient C of the interrupted flow noise data was investigated.

6. Results and discussions

The basic noise emission levels of the study vehicles in Thailand regressed as a function of speed in the interrupted flow condition are illustrated in Figs. 4-12. All of them, except Tuk-tuks, are also compared with the interrupted REMELs for vehicles in the FHWA TNM. However, some vehicle types in Thailand and FHWA TNM are differently defined, the comparison should then be made with care. For example, the automobiles in the FHWA TNM mainly include both passenger cars and light trucks, but in this study they are segregated to two different types. Therefore, both of them are compared with the automobiles in the FHWA TNM. Heavy trucks with the definition in this study are focused on single-unit trucks with 10 wheels, but they include both single-unit trucks and tractor trailers in the FHWA TNM. Although the other vehicle types such as medium trucks and buses are defined with the same definitions with those in the FHWA TNM, the characteristics of vehicles in aspects of vehicle size, engine, locations of noise sources, and so on are different from country-to-country that make the noise levels of vehicles in both countries not identical even the same type.

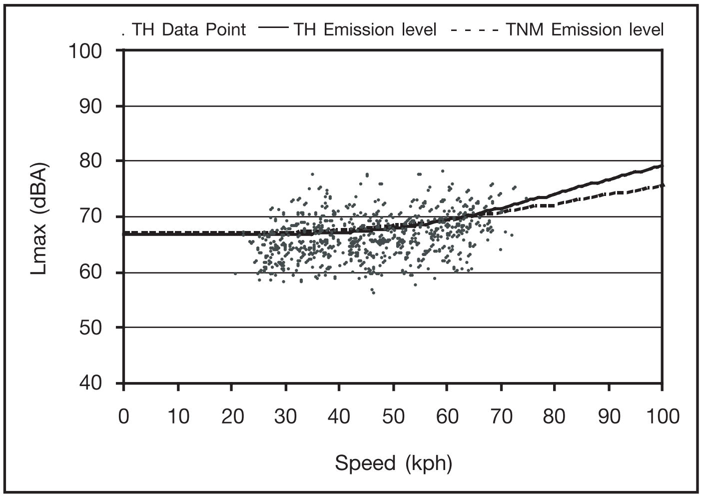

Fig. 4 Interrupted flow noise emission levels for Thai passenger cars versus FHWA TNM automobiles

The interrupted flow basic noise emission levels for Thai passenger cars in Fig. 4 are closely resembled with those for the FHWA TNM automobiles but slightly higher at the speed over 80 kph. This may be implied that the noise levels of FHWA TNM automobiles are close to those of passenger cars in Thailand, or the FHWA TNM automobiles consist primarily of passenger cars rather than light trucks or other vehicles in the same group.

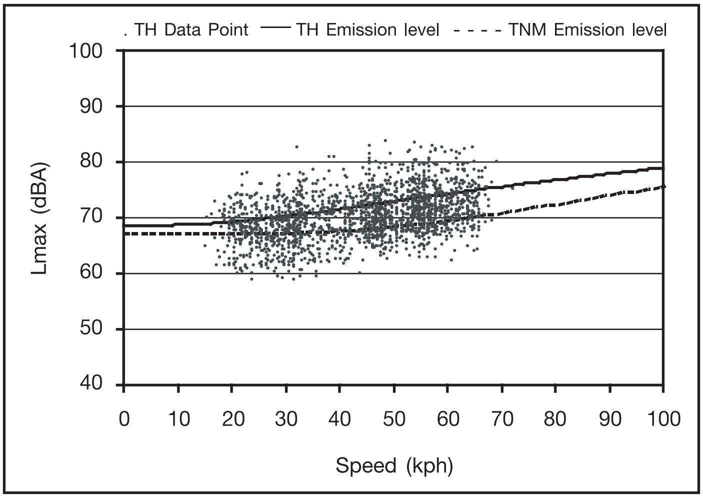

Fig. 5 Interrupted flow noise emission levels for Thai light trucks versus FHWA TNM automobiles

As Fig. 5 shows, Thai light trucks are about 1-5 dB noisier than passenger cars and also FHWA TNM automobiles but tend to be equivalent to passenger cars at 100 kph. The same explanatory reason with passenger cars as stated earlier can probably be applied. It should be noted that if the noise data of both passenger cars and light trucks are aggregated in only one vehicle group, the data points will be more widely scattered and the obtained regression equation will have higher error sum-of-squares making the model not fit to the observed data appropriately.

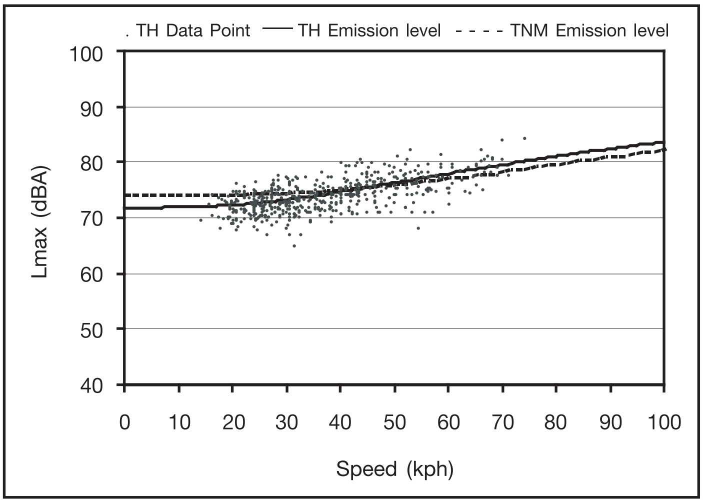

Fig. 6 Interrupted flow noise emission levels for Thai medium trucks versus FHWA TNM medium trucks

The Thai medium trucks are slightly quieter than FHWA TNM medium trucks at speed ranging from 0-40 kph, but approximately 2 dB noisier above 40 kph as shown in Fig. 6. They generate more noise than light trucks for the entire speed range, approximately 3-4 dB.

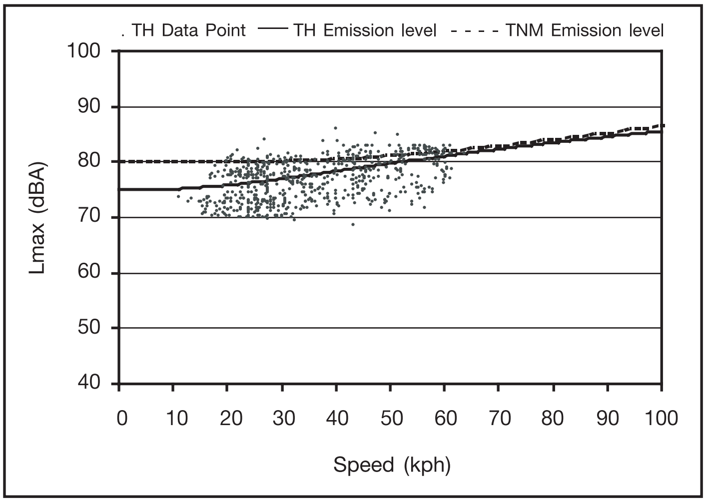

Fig. 7 Interrupted flow noise emission levels for Thai heavy trucks versus FHWA TNM heavy trucks

It is obviously shown in Fig. 7 that there is a significant difference up to 5 dB for Thai and FHWA TNM heavy trucks at very low speed, but both of them tend to be similar at speed over 60 kph. One point that should be noticed is Thai heavy trucks consist of only 10-wheel single unit trucks, while they include tractor trailers in FHWA TNM. This reason may result in such the difference between Thai and FHWA TNM heavy trucks.

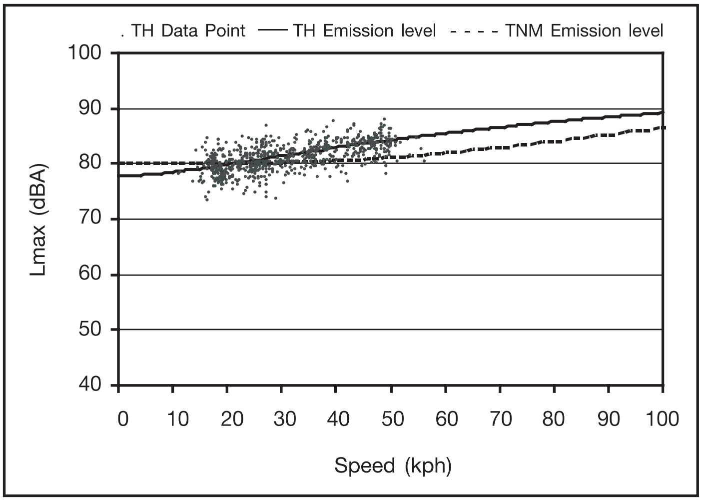

Fig. 8 Interrupted flow noise emission levels for Thai tractor trailers versus FHWA TNM heavy trucks

As shown in Fig. 8, the tractor trailers, which include full-trailers and semi-trailers, are the noisiest vehicles in Thailand. They generate noise levels of 3-5 dB significantly higher than 10-wheel heavy trucks. In addition, they are also noisier than FHWA TNM heavy trucks at speed over 20 kph.

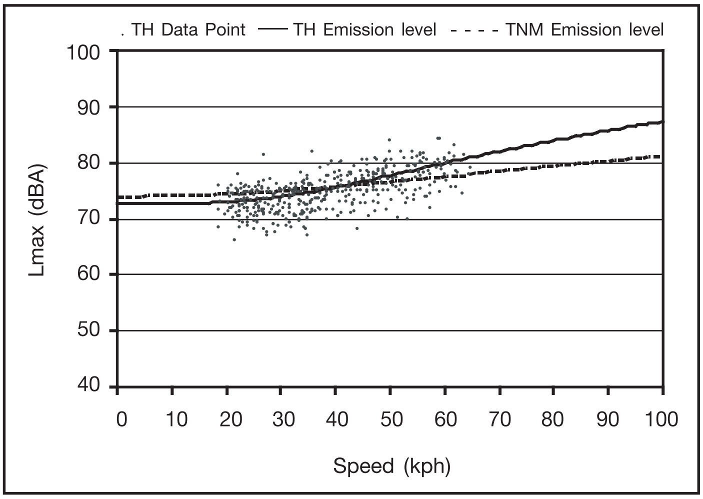

Fig. 9 Interrupted flow noise emission levels for Thai buses versus FHWA TNM buses

As Fig. 9 shows, there is a similarity between noise levels for Thai and FHWA TNM buses at speed of 0-35 dB, but Thai buses are noisier at higher speed up to 8 dB at 100 kph. It is noted that noise levels of Thai buses are between medium and heavy trucks at speed below 60 kph and higher than heavy truck at higher speed.

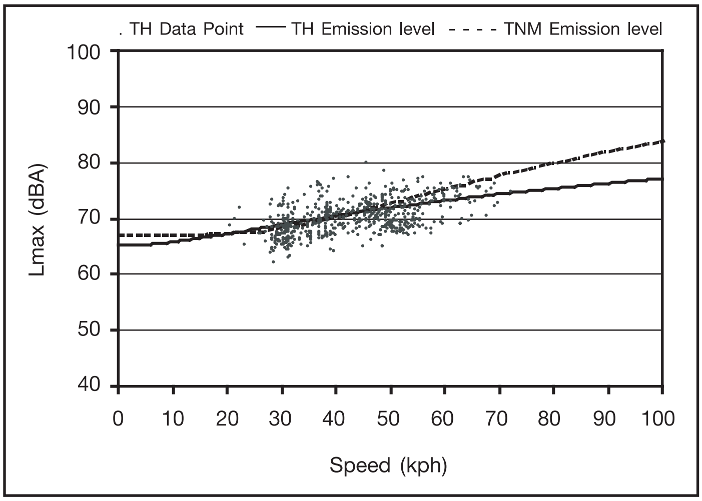

Fig. 10 Interrupted flow noise emission levels for Thai motorcycles versus FHWA TNM motorcycles

Thai motorcycles are slightly quieter than passenger cars at speed below 15 kph and quite similar to light trucks at speed over 30 kph. They are also 5 dB quieter than FHWA TNM motorcycles at speed over 50 kph as illustrated in Fig. 10. This is because Thai motorcycles and FHWA TNM are not identical. The Harley-Davidson's motorcycles which are used as the representative of the US motorcycles are generally larger than those in Thailand.

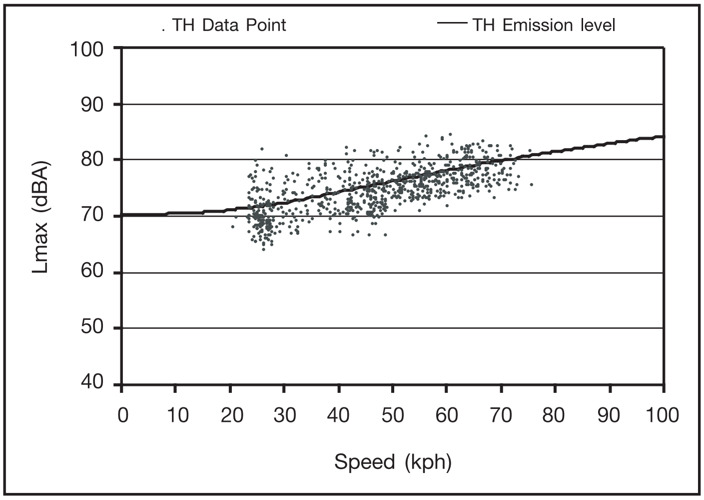

Fig. 11 Interrupted flow noise emission levels for Tuk-tuks

As Fig. 11 shows, Tuk-tuks are slightly quieter than medium trucks at low speed range, but tend to be similar at speed over 50 kph. Even though their configurations look somewhat like motorcycles, they generate noise as loud as the medium trucks do.

The comparison of interrupted noise emission levels among vehicle types in Thailand is presented in the following figure.

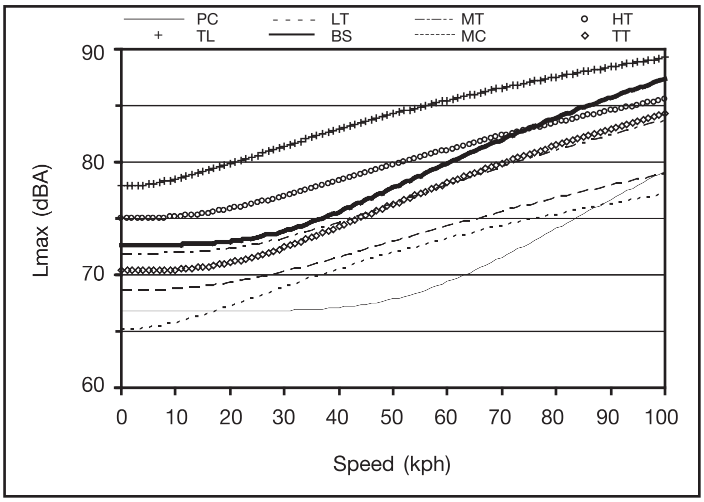

Fig. 12 Interrupted flow noise emission levels for all Thai vehicle types

Table 4 summarizes the results of the regression equations including coefficients (A and B), constant (C), and adjustment term (ΔE) as in Eq. (11). The coefficient of determination (R^2) is also presented.

Table 4 Regression result

Vehicle type	A	B	C	ΔE	R^2
PC	58.6906	-40.1508	65.1256	1.676	0.108
LT	25.2948	26.0775	66.7788	1.826	1.164
MT	30.1296	22.5272	71.2860	0.568	0.408
HT	22.8814	37.7368	73.7518	1.150	0.208
TL	19.1826	50.0742	77.3763	0.472	0.376
BS	36.8660	12.6402	71.8574	0.808	0.394
MC	19.8115	36.4051	64.3292	0.801	0.254
TT	30.2533	22.3933	69.2138	1.161	0.437

From the regression results of basic noise emission models in Table 4, the coefficients of determination (R^2) of all vehicle types roughly range from 0.1 to 0.4. The reason the R^2 are not so high is because the vehicles were randomly selected from the vehicle population on highways in which many of them generated noise levels very differently even in the same type. According to the nature of traffic noise as discussed, the data points are therefore widely scattered. Similarly, the results of FHWA show the R^2 values of the US vehicles in the same way as shown in the following table.

Table 5 R^2 values for FHWA TNM interrupted flow noise emission models

Vehicle type	R^2
Automobile (AU)	0.087
Medium truck (MT)	0.000
Heavy truck (HT) (2sites)	0.026, 0.064

The values of R^2 for all vehicle types more than zero indicate that the regression models more reasonably represent the noise emission characteristics of vehicles in Thailand than using the average values. The regression line outside the ranges at which the field data are collected is extrapolated, it therefore should be used with care.

7. Conclusions

The basic noise emission levels of eight vehicles types in Thailand are developed in the condition of interrupted flow traffic. The regression results show the significant differences among vehicle types. In addition, the noise levels of vehicles in Thailand are compared with those of FHWA TNM vehicles. However, some definitions of the classified vehicles between two countries are different i.e. FHWA TNM automobiles VS Thai passenger cars and light trucks, FHWA TNM heavy trucks VS Thai heavy trucks and tractor trailers. Also, the vehicle characteristics in aspects of size, weight, and noise source that are not identical from country to country make the noise emission levels different. At the normal traffic composition which is mostly accommodated by passenger cars and light trucks (or combined as automobiles according to FHWA TNM), the equivalent noise levels (i.e. L_{Aeq} 1h) at intersections in Thailand will be higher than those in the US. There are no significant differences between soft and hard ground as well as concrete and asphaltic pavement. Moreover, motorcycles which are plentiful in Thailand's roadways and the exotic vehicles like Tuk-tuks will result in the traffic noise analysis and evaluation in Thailand considerably different from the other countries.

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