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APPLYING MATHEMATICAL MODELING TO PREDICT ROAD TRAFFIC NOISE IN PHUKET PROVINCE, THAILAND

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ABSTRACT: Road traffic is the most significant source of noise in an urban city and is considered not only an environmental nuisance but also a threat to public health. Therefore, this study aimed to determine road traffic noise levels in Phuket Province, including Muang Phuket, Thalang, and Kathu District; and to compare them with predicted noise levels using NMTHAI 1.2. Traffic noise level, traffic volume and speed of vehicles were measured on main roads including Yaowarat, Ratsada, Montri, Patipat, Ban Muangmai, Ban Kain, Ban Lipon, Baramee and Vichitsongkram Road. The results showed that traffic noise in Muang Phuket, Thalang and Kathu Districts were 70.0-70.9, 72.9-74.7 and 74.6-74.8 dBA, respectively. The result revealed that traffic noise levels obtained from the model were higher than measured noise at an average of 4.8±2.3 dBA. A high correlation was observed between predicted and measured traffic noise levels ($R^2 = 0.655$, $P < 0.01$). Speed of vehicles and traffic volume were key variables affecting traffic noise level with a correlation coefficient of 0.752 and 0.702 at 99% confidence level, respectively. The model performed reasonably well under different traffic noise conditions and could predict traffic noise of other cities in Thailand.

Keywords: Road Traffic Noise, NMTHAI1.2, Phuket, Thailand

1. INTRODUCTION

Road traffic is the most significant source of noise in the city [1-4]. Epidemiological evidence indicates that those chronically exposed to high levels of environmental noise have an increased risk of cardiovascular diseases such as myocardial infarction [5-8]. Therefore, noise pollution is considered not only an environmental nuisance but also a threat to public health [7]. In addition, traffic noise in urban areas is an environmental problem resulting from urbanization such as acceleration of infrastructure construction [9]. However, road traffic noise problems in many cities due to population increase stems from accelerated growth, an incessant growth in the number of vehicles and the ever-expanding road network, which add to the already overcrowded streets [10-11]. These had lead researchers in many countries to investigate and characterize traffic noise pollution problems [12-21].

Phuket Province is the biggest island located in southern Thailand. Because of its beautiful beaches, Sino-Portuguese architecture and historical town attractions, Phuket has become a famous and popular province among foreign tourists. According to the Department of Tourism [22], the total number of visitors to Phuket increased from 11.96 million in 2014 to 13.49 million in 2016. In addition, the number of vehicles in Phuket increases annually, resulting in an increase in road traffic noise. According to the report of the Pollution Control Department [23], average noise levels ($L_{Aeq,\,24\,h}$) at the roadside area of each Province are presented in Figure 1. Among those, Phuket was associated with the highest maximum noise levels. Hence, road traffic noise can have a significant impact on people residing in communities located along the road [24]. These problems lead to annoyance and affect the quality of life. Currently, there are 27 noise monitoring stations in 13 provinces providing noise level data in Thailand [23]. However, noise levels of other provinces in Thailand should be considered using measurement or noise prediction model for protecting the health of people at those provinces.

Presently, various noise modeling software packages including Canada A, Lim A, CRTN, and TNM 1.0 have been applied in many countries such as Australia, the US and European countries [17, 25-26]. NMTHAI 1.2 was developed by the Environmental Research and Training Center, Ministry of Natural Resources and Environment of Thailand and is commonly used to predict road traffic noise in environmental impact assessments [27]. Moreover, compared with the TNM 1.0 (Traffic Noise Model) developed by the US Department of Transportation, the correlation coefficients between measured and predicted noise levels were found to be 0.94 and 0.89 for

NMTHAI 1.2 and TNM 1.0, respectively. Therefore, this study was conducted to evaluate traffic noise levels on the main roads of Phuket and compare them with predicted noise levels using NMTHAI 1.2. The speed and numbers of vehicles were counted to quantify the sound level using a predictive model. When the model provides a reasonable noise level, the number and speed of vehicles can be used as data to predict traffic noise levels in the other cities.

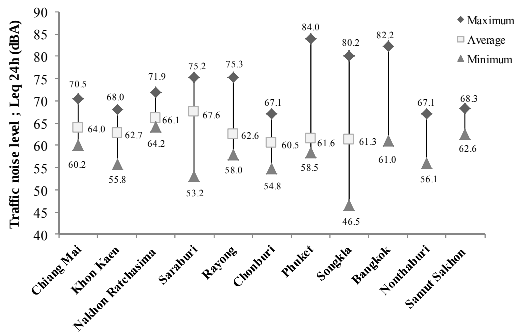

Fig. 1 Average noise levels (Leq 24 hr.) at the roadside area of selected Province [23]

2. MATERIALS AND METHODS

2.1 Goal and Scope of the Study

The goal of this study was to compare traffic noise levels that were calculated from the predictive model and measured noise levels from actual traffic. This work was designed as a cross-sectional study by measuring road traffic noise level, traffic volume and speed of vehicles at measurement points. Data on traffic volumes, the ratio of the number of large vehicles to the total number of vehicles, type of vehicle and speed of vehicle were all used as input data for the NMTHAI 1.2 model to predict traffic noise level. Additionally, the number of vehicles including personal car, motorcycle, truck and heavy truck were hourly counted during morning and evening rush hours (7:00 to 8:00 and 16:00 to 17:00). Moreover, each study site was measured for three days (both weekdays and weekends) to obtain the average noise level.

2.2 Study Areas

Traffic noise level, traffic volume and speed of vehicles were measured on the main roads in Muang Phuket (Pathipat, Ratsada, Yaowarat and Montri Roads), Thalang (Thepkasattri Road in Ban Muangmai, Ban Kain and Ban Lipon) and Kathu (Vichitsongkram and Baramee Road) Districts as shown in Figure 2.

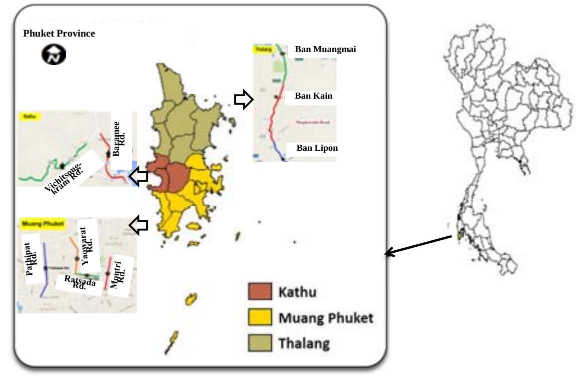

Fig. 2 Investigated areas of noise measurement

2.3 Road Traffic Noise Measurements

Road traffic noise measurements were performed using the Sound Level Meter (RION NL-21). Noise level parameters, i.e., $L_{Aeq,1\ h}$, L_{day}, L_{ight}, and $L_{Aeq,\ 24\ h}$ were measured at selected sites on Yaowarat, Pathipat, Ratsada, Montri, Thepkasatthri, Baramee and Vichitsongkram Road. The sound level meter was set on a tripod at a height of 1.2 m above ground level at a distance of 1 to 5 meters from the roadside [28]. In addition, the data on a number of vehicles and the speed of vehicles were collected during traffic noise measurement.

2.4 Traffic Noise Prediction

The NMTHAI 1.2 model, created by the Environmental Research and Training Center [21], was used as the predictive model. The assumptions of this model comprised: (1) vehicles moved on a straight road at steady speed; (2) equal distances between the cars ahead and behind were kept on the road; (3) the average speed of vehicles was from 30 to 140 km/h and (4) traffic volume was not limited. Traffic noise levels, obtained from the model, were predicted using Equation (1) shown below.

$$L_{eq} = PWL - 10log2ld + Ld + Lg \qquad (1)$$

Where;

PWL = 67.8+20.4logV+10log ((1-a) +5.37a)
a = Ratio of large vehicles to the total number of vehicles
l = Distance from the traffic lane to the receiving point (m)
d = Average distance between cars (m)
Ld = The correction value for diffraction
Lg = The correction value for ground surface attenuation

3. RESULTS AND DISCUSSION

3.1 Road Traffic Noise Level and Related Factors

The results showed that traffic noise levels ($L_{Aeq, 24 h}$) were 70.0 to 70.9, 72.9 to 74.7, and 74.6 to 74.8 dBA in Muang Phuket, Thalang and Kathu District, respectively. Hourly noise levels of each road in Muang Phuket, Thalang and Kathu are presented in Figure 3. Comparing with the study of road traffic noise in Bangkok and Pathumthani Province, Leq, 24 h was in the range of 74.1 to 83.7 and 72.7 to 79.9 dBA, respectively [29-30]. The results revealed that traffic noise levels in Phuket are higher than the ambient noise level setting at 70 dBA but lower than those traffic noise levels of Bangkok and Pathumthani Province. Thus, there is an association between the expansion of the economy, travel and tourism of Bangkok and vicinity and road traffic noise levels [17, 31]. However, traffic noise levels on each road in Muang Phuket did not differ. Yaowarat, Pathipat, Ratsada and Montri Roads are located in the old town and commercial areas of Muang Phuket. Along these roads, many residential homes and schools are located. Accordingly, the traffic on these roads was crowded during rush hours. Thus, the maximum noise level ($L_{Aeq, 1 h}$) was found to be 75.0 dBA from 15:00 to 16:00 on Pathipat Road. In Talang District, Thepkasatthri Road was the main entry road to Phuket Province. This road passes Banmuang Mai, Ban Kain and Ban Lipon Subdistricts. The maximum noise level ($L_{Aeq, 1 h}$) was found to be 77.0 dBA from 16:00 to 17:00 in Banmuang Mai. In Kathu District, several famous tourist places including Patong and Kamala Beaches are located in this area. Thus, abundant transport takes a tourist from the town to the beach, i.e., rental cars, medium-sized buses, taxis and motorcycle taxis. The maximum noise level ($L_{Aeq, 1 h}$) was 76.0 dBA from 19:00 to 20:00 on Vichitsongkram Road. According to a report of Pollution Control Department [23], the maximum noise level at roadside areas of the selected province in 2015 was recorded to be 82.2, 75.3, 75.2 70.5, and 68.0 dBA in Bangkok, Rayong, Saraburi, Chiang Mai, and Khon Kaen, respectively. The maximum traffic noise levels in Phuket observed from this study is similar to the traffic noise levels of Saraburi and Rayong which considered as industrial provinces, but higher than that of Chiang Mai and Khon Kean. These because a number of tourists arriving at Phuket is greater than that of Chiang Mai and Khon Kean Provinces. Accordingly, a total number of visitors to Phuket, Chiang Mai, and Khon Kean were reported to be 3.583, 2.097, and 0.507 million in 2016, respectively [32]. The results indicated that expansion of economy, travel and tourism has been subjected to a persistent increase in road traffic [17]. In addition, the LAeq, 24 h in Hanoi and Ho Chi Minh City were in the range of 73 to 79 and 71 to 77 dBA, respectively [33]. This data also showed that road traffic noise in the Capital Cities of Thailand and Viet Nam was higher than in Phuket Province.

Moreover, the results showed that daytime and nighttime equivalent noise levels (L_{dn}) in Phuket Province ranged from 69.8 to 75.8 dBA. Maximum daytime and nighttime equivalent noise levels in Muang Phuket were 75.8 and 73.4 dBA, found on Ratsada and Montri Roads, respectively. These results indicated that daytime and nighttime equivalent noise in investigated areas exceeded the Environment Noise Standard of Japan for residential area, which should not exceed 55 and 45 dBA for daytime and nighttime, respectively [34].

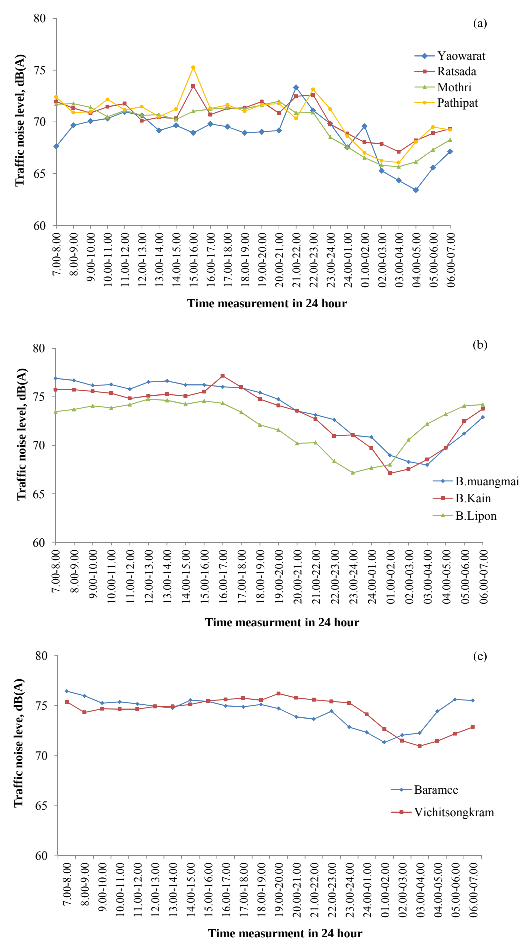

Fig. 3 Hourly noise levels in (a) Muang Phuket, (b) Thalang and (c) Kathu

Speed of vehicle, traffic volume, the ratio of trucks and heavy trucks to the total number of vehicles, number of lanes, and distance from the traffic lane to the receiving point were considered as related factors of traffic noise shown in Table 1.

The highest traffic volume in Muang Phuket was found on Ratsada Rd., which had 1,822 vehicles/h. The percentages of motorcycles, cars, and trucks and heavy trucks were 59.4, 39.1, and 1.5% of total vehicles, respectively. The highest traffic volume in Thalang was found in Ban Kain, which had 4,501 vehicles/h. The percentages of motorcycles, cars, and trucks and heavy trucks in Thalang were 15.5, 79.2 and 5.3% of total vehicles, respectively. The highest traffic volumes in Kathu was found on Baramee Rd., which had 2,666 vehicles/h.

The percentages of motorcycle, car, and truck, and heavy truck in Kathu were 58.7, 39.4, and 1.9% of total vehicles, respectively. The percentage of the truck and heavy truck to a total of vehicles in Muang Phuket, Thalang and Kathu ranged from 0.28-1.48, 3.19-6.91, and 1.88-2.20, respectively.

The number of traffic lanes in Muang Phuket, Thalang and Kathu were 1, 2 and 1 lane, respectively. Speeds of the vehicle in Muang Phuket, Thalang and Kathu were in the range of 25-43, 60-70, and 43-57 km/h, respectively. The highest speed of vehicles in Muang Phuket was found on Ratsada Rd., an average of 43 km/h. The highest speed in Thalang was found in Ban Kain, with an average of 68 km/h. The highest speed in Kathu was found on Baramee Rd. (54 km/h). The number of lanes in Muang Phuket, Thalang and Kathu were 2, 4 and 2 lanes, respectively. The distance from roadside to measured points in Muang Phuket, Thalang and Kathu were 1.3-1.6, 2-3, and 1.8-2.2 m, respectively.

3.2 Road Traffic Noise Prediction

Traffic volume, speed of the vehicle, the ratio of large vehicles to the total number of vehicles, distance from a traffic lane to receiving a point, and average distance between the vehicles were input data for the model. The result showed that applying the model provided a noise level consistent with the measured data as shown in Figure 4. However, the smallest difference between measured and estimated noise levels exceeded 1.4 dBA, while a related study found that the mathematical model overestimated the contribution of traffic noise with an error larger than 3 dBA [35]. As shown in Eq. (1) and Table 1, the traffic noise level were sensitive to the ratio of the number of large vehicles to a total number of vehicles, traffic volume, and speed of the vehicle. In addition, analyzing the results of the model indicated that the mathematical model overestimated the contribution of traffic noise, especially in Thalang. In addition, Pearson correlation was used to compare predicted and measured noise levels. As shown in Figure 5, the result from correlation tests on predicted and actual noise levels showed that they provided no significant difference with the correlation coefficient values (R^2 = 0.655, $P < 0.01$). The important variables affecting traffic noise level were the speed of vehicles, traffic volume and ratio of the number of large vehicles to a total number of vehicles. The result indicated that the speed of vehicles and traffic volume were associated with traffic noise level with regression coefficients of 0.75 and 0.70 at 99% confidence level, respectively. Therefore, the speed of vehicles and traffic volume should be controlled to help reduce road traffic noise in residential areas.

As shown in Figure 4, the results of traffic noise levels obtained from the model were higher than measured noise with the mean deference of 4.8±2.3 dBA. This is consistent with the findings of other studies [25, 8, 17] as shown in Table 2. However, a correlation coefficient (R^2) between the predicted and measured traffic noise levels were found to be 0.66 indicated that predicted levels associate closely with the measured levels.

In the UK, the Calculation of Road Traffic Noise (CRTN) Model, developed by the United Kingdom Department of Environment is commonly used to predict road traffic noise levels (L_{eq} and L_{10}). The traffic volume, the speed, the percentage of heavy vehicles, and the gradient are required for traffic noise prediction [36]. In addition, the results from the study of Kim et al., [37] described that the mean difference between their predicted and measured levels was around +1.4 and -1.2 dBA for low-range and high-range noise levels, respectively. In Hong Kong, CRTN has been adopted to estimate traffic noise from the road. From the study of Mak, Leung, and Jiang [16], a similar trend between predicted and measured noise levels were found with the correlation coefficient (R^2) of 0.933. Therefore, CRTN is suggested as useful tools in predicting traffic noise levels during the building planning stage.

Thus, the results obtained from this work shows that the NMTHAI1.2 is able to produce accurate predictions of the hourly traffic noise level. Total traffic volume, the ratio of large vehicles to the total number of vehicles, and the speed of the vehicle are important factors affecting traffic noise levels [38]. Additionally, the study of Muralikrishna and Manickam [39] indicted that the noise level is always changing with the number, type, and speed of the vehicles. Those results are consistent with this study. Thus, the prediction model proposed in this study may serve as a crucial tool for traffic noise forecasting and noise abatement measures in urban areas.

Table 1 Traffic noise related factors

Study areas	$L_{Aeq,\,24\,h}$ (dBA)	Speed of vehicle (Km/h)	Traffic volume (Vehicle/h)	T and HT (% of total vehicles)	Number of lanes	Distance (m)
Muang Phuket	70.3 ± 0.4	35.5 ± 6.1	1386 ± 328	0.99 ± 0.51	2	1.5 ± 0.1
- Pathipat	70.2 ± 0.3	35.3 ± 3.5	1452	0.28	2	1.6
- Ratsada	70.9 ± 0.3	37.9 ± 4.3	1822	1.48	2	1.6
- Yaowarat	70.0 ± 0.8	26.6 ± 0.7	1907	1.00	2	1.3
- Montri	70.2 ± 0.3	40.3 ± 2.9	1173	1.19	2	1.5
Thalang	73.9 ± 0.9	67.5 ± 3.3	4412 ± 94	5.11 ± 1.86	4	2.7 ± 0.6
- Ban Muangmai	74.7 ± 0.4	67.6 ± 2.3	4314	6.91	4	3
- Ban Kain	74.0 ± 1.4	67.8 ± 4.0	4501	5.24	4	2
- Ban Lipon	72.9 ± 0.4	67.2 ± 4.0	4420	3.19	4	3
Kathu	74.7 ± 0.1	51.0 ± 4.8	2402 ± 374	2.04 ± 0.23	2	2.0 ± 0.3
- Vichitsongkram	74.8 ± 1.0	47.7 ± 4.2	2173	2.20	2	1.8
- Baramee	74.6 ± 0.4	54.3 ± 2.6	2666	1.88	2	2.2

Remark: T: Truck; HT: Heavy Truck

Table 2 The difference between predicted and measured values of traffic noise levels of each study

Researcher	Model	Number of the sample (n)	Value of differences (dBA)	Mean of deference (dBA)	R^2
Osifeko and Odufuwa (2018)	CRTN	12	1.0-5.0	3.8±1.2	-
	RLS90	12	2.0-6.0	3.8±1.3	-
	CNR	12	0.0-2.0	1.5±0.6	-
	FHWA	12	0.0-3.0	1.5±0.9	-
Jamrah (2006)					
- Day time	CRTN	28	1.0-18	5.9±4.6	-
- Night time	CRTN	28	1.0-9.0	2.9±2.5	-
Ece et al.(2018)					
- Day time	SoundPLAN®	4	3.0-10	4.8±3.9	0.71
- Night time	SoundPLAN®	4	1.0-4.0	2.8±1.3	0.79
This study	NMTHAI1.2	54	1.4-10	4.8±2.3	0.66

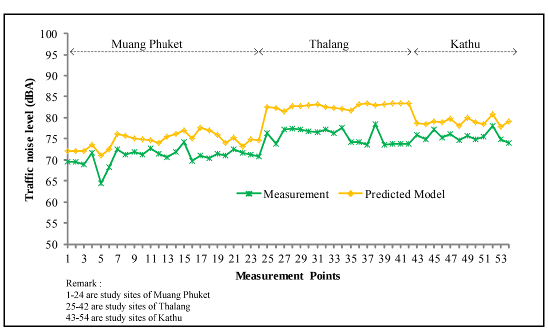

Fig. 4 Comparison of modeled traffic noise and measured noise level of each measurement points

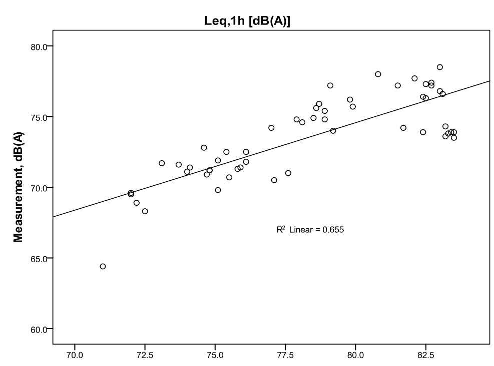

Fig. 5 Statistical relationship between predicted and measured traffic noise level

4. CONCLUSIONS

Traffic noise levels (LAeq, 24 h) of Muang Phuket, Thalang and Kathu District were 70.0 to 70.9, 72.9 to 74.7, and 74.6 to 74.8 dBA respectively. It indicated that the average equivalent noise level of all investigated areas exceeded the Ambient Noise Standard of Thailand, setting at 70 dBA. As alternative ways for traffic noise investigation, NMTHAI 1.2 was used to predict traffic noise levels in this study. The results of road traffic noise levels obtained from the model were higher than measured noise with the mean deference of 4.8±2.3 dBA. However, a high correlation was observed between predicted and measured traffic noise levels ($R^2 = 0.655$, $P < 0.01$). The traffic noise levels were sensitive to the ratio of large vehicles to a total number of vehicles, traffic volume, and speed of vehicles. Therefore, NMTHAI 1.2 model seems appropriate for use in predicting the road traffic noise level in urban areas. Moreover, it may be used in assessing proposed and existing urban planning developments and mitigation alternatives in a cost-effective manner. However, the annoyance level from road traffic noise in urban and touristic areas are recommended for further studies.

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