Evaluating the Traffic Noise Levels at Median U-Turns under Heterogeneous Traffic Conditions in Makassar City

Muralia Hustim
Department of Environmental Engineering, Universitas Hasanuddin, South Sulawesi 90245, Indonesia
muraliahustim@ft.unhas.ac.id (corresponding author)

Hardianti Alimuddin
Department of Environmental Engineering, Universitas Hasanuddin, South Sulawesi 90245, Indonesia
hardianti@unhas.ac.id

Nurul Azizah Syafruddin
Department of Environmental Engineering, Universitas Hasanuddin, South Sulawesi 90245, Indonesia
nurulazizahsyafruddin@gmail.com

Pertiwi Andarani
Department of Environmental Engineering, Universitas Diponegoro, Central Java 50275, Indonesia
andarani@ft.undip.ac.id

Muh. Isran Ramli
Department of Civil Engineering, Universitas Hasanuddin, South Sulawesi 90245, Indonesia
isranramli@unhas.ac.id

Sitti Asmah Hassan
Department of Geotechnics & Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
sasmah@utm.my

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ABSTRACT

This study examines the effect of the traffic noise levels in the presence of Median U-Turns (MUTs). Using quantitative research methods, a Sound Level Meter (SLM) was employed to take direct measurements at 30 sampling points in five major roads of Makassar City. The field measurements revealed that the noise levels consistently exceeded 75 dB, surpassing the national noise limit of 70 dB. Motorcycles dominated (65%) that noise, while heavy vehicles contributed up to 9% according to the traffic composition analysis. It was found that the MUT width, vehicle volume, and speed variations contributed to the elevated noise levels. Metro Tanjung Street exhibited lower noise levels due to the presence of fewer heavy vehicles, despite having a larger vehicle volume than that of wider roads, like Pettarani Street. Most vehicles at speeds below 30 km/h contributed to increased noise. The ASJ-RTN 2008 noise level prediction model showed that locations with MUTs had noise levels that were 7–10 dB higher. The model exhibit strong accuracy with an RMSE of 2.13 dB. This study highlights the significant role of the MUT design, traffic flow, and vehicle composition in influencing the urban noise generated.

Keywords-transportation; noise; median U-turn; road; pollution

I. INTRODUCTION

Transportation plays an essential role in facilitating the human mobility and daily activities. Human activities would become slower and more difficult to sustain without a proper transportation infrastructure [1]. In Makassar City, the number of registered vehicles continues to increase in parallel with the population growth [2]. Private vehicles, including motorcycles and cars, have exhibited an annual growth rate of 10%, whereas the expansion of the road infrastructure remains limited, growing at just 0.05% per year [3].

The urbanization has led to increased traffic flow, exacerbated by the roadside parking, intersection congestion, and the use of MUTs, which replace the direct left turns with U-turns via wide medians [4]. These configurations are likely to cause delays and queues, generating congestion and environmental issues, such as noise pollution [5]. Traffic noise, a significant source of environmental pollution, can cause adverse health effects, including hearing loss [6]. The urban noise is the most important environmental health risk, as indicated by the European Environment Agency (EEA) [7], with rising levels attributed to urbanization, increased vehicle use, and population growth [8].

Many previous studies on traffic noise and its impact on health and the environment predominantly focus on general road noise, signalized intersections, or specific vehicle types. However, the influence of MUTs under heterogeneous traffic conditions has received limited attention. Previous studies on MUTs have primarily focused on operational performance, examining indicators, such as delay, fuel consumption, and emissions [9]. However, a detailed analysis of their acoustic implications, particularly in mixed traffic environments typical of Indonesian cities, remains limited. Therefore, this study aims to fill a knowledge gap in the literature by addressing the noise levels at MUTs and advancing the understanding of the noise pollution caused by the vehicles in Makassar City, serving as a case study.

II. MATERIALS AND METHODS

A. *Study Area and Sampling Points*

The study area was located in MUTs at five major streets in Makassar City with 30 sample points: 7 on Veteran Street, 9 on Metro Tanjung Street, 4 on Sultan Alauddin Street, 6 on A.P. Pettarani Street, and 4 on Hertasning Street (Figure 1). These roads were selected due to their high frequency of MUTs.

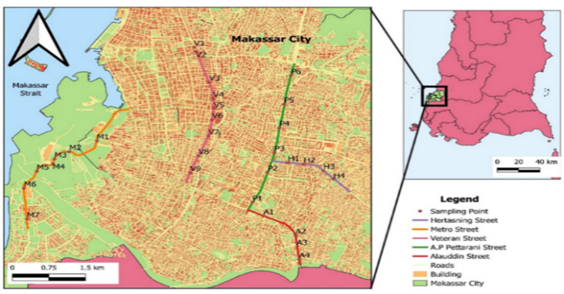

Fig. 1. Study area.

The road geometric characteristics and MUT design were also considered as parameters influencing the traffic flow, as depicted in Table I. The number of lanes, Road Width (RW), Road Median Width (RMW), and MUT Width (MW) were also observed, as these attributes can affect the ambient noise level.

TABLE I. ROAD CHARACTERISTICS

Street	MUT	Road geometric data (Meter)			
		Lanes	RW	MW	RMW
Pettarani	AP1	8	14.00	25.00	4.10
	AP2	8	14.00	24.00	4.00
	AP3	8	14.00	25.00	3.90
	AP4	8	14.00	25.00	4.20
	AP5	8	14.00	23.00	4.00
	AP6	8	14.00	24.00	2.60
Hertasning	H1	4	8.05	9.55	4.10
	H2	4	9.40	8.40	4.50
	H3	4	9.40	9.40	6.45
	H4	4	9.15	18.25	6.50
Alauddin	A1	4	7.30	12.10	1.00
	A2	4	7.10	9.90	1.00
	A3	4	7.10	9.90	1.00
	A4	4	6.90	24.90	1.00
Metro tanjung	M1	4	18.30	7.15	3.00
	M2	4	16.40	7.35	2.97
	M3	4	16.70	7.30	3.00
	M4	4	17.20	7.15	2.50
	M5	4	16.60	7.85	3.00
	M6	4	17.20	6.90	3.30
	M7	4	16.45	7.38	2.99
Veteran	V1	4	9.00	3.90	2.75
	V2	4	9.00	2.90	2.30
	V3	4	9.00	3.80	2.30
	V4	4	9.00	3.30	2.30
	V5	4	9.00	3.50	2.30
	V6	4	9.00	3.50	2.40
	V7	4	9.00	3.30	1.30
	V8	4	9.00	3.10	2.30
	V9	4	9.00	3.80	2.30

B. *Data Collection*

This study employs four primary data sets: noise levels, vehicle volumes, vehicle speeds, and horn frequency. These variables were essential for evaluating the noise emission caused by the movement of vehicles. The SLM was used to measure the levels of noise, while the traffic volumes were quantified through an automatic counter and the vehicle speeds with a speed gun. Video recording was also used to examine the traffic flow characteristics. The data collection is illustrated in Figure 2.

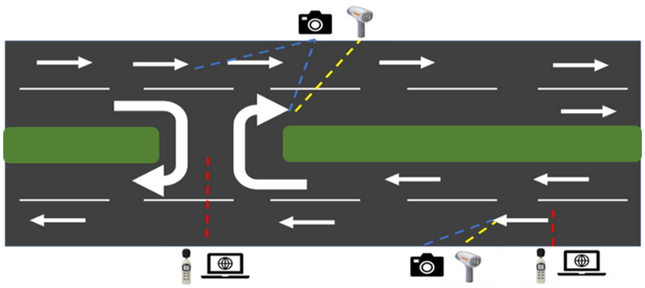

Fig. 2. Measurement methods.

The SLM was positioned at a minimum distance of 1 m from the edge of the roadway, with the tripod height set at 1.2 m above the road surface. A windscreen was attached to the SLM, which was oriented toward the dominant noise source. Measurements were taken from 07:00 to 18:00, local time, with a 10-min sampling every hour [10]. Observations were made on sunny days at each sampling point.

C. Data Analysis

1) Noise Level Measurement

The noise analysis was conducted by generating a frequency distribution table and calculating the key numerical indicators. This involved organizing the noise data into class intervals and counting the occurrences within each interval. From this distribution, the equivalent continuous noise level (LAeq) was determined, representing the steady noise level over a specified period despite the fluctuations. LAeq provides a comprehensive measure of the noise exposure and is calculated as shown in [11]:

$$\mathrm{LAeq} = \mathrm{LAeq50} + 0.43\,(\mathrm{LAeq1} - \mathrm{LAeq50}) \quad (1)$$

$$\mathrm{LAeq_{day}} = 10 \times \log(10) \times \frac{1}{hour/day} \times 10^{(\mathrm{LAeq}\,\frac{1}{10})} + 10^{(\mathrm{LAeq}\,\frac{2}{10})} \quad (2)$$

where LAeq is the equivalent noise level; LAeq50 is the 50% noise indicator; and LAeq1 is the 1% noise indicator in the area.

2) Noise Prediction Using the ASJ-RTN Method 2008

The predicted noise level analysis was calculated using the ASJ-RTN 2008. This study builds upon previous studies that have adapted this model to predict the traffic noise under heterogeneous traffic conditions, characterized by typical vehicle speeds below 30 km/h [12]. The input data included the average speed, volume by vehicle type, number of lanes, lane width, median width, distance from the prediction point to the sound source, noise data or LAeq, and day [13].

This study predicted the noise on the road section and MUT to determine the noise level generated by vehicles, using the required input data. Then, the calculation of the two predictions at one observation point utilizing different distances can be conducted through [13]:

$$\mathrm{Lsum} = 10\log\left(10\mathrm{Laeq1}/10 + 10\mathrm{Laeq2}/10\right) \quad (3)$$

where Laeq1 is the noise level on the road section and Laeq2 is the noise level in the MUT. This modeling approach is based on the assumption that the vehicle-generated noise propagates outward from its source and interacts with the surrounding environment before reaching the receiver. The results of this modeling process represent the cumulative noise exposure at key urban locations, capturing the combined effects of the traffic volume, vehicle speed, road geometry, and environmental conditions on the sound propagation. The noise predictions reflect the conditions in the MUT area, which are influenced by the volume and speed of the vehicles, as well as the road characteristics. This study accumulates the prediction noise on the MUT section and the road section, which are considered the total prediction noise in the MUT area.

3) Statistical Analysis

Univariate and bivariate analyses were conducted to determine the effect of the noise level with and without MUT on the road. The comparative statistical analysis used in this study is the paired sample T-test. Before conducting the t-test, the normality of the data distribution was assessed using the Shapiro-Wilk test. The T-test was performed to determine whether there was a difference in the presence of MUTs on the road. The level of significance (p) used is 0.05. The analyses were carried out using IBM SPSS Statistics [14].

4) Validation Method

The validation process included both simulation studies and the application of established analytical models to evaluate the reliability of the field measurements. A quantitative evaluation of model performance was conducted using the Root Mean Square Error (RMSE), a valid statistical measure of a model's accuracy. RMSE indicates the average error between the observations and forecasts. Prior research has demonstrated that in specific scenarios, RMSE can offer more valuable insights than alternative evaluation models, such as the Mean Absolute Error (MAE) [15].

5) Quality Assurance

When conducting the noise level measurements, it is essential to consider the weather conditions and other factors. Occasional interruptions, such as the rainfall, sirens, or continuous horn sounds, may necessitate pausing the data collection to prevent the bias. To enhance the precision of the noise level data, the SLM was programmed to record data every s, resulting in 600 measurements over a 10-min period.

III. RESULTS AND DISCUSSION

A. Noise Level Measurement

As shown in Figure 3, the noise levels along the five main roads in MUT consistently exceeded 70 dB, surpassing the Indonesian standard for commercial and service zones [10], indicating that the local anthropogenic activities and traffic are significant contributors. Previous studies suggest that two- and three-wheeled vehicles comprise approximately 65% of the traffic, while heavy vehicles account for around 9% [16], both of which significantly contribute to the noise levels. In Indonesia, the environmental noise standards are typically based on land use categories, which can themselves be sources of road noise. However, there is insufficient evidence to justify the distinct noise policies between the urban and rural areas [17]. Further analysis is needed to determine whether the noise levels are primarily influenced by the traffic, surrounding activities, or specific MUT characteristics. A comparison of the noise levels and MUT characteristics (Table I) revealed that Pettarani Street, with a wider MUT (23–25 m), recorded the highest noise levels. This suggests that a greater width, potentially linked to a higher traffic volume and fluctuating vehicle speeds, may contribute to elevated noise in this area. Vehicles performing U-turns often decelerate and accelerate, leading to increased engine and tire noise near the median openings. Additionally, if U-turns are not smoothly accommodated, they may result in idling or queuing, which can elevate the localized noise levels.

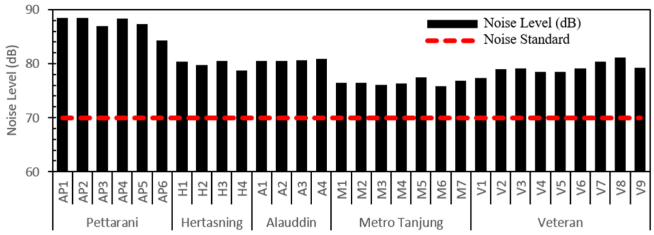

Fig. 3. Noise level measurement.

B. *Volume of Vehicles*

Figure 4 demonstrates that, on road segments without MUT, the motorcycle traffic consistently dominates the vehicle volume on Pettarani, Alauddin, Hertasning, and Veteran Streets across all sampling points. In contrast, Metro Tanjung Street exhibits greater variability; at sampling points M2 and M5, the number of low vehicles exceeds that of the motorcycles and heavy vehicles, whereas the other points resemble Veteran Street, where motorcycles are the predominant mode of transportation. These findings support earlier research indicating that the heavy vehicle volume has a significant impact on the traffic noise levels [18]. Figure 5 depicts the vehicle distribution on road sections with MUTs. Motorcycles remain the dominant vehicle type across all roads, except at M2 on Metro Tanjung Street, where low vehicles (818 units) surpass the motorcycles (633 units) and heavy vehicles (4 units). Notably, M5 on Metro Tanjung has the highest total number of vehicles, which corresponds with the high noise levels at this location (Figure 3). The vehicle volume significantly influences the traffic flow and can reduce the variability of the gap distances within MUT areas as the volume increases [19]. Higher traffic volumes are also associated with elevated noise levels in and around MUTs. The placement and number of MUTs along a roadway are often determined by the traffic volume. Interestingly, despite Metro Tanjung Street recording a higher total vehicle volume than the other roads, the noise levels at its sampling points were relatively lower. As shown in Figure 5, the number of heavy vehicles on the MUT section of Metro Street is lower compared to the other roads. This aligns with findings indicating that heavy vehicles generate higher sound power levels than other vehicle types [20].

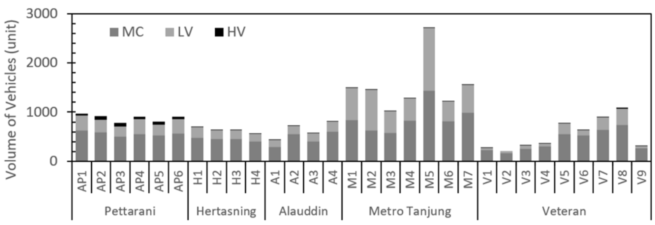

Fig. 4. Volume of vehicles without U-turn.

C. *Speed of Vehicles*

Figures 6-7 present the vehicle speeds on both the road and MUT sections. On the road section (Figure 6), Metro Tanjung and Veteran Streets show higher speeds, particularly for motorcycles. A similar trend is observed on the MUT section (Figure 7), though both streets also exhibit reduced speeds on the MUT, which may help lower the accident risk, which is frequently associated with the U-turn areas [21].

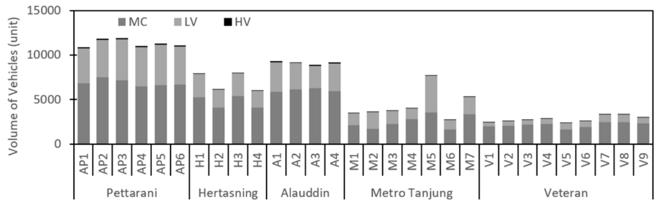

Fig. 5. Volume of vehicles with U-turn.

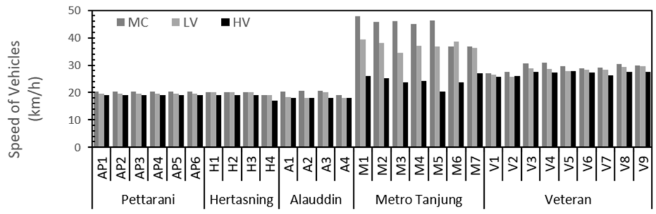

Fig. 6. Speed of vehicles without U-turn.

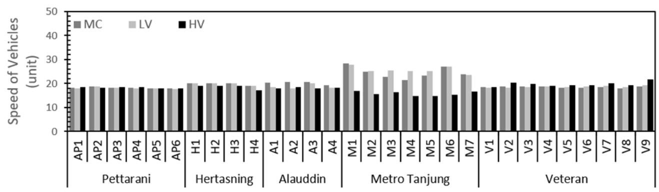

Fig. 7. Speed of vehicles with U-turn.

On the other hand, Hertasning, Alauddin, and Pettarani Streets share the same speed throughout the road and MUT segments. According to [12], speeds of less than 30 km/h indicate an unstable traffic flow, suggesting that all sampled points operate under such conditions. Low speeds with high traffic volumes could lead to congestion as well as increased noise levels. An effective MUT design should consider the gap acceptance and align with the traffic volume and road capacity [22]. Typically, the vehicle noise increases with speed. Compared to heavy vehicles, this relationship is stronger for light vehicles. Contrary to the noise produced by the tire friction on the pavement, the noise generated by large vehicles is primarily caused by the engine and exhaust system, and does not vary significantly with speed [23].

D. *Noise Level Prediction Model (ASJ-RTN 2008)*

1) *Noise Level Prediction with MUT*

ASJ specifies that the car sound power levels under unsteady and steady conditions are different, with unsteady traffic producing higher sound power. Even though ASJ mentions thee unsteady conditions as speeds below 40 km/h, other studies, such as [12], consider speeds below 30 km/h to be unsteady for mixed traffic. To evaluate the predicted versus the measured interference, the noise levels from MUT (vehicle U-Turn) and road sections (vehicle straight) were combined. As portrayed in Figure 8, the predicted noise levels are the highest on Alauddin and Pettarani Streets, followed by

Hertasning Streets, all of which exceed 80 dB. In contrast, Metro Tanjung and Veteran Streets show lower predicted levels, below 80 dB. These differences are due to variations in the traffic flow, road geometry, and the mix of steady and unsteady vehicle movement. The ASJ-RTN 2008 model accounts for these factors and supports the finding that high-volume, unsteady conditions cause significant noise generation. Furthermore, disruptions in the traffic flow can lead to congestion, resulting in frequent acceleration and deceleration, both of which increase the noise emissions. This result is consistent with previous findings, according to which the traffic flow stability has a significant impact on the noise generation [24].

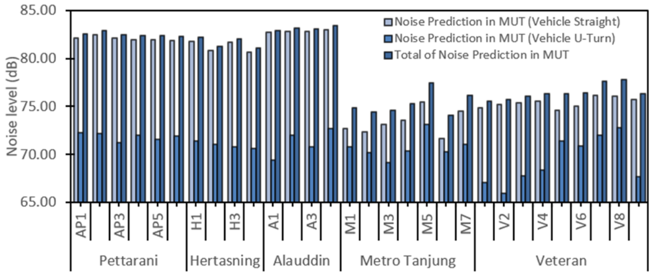

Fig. 8. Noise level prediction with MUT.

The vehicle volume plays a critical role in influencing the predicted noise levels. The findings of this study reveal that significant disparities in the noise levels between the regular road sections and MUT segments are closely linked to high traffic volumes. These results align with those of previous studies that have demonstrated a strong correlation between the noise intensity and the number of vehicles, particularly cars, buses, and trucks [25]. Additionally, the type of traffic along the MUT corridor significantly influences the noise outcomes. Heavy vehicles, for instance, produce more noise than other vehicles when performing turning movements. Also, most intersections are associated with elevated noise levels as the number of heavy vehicles increases.

2) *Noise Level Prediction without MUT*

This study predicts the noise levels using the ASJ RTN-2008 method, assuming no U-turns. Therefore, a steady vehicle speed of at least 30 km/h is assumed. The vehicle count is considered only for straight-through movements and does not include U-turns. Hence, at each MUT sampling location, the overall vehicle count includes both straight and U-turn movements.

According to Figure 9, the highest recorded noise level was observed on Alauddin Street, sampling point A4, reaching 74.50 dB. In contrast, the lowest noise level was measured on Metro Street at 66.50 dB. The exposure difference and measurement range reveal the distinct urban road segments, which vary with the range of influences, including the road configuration, traffic patterns, vehicle speeds, and the neighboring area. These results strongly emphasize the focus and attention on a singular location's analysis while studying the urban spatial noise [26].

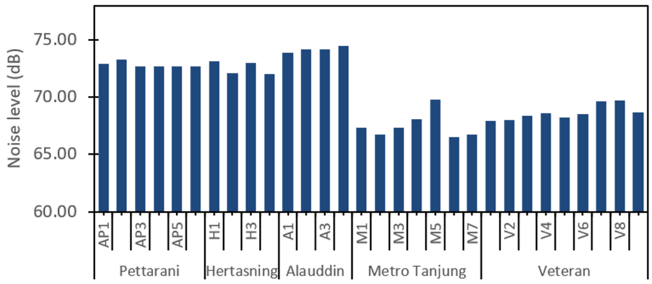

Fig. 9. Noise level prediction without MUT.

A clear disparity in the noise levels between road segments with and without MUTs is observed, with differences ranging from 7 to 9 dB, as shown in Figure 10. Pettarani and Hertasning Streets exhibit the largest increase, nearing 10 dB, indicating a strong correlation between the MUT density and elevated traffic noise. This is statistically supported by the paired sample t-test (Table II). Beyond acoustics, these findings have critical implications for the public health and urban policy. Notably, a 10 dB increase in the road traffic noise has been associated with a 1.08-fold rise in the risk of ischemic heart disease, emphasizing the public health implications of unmanaged urban noise [27]. Regarding the urban planning, the uncontrolled development of MUT within densely populated areas may unintentionally lower the ecological value of the areas, especially of the ones where the noise barriers are inadequate [28].

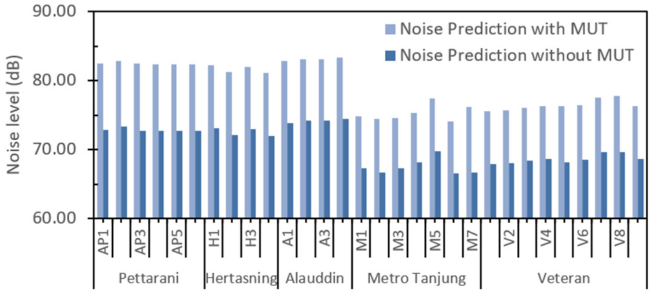

Fig. 10. Difference between noise level prediction with and without MUT.

TABLE II. PAIRED T-TEST RESULTS ON NOISE LEVELS WITH AND WITHOUT MUT ON ROAD

	Paired difference			
	Mean	SD	T-Test	p
Noise Levels with and without MUT on road	8.507	0.860	-54.125	< 0.05

Abbreviations: SD, Standard Deviation; p, significance of t-test

E. *Model ASJ-RTN 2008 Validation*

According to the ASJ-RTN 2008 model, the prediction is considered acceptable if the mean difference between the measured and predicted values is ≤ 3 dB. As displayed in Table II, the comparison between the measured and predicted data at all sampling points falls within this acceptable range, except for Jalan Pettarani. This variation may be due to external sound sources, such as horn noise, that were not included in the prediction model. Additionally, the characteristics of the road and surrounding activities may contribute to variations in non-traffic noise.

TABLE III. COMPARISON BETWEEN NOISE MEASUREMENT AND NOISE LEVEL PREDICTION

Street	Points	Noise level (dB)	Noise prediction (dB)
Pettarani	AP1	88.50	82.53
	AP2	88.50	82.89
	AP3	87.00	82.44
	AP4	88.40	82.41
	AP5	87.30	82.38
	AP6	84.30	82.31
Hertasning	H1	80.40	82.18
	H2	79.70	81.24
	H3	80.50	82.04
	H4	78.80	81.10
Alauddin	A1	80.50	82.90
	A2	80.50	83.15
	A3	80.60	83.07
	A4	80.90	83.39
Metro tanjung	M1	76.50	74.86
	M2	76.50	74.45
	M3	76.10	74.58
	M4	76.40	75.30
	M5	77.51	77.47
	M6	75.80	74.07
	M7	76.80	76.13
Veteran	V1	77.40	75.57
	V2	79.00	75.69
	V3	79.10	76.10
	V4	78.50	76.36
	V5	78.50	76.30
	V6	79.10	76.43
	V7	80.40	77.60
	V8	81.10	77.77
	V9	79.30	76.34

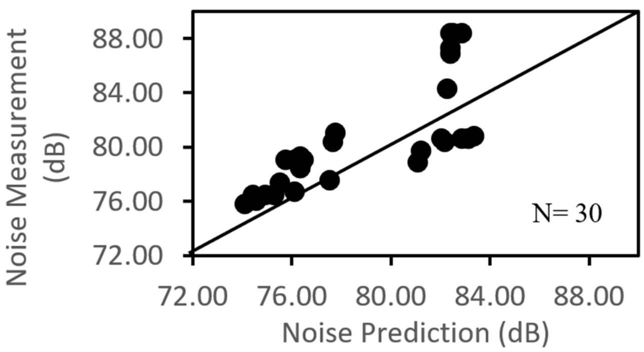

Fig. 11. Comparison between noise measurement and noise level prediction.

Additionally, this study reveals an RMSE of 2.13 between the measured and predicted noise levels, as illustrated in Figure 11. This confirms that the model is reasonably valid. The accuracy may be slightly affected by the fact that the ASJ-RTN ble2008 model does not account for the horn sounds, while heterogeneous traffic in Indonesia often involves frequent honking. However, the results of this study effectively reflect the noise levels generated at MUTs under heterogeneous traffic conditions on urban arterial roads.

IV. CONCLUSION

Steady and unsteady traffic conditions have a significant impact on the road noise levels. This study found that in Indonesia's heterogeneous traffic environment, particularly at Median U-Turns (MUTs), the unsteady conditions caused by the vehicle queuing and lane misuse substantially increase the noise pollution. The vehicle speed and MUT geometry directly influence the traffic dynamics, with wider MUTs associated with greater vehicle interactions and elevated noise levels. The findings indicate that MUT-related noise can increase by approximately 7–9 dB, underscoring the need for the careful regulation of MUT placement and design as a noise mitigation strategy in urban areas. Moreover, it is important to note that the scope of this study was limited to five arterial roads in Makassar, and thus may not fully represent the broader urban conditions or community diversity.

Additionally, this study did not comprehensively examine the optimal MUT width (MW) for minimizing the noise, which remains a critical area for future research. Further studies should also investigate specific mitigation measures, such as physical noise barriers, alternative geometric configurations, or strategic siting of MUTs in sensitive areas. From a policy perspective, urban planners should integrate noise control strategies into the MUT design, especially near residential, educational, or healthcare zones, to reduce the health impacts. Moreover, future research should address the socio-economic implications of the chronic exposure to MUT-induced noise, especially in densely populated or low-income neighborhoods, and further investigate the individual noise contributions of different vehicle types. It is important to note that the scope of this study was limited to five arterial roads in Makassar, which may not fully represent broader urban conditions or community diversity.

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