Prediction of Traffic Noise Levels at Signalized Four-Way Intersections in Makassar

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ABSTRACT

The current study predicted and mapped the traffic noise levels at four-way intersections of Dr. Ratulangi Street to Jenderal Sudirman Street in Makassar using SoundPLAN 9.0. Noise data were collected at six observation points over four days, covering both the working and non-working conditions. The results indicated that on the working days, the noise levels exceeded the urban standards and peaked at 76.49 dB at Point 4. On non-working days, the levels were generally lower, but in some points the noise was above the limit. The SoundPLAN 9.0 model achieved good accuracy, with low prediction error. The noise distribution maps revealed the highest concentrations near the intersection and along major approaches. This underscored the need for mitigation measures, such as optimized signal timing or noise barriers, to improve the environmental quality. The results also provided practical insights for integrating the noise management into the traffic regulation and urban planning policies in rapidly growing cities.

Keywords-urban noise pollution; traffic noise; signalized intersection; noise mapping; SoundPLAN 9.0; environmental noise standards

I. INTRODUCTION

Noise refers to unwanted sounds that cause disturbance or pose health risks [1]. Urbanization and industrialization have increased the environmental noise, exposing the public to continuous annoying sounds [2]. Beyond the environmental quality, noise also affects the resident fulfillment as well as the general well-being and health, generating the need for research on noise pollution to mitigate its widespread impacts [3-5].

Transportation is a key factor in the environmental problems, including traffic congestion and noise [6]. The rise in population-driven motor vehicle ownership has led to elevated noise levels in urban areas, accounting for nearly 80% [7, 8]. Major intersections, which are important for urban mobility, also contribute to noise pollution [9]. The frequent traffic at these locations often generates high noise levels, causing challenges to the urban environment. For example, a study in Baghdad found that the high traffic volumes, congestion, and delays significantly increased noise [10], whereas a research on the time headway highlighted the role of the traffic flow and vehicle distribution in the noise generation [11]. Intersections, as convergence points, are prone to conflicts, queues, and delays, while those near commercial and public facilities face intensive noise during the peak hours [12, 13].

Makassar City, an urban center in eastern Indonesia with 1.423.877 residents and an area of 175.77 km², faces several issues regarding the environmental quality, especially due to the traffic noise [14]. The average noise levels along its main roads are estimated at 78.1 dB, exceeding the permissible standard of 70 dB [15]. A representative case is the Dr. Ratulangi-Jenderal Sudirman corridor, a collector road with six four-way intersections, heavy traffic flow, and dense commercial activity. This area exemplifies the typical urban conditions in Makassar, where the high traffic volumes and surrounding land use intensify the noise exposure.

Previous research supports these observations. For instance, authors in [16] found that the urban morphological changes, such as commercial densification and intensified land use, degraded the intersection performance, while they elevated the noise and pollution over time. Similarly, in [17], the traffic volume, speed, and road classification were identified as key noise level predictors. It has also been confirmed that the vehicular stream characteristics strongly influenced the intersection noise, with models predicting levels up to 73.89 dB, highlighting the need for multifactorial analysis in urban settings [18].

Despite the global progress in traffic noise modeling, in Indonesia, research using SoundPLAN 9.0 model is particularly limited. The present study addresses this gap in Makassar by measuring the noise levels at signalized four-way intersections, predicting the traffic noise with SoundPLAN 9.0, and mapping the noise distribution to identify the high-impact areas. Similar approaches have been successfully implemented elsewhere, such as in Kandy City, Sri Lanka, where simulation-based noise assessments validated with field data effectively mapped the noise propagation around complex junctions using FHWA TNM and CNOSSOS-EU standards [19].

II. RESEARCH METHODS

A. *Research Design*

This study employed a quantitative approach involving literature review, field measurements, and data analysis. The objective was to assess the traffic noise at signalized four-way intersections along the Dr. Ratulangi–Jenderal Sudirman corridor in Makassar. Six observation points were selected, three on each road, representing typical traffic conditions with surrounding commercial and public facilities. Measurements were recorded from 06:00 to 19:00 (Central Indonesian Time) over four days, one working day and one non-working day on each road. The overall methodology is summarized in Figure 1.

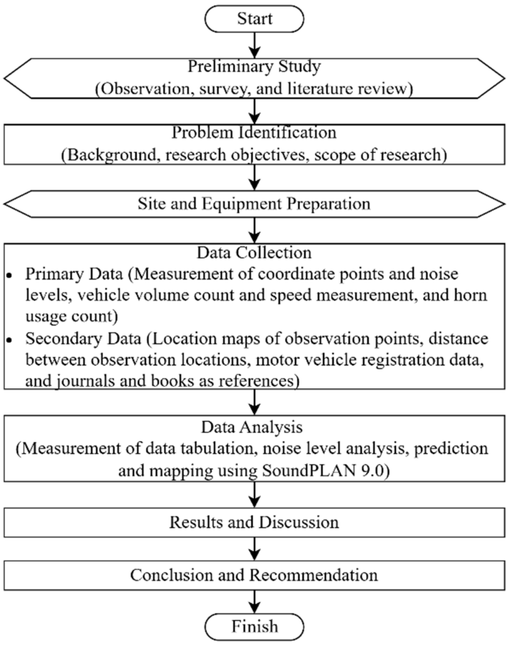

Fig. 1. Flowchart of the research methodology.

B. *Data Collection Method*

Data were collected through both direct (primary) and indirect (secondary) methods. The location map of the observation points can be seen in Figure 2.

Fig. 2. Location map of observation point.

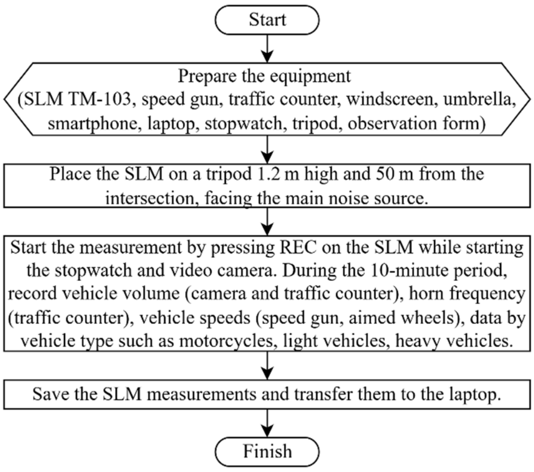

Fig. 3. Flowchart of primary data collection procedure.

The international guidelines have proposed a minimum measurement interval of 15 min for the environmental noise source assessments [20]. In this study, a 10-min interval was adopted according to the Indonesian standard [21]. Due to the limited availability of the sound level meter and the need to conduct simultaneous measurements at multiple observation points, the Decibel X Pro application was used at point 4, calibrated against the TM-103 deploying linear regression [22]. The flowchart in Figure 3 outlines the systematic process, emphasizing the coordination between the data types and the sequence from preparation to processing.

C. *Data Analysis Method*

The analysis involved three main components:

- Noise Level Calculation: The daytime A-weighted equivalent continuous sound levels (*LAeq,day*) were computed using the logarithmic energy averaging method [23]:

$$LA_{eq,day} == 10 \times \log(10) \times \frac{1}{hourperday} \times 10^{LA_{eq}\,0.1} + 10^{LA_{eq}\frac{n}{10}} \quad (1)$$

- Noise Prediction: Traffic, geometry, and land-use data were entered into SoundPLAN 9.0 to estimate the noise at unmeasured points. The software accounted for reflections, topography, and meteorological factors, providing reliable forecasts for the urban conditions.
- Spatial Mapping: Contour maps were generated to visualize the noise distribution across intersections, highlighting the areas exceeding the permissible limits. Compared with earlier work using simpler methods [24], this approach integrated multi-day, multi-point measurements with spatial modeling for greater accuracy.

III. RESULTS AND DISCUSSION

A. Characteristics of Traffic Noise Levels

Traffic strongly influenced the noise levels, with Motorcycles (MCs) and Light Vehicles (LVs) dominating the overall noise, while Heavy Vehicles (HVs) contributed disproportionately. The peak-hour traffic volumes and frequent horn use increased the noise, while higher speeds reduced it. Figure 4 illustrates the average Leq10 noise levels for all points. It was observed that Leq10 levels were higher on working days, with Points 1, 3, and 4 exceeding the limits, Point 2 being slightly above the minimum, and Points 5 and 6 being compliant, highlighting the traffic's impact on noise.

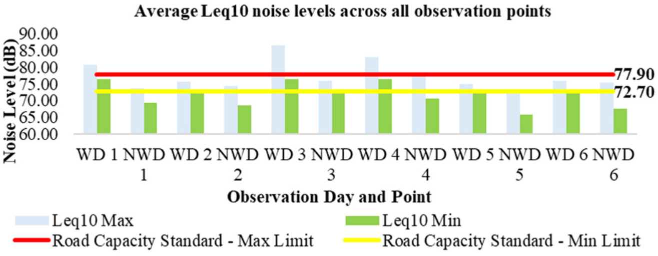

Fig. 4. Average Leq10 noise levels across all observation points.

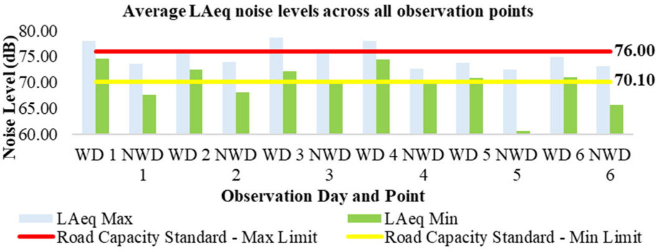

Fig. 5. Average LA_{eq} noise levels across all observation points.

Figure 5 depicts the average LA_{eq} noise levels at all points. The LA_{eq} levels exceeded the limits at Points 1 - 4 on working days but complied on non-working days, while Points 5 and 6 met the standards on all days. This indicated that the busy traffic and commercial activity led to higher noise on working days.

B. Traffic Noise Level Analysis

1) Noise Level Analysis

The $LA_{eq,day}$ values were compared with the noise level quality standards for land use or activity areas (Figure 6) [25]. The highest $LA_{eq,day}$ noise level was recorded at Point 3 during a working day, whereas the lowest was observed at Point 5 on a non-working day. To assess the compliance with applicable noise standards, the surrounding land use types should be classified, as each had different permissible noise limits.

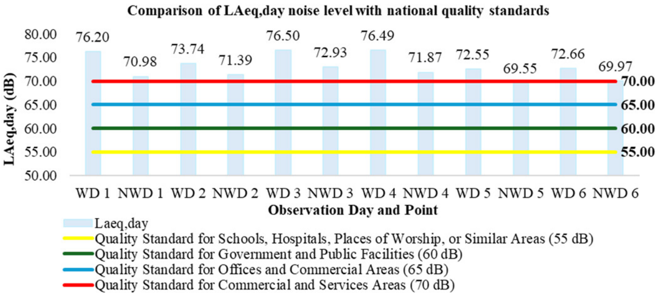

Fig. 6. Comparison of $LA_{eq,day}$ noise level with national quality standards.

2) Traffic Noise Level Parameters

a) Vehicle Volume

On working days, the MC and LV volumes peaked at Point 6 (64,576 and 57,016, respectively) while HVs were the highest at Point 4 (522). This reflects increased commuting and activity, with MCs and LVs causing congestion and noise, and HVs contributing the most per-unit noise, complying with the findings of [26].

b) Vehicle Speed

MC speeds peaked at 31 km/h, LVs at 23 km/h at certain points, and HVs reached 17 km/h on non-working days. Higher speeds generally reduce the engine noise duration and further the measured noise, whereas the slower speeds from congestion increase the noise, showing an inverse relationship between the speed and traffic noise [27].

c) Horn Frequency

The horn frequency peaked on working days at Point 1, with 2,160 instances from MCs and 2,586 from LVs, while HVs peaked at Point 3 with 96 occurrences. The high horn use is linked to congestion, serving both communicative and psychological purposes. A study in Taipei showed that the delays and congestion increased honking, highlighting a significant correlation between the horn use and driver behavior [28]. Similarly, authors in [29] found that honking could add 2-5 dB to the traffic noise, which is influenced by the traffic volume and speed.

C. Traffic Noise Level Prediction Using SoundPLAN 9.0

Direct measurements and SoundPLAN 9.0 predictions on working days revealed a 3.90 dB gap at Point 1 (76.20 dB versus 72.30 dB), probably due to the fluctuating traffic and dense commercial activity. Points 2 and 3 exhibited smaller differences (1.44-2.70 dB), while Points 4 - 6 demonstrated a close agreement. Overall, SoundPLAN 9.0 predicted noise well in stable traffic areas, with some variation in highly dynamic zones. On non-working days, SoundPLAN 9.0 predictions closely matched the direct measurements, with differences from 0.72 dB (Point 1) to 2.73 dB (Point 3). Points 5 and 6 had the smallest gaps (0.75 dB and 1.87 dB), indicating high accuracy. Slight underestimations at Points 2 - 4 suggested that the model might have missed irregular traffic or holiday activities, but the overall predictions remained reliable. The predicted values from SoundPLAN 9.0 were compared with field measurements. On working days, the differences ranged between 0.34% and 5.12%, while on non-working days, the range was 1.01%-3.74%. The Root Mean Square Error (RMSE) was 2.07 dB, confirming that SoundPLAN provided consistent predictions of traffic noise in the urban context.

D. The Distribution Mapping of Traffic Noise Levels Using SoundPLAN 9.0

Traffic noise distribution maps generated with SoundPLAN 9.0 visualized the noise levels at observation points on both working and non-working days using a green-to-purple gradient [30]. Figure 7 presents a color-coded map of the noise levels along with the legend used in the distribution maps.

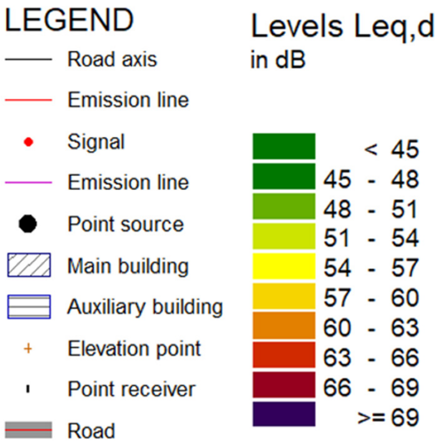

Fig. 7. Color scale and legend used for noise distribution maps.

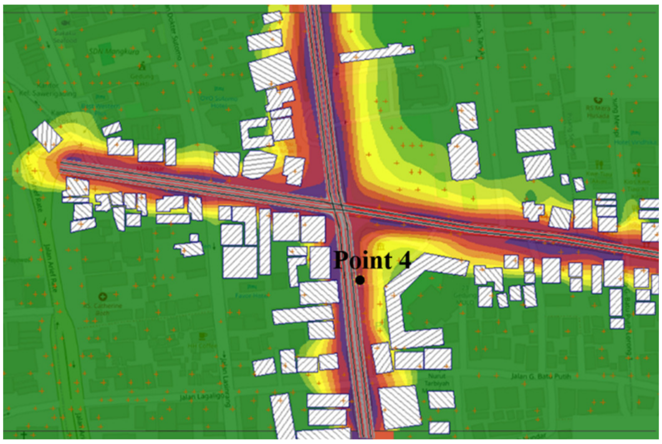

Fig. 8. Noise distribution map for a working day showing the highest levels near the intersection.

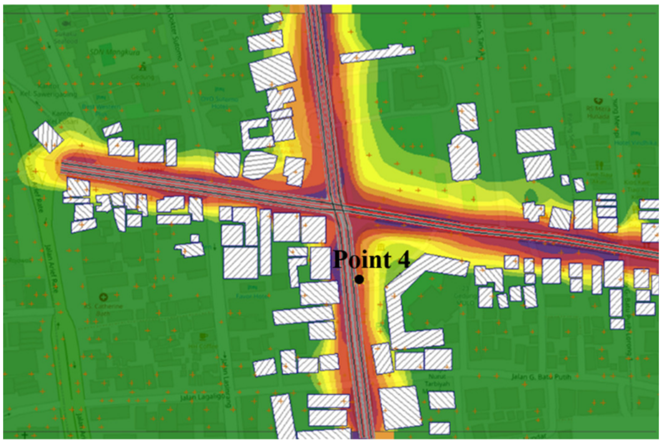

Fig. 9. Noise distribution map for a non-working day showing the reduced levels.

Spatial noise maps from SoundPLAN identified consistent hotspots near intersections and busy approaches, with areas 20 - 30 m from intersections often exceeding 75 dB. These maps in Figures 8 and 9 highlighted critical zones for mitigation, such as noise barriers or optimized signal timing.

E. Discussion and Implications

All measurements were conducted under normal weather conditions without rainfall or extreme wind, and no major construction projects or public events occurred near the intersections. These cases minimized potential external influences on the data. Future studies could include meteorological and event-based factors to further enhance the prediction robustness.

The results indicated that the traffic noise at signalized intersections in Makassar often exceeded the national limits. The findings were consistent with those of previous studies showing intersections as noise hotspots due to the congestion, braking, and horn use. An important background factor in Makassar is the frequent use of vehicle horns as a communicative tool in congested areas. This cultural driving practice significantly contributed to elevated noise levels. Compared to cities where the horn use is more strictly regulated, the results emphasized how the socio-cultural aspects of the driving behavior could shape the traffic noise patterns in urban environments.

Beyond technical accuracy, these findings highlighted important urban planning and public health implications. Excessive traffic noise was linked to health risks, such as stress, sleep disturbance, and reduced cognitive performance, particularly in sensitive groups, like children, the elderly, and hospital patients. Integrating noise prediction tools into the planning processes allowed authorities to protect the vulnerable populations and design healthier, more livable cities. By demonstrating both the scale of the problem and practical pathways for intervention, this study contributed to evidence-based strategies for managing the environmental quality in the growing urban areas.

IV. CONCLUSION AND RECOMMENDATIONS

This study investigated the traffic noise at four-way intersections of Dr. Ratulangi Street to Jenderal Sudirman Street in Makassar using SoundPLAN 9.0. Noise data were collected at six observation points over four days, on both working and non-working conditions. Based on field measurements and SoundPLAN predictions, the following conclusions are drawn:

- The traffic noise at Makassar's signalized four-way intersections generally exceeded the standards. On working days, Point 4 reached 76.49 dB, while on non-working days the lowest level was 69.55 dB at Point 5, which still outperformed the limits for sensitive areas, like hospitals and places of worship.
- SoundPLAN 9.0 predicted the noise levels accurately, with a Root Mean Square Error (RMSE) of 2.07 dB.
- The noise mapping highlighted higher levels near major intersections and busy roads, offering practical insights for urban planners. These included locating noise-sensitive buildings strategically, installing barriers, optimizing the traffic signal timing, and enforcing horn regulations.

This study is among the first in Indonesia to combine multi-day, multi-point noise measurements with spatiotemporal mapping at intersections. Future work should focus on comparing the noise levels between signalized and non-signalized four-way intersections or conducting noise measurements and predictions in other locations with different traffic and environmental characteristics. Other than that, SoundPLAN 9.0 could be compared with other noise models to assess the performance in varied urban conditions, and involve stakeholders to support effective, community-endorsed mitigation strategies.

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