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Determining the Impact of Vehicle Traffic on Selected Noise Level Indicators in the Vicinity of the Unsignalized Intersection - A Case Study

Putu Alit Suthanaya, Putu Preantjaya Winaya, Pandu Anantakusuma

Abstract – *There is a growing concern about the negative impact of road traffic noise on mental and physical health in developing countries. Road traffic noise models are important for preparing prevention and mitigation plans in order to minimize noise levels. The majority of the researches have focused to model traffic noise on-road section for uninterrupted flow conditions. Research on traffic noise modeling for interrupting flow situations has been mainly focused on the intersection controlled by traffic light and roundabouts. A little attention has been given to model traffic noise at unsignalized intersections. The objective of this study has been to investigate the contribution of the traffic parameters and performances on the noise level at unsignalized intersections based on simple regression and multiple linear regression analyses. The noise level indicators have included Leq, L10, L50 and L90. The results have indicated that the traffic performance variables such as the degree of saturation and the average delay had a positive correlation with the traffic noise level. However, traffic volume had a higher relationship with the noise level compared to the traffic performance variables. Since the traffic composition has been dominated by motorcycles, it has been found out that the volume of motorcycles was the best predictor of the variation in traffic noise level.* ***Copyright © 2021 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Traffic Noise, Traffic Parameters, Traffic Performances, Unsignalized Intersection, Regression*

Nomenclature

C	Intersection capacity
Co	Intersection basic capacity
D	Intersection delay
dB(A)	The "A" weighted decibel
DG	Intersection geometric delay
DT	Traffic delay
DS	Degree of saturation (volume/capacity ratio)
F_W	Road width adjustment factor
F_{CS}	City size adjustment factor
F_{RSU}	Road environment, side friction, and unmotorized adjustment factor
F_{LT}	Left turn adjustment factor
F_{RT}	Right turn adjustment factor
F_{MI}	Minor road flow ratio adjustment factor
HV	Heavy vehicle
LV	Light vehicle
Leq	Equivalent continuous sound level
L10	Noise level exceeded for just 10% of the time
L50	Noise level exceeded for just 50% of the time
L90	Noise level exceeded for just 90% of the time
MC	Motorcycle
V	Traffic volume
Veh	Vehicle

I. Introduction

Road traffic noise is a collective sound energy produced by the motor vehicles on a road and has a detrimental effect on public health [1]. Although in general there is a community perception that traffic noise impact is less important compared to air pollution [2], the detrimental effect of the road traffic noise on mental and physical health such as communication difficulty, sleep disturbance, decreased working performance, hearing loss, cardiovascular problems, nervousness and stress, is becoming widely recognized, in both developed and developing countries [3]-[11]. One way to reduce the noise level is by using acoustic insulation material for buildings such as composite brick made of cellulose fibers [12]. The noise produced is influenced by many factors such as traffic volume, pavement surfaces, type of vehicles, speed, horn, and type of intersections [13]. The road geometry and the vehicle conflict at an intersection also influence the noise produced by vehicular traffic [2].

Various models of traffic noise have been developed.

The model can be applied to estimate traffic noise in order to prepare preventive and mitigation measures for minimizing the impact. Many studies have been conducted to model road traffic noise on-road segments for uninterrupted flow conditions. Various traffic noise

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prediction models have been developed particularly in the developed countries, for example, the FHWA model in the US [14], [15], the CRTN model in the UK [16], the RLS90 model in Germany [17], the Italian CNR model in Italy [18], the NMPB-Routes-2008 in France [19], the ASJ RTN-Model 2008 in Japan [20], the Son Road model in Switzerland [21], and the Nord 2000 model in Scandinavian [22]. In Japan, road traffic noise prediction models have played important roles in noise assessment in the future environment. The Acoustical Society of Japan has published ASJ and ASJ RTN-Models. The parameters considered include types of road, traffic volume, running speed, distance, and meteorological conditions [23]. A study in Antalya city has developed a traffic noise model by using SoundPLAN software. Data collected include road network, traffic volume, velocity, traffic composition, geographic, topographic, and meteorological data. They have found out that heavy vehicle speed produced louder noise than light vehicle speed [24]. Another research has focused on the development of the road traffic noise model to be used in Japan and Netherlands for various road surfaces. They have claimed that the model could predict traffic noise accurately with average differences with the measured levels was only 1.3 dB [25]. A research in Varanasi city, India has used multiple linear regression analysis to model traffic noise. The variables considered include Noise Range (*NR*), percentage of heavy vehicles (*p*), the weighted traffic volume (*Qw*), and noise climate (*NC*).

The coefficient of determination value has been found to be 0.809 [26]. All the above models are based on the uninterrupted traffic flow consideration. The noise produced by road traffic is louder near intersections.

Traffic noise is affected significantly by vehicle speeds, braking, and acceleration as traffic conflict from different directions occurs [27], [28]. Many studies have been conducted in order to measure and develop a traffic noise model at an intersection with traffic lights.

Variations of the noise level are caused by the changes in green and red lights in the approaches of the intersection. The pattern of traffic movement at the intersection makes it difficult to predict traffic noise accurately [29]. A study in Japan has reported that the noise level near a signalized intersection tends to be higher for about 2.4 dBA compared to uninterrupted flow conditions [30]. Another study in the city of Cartagena, Colombia, has reported that traffic volume at the intersections has not correlated well with noise levels [31]. A traffic noise model for road intersections has been also developed by considering several variables such as the type, coordinates, speed, and acceleration of each vehicle [32]. It has been found out that different traffic controls for unsaturated flow conditions have not affected the noise level. An investigation on traffic noise at a signalized intersection has also been conducted by applying the Dutch noise model [29]. It has been found out that there is no significant difference between the predicted and the observed levels. The findings have stated that the noise has increased when vehicle speed has exceeded 50 km/h. A study in Dhaka has identified the main sources of traffic noise at road intersections, has suggested potential mitigation strategies [33], and has discovered that, regardless of the traffic conditions, the amount of noise at road intersections exceeds the permissible maximum. They have stated that the main sources of traffic noise have been the engine, the exhaust system, the aerodynamic friction, and the use of horns. Another study in India has developed a noise model for road traffic based on a regression model. It has been discovered that three-wheelers and heavy vehicles contribute more than four-wheelers and two-wheelers [34]. A similar study on modeling traffic noise at intersections has considered various variables such as traffic characteristics, geometric, road surface, and traffic management [35]. It has been found out that the main contributors to traffic noise include traffic volume, road surface, and speed. Several studies have focused on measuring and developing a model of traffic noise at a roundabout. It is widely assumed that traffic noise at a roundabout is lower than at a signalized intersection. The roundabout is regarded as the most suitable type of intersection in the residential area [36], [37]. A comprehensive review on the performance of modern roundabouts has been conducted in [38]. An investigation of road traffic noise at a roundabout close to Ramat Park, Benin City, Nigeria, has recommended the traffic laws enforcement and relocation of parking facilities in order to reduce the noise level [39]. A traffic noise model at a signalized roundabout in Poland has been developed based on a multiple regression method [40]. They have considered several independent variables related to traffic in the intersection taking into account the variables relating to traffic volume as well as traffic distribution (percentage participation of each traffic movement in the intersection) and traffic composition (percentage of noisy vehicles in the intersection – heavy vehicles, buses, and motor-cycles). Most of the studies about traffic noise at an intersection have been focused mainly on intersections controlled by traffic lights and roundabouts. Traffic noise models that have been developed in developed countries cannot be applied directly to developing countries, since the traffic characteristics are significantly different. Traffic characteristics at signalized intersection and roundabout are different from the ones at unsignalized intersection.

Little attention has been given to the contribution of the traffic parameters and performances on the traffic noise level at unsignalized intersections. The objective of this study has been to investigate the contribution of the traffic parameters and performances on the noise level at unsignalized intersections based on simple regression and multiple linear regression analyses for a typical traffic condition in a developing country.

This paper is organized into four sections. Section I describes the introduction, Section II deals with materials and methods, Section III concerns with results and discussion, and finally, the conclusion is presented in Section IV.

II. Materials and Methods

Figure 1 shows the study location at an unsignalized intersection of Teuku Umar Street - Demak Street, Denpasar City, Bali, Indonesia. Denpasar City has an area of 127.78 km^2 with a total population of 947.100 persons. The traffic volume in the majority of the road network increases from time to time. Traffic jams have been experienced particularly during the morning and afternoon peak hours. As the traffic volume continues to increase, energy consumption, air pollution, and traffic noise also continue to increase. Traffic noise mitigation strategies will require a good understanding of factors that influence traffic noise. Figure 1 shows the geometric of the intersection. The main road has been Teuku Umar Street (14 m width) and the minor roads have been Demak and Kertapura Street (5 m width). The noise level measurements have been carried out using the Extech SDL600 model sound level meter. This sound level meter has recorded the noise level and it has stored it in the memory card. The results of the reading of the sound level meter per second have been grouped into 15 minutes intervals. The sound level meter has been placed at the northeast corner of the intersection on a tripod so that the position of the microphone has been about 1.5 meters high against the ground [41] with a distance of 3 m from the edge of the road (Figure 1). The sound level meter has been located far enough away from high buildings or high walls that can reflect sound. The traffic volume has been recorded by using a video camera for 12 hours from 06.00am to 06.00pm (simultaneously with the noise level measurement). The video camera has been positioned close to the sound level meter with a height of about 3 meters above the ground. The traffic volume has been classified into motorcycles (MC), Light Vehicles (LV), and Heavy Vehicles (HV). Traffic volume recording has been carried out for 900 seconds (15 minutes) for one-time recording (a logarithmic sum), at the same time with the traffic noise level measurements. In order to synchronize the noise level and the traffic volume measurements, the devices have been turned on at the same time starting at 06.00am and then stopped at 06.00pm.

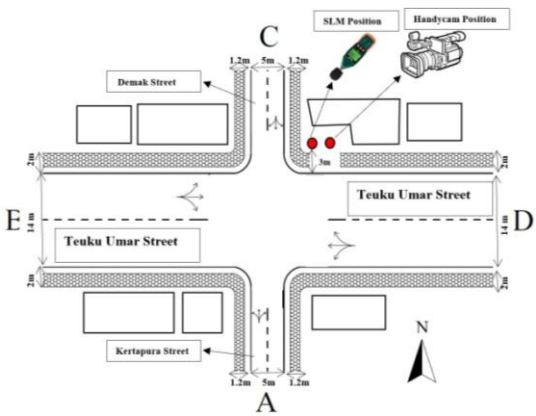

Fig. 1. Study Location at Unsignalized Intersection of Teuku Umar Street – Demak Street, Denpasar City, Bali, Indonesia

There have been 48 data sets of the traffic noise and traffic volume obtained during that period. The traffic volume has been calculated firstly based on the total volume (measured in veh/15 minutes) and secondly based on the passenger car unit (measured in pcu/15 minutes) in order to investigate which parameter has a higher relationship with the noise level.

The value of the passenger car unit has been obtained from the Indonesian Highway Capacity Manual (IHCM) based on the passenger car equivalent conversion factor of 1.3 for heavy vehicle and 0.5 for motorcycle [42]. The traffic noise level model has been obtained from the results of a simple and multiple linear regression analysis.

The dependent variables considered include Leq (Y1), L10 (Y2), L50 (Y3), and L90 (Y4). Table I shows the independent variables and their value ranges included for a simple regression analysis. Table II presents the independent variables used for a multiple linear regression analysis. The intersection capacity (Eq. (1)) and the degree of saturation (Eq. (2)) have been calculated based on the Indonesian Highway Capacity Manual procedure [42] as follows:

$$C = C_o \times F_W \times F_M \times F_{CS} \times F_{RSU} \times F_{LT} \times F_{RT} \times F_{MI} \quad (1)$$

$$DS = V / C \quad (2)$$

where C is the actual capacity (pcu/hour), C_o is the basic capacity in the ideal condition (pcu/hour), F_W is the road width adjustment factor, F_M is the median adjustment factor, F_{CS} is the city size adjustment factor, F_{RSU} is the road environment, side friction and unmotorized adjustment factor, F_{LT} is the left turn adjustment factor, F_{RT} is the right turn adjustment factor, F_{MI} is the minor road flow ratio adjustment factor, DS is the degree of saturation, and V is the traffic volume.

TABLE I
INDEPENDENT VARIABLES FOR A SIMPLE REGRESSION ANALYSIS

No.	Independent variables	Descriptive statistic		
		Min	Avg	Max
1	Traffic volume (veh/15 min)	311	737	1.696
2	Traffic volume (pcu/15 min)	171	737	989
3	Degree of saturation	0.35	0.95	1.0
4	Delay (s/veh)	7.63	21.73	56.42

TABLE II
INDEPENDENT VARIABLES FOR A MULTIPLE LINEAR REGRESSION ANALYSIS

No.	Independent variables	Symbol
1	Total Traffic volume	Ln TotVeh (X1)
2	Volume of motorcycles	Ln MC (X2)
3	Volume of light vehicles	Ln LV (X3)
4	Volume of heavy vehicles	Ln HV (X4)
5	Percentage of motorcycles	Ln %MC (X5)
6	Percentage of light vehicles	Ln %LV (X6)
7	Percentage of heavy vehicles	Ln %HV (X7)
8	Degree of saturation	Ln DS (X8)
9	Delay	Ln Delay (X9)

The traffic delay has been also calculated based on the Indonesian Highway Capacity Manual procedure [42] as follows:

$$D = DG + DT_i \quad (\text{s/pcu}) \tag{3}$$

where D is the intersection delay, DG is the intersection geometric delay, and DT_i is the traffic delay. The model performances have been evaluated based on the coefficient of determination (R^2) values. The closer the value to one is, the stronger the influence between the independent variable on the dependent variable is. It is hypothesized that the higher the traffic volume is, the higher the traffic noise level is, and the traffic composition will influence the noise level.

III. Results and Discussion

III.1. Traffic Volume and Composition

Figure 2 shows the variation of the traffic volume over a 12-hour survey period. From the figure, it can be seen that the highest volume of traffic passing the intersection of Teuku Umar - Pura Demak Street has been motorcycles (MC) with the highest volume of 1,417 vehicles, which has occurred at 05.15 - 05.30 p.m. Figure 3 presents the traffic composition. The traffic volume has been dominated by motorcycles (78.6%), followed by light vehicles (20.2%) and then heavy vehicles (1.2%).

Figure 4 describes variation in the total traffic volume (measured in vehicles/15 minutes) over a 12-hour survey period. The traffic volume has tended to be lower in the morning and then it has increased sharply at about 07.45am. After that, the traffic volume has been relatively constant and has reached the afternoon peak at about 05.15-05.30 pm, with a total traffic volume of 1,696 vehicles/15 minutes.

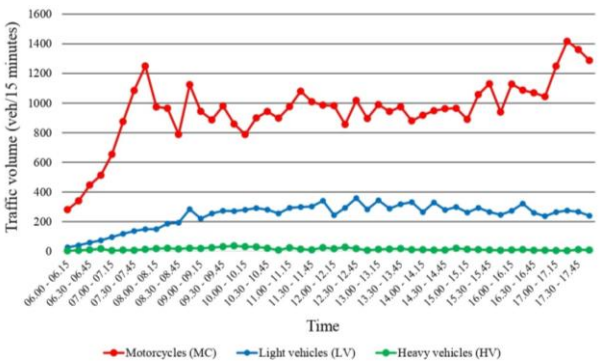

Fig. 2. Traffic volume for each type of vehicles (vehicles/15 minutes)

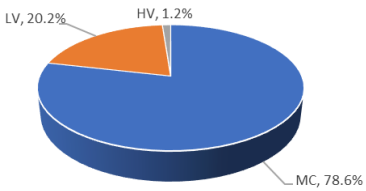

Fig. 3. Traffic composition

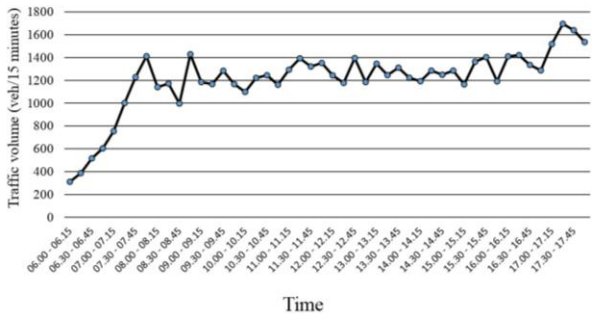

Fig. 4. Total traffic volume (vehicles/15 minutes)

III.2. Traffic noise

Figure 5 shows the fluctuation of the traffic noise measured every 15 minutes over a 12-hour period, in terms of Leq, L10, L50, and L90. Variation of the traffic noise tended to follow the variation in the traffic volume during the 12-hour survey period. The traffic noise has tended to be lower in the morning and then it has increased sharply at about 07.45am. After that, there has been only a little fluctuation and then it has increased at about 05.15pm.

III.3. Relationship Between Traffic Noise and Traffic Volume and Performances Based on a Simple Regression

The relationship between traffic noise and traffic volume and performances has been calculated based on a simple regression analysis. In general, based on a simple linear regression and non-linear analyses, it has been found out that the relationship between traffic noise and traffic volume and performances has tended to be logarithmic. Table III shows the results of the logarithmic relationship. Based on the coefficient of determination values, it can be seen that the relationship for L90 and Leq had the highest R^2 value. The L90 model with the coefficient of determination value 0.69 has indicated that the traffic volume variable (measured in veh/15 min) explains about 69% variation in the traffic noise. The traffic volume measured in units of veh/15 minutes has tended to have a higher coefficient of determination than if measured in units of pcu/15 minutes.

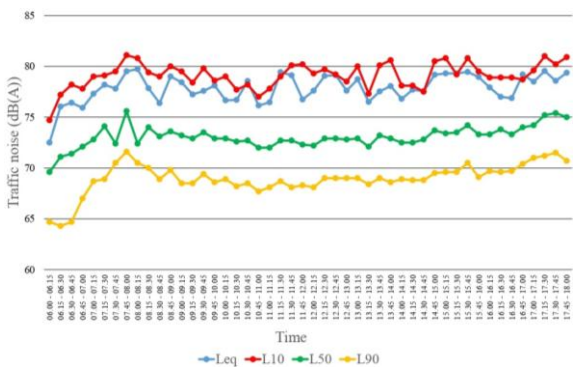

Fig. 5. Traffic noise variation

The increase in the traffic volume, the degree of saturation, and the delay have tended to be followed by the increase in the traffic noise. The increase in the degree of saturation and average delay has been expected to be followed by the increase in the noise level. The relationship presented in Table III indicates that the degree of saturation and the average delay have a significant positive correlation with the traffic noise. This indicates that the increase in the degree of saturation or *V/C* ratio and the average delay contribute to the higher noise level. The increase in the average delay will cause an increase in the braking and acceleration activities that affect noise level [27], [28]. However, this finding has been different from the previous studies at signalized intersection [43], [44], when traffic jam has occurred. The traffic noise measurement during the traffic jam at signalized intersection due to an idle vehicle condition, which has caused the source of noise from the road-tire interaction, has not been recorded. The policy implication of this finding is that the traffic management measure required at unsignalized intersection to reduce the noise level is by reducing the degree of saturation and average delay to make traffic move smoothly.

III.4. Relationship Between Traffic Noise and Traffic Parameters and Performances Based on a Multiple Linear Regression

Table IV presents the results of the multiple linear regression model for Leq, L10, L50 and L90. The independent variables considered include the volume of motorcycles (LnMC), the light vehicles (LnLV), the heavy vehicles (LnHV), the total vehicles (LnTotVeh), the percentage of motorcycles (Ln %MC), the percentage of light vehicles (Ln %LV), the percentage of heavy vehicles (Ln %HV), the Degree of Saturation (Ln DS) and the delay (Ln Delay). Based on the stepwise method, it has been found out that only the volume of motorcycles (LnMC) has been included in the model.

This indicates that, since the proportion of motorcycles predominates the traffic composition (78.6%), the traffic noise has been mainly influenced by the volume of motorcycles. The highest coefficient of determination has been found for L90 model with an R^2 value of 0.79. The volume of motorcycles (Ln MC) can explain 79% of the variation in traffic noise L90. The volume of motorcycles (Ln MC) can explain 52% of the variation in Leq, 43% in L10, and 60% in L50. It has been hypothesized that the higher the traffic volume is, the higher the traffic noise level is. Based on Figures 2 and 5, it has been identified that a similar variation has been observed between traffic volume and traffic noise during a 12-hour survey period.

The increase in the traffic volume has tended to be followed by an increase in the traffic noise. This is also supported by the positive relationship between traffic volume and traffic noise as presented in Table III. This finding is in line with several studies [26], [36], but it is different from a study conducted in the city of Cartagena, Columbia [31], which has claimed that there is no significant correlation between traffic volume and traffic noise at an intersection. The low correlation between traffic volume and noise level in the city of Cartagena might be caused by several factors such as the intense use of horns and the extreme noise from some vehicles [34]. Table IV further describes that only the volume of motorcycles (MC) has been included in the multiple linear regression model. This finding is different from a study that has been conducted in India [35], which has stated that three-wheelers and heavy vehicles contribute more than four-wheelers and two-wheelers. Although the traffic noise produced by a heavy vehicle is higher than a motorcycle, the noise generated at an intersection is also influenced mainly by the traffic composition. Future research direction is to investigate various traffic management strategies that can be implemented to reduce the average delay at unsignalized intersections and, therefore, reducing the noise.

TABLE III
RESULTS OF SIMPLE REGRESSION ANALYSIS ON THE RELATIONSHIP BETWEEN TRAFFIC NOISE AND TRAFFIC VOLUME AND PERFORMANCES

Independent variable	Traffic noise	Model	R^2
Traffic volume (veh/15 min)	Leq	y = 2.8716ln(x) + 57.6017	0.46
	L10	y = 2.3814ln(x) + 62.3128	0.37
	L50	y = 2.2887ln(x) + 56.9083	0.50
	L90	y = 3.8069ln(x) + 42.0982	0.69
Traffic volume (pcu/15 min)	Leq	y = 2.583083ln(x) + 60.922813	0.44
	L10	y = 2.125157ln(x) + 65.178214	0.35
	L50	y = 1.993758ln(x) + 59.981436	0.43
	L90	y = 3.367219ln(x) + 46.875893	0.62
Degree of saturation (DS)	Leq	y = 2.404ln(x) + 78.091	0.66
	L10	y = 0.081ln(x) + 80.822	0.06
	L50	y = 0.169ln(x) + 74.986	0.54
	L90	y = 0.110ln(x) + 70.515	0.21
Delay	Leq	y = 1.5314099ln(x) + 73.3638761	0.51
	L10	y = 0.0442256ln(x) + 80.6848559	0.03
	L50	y = 0.0952651ln(x) + 74.6910698	0.32
	L90	y = 0.0819198ln(x) + 70.2641777	0.21

TABLE IV
MULTIPLE LINEAR REGRESSION MODEL

Dependent Var	Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	R^2
Leq	(Constant)	55.814	3.131		17.825	.000	
	LnMC (X1)	3.233	.459	0.721	7.047	.000	0.52
L10	(Constant)	60.594	3.130		19.360	.000	
	LnMC (X1)	2.716	.459	0.658	5.923	.000	0.43
L50	(Constant)	54.605	2.245		24.320	.000	
	LnMC (X1)	2.706	.329	0.772	8.255	.000	0.60
L90	(Constant)	38.994	2.277		17.127	.000	
	LnMC (X1)	4.395	.334	0.889	13.172	.000	0.79

IV. Conclusion

Road traffic noise becomes a growing concern of the government in a developing country, including Indonesia. Therefore, it is important to understand the factors that contribute to the noise level, particularly at an intersection, as the noise level is higher compared to the road section. Various traffic noise prediction models have been developed especially in developed countries.

However, these models could not be applied directly to developing country because of the significant difference in the road geometric and the traffic characteristics. Unlike in developed countries, the traffic composition in a developing country is dominated by motorcycles. The research has shown that the traffic noise level at unsignalized intersections has been significantly correlated with the traffic volume. The increase in the traffic volume tended to be followed by the increase in the noise level. The traffic volume had a higher relationship with the traffic noise if compared to the traffic performance variables. The traffic composition has also influenced the noise level. Since the traffic composition has been dominated by the motorcycles, the volume of motorcycles has become the main predictor of the traffic noise level. Differently from the study at signalized intersection when a traffic jam has occurred, the traffic performance variables such as the degree of saturation or V/C ratio and the average delay have been found to have a positive correlation with the noise level.

The increase in the average delay would cause an increase in braking and acceleration activities, which lead to an increase in the noise level. A policy intervention such as implementing traffic management measures to reduce the average delay is required. Future research direction is to find the optimum traffic management strategies in order to reduce the average traffic delay and the noise level at unsignalized intersection.

Acknowledgements

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