Jordan Journal of Civil Engineering, Volume **18**, No. **2**, **2024**
DOI: https://doi.org/10.14525/JJCE.v18i2.14

Jordan Journal of Civil Engineering

Journal homepage: https://jjce.just.edu.jo

Modeling of Traffic Noise along Urban Arterials in Irbid City of Jordan

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ARTICLE INFO

Article History:
Received: 26/12/2023
Accepted: 23/3/2024

ABSTRACT

Traffic-related noise pollution is a recurring problem in large and medium-sized cities. The objective of this study is to quantify traffic-noise levels along selected urban arterials and model the generated traffic noise based on traffic and pavement characteristics. Urban arterial and collector streets in Irbid city, Jordan, were taken as a case study. The city is considered an example of a medium-sized city. 65 urban arterial and collector sections were selected to achieve the stated objective. For each section, ten noise measurements were taken using a time interval of 2.5 minutes for each observation. The statistical pass-by method was used to measure 650 external-noise observations. In addition, data on traffic, pavement and section geometric characteristics was obtained through field measurements. The collected traffic characteristics, including traffic flow, percentage of trucks and speed in each direction of travel, were obtained. In addition to the measurement of pavement macrotexture depth, an international roughness index was measured using a smartphone application.

Investigation of the collected noise data indicated that urban streets experienced high noise levels, reaching maximum and average values of 82 and 77.2 dB(A), respectively. The results of the analyses showed that an increase in each of the included traffic characteristics resulted in significantly higher noise levels. For example, an increase in speed from 35 to 55 km/h would increase noise by 2.7 dB(A). In addition, the interaction term of roughness index and pavement macrotexture depth was found to increase the generated noise. Finally, the results of the analysis indicated that both multivariate linear -and exponential-regression models are suitable to model the generated traffic noise. Each model explained approximately 54% of the noise variability. Probably, traffic composition and vehicle-power type heterogeneity might reduce the level of explained variability.

Keywords: Traffic noise, Urban arterials, Pass-by method, Noise modeling, Jordan.

INTRODUCTION

The major goal of transportation is to transport people and goods in an effective, efficient, economical and sustainable manner. However, the growth in traffic volumes has led to considerable negative impacts, such as traffic accidents, air pollution and noise pollution. Noise is an unwanted sound and creates annoyance

(Amoatey et al., 2022; Recio et al., 2016; Kim, 2007). Khreis et al. (2016) indicated that traffic noise had been associated with all-cause premature death, cardiovascular death, adverse productive outcomes and an increased risk of stress and aggression. In addition to lowering academic and occupational performance, the adverse health effects of traffic noise include high blood pressure, decreased human hearing sensitivity, ischemic heart disease, artery disease, anger, anxiety, headaches, disturbed sleep, stress and psychological disorders (Gilani & Mir, 2021; Roswall et al., 2017; Vijay et al., 2015). However, these effects also largely depend on the level of noise and the length of exposure. Therefore, many countries have set general regulations and policies to limit noise to an acceptable level.

Several studies have indicated that highway traffic is the major source of environmental noise (Murphy & King, 2007). In addition to traffic volume, speed and composition, the traffic-noise level is generally affected by the vehicle's propulsion system, aerodynamics and tire-pavement interaction (Abdur-Rouf & Shaaban, 2022; Kamineni et al., 2019; Murat & Ebru, 2016). However, vehicle-engine design and body-shape improvements reduce the noise generated by propulsion and aerodynamic effects (Yang et al., 2011; Bravo et al., 2012; Al-Masaeid & Fayyad, 2018). For example, compared to gasoline cars, Al-Masaeid and Bani Hani (2023) concluded that the use of hybrid and electric cars may reduce the noise by 5 and 12 dB(A), respectively.

In developing countries, such as Jordan, traffic-noise issue is much more complicated compared with developed countries due to two reasons. First, an efficient public-transport system is not yet well developed; thus, most residents are using private vehicles (Al-Masaeid & Shtayat, 2016). This situation creates high congestion and associated noise levels. And second, lack of well planning of land use and transport infrastructure (Al-Masaeid & Khaled, 2023; Al-Masaeid, 1997). As such, most of residents' houses and vital premises such as hospitals or schools are clustering around transport highways and consequently increasing the residents' duration and frequency of noise exposure. Therefore; it is crucial for developing countries to explore traffic-noise contributing factors, model traffic noise and identify possible mitigation measures.

The objective of this study is to quantify traffic-noise levels along selected urban arterials and model the generated traffic noise based on traffic and pavement characteristics. To achieve this objective, urban arterial and collector streets in Irbid city were taken as a case study. The city is considered a medium-sized city with a population of about 350 thousand inhabitants. It is the center of the Irbid governorate, which has a population of 2.1 million inhabitants. Noise measurements were performed using the statistical pass-by method under heterogeneous traffic compositions and vehicle-power types. In Jordan, hybrid and electric cars constitute about 50% and 5.5% of the total vehicles, respectively. It is believed that the measurement and development of noise models for arterials in Jordan are crucial for two reasons. First, the study will explore levels of noise along arterials and whether such levels are acceptable according to the worldwide standards. Second, the developed noise model would provide a valuable tool for urban engineers and practitioners to estimate noise level for a given arterial.

BACKGROUND

Literature has indicated that highway traffic is the main source of environmental noise (Yang et al., 2011). Traffic-noise levels are often influenced by the vehicle's propulsion system, aerodynamics and tire-pavement interaction, in addition to traffic volume, speed and composition. The five primary sources of noise for moving vehicles are the engine (power train), intake system, exhaust system, aerodynamic turbulence (wind) and tire-pavement interaction (Braun et al., 2013). Yang et al. (2011) indicated that engine noise predominates at low speeds, whereas aerodynamic noise is only significant at high speeds. Therefore, at normal or average traffic speeds, tire-pavement interaction noise is the main source for cars with a speed higher than 40 km/h and for trucks with a speed higher than 70 km/h (Li, 2018).

Empirical studies revealed that noise level increases linearly with traffic speed for all vehicle classifications (Al-Masaeid & Bani Hani, 2023; Vijay et al., 2015). For example, Vijay et al. (2015) reported that noise level increases by nearly 4-5 dB(A) for a speed increase from 35km/h to 55 km/h. Other studies found that the magnitude of traffic noise is influenced by traffic volume, traffic composition and road type (Subramani et al., 2012; Freitas et al., 2012). For example, Suthanaya (2015) and Abo-Qudais and Alhiary (2007) concluded that noise increases with the increase in traffic volume and percentage of trucks.

In addition, traffic noise is significantly influenced by asphalt-pavement surface properties. The impact of pavement-surface condition, expressed in terms of the international roughness index IRI, on traffic noise was confirmed in different studies (Al-Masaeid & Bani Hani, 2023; Chen et al., 2016). Although the increase in the IRI would reduce traffic speed (Al-Masaeid et al., 1998), the increase in the IRI was found to significantly increase the noise level. Furthermore, studies reported that the increase in pavement-texture depth (TD) might increase the generated noise (Chen et al., 2016).

Methodologies for measuring noise levels have been discussed in the literature (Li, 2018). They consist of on-board, in-vehicle and far-field noise measurements. Statistical pass-by, controlled pass-by and time-averaged wayside are some of the techniques that fall under the category of far-field measures. Each technique has a distinct intended use and set of tools. In order to measure exterior noise, for instance, both statistical pass-by and controlled pass-by methods are used; however, the statistical pass-by method uses a random sample of typical vehicles that are measured one at a time, while the controlled pass-by method uses a small number of carefully chosen vehicles that are driven past the measurement site at a controlled speed. The statistical pass-by method works well for assessing how much traffic noise affects nearby residential areas or pedestrians (Sandberg, 2001). This method measures the average level of traffic noise and assesses outdoor-traffic noise (Ling et al., 2021).

METHODOLOGY AND DATA COLLECTION

To achieve the objective of this study, 15 urban multi-lane arterial and collector streets in Irbid city were selected. 65 pavement sections along the designated urban streets were chosen based on a predetermined criterion. Each street section is 100 m in length. For each section, data on external noise, traffic, pavement and geometric characteristics was collected. All field measurements were carried out in the autumn of 2022 and during the daytime. Noise measurements, using the statistical pass-by method, were performed under calm-wind conditions (speed < 4 km/h) and at a comfortable temperature of 20-25°C. All noise measurements were collected on workdays and during 9:00-11:00 AM and 3:00-5:00 PM. The selected flexible-pavement sections, noise measurement, traffic characteristics, pavement IRI and TD measurements, as well as section geometric variables are explained in the following sub-sections.

Selection of Pavement Sections

The measurement sections are located along 15 urban streets. The speed limit for the selected streets ranged from 40 km/h to 60 km/h. Sections selected for noise measurements were chosen to be straight and level, far from traffic-control devices, intersections and traffic-calming measures and far from cross-drainage structures and buildings. Also, each pavement section should have a constant width and a uniform surface condition. A selected section should be far from the nearby intersection by at least 50 m. This criterion was adapted to avoid possible effects due to traffic acceleration or deceleration. Finally, there should be no type of physical obstruction between the noise-measuring device and the noise source at the measuring location, such as parked vehicles or barriers (Badandi, 2023; Burns, 1981).

Noise Measurements

Noise was measured using the statistical pass-by method. The sound-level meter, SLM, was employed to determine the generated traffic external noise. The instrument is installed in the middle of the pavement section, at a height of 1.2 meters on a tripod and at a distance of 7.5 meters from the centerline of the outside traffic lane. The SLM equipment is used to collect the noise from traffic passing along the selected street, using an interval of 2.5 minutes. This interval was adopted to be enough to measure traffic speeds, traffic flows and percentages of trucks in both directions of travel.

For each pavement section, 10 observations were obtained. The microphone was held parallel to the direction of the traffic flow. At the end of each interval, the noise value was recorded. During measurement, the SLM was set on an A-weighting scale with a “high" level and a "fast" level and the SLM reacted to changes in sound in 0.125 sec. As it might be expected, the fast setting provides a higher resolution and a more detailed image than the slow setting and is more responsive to brief, quick sounds. During measurements, if a vehicle honked during the observation interval, the observation was repeated. Figure 1 shows the instrument setup.

Figure (1): Instrument setup during noise measurements

Traffic-characteristics Measurement

For each 2.5-minute interval, the number of vehicles passing in front of the SLM in each direction of travel on the street was counted manually and recorded separately. Also, the percentage of trucks in each direction of travel was estimated and recorded in each measuring interval. It is worth mentioning that most of the trucks are light trucks, including vans, pick-ups and mini-buses. Furthermore, the speed of vehicles in each direction of travel was measured using a short trap of 25-m length. Along urban arterials, the maximum traffic speed is 60 km/h; therefore, the use of a trap length of 25 m is not unreasonable (Russell et al., 1976).

Pavement-condition Characteristics Measurement

In this study, pavement-condition characteristics were evaluated using the IRI and TD. The IRI is a measure that describes surface irregularities and is considered a pavement-performance measure and quality-assurance measure for ride quality. In Jordan, automated laser profiler equipment is not available to measure the IRI. Therefore, a smartphone application (TotalPave) was chosen in this study to measure pavement-surface IRI (Islam et al., 2014). The licensing for using TotalPave was obtained through direct communication with the company that developed this application, which is based in New Brunswick, Canada. The Samsung Galaxy A11 smartphone was employed as the data-logger device for this study. A test vehicle was driven at the street speed limit. The car was being driven as closely as possible, parallel to the middle of the road. It's crucial to situate the smartphone inside the vehicle, so that it is directly across from the driver's eyes. The holder holds the smartphone in place on the windscreen (see Figure 2). The interface of TotalPave was created so that the driver can simply access all screen data and activate screen buttons. As the test vehicle attained the required uniform speed, the button in the TotalPave app. was activated. Once the 100-meter section is surveyed, the data is uploaded to the TotalPave web service and ultimately the IRI for every pavement section is obtained. Figure 3 presents a sample of pavement section with their IRIs obtained using the TotalPave application.

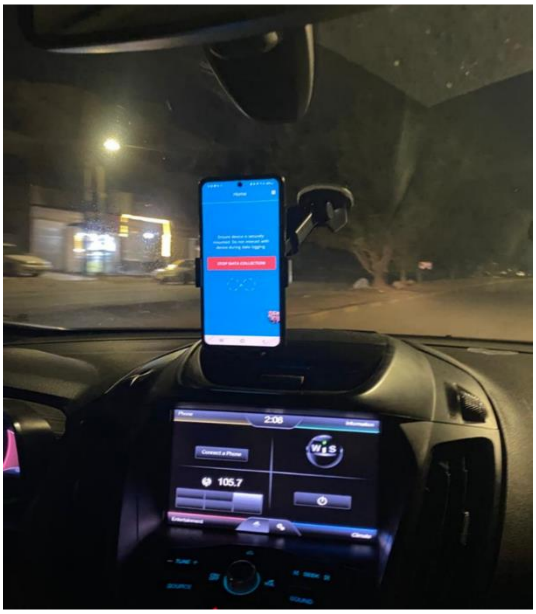

Figure (2): Mobile device on the windshield

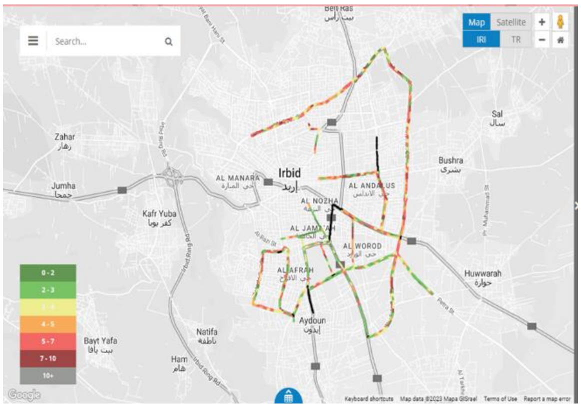

Figure (3): The selected street sections and their IRIs as estimated using TotalPave

The texture-sand patch method was used to determine the macro-pavement texture depth TD for the selected pavement sections. The TD of the pavement surface is determined in the field using the sand-patch test method (ASTM E 965-96). In the study, the pavement surface was evenly covered with a 50-cubic-cm volume of sand in the shape of a circle, filling in any surface voids. In the field, for measurements, we were taken to estimate the diameter of a circle and the average value was obtained. The mean texture depth was computed as shown in Equation (1) (ASTM standards, 2015).

$$TD = \frac{4\,V}{\pi\,D^2} \quad (1)$$

where:

TD: mean texture depth, mm.

V = volume of glass or sand beads, in cubic mm and

D = average diameter of the sand patch, in mm.

Geometric Measurements

Geometric measurements include the width of the traveled way in each direction of travel as well as the median width. Also, the distances from the location of the SLM instrument to the upstream and downstream intersections were measured and recorded. It is worth mentioning that all selected sections are level with longitudinal slopes of less than 2%. Figure 4 shows geometric variables.

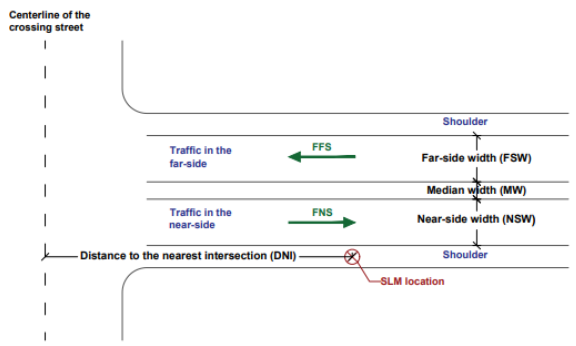

Figure (4): Geometric data of the street section

ANALYSIS AND MODELING

In this study, the developed data base includes 650 observations (65 pavement sections * 10 noise observations on each section). The descriptive characteristics of the collected data are presented in Table 1. As shown in the table, traffic flow in the near-side, FNS, varied from 96 veh/h to 1872 veh/h and the corresponding percentage of light trucks, TNS, varied from 1% to 70%, with an average of about 22%. Traffic flow on the far side, FFS, varied from 24 veh/h to 1896 veh/h and the associated light truck percentage, TFS, ranged from 1% to nearly 71%, with an average of about 21%. It is worth mentioning that light trucks include pick-ups, vans and mini-buses. The measured noise level, N, was found to vary from 68 dB(A) to 82.4 dB(A), with average and standard-deviation values of 77.22 and 2.53, respectively. These noise levels are relatively high when compared with standards in developed countries. The measured traffic speed, S, was found to vary from 3km/h to 57 km/h, with an average value of about 33 km/h. The IRI for the investigated sections varied from a minimum of 1.42 m/km to a maximum of 9.6 m/km., with these values corresponding to excellent to very poor pavement conditions, respectively. The TD for the surveyed section varied from 0.4mm to 0.88 mm. Clearly, the variability in the texture depth is relatively small, which indicates that the gradations of asphalt mixtures are nearly similar.

Finally, the street nearside width, NSW, varied from 6.5m to 13.65m, while the far-side width ranged from 6.5m to 11.8m. Irrespective of urban street type, each street direction consists of 2-4 lanes; however, most streets are not marked. All selected streets are divided, with the median, MW, varying from 0.5m to 5.7m. The distance from the selected section to the nearest intersection, DNI, was measured in the field and varied from 70m to 810m.

Table 1. Descriptive statistics of the included variables

Variable	Unit	Minimum	Maximum	Mean	Std. Deviation
FNS	100 veh/h	0.96	18.72	9.17	3.84
TNS	%	1.00	70.00	22.43	11.92
FFS	100 veh/h	0.24	18.96	8.87	3.47
TFS	%	1.00	70.59	20.90	11.3

NS	dB (A)	68.0	82.4	77.22	2.53
S	km/h	3.0	57.0	32.64	7.87
IRI	m/km	1.42	9.6	3.68	1.66
TD	mm	0.4	0.88	0.56	0.11
NSW	m	6.50	13.65	9.36	1.59
MW	m	0.50	5.70	2.78	1.36
FSW	m	6.50	11.80	9.46	1.53
DNI	m	70	810	250.9	162.94

The correlation matrix, using Pearson product-moment correlation, was constructed to investigate the relationship between noise and the included variables. The correlation matrix between noise and each of the included variables is shown in Table 2. As shown in the table, the noise is positively and significantly correlated with FNS, FFS, TNS, TFS and S. Figures 5 and 6 illustrate the scatter plots between the measured noise and FNS and FFS, respectively. Clearly, these figures indicate that an increase in traffic flows in both directions of travel would increase the level of traffic noise. However, it is worth mentioning that there was considerable multi-collinearity between the TFS and TNS and between the TFS and FFS. Therefore, the TFS variable would be excluded from modeling to avoid multi-collinearity problems. The scatter plot between the measured noise and the traffic speed is shown in Figure 7. As expected, an increase in traffic speed may increase the generated noise.

In addition, Table 2 illustrates that noise is significantly correlated with the TD and IRI*TD. The term IRI*TD represents the product of international roughness index and texture depth or the interaction term. Although the noise was found to be correlated with the IRI, the correlation coefficient was small and insignificant at the 95% confidence level. In fact, most noise measurements were carried out at low traffic speeds and this issue may reduce the effect of tire-pavement interaction. In the study, only 105 noise measurement observations were carried out at speeds higher than 40 km/h. The analysis also indicated that the noise level is significantly correlated with the geometric variables, including NSW, MW and FSW. Further analysis revealed clearly that all these geometric variables are strongly and significantly correlated. Furthermore, Table 2 shows that the noise is negatively correlated with the DNI.

Table 2. Correlation between the measured noise and the included variables

Variable	r-Coefficient	p-value
FNS	0.448	<0.001
TNS	0.139	<0.001
FFS	0.470	<0.001
TFS	-0.174	<0.001
S	0.348	<0.001
IRI	0.046	0.243
TD	0.211	<0.001
IRI*TD	0.110	<0.001
NSW	0.216	<0.001
MW	0.328	<0.001
FSW	0.236	<0.001
DNI	-0.200	<0.001

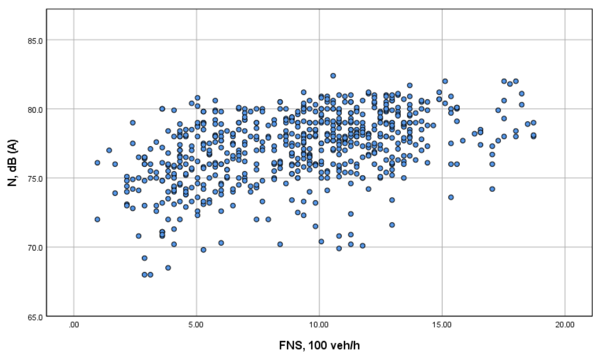

Figure (5): Scatter plot between measured noise and traffic flow in the near side

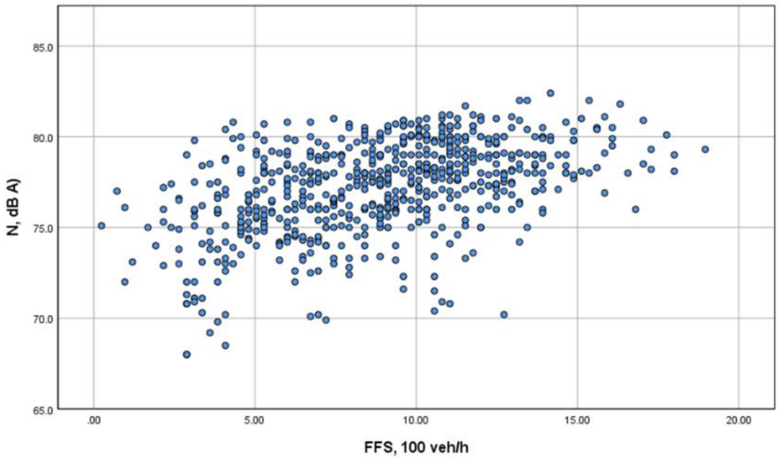

Figure (6): Scatter plot between measured noise and traffic flow in the far side

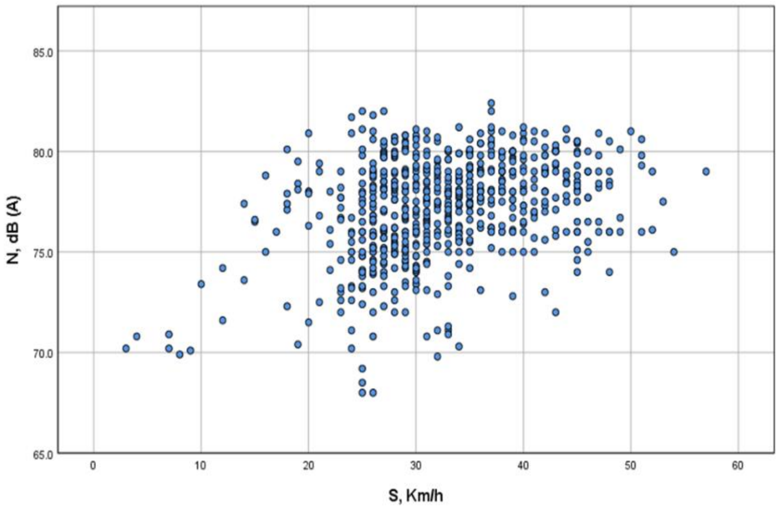

Figure (7): Scatter plot between measured noise and traffic speed

Based on multiple linear-regression analysis, the following regression equation was developed to estimate the generated noise:

$$N = 66.205+0.277FNS+0.067TNS+0.182FFS+0.133S+0.442IRI.TD-0.002DNI \quad (2)$$

The above regression equation and all its parameter estimates were found to be significant at the 95% confidence level. Table 3 presents the statistical characteristics of Eq.2. Furthermore, the coefficient of multiple determination of the above equation is 0.54. An investigation of residuals indicated that they were randomly distributed and no outliers were observed (Badandi, 2023). The regression equation explained about 54% of the variability in noise level. As shown in Eq. (2), 1000 vehicles on the near side would increase the noise level by 2.77 dB(A), while 1000 vehicles on the far side would increase the generated noise by 1.82 dB(A). Also, the equation indicates that an increase in truck percentage from 0% to 20% may increase the noise by 1.34 dB(A). The equation indicates that an increase in traffic speed from 30 km/h to 50 km/h would increase the noise by 2.66 dB(A). The above model equation shows that noise increases with an increase in the product of pavement roughness and texture depth. Finally, noise is slightly reduced with the increase in distance from the nearby intersection. Clearly, Table 3 shows that as the distance from the nearby intersection (DNI) increases, the generated-noise level would be significantly reduced (negative t-value is associated with DNI variable, see Table 3).

Table 3. Statistical characteristics of the noise model in Eq. 2

Analysis of variance					
Variable	**Sum of Squares**	**DF**	**Mean Square**	**F-value**	**P-value**
Regression	22650929	6	377.655	129.726	0.000
Residual	1871.877	643	2.911		
Total	4137.806	649			
$R^2 = 0.548$	Adj. $R^2 = 0.543$				
Regression parameters estimates					
Variable		**Parameter Estimate**	**Standard Error**	**t- value**	**P-value**
Constant		66.848	0.445	150.199	0.000
FNS		0.277	0.026	10.662	0.000
TNS		0.067	0.066	11.234	0.000
FFS		0.177	0.028	6.351	0.000
S		0.133	0.009	14.822	0.000
IRI*TD		0.442	0.052	8.422	0.000
DNI		-0.002	0.0	-5.171	0.000

It is worth mentioning that an exponential model was developed to estimate the generated-noise level in this study. The developed model equation has the following form:

$$Ln(N) = 4.211+0.004FNS+0.001TNS+.002FFS+ 0.002S+0.006IRI.TD-2.986E\text{-}5DNI \quad (3)$$

The above regression equation and all its parameter estimates were found to be significant at the 95% confidence level. Also, the coefficient of determination is 0.54. Compared with the linear model in Eq.2, the exponential model in Eq.3 did not add any improvement, specifically in terms of noise-variability reduction. Therefore, it is recommended to use the linear form to estimate the noise level along urban arterials and collector streets in Irbid city.

RESULTS AND DISCUSSION

This study investigates the effect of traffic volume and speed, pavement condition and street geometric variables on the external noise along urban arterial and collector streets in Irbid city. Although several studies focused on noise estimation, none of these studies included these variables in a comprehensive study. For example, studies in Jordan did not investigate the impact of pavement conditions on the generated noise (Abo-Qudais & Alhiary, 2007; Jamrah et al., 2006; Banihani & Jadaan, 2012).

The results of noise measurements showed that noise varied from 68 dB(A) to 82.2 dB(A), with an average value of 77.2 dB(A). These values are relatively high and are considered unhealthy for pedestrians or residents of neighborhoods adjacent to these streets. In fact, different countries set a maximum acceptable noise level of 65 dB(A). Thus, it is vital for Jordan to develop mitigation measures that aim to reduce traffic noise along the streets. These measures may include a reduction in traffic levels and an improvement in pavement-surface condition. Probably, the improvement of public transport may positively contribute to the reduction of traffic volumes along urban arterial and collector streets.

The results of this study confirmed the impact of traffic flows in both directions of travel on the generated noise. This result is consistent with previous findings, which indicated that traffic flow significantly increases the generated-noise level (Alkheder, 2023; Ibili et al., 2022; Mishra et al., 2021; Freitas et al., 2012). Also, the results of this study indicated that traffic composition greatly influences external noise. It was found that an increase in the percentage of light trucks, such as pick-ups, vans and mini-buses, would increase the noise level, specifically trucks on the near side. Again, this result is compared favorably with the findings of previous studies (Subramani et al., 2012; Ramakrishna et al., 2021). Furthermore, traffic speed has a significant impact on traffic noise, as concluded in this study. According to Eq.2, an increase in traffic speed from 35 km/h to 55 km/h would increase the maximum generated noise by about 2.7 dB(A). However, this increase is lower than that obtained in previous studies, which was from 4 dB(A) to 5 dB(A) (Vijay et al., 2015; Freitas et al., 2012). Again, this result is not illogical, because considerable percentages of electric-power and hybrid vehicles have been introduced in the vehicle fleet during the last two years.

Investigation of the correlation matrix indicates that pavement roughness had no considerable effect on external noise. However, previous field studies reported that IRI has a great impact on external noise (Al-Masaeid & Bani Hani, 2023). Probably, the effect of IRI on noise levels would be much stronger at high traffic speeds. In this study, about 84% of the noise measurements were conducted at a speed of 40 km/h or less. In the same sense, the pavement texture had a low impact on the noise level and would be clearer under high traffic speeds, while most of the noise measurements in this study were conducted under low-to-medium traffic speeds. Despite that, the interaction between pavement roughness and texture was found to significantly influence the noise level. Again, this result is compatible with the findings concluded by Chen et al. (2016). Thus, rough pavement with a large texture depth would generate a higher noise level. Thus, to reduce the noise level, it is recommended to use densely graded asphalt and maintain the pavement in good condition. The literature revealed that pavements with open grades may increase the generated traffic-noise level (Freitas et al., 2012; Liao et al., 2014).

Pavement-section geometric variables, including widths of the near-side and far-side pavement and median widths, were found to have no effects on the generated traffic noise. The pavement widths varied from two-lane to four-lane in each direction, with median widths ranging from 0.5m to 5.7m. However, for a given pavement section, the widths are the same in each direction of travel. Probably, the distribution of traffic on lanes is much more important in this regard. It is worth mentioning that all selected pavement sections were level with varying distances from the nearest intersection. Results of the modeling and correlation matrix indicated that traffic noise reduced with an increase in distance from the nearest intersection. This result is logical and consistent with the results of previous studies (Goussous et al., 2014; Jamrah et al., 2006; Banihani & Jadaan, 2012; Younes et al., 2021).

It is worth mentioning that the forms of the developed models are comparable with the mathematical forms of the developed noise model in the literature. For example, multi-variate linear-and exponential-regression models were found to be suitable for modeling external noise (Al-Masaeid & Bani Hani, 2023; Alkheder, 2023; Chen et al., 2016). Despite the fact that all measures were considered to avoid the impact of weather conditions on the measured noise, such as noise measurements under calm-wind conditions and temperatures in the range of 20–25°C, the coefficient of determination for each noise model was moderate-to-low. This issue may be explained by the fact that the distribution of vehicle-power types in the same section or in different sections is heterogeneous. In addition to gasoline and hybrid vehicles, many electric-powered vehicles have been introduced in the last two years; this factor may influence the variability in noise estimates. By the end of 2022, hybrid and electric-powered vehicles will constitute approximately 50% and 5.5% of the total vehicle fleet in Jordan, respectively. A recent study conducted in Jordan, using a controlled pass-by method indicated that hybrid and electric cars might lower noise levels by 5 dB(A) and 12 dB(A), respectively, when compared with noise generated by gasoline-powered vehicles (Al-Masaeid & Bani Hani, 2023).

Finally, while the specific results relate to Irbid city, the authors believe that the results are applicable for medium-sized cities in developing countries that have similar planning, land use and topographic structure. However, the study has the following limitations; first, traffic characteristics have a profound impact on the generated-noise level; thus, prediction of noise level beyond the range of traffic level, traffic composition or vehicle-power type would provide incomparable values. Second, all measurements were carried out under calm-weather and moderate-temperature conditions; therefore, measurements under adverse-weather conditions may affect the obtained results.

CONCLUSIONS

This study investigated the noise level along urban arterials and collector streets under heterogeneous traffic composition and vehicle-power types. Based on the results of this study, the following points were concluded:

1. Field measurements indicated that noise levels along urban streets are relatively high, reaching about 82 dB(A) and an average value of 77 dB(A). Thus, suitable noise-mitigation measures should be adapted to reduce traffic noise and enhance the urban environment.
2. Traffic flows in both directions of travel were found to be significantly influenced by the generated external noise. However, traffic on the near side had a greater impact on noise level when compared with traffic on the far side.
3. The increase in the percentage of trucks, including pick-ups, vans and mini-buses, may significantly increase external noise. An increase in the percentage of trucks from 0% to 20% would increase the noise by 1.34 dB(A).
4. Similar to previous studies, this study confirmed the effect of traffic speed on the noise level. This study shows that an increase in traffic speed from 35 km/h to 55 km/h would increase the noise by about 2.7 dB(A).
5. The interaction between pavement roughness and macrotexture depth increases the generated traffic noise. Therefore, it is recommended to maintain flexible pavement in good condition and use a surface layer with densely graded asphalt.
6. The impact of traffic at intersections on the measured noise at pavement sections located far away from an intersection is negligible, especially if the section is located at a distance longer than 70 m from the nearby intersection.
7. The results of this study indicate that both multi-variate linear – and exponential-regression models are suitable to model external noise along urban arterials and collector streets. For simplicity, it is recommended to use the linear model for noise estimations.

Acknowledgements

The authors of this study highly appreciate the help offered by the TotalPave Company, which is based in New Brunswick, Canada. The ToalPave application was used to estimate flexible pavement roughness, IRI.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability

All data, models or codes that support the findings of this study are available and can be obtained from the corresponding author upon reasonable request.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this research paper.

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