Development of a Statistical Model for Predicting Traffic Noise (Case Study: Irbid-Jordan)

Taisir Khedaywi [1], Nabil AlKofahi [2)* and Lila Alomari [3]

[1] Professor, Jordan University of Science and Technology, Jordan. E-Mail: Khedaywi@just.edu.jo
[2] Doctor, Jadara University, Jordan. E-Mail: Alkofahi@jadara.edu.jo
[3] MSC, Jordan University of Science and Technology, Jordan. E-Mail: lailaalomari@yahoo.com

ABSTRACT

Traffic noise has been recognized as environmental pollution in many cities. This study aims to develop a statistical model that can estimate road traffic noise as a function of traffic volume (passenger cars, medium vehicles, heavy vehicles), speed, number of lanes, pedestrian volume, parking type (on-street and off-street), grade of the road segment and temperature to study the impact of these variables on the noise level. Thirty sites were selected in urban areas for arterial and ring roads in Irbid city. These sites were categorized as: traffic signal intersections, roundabouts and sections. The model shows that heavy vehicle volume is the main influencing factor that affects the noise level. Also, increasing the number of lanes by one lane in any approach will increase the noise level by 0.50 dB (decibel). Holding other factors constant, the model shows that the increase of (1 km/hr) in speed will increase traffic noise by 0.15 dB. Results show that the present and predicted noise level in the future (2030) is high and exceeds the maximum allowable limit (60 dB) for all sites. The developed model compared with the British method [Calculation of Road Traffic Noise (CRTN)] was found to be compatible.

KEYWORDS: Traffic noise, Traffic noise model, Predicted noise, CRTN.

Highlights:

- The multiple linear regression model can be used to represent and predict the data relationships.
- Heavy vehicle volume is the main influencing factor that affects the noise level.
- The CRTN method to predict the noise level was valid.
- The noise level during the peak hours has exceeded the allowed values in Irbid.

INTRODUCTION

Noise is represented in those voices that are not consistent with being heard by the human and that humans do not enjoy. There is a range of noise levels that have many effects, varying from one person to another. The population growth and the development of activities in large cities have a significant influence on the development of the transportation sector. A high growth rate of vehicles has followed the increase of population; this condition has increased traffic noise produced by vehicles, which has negative effects, such as communication difficulties, increase in stress, sleep disturbances and hearing problems. Machines and transportation systems cause the main noise sources, so the weakness in urban planning may lead to noise pollution and the presence of residential areas near industrial places can significantly lead to noise pollution in residential areas.

Most of the solutions that municipalities and governments have taken to solve the problem of congestion have focused on solving the problem of intersections by converting them into traffic signals or roundabouts, not solving the problem of road capacity, especially as this is not possible within cities because of nesting roads with residential neighbourhoods and

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multiple complex uses. So, the solutions to increase capacity were few in cities, which created the problem of traffic congestion and thus traffic noise.

This study was conducted in Irbid city of Jordan. The population of this city is constantly increasing (Department of Statistics, 2018). After the Syrian crisis, large numbers of refugees entered Jordan, so this development has created a serious problem of traffic noise due to traffic congestion. The increase in the population of Irbid is linked to the increase in the number of vehicles in the city and the increased need for transportation, so we have a very serious problem of traffic noise, which is one of the most negative ones for people.

The main objectives of this research are to develop a statistical model to estimate road traffic noise as a function of many variables. Besides, the study seeks to forecast the level of traffic noise resulting from a variety of vehicles (growth and numbers) at specific speeds in the future (in 2030). Finally, the study aims to evaluate the average traffic noise level value in each site related to a standard level.

LITERATURE REVIEW

Many studies have pointed to the adverse impact of traffic noise on human health and its association with some serious diseases, as well as sleeping disorders and other influences.

Noise an undesirable sound that causes discomfort and harmful effects on human health (Santika et al., 2017). It is a rough and irregular voice that causes strong vibrations of the eardrum. Traffic noise is defined as the noise caused by the movement of vehicles on roads. With an increase in population growth, the need for different modes of transport will increase so that traffic noise will increase (Mishra et al., 2010).

Traffic noise has been recognized as one of the sources of environmental pollution in many cities (Suthanaya, 2015). The results of previous studies showed an association between exposure to traffic noise and various diseases, such as cardiovascular diseases. The obesity risk increases with noise exposure because, short sleep periods increase appetite and reduce human energy (Chew and Wu, 2016).

Kim et al. (2017) discussed the acoustical building performance for natural ventilation systems and predicted traffic noise levels for inhabitants residing in urban settlements. The authors combined an algorithm to predict traffic-noise levels (calculation of road traffic noise) with the Federal Highway Administration Traffic Noise Model's. Therefore, they analyzed various traffic noise prediction methods to calculate sound attenuation during propagation outdoors based on the International Organization for Standardization norm 9613. The results of the simulations indicated that “the integrated noise evaluation method can successfully predict the acoustic performance of natural ventilation systems in urban areas.

Baffoe and Duker (2018) measured noise levels at 50 monitoring stations and a land-use regression model applying multiple linear regression (MLR) was developed to predict noise level. The measured and the predicted noise (Lyons empirical model) levels were compared. The authors concluded that the results of MLR model did not show any significant differences with those of the Lyons model. The model performance indicators showed a high correlation of R^2 (0.961). The resulting maps showed a heterogeneous distribution of noise pollution levels in the community. The method for evaluating the spatial pattern of noise pollution in a community was useful, thus making it a useful tool for urban planning, epidemiological studies and environmental management.

Ramakrishna et al. (2017) studied the ambient and traffic noise levels from samples taken for 10 hrs from 7 am. The results showed that the ambient noise levels were beyond the permissible limits at the urban locations based on many parameters such as Lavg, Leq, NPL and NC for residential, commercial, industrial and silent zones. It is noted that high noise levels were recorded due to vehicular flow at the sampling locations. Ramakrishna et al. (2021) studied the traffic noise in Vijayawada India at four locations: residential, commercial, industrial and silent zones. The authors measured the traffic flow and noise levels during three days. The results showed that the equivalent sound levels (Leq) at all the four locations are acceptable and depend on traffic flow and heavy vehicles (%). Besides, multiple linear regression (MLR) and artificial neural network (ANN) models were developed. They concluded that the ANN model was better than the MLR model with respect to the actual data for the prediction of noise level.

Obaidat (2011) developed a spatial map of noise levels due to traffic movements at 29 signalized intersections in Amman- Jordan utilizing the Geographic Information System (GIS). Noise data was: the highest recorded noise level collected in three congested traffic peak periods at some signals was 80 dB, while the lowest was 34 dB. Some intersections showed higher noise levels than acceptable in residential areas at city canters (65 dB for daytime and 55 dB for night time). The author found that GIS maps could be useful for planning and other environmental management applications in cities.

Monazzam et al. (2015) used the GIS to assess spatial changes in traffic noise pollution in Tehran-Iran. The results indicated that the equivalent sound levels did not show statistically significant differences between weekdays and between morning, afternoon and evening hours. As revealed from three peak hours on middle weekdays from 91 stations, the maximum equivalent sound level (Leq) was 84.2 dB(A), while the minimum equivalent sound level (Leq) measured was 59.9 dB(A). The average was higher than the national standard limit at all stations. The authors recommended using sound walls at some highways.

The Calculation of Road Traffic Noise (CRTN) model is one of the first developed models to predict noise levels due to road traffic. It has been widely used in the United Kingdom, Australia, New Zealand and Hong Kong. CRTN model is the sole instrument for the assessment of road traffic environmental impacts by local authorities. The performance of the CRTN model was found to be different under different prevailing conditions (Steele, 2001). Sheng et al. (2015) used the CRTN model to predict traffic noise of motorcycles in an Asian city. The results showed that the performance of the CRTN model is satisfactory in predicting roadside traffic noise levels, with R^2= 0.832 and a mean difference of +0.52 dB (A) between the measured and predicted values. The performance of the CRTN model is also satisfactory in predicting the vertical distribution of traffic noise levels, with R^2=0.836 and a mean difference of +0.28 dB (A) between the measured and predicted values.

Banihani and Jadaan (2012) evaluated road traffic noise pollution in Amman. They used the CRTN method to predict noise levels at nine sites. They concluded that there was noise pollution at the studied locations. The authors carried out a social survey to assess the impacts of road traffic noise on residents. The results showed that road traffic noise is a major concern for communities living in the vicinity of streets in urban areas.

Imam and Jamrah (2012) examined whether Bus Rapid Transit (BRT) was a useful option to reduce the transportation-related emissions in cities. They investigated twenty cases from fifteen cities in Europe. The energy consumption and Carbon Dioxide (CO_2) emissions produced by these operating transit systems were calculated. The results showed that the use of BRT systems had significant reductions in CO_2 emissions in all cities. Abusalem et al. (2019) focused on environmental issues in an urban area. The study revealed that the concentration of air pollutants showed a high correlation with traffic flow and prevailing road gradients.

FIELD WORK

Methodology

Noise resulting from traffic in Irbid was measured for thirty different locations all over the city. These sites were selected in coordination with the Department of Traffic at Irbid Municipality. Sites studied were classified into 1) Arterial roads which are the roads that start from the centre of the city to the outskirts of the city. 2) Ring roads, which are the roads that do not pass through the centre of the city and go around the city. 3) Downtown areas or central business districts (CBDs), which are the areas in the centre of the city. These sites included sections (main ring road, arterial roads) or intersections that include roundabouts and traffic signals.

Field measurements were collected during the weekdays for two peak hours during the morning peak (7:15 to 8:15 am) and the evening peak (2:30 to 3:30 pm). A one-minute interval time series was taken to record the readings; (10-15) noise readings were taken during one minute. Then, the average noise value was calculated for every minute (3-15) readings of speed were taken to represent the average speed for each minute, with types as passenger car, medium vehicle and heavy vehicle.

There were some notes and considerations for dealing with different conditions and variables in conducting this research:

A- Heavy vehicles (buses with a capacity from 25 to 50 passengers, large-size trucks, trailers and single-unit trucks).

B- The speed of vehicles was measured in this section using a radar device, with attention to that the angle between the device and the vehicle the speed of which is to be measured should be close to zero to give an accurate reading. To verify this, it is proposed to have a distance of about 50 m far, the speed measurements were monitored by the presence of the person required to measure the speed within own vehicle from the rear glass by the radar device which was directed to the vehicles that come forward from the front of the vehicles (on the dashboard).

C- At the same time, noise generated from the different movement of vehicles was measured in this section of road by using the Sound Level Meter device, so 10-15 readings were taken every minute, depending on the traffic flow and the ability of a person to measure and record readings manually. Then, the average of these readings was calculated per minute; a short period was chosen between each reading and the following one due to large variation obvious in the noise level at every second.

D- The last part of the field measurements includes the weather temperature and a general description of the road geometry including the following: 1) The number of lanes on that approach by which field measurements are performed. 2) Parking type (on-street parking / off-street parking). 3) Presence of grade (exists/ not exist). If the grade value is more than 2%, it will affect the speed and therefore affect the traffic noise and if it is less than 2%, the grade is not existing and does not affect the speed of the vehicle.

Sections of Arterial and Ring Roads

The study was conducted in different locations; one of these was the arterial streets and ring roads. The chosen samples depend on the relative importance of these streets and roads. The sites from which the data was collected were relatively far from any intersections. These distances will give more representation of the real speeds and the resulting traffic noise. To collect a one-hour data, a period of 30 minutes has been taken for each direction .The steps of data collection on the dependent and independent variables were at the same time as follows:

A- Recording vehicle volume and pedestrians who passed the selected section; then, creating a composite type rating for the three types mentioned.

B- The speed of vehicles was measured using a radar device about 150 ft (50 m) far.

C- The noise of vehicles' movement was measured by using the Sound Level Meter device, so 10-15 readings/ minute were taken, which depends on the traffic flow and the ability of a person. Then, the average of these readings was calculated every minute.

D- Temperature and the road geometry measurements include several lanes/ approach, parking type (on-street parking) and the presence of grade (Exists/ does not exist); if the grade value is more than 2%, it will affect the speed and the traffic noise.

Traffic Signal Intersection

The choice of the samples depends on the relative importance of the signalized intersections. The sites from which the data was collected were relatively the most important intersections. They have been chosen for the measurement of noise, speed and traffic volume and types after exiting the traffic signal to different directions, where when entering the traffic signal, it will be most of the time red. The speeds are approaching zero in this case, in addition to the formation of a queue, where the length of this queue varies from time to time. The noise generated by traffic is therefore very low, because there is no direct traffic movement. When the colour becomes green to one of those approaches, the gradual movement will begin, but initially, vehicle speed does not reflect the real speed. The first four vehicles will be excluded, taking the fifth vehicle speed that enters the intersection and then goes out of the intersection. The process measurement was taking place upon vehicles entering the intersection and then exiting it.

The locations of measurement must be close to the traffic signal by150 - 300 ft (50 - 100 m), where the speed of the vehicles reaches the normal level. Therefore, the noise and volume were measured in the same area. The only difference is the location where the data collection team will stand.

There are two cases for the signalized intersections:

A- If the intersection is 4-leg, the duration of each part is 15 minutes. These sites are located at a distance of 150-300 ft (50 - 100 m) from inside the intersection, to give a chance for vehicles to enter the intersection and then go out and move at a normal speed.

B- If the intersection is a 3-leg intersection (traffic signal), all measurements were taken at 3 locations, where the duration of each part is 20 minutes. Speed measurements were treated the same as for 4-leg intersections as was mentioned earlier.

Roundabout Intersections

The study was conducted at different locations, among which were the roundabout intersections. The choice of the samples depends on the relative importance of these roundabouts .The study dealt with three-leg and four-leg roundabouts.

In the first type, the main street usually represents a continuing trend that has no entry angle. In this case, as at arterial or ring roads, the collection process is done in the same manner as mentioned. The only difference is the location where the data collection team will stand.

It was observed that pitfalls were placed before entering the roundabout to reduce the speed. The measurements of speed and noise were taken in areas outside the roundabout by 90-180 ft (30 - 60 m). This distance will give more representation of the real speeds and the resulting traffic noise. The steps of data collection about the dependent and independent variables were the same as previously mentioned. The difference is only in the location where the data collection team will stand. The data was collected in 3 or 4 parts; each part amounted to 20 or 15 minutes.

RESULTS

Description of Noise Levels

The average measured traffic noise levels at all sites showed little variation ranging from 68 to 83 dB (A). Speed was recorded at all locations to be 12.4 -42.3 mph (20-68 kph). There was an interference of the noise readings during the measurement process that resulted from vehicle traffic on other approaching roads. Noise levels at all locations exceeded the limits of Jordanian standards (60 dB).

As shown in Figure 1, Petra Street and Amman Street were found to have higher noise levels (81 dB) because of heavy traffic and high speed. The average noise level for all locations of Irbid reached 76 dB. The results showed that Al-Shamlai complex site recorded the lowest noise level (68 dB), where the speeds were somewhat lower in this location compared to other places, despite the high percentage of heavy vehicles registered found to be 13%. The intersection of Wasfi Al Tal Street with King Abdullah II Street (traffic signal of Grenada College) has an average of 80 dB noise level with a mean speed of 50 km/hr. It was found that the noise level for all areas in Irbid exceeded the accepted standard value (60 dB) in Jordan.

Calculation of Road Traffic Noise (CRTN) Method

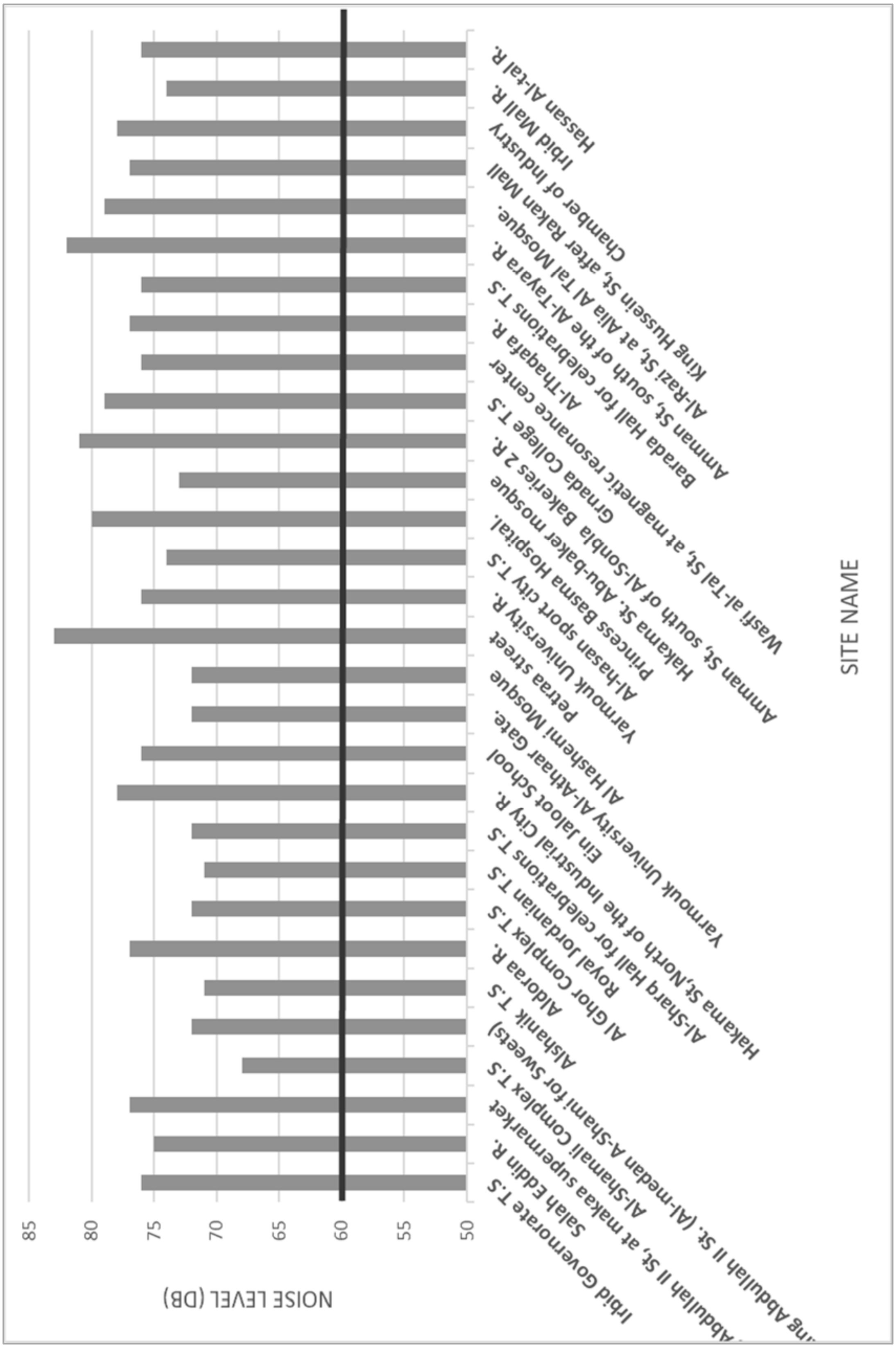
The Calculation of Road Traffic Noise (CRTN - ISBN 0 11 550847 3) program model was used by the Department of Transport in 1988. It provides a basic platform for calculating road traffic noise levels for non-complex situations. The model is limited; for example, a separate calculation will be needed to take account of any complex arrangements of reflecting surfaces (NPL-Department of Transport, 1988). Some called it a British method.

As shown in Table 1, thirty locations are arranged in column 1 with their names as in Figure 1. The currently predicted levels (Y) were calculated together, because the data cannot be divided into three cases to predict a sub-model for each case. Total hourly volume for different types is in column 2, while the heavy vehicle (H.V.) % is in column 4. The mean speed was calculated from the measured values as shows in column 3.

By using this method, the fifth column represents the average of the measured noise (dB) values during the peak hour, while the sixth column represents the expected values of the average noise levels for the current situation using the CRTN method. This method requires total hourly traffic volumes, mean speeds and the percentage of heavy vehicles for each site; the seventh column represents the predicted values of the average noise levels (Z) for the current situation using the regression model by Statistical Package for Social Sciences (SPSS: 26-2018) software. The future predicted noise level in 2030 (dB) is calculated by model as in column 8.

Table 1. **Current measured, current predicted and future predicted noise levels**

Site Number	Total Hourly Volume	Mean Speed (mph) (1 kph = 0.621 mph)	H.V. %	Average Current Measured Levels (X) dB	Average Current Predicted Levels (Y) Using the CRTN Method, dB	Average Current Predicted Levels (Z) Using a Multiple Regression Model. dB	Future Predicted Noise Level in 2030 (dB)
1	584	13.0	3.8	71	67.5	66	81
2	1212	23.2	4.4	79	70.8	64	84
3	644	12.5	3	72	67.6	61	81
4	678	18.6	14.7	75	71	74	84
5	773	23.0	6	76	69.5	66	83
6	991	17.1	3.1	72	69.1	60	82
7	511	19.8	7.6	73	68	65	81
8	804	21.7	10.3	77	70.8	76	84
9	582	14.8	13.9	68	70.6	72	84
10	1259	27.6	2.9	77	71	61	84
11	1533	29.7	6.4	81	73.3	68	86
12	779	21.7	14.5	76	71.5	76	85
13	899	27.0	12.2	78	72	70	85
14	1259	23.5	8.8	77	72.4	78	85
15	1099	21.6	3	76	69.7	76	83
16	1024	20.8	9.8	71	71.7	76	85
17	1249	22.4	11	77	72.9	77	86
18	695	18.4	2.6	72	67.3	62	80
19	1044	24.6	10.7	75	72.2	77	85
20	1060	32.4	8.9	76	72.6	63	86
21	1471	31.3	4.9	80	72.9	82	86
22	749	39.9	5.5	76	71.3	71	84
23	611	14.9	16.9	76	71.5	66	85
24	886	24.2	4.7	72	69.7	63	83
25	1167	26.2	6.7	77	71.8	62	85
26	1270	31.0	8.3	81	73	68	86
27	1991	42.2	6.8	83	76.2	66	89
28	759	19.2	9.7	72	70.3	74	83
29	1210	15.5	6.4	73	71.5	76	85
30	1011	25.5	0	79	70.6	77	84
Average	994	23.6	7.6	76	71	70	84



T.s: Traffic Signal, R: Roundabout, St: Street, ▬▬ Max. allowable value.

Figure (1): The average noise levels for all sites

The results show that the CRTN model predicts the traffic noise level with R^2 as a goodness-of-fit measure for linear regression models (R^2) = 50%, as shown in Figure 2, indicating that the predicted noise levels correlate with the measured levels. The regression models were developed to analyse the data using SPSS software. For each case of arterial and ring road sections, signalized intersections and roundabout intersections, the Multiple Linear Regression model for traffic noise level was developed. In addition, for the general (whole) cases, a general Multiple Linear Regression model for traffic noise level was developed too. The following are the Multiple Linear Regression models for all cases:

A- Arterial and ring road sections: number of sites = 15 and measured data = 900.

$$\begin{aligned} Noise\ level\ (dB) &= 72.1 + 0.11\,S + 0.25\,P.c + 0.53\,M.v + 0.97\,H.v \\ &- 0.03\,N.l - 0.77\,P.t - 0.12\,T \\ &- 0.13\,P.n - 0.30\,U.g. - 0.76\,N.g \end{aligned} \quad (1)$$

with R^2 = 52.7%

B- Signalized intersections: number of sites = 9 and measured data = 540.

$$\begin{aligned} Noise\ level\ (dB) &= 55.4 + 1.47\,S + 0.23\,P.c + 0.10\,M.v + 0.68\,H.v \\ &+ 1.4\,N.l - 0.10\,P.t + 0.22\,T \\ &+ 0.15\,P.n - 0.19\,D.g. + 1.9\,N.g \end{aligned} \quad (2)$$

with R^2 = 65.3%

C- Roundabout intersections: number of sites = 6 and measured data = 360.

$$\begin{aligned} Noise\ level\ (dB) &= 76.9 + 0.04\,S - 0.03\,P.c + 2.50\,M.v + 0.31\,H.v \\ &+ 0.64\,N.l + 0.3\,P.t - 0.29\,T \\ &- 0.09\,P.n - 0.57\,N.g \end{aligned} \quad (3)$$

with R^2 = 41.5%

D- The general case

$$\begin{aligned} Noise\ level\ (dB) &= 63.9 + 0.15\,S + 0.2\,P.c + 0.51\,M.v + 0.8\,H.v \\ &+ 0.5\,N.l + 0.05\,T \\ &+ 0.09\,P.n - 0.04\,U.g. \end{aligned} \quad (4)$$

with R^2 = 48.5 %

where:

S: Speed (mph), *P.c*: Passenger car number, *M.v*: Medium vehicle number, *H.v*: Heavy vehicle number, *N.l*: Number of the lanes, *T*: Temperature, *P.n*: Pedestrian number, *P.t*: Parking type, *U.g*: Upgrade, *D.g:* Down grade, *N.g*: No grade**.**

For the general case, the results show that the Multiple Linear Regression model for this data to predict the traffic noise level is with R^2 = 48.5%, as shown in Figure 3, which indicates that the predicted noise levels correlate with the measured levels.

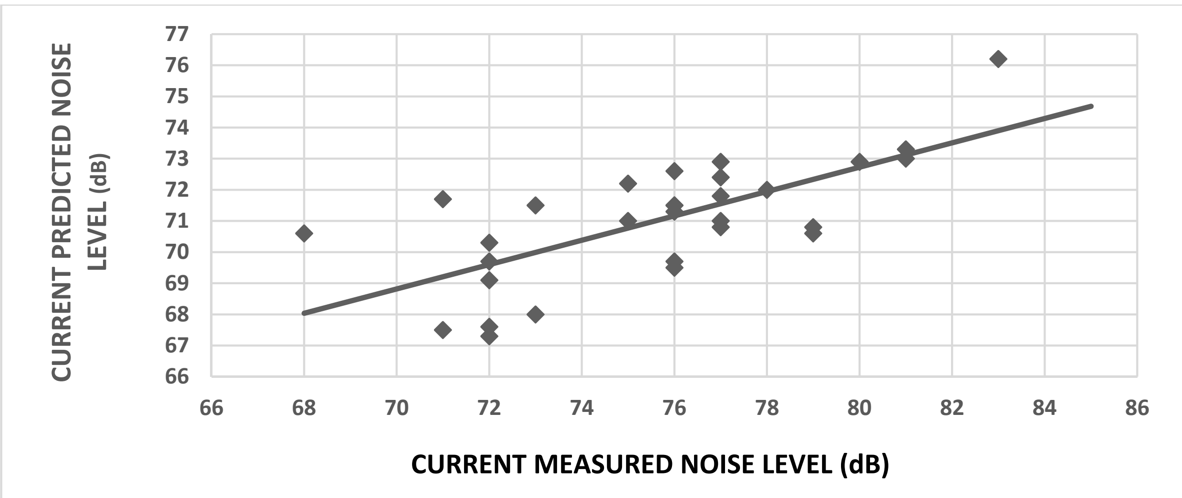


Figure (2): Relationship between the current measured and predicted noise levels using the CRTN method, for general case (R^2= 50 %)

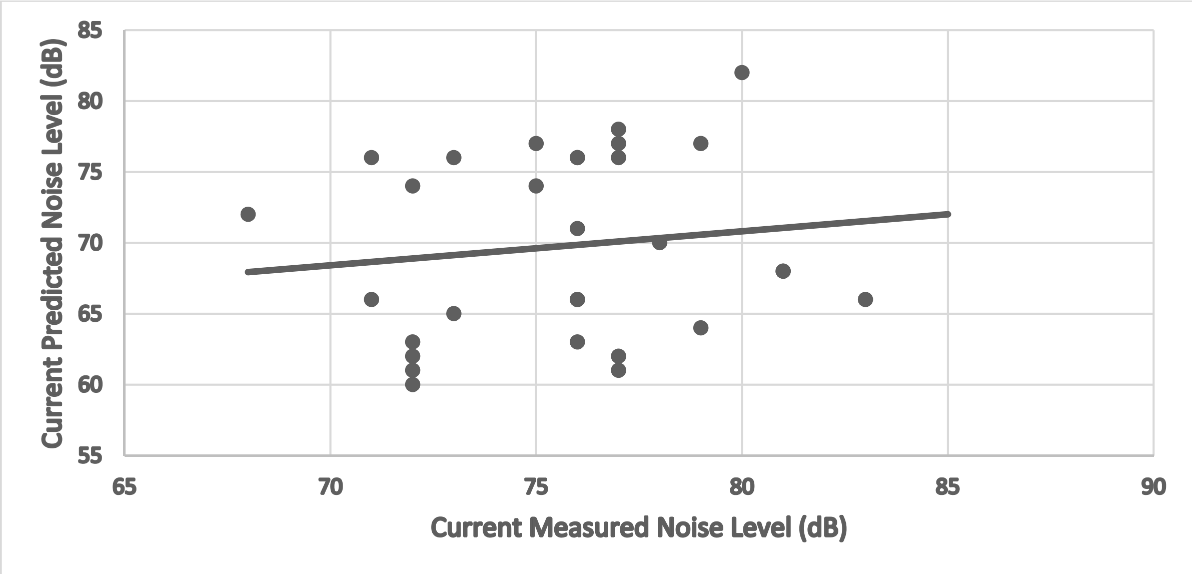


Figure (3): Relationship between the current measured and predicted noise levels using a multiple regression model for general case (R^2 = 48.5%)

The results from the Multiple Linear Regression model were compared with those obtained by using the CRTN method. As shown in Table 1, using the CRTN method is relatively close to using the regression model. These two methods gave values of noise levels that were less than measured. The average value of current measuring noise levels of all sites was 76 dB, while using the CRTN method gave 71 dB and using the regression model gave 70 dB. The last column in Table 1 show the future predicted values of the noise levels in 2030 for all sites using the developed model. The current noise levels and predicted future noise levels in 2030 were found to exceed the maximum allowable limit of 60 dB(A).

DISCUSSION

The results from the Multiple Linear Regression model indicated that traffic noise depends on ten, ten, nine and eight factors (independent variable) for arterial and ring road sections, signalized intersections, rctions and general (whole) case, respectively. These are: Speed, Passenger car, Medium vehicle, Heavy vehicle, Number of lanes, Parking type, Temperature, Pedestrian number and Grade of the road, as shown in Equations. (1, 2, 3 and 4). In general, the results of R^2 are related to the number of data measured. As the number of data increases, the R^2 value increases.

The results of the general model indicated that the traffic volume of heavy vehicles is the most important. The model shows that an increase of 1 heavy vehicle volume adds a noise level of about 0.8 dB, as the proportion of the average of heavy vehicles on the roads is 7.6%. This result is compatible with previous studies such as (Suthanaya, 2015).

The relationship between the previous dependent and independent variables has a linear form, with R-square = 48.5% and the correlation coefficient (r) = 0.7, which indicates a good relationship. In this type of study, it is difficult to separate and control the variables in an open area.

Analysis of the general model's results indicated that the increase of 0.61 mph (1kph) in speed within the limit of 12.4 - 42.3 mph will increase traffic noise by about 0.15 dB. However, parking type, downgrade and no grade variables are significant predictors which were excluded from the model.

The variation of noise level for all sites was 68 to 83 dB (average = 76 dB) which exceeds the maximum allowable limit (60 dB) in Jordan. This is similar to the noise values in Amman (Al-Dakhlallah et al., 2013, Jadaan et al., 2013; Jadaan et al., 2015).

The results of calculation of prediction traffic noise by (CRTN) method levels (Y) are lower than the measured ones (X). As shown in Table 1, the predicted levels (Z) by the Multiple Linear Regression model for all sites are also lower than the measured ones (X). The predicted future noise levels in 2030 are found to exceed the maximum allowable limit at a specific speed for all sites.

CONCLUSIONS

The following conclusions are drawn from this study:

1. The Multiple Linear Regression model predicts the traffic noise level for each case: arterial and ring roads sections (R^2 = 52.7 %), signalized intersections (R^2 = 65.3 %), roundabout intersections (R^2 = 41.5%) and general case (R^2 = 48.5 %), with a correlation coefficient (r) = 0.7, which indicates a good relationship.
2. The low values of R^2 are related to little number of data, while the medium values of R^2 related to the difficulty of separation and control of the variables in an open area as in this type of study.
3. It was found that heavy vehicle number is the main influencing factor that affects the noise level.
4. The using of the CRTN method to predict the noise levels was valid and the results relatively similar to those obtained from using the Multiple Linear Regression model.
5. The noise level during the peak hours has an average of 73 dB (68 - 83 dB) exceeding the allowed value (60 dB) in most areas in Irbid.

Conflict of Interests

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

Data Availability

The data used to support the findings of this study are available and can be obtained from the corresponding author upon request.

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