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Developing a Traffic Noise Prediction Model For Jordanian Conditions

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Abstract

The growth in magnitude and various impacts of traffic noise has created an increasing attention on the prediction and control of noise levels. This study aims at developing a noise level prediction model under the local conditions of Amman, the capital of Jordan. Thirty four sites, representing different characteristics, were selected for use in model development. The resulting prediction model incorporated variables describing traffic and site conditions including traffic volume, composition and speed, gradient, and distance from the source as affecting factors, the trial model expresses noise level by the index L_{10} (1hr). The developed model was validated by comparing its predicted noise levels with those measured. Further evaluation of the model was carried out by comparing its predictions with those obtained using the British Calculation of Road Traffic Noise (CRTN) model. The developed model was found to produce more accurate results, under Jordanian traffic conditions, than the CRTN model with an average error of only 3.2%.

Keywords: traffic noise, prediction, CRTN, modeling, Jordan

1. Introduction

One of the most important types of pollution encountered as a result of the evolvement of different transportation systems during the past decade is noise pollution. Recent studies have shown that noise can negatively affect human health and behavior on the short and long scales [1, 2, 3, 4]. Noise levels were also found to have significant costs on surrounding properties as an indirect negative effect [5]. Although its management is a challenging task for environmental managers and urban planners, it is important that noise levels generated by the different transportation systems be assessed and controlled.

This study aims at developing a model for predicting noise levels along urban arterials of Amman, the capital of Jordan. The developed model uses multiple regression which incorporates a number of affecting factors for which data were available. The model is validated and further evaluated by comparing its results with those obtained using the well-known British Calculation of Road Traffic Noise (CRTN) prediction model.

2. Literature Review

Limited studies have been carried out to evaluate and the magnitude of traffic noise in Jordan [1, 6, 7] but no effort has been done towards the development of traffic noise prediction models under Jordanian conditions.

Internationally, the most common traffic noise prediction models are the American Federal Highway Administration (FHWA) model and the British Calculation of Road Traffic Noise (CRTN) model. The first model calculates noise level through a series of adjustments to a reference sound level; the reference level is the Vehicle Noise Emission Level, which refers to the maximum sound level emitted by a vehicle pass-by at a reference distance of 15 meters. Adjustments are then made to the emission level to account for traffic flow, distance, and noise shielding.

Many noise prediction models have been developed in the past few decades for traffic noise assessment and predictions. These include such models as Federal Highway Administration (FHWA), Calculation of Road Traffic Noise (CRTN), and Richtlinien für den Lärmschutz an Straben (RLS-90) noise models.

Some of the developed models were of general nature and treated the general traffic conditions [8, 9] while others treated specific traffic conditions such as noise under interrupted traffic flow conditions [10], during daytime [9], for stationary and mobile sources [10] and considering the impact of honking on traffic noise [13]. The various models and their performance have also been evaluated [14, 15].

The general methodology of the second model is to obtain a basic noise level at a reference distance of 10m away from the nearside carriageway edge. Various adjustments are then made for traffic flow, percentage of heavy vehicles, gradient, road surface, distance, barrier etc. Those adjustments are added to the basic L10 value to get the final hourly L10 value.

Almost all traffic noise prediction algorithms are essentially of the same or very similar formula. Models that use the value L_{eq} such as the FHWA model generally have the form shown in Eq. (1).

$$L_{eq} = L_0 + \sum L_i \quad (1)$$

Where,

L_0: Basic noise level for a stream of vehicles under specified unchanged conditions.

L_i: Corrections to take into account changes in traffic conditions (Including number of vehicles, types of vehicles, road surface type, gradient, speed, barrier...etc.).

The developed statistical models are based on assumptions and simplifications that are necessary in order to produce satisfactory prediction accuracy. Noise levels are estimated as a function of traffic variables under homogeneous traffic conditions, then, adapted to predict noise level under diverse traffic conditions [11, 12].

3. Methodology

Measurements of noise levels were made at each of the 34 selected sites. Different data were also collected on traffic and road factors affecting noise levels including traffic volume, traffic composition, traffic speed and road geometry.

A Bruel and Kjaer type 2215 Precision sound level meter was used for measuring L_{10} (1hr) noise level. Readings were taken during two 1-hour periods between 7:00 and 8:00 and between 19:00 and 20:00.The two periods which are 12 hours apart aimed to cover the morning and evening peak traffic conditions. The measurements were taken during working days in summer. The device was held in arm about 1.2m above the ground level and at a distance of 3.5m from the near side curb of the road.

Classified manual traffic volume counts were conducted at the selected locations by counting number of various types of vehicles for 5 minutes duration during four daytime intervals (7:00-7:05 ,7:15-7:20 ,7:30-7:35 ,7:45-7:50) and four nighttime intervals (19:00-19:05, 19:15- 19:20, 19:30-19:35, 19:45-19:50).

Speed data were provided by the Jordanian Traffic Institute. These speed measurements were made using Laser Speed Detection Radar LTI 20-20. The device has speed accuracy of ±2 km/hour, with laser power output of 52 Micro-Watt.

Data related to road geometry at the selected sites were obtained from the Ministry of Public Works and Housing. The road surface at all locations was of bituminous type and therefore considered hard ground for the purpose of this study.

The data obtained was analyzed in order to develop mathematical relations between the different factors and the level of traffic noise. The site readings were grouped into categories of similar conditions, in order to correctly isolate the contributions of the different factors. Thus, the effect of each factor on noise level is identified separately as explained in the following parts.

4. Data Analysis

Noise levels measured at 34 locations for both day and night time are listed in Table 1.

The results of noise measurements show that the noise levels at all locations are significantly high and exceed the maximum allowable noise level adopted in Jordan which is 63 dB(A).

The collected data related to traffic conditions and road gradient are presented in Table 2 while the data measured separately for vehicle speed and distance from source are listed in Table 3.

4.1. Speed-Noise Relationship

Using the noise levels VS speed data obtained, linear regression was used to establish a mathematical relationship as shown in Figure 1. The regression coefficient 0.208 describes the relation between speed and noise levels with an R squared value of 0.91; this means that for every single increase in vehicle speed, the noise level is expected to increase by 0.208 dB(A). The R squared value is high enough to be acceptable, and we can use this factor in the final model.

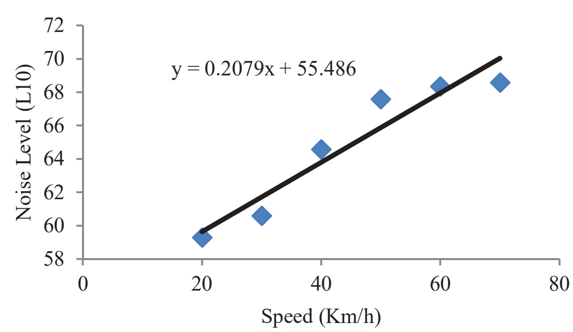

Fig. 1. Data plot of noise level L_{10} vs speed

The intercept (55.49) represents the contribution of all other factors except speed. It was therefore ignored.

Table 1: Measured day-time and night-time noise levels L10 (1hr) at the studied sites

Location Number	Description	L10 (night time) dB(A)	L10(day time) dB(A)
1	Interior circle	73	71
2	First circle	56	64
3	Second circle	61	66
4	Third circle	64	67
5	Fourth circle	67	66
6	Fifth circle	68	70
7	Sixth circle	67	67
8	Seventh circle	65	68
9	Eighth circle	70	73
10	Sport city circle	68	78
11	Abdoun circle	66	66
12	Swieleh circle	70	71
13	Gardens Street	70	72
14	Safeway-Gardens junction	73	71
15	Princess Basma street	61	69
16	AlIstiqlal street	73	79
17	Abu Nsair Street	73	75
18	Al-Madina Al-Munawara street	67	70
19	Airport Highway	78	80
20	Al-Sakhra Almosharafa street	66	73
21	Queen Rania street	72	72
22	King Abdullah II street	76	78
23	Prince Ali Bin Hussien street	70	71
24	Prince Shaker street	71	66
25	Al-Sinaa' street	70	73
26	Jordan street	74	77
27	Al-Mahatta street	72	80
28	King Hussien street	74	76
29	Khalil Alsaket street	69	68
30	Cairo street	70	70
31	Khalid Bin Alwaleed street	66	71
32	Zahran street	80	79
33	South buses terminal	71	71
34	Raghdan buses terminal	73	79

Table 2: Measured traffic and road parameters

			Day Time		Night Time	
Location #	Speed (Km/hr)	Gradient %	Volume (Vehicle /hr)	Heavy Vehicles %	Volume (Vehicle/ hr)	Heavy Vehicles %
1	40	0.87	1944	15.3	1956	19.0
2	30	3.20	1802	5.3	804	6.3
3	30	1.20	2314	8.1	1522	7.3
4	40	2.00	2133	7.3	1258	9.2
5	40	2.00	1978	4.2	2417	8.8
6	40	1.50	2256	19	2604	10.6
7	40	0.71	2088	6.3	1800	6.0
8	40	1.00	1068	9.3	888	8.1
9	40	0.33	2376	21	2196	8.2
10	40	3.20	2640	8.6	2472	8.3
11	30	4.20	2424	10.4	3048	4.3
12	30	5.90	1872	17.3	1956	15.3
13	50	2.50	1452	8.3	2945	11.2
14	60	0.37	2258	9.6	3241	10.3
15	60	3.10	1354	11.6	1078	13.6
16	60	5.00	2614	18.7	2454	10.9
17	70	2.10	792	15.1	1512	7.4
18	60	0.55	3456	7.6	3336	7.9
19	80	0.62	2748	22.3	3216	10.1
20	70	0.30	1053	12.1	1385	8.3
21	70	2.20	5616	8	3576	10.4
22	80	2.00	3482	20.2	3168	11.4
23	60	4.00	1156	10.8	1359	6.9
24	50	0.50	963	7.5	1116	7.5
25	60	2.00	836	23.2	1145	16.4
26	80	4.00	1698	13.2	2189	11.2
27	60	0.70	2896	22.4	3286	18.5
28	50	6.00	1488	10.5	1188	8.1
29	40	3.50	612	4.5	912	4.0
30	60	2.70	684	6.1	816	5.9
31	60	1.10	2472	6.3	2004	8.4
32	60	1.10	4764	10.3	2868	6.3
33	50	3.40	3845	19.9	2496	16.3
34	50	0.70	5498	21.9	3857	14.8

Table 3: Measured L_{10} at individual speed passes and at individual distances

Speed (KM/h)	L10	Distance (m)	L10
20	59.3	3	62.2
30	60.6	7	57.5
40	64.6	19	51.2
50	67.6		
60	68.36		
70	68.6		

4. 2. Distance-Noise Relationship

The same linear regression method was used to establish the mathematical relation between noise level and the distance to the noise source as shown in Figure 2.

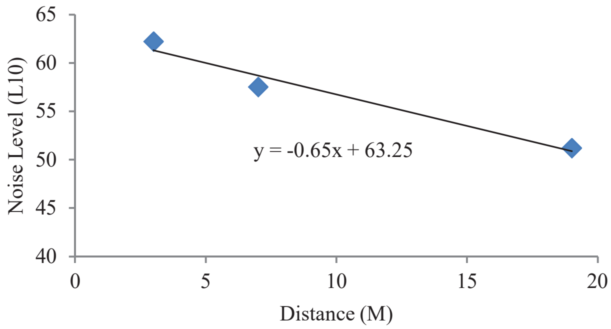

Fig. 2. Data plot of noise level L_{10} vs distance from source, along with the resulting linear trend line

The regression coefficient -0.65 describes the relationship with an R squared value of 0.96 which means that for every increment increase in distance, the noise is expected to decrease by 0.65 dB(A). The R squared value is high enough to include this factor in the final model.

4. 3. Volume-noise relationship

For the purpose of investigating the contribution of traffic volume to noise levels, sites that had similar Speed, environment, gradient, and percentage of heavy vehicles were isolated into groups. For each group, a linear regression relationship was established between Volume and Noise Level. The resulting equations and R-squared values for each group are shown in figures 3 through 6.

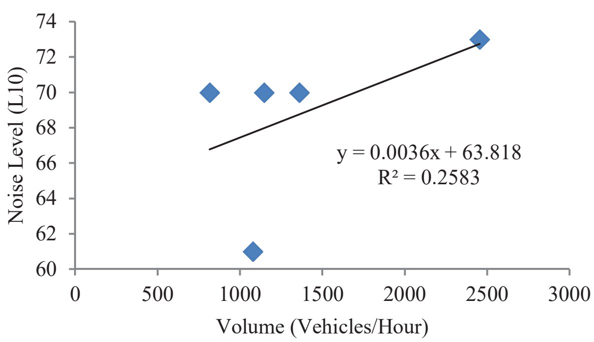

Fig. 3. Data plot of noise level L_{10} vs volume for the first group (locations 15, 16, 23, 25 and 30)

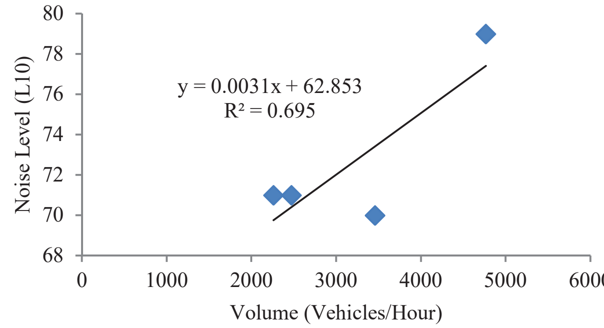

Fig. 4. Data plot of noise level L_{10} vs volume for the second group (locations 18, 14, 31 and 32)

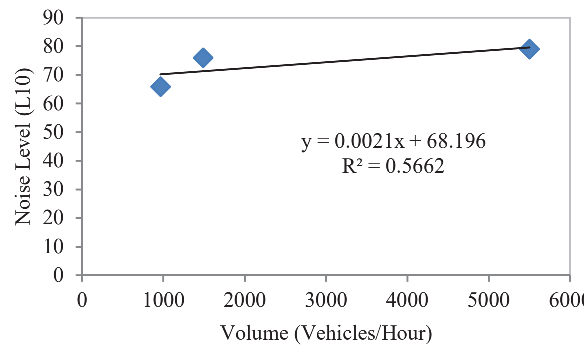

Fig. 5. Data plot of noise level L_{10} vs volume for the third group (locations 34, 24 and 28)

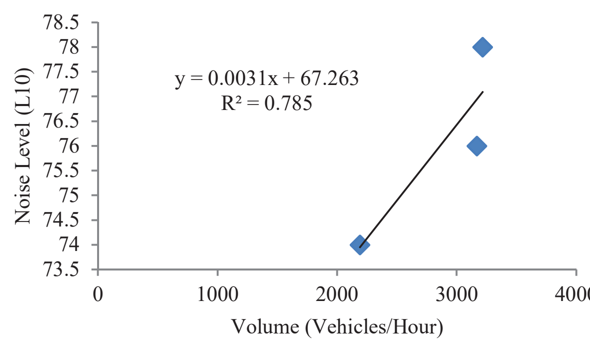

Fig. 6. Data plot of noise level L_{10} vs volume for the fourth group (locations 19, 22 and 26)

The intersect that resulted in the equations is not considered; it represents the contribution of all other factors except Volume, including the base noise level L0, and was therefore ignored. Only the coefficient of X in the equation is considered.

Because the value of R^2 differs from one group to the other, and is very low on some of the group results (such as group 1), we can't consider the factors obtained from every group to have the same precision. Depending on the value of R-Squared, a weighted average of the coefficient can be determined. This will assure that most of the values of the factor be taken from groups were R squared value was high, assuring more precision for our equation. The weighted average is determined using the following equation:

$$A = \frac{A_1R_1^2 + A_2R_2^2 + A_3R_3^2 + A_4R_4^2}{R_1^2 + R_2^2 + R_3^2 + R_4^2} \quad (2)$$

Where A= weighted average of the coefficient.
$A_{1,2,3..}$= coefficient for each group
$R^2_{1,2,3...}$= R^2 value for each group

Using this equation, we get A= 0.00291
It can be concluded that for every increment increase in Vehicle Volume, the Noise Level is expected to increases by 0.00291 dBA. This value, however small, does cause a slight change in noise levels with vehicular volumes, especially because volumes are expected to be higher than 1000 vehicles/hour on roads where noise levels are considered. Depending on this conclusion, noise can be seen to increase about 3 dBA for every one thousand vehicle on road.

4.4. Heavy Vehicles Percentage-Noise Relationship

A similar approach was used to isolate the contribution of Heavy Vehicles Percentage (HVP) to noise levels and the results are presented in Figures 7 through 12.

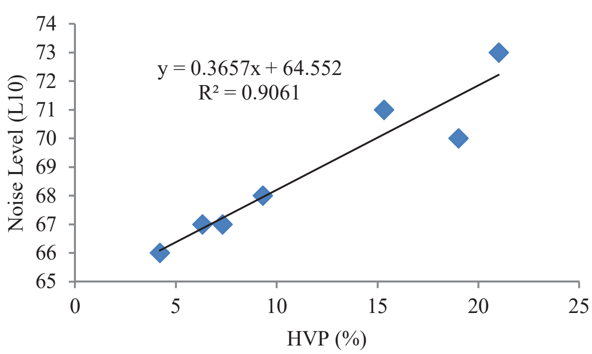

Fig. 7. Data plot of noise level L_{10} vs HVP for the first group

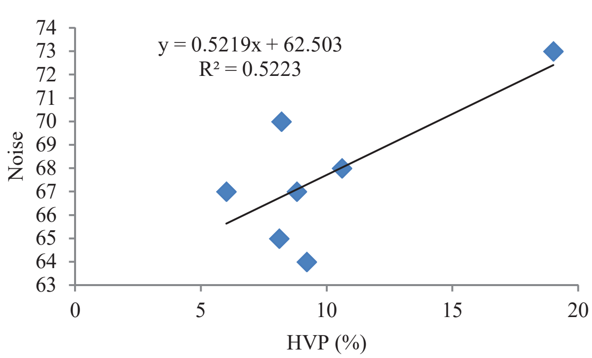

Fig. 8. Data plot of noise level L_{10} vs HVP for the second group

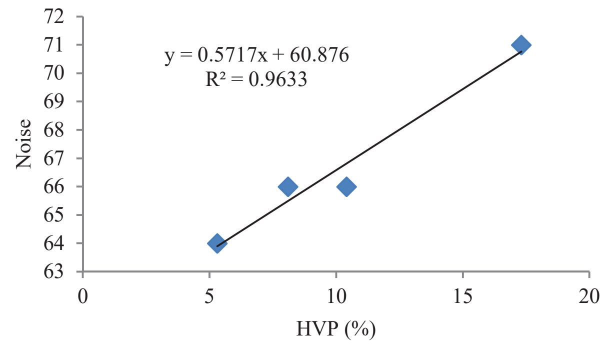

Fig. 9. Data plot of noise level L_{10} vs HVP for the third group

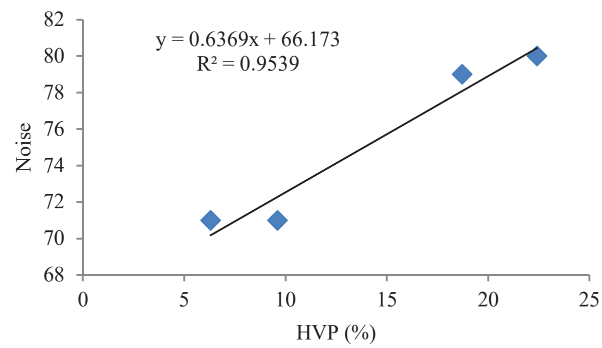

Fig. 10. Data plot of noise level L_{10} vs HVP for the fourth group

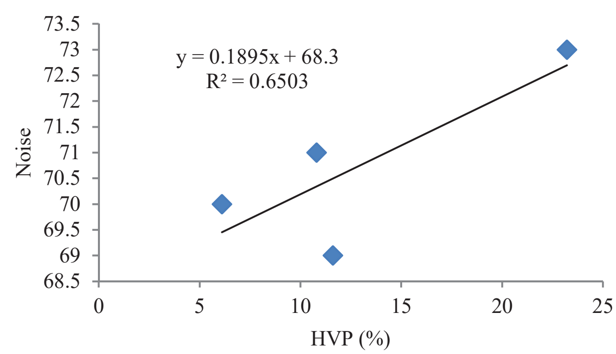

Fig. 11. Data plot of noise level L_{10} vs HVP for the fifth group

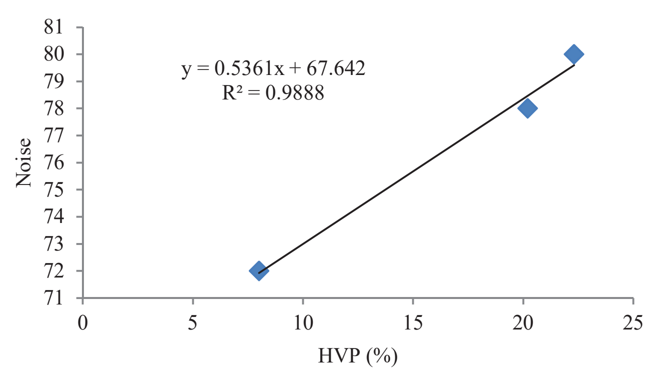

Fig. 12. Data plot of noise level L_{10} vs HVP for the sixth group

The Weighted average of the coefficient linking HVP with noise levels was similarly found using R^2 Weighted Average. It was found to be: A=0.4546. In other words, for every single increment in the HVP noise levels are expected to increase by 0.4546. This factor is noted to be a lot higher than the factor associated with vehicle volumes; which signifies the higher contribution of heavy vehicles to noise levels.
The use of weighted average assured that this value can be used for prediction with good precision. It is noted that the values of R squared obtained from these groups were higher than other factors, indicating a better regression.

4. 5. Gradient-Noise Relationship

The road gradient (slope) has an indirect effect on the noise levels produced. It is generally true that higher uphill slope will result in less traffic speeds but this may not cause a decrease in noise levels even though speeds have decreased. The reason for this is that vehicles need more engine output to overcome the high slope and rise uphill even at low speeds causing vehicles to produce more noise.
In the case of downhill, the engine output will decrease and cause a drop in noise levels. In order to correctly represent the effect of slope on noise levels, a mathematical equivalence of slope has to be established and translated to fit the equations. To do that, the increase in force needed to overcome uphill slope is mathematically derived.

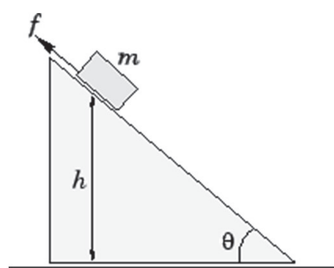

Fig. 13. Vehicle rising upwards on a slope

Considering a vehicle with mass m rising upwards on a slope of ϴ as shown in figure XIII, the extra force needed to overcome the slope is equal to the component of m that is parallel to the slope as shown in Eq. (4).

$$f_{extra} = m \sin(\Theta) \quad (4)$$

The extra force will result in more engine output, hence an increase in noise. To find the amount of increase, the force increase will be translated to equivalent speed increase using classic physical relationship between Force, Mass and Acceleration as in Eq. (5).

$$f_{extra} = m\, a_{extra} \quad (5)$$

Assuming average vehicle mass of m and duration of T seconds is spent on the slope, equivilant speed increase can be found by rearranging Eq. (5).

$$a_{extra} = \frac{f_{extra}}{m}$$

$$S_{equivilant} = T \times a_{extra} = T \times \frac{f_{extra}}{m} = T \times \frac{m \sin(\Theta)}{m} = T \times \sin(\Theta)$$

The duration S can be found by simply dividing the length of the incline (considered 15 meters) by the average speed of the road, hence the equivalent speed becomes as shown in Eq. (6).

$$S_{equivilant} = \frac{L}{S} \times \sin(\Theta) \quad (6)$$

It can be concluded that the effect of inclination on noise levels can be added to the speed variable of our model by adding $\frac{L}{S} \times \sin(\Theta)$ to our total speed.
This effect is reversed in declining slopes (less engine force is needed causing drop in noise levels that can be represented by decreasing speed in our equation).

4.6. Model Development

The final model representing the noise levels under traffic conditions of Jordan can be established by combining the different factors and their coefficients. It should be noted that the base noise L0 (that is the level of noise when no vehicles are present) is the minimum noise level expected and each factor causes an increase on that base level. The final model was found to have the following form of Eq. (3).

$$L_{10} = L_0 + 0.208\left(S \pm \frac{L}{S}\sin(\Theta)\right) + 0.00291V + 0.4546P - 0.65D \quad (3)$$

Where,
L0: Base noise level (dBA)
S: Traffic speed (Km/h)
L: Length of inclination/declination (generally considered 15 meters)
ϴ: Road Slope
V: Traffic volume (Vehicles/hour)
P: Percentage of heavy vehicles
D: distance from observer (m)

This Equation was developed on the basis that relations between different factors and noise levels is linear, although this is not necessarily the case. This is why this model will only give realistic results on certain margins for the factors related. On the local scale, the roads forming the local network all lie within those margins, and as such the model can be applied under local conditions. The model was also validated and adjusted as explained in the following section, to obtain more accurate results fitting real data and be able to correctly predict noise levels with confidence.

4. 7. Validation and Adjustment

The mathematical model was tested by gathering data points and comparing actual values to model results. The model produced very encouraging results. About 70% of the points were predicted with very high accuracy of ±3 dB, 15% of the points had an acceptable accuracy of ±6 dB, and 15% of the points had major errors of almost ±10 dB.

To enhance the accuracy of prediction further, the model was calibrated using multiple linear regression analysis between observed and predicted noise levels. The best fit equation was extracted on the basis of scatter plot as shown in Figure 14.

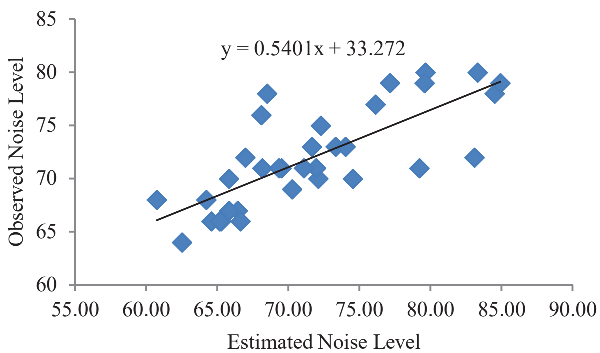

Fig. 14. Scatter plot of estimated vs observed readings established for the purpose of model adjustment

4.8. Model Comparison

Comparing the model developed in this study with other models will provide important information that can benefit and help with future predictions. In this section, the adjusted model developed will be compared with the British CRTN model. Table 4 shows the comparison between results obtained by CRTN predictions for the conditions faced on the locations studied, and the predictions made using the adjusted model. It can be seen that the developed Model produces more accurate predictions with only 3.2% error than the CRTN with 8% error.

5. Conclusion

Traffic noise assessment is an important environmental aspect. A model describing the relationship between a number of traffic and site variables and noise level was developed, discussed and presented in this study for assessment and prediction of traffic noise under Jordanian conditions.

The model is validated with measured noise levels and found to be valid under local conditions producing statistically significant predictions. The British CRTN noise prediction model was also assessed and found to be valid for those conditions. However, comparing the CRTN and the Developed Model revealed an average CRTN error of 8% while the average Developed Model error was only 3.2%. The model, therefore, performs reasonably well under different traffic conditions and could be implemented for the calculation of road traffic noise under interrupted traffic flow conditions in urban areas of Jordan cities.

Table 4: Comparison between actual values, CRTN predictions and adjusted model predictions for L_{10} noise levels

Location	L_{10} Actual	L_{10} Predicted CRTN	L_{10} Adjusted model
1	71	66.69	70.80010128
2	64	60.43	67.02418084
3	66	62.94	68.5059069
4	67	63.15	69.14294421
5	66	65.89	68.13819078
6	70	66.5	72.20632908
7	67	63.43	68.81339711
8	68	61.05	67.95226082
9	73	64.81	72.86414038
10	78	66.21	70.26150974
11	66	65.75	69.25500228
12	71	67.49	70.08231977
13	72	68.05	69.43517159
14	71	68.41	72.12300491
15	69	65.04	71.21023828
16	79	68.7	74.93463898
17	75	65.89	72.30471471
18	70	68.09	73.51862078
19	80	70.08	78.25952723
20	73	65.14	71.96352042
21	72	70.22	78.14347361
22	78	70.63	78.90527728
23	71	65	70.70313761
24	66	62.41	68.45397148
25	73	65.43	73.24263531
26	77	69.6	74.38426917
27	80	69.93	76.27488084
28	76	64.47	70.03386922
29	68	60.64	66.06774635
30	70	62.16	68.80640121
31	71	66.15	71.66013511
32	79	67.24	76.24456873
33	71	68.54	76.04541092
34	79	69.37	79.12146926

Average CRTN Error = 8%

Average Developed Model Error = 3.2%

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