Developing Roadway Traffic Noise Prediction Models for the City of Amman

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Abstract: Traffic noise is one of the negative impacts of transportation systems. Other environmental impacts, such as air pollution, have been studied extensively and received enough academic attention. On the other hand, traffic noise has not received sufficient attention in developing countries; there is a need for in-depth research studies in this field to highlight this issue, spread awareness, and find solutions for this ever-increasing problem. This research aims to develop noise prediction models for Amman's roadway network, using current levels of traffic noise measured at 20 locations, as well as past levels of traffic noise measured at these same locations measured back in 2005; as part of a previous study. The measurements were taken in the morning peak hour (07:30 – 08:30 am), and the evening peak hour (07:30 – 08:30 pm), in weekdays (Sunday to Thursday), during July and August of 2013.The results of field measurements showed high level of traffic noise exceeding the universal accepted level of 63 dB(A) adopted by the 2003 Environmental protection law in Jordan, in all 20 locations, which raised the flag for urgent mitigation actions and plans to be taken and adopted, as soon as possible. The developed model showed high confidence estimates of current and future levels of traffic noise. Thus the developed model could be applied to predict the traffic noise levels at other locations in Jordan, and elsewhere. Conclusions and recommendations are presented at the end of this research。

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Key Words: Traffic, Noise, Amman, Prediction Model

1. Introduction

Noise, which is defined as unwanted or excessive sound, is considered a serious issue that affects the environment, quality of life, and health. It can be annoying, interfere with sleep, work, or recreation, and in extreme cases it may cause physical and psychological damage. Some of the most prevailing sources of noise in urban and rural environments come from transportation systems.

Figure 1.1 shows the distribution of the different noise sources to which the general public is exposed. Indeed, as other studies have already shown, traffic is the major noise pollution source. Highway traffic noise is a major contributor to overall transportation noise. Noise level is not constant and the noise levels vary with the number, type, and speed of the vehicles.

While noise in metropolitan area comes from different sources, such as: emergency vehicles, waste collection, and construction works, these activities are essential for the community and the life of inhabitants. Traffic, which is one of main sources of noise, is the movement of people and goods yet it results in undesirable noise. Noise directly affects the quality of the living environment, with increasing evidence that excessive noise has negative impacts on public health in many aspects. According to the World Health Organization (WHO), noise is considered as the third hazardous environmental pollutant right after air and water pollution (WHO, 2005). Highway traffic noise is a major contributor to overall transportation noise. It is not constant as noise levels vary with the number, type, and speed of vehicles.

So far, noise pollution has not received enough attention in developing countries; this lack of recognition could be contributed to three valid reasons: perception of noise is highly subjective and can vary from one person to another; unlike air and water pollution, noise has a short decay time and thus does not last long in the environment; finally, the impact of noise on people is subtle, so it appears gradually, and therefore it becomes difficult to associate the cause with the effect.

Highway traffic noise has not been actively researched in Jordan compared to other countries in recent years. With the increase in the number of licensed motor vehicles in Jordan year on year, it is expected that the problem of noise pollution will increase with the levels continuously rising. Table 1 shows the number of licensed vehicles in Jordan (from 2001- 2012) and the percentage of change from year to year. The interesting fact is the high percentage of licensed vehicles in Amman; making up 79.35% of the total vehicles of Jordan, with a total of (963,211) vehicles in 2012.

The total inhabitants of Amman in 2011 was: 2,473,400, thus, car ownership per 1000 inhabitants in Amman was 389.5; this is considered a high rate when compared to developing countries, the vehicles per 1000 people in Egypt, and Yemen are 35, and 45 in 2009 respectively (World Bank Data, 2011).

Table 1: Number of Licensed Vehicles and Percentage of change from 2001- 2012 in Jordan

Year	No. of Vehicles	% Change
2001	419,591	-
2002	542,812	29.4
2003	566,610	4.4
2004	614,614	8.5
2005	679,731	10.6
2006	755,477	11.1
2007	841,933	11.4
2008	905,592	7.6
2009	994,753	9.8
2010	1,075,453	8.1
2011	1,147,258	6.7
2012	1,213,882	5.8

2. Study Objective

This study collected noise data from 20 different locations on the road network in the city of Amman. The collected noise data were compared to the acceptable noise levels, and to the measurements taken in 2005. In addition, the collected data were used to develop models for highway traffic noise prediction. The performance of the model was compared with other models available in the literature. The overall goal of this research is to evaluate the current status of noise pollution in Amman, and to develop a model for roadway traffic noise in Amman, then to propose solutions for the problem through the following steps:

- Determination of the case study roads
- Collection of noise data on the chosen roads, using an electronic sound level meter
- Evaluation of the data
- Comparison with the previous study carried out in 2005 (Jamrah et al.,2006)
- Development of a roadway traffic noise model using the collected data
- Application of other models from the literature on the collected data to compare their outcomes against the developed model

3. Methodology

In order to cover as large as area as in Amman, twenty locations were chosen for this study, shown in Table 2. These locations were chosen amongst the 28 locations investigated by Jamrah et al. in 2005. The main advantage of examining the same locations is the availability of this historic data; thus allowing the study of traffic noise growth over time.

Table 2: Chosen Locations in Amman

No.	Location	No.	Location
1	Ministry of Interior Roundabout	**11**	Al-Sina'a Street
2	1st Circle	**12**	Sweileh Roundabout
3	2nd Circle	**13**	Queen Rania Street
4	3rd Circle	**14**	Sport city Roundabout
5	4th Circle	**15**	Gardens Street
6	5th Circle	**16**	Jabal Alhussein
7	8th Circle	**17**	Al-Urdon Street
8	Airport Highway	**18**	Al-Malek Hussein St
9	Abdoun Mall	**19**	Alistiklal Street
10	Sweifyah	**20**	Al-shaheed street

Road traffic noise was measured at 20 locations in Amman. The noise level in each location was measured using a Wensn (WS1361) Digital Sound Level Meter. The noise was measured 1.5 m above the ground level; accepted as the average human ear level, with the microphone directed towards the noise source. All the measurements were taken on weekdays in the summer of 2013 (July and August). The streets were dry, and the measurements were carried out twice at each location; once during the morning peak hour (07:30 am -08:30 am), and once during the evening peak hour (07:30 pm – 08:30 pm).

4. Literature Review

In the study by Mofeed el al. (2013), measurements of traffic noise levels were taken on Al-Shaheed Street in Amman. The noise levels in the absence of barriers were: L_{eq} between 60 dB(A) and 77 dB(A), L_{10} values ranged between 64 dB(A) and 80 dB(A) while L_{90} ranged between 51 and 77 dB(A). On the other hand, in the presence of barriers, the values decreased noticeably, L_{10} and L_{90} values range between 66 dB(A) and 69 dB(A), 56 dB(A) and 58 dB(A) respectively. As for the relation between traffic and noise, especially heavy vehicles, it was found that a 27% reduction in medium heavy vehicles results in 3% reduction in noise levels, while a 25% reduction in buses results in 3% reduction of noise levels. Finally, a 25.5% reduction in light vehicles results in a 2.5% decrease in noise levels.

In 2008, Obaidat has combined field data with an analytical approach to spatially map noise levels due to traffic movements at relatively high traffic volume signalized intersections in Amman city at 29 locations, utilizing the potential of Geographic Information Systems (GIS). Data were collected in three different highly congested traffic peak periods: 7:30 a.m.-9:00 a.m., 1:30 p.m.-3:00 p.m., and 9:00 p.m.-11:00 p.m. using a portable precision sound level meter with range of 34 to 134 decibels (dB). The highest recorded noise level at some signals was 80 dB, which is higher than the accepted level i.e., 63 dB, while the lowest was 34 dB

In 2005, Jamrah et al. measured the noise levels in Amman through 28 locations, two measurements a day for one hour; morning and evening peak-hour. The Calculation of Road Traffic Noise (CRTN) model was used to predict the noise levels in most locations. The results shows that the noise levels lay between 46 dB(A) and 81 dB(A) during the day time and 58 dB(A) and 71 dB(A) during the night. This research was further used as a reference to evaluate, assess and compare the current traffic noise.

5. Results of the Study

Measured noise level (L_{eq}), level L_{90}(1hr), L_{10}(1hr), and Traffic noise Index (TNI), at the 20 locations in the city of Amman, are listed in Table 3 for the morning period, and Table 4 for the evening period.

Table 3: Measured Morning Noise Levels

Location	L_{eq}	L_{10}	L_{90}	TNI
1	83	84	72	90
2	84	84	66	109
3	84	82	68	94
4	87	81	67	93
5	80	81	70	84
6	79	82	72	83
7	76	81	71	81
8	76	78	70	73
9	78	78	70	72
10	80	82	70	88
11	83	83	73	83
12	83	83	73	83
13	81	84	74	85
14	79	83	74	80
15	78	82	73	79
16	77	80	73	71
17	78	81	72	78
18	78	81	72	78
19	82	85	76	80
20	87	87	74	94
Maximum	87	87	76	109
Minimum	76	78	66	71
Average	80	82	72	83
SD	3	2	3	9

From the results of the morning readings we notice the following**:**

- Minimum L_{eq}, L_{10}, L_{90}, TNI are 76, 78, 66, 71 respectively, and all are exceeding the maximum allowable limit of 63 dB(A).
- Maximum L_{eq} was at Al-Shaheed street, which could be explained due to the following :
  - Traffic Congestion on this street
  - Driver behavior/use of vehicle horns
- The maximum TNI was recorded at 1st circle Location with a value of 109, where the L_{90} (1hr) was 84 dB(A). This could be explained by the cobbled street at that location, since the stone pavement causes a remarkable noise when vehicles drive through.. Cobbled pavements are usually used on pedestrian streets to alert them about approaching traffic.
- Jabal Al-Hussein and Abdoun Mall locations have the minimum values of TNI: 71 and 72 respectively. Despite the congestion, there is a very limited use of vehicle horns, due to the control by police officers present at these locations.

Table 4: Measured Evening Noise Levels

Location	L_{eq}	L_{10}	L_{90}	TNI
1	79	81	70	83
2	77	79	69	79
3	78	79	67	85
4	80	79	67	85
5	87	75	66	73
6	81	84	77	75
7	75	77	67	76
8	81	83	77	73
9	79	79	68	83
10	88	77	67	78
11	83	85	75	85
12	82	81	74	72
13	77	79	70	78
14	77	79	68	82
15	75	78	71	69
16	79	81	74	72
17	77	79	75	61
18	84	81	72	80
19	82	82	73	80
20	81	83	76	74
Maximum	88	85	77	85
Minimum	75	75	66	61
Average	80	80	71	76
SD	4	3	4	6

Evening results show the following:

- The maximum, minimum, and average of L_{eq}, L_{10}(1hr), L_{90} (1hr), and TNI for the evening period at the 20 locations are less than that of the morning period.
- Al-Urdon Street has the lowest TNI, with a value of 61, which could be a result of non-congested flow and the speed limit control.
- The 8th circle, and Gardens street has the lowest values of L_{eq},

- Sweifyah has the maximum L_{eq} value of 88 dB(A). The traffic was congested and there was extensive use of amplifiers in the vehicles. The presence of large engine pick-ups was noticed.

6. Comparison with 2005 Traffic Noise Data

In order to assess the growth of traffic noise in Amman, a comparison with the 2005 study was carried out. The results show an average of 20%, 24% increase in traffic noise level L_{10} (1 hr) in the morning period and evening period, respectively. An average of 29%, 31% increase in traffic noise level L_{90} (1 hr) occurred in the morning period and evening period, respectively. These results are consistent as the traffic volumes have increased, and almost all of the readings in 2013 are higher than the 2005 readings. An average increase of 29% in L_{90} (1 hr) occurred between 2005 and 2013 in the morning period, while an average increase of 31% in L_{90} (1 hr) occurred in the evening period.

7. Review of Previous Models

7.1 Burgess Model:

This model was developed by Burgess in 1977, and was applied for the first time in Sydney, Australia. This model considers only three factors : the traffic volume (Q), the percentage of heavy vehicles, and the distance between the source and receiver (d), as follows:

$$L_{eq} = 55.5 + 10.2Log(Q) + 0.3P - 19.3Log(d) \quad (1)$$

where :

Q : Traffic Volume (veh/hr)

P: Percentage of Heavy Vehicles

d : Half width of roadway (m)

7.2 Griffith and Langdon Model:

Griffith and Langdon developed a model in 1968, which depends on the three factors, traffic volume, percentage of heavy vehicles, and the distance between the source and receiver, to calculate the L_{10}, L_{50}, and L_{90} through the following relations:

$$L_{10} = 61 + 8.4\ Log\ (Q) + 0.15\ P - 11.5\ Log(d) \quad (2)$$

$$L_{50} = 44.8 + 10.8\ Log\ (Q) + 0.12\ P - 9.6\ Log(d \quad (3)$$

$$L_{90} = 39.1 + 10.5\ Log\ (Q) + 0.06\ P - 9.3\ Log(d) \quad (4)$$

Then, and through Equation (5), the L_{eq} is calculated depending on L_{10}, L_{50}, and L_{90} as follows:

$$L_{eq} = L_{50} + 0.018(L_{10} - L_{90})^2 \quad (5)$$

7.3 Garcia and Bernal Model

Garcia and Bernal developed a model in 1985, and the general form of their model is shown in Equation (6), this model consider the following factors: Traffic volume (Q), Percentage of heavy vehicles (P), average flow speed (V), and the width of the roadway (2d).

$$L_{eq} = \alpha_1\ Log(Q) + \alpha_2\ P - \alpha_3\ Log(2d) - \alpha_4\ V + \alpha_5 \quad (6)$$

where:

Q : Traffic Volume (Veh/hr)

V : average speed (km/hr)

P : Percentage of Heavy Vehicles (%)

d : half width of roadway (m)

$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$: coefficients

Cirianni and Leonardi (2011) formulated the model as shown in Equation 7:

$$L_{eq} = 9656\ Log(Q) + 0.166\ P - 0.055\ V + 45.081 \quad (7)$$

7.4 The CoRTN Model:

The Calculation of Road Traffic Noise (CoRTN) Model was developed originally by the Department of Transport in the UK. A revised equation for the calculation of L_{eq} (Equation 8) was obtained by Cirianni and Leonardi (2012), which takes into account the following factors : traffic volume, speed, roadway width, and percentage of heavy vehicles, (Cirianni et al, 2012):

$$L_{eq} = \alpha_1\ Log(Q) + \alpha_2\ Log(V+40+500/V) + \alpha_3 Log(15/d) + \alpha_4\ P + \alpha_5 \quad (8)$$

where:

Q: traffic volume (veh/hr)

V: average speed (km/hr)

P : percentage of Heavy Vehicles (%)

d : half width of roadway (m)

$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$: coefficients

The formula of the recalibrated model is:

$$L_{eq} = 10.213\ Log(Q) + 6.69\ Log(V+40+500/V) + - 1.544\ Log(15/d) + 0.103\ P + 44.62 \quad (9)$$

A summary plot for all the models are shown in Figures 1 and 2 for the morning and evening periods, respectively. It is concluded that these models need calibration before they could be readily used in Amman.

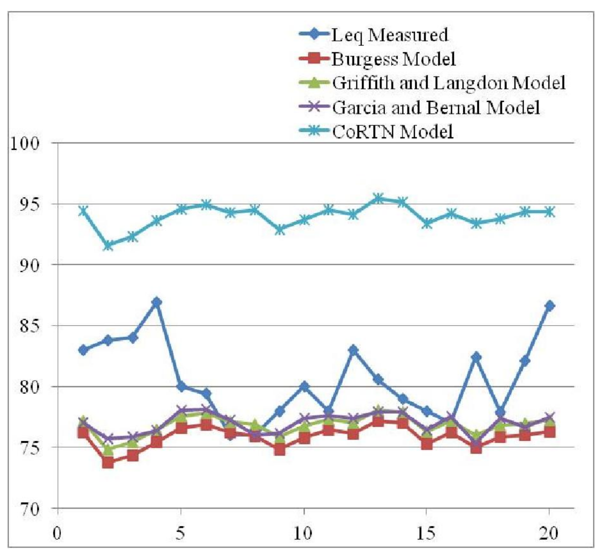

Figure 1: Summary of the Previous Models for the Morning Period

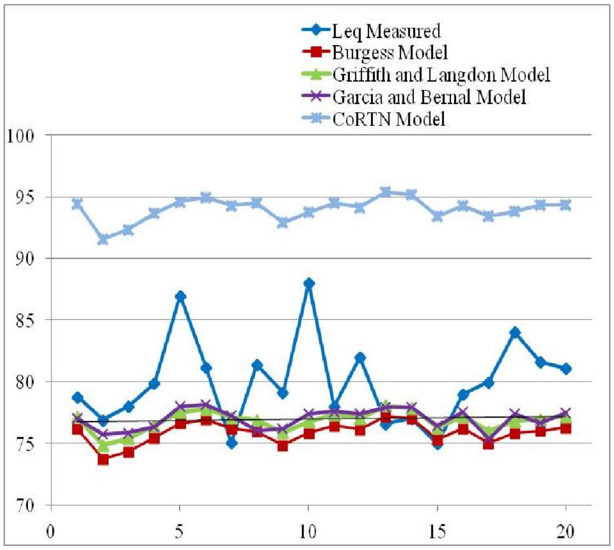

Figure 2: Summary of the Previous Models for the Evening Period

8. Developing a Traffic Noise Model for Amman

In order to develop a model for the noise levels in Amman, all the factors related to traffic that contributes in noise should be considered. The list of the factors would include:

- Traffic volume : the more the traffic volume, the higher sound level
- Traffic speed: this factor affects the noise in two opposite ways. First, the higher the speed of vehicles, the louder the noise due to the air resistance against the vehicle. Second, at lower speeds when the engine is running at high revolutions per minute (RPM) or operating at low gear it produces loud noise. Nevertheless vehicle horn is more likely to be used at low speeds and in congested traffic.
- Type of the traffic (heavy vehicles): Large and big vehicles, such as trailers, and trucks, cause louder noise because of the large engines and volume of the body of vehicle. Therefore, larger size vehicles (Pick-ups and SUV's) produce a higher noise than smaller ones (Sedans).
- Road Surface: affects the noise due to tire friction with the surface of the road.
- Road Gradient: in uphill gradients, engines are operating at high RPM, where in downhill gradients, braking and low gear are more used.
- Behavior of drivers: example of which are instant accelerating and braking, the habit of using the horn, or the high volume of the vehicle sound system or amplifiers (for advertising their products: like gas trucks, vegetable vendors, etc), are all factors that can directly affect the noise. This factor is more difficult to quantify.

Using the measurable parameters that affect the traffic noise level, the proposed model can be expressed as:

$$L_{eq}=f(Q, V, P, P_s, G, T) \quad (10)$$

where :

Q : Traffic Volume (Veh/hr)

V : Speed (km/hr)

P: Percentage of heavy vehicles

P_s: Percentage of large pick-ups and SUV's

G : Gradient of Road (%)

T : Pavement Texture depth (in mm) using the Sand Patch Method

Considering that:

1. The surface of roads in Amman is mainly asphalt pavement (all designated locations have asphalt pavement except the 1st circle location which has stone or cobbled pavement). Asphalt pavements have different surface textures, due to the asphalt mix design, age of asphalt pavement, traffic volumes, and weather conditions. It was important to quantify the condition of the pavement surface at each location, through a "simplified texture pavement method".
2. Gradient of roads ranged from 2% to 4% in the 20 locations of the study. As there was no major variation amongst them this variable was eliminated.
3. Large-pickups, and large SUV's were combined into a "heavy vehicle percentage" variable.

The formula could be rewritten as:

$$L_{eq}=f(Q, V, P,T) \quad (11)$$

The basic factors of the proposed model are listed in Table 3 at all 20 locations of the study. Applying the modified model on the collected data, resulted in the following equation:

$$L_{eq}=a + b\,Log(Q) +c\times P + d\times T \quad (12)$$

The Table of Predictors from calibrating the model, using stepwise regression is summarized in Table 3. The model was developed using Minitab software as follows: α-to-Enter: 0.15; α-to-Remove: 0.15.

Table 3: Stepwise Regression

Step	1	2	3
Constant	67.41	66.67	16.70
P	28.90	28.60	23.50
T-Value	10.16	10.63	8.06
P-Value	0.00	0.00	0.00
T		0.28	0.68
T-Value		2.31	4.06
P-Value		0.027	0.00
Log Q			14.30
T-Value			3.15
P-Value			0.003
S	1.80	1.70	1.53
R-Sq	73.11	76.49	81.56
R-Sq (adj)	72.40	75.22	80.02

Therefore, speed (V) could be dismissed, and the final model equation after calibration is:

$L_{eq}=16.7 + 14.3\,Log(Q) +23.5P + 0.676T$ (13)

It has the following statistical values:

Standard Error (S) = 1.53063

R-Squared = 84.6%

R-Squared (adjusted) = 81.0%

S is the square root of the mean squared error; therefore, the smaller the value of S, the stronger the linear relationship. R-squared adjusted is the version of R-squared that has been adjusted for the number of predictors in the model.

The correlation matrix is summarized in Table 4. In Table 4, the "Coef" column contains the coefficients from the regression equation. The "SE Coef" stands for the standard error of the coefficient which is useful in constructing confidence intervals and performing hypothesis tests.

Table 4: Correlation Matrix

Predictor	Coef	SE Coef	T	P
Constant	16.70	15.93	1.05	0.301
Log Q	14.336	4.557	3.15	0.003
P	23.511	2.915	8.06	0.000
T	0.6765	0.1667	4.06	0.000

Table 5: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	196.53	49.13	46.01	0.00
Residual Error	15	16.018	1.068		
Total	19	212.55			
Source	DF	Seq SS			
Log Q	1	53.72			
P	1	280.74			
T	1	38.57			

The Analysis of Variance consists of calculations that provide information about levels of variability within a regression model and forms a basis for tests of significance. The "Analysis of Variance" portion of the MINITAB output is shown in Table 5. The degrees of freedom are provided in the "DF" column, the calculated sum of squares terms are provided in the "SS" column, and the mean square terms are provided in the "MS" column.

The P-value for the F test statistics = 46.01 is less than 0.001, which provides strong evidence against the null hypothesis (H_0 is rejected) and confirms that the independent parameters provide valuable information for predicting $L_{eq.}$ The regression relation is considered significant and the independent variables have explanatory or predictive power. The sequential sums of squares (Seq SS) measures the reduction in the residual sums of squares provided by each additional term in the model.

Application of the proposed model gives the results shown in Table 6 for the morning period, and Table 7 for the evening period. The R^2 of the Model is 0.78, which is considered acceptable in comparison to the other models. Illustration of the results is shown in Figure 3 and Figure 4 at the 20 locations for the morning and evening period, respectively.

Table 6: Traffic noise - L_{eq} (1hr) Measured and Predicted for the Morning Period

Location	L_{eq} Measured	L_{eq} Predicted	Relative Error
1	83	83	0.00%
2	84	84	0.12%
3	84	83	1.43%
4	87	86	0.80%
5	80	81	1.13%
6	79	79	0.38%
7	76	79	3.68%
8	76	79	3.68%
9	78	79	0.64%
10	80	81	0.63%
11	83	84	1.45%
12	83	85	1.93%
13	81	82	0.74%
14	79	81	2.28%
15	78	79	1.41%
16	77	79	2.86%
17	78	78	0.00%
18	78	78	0.13%
19	82	82	0.12%
20	87	86	1.03%

Table 7: Traffic noise - L_{eq} (1hr) Measured and Predicted for the Evening Period

Location	L_{eq} Measured	L_{eq} Predicted	Relative Error
1	79	79	0.38%
2	77	78	1.69%
3	78	77	1.67%
4	80	78	2.25%
5	87	85	2.41%
6	81	80	0.99%
7	75	75	0.13%
8	81	79	2.72%
9	79	78	1.77%
10	88	86	2.84%
11	83	84	0.72%
12	82	82	0.00%
13	77	77	0.52%
14	77	77	0.00%
15	75	75	0.40%
16	79	78	1.90%
17	77	75	2.08%
18	84	80	5.00%
19	82	81	1.71%
20	81	82	1.36%

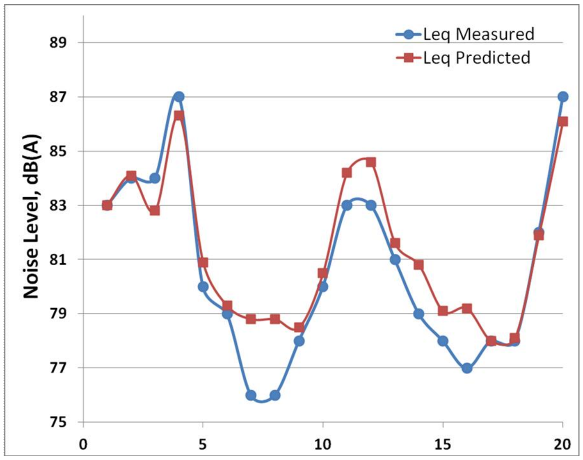

Figure 3: Traffic Noise Measured and Predicted using the Proposed Model for the Morning Period

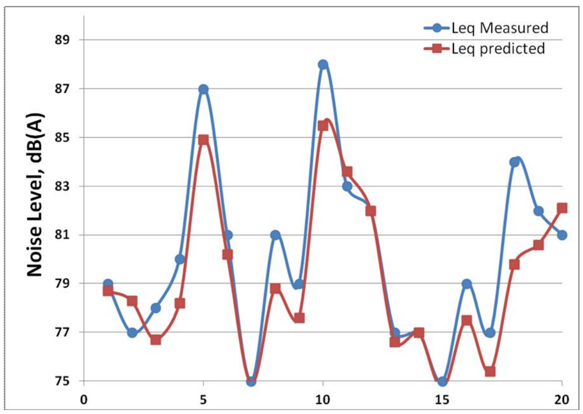

Figure 4: Traffic noise Measured and Predicted using the Proposed Model for the Evening Period

With the proposed model for the the morning and evening period, the average of the Relative Error was 1.22% and 1.53%, respectively.

The R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression.The R^2 represents the proportion of variation in the dependent variable that is accounted for by the regression model and has values from zero to one. If it is equal to one, the entire observed points lie on the suggested least square line, which means a perfect correlation exists. The R^2 was calculated to be 0.84 for both periods using the Minitab Software, which makes the model both acceptable and applicable. The adjusted R-squared compares the explanatory power of regression models that contain different numbers of predictors; thus the R-Squared value is adjusted for the number of variables included in the regression equation. It was found to be 0.81 for the developed model.

9. Conclusions and Recommendations :

Traffic noise in Amman has reached very high levels in both morning and evening periods; this requires urgent actions. The developed model for the city of Amman could be used to predict traffic noise levels effectively. The four significant variables found to affect noise were : traffic volume (Q), percentage of heavy vehicles (P), texture of the pavement (T), and speed of vehicle (V) and were all included in the proposed model.

Recommendations :

- Further Studies:
  - Apply the model on other cities in Jordan to check its validity on locations outside Amman.
  - periodic monitoring of traffic noise is suggested; to highlight the importance of this issue and raise awareness among decision makers.
- Improvement of Public Transport/Transit: in order to reduce the use private cars in transportation, which leads to resolving more than one problem, such as: traffic congestion, accidents, traffic noise, air pollution, and fuel consumption.
- Laws and Regulations: there should be recognized provisions for the operation of heavy vehicles in the city due to their severe environmental and traffic impacts
- Law enforcement: to tighten permissible limits, there is a need to concentrate efforts on illegal vehicle modifications such as muffler alterations.
- Spread awareness: traffic noise has to become an issue of public concern and raise the attention to the government.
- Reduce the number of vehicles: especially large engine ones- that cause a higher noise, through laws and regulations, and by presenting a modern, reliable public transport system.
- Use of Noise Barriers & Technologies.
- Application of Traffic Noise Level Requirements: for new designs or development projects.
- Land Use Planning: incorporating mitigation of traffic noise in town planning strategies.

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