University of Baghdad
College of Engineering

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 29 Number 4 April 2023

Effect of Surface Pavement Type on Traffic Noise

Amjed J. Abed *
MSc. Student
Dept. of Civil Engr.
College of Engr.-Univ. of Baghdad
Baghdad, Iraq
amjed.abed2001m@coeng.uobaghdad.edu.iq

Amjad H. Albayati
Prof., Ph.D
Dept. of Civil Engr.
College of Engr.-Univ. of Baghdad
Baghdad, Iraq
a.khalil@uobaghdad.edu.iq

Yu Wang
Assist. Prof., Ph.D
School of Science, Engr., and Environ., - Univ. of Salford
Manchester, England
cy.wang@salford.ac.uk

ABSTRACT

This paper investigates the issue of surface-type effects on traffic noise in Baghdad. Since the raw materials for both flexible and rigid paving are available from local sources, the decision on selecting the type of paving which depends on the budget of the project and the road's importance and function. Knowing that for high traffic volumes and a high percentage of heavy vehicles, rigid pavement is more suitable compared to flexible pavement. In Baghdad, some highways consist of flexible pavement and others of combined pavement (flexible segments and rigid segments), so the study of the effect of surface type on traffic noise becomes an important matter. This study selected three highways: one with flexible pavement and two with the combined pavement. The results showed that the traffic noise generated by traffic on rigid pavement generates more noise than traffic on flexible pavement by about 2 dBA. A prediction model was generated to predict traffic noise depending on five variables (vehicle speed, traffic volume, skid number, distance between the edge of the inner lane and the sound level meter, and surface type). The measured traffic noise levels ranged from 73.23 to 82.86 dBA, which exceeded the permitted limits compared to the permissible Iraqi standards.

Keywords: Traffic noise, Flexible pavement, Rigid pavement.

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2023.04.01

Article received: 29/12/2022
Article accepted: 02/03/2023
Article published: 01/04/2023

تأثير نوع رصف الطريق على ضوضاء المرور

* أمجد جبار عبد
طالب ماجستير
قسم الهندسة المدنية –جامعة بغداد

أمجد حمد البياتي
أستاذ, دكتوراه
قسم الهندسة المدنية –جامعة بغداد

يو وانغ
أستاذ مساعد, دكتوراه
كلية الهندسة –جامعة سالفورد

الخلاصة

يدرس هذا البحث مشكلة تأثير نوع السطح على الضوضاء المرورية في مدينة بغداد. حيث أن المواد الخام من كلا نوعي الرصف المرن والصلب متوفرة من مصادر محلية، فإن قرار اختيار نوع الرصف يعتمد على ميزانية المشروع وأهمية الطريق ووظيفته، مع العلم أن لأحجام المرور المرتفعة والحركة المرتفعة ولنسبة المركبات الثقيلة العالية، يعتبر الرصيف الصلب أكثر ملاءمة مقارنة بالأرصفة المرنة. في مدينة بغداد، تتكون بعض الطرق السريعة من رصف مرن والبعض الآخر بأرصفة مشتركة (مقاطع مرنة ومقاطع صلبة)، لذلك تصبح دراسة تأثير نوع السطح على ضوضاء المرور مسألة مهمة. في هذه الدراسة، تم اختيار ثلاثة طرق سريعة، أحدها به رصيف مرن واثنان بهما رصف مرن وصلب. أظهرت النتائج أن ضوضاء المرور الناتجة عن حركة المرور على الأرصفة الصلبة تولد ضوضاء أعلى من حركة المرور على الرصيف المرن بحوالي 2 ديسيبل. تم إنشاء نموذج تنبؤ للتنبؤ بضوضاء حركة المرور اعتمادًا على خمس متغيرات (سرعة السيارة، حجم حركة المرور، رقم الانزلاق، المسافة بين حافة الممر الداخلي وجهاز قياس مستوى الصوت، بالإضافة الى نوع السطح). تم قياس مستويات ضوضاء حركة المرور. من 73.23 إلى 82.86 ديسيبل والتي وجدت أنها تتجاوز الحدود المسموح بها مقارنة بالمعايير العراقية المسموح بها.

الكلمات الرئيسية: ضوضاء المرور، الرصف المرن، الرصف الصلب.

1. INTRODUCTION

Road traffic noise is a complicated phenomenon due to the involvement of several variables. The traffic noise levels generated depend on the traffic flow, the speed of the stream, and the heavy vehicle percentage **(Ali and Albayati, 2022)**. The source of generated noise from an individual vehicle is divided into two sources, first, from the vehicle itself, such as engine noise, exhaust systems, and engine cooling systems; while the second source is from the air dynamics of the vehicle while moving and the interaction of tire-pavement **(Ali et al., 2018).** Action is taken to reduce the traffic noise from its sources, such as using hybrid vehicles and electrical engines **(Li et al., 2016).** The road pavement surface was also studied, and several techniques were invented that showed adequacy in decreasing traffic noise, such as porous asphalt pavement for flexible pavement roads and grinded surfaces for concrete pavement roads **(Skarabis and Stöckert, 2015).** Other parameters affect the traffic noise levels, such as the distance between sound receivers and the road, the geometry of the roadside, the ground cover for the area beside the roadway, the availability and type of the noise barrier, and the weather conditions **(Azodo et al., 2019).** Economic development, industrialization, and urbanization increased not only highway traffic but also elevated noise levels. As a result, it is now required to assess the features of traffic noise in relation to different types of pavement surfaces, vehicle types, and vehicle speeds **(Cho and Mun, 2016)**.

Determining the traffic noise levels that may occur or have already occurred is crucial during the planning and designing stages and after constructing new roadways. Thus, noise prediction and mathematical dispersion models are applied. The method used to measure noise levels varies by country. Many more developed nations have created their own models for the prediction and dispersion of noise. Models from other countries are used by countries without their own models, whether or not they have been adjusted for local conditions **(Pozder, 2012).** Parnell & Samuels, 2006 studied the influence of various types of road pavement surfaces on traffic noise in Australia. The results of the study showed that the quietest pavement was stone matrix asphalt pavement, dense graded asphalt pavement, chip-sealed pavement, and concrete pavement, respectively **(Samuels and Parnell, 2007)**. Seung & Mun, 2008 studied the effect of various types of road pavement surface along the southbound side of the Jungbu Inland Expressway in South Korea. The location studied was divided into nine segments, and the vehicles were classified into eleven classes. The analysis of measured data showed that the asphalt pavement surface has higher acoustical benefits than the concrete pavement surface for passenger and heavy vehicles **(Cho and Mun, 2008)**. Lakušić and his coworkers investigated the effect of different surface pavement types on road traffic noise at the Llova Bridge in Croatia **(Lakušić et al., 2010)**. The former road surface type was concrete, rehabilitated by placing an asphalt surface. Various variables were considered during the data analysis, such as vehicle speed, surface condition, and surface evenness. The results showed that the noise levels measured on the concrete surface were higher than the traffic noise on the asphalt concrete surface due to the evenness of the surface and the incompetent execution of the expansion joints of the concrete pavement.
In Bosnia and Herzegovina, Pozder, 2012, studied the effects of the pavement surface on traffic noise levels. The data measurement was at 70 sites on the road network. The result showed the generation of a traffic noise prediction model considering the surface condition **(Pozder, 2012)**.
Awwal and others studied the traffic noise levels on the Skudai-Pontian Highway in Johor, Malaysia **(Awwal et al., 2021)**. The study aimed to assess the noise levels on two types of pavement. The traffic characteristics were measured, as well as the traffic noise. The data were used to calculate the predicted noise levels using five different prediction models. It was found that all models did not suit the observed noise, except the Penang noise model. The model was developed to fit the predicted traffic noise for specific conditions. Therefore, it can be deduced that pavement type and traffic condition impact traffic noise, and creating a customized traffic noise model for each pavement and traffic condition can assist in planning future changes in traffic noise circumstances.
The current study is interested in assessing roadside noise levels on existing roadways with asphalt and concrete pavements. Also, it includes a prediction for the noise level in terms of vehicular stream characteristics, i.e., speed, volume and distance from the noise source besides the surface texture of pavement as evaluated by the skid number. The prediction model has been developed using MINITAB V16 software.

2. ROAD SURFACE PAVEMENT

Road surface pavement can be divided into two types: asphalt concrete pavement and concrete pavement.

2.1 Asphalt cement pavement

This type of pavement typically consists of a base course, binder course, and surface course layers. **Fig. 1** shows a typical asphalt-cement cross-section of a road. Hot mix asphalt (HMA) is the typical type of surface layer. The layer is produced by mixing hot asphalt with graded aggregate and mineral fillers such as limestone and Portland cement **(Albayati, 2018)**. Many modifications occurred, and the results were warm mix asphalt, porous asphalt, and open-graded hot mix asphalt **(Bendtsen and Andersen, 2005).**

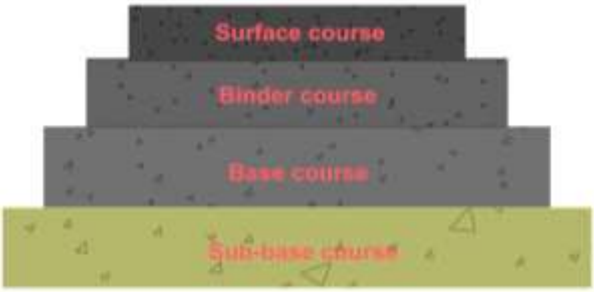

Figure 1. Typical HMA road layers

2.2 Portland cement pavement (PCC)

This type of pavement consists of a concrete slab placed on a sub-base layer. A concrete slab is produced by mixing Portland cement with fine and coarse aggregate. **Fig. 2** shows a typical section of concrete pavement.

Figure 2. Typical PCC road layers

3. TRAFFIC PREDICTION MODELS

Many models were generated to predict road traffic noise around the world. These models can't be applicable in all countries due to various factors, such as vehicle specifications, vehicle categorization, and weather conditions from one region to another. Large-scale studies have shown that combining proven prediction models with field measurements is preferable to relying only on field measurements because they demand many resources **(Van Renterghem et al., 2014)**.

Bolt and Rosenblith generated a noise prediction model in the United States. In this model, the basic was the L_{50} with traffic conditions of vehicles speeds 35-45 mph **(Bolt and Rosenblith, 1952)**. and at a distance of 20 feet. Eq. (1). shows the prediction model **(Vij and Agrawal, 2013)**.

$$L_{50} = 68 + 8.5log(V) - 20log(d) \tag{1}$$

where:
L_{50} is the sound level exceeded for 50% of the time of the measurement period (t), dBA.
V is the hourly volume (veh/hr).
d is the distance from the center of the inner lane to the observation point in feet.
Nickson, 1965 model's condition was that the mean speed of vehicles is 40 mph and 10% heavy vehicle percentage. Lamure, 1965 made developments on Nickson's model to be applied for traffic volumes of (1200-5000) veh/hr and a heavy vehicle percentage of 15%. Nickson model and Lamure model are adopted in Eq. (2) and (3), respectively **(Vij and Agrawal, 2013)**.

$$L_{50} = 50 + 10\ log(V/D) \tag{2}$$

$$L_{50} = 52 + 10\ log(V/D) \tag{3}$$

In England, Johnson and Saunders, (1968), cited in **(Kamil and Al-jameel, 2022)**, developed a prediction model with more complexity. The limitation of the model is that the heavy vehicle percentage is 20%. They also studied the effect of ground cover and the road gradient, and correction factors were considered. Eq. (4). shows the Johnson and Saunders model.

$$L_{50} = 3.5 + 10\ log(VS^3/D) \tag{4}$$

In 1972, Wesler developed a method named TSC. It provided a computerized traffic noise prediction method. The concept of the model was to calculate the noise generated by light vehicles and heavy vehicles separately. Then the summation represents the total noise. Eq. (5). represents the TSC model.

$$L_{eq} = 2.4 + L_{50} + 10log(V/DS) - A \tag{5}$$

where A is the sum of the correction factors due to weather, ground absorption, noise barriers, and reflections due to surrounding objects. The TSC software program provides statistical models converting the L_{eq} to L_{10}, L_{90}, and L_{50} **(Wesler, 1972)**.
In Australia, Burgess, 1977 developed a traffic noise model depending on L_{eq}, which can be calculated from Eq. (6) **(Kamil and Al-jameel, 2022)**.

$$L_{eq} = 55.5 + 10.2log(V) + 0.3P - 19.3log(d) \tag{6}$$

A prediction model was generated in France by the "Centre Scientifique et Technique du Batiment" (C.S.T.B.) based on L_{eq} and L_{50} as shown in the following equations **(Quartieri et al., 2009)**.

$$L_{eq} = 0.65\ L_{50} + 28.8 \tag{7}$$

$$L_{50} = 11.9l\ og(Q) + 31.4 \tag{8}$$

while for roads and highways in urban areas when the hourly volume is less than 1000 veh/hr the following equation is used:

$$L_{50} = 15.5log(Q) - 10log(L) + 36 \tag{9}$$

In Italy, a prediction model was developed by the "Consiglio Nazionale Delle Ricerche" and then improved by Cocchi. The model is based on a linear source relation between traffic parameters and noise levels. Traffic noise can be calculated from Eq. (10)**(Quartieri et al., 2009)**.

$$L_{A_{eq}} = \alpha + 10\, log(Q_L + \beta Q_P) - 10\, log(d/\, d_o) + \Delta L \tag{10}$$

where:
Q_L is the hourly volume for light vehicles (veh/hr)
Q_P is the hourly volume for heavy vehicles (veh/hr)
d_0 is the reference distance of 25 meters (m)
d is the distance between the lane center and the observation point on the road's edge (m).
ΔL is the adjustment factor
α, β is parameters affected by the road and vehicle type (in Italy, α=35.1 and β=6)

4. METHODOLOGY

4.1 Location Selection

The locations selected in the study tended to cover all concrete pavement highways and Baghdad city's main asphalt pavement highways. The studied locations are given in **Table 1. Fig. 3** shows the map location for the selected roads.

Table 1. Locations selected for the study

Location name	Location Symbol	Surface type	Coordinates	
			N	E
Salah-Aldeen Highway	1	HMA	33°21'24.31"	44°18'0.36"
Salah-Aldeen Highway	2	PCC	33°19'3.59"	44°18'6.78"
Mohamed Al-Qasim Expressway	3	PCC	33°23'52.84"	44°21'52.82"
Mohamed Al-Qasim Expressway	4	HMA	33°21'54.15"	44°23'22.91"
Abu Ghraib Expressway	5	HMA	33°19'45.67"	44°18'51.10"

4.2 Devices Used in the Study

During the process of measuring the road traffic noise, the following devices were used:
1. Sound level meter, using a CEM (DT-8852 DATA LOGGER) model device.
2. Speed Gun detector, using a Bushnell model velocity speed gun for detecting vehicles' speed at locations.
3. British pendulum tester for skin number measurements.

Figure 3. Map for the selected location in Baghdad

4.3 Test Procedure

In each location, the sound level meter was set at the height of 1.5 meters. The vertical distance between the edge of the inner lane and the sound level meter was 1, 3, 6, and 9 meters. The sound level recording duration was one hour.
Vehicle spot speed was measured with a speed gun, pointed in the vehicle's direction and manually recorded simultaneously with the sound levels. The speed and frequency were analyzed, and the 85-percentile speed was computed and used for each study hour.
Traffic volume was also counted manually during the same duration, taking into consideration the vehicle type. The vehicles were classified into two categories: passenger cars and heavy vehicles. Since all locations with flat terrain, a passenger car equivalency factor of 1.5 was used to convert the heavy vehicles into equivalent passenger cars.
Every location was tested in the three-time interval, 5-6 AM, 7-8 AM, and 9-10 PM, during weekdays only. The weather conditions during the data collection were clear, with low wind speeds. In each location, the selected data collection section avoided any traffic streams obstructions such as intersections, interchanges, bumps, pedestrian crossings, and surface distortions and had no acceleration or deceleration lanes. **Fig. 4** shows the measuring procedure.

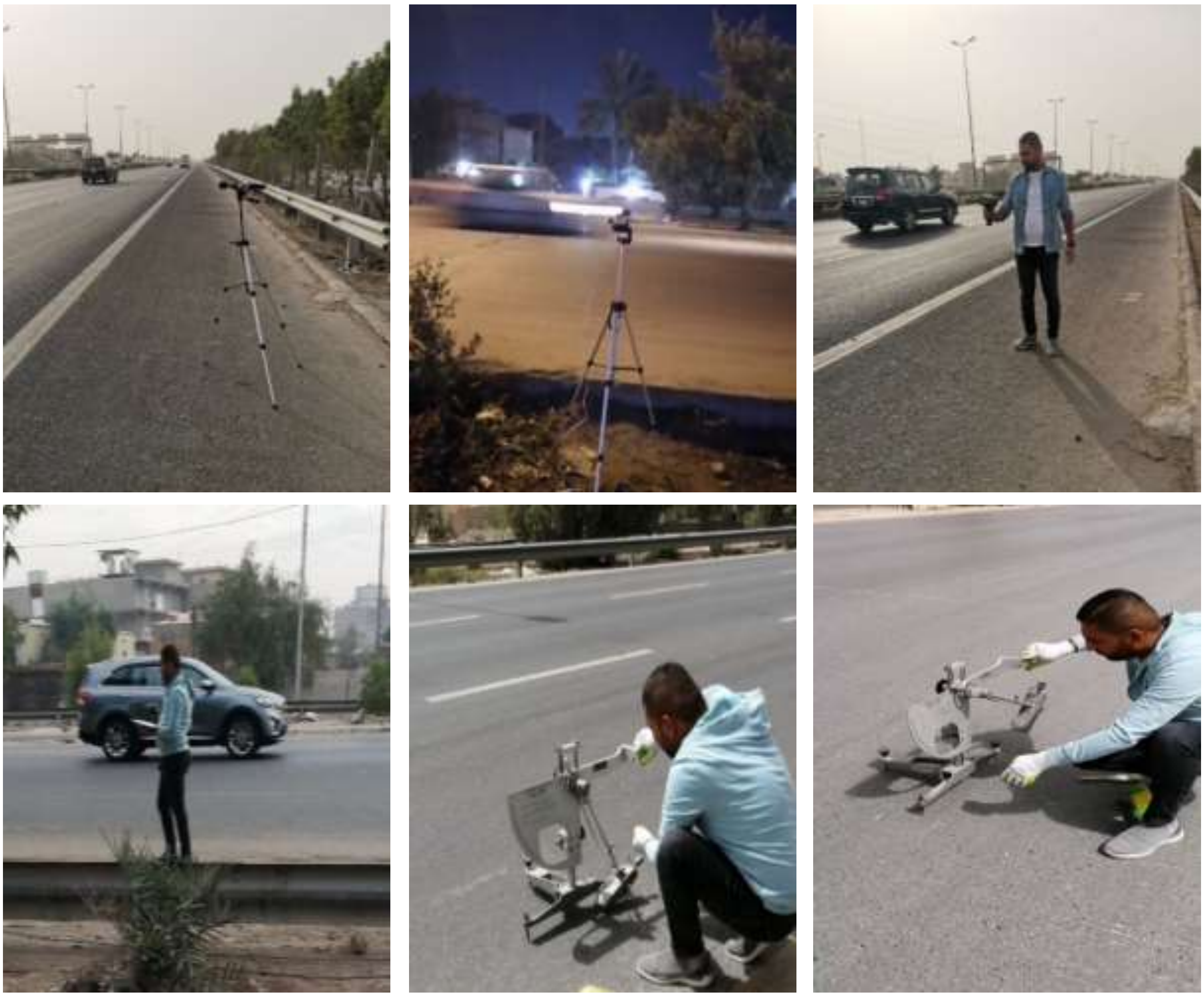

Figure 4. Data measurement procedure for concrete and asphalt pavement

5. RESULTS AND DISCUSSION

The road traffic noise was measured in the selected locations, as shown in **Table 2**, where average values for several measurements for PCC and HMA road surface type locations were taken. The average values of L_{eq} for HMA and PCC roads are given in **Table 3.**
A comparison between the measured $L_{eq(average)}$ for different types of surfaces and the Iraqi standards is conducted as given in **Tables 3 and 4.**

where $L_{eq(average)}$ is calculated as:

$$L_{eq(average)} = \sum_i L_{eqi}/N \tag{11}$$

where N is the number of readings

It is found that the noise levels measured from PCC surfaces exceeded the that measured from HMA surfaces.

Table 2. Average L_{eq} measured for selected locations

Location	Surface Type	L_{eqi} measured 5-6 AM (dBA)	L_{eqi} measured 7-8 AM (dBA)	L_{eqi} measured 9-10 PM (dBA)
1	HMA	73.23	75.27	76.11
2	PCC	76.77	82.17	79.20
3	PCC	76.57	82.86	79.34
4	HMA	75.48	81.73	78.93
5	HMA	76.86	79.72	78.43

Table 3. The average L_{eqi} for each type of pavement

Pavement surface Type	L_{eqi} (Average) Daytime dBA	L_{eqi} (Average) Nighttime dBA
PCC	79.59	79.27
HMA	77.04	77.82

Table 4. The Iraqi specification limits for sound levels **(Presidency of Iraqi Government, 2015)**

Location	Day Time dBA	Night Time dBA
Hospitals	50	40
Residential areas	60	50
Residential areas (suburbs)	55	45
Hotels	55	50
Schools, kindergartens, universities, and institutes	55	45
Industrial areas, governmental facilities	70	65
Utilities and commercial areas	65	60
Airports, Railway stations, and Harbors	70	60
Cultural and protect urban area	60	50
Recreation areas	60	50
Mixed residential areas and industrial areas (vice-versa)	60	45

These findings agreed with **(Lakušić et al., 2010; Awwal et al., 2021; Cho and Mun, 2008)**. The measured noise levels in all locations were higher than the permissible levels limited by Iraqi standards. The results are shown in **Fig. 5.** A prediction model is generated per the measured data (sample of them) given in **Table 5.**

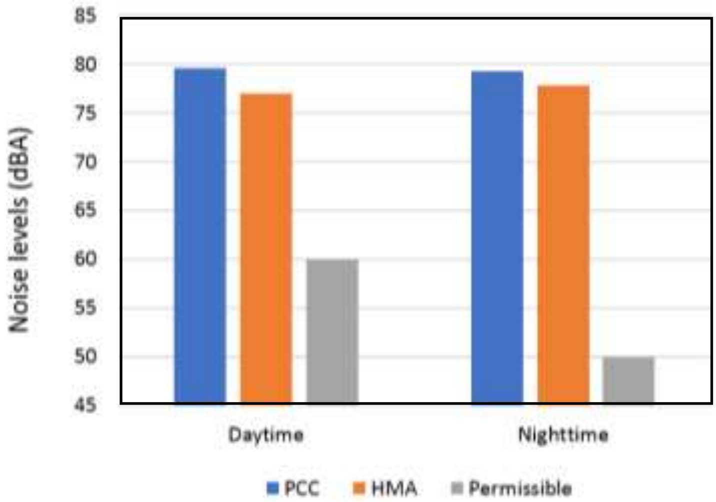

Figure 5. $L_{eq\ (Average)}$ for different road surface types

Table 5. A sample of measured data for location 5, SN. of 54

Time	Distance (m)	Speed (km/hr)	Volume (pc/hr)	Surface Type	L_{eq} measured (dBA)
5-6 AM	1	113	1077	HMA	80.66
5-6 AM	3	113	1107	HMA	77.6
5-6 AM	6	115	1009	HMA	75.05
5-6 AM	9	110	1038	HMA	74.16
7-8 AM	1	109	2974	HMA	83.57
7-8 AM	3	109	3097	HMA	80.73
7-8 AM	6	107	3078	HMA	78.66
7-8 AM	9	109	3139	HMA	75.95
9-10 PM	1	108	3303	HMA	83.92
9-10 PM	3	108	3338	HMA	79.22
9-10 PM	6	110	3210	HMA	76.47
9-10 PM	9	107	3297	HMA	74.11

The model includes the vehicle speed, traffic volume, skid number, distance between the inner edge of the road and the sound level meter, and the type of road surface. The data were analyzed using the Minitab 16 software program, and the resulting model is given as:

$$L_{eq} = 61.8 + 0.215S + 0.00206V - 0.773D - 0.127SN - 0.847T \qquad (12)$$

where:
S is the 85-percentile speed for the stream (km/hr.).
V is traffic volume (pc/hr).
D is distance between noise level meter and inner edge of the road (m).
SN is skid number for road surface.
T is the type of road surface (assumed 1 for PCC and 2 for HMA).

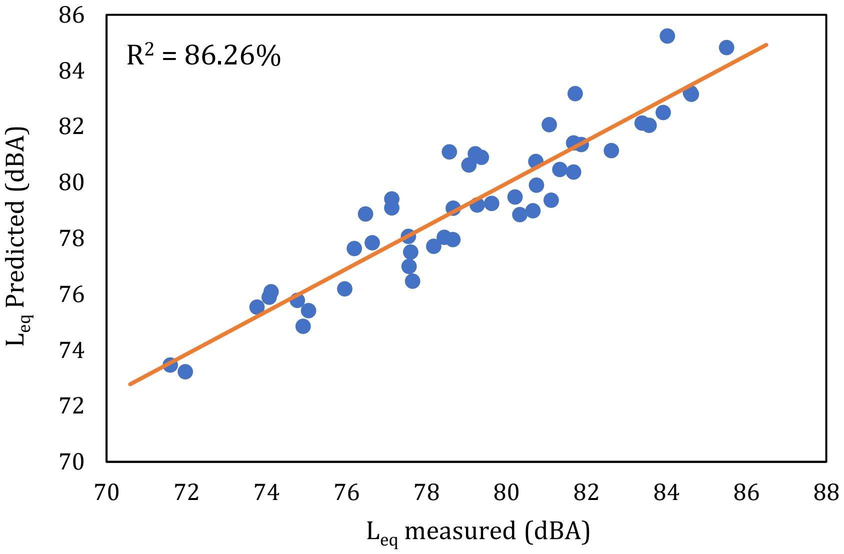

Figure 7. Prediction model results

6. CONCLUSIONS

This paper studied the traffic noise on three different highways in Baghdad city. Two of the selected highways consist of two segments with different surface types (PCC and HMA). The results showed that the traffic noise generated was higher for PCC roads as compared to the traffic noise for HMA roads. Traffic noise levels measured ranged from 73.23 to 82.86 dBA. The measured noise levels showed to be higher than the limits permitted by the Iraqi standards for all locations. For PCC highways, the noise levels were 32.65 % and 58.54 % higher than the permissible levels for daytime and nighttime, respectively. For HMA highways, the noise levels were 28.40% and 55.64% higher than the permissible levels for daytime and nighttime, respectively.

A prediction model was generated depending on five variables: vehicle speed, traffic volume, skid number, the distance between the sound level meter and the inner edge of the road, and surface type. The generated model shows an acceptable ability for prediction since R^2 was found to be 86.26%.

NOMENCLATURE

C.S.T.B. = Centre Scientifique at Technique du Batiment.
dBA = decibel A-weighted.
HMA = Hot Mix Asphalt.
L_{10} = the sound level exceeded for 10% of the measurement period (t), dBA.
L_{50} = the sound level exceeded for 50% of the measurement period (t), dBA.
L_{90} = the sound level exceeded 90% of the measurement period (t), dBA.
L_{eq} = hourly equivalent sound level, dBA.
PCC = Portland Cement Concrete.
SN = Skid Number, unitless.
TSC = Transportation Systems Center.

REFERENCES

Albayati, A.H., 2018. Performance Evaluation of Plant Produced Warm Mix Asphalt. *Journal of Engineering*, 24(5 SE-Articles), pp. 145–164. doi:10.31026/j.eng.2018.05.10.

Ali, S.M., Hama, A.R. and Ali, Y.M., 2018. A study of Land Zoning in the base of Traffic Noise Pollution Levels using ArcGIS: Kirkuk City as a Case Study. *Al-Khwarizmi Engineering Journal*, 13(4), pp. 137–151. doi:10.22153/kej.2017.06.002.

Ali, S. S., and Albayati, A. H. K., 2022. Traffic Noise in Arterial Streets: Case of Kirkuk City. *Journal of Engineering*, 28(12), pp. 137–154. doi: 10.31026/j.eng.2022.12.10.

Awwal A., Mashros N., Hasan, S.A., Hassan, N.A., Darus N, and Rahman, R., 2021. Road Traffic Noise for Asphalt and Concrete Pavement. IOP Conference Series: Materials Science and Engineering, 1144(1), p. 012082. doi:10.1088/1757-899x/1144/1/012082.

Azodo, A.P., Onwubalili, C. and Mezue, T.C., 2019. Assessment of Observed Building Structure Setback of Shops along an Arterial Road and Noise Intrusion Level. *Journal of Engineering*, 25(12), pp. 62–71. doi:10.31026/j.eng.2019.12.05.

Bendtsen, H. and Andersen, B., 2005. Experiences with thin noise reducing pavements. *Forum Acusticum Budapest 2005: 4th European Congress on Acustics,* (January 2005), pp. 1183–1187.

Cho, D.S. and Mun, S., 2008. Development of a highway traffic noise prediction model that considers various road surface types. *Applied Acoustics*, 69(11), pp. 1120–1128. doi:10.1016/j.apacoust.2007.06.004.

Cho, D.S. and Mun, S., 2008. Study to analyze the effects of vehicles and pavement surface types on noise. *Applied Acoustics*, 69(9), pp. 833–843. doi:10.1016/j.apacoust.2007.04.006.

Cho, H.T. and Mun, S., 2016. Adaptive Noise Parameter Determination Based on a Particle Filter Algorithm. *Mathematical Problems in Engineering*, 2016. doi:10.1155/2016/3570509.

Kamil, B.A. and Al-jameel, H.A.E., 2022. Impact of Traffic Characteristics and Pavement Surface Condition on Noise Level for Rigid Pavement. IOP Conference Series: Earth and Environmental Science, 961(1). doi:10.1088/1755-1315/961/1/012101.

Lakušić, S., Stančerić, I. and Ahac, M., 2010. Influence of different pavement surface on noise levels in passenger car. First International Conference on Road and Rail Infrastructure (CETRA 2010), 17-18 may, Opatija, Croatia.

Li, Q., Qiao, F. and Yu, L., 2016. Impacts of pavement types on in-vehicle noise and human health. *Journal of the Air and Waste Management Association*, 66(1), pp. 87–96. doi:10.1080/10962247.2015.1119217.

Pozder, M., 2012. Research on the Effects of Pavement Surface Condition on Road Traffic Noise. *Archives for Technical Sciences,* 1(8), pp. 57–64. doi:10.7251/afts.2013.0508.057p.

Presidency of Iraqi Government, 2015. Law of Noise Pollution Control (in arabic). pp. 1–9.

https://www.moj.gov.iq/uploaded/4390.pdf.

Quartieri, J., Mastorakis, N.E., Iannone, G., Guarnaccia, C., D'Ambrosio, S., Troisi, A., and Lenza, T.L.L., 2009. A Review of Traffic Noise Predictive Noise Models. *Recent Advances in Applied and Theoretical Mechanics*, pp. 72–80.

Samuels, S., and Parnell, J., 2007. A recent investigation into the influences of some australian asphalt pavement surfaces on road traffic noise. ICSV14, 9-12 July 2007, Cairns - Australia

Skarabis, J. and Stöckert, U., 2015. Noise emission of concrete pavement surfaces produced by diamond grinding. *Journal of Traffic and Transportation Engineering* (English Edition), 2(2), pp. 81–92. doi:10.1016/j.jtte.2015.02.006.

Van Renterghem T, Attenborough K, Maennel M, Defrance, J., Horoshenkov, K., Kang, J., Bashir, I.,Taherzadeh, S., Altreuther, B., Khan, A., Smyrnova, Y., and Yang., H., 2014. Measured light vehicle noise reduction by hedges. *Applied Acoustics*, 78, pp. 19–27. doi:10.1016/j.apacoust.2013.10.011.

Vij, G.S. and Agrawal, M.L., 2013. A review paper on R & D efforts in assessing the traffic noise on highways. *Recent Research in Science and Technology*, 5(5), pp. 54–58.

Wesler, J.E., 1972. Manual for Highway Noise Prediction (Short Version). Edited by (U.S.) John A. Volpe National Transportation Systems Center. https://rosap.ntl.bts.gov/view/dot/10823.