Prediction models for distress noise generated due to tire-pavement surface interaction

Dr. Ammar A. M. Shubber¹, Dr. Rasha H. A. Al-Rubaee², Mustafa Hadi Taher³

1. Lect. at Civil Engineering Department University of Technology, Email: 40162@uotechnology.edu.iq
2. Lect. at Civil Engineering Department University of Technology, Email: 40323@uotechnology.edu.iq
3. Engineer in the Mayoralty of Baghdad, Email: m_almusuy@yahoo.com

ABSTRACT

The major objective of this research is to assess the distress noise generated due to tire-pavement surface interaction for different modes and to evolve a noise prediction model for any manner taking into consideration the different factors impacting the distress noise generation. Seven flexible and four rigid pavement roads were chosen for the calculation of the noise in Baghdad city. Tire-pavement interaction noise was calculated using Onboard Sound Intensity (OBSI) Method by restricting the noise generated from the vehicle exhaust and the engine systems. Prediction models were developed for assessing tire pavement noise from vehicle speed, pavement age, wheel load, mean texture depth (MTD) and pavement distresses. Four statistical models were obtained from this research to assess the distress noise generated due to tire-pavement surface interaction using linear regression stepwise method. These models showed the effect of different types of distresses in addition to the factors that have been taken into consideration on tire pavement noise. Vehicle speed was the greatest considerable variable influencing the noise generated due to tire-pavement surface interaction. Some distresses and factors have been excluded from the models due to their poor relationship with tire-pavement noise. These models have been categorized based on the type of pavement surface (flexible or rigid) and the presence or absence of pavement distresses. The predicted statistical models were verified with calculation, by comparing the data estimated by the models and data form field tests. Therefore, it can be used as a method of detecting distresses rather than visual inspection.

Keywords: prediction model, pavement distress, tire-pavement noise, statistical model, Tire-pavement interaction, Onboard Sound Intensity.
1. Introduction

One of the most critical problems facing developed countries is traffic noise. However, traffic cannot be easily restricted or reduced within urban cities. Interaction between tires and pavement contributes to the main role in traffic noise in most major urban streets. Therefore, preventive measures in tire noise generation mechanisms have become very necessary [1].

Vehicle noise can be categorized into three types: aerodynamic noise, propulsion (power train) noise and tire-pavement noise. Noise can be produced as the tire passes over the pavement. In recent times, engines become less noisy due to improving the aerodynamic design of the vehicle, therefore tire pavement noise is the most important source of the vehicle noise [2].

The most important elements influencing tire pavement interaction noise can be distributed into five groups: environmental standards, driver effect elements, pavement-related, tire-related elements and tread pattern elements [3].

In recent years, traffic noise measurement methods have been developed; these methods can be categorized into three groups: road noise measurement method, measurement of noise at source and laboratory noise measurement method [4].

Recently, many studies have been carried out on ways to detect pavement distresses. Most of these studies focus on automatic measurement methods such as camera, laser, accelerometer, and acoustic for different types of distresses. These methods can be used to detect distresses as an alternative method of visual examination to reduce the time and effort required for the examination [5], [6].

Tire pavement noise models can be classified into three types: statistical models, hybrid models and deterministic models [7].

Syamkumar et al. [8] established a model consists of six different types of vehicles and two types of pavement surface were tested. Test sites consist of four cement concrete pavement (rigid) and eight asphalt concrete pavements (flexible). The measurement method used in this model is controlled pass–by method (CPB). The statistical model shows that the level of tire pavement noise in rigid pavement type is greater than flexible pavement type.

Jabar et al. [9] developed a statistical model consists of four different types of vehicle and one types of pavement surface were tested. Test sites were seven asphalt concrete pavements (flexible). The measurement method used in the model is Onboard Sound Intensity (OBSI) method. This statistical model demonstrates that the level of tire pavement noise in flexible pavement type increases with age.

Another Model was developed by National Center for Asphalt Technology (NCAT), sponsored by Colorado Department of Transportation (CDOT) and Federal Highway Administration (FHWA). Forty-
six various pavements were tested in the NCAT test path, most of which were tested Hot Mix Asphalt (HMA). The sound levels were calculated utilizing two methods, close-proximity sound intensity (CPI) and close-proximity trailer (CPX). Seven different tires have been tested at a speed of 35 mph. The study classified the noise levels for four sorts of pavements based on aggregates gradations [10].

Kephalopoulos et al. [11] had done study on the relationship between tire pavement interaction noise and powertrain noise for five different sorts of vehicles. It has been shown that the speed has the greatest impact on tire pavement interaction noise than the propulsion noise. Also, it proved that the total power of tire pavement interaction noise and propulsion noise is the overall acoustic power level of the vehicle.

Zhang et al. [12] improved model to predict mean texture depth (MTD) of the pavement depend on tire pavement interaction noise and vehicle speed. All tests were conducted at National Center for Asphalt Technology (NCAT) by using the same tire. The noise was calculated by utilizing a single microphone installed under the moving vehicle. Principal Component Analysis (PCA) statistical analysis method is used to recognize the important input about the pavement condition from noise data collected.

2. Data Collection

Acoustic data was calculated for various pavement types (flexible and rigid), various test vehicles (Nissan Sunny and Toyota Bus), various speeds (40, 56, and 72) km/h, different types of tires (Bridgestone215/70/R17, 5 Dunlop185/70/R14, and Silver stone 185/70/R14) and various pavement distresses. The overall noise level in this study were calculated by Onboard Sound Intensity (OBSI) method using sound level meter single probe 1 kHz (Lutron 801) with Sound Level Meter Calibrator device.

2.1. Site Selection

Eleven roads were chosen to make sure that most of the main roads in Baghdad city were covered. These roads are divided into seven roads of flexible pavement and four roads of rigid pavement represented in the following roads (Omar Bin Al Khatab, Ali bin Abi Talib, Mohammad Al-Qasim (Alwaziria), Abi Talib Street, Al Rayahin, Damascus Street, Mohammed Baqir al-Sadr) and four roads of rigid pavement represented in the following roads (express no.1 R7, Salahaddin highway, Mohammad Al-Qasim Highway, Salhia Street). All roads contain distresses except for two roads because they are newly constructed.
2.2 Methods of Measurement

Testing of all roads was carried out using the Onboard Sound Intensity (OBSI) Method as shown in Figure 1 to calculate the pavement noise resulting from the tire-pavement interaction noise. The focus was on pavement distresses such as rutting, potholes, corner break and other distresses. By setting the single probe of one microphone at the right back tire, the microphone is placed at specific distance according to (AASHTO, 2016) [13]. Each section is tested at three different speeds (40, 56, 72 km/h) or (25, 35, 45) mph with constant speed (±1 mph) over the test section and each speed is repeated twice according to the probe location leading and trailing, and then the average of the two values tested is taken, all these sections have the same length as 440 ft or 134 m according to (AASHTO, 2016) [13].

![Figure 1 OBSI Method setup](image)

3. Description of the Model

3.1 Framework of the Model

Four possibilities are there to relate tire pavement noise with pavement distresses (flexible and rigid) and parameters (MTD, vehicle speed, wheel load, pavement age). The tire pavement noise can be from the pavement distresses, parameters, or a combination of the two, based on the type of pavement. Four model types can be described as below:

1. Model type (flexible without distress): parameters (MTD, vehicle speed, wheel load, pavement age) are considered as independent variables, and the tire pavement surface without distress noise are calculated directly from the parameters.
2. Model type (rigid without distress): parameters (MTD, vehicle speed, wheel load, pavement age) are considered as independent variables, and the tire pavement surface without distress noise are calculated directly from the parameters.

3. Model type (flexible with distress): A Combinations of the parameters (vehicle speed, wheel load, and pavement age) and flexible pavement distress are considered as independent variables, and the tire pavement surface with distress noise are calculated directly from this combination.

4. Model type (rigid with distress): A Combinations of the parameters (vehicle speed, wheel load, and pavement age) and rigid pavement distress are considered as independent variables, and the tire pavement surface with distress noise are calculated directly from this combination.

3.2 Initial Variable Selection

In this paper, the temperature is not considered as an independent variable in the model, because all the OBSI results were corrected according to reference temperature 20°C according to the formula in (AASHTO, 2016) [13] as Eq. (1):

\[ \text{IL Normalized (dBA)} = \text{IL Measured (dBA)} + 0.040 \times (\text{Air Temp}° \text{F} - 68° \text{F}) \]  
Equation (1)

IL Measured: sound intensity level measured.
Air Temp: ambient air temperature during test period.
IL Normalized: sound intensity level after normalized.

Tire pavement noise level is considered as a dependent variable of the model, which is measured by A-weighting Sound Pressure Level (dBA). The independent variables were expressed by symbols in the equations of models built as follows:

vehicle speed (V), wheel load (W), mean texture depth (MTD)(M), pavement age (A), high blowups (HB), high punchouts (HP), faulting (F), low patching (LPA), high patching (HPA), bleeding (B), high joint spalling (transverse)(HS), high corner break (HC), high longitudinal cracking (HL), high transverse cracking (HT), medium joint spalling (transverse)(MS), high potholes (HPO), low potholes (LPO), high raveling (HR), low raveling (LR), rutting (R), high fatigue cracking (HF), high joint reflection (HJ), high lane joint cracking (HLA), high transverse cracking (HTC), medium longitudinal cracking (ML).

3.3 Regression Methods

The four statistical models are prepared using SPSS software version 23 for verification of the results for tire-pavement interaction noise. Prediction models have been built through the use of the method of
stepwise multiple regression analysis, which removes the variables that do not affect significantly depending on the proportion of the correlation between the independent variables and the dependent variable which represents the tire pavement noise level. The regression models performed below as Eq. (2): 

\[ Y = C + \sum I_1X_1 + \sum I_2X_2 + \sum I_3X_3 + \ldots \]  

Equation (2)

Where: (Y) dependent variable, (X) independent variable, (C) Constant and (I) coefficient

4. Final Models Selection

Table 1 illustrates the summary of prediction models that were created in this study. The table shows that models were created depending on the type of pavement (flexible and rigid) where each type contain two models, one with distresses and the other does not contain distresses. The table also demonstrates the number of variables that were removed by stepwise multiple regression analysis method and value of R^2 for each model. Tire type has not been adopted as a variable due to wheel load of the vehicle as an alternative.

| Model type                  | R^2 value | Variables Entered | Variables Removed | Number of 70% of the data | Model                                      |
|-----------------------------|-----------|-------------------|-------------------|--------------------------|--------------------------------------------|
| flexible without distress   | .980      | (V, M, A, W)      | -                 | 132                      | OBSI dBA = 68.754 + .215V + .902A + .017W - 4.408M |
| rigid without distress      | .994      | (V, M, W)         | (A)               | 132                      | OBSI dBA = 69.702 + .219V + .017W + 4.867M  |
| flexible with distress      | .987      | (V, B, W, HR, HPO, LPO, LR, R, A, HF, ML, HTC) | (HJ, HLA)        | 170                      | OBSI dBA = 65.379 + .216V - 6.916B + .025W + 5.818 HR + 7.838 HPO + 6.268 LPO + 4.443 LR + 2.496R + .339A + 1.335 HF - .926 ML - 737 HTC |
| rigid with distress         | .990      | (V, W, LPA, HPA, HS, HB, HT, HL, HP) | (A, F, HC, MS)   | 140                      | OBSI dBA = 67.068 + .219V + .028W - 3.917LPA - 3.296 HPA + 1.446 HS + 3.191 HB - 1.543 HT - 1.856 HL + 1.891 HP |

5. Validation of the Models

Table 2 illustrates models validation where 30% of the data was not used in the model. Using paired T test to find correlation between data estimated by model and data from test. It is obvious that, the correlation is
very strong between them. Figure 2 demonstrates models validation in which it is obvious that, the $R^2$ value is very high between data estimated by the model and field test data.

| Model type                      | Number of data | Paired Samples Correlations |
|---------------------------------|----------------|-----------------------------|
| flexible without distress       | 57             | .991                        |
| rigid without distress          | 57             | .997                        |
| flexible with distress          | 73             | .994                        |
| rigid with distress             | 61             | .994                        |

(A) Validation for flexible model without distress

(B) Validation for rigid model without distress

(C) Validation for flexible model with distress

(D) Validation for rigid model with distress

Figure 2 Validation of the models

6. Conclusions

1. Some variables were removed and other variables were kept depending on the degree of correlation between the input variables and output variables and the value of the $R^2$ using stepwise
method. Vehicle speed is the greatest considerable variable influencing the noise generated due to tire pavement surface interaction.

2. The models demonstrate that the sound intensity level for distressed pavement was higher than that for pavements without distresses and this increment varies depending on the type of distress and its severity, type of vehicle, type of surface and age of the road.

3. The models can be used to assist the road engineer by evaluating roads, forecasting pavement distresses and compare the tire pavement noise levels from surfaces using an Onboard Sound Intensity (OBSI) Method.

7. Recommendations
It is proposed to increase the verification of the models to ensure accuracy, in addition to the expansion of the database variables by adding other parameters that have effect on tire pavement noise, for example, different types of pavement surfaces, vehicles tires and pavement distresses.

8. Acknowledgments
The authors would like to thank University of Technology/Civil Engineering Department and mayoralty of Baghdad in the Iraq for facilitating and providing assistant data and advices.

References
[1] Vázquez, V., et al., Surface Aging Effect on Tire/Pavement Noise Medium-Term Evolution in a Medium-Size City. Coatings, 2018. 8(6): p. 206.
[2] Donavan, P.R. and R. Schumacher, Exterior noise of vehicles—Traffic noise prediction and control. Handbook of noise and vibration control, 2007: p. 1427-1437.
[3] Li, T., Influencing Parameters on Tire–Pavement Interaction Noise: Review, Experiments, and Design Considerations. Designs, 2018. 2(4): p. 38.
[4] Ohiduzzaman, M., et al., State-of-the-art review on sustainable design and construction of quieter pavements—Part 1: traffic noise measurement and abatement techniques. Sustainability, 2016. 8(8): p. 742.
[5] Coenen, T.B. and A. Golroo, A review on automated pavement distress detection methods. CogentEngineering, 2017. 4(1): p. 1374822.
[6] Miller, J.S. and W.Y. Bellinger, Distress identification manual for the long-term pavement performance program. 2014, United States. Federal Highway Administration. Office of Infrastructure.
[7] Li, T., R. Burdisso, and C. Sandu, Literature review of models on tire-pavement interaction noise. Journal of Sound and Vibration, 2018. 420: p. 357-445.
[8] Syamkumar, A., K. Aditya, and V. Chowdary. *Development of mode-wise noise prediction models for the noise generated due to tyre-pavement surface interaction*. in *Advanced Materials Research*. 2013. Trans Tech Publ.

[9] Jabar, H. F., Abdul-Amir, R. H. & Shubber, A. A. 2018. DEVELOPING AN EVALUATION MODEL OF TIRE/PAVEMENT NOISE. Global Journal of Engineering Science and Research Management.

[10] Hanson, D.I. and R.S. James, *Colorado DOT tire/pavement noise study*. 2004, Citeseer.

[11] Kephalopoulos, S., M. Paviotti, and F. Anfosso-Lédée, *Common noise assessment methods in Europe (CNOSSOS-EU)*. 2012, Publications Office of the European Union. p. 180 p.

[12] Zhang, Y., J.G. McDaniel, and M.L. Wang. *Pavement macrotexture estimation using principal component analysis of tire/road noise*. in *Nondestructive Characterization for Composite Materials, Aerospace Engineering, Civil Infrastructure, and Homeland Security 2014*. 2014. International Society for Optics and Photonics.

[13] AASHTO, T., *Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method*. 2016. p. 17.