Kufa Journal of Engineering
Vol. 10, No. 2, April 2019, P.P. 101-113
Received 29 May, 2018, accepted 26 June 2018

DEVELOPING A MODEL FOR EVALUATION OF TIRE NOISE ON DIFFERENT TEST PAVEMENT SECTIONS

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http://dx.doi.org/10.30572/2018/kje/100208

ABSTRACT

The objective of this study is to develop a model for evaluating tire/ pavement noise of the various in-service pavement sections in Baghdad city. The scope of this work includes field noise measurements for three selected conventional asphalt concrete roads which are (Senaha Street constructed in 2010), Palestine Street (resurfaced in 2012) and Street2 Locality902 (newly resurfaced in 2017) and one concrete Muhammad Al-Kassim (constructed in 1983). The tested section was selected according to AASHTO TP76 which requires the length of the section to be 440 ft. at varying constant speeds such as(20,40,60,80) km/h using two types of tire (235/45R18, 185/65R15) KUMHO tire and at a different temperature from(10-32)°C. The test Method used in this study is the On-board sound intensity (OBSI) technique that measures tire-pavement noise at the source applying specialized microphones fixed on the right rear tire near the tire-pavement interface. OBSI had been used withseparateprobesoundlevelmetermodelSL-4013. The results showed for tires type (235/45R18)and (185/65R15) an average differences of about (6, 8.6, 9.4, 3) dB(A) was observed between Asphalt Concrete (AC) sections and Portland Cement Concrete (PCC) section at speed (20, 40, 60and 80) km/h. respectively. Noise increases in about 5-10 dB (A) for each increase of 20 km / h, and there is a decrease in the noise of about one decibel for the 10°C increase in temperature.

KEYWORD: Tire/pavement noise, OBSI, Lurton Data, sound level, separate probe.

1. INTRODUCTION

The tire-pavement noise is a problem of increasing concern for road agencies in most developed countries. It is also a factor among the pavement functional properties that is making its way into the considerations for pavement type selection. At speeds more than 40 km/h, tire-road interaction is the main source of highway noise (Sandberg and Ejsmont, 2002). It is expected that tire-road noise accounts for about 75–90% of the overall highway noise energy. The test method used in this study is the popular method on-board sound intensity (OBSI) technique (Erwin Kohler, (2009). OBSI is the most popular technique to measure tire-pavement noise, which gives more detail for tire-pavement noise level at the source. This method has gained fame, and its use has become increasingly common in the United States because pavement acoustics can be studied in detail. Also, the use of (OBSI) gives a full description of the road when used as a testing method. This paper explains the basic concepts of OBSI whose details are available in (AASHTO TP 76-12, 2011) and its development for the simple reason that the method offers itself to future implementation in pavement management systems. To simplify innovation, this paper gives an overview about noise measurement methodologies focusing on the On-Board Sound Intensity (OBSI) method with a single probe and a practical application of this technique to determine the effects of environmental conditions and vehicle speeds on tire/pavement noise. Four different site locations have been selected in Baghdad city with four different speeds: 20, 40, 60and 80 km/h were used for testing with the target of determining the rate of change of the overall sound intensity level with respect to speed. The data have been taken when the street is almost empty so that no additional noise effect on the measured value. In addition. The idea of this study is to use the sound intensity system of tire/pavement noise for evaluating the performance of highway pavements in-situ and show the variability of tire/pavement noise measured with the On-Board Sound Intensity (OBSI) method. This research also studies the effects of vehicle speed, the influence of temperature, effects of different used tires and the role each acting in the generation of noise at the tire-pavement interface**.** The sound is measured in decibels dB (A) correspond to human hearing A-weighting scale (Robert Bernhard, Roger L. Wayson2004).

This process only required the use of a fixture to hold the SI (sound intensity) microphones and can be readily used on most vehicles. This method can be used anywhere to get reliable results. Different temperatures ranging from (10° to 32°) °C is used and the measurements continued for several months (from October 2017 to Jan 2018).

2. METHODOLOGY

Tire-pavement noise was measured with (OBSI) technique according to the American Association of State Highway and Transportation Officials (AASHTO standard TP 76-12,2011) OBSI apparatus (see the left panel of Fig. 1 was used during the test. The diagram model of the system is presented in the right panel of Fig. 1.

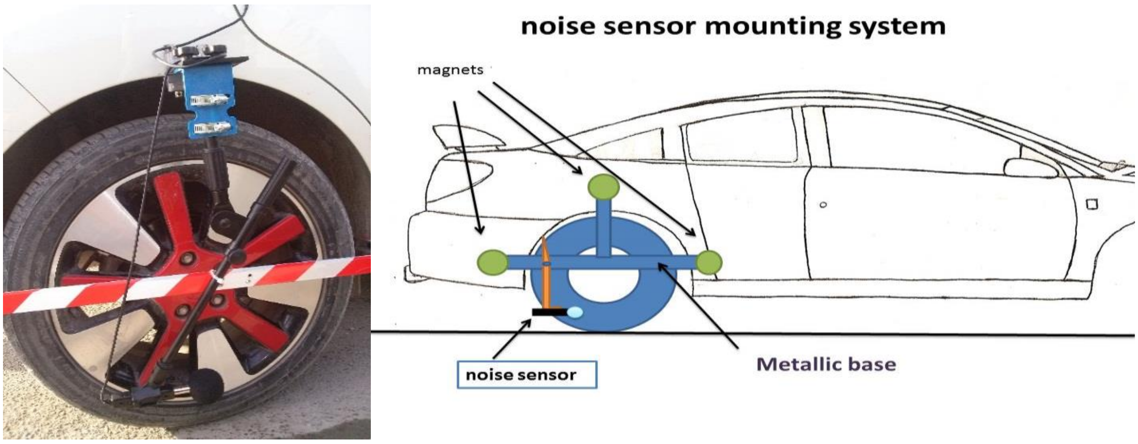

Fig. 1. Test vehicle sensor On-Board Sound Intensity (OBSI) system.

3. TEST PROCEDURE

Data is acquired over a 440-ft section of pavement at a constant speed 20, 40, 60, 80 and 100 km/h depending on local conditions. The timelines for every speed were selected to test 440 ft. (134 m) of the sections according to (AASHTO TP 76 -12, 2011). Single probe of one microphone is placed at the right back tire (passenger side). As shown in Fig. 1, the microphone see is located at distance (3) inches (76.2 mm) over the pavement surface and (4) inches (101. 6 mm) from the side of the tire. The test is repeated two times on the same pavement section. The result is the average value of the two trails of measurements.

3.1. Description of Test Parameters

The OBSI system used to reach real measurements contains:

- Devices: sound measuring devices were used (one sound level meter with the separate probe, RS-232 Model: SL-4013, 1 kHz. One microphone for sound intensity, 10 m extension cables).
- Software: multi-displays, data acquisition software model: SW-U801-WIN, Iso-9001, CE, And IEC1010, cable for RS232 interface to USB port model: USB-01. The measured data are sent to computer to be processed using Lurton Data Acquisition software (Software for u-p instrument DMM) to obtain the sound intensity. See Fig. 2.

- The air pressure of tires were checked before staring the test. Cones were used to mark the beginning of each test section. The speed was monitored by GPS speedometer. The test used two vehicles for measurements, KIA soul model 2016 having gross weight of 1820 Kg, and KIA Rio model 2017 having gross weight of 1600 Kg.

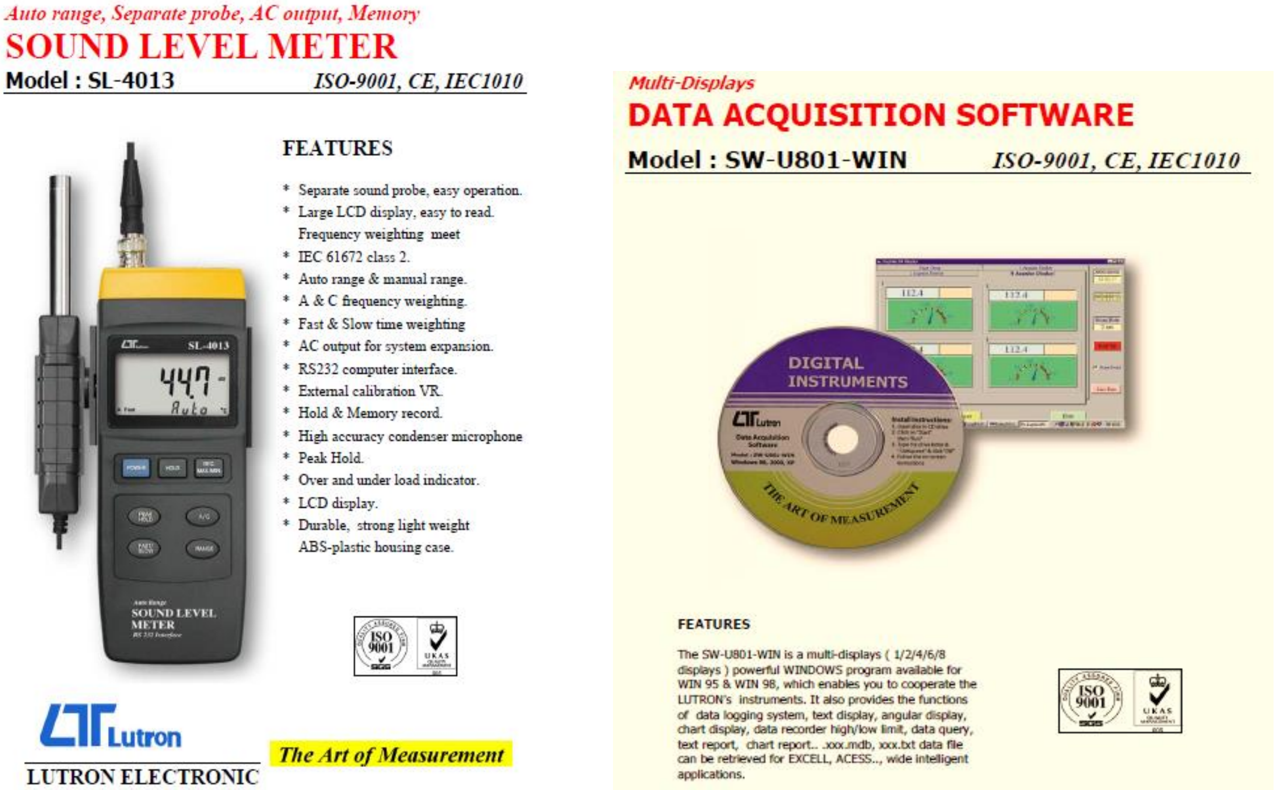

Fig. 2. Sound Level Meter and Data acquisition software.

3.2. Test Sites and weather condition

The test includes four test section according to(AASHTO Specification TP 76-12, 2011) which requires test sections 440 ft. to put a shape on the performance of different pavements for the tire/pavement noise generation such as (Sinaha street, Palestine, Muhammad-AL-Kassim highway concrete pavement, Street 2 Locality 902 (new resurfaced asphalt pavement). Testing speed (20, 40, 60, and 80) km/h, the air temperatures, barometric pressure was also measured and recorded during testing. Two tires were used like

(235/45R18, 185/65 R15) KUMHO Tire in the test. Details of The site locations and surface types are given in Table1, Table 2 and Fig.3 shows the test section.

Table 1. The test site for the first run by SOUL car tire (235/45R18).

Site	Route	Surface(year of construction)	Weather condition
1	Sinaha	Asphalt(2010)	25°/1012mbar/19%humidity
2	Palestine	Asphalt(2012)	27°/1012mbar/19%humidity
3	Street2 /902 Locality	Asphalt overlay(2017)	13°/1014mbar/50% humidity
4	Muhammad –AL-Kassim	Concrete(1983)	32°/1010 mbar/19% humidity

Table 2. The test site for the second run by RIO car tire (185/65R15).

Site	Route	Surface(year of construction)	Weather condition
1	Sinaha	Asphalt(2010)	13°/1014mbar/36%humidity
2	Palestine	Asphalt(2012)	14°/1012mbar/53%humidity
3	Street2 /902 Locality	Asphalt overlay(2017)	10°/1020mbar/41% humidity
4	Muhammad –AL-Kassim	Concrete(1983)	13°/1012 mbar/58% humidity

Fig. 3. Test pavement sections Street2 Locality902, Sinaha Street, Palestine Street and Muhammad-AL-Kassim highway. Respectively.

3.3. Temperature effect on tire/pavement noise:-

In this research, three tests were performed. The only variable considered in this work is the temperature. The following factors were considered constant: (Hans Bendtsen, Qing Lu and Erwin Kohler, 2009):-

- The same acoustic measurement equipment.
- Same tire measurement.
- Same rubber hardness and inflation pressure of the measurement tire.

- No changes in age, tear and wear of tire.
- Measure tire fixed on the same vehicle.
- Measurement operator is same.
- No changes in pavement condition, the same section was followed for each three test.

Case study/ Palestine Street measured by using tire (235/45R18) KUMHO at a different temperature as shown in the Table 3.

Table 3. The results of three test for the same section of Palestine Street, by use of Soul car tire235/45R18 at different temperature and constant speed 60 km/h.

Number of tests	Date	Time	Temperature(Celsius)	Average dBA
First test	13-Oct-17	11:02:22 AM	32°	89.1
Second test	21-Nov-17	11:28:20 AM	21°	90.2
Third test	12-Jan-18	8:12:28 AM	11°	91.2

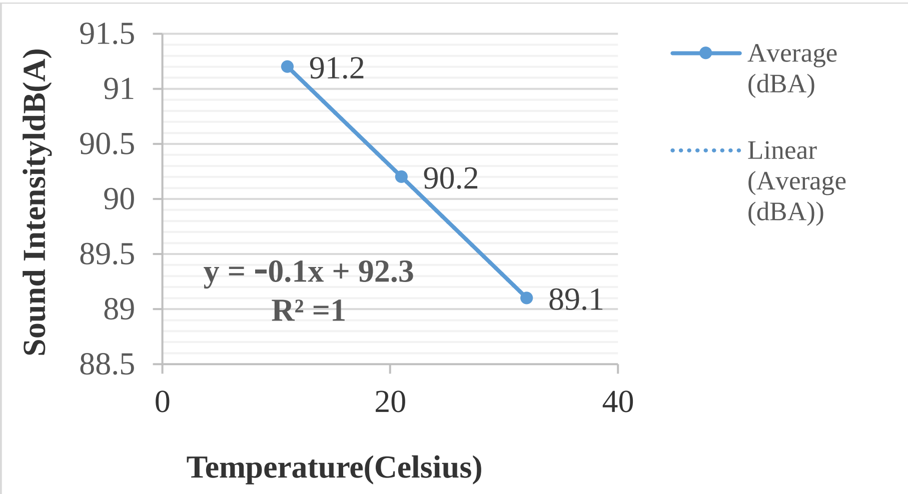

Fig. 4. The influences of air temperature on the sound intensity level at a constant speed of 60 km/h.

R-squared (R^2) is a measure of the goodness of fit of the trend line to the data value of R range from (0-1).in Fig. 4 a value of R^2 is equal to 1 which indicates a perfect fit. The effects of air temperature changes with OBSI measurements were studied only on one kind of surface (a 2-inch asphalt resurfaced in 2010), the results are consistent with other research in literature. For, example Mogrovejo, et al., (2012) have stated that the temperature effects on tire-pavement noise by experimental methods. It is shown that the noise level will decrease with increasing air temperature. Fig. 4 shows that there is a decrease in noise level when the temperature increases. It is possible to find the average of these slope values and to determine the average decrease in noise for all measurements. The R2 values derived from the equations represent the relationship between noise and air temperature which are acceptable. Overall. The effect of temperature is raised about one decibel for the 10°C decrease in temperature.

3.4. Speed effect on test results:

1- The first test was done on a selected test section with various speed such as 20, 40, 60 and 80 km/h the tire type was 235/45 R18 at a different temperature range (13°-32°) C°. The measurement results for two trails as seen in Fig.5 since the average correction term is below 1 dB, both the temperature and pressure effects did not have a strong effect on the noise levels, and therefore, were not applied to the measurements (Illingworth and Rodkin, 2010)

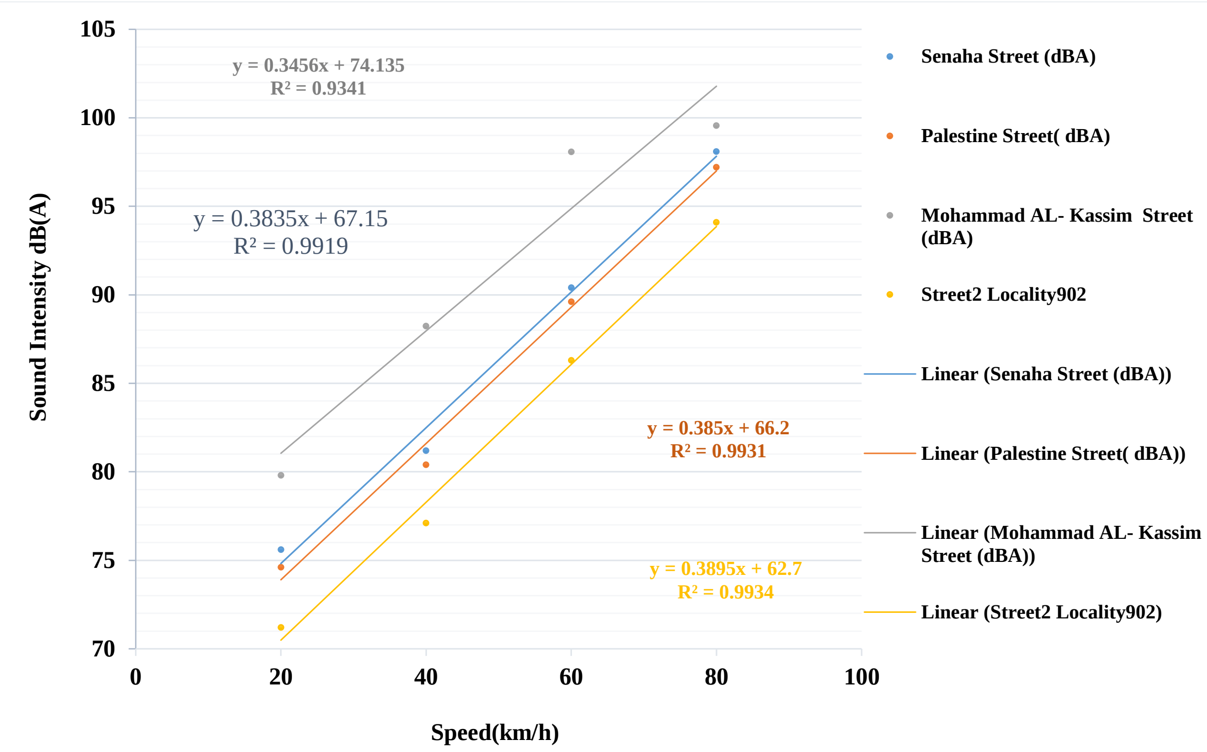

Fig. 5. Different Pavement Sections with Different Speed by using Tire Type (235 /45 R18).

2- The second test was done for the same selected section with speed 20, 40, 60 and 80 Km/h. The measurement results for two trails none of the data have been temperature corrected due to the fact that there was nearly no big difference in air temperature during Measuring the temperature range from (10°-14°) Celsius for tire type (185/65R15) as seen in Fig.6.

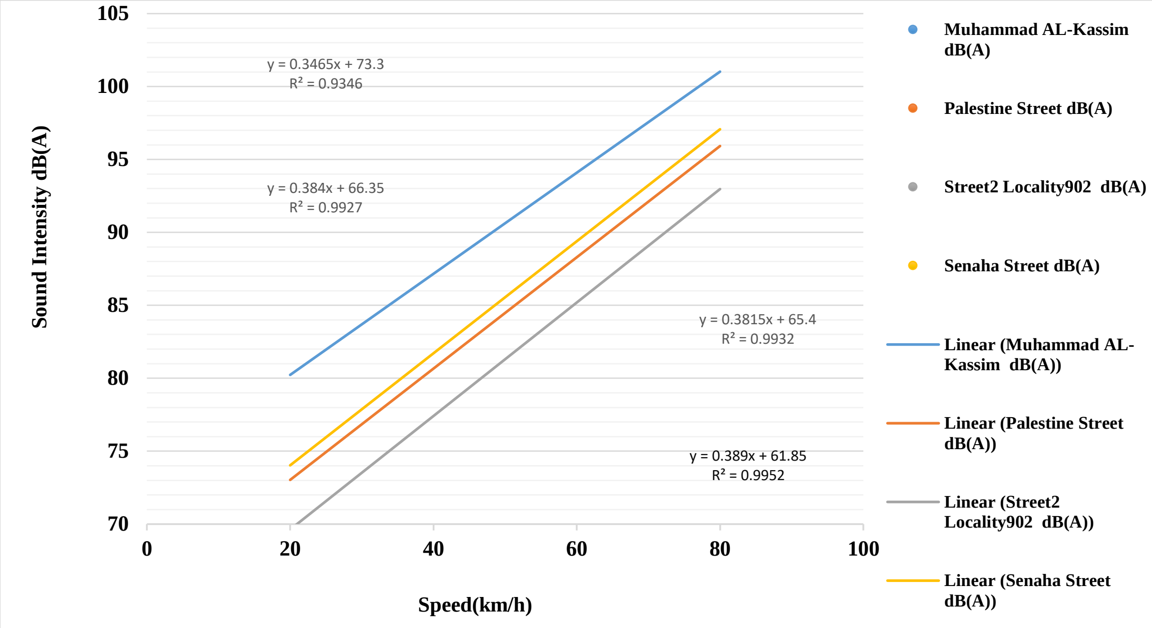

Fig. 6. Different Pavement Sections with Different Speed by using Tire Type (185 /65 R15).

As seen in Fig. 5 and Fig. 6 for the two type of tires, the highest average noise level was observed for the PCC section (Mohamed-AL-Kassim highway) in comparison with the three AC sections. In addition, the PCC section had rough surface characteristics based on the manual observations apart from the joints, which could have increased the noise levels greatly.

4. REGRESSION ANALYSIS METHOD

To model the tire/pavement noise behavior and to determine the effects of speed, tire width, temperature and pavement age on the noise a multiple regression analysis was done for one type of pavement only (asphalt pavement) based on 24 test results as seen in Table 4**.** Descriptive Statistics. N represents the number of tests. In Table 5, Coefficient of the first model stated in the following equation:

OBSI Average dB (A**)** =50.553 + 0.380ν - 0.081c + 0.248T+ 0.037W

OBSI= On-board sound intensity dB (A); ν = vehicle speed (km/h); c=Temperature (Celsius)

W = Tire width (mm) T= pavement age (year)

R^2 from the Model Summary Table 6 is equal to 0.986, the high value of R^2 seen as proof of a good fit and variables have a great role to play in the model from Table 7. ANOVAa the value of F is equal to 165.966 is high as shown by the p-value in the column Sig. This means that the variables played an important role in the model also, P-value (sig) is less than 0.05 indicates that coefficients are substantial at a 95 % confidence level. From Table 7 it can be seen that pavement age (T), vehicle speed, tire width, and temperature are statistically important in affecting tire-pavement noise, a positive coefficients value indicates that tire/pavement noise increases with pavement age, vehicle speed, tire width. The negative coefficient indicates that tire/pavement noise decrease when temperature increase.

Table4. Descriptive Statistics

	Mean	Std. Deviation	N
Average dBA	84.1577	9.19029	24
speed(km/h)	50.0000	22.84161	24
CELSIUS	17.0000	6.64635	24
pavement (age)	4.6667	3.47246	24
tire width	210.0000	25.53770	24

Table5.Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	50.553	4.576		11.047	.000	40.975	60.132
speed(km/h)	.380	.015	.945	24.811	.000	.348	.412
Temperature(Celsius)	-.081	.126	-.059	-.643	.528	-.345	.183
pavement (age)	.755	.168	.285	4.494	.000	.404	1.107
tire width(mm)	.059	.027	.165	2.177	.042	.002	.116

a. Dependent Variable: Average dBA

Table6. Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.986[a]	.972	.967	1.67860	.972	167.60	4	19	.000	1.509

a. Predictors: (Constant), tire width, pavement (age), speed(km/h), Temperature(CELSIUS)

b. Dependent Variable: Average dBA

OBSI (Average dBA) =39.965 + 0.380 ν - 0.081c+ 0.755T+ 0.013L

OOBSI= overall on-board sound intensity, dB (A); ν = vehicle speed (km/h)
L = vehicle weight (kg); T= pavement age (year); c=Temperature (Celsius)

Table7.ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1889.077	4	472.269	167.609	.000[b]
	Residual	53.536	19	2.818		
	Total	1942.613	23			

a. Dependent Variable: Average dBA
b. Predictors: (Constant), tire width, pavement (age), speed(km/h), CELSIUS

The second model contain vehicle weight (Kg), temperature(c°), speed km/h, and pavement age based on24 reads from Table8. The regression model from Table 9 .Coefficient is stated bellow:

Table 8. Descriptive Statistics.

	Mean	Std. Deviation	N
Average dBA	84.1577	9.19029	24
speed(km/h)	50.0000	22.84161	24
Temp(CELSIUS)	17.0000	6.64635	24
pavement (age)	4.6667	3.47246	24
Vehicle weight(kg)	1710.0000	112.36586	24

Table 9. Coefficients[a].

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	39.965	9.353		4.273	.000	20.389	59.542
	speed(km/h)	.380	.015	.945	24.811	.000	.348	.412
	Temperature(Celsius)	-.081	.126	-.059	-.643	.528	-.345	.183
	pavement (age)	.755	.168	.285	4.494	.000	.404	1.107
	Vehicle weight(kg)	.013	.006	.165	2.177	.042	.001	.026

a. Dependent Variable: Average dBA

For the second model R^2 is presented in Table 10. While, model Summaryb and F value are shown in Table11. ANOVA[a].is similar to the first model which includes pavement age, different speed, test vehicles weights and temperature. R^2 is equal to 0.986 indicating that generally, the models for each vehicle fit the measurement data. The results show that at a 95 % confidence level, pavement age, vehicle speed, temperature and vehicle weight are statistically significant in affecting tire/pavement noise**.**

Table10 .Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.986[a]	.972	.967	1.67860	.972	167.61	4	19	.000	1.509

a. Predictors: (Constant), Load(kg), pavement (age), speed(km/h),Temperature(CELSIUS)

b. Dependent Variable: Average dBA

Table11.ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1889.077	4	472.269	167.609	.000[b]
	Residual	53.536	19	2.818		
	Total	1942.613	23			

a. Dependent Variable: Average dBA

b. Predictors: (Constant), Vehicle weight(kg), pavement (age),speed(km/h),Temperature (Celsius)

5. CONCLUSIONS

The study of tire-pavement noise allowed for the following conclusions:

1. The use of digital sound level meter for noise pavement recording, pavement evaluation, subsequent classification. It is Easy, simple, need less time in seconds and far from risk compare to visual inspection.
2. 2-There is an important variation on the noise generated by tire/pavement interaction measured at different speeds the change in the sound intensity dB (A) for every 20 km/h variation is in the range that may be noticed by human hearing. Taking into account that a

human ear can observe a change in noise level as low as 3 dBA, the overall noise increases by about (5-10) dBA for every 20 km/h increment.

3. The relationship between tire-pavement noise and air temperature can be approximated by a linear relation. For 10 decrease in temperature, there is an increase about one decibel which indicates a small influence of air temperature on tire/pavement noise levels. For this reason, corrections are recommended for measurements at different temperatures, especially if measurements are made at relatively high temperatures.
4. Tire-pavement noise level basically increases with pavement age. For newly paved overlays sound intensity measured on, Street 2Locality 902 is lower than the values measured on Muhammad AL-Kassim Street Sinaha Street, Palestine Street.
5. Multiple linear regression analysis on all sites and with two types of tire shows that sound intensity (dBA) Increases with pavement age, vehicle speed, tire width. and vehicle load. While it decreases when temperature increase.

6. ACKNOWLEDGMENT

The authors would like to thank the staff of the Civil Engineering Department / University of Technology for their assistance and support and Projects Office Mayoralty of Baghdad in the Iraq for facilitate and provide assistance data.

7. REFERENCES

AASHTO TP 76-12 designation, (2011), “Standard Method for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method in AASHTO”. American Association of State Highway and Transportation Officials, pp.1-6

Erwin Kohler (2009) tire-pavement noise measurement with the on-Board Sound intensity method (OBSI) Paper ICMPA154 OARD METHOD, 8th International Conference on Managing Pavement Assets, pp.4-6

Hans Bendtsen, Qing Lu, Erwin Kohler, (2009), “Temperature influence on road traffic noise”. Californian OBSI measurement study Report 169, pp.43-44

Illingworth, Rodkin, (2010), “Tire-Noise Performance of Montana Highway Pavements505 Petaluma Boulevard South Petaluma”. California 94952, pp.12-13

Mogrovejo, D.E., Flintsch, G.W., de León Izeppi, E.D. and McGhee, K.K., (2014), "Effect of air temperature and vehicle speed on tire/pavement noise measured with on-board sound intensity methodology". IRF, p.34.

Robert Bernhard, Roger L. Wayson (2004), "An Introduction to Tire/Pavement Noise of Asphalt Pavement". Purdue University, University of Central Florida, pp.5-8

Ulf Sandberg, Jerzy A. Ejsmont, (2002), "Tire /Road Noise Reference Book", pp. 1-5.