Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 12 Volume 26 December 2020

Civil and Architectural Engineering

Development of Regression Models for Predicting Pavement Condition Index from the International Roughness Index

Muataz Safaa Abed*
MSc of Highways and Transportation Engineering
Department of Engineering in Al-Diwaniyah Governorate
Al-Diwaniyah, Iraq
Email: **muatazmuataz25@gmail.com**

ABSTRACT

Flexible pavements are considered an essential element of transportation infrastructure. So, evaluations of flexible pavement performance are necessary for the proper management of transportation infrastructure. Pavement condition index (PCI) and international roughness index (IRI) are common indices applied to evaluate pavement surface conditions. However, the pavement condition surveys to calculate PCI are costly and time-consuming as compared to IRI. This article focuses on developing regression models that predict PCI from IRI. Eighty-three flexible pavement sections, with section length equal to 250 m, were selected in Al-Diwaniyah, Iraq, to develop PCI-IRI relationships. In terms of the quantity and severity of each observed distress, the pavement condition surveys were conducted by actually walking through all the sections. Using these data, PCI was calculated utilizing Micro PAVER software. Dynatest Road Surface Profiler (RSP) was used to collect IRI data of all the sections. Using the SPSS software, linear and nonlinear regressions have been used for developing two models between PCI and IRI based on the collected data. These models have the coefficients of determination (R^2) equal to 0.715 and 0.722 for linear and quadratic models. Finally, the results indicate the linear and quadratic models are acceptable to predict PCI from IRI directly.

Keywords: pavement evaluation, International Roughness Index, Pavement Condition Index, pavement roughness.

تطوير نماذج الانحدار للتنبؤ بمؤشر حالة التبليط من مؤشر الخشونة العالمي

معتز صفاء عبد *
ماجستير في هندسة الطرق و النقل
قسم الهندسة – ديوان محافظة الديوانية

الخلاصة

يعد التبليط المرن عنصر مهم في البنى التحتية للنقل. لذلك ، فإن تقييم أداء التبليط المرن ضروري للإدارة السليمة للبنى التحتية للنقل. تعد مؤشرات حالة التبليط PCI و الخشونة العالمي IRI من بين المؤشرات الشائعة التي يتم تطبيقها لتقييم حالة سطح

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2020.12.05

Article received: 29/3/2020
Article accepted: 14/7/2020
Article published:1/12/2020

التبليط. ومع ذلك ، فإن عمليات مسح حالة التبليط المطلوبة لحساب PCI مكلفة ومضيعة للوقت مقارنة مع IRI. تركز هذه الدراسة على تطوير نماذج الانحدار التي تمكننا من الحصول على قيم PCI من IRI. تم اختيار ثلاثة وثمانين مقطعًا من التبليط المرن ، بطول مقطع 250 متر ، في محافظة الديوانية في العراق لتطوير علاقات بين PCI و IRI. تم أجراء عمليات مسح حالة التبليط ، تثبيت نوع وكمية وشدة كل ضرر تمت ملاحظته ، من خلال المشي عبر جميع المقاطع المختارة. باستخدام هذه البيانات ، تم حساب PCI بالاستعانة ببرنامج (Micro PAVER). تم الاستعانة بجهاز (Dynatest Road Surface Profiler) لجمع بيانات IRI لجميع المقاطع. تم تطبيق معادلات الانحدارات الخطية وغير الخطية لتطوير نموذجين بين PCI و IRI بناءً على البيانات التي تم جمعها وباستخدام برنامج SPSS. أن معاملات (R^2) للنماذج الخطية والتربيعية الناتجة هي 0.715 و 0.722 على التوالي. اخيراً، تشير النتائج إلى أن النماذج الخطية والتربيعية مقبولة للحصول على PCI من IRI مباشرة.

الكلمات الرئيسية: تقييم التبليط، مؤشر الخشونة العالمي، مؤشر حالة التبليط، خشونة التبليط.

1. INTRODUCTION

Roadway pavements are constructed to provide safe, quick, and comfortable travel. The lack of these features refers to functional insufficiency in the pavement. The accurate and reliable evaluation of the pavement surface network condition is necessary for an effective pavement management system (PMS) **(ASTM, 2017)**. However, the complete performance evaluation of pavement is wider than just an evaluation of the surface distresses. Other factors, such as friction, structural capacity, and ride quality, are also necessary components for a useful PMS. Presently, the ride quality is considered as an essential component of pavement performance and driver satisfaction **(Elhadidy et al., 2019)**. Various indices, which are used for the evaluation of pavement performance, such as Pavement Condition Index (PCI), International Roughness Index (IRI), Present Serviceability Rating (PSR), Pavement Condition Rating (PCR), etc. have been generally utilized to specify maintenance techniques for the pavements **(Shah et al., 2013).**

The PCI is a widely used index to pavement condition evaluation by the USA Corps of Engineers. It is computed through a visual inspection survey method that includes measuring the type, severity, and quantity of each pavement distress **(Shahin et al., 1978, Garber and Hoel, 2009)**. So, this index is a numerical indicator that gives an amount of the current condition of pavement based on observed distresses on the pavement surface. PCI varies between 0 and 100 (where 100 represents pavements in perfect condition) **(Shahin, 2005, ASTM, 2017)**. The condition of the overall pavement section has been obtained by an average of the PCIs for several sub-segments **(Attoh-Okine and Adarkwa, 2013)**.

The IRI was a product of the International Road Roughness Experiment (IRRE), managed by research groups from several countries (Brazil, United States… etc.) to recognize such an index. Therefore it is called international roughness index. IRI values is ranging between zero and sixteen, where zero refers to a smoother pavement while sixteen represents a rougher pavement **(Sayers, 1995)**. The IRI is defined as a ratio of the accumulated suspension vertical movement of a vehicle divided by the distance traveled which is obtained from an athletic representation of a simulated quarter-car traveling a measured profile at eighty km/hour **(Sayers, 1998)**. Also, the measured profile is obtained using a road-meter installed on a vehicle **(Shahin, 2005).** Due to the IRI (stability over time and transferability throughout the word), it has become a widely used parameter, presumably, the most employed road index worldwide **(Zamora Alvarez et al., 2018).** So, for IRI determination, AASHTO and ASTM recommend that the test section's length should be not less than 0.1 miles **(AASHTO-R43, 2013, ASTM-E867, 2002)**.

Many devices, procedures, and systems are used to calculate and represent pavement roughness worldwide. These techniques are different in many aspects, such as technical complication, accuracy, cost, and use speed. Dynatest Road Surface Profilometer (RSP) system is one of these techniques and is designed to provide high-quality, advanced, automated pavement roughness. In addition, this system is regarded as a measurement solution for engineers in the world. It can operate by one person and collect data at speed ranging from 25 to 110 km/hour. Consequently, the RSP could be used in various types of roads effectively **(DYNATEST, 2005)**.

The pavement condition evaluation provides important information about the pavement used to pave performance analysis, determine maintenance priorities, expect maintenance requirements, and fund allocation **(Timm and McQueen, 2004).**

Accordingly, the pavement condition surveys provide an evaluation of the condition acceptability of a pavement section and details that need to create a decision relating to maintenance needs and methods.

In Al-Diwaniyah city, the flexible pavement network suffers from the absence of an appropriate pavement management system, and effective maintenance techniques are absent. Also, the application of pavement condition indices is absent, whereas the selection of the best pavement maintenance time and technique depends on the evaluation of the pavement situation. Therefore, a determination of PCI is required to identify the proper technique of pavement maintenance and rehabilitation. However, the pavement condition surveys to calculate PCI is costly and time-consuming as compared to IRI.

2. OBJECTIVES

The objective of this study is the development of reliable and accurate models between PCI and IRI. Accordingly, the development of these models is necessary to guide the agencies and engineers to proper scheduling of flexible pavement maintenance and reduce the need for working hours and data collection costs.

3. LITERATURE REVIEW

(Saleh et al., 2008) presented a relationship to predict pavement condition index from observed pavement distresses of flexible pavement. Eighty flexible pavement sections in 4 sites in the study area were selected to build this relationship. The collected data included eleven pavement distress types: alligator cracking, longitudinal and transverse cracking, block cracking, slippage cracking, patching, rutting, bleeding, pothole, depression, and polishing. The PCI values were computed using the Micro PAVER software system of all pavement sections. A stepwise regression method, using the SPSS computer package, applied to determine this relationship. The resulted relationship is obtainable in the following equation:

$$PCI = 85.336 - 0.4416 * Slip - 37.2875 * RD - 2.3254 * Poth \quad (1)$$

where:
$R^2 = 0.787$
Slip = slippage crack (m^2), RD = Rut depth (in mm), Poth = potholes (in number).

In India, a relationship between IRI and pavement distresses was developed by Prasad **(Prasad et al., 2013)**. Bump Integrator was applied to collect pavement roughness data, which was calibrated by MERLIN (machine for evaluating roughness using low-cost instrumentation). The determination coefficient reached 0.66.

A study by Mubaraki was conducted, which focused on a correlation between IRI and some distress types **(Mubaraki, 2016)**. The distresses involved raveling, rutting, and cracking. Three correlations have been developed involving IRI against raveling, rutting, and cracking. The analysis results indicated the raveling and cracking correlate with IRI, and it might be specified as ride quality distress. At the same time, the rutting did not show a significant correlation with IRI.

Abdelaziz et al. developed ANNs and regression models to predict IRI as a function of pavement distresses depend on the LTPP database. The developed models were IRI prediction as a function of age, IRI initial, transverse cracking (all severities), alligator fatigue cracking (all severities), and standard deviation of the rut depth (SDRUT). The R^2 of regression analysis was 0.57, while the R^2 was 0.75 of the ANNs model **(Abdelaziz et al., 2017, Abdelaziz et al., 2020)**.

The presented studies displayed that PCI and IRI are both functions of the pavement distresses. Consequently, relationships between and PCI should be developed. Few researchers developed this relationship with acceptable statistical validity.

A study was conducted by **(Dewan and Smith, 2002)** to develop a model between the international roughness index and pavement condition index for asphalt pavement. The length of the test section is equal to 500 ft (152.4 m. The resulted relationship is as the following:

$$IRI = 0.0171(153 - PCI) \quad (2)$$

where IRI is in m/km

(Park et al., 2007) presented research to develop a relationship between PCI and IRI. Data-Pave software provided the roughness data of pavement sections from the North Atlantic region, which inspected LTPP research. Moreover, PCI values of the same sections calculated by using Micro PAVER software depend on distress data, which are provided by the LTPP database. The resulted models are obtained in the following equations:

$$Log\ PCI = -0.437\ log\ IRI + 2 \quad (3)$$

$$Log\ PCI = -0.481\ log\ IRI + 1.94 \quad (4)$$

R^2 values are 0.59 and 0.66 for Eq. (3) and Eq. (4) respectively.

IRI-PCI relationship was developed using neural network modeling by **(Vidya et al., 2013)**. Forty-three sections were surveyed, IRI values were measured manually by using MERLIN and PCI values calculated by a visual inspection method. The R^2 of the developed model is 0.86, which indicates satisfactory predictions.

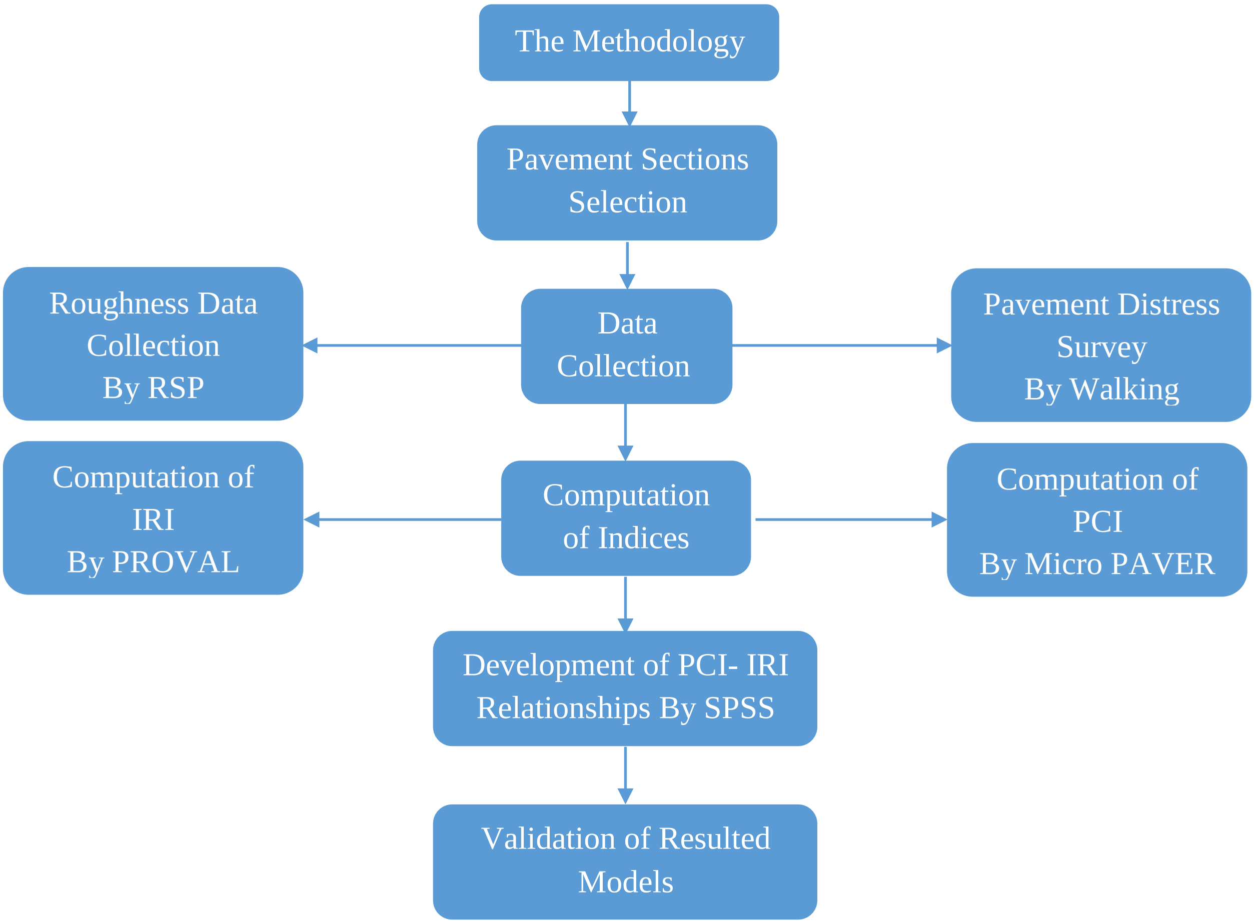
In Columbia, **(Arhin et al., 2015)** presented relationships to correlate PCI with IRI according to functional classification and pavement type. Throughout this study, specialized equipment was used to acquire IRI values, while PCI values were collected depending on the subjective evaluating of the pavement distress. The R^2 values of the resulted models are ranging between 0.56 and 0.82. These models are presented in **Table 1**.

Table 1. PCI- IRI models according to functional classification and pavement type.

Equations according to functional classification		Equations according to pavement type	
Freeways:	$PCI = 110.73 - 0.215\ (IRI)$	Asphalt:	$PCI = 120.02 - 0.224(IRI)$
Arterials:	$PCI = 114.15 - 0.206\ (IRI)$	Composite:	$PCI = 113.73 - 0.203\ (IRI)$
Collectors:	$PCI = 115.32 - 0.217\ (IRI)$	Concrete:	$PCI = 110.01 - 0.172(IRI)$
Locals:	$PCI = 110.31 - 0.186\ (IRI)$		

4. STUDY METHODOLOGY

The following chart explains the methodology of the present study:



5. PAVEMENT SECTIONS SELECTION

A total of eighty-three segments of flexible pavement in Al-Diwaniyah, Iraq, was used to develop PCI-IRI relationships. The pavement section length is equal to 250 meters. These sections are distributed in fifteen roads in the study area. The selected sections were uniform in numerous characteristics such as climate and topography. The selected sections also have the condition and roughness pavement variety from poor to good and have the same lengths.

6. DATA COLLECTION

6.1 Pavement Condition Index Data

Each observed distress's quantity and severity were collected depending on surveying by visual inspection of each section. A datasheet, hand odometer wheel, and tape were used in the surveying, as shown in **Fig. 1**. The manual of **(ASTM, 2017)** was adopted during the survey. Many types of distresses varied in severity and quantity, were observed in each selected pavement section. The observed pavement distresses were alligator cracking (all severities), block cracking (all severities), lane-shoulder drop off (low and medium severities), bumps and sags (all severities), corrugation (all severities), depression (all severities), transverse and longitudinal cracking (all severities), rutting (medium and high severities), patching (all severities), potholes (all severities), polished aggregate, and raveling (all severities). Based on these data, MicroPAVER software was used to determine PCI values for all sections in the present study.

6.2 International Roughness Index Data

Dyna-test Road Surface Profiler (RSP) system was used to collect the longitudinal profile elevations. The roughness measurement of all sections was conducted using the RSP system, which was installed on a pickup truck, as shown in **Fig. 2**. Each section's left lane was used to conduct the roughness measurements because it represents the most trafficable lane in the study area. Profile Viewing and Analysis software, version 3.61, **(PROVAL, 2016)** was utilized to calculate IRI for each pavement segment by analyzing data achieved by the RSP.

Figure 1. Pavement distresses measurements.

Figure 2. The RSP installation.

7. ANALYSIS OF DATA

IRI and PCI data were collected to determine the relationships between IRI and PCI. **Fig. 3** demonstrates the PCI values of all the selected sections. It can be shown from this figure that the condition of all the pavement sections ranging from serious, very poor, poor, fair to satisfactory, which means the pavement conditions of the selected sections were varied through these sections.

Also, the most frequent PCI values are between 55 and 41, which are frequent 35 times. While PCIs between 25 and 10 is the least frequent, which are frequent two times. The average PCI of all sections in the present study is equal to 53.

Fig. 4 demonstrates the IRI values of all selected sections. As shown in this figure, the IRI values are ranging between 1 and 9 m./km. Besides, the IRI values between 4.9 and 4 m/km are the most frequent, which are frequent 24 times. While IRI between 8.9 and 8 are the least frequent, which are frequent two times. The average IRI of all sections in the study area is equal to 4.346 m/km.

From the collected data, section number 47 has the highest value of IRI in the present study. Also, it suffers from very poor condition of the pavement. It has the least value of PCI. While, section number 9 has an acceptable roughness of pavement, where the IRI value is 1.951 m/km, with the highest PCI value. Section number 79 has a satisfactory condition of the pavement, where the PCI value is 76, and it has the least value of IRI in the study area.

Accordingly, while the pavement roughness is increasing, the pavement deterioration is accelerating.

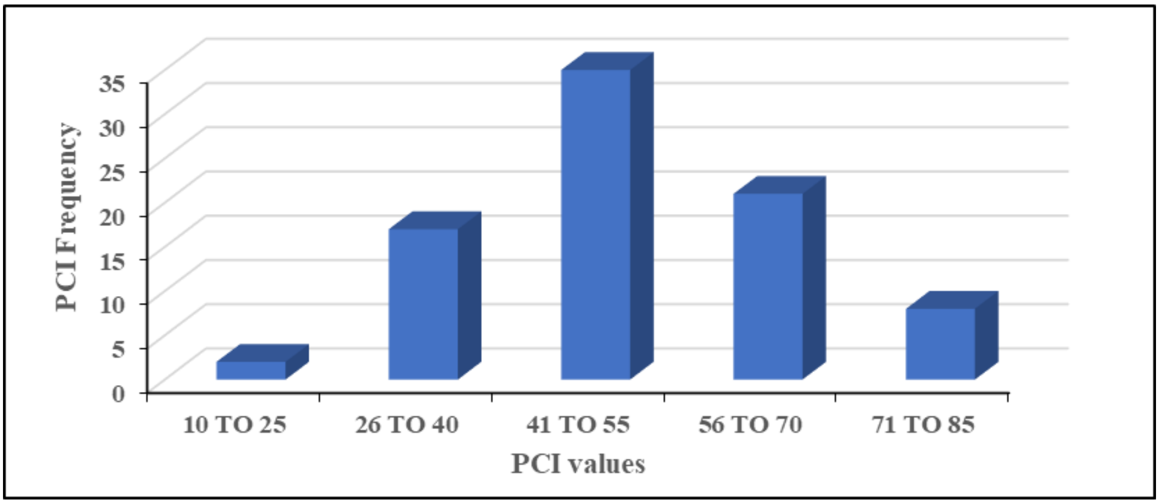


Figure 3. PCI values frequency in the present study.

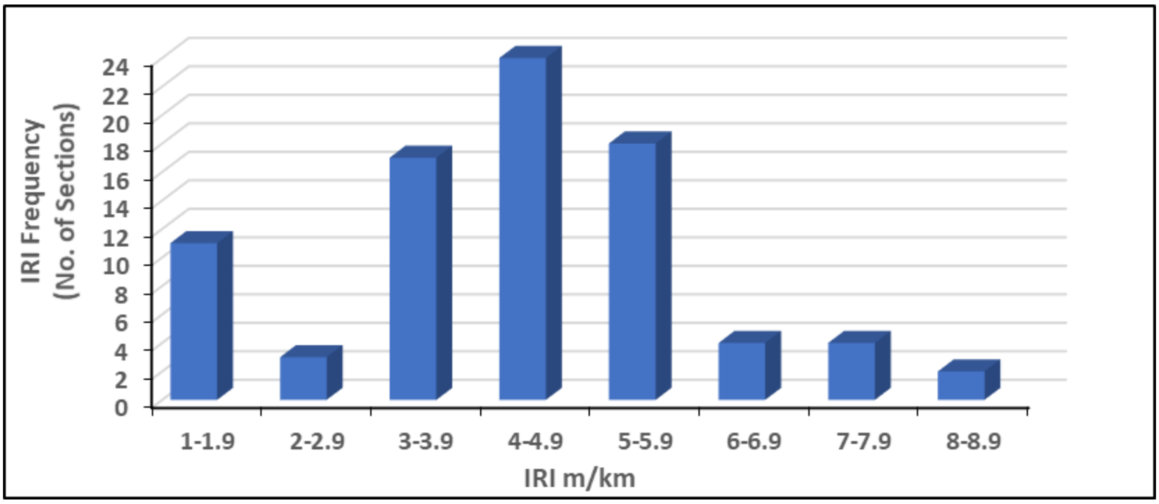


Figure 4. IRI values frequency in the present study.

8. DEVELOPMENT MODELS

The PCI and IRI data have been utilized for modeling and validation to develop a PCI-IRI relationship. IRI values have been taken as an independent variable, while PCI values have been considered as a dependent variable. Kolmogorov-Smirnov (K-S) test using SPSS software was applied to check the normality distribution of PCI and IRI values. A confidence level of 95% is used. From (K-S) results, the P-value is greater than 0.05; thus, the null hypothesis is proved. So, the distributions of PCI and IRI data are normal.

75% of the observed values, data of 63 sections, were used to build the models which were randomly selected by SPSS software. At the same time, the data of the remaining sections were kept of a validation process. SPSS software was used to determine a correlation degree and recognize a suitable relationship between IRI and PCI. Many trials have been conducted to identify the relationship forms, as shown in **Table 2**.

From **Table 2**, correlation coefficients of all the suggested relationships are varied from 0.768 to 0.849, which indicated an acceptable correlation of IRI with PCI. Also, the P-values of ANOVA (Analysis of Variance) test of all suggested relationships are close to zero, indicating that all these forms are acceptable as relationships correlate to PCI with IRI. Accordingly, (A) and (B) suggestion relationship forms are selected because they have high correlation coefficients (R) and determination coefficients (R^2).

Table 2. Suggested relationship forms.

Relationship Type		Suggestion Relationship Forms	R	R^2	P-value
A	Linear.	$PCI = x + (y * IRI)$	0.846	0.715	< 0.001
B	Quadra.	$PCI = x + (y1 * IRI) + (y2 * IRI^2)$	0.849	0.722	< 0.001
C	Inver.	$PCI = x + (y / IRI)$	0.769	0.593	< 0.001
D	Log.	$PCI = x + (y * \ln IRI)$	0.836	0.696	< 0.001
E	Comp.	$PCI = x * (y^{IRI})$	0.821	0.674	< 0.001
F	Power	$PCI = x * IRI^{y}$	0.781	0.606	< 0.001
G	Grow.	$\ln (PCI) = x + (y*IRI)$	0.821	0.674	< 0.001
H	Exp.	$PCI = x * (e^{(y*IRI)})$	0.821	0.674	< 0.001

Note: x, y are constants

Linear regression analysis was applied to build the model (A). In addition, the nonlinear regression analysis was used to build the model (B). **Tables 3** and **4** illustrate the statistic results for the developed models. The final models between IRI and PCI are presented in Eq. (5) and Eq. (6):

A: $PCI = -6.647\,IRI + 80.878$ (5)

B: $PCI = -9.031\,IRI + 0.283\,IRI2 + 85.119$ (6)

Table 3. The statistic results for the A model.

R	0.846
R square	0.715
Adjusted R square	0.713
Standard error of estimate	7.059

ANOVA					
Source	Sum of square	Df	Mean of squares	.	P-value
Regression	7630.822	1	7630.822	153.175	0.000
Residual	3038.894	61	49.819		
Total	10669.714	62			

parameter	Estimated Parameter B	t	P-value
(constant)	80.878	32.530	0.000
IRI	-6.647	-12.376	0.000

Table 4. The statistic results for the B model.

R	0.849
R square	0.722
Adjusted R square	0.713
Standard error of estimate	7.036

ANOVA					
Source	Sum of square	Df	Mean of squares	F	P-value
Regression	7698.217	2	3849.107	77.723	<<0.001
Residual	2971.499	60	49.526		
Total	10669.713	62			

Parameters	Estimated Parameter B	Std. Error
(constant)	85.119	4.4
IRI	-9.031	2.113
IRI^2	0.283	2.43

9. MODELS VALIDATION

A validation process of the developed models is a significant step in the building of the regression models. This process aims to evaluate developed models' ability to predict PCI and identify a prediction accuracy. The validation data, the reserved data of twenty sections, were used to determine PCI by substituting IRI values in (A) and (B) models.

For validation purposes, a paired T-test was conducted between the predicted and measured PCI values of the validation data. From **Table 5**, the t tabulated value, which is determined as explained in the Appendix, is more than the t calculated value. Subsequently, the null hypothesis is accepted, which means there is no significant difference between the predicted and measured values of (A) and (B) models at the 0.05 confidence level.

Table 5. Paired T-test of predicted and measured PCI values for A and B models.

	A Model				B Model			
	Average	No.	Std. dev.	Correlation	Average	No.	Std. dev.	Correlation
Meas. PCI	49.85	20	13.576	0.920	49.85	20	13.576	0.919
Pred. PCI	51.8	20	9.574		51.65	20	9.325	
t. Calcu.	1.438				1.294			
t. tabul.	2.09302				2.09302			

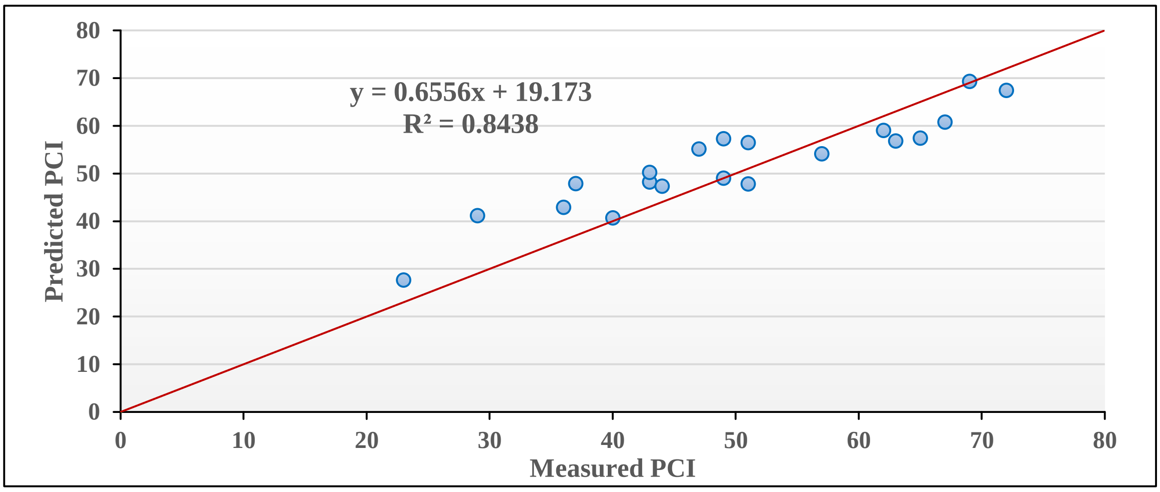


Figure 5. The validation of the A model.

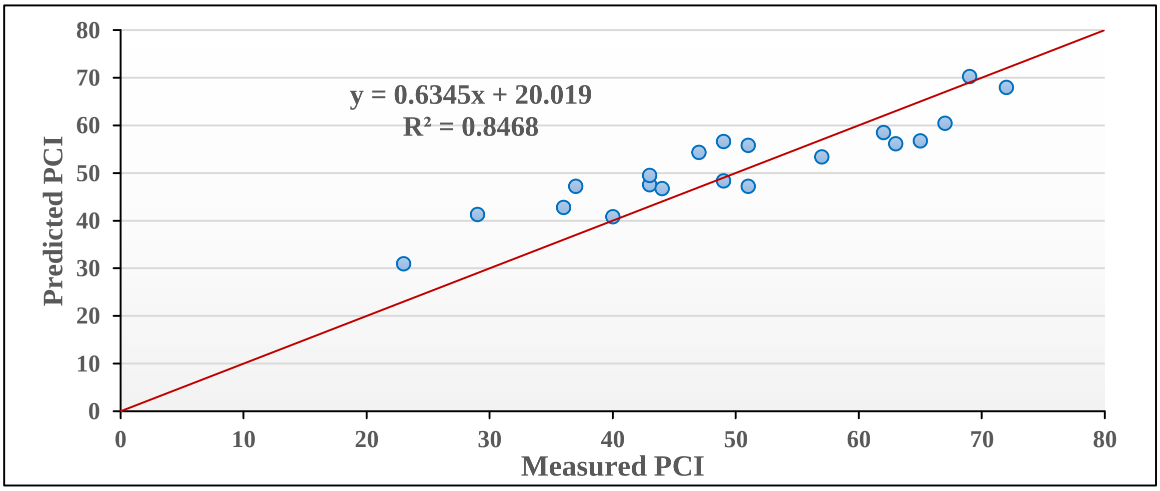


Figure 6. The validation of the B model.

As presented in **Fig. 5** and **Fig. 6**, plots were drawn between the predicted and measured PCI of the validation data with a view to validation. Lines in 45^o have been drawn to explain the distribution of points. From **Fig. 5** and **Fig. 6**, it can be observed that most of the points are close to this line, and the other points are not very far off. Also, R^2 values are 0.8438 and 0.8468 for (A) and (B) relationships, respectively. Thus, (A) and (B) models are considered to be valid. Therefore, these models can be used to predict PCI from IRI for flexible pavement.

10. DISCUSSION OF RESULTS

From the analysis of results, it can be understood that when the pavement condition was deteriorating, the PCI values were decreasing, and IRI values were increasing. But, a variation pattern between PCI and IRI is unsteady throughout the selected sections in the present study. This pattern has happened because the noticed pavement distress in the study area has various effects on PCI and IRI, where many distress types have an impact on IRI more than PCI and vice versa.

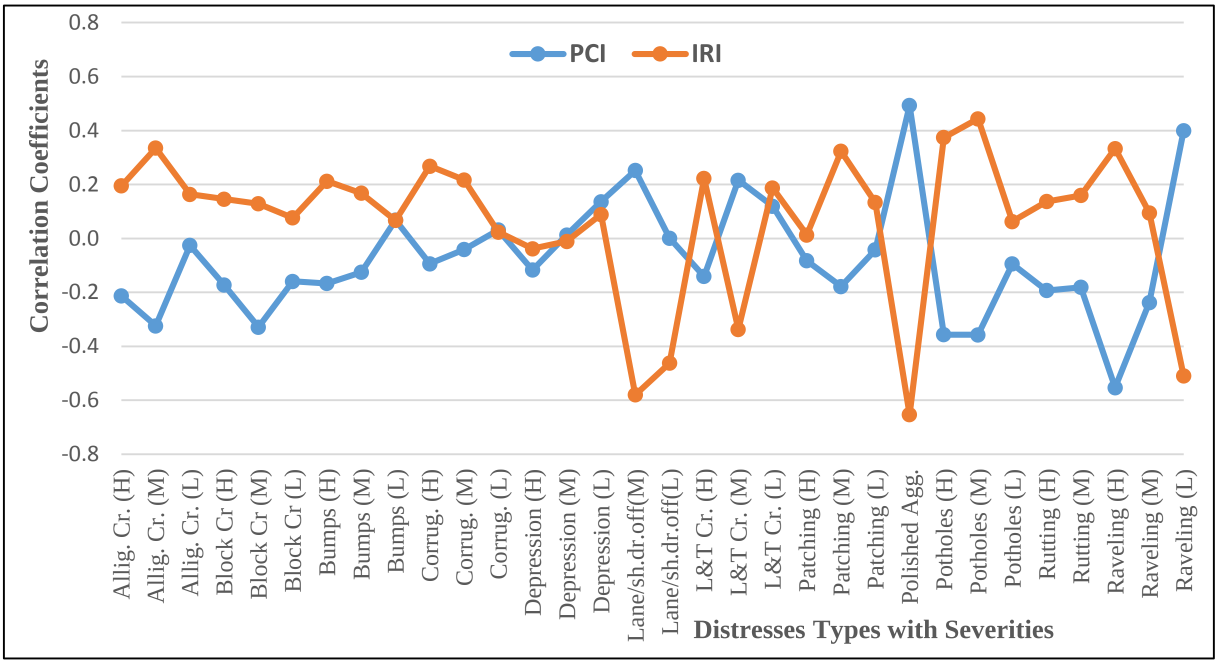


Figure 7. The correlation coefficients between the distresses and IRI, PCI.

As obvious in **Fig. 7**, most of the noticed distress types are correlated in an adverse correlation with PCI and a direct correlation with IRI. In contrast, the correlation coefficients (R) of these distress types with PCI differ from that of IRI. From **Fig. 7**, the high severity corrugation has the R equal to 0.269 and -0.095 with IRI and PCI, respectively. That means the high severity corrugation has a magnitude of the adverse effect on PCI less than an amount of the IRI's direct effect. Also, the raveling (low severity), polished aggregate, and transverse and longitudinal cracking (medium severity) are correlated in a direct correlation with PCI and in an adverse correlation with IRI, and the R of these distress types with IRI differ from with PCI. Whilst, there are distress types that have almost the same effect on IRI and PCI, such as longitudinal and transverse cracking (low severity), corrugation (low severity), depression (high severity), and bumps (low severity).

Based on the above, there are no steady patterns of the distress types that are effective on IRI and PCI. Therefore, the coefficient (R^2) values decreased when A and B models had developed, to be 0.715 and 0.722 for A and B relationships, respectively.

11. CONCLUSIONS

The present study focused on developing relationships between PCI and IRI using eighty-three sections for flexible pavements selected in Al-Diwaniya city. The conclusions of this study can be drawn as the following:

- The linear and quadratic relationships are adequate to predict of pavement condition index from the international roughness index.
- The variation patterns between IRI and PCI are not steady because the noticed pavement distresses in the study area have various effects on PCI and IRI.
- The prediction of PCI from IRI by these models has reduced the need for PCI's subjective measurements, then reduced the need for allocating funds and working hours.
- The resulted models of this research can be applied to prepare the priorities of pavements maintenance and rehabilitation.

REFERENCES

- AASHTO-R43 2013. Standard Practice for Quantifying roughness of pavements. American Association of State Highway and Transportation Officials.
- ABDELAZIZ, N., ABD EL-HAKIM, R. T., EL-BADAWY, S. M. & AFIFY, H. A. 2017. Validation and improvement of pavement ME flexible pavement roughness prediction model using extended LTPP database. *96th Annual Meeting of the Transportation Research Board, Washington D.C., USA.*
- ABDELAZIZ, N., ABD EL-HAKIM, R. T., EL-BADAWY, S. M. & AFIFY, H. A. 2020. International Roughness Index prediction model for flexible pavements. *International Journal of Pavement Engineering,* 21**,** 88-99.
- ARHIN, S. A., WILLIAMS, L. N., RIBBISO, A. & ANDERSON, M. F., 2015. Predicting pavement condition index using international roughness index in a dense urban area. *Journal of Civil Engineering Research,* 5**,** 10-17.
- ASTM-E867 2002. Terminology Relating to Vehicle-Pavement Systems. American Society for Testing and Materials.
- ASTM 2017. D6433: Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys.
- ATTOH-OKINE, N., and ADARKWA, O., 2013. Pavement condition surveys–overview of current practices. *Delaware Center for Transportation, University of Delaware: Newark, DE, USA.*
- DEWAN, S. A. & SMITH, R. E., 2002. Estimating International Roughness Index from pavement distresses to calculate vehicle operating costs for the San Francisco Bay area. *Transportation research record,* 1816**,** 65-72.
- DYNA TEST 2005. 5051 Mark III/IV, Road Surface Profiler test systems, Owner's Manual. *In:* DYNA TEST (ed.).
- ELHADIDY, A. A., EL-BADAWY, S. M. & ELBELTAGI, E. E., 2019. A simplified pavement condition index regression model for pavement evaluation. *International Journal of Pavement Engineering***,** 1-10.
- GARBER, N. J., and HOEL, L. A., 2009. Traffic and Highway Engineering (ed.). *Cengage Learning, Australia*.

- MUBARAKI, M., 2016. Highway subsurface assessment using pavement surface distress and roughness data. *International Journal of Pavement Research and Technology*, 9**,** 393-402.
- PARK, K., THOMAS, N. E., and WAYNE LEE, K. 2007. Applicability of the international roughness index as a predictor of asphalt pavement condition. *Journal of Transportation Engineering*, 133**,** 706-709.
- PRASAD, J. R., KANUGANTI, S., BHANEGAONKAR, P. N., SARKAR, A. K. and ARKATKAR, S. 2013. Development of relationship between roughness (IRI) and visible surface distresses: a study on PMGSY roads. *Procedia-Social and Behavioral Sciences,* 104.
- PROVAL. 2016. *View and analyze pavement profiles* [Online]. Available: www.roadprofile.com [Accessed].
- SALEH, S. E., AWDA, G. J. & AHMED, N. G., 2008. Development of pavement condition index model for flexible pavement in Baghdad City. *Journal of Engineering,* 14**,** 2120-2135.
- SAYERS, M. W., 1995. On the calculation of international roughness index from longitudinal road profile. *Transportation Research Record*.
- SAYERS, M. W., 1998. The little book of profiling: basic information about measuring and interpreting road profiles. University of Michigan, Ann Arbor, Transportation Research Institute.
- SHAH, Y. U., JAIN, S., TIWARI, D. and JAIN, M. 2013. Development of overall pavement condition index for urban road network. *Procedia-Social and Behavioral Sciences,* 104**,** 332-341.
- SHAHIN, M. Y. 2005. *Pavement management for airports, roads, and parking lots,* Springer New York.
- SHAHIN, M. Y., DARTER, M. I., and KOHN, S. D., 1978. Development of a Pavement Condition Index for Roads and Streets. CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN ILL.
- TIMM, D. H., and MCQUEEN, J. M., 2004. A study of manual vs. automated pavement condition surveys. *Alabama, EE. UU: Auburn University*.
- VIDYA, R., SANTHAKUMAR, S. M., and MATHEW, S., 2013. Estimation of IRI from PCI in construction work zones. *International Journal on Civil and Environmental Engineering,* 2**,** 1.
- ZAMORA ALVAREZ, E. J., FERRIS, J. B., SCOTT, D. and HORN, E., 2018. Development of a discrete roughness index for longitudinal road profiles. *International Journal of Pavement Engineering,* 19**,** 1043-1052.

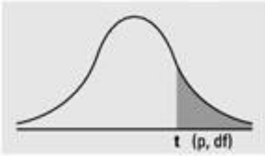
Appendix A

The T-tabulated of the paired t-test is determined from **Table (A-1)**, where the validation sections (n) are twenty sections. Also, the confidence level is 95% in the present study.

So, $df = n - 1 = 20 - 1 = 19$ and $P = \frac{0.05}{2} = 0.025$ ➡ t-tabulate = 2.09302

Table (A-1). The t-tabulated values.

Numbers in each row of the table are values on a *t*-distribution with (*df*) degrees of freedom for selected right-tail (greater-than) probabilities (*p*).



df/p	0.40	0.25	0.10	0.05	0.025	0.01	0.005	0.0005
1	0.324920	1.000000	3.077684	6.313752	12.70620	31.82052	63.65674	636.6192
2	0.288675	0.816497	1.885618	2.919986	4.30265	6.96456	9.92484	31.5991
3	0.276671	0.764892	1.637744	2.353363	3.18245	4.54070	5.84091	12.9240
4	0.270722	0.740697	1.533206	2.131847	2.77645	3.74695	4.60409	8.6103
5	0.267181	0.726687	1.475884	2.015048	2.57058	3.36493	4.03214	6.8688
6	0.264835	0.717558	1.439756	1.943180	2.44691	3.14267	3.70743	5.9588
7	0.263167	0.711142	1.414924	1.894579	2.36462	2.99795	3.49948	5.4079
8	0.261921	0.706387	1.396815	1.859548	2.30600	2.89646	3.35539	5.0413
9	0.260955	0.702722	1.383029	1.833113	2.26216	2.82144	3.24984	4.7809
10	0.260185	0.699812	1.372184	1.812461	2.22814	2.76377	3.16927	4.5869
11	0.259556	0.697445	1.363430	1.795885	2.20099	2.71808	3.10581	4.4370
12	0.259033	0.695483	1.356217	1.782288	2.17881	2.68100	3.05454	43178
13	0.258591	0.693829	1.350171	1.770933	2.16037	2.65031	3.01228	4.2208
14	0.258213	0.692417	1.345030	1.761310	2.14479	2.62449	2.97684	4.1405
15	0.257885	0.691197	1.340606	1.753050	2.13145	2.60248	2.94671	4.0728
16	0.257599	0.690132	1.336757	1.745884	2.11991	2.58349	2.92078	4.0150
17	0.257347	0.689195	1.333379	1.739607	2.10982	2.56693	2.89823	3.9651
18	0.257123	0.688364	1.330391	1.734064	2.10092	2.55238	2.87844	3.9216
19	0.256923	0.687621	1.327728	1.729133	2.09302	2.53948	2.86093	3.8834
20	0.256743	0.686954	1.325341	1.724718	2.08596	2.52798	2.84534	3.8495
21	0.256580	0.686352	1.323188	1.720743	2.07961	2.51765	2.83136	3.8193
22	0.256432	0.685805	1.321237	1.717144	2.07387	2.50832	2.81876	3.7921
23	0.256297	0.685306	1.319460	1.713872	2.06866	2.49987	2.80734	3.7676
24	0.256173	0.684850	1.317836	1.710882	2.06390	2.49216	2.79694	3.7454
25	0.256060	0.684430	1.316345	1.708141	2.05954	2.48511	2.78744	3.7251
26	0.255955	0.684043	1.314972	1.705618	2.05553	2.47863	2.77871	3.7066
27	0.255858	0.683685	1.313703	1.703288	2.05183	2.47266	2.77068	3.6896
28	0.255768	0.683353	1.312527	1.701131	2.04841	2.46714	2.76326	3.6739
29	0.255684	0.683044	1.311434	1.699127	2.04523	2.46202	2.75639	3.6594
30	0.255605	0.682756	1.310415	1.697261	2.04227	2.45726	2.75000	3.6460
z	0.253347	0.674490	1.281552	1.644854	1.95996	2.32635	2.57583	3.2905
CI	———	———	80%	90%	95%	98%	99%	99.9%