Developing International Roughness Index (IRI) Model from visible pavement distresses

Hasan H Joni¹, Mami M Hilal² and Muataz S Abed³

¹² Assistant Prof. Dr., Department of Civil Engineering, University of Technology, Baghdad, Iraq.
³Engineer in Governorate of AL-Diwaniyah, AL-Diwaniyah, Iraq.

Email: hassan_jony@yahoo.com

Abstract. The pavement maintenance, rehabilitation, and design methodologies need an appropriate evaluation of the pavement functional condition. The roughness is generally recognized as a measure of the pavement functional capacity. The roughness of pavement is measured using IRI, which depends on the quantity of distresses existing on the pavement surface. This study focuses on developing a model to predict the roughness (IRI) from the flexible pavement distresses. Accordingly, 83 flexible pavement sections were selected in AL-Diwaniyah city roadways, Iraq. The length of the section is equal to 250 meters. Distress data were collected manually, in terms of amount and severity. The IRI data were collected from all sections using the Dynatest Road Surface Profiler (RSP) test system. Using SPSS software, a stepwise multiple linear regression has been used to develop the model between the IRI and visible pavement distresses depending on the data collected. The resulting equation was found among the IRI and percentages of polished aggregate, high and medium severity potholes, medium severity alligator cracking, medium severity patching, high severity raveling, and high severity corrugation. The results indicate that this model is strong enough for the prediction of the International Roughness Index.

Keywords
International Roughness Index, IRI, Pavement Roughness, Pavement Distress

1. Introduction
Evaluation of pavement is a method which is fulfilled by field testing and measurements to describe the condition of the pavement structure, both functionally and structurally. The condition of pavement structural indicates the pavement capability to carry the present and future traffic volumes, while the functional condition indicates its capability to supply a smooth, safe and a good ride quality surface for the vehicle traffic. In addition, roughness is principally a measure of riding quality of the roadway pavement surface [1]. Shahin pointed out that the roughness is an important measure of comfort and safety of pavement riding [2]. A phenomenon that is produced from the interaction of any automobile that drives over the road surface and pavement surface is called
pavement roughness [3]. Also, Sayers [4] mentioned that the pavement roughness is the variations in elevation of pavement surface that make vibrations in traversing automobiles at a given point of time. Roughness is generally measured by international roughness index (IRI) and it is generally reported in inches/mile or meters/kilometer.

There are many systems and methods of calculating and representing pavement roughness differing exceedingly in aspects of the technical complication, use speed, the accuracy of results, and cost. The Dynatest Road Surface Profilometer (RSP) is prudently designed to give an advanced, high-quality, automated pavement roughness, and regarded measurements solution for engineers worldwide. It is capable of real-time continuous highway-speed measurements of the longitudinal profile (IRI). The RSP system was developed to address market desires for a portable, vehicle-independent system that can be quickly and easily moved between various vehicular platforms. The RSP is operable by one person, that being the driver of the vehicle. The RSP can collect data at speeds between 25 km/hr. to 110 km/hr. Therefore, it could be used in all types of roadways successfully. On the other hand, visual surveys are mostly conducted to specify the type, severity, and amount of distress. There are several approaches for managing the surveys of pavement distresses that are adopted by various agencies. One of these approaches is a collection of distress information by walking through the section.

Through the present study, the works focused to predict adequate relationship between international roughness index (IRI) and pavement distresses, the government departments concerned may need only distress data to estimate the IRI. The objective of the study is to develop a model between the IRI and the pavement distresses and to examine the effect of pavement distress kinds on pavement roughness.

2. Literature Review
Roughness assessment has received great care from numerous airport and highway agencies in the world in the last four decades. It is the fundamental element of pavement serviceability, and several different roughness measures are presently used to estimate pavement serviceability. The transportation engineers should routinely make condition surveys, to identify the pavement condition. These condition surveys have to include observation of the strength characteristics (e.g. rutting, cracking, and pavement roughness) [5].

The IRI is a statistic applied to assess the quantity of pavement roughness in a measured longitudinal profile. It is calculated from a single quarter–car simulation a computer program to compute the IRI statistic from longitudinal profile [6, 7].

The IRI has obtained the greatest acceptance worldwide that was primarily developed in research by the National Cooperative Highway Research Program (NCHRP) and then developed and validated by The World Bank [8], where the World Bank supported a major study in Brazil from 1976 to 1981 that produced the development of this index [9]. In addition, Du et al. mentioned that the major advantages of the IRI include its being stable over time and transferable throughout the world [10].

Various agencies and researchers have established models to forecast roughness depending on pavement distresses. In spite of that, a few popular distresses that normally exist on the major and minor roadway networks in the developing countries have not been considered by most researchers and agencies. In the Indian state of Rajasthan, a model has been developed between the IRI and distresses usually noticed on Indian roadways such as potholes, cracking, raveling, rutting, and patching. All these distresses have been obtained in terms of severity and quantity. 395 uniform sections (different functional classes) of 100m length were used to collect pavement distress data that was applied to predict the model between roughness and distresses. The determination corresponding coefficient (R2 value) of the regression model reached upto 0.986 [11].
Mactutis, et al. [12] had done research on the relationship between IRI and pavement distresses using a large database. The model correlates the IRI with initial IRI values, rut depths, and fatigue cracking according to the following equation:

\[
\text{IRI} = 0.382 + 0.597 \text{IRI initial} + 0.0094 \text{fatigue\%} + 0.00847 \text{rut depth} \quad (R^2 = 0.71) \quad (1)
\]

Prasad, et al. [13] established a model between the pavement roughness and pavement distresses of PMGSY roads in India. The pavement distress data was collected for every 50 meters individually. Bump Integrator was used to collect data of pavement roughness that was calibrated by using MERLIN. Establishment of a regression equation between the IRI value and the noticeable distress depending on the data collected in the field. The determination corresponding coefficient ($R^2$ value) reached up to 0.66.

3. Study Methodology
The major objective of this study is the development of the model between the IRI and the noticeable pavement distresses for AL-Diwaniyah city roadways, so that proper surveys and measures for pavement sections can be taken to build the model. The following stages in developing the model are described briefly below: (i) selection of pavement sections, (ii) pavement distress survey and IRI data collection, and (iii) development of model between IRI and pavement distresses.

4. Pavement Sections Selection
Fifteen asphalt concrete roads distributed in AL-Diwaniyah city have been included all the pavement sections. A total of 83 sections of flexible pavement, with 250 meters in length, in the study area were used. The sites selected were uniform in several characteristics like topography, climate, besides that there were other characteristics as discussed in section selection criteria. The selected site sections must have the following: (i) roughness and condition of pavements range from very poor to good and contain as far as possible all the various kinds and severity degrees of distress (ii) the selected sites are to be as close as possible to each other to minimize the travel time between sites (iii) lengths of segments are to be of the same length (250m in the flexible pavement) (iv) the sites are to be as straight as possible, not curved (if they were curved, the curves were to be gentle enough).

5. Data Collection

5.1 International Roughness Index Data
The longitudinal profile elevation measurements are collected by Dynatest Road Surface Profiler (RSP) test system. As shown in Plate 1, a pickup truck is selected to install the RSP and conduct the measurements for all selected pavement sections. All measurements are carried out in the left lane for each road. This lane represents the lane with the highest traffic. The longitudinal elevation profile obtained by the RSP system for each pavement section is used to compute the IRI; where the collected data are analyzed using Profile Viewing and Analysis (ProVAL 3.61) software.
5.2 Pavement distress survey
Surveying by walking along each section was performed to collect the data on the type, quantity, and all measurements required to identify the intensity of each distress by using the data sheet, Hand Odometer Wheel, straight edge, tape, and camera. The manual presented by ASTM [14] is adopted during the inspection survey. Each section in the study area includes several types of distress that vary in quantity and severity. The pavement distresses observed are alligator cracking (at three severity levels), block cracking (at three severity levels), bumps and sags (at three severity levels), corrugation (at three severity levels), depression (at three severity levels), lane/shoulder drop off (at two severity levels), longitudinal and transverse cracking (at three severity levels), patching (at three severity levels), polished aggregate (no degree of severity), potholes (at three severity levels), rutting (at two severity levels), and raveling (at three severity levels). The data of all the pavement distress parameters were converted into the percentage of the total area of the section using the following equation:

$$\text{PAD} = \frac{\text{AD}_i}{\text{Ai}} \times 100$$  \hspace{1cm} (2)

Where:
- PAD: Percentage area of distress,
- AD$_i$: Area, length or number of distress,
- Ai: Total area of the pavement section considered.

6. Analysis of Data
The pavement distresses and IRI data are collected for 83 test sections, covering 15 roads in AL-Diwaniyah city. These data were used to build the IRI and pavement distresses model. Figure 2 shows the IRI values of all sections in the study area. It can be seen from the figure that the measured IRI values range from 1 m/km to less than 9 m/km. Also, the IRI values between 4 and 4.9 m/km are the most frequent in the study area with frequency equal to 24 times. On the other hand, the IRI values between 8 and 8.9 are the least frequent with a frequency of only two times.

Figure 3 demonstrates the pavement distresses observed with severities for each distress type in the study area. As shown in the figure 3, the raveling is the most common distress type in the study area, especially with medium intensity which is frequent in 76 sections, in addition, the longitudinal and transverse cracking with medium severity is repeated in 66 sections. While the block cracking with low severity is found only in one section. The polished aggregate without the level of severity is apparent in 13 sections.
Accordingly, the selected pavement sections have varied in pavement roughness and pavement distresses, that means the approach to select of the pavement sections with various roughness was perfect.

![Figure 2](image1.png)

**Figure 2.** International Roughness Index values in the Study Area.

![Figure 3](image2.png)

**Figure 3.** Pavement Distresses Observed with Severities for each Type in the Study Area.

### 7. Model development

For developing a model to predict IRI, the pavement distresses and IRI data have been used for modeling and its validation. For building this model, the IRI value is occupied as the dependent variable and the observed pavement distress parameters were considered as independent variables. 32 variables were acquired by considering every intensity level of distress as an independent variable. SPSS software version 22 was used to check normal distribution of variables. Kolmogorov-Smirnov (K-S) test was used for this check because this test offers a more refined analysis of the data, treats individual observations straightly and assumes continuity of the degree of freedom [15]. In this test, there are two hypotheses; the null hypothesis and the alternative hypothesis. The principle of null hypothesis testing is that the variables are distributed normally. A confidence level of 95 percent, so a significant level of 0.05, is applied. From (K-S) test results, the Sig. (P-value) is greater than (5%) therefore, the null hypothesis is proved. Consequently, the distributions of IRI and PCI data
are normal.

A stepwise multiple linear regression has been used to build the roughness model between the IRI and visible pavement distresses using SPSS program because it is a function of more than one predictor variable. Data of 64 sections (approximately 75 percent of the observed values) randomly selected by SPSS software were used for building the model and the data on remaining (19 sections) were kept for the objective of model validation.

Only seven variables were considered out of the thirty-two variables for the development of the model based on a stepwise multiple linear regression approach. The developed model is shown in the flowing equation:

\[
\text{IRI m/km} = 3.551 - 5.153* \text{PO} + 121.522* \text{HM} + 84.161*\text{AM} + 24.57*\text{PM} + 3.736*\text{RAH} + 44.738*\text{COH} + 287.159*\text{HH}
\]  

(3)

Where:
- IRI: international roughness index
- PO: polished aggregate (% of the area)
- HH & HM: high and medium severity potholes (% of the area)
- AM: medium severity alligator cracking (% of the area)
- PM: medium severity patching (% of the area)
- RAH: high severity raveling (% of the area)
- COH: high severity corrugation (% of the area)

Table 1 demonstrates the statistics for the developed model. It has been noticed from table 1 that the multiple R = 0.885 for the model means good correlation, and the R² = 0.784 means a good fit model. Also, the ‘P-value’ for the analysis of variance test for the model is equal to 0, indicating that the model is acceptable, as well as the ‘P-values’ for all the variables are either equal or close to 0 that means all the distress parameters play a significant role in the model.

**Table 1. Statistics for the Roughness Model**

| Regression Statistics |  |
|-----------------------|--|
| Multiple R            | 0.885 |
| R square              | 0.784 |
| Adjusted R square     | 0.756 |
| Standard error of estimate | 0.809 |

| ANOVA Results         |  |
|-----------------------|--|
| Source                | Sum of square | Df | Mean of squares | F | Sig. (P-value) |
| Regression            | 128.368       | 7  | 18.338          | 27.991 | 0.000 |
| Residual              | 35.377        | 54 | 0.655           |       |         |
| Total                 | 163.746       | 61 |                 |       |         |

| Statistics            | Estimated Parameter (B) | T   | Sig.(P-value) | Standardized Coefficients (Beta) |
|-----------------------|-------------------------|-----|---------------|---------------------------------|
| Distress parameters   |                         |     |               |                                 |
| PO                   | -5.153                  | -6.320 | 0.000        | -0.429                          |
| HM                   | 121.522                 | 4.108 | 0.000        | 0.276                          |
| AM                   | 84.161                  | 5.258 | 0.000        | 0.346                          |
| PM                   | 24.57                   | 3.142 | 0.003        | 0.210                          |
| RAH                  | 3.736                   | 3.326 | 0.002        | 0.217                          |
| COH                  | 44.738                  | 3.420 | 0.001        | 0.219                          |
| HH                   | 287.159                 | 2.599 | 0.012        | 0.176                          |

8. Model Validation
The objective of the validation process is to evaluate the capability of the suggested model to predict of international roughness index and measures the prediction accuracy for the validation period. It has been previously mentioned that data of 19 sections were reserved aside to validate the model which have not been used in the model building. These data were used to estimate the IRI values by substituting the pavement distress parameters values in the model developed which is represented in Equation (4), as presented in table 2. Using Excel software, a plot is being drawn between the observed IRI, which is measured by using the Dynatест Road Surface Profilometer (RSP), and predicted IRI values of these sections for validation purpose, as presented in figure 4. A 45° line has been drawn to clarify the distribution of plotted points on every side of the line. From figure 4, it can be noticed that most of the points are close to the 45° line and the other points are also not very far off as well as, the \( R^2 \) value is 0.8557, thus, the developed model is considered to be valid.

**Table 2.** Prediction of IRI Values Using the Developed Model.

| No. | IRI by RSP m/km | PO % | HM % | AM % | PM % | RAH % | COH % | HH % | IRI predicted m/km |
|-----|----------------|------|------|------|------|-------|-------|------|-------------------|
| 1   | 3.984          | 0    | 0.0008 | 0    | 0    | 0.0184| 0.0088| 0.0004 | 4.226             |
| 2   | 4.693          | 0    | 0.0008 | 0    | 0    | 0.0316| 0     | 0.0008 | 3.996             |
| 3   | 4.77           | 0    | 0.0016 | 0.0192| 0    | 0    | 0     | 0     | 5.361             |
| 4   | 5.711          | 0    | 0.0016 | 0.02 | 0.01 | 0    | 0     | 0.0016 | 6.134             |
| 5   | 5.087          | 0    | 0.0036 | 0    | 0    | 0.004 | 0     | 0.0022 | 4.636             |
| 6   | 5.72           | 0    | 0.0036 | 0    | 0    | 0.124 | 0     | 0.0004 | 4.574             |
| 7   | 4.95           | 0    | 0.0004 | 0.008 | 0.02 | 0.0504 | 0     | 0.0004 | 5.067             |
| 8   | 4.646          | 0    | 0    | 0    | 0    | 0.1196 | 0     | 0     | 3.998             |
| 9   | 3.62           | 0    | 0.0004 | 0    | 0    | 0    | 0     | 0.0004 | 3.714             |
| 10  | 3.919          | 0    | 0.0004 | 0.0136| 0    | 0    | 0     | 0     | 4.744             |
| 11  | 5.047          | 0    | 0    | 0.0048 | 0    | 0.0512 | 0     | 0.0024 | 4.835             |
| 12  | 7.589          | 0    | 0.0076 | 0.0072| 0    | 0.1468 | 0     | 0.004  | 6.778             |
| 13  | 3.235          | 0    | 0    | 0.0056 | 0    | 0    | 0     | 0     | 4.022             |
| 14  | 4.941          | 0    | 0.0024 | 0.0072 | 0.0324 | 0.0164 | 0.0032 | 0.0004 | 5.564             |
| 15  | 4.604          | 0    | 0.0011 | 0    | 0    | 0.3   | 0     | 0     | 4.811             |
| 16  | 4.143          | 0    | 0    | 0.004 | 0    | 0.068 | 0     | 0     | 4.142             |
| 17  | 5.169          | 0    | 0.0004 | 0    | 0    | 0.3409 | 0     | 0     | 4.879             |
| 18  | 1.265          | 0.4114 | 0    | 0    | 0    | 0     | 0     | 0     | 1.431             |
| 19  | 1.121          | 0.4063 | 0    | 0    | 0    | 0     | 0     | 0     | 1.457             |

![Figure 4](image.png)

**Figure 4.** Plot between Predicted IRI and Measured IRI values.

**9. Discussion of Regression Results**

From SPSS software, seven variables were considered for the development of the roughness model, these are polished aggregate, high and medium severity potholes, medium severity alligator...
cracking, medium severity patching, high severity raveling, and high severity corrugation. From table 1, it is apparent from the standardized coefficient (Beta) values, the first independent variable polished aggregate which has the highest effect in the prediction of the IRI because the value of beta is the highest one (0.429). The second variable is the medium severity alligator cracking; beta value being (0.346). Beta value for the medium severity potholes is (0.276) and its rank is the third. The fourth variable is the high severity corrugation; beta value is (0.219) and beta value for the variable high severity raveling is (0.217) and its rank is the fifth. The sixth variable is the medium severity patching; beta value is (0.210). The last independent variable which is least affected in the prediction of the (IRI) is the high severity potholes, its beta value being (0.176).

10. Conclusions and Recommendations
In this study, flexible pavement sections from AL-Diwaniyah city roadways were selected to develop the model between the IRI and observed pavement distresses. The developed model was built and checked and the R² value reaches to 0.784. The results of this research indicate the following:
- The developed model may be adequate for the prediction of the international roughness index.
- The percentage of polished aggregate has the highest effect in the prediction of the IRI followed by the percentage of medium severity alligator cracking, medium severity potholes, high severity corrugation, high severity raveling, medium severity patching, then the percentage of high severity potholes.
- Any increase in the roughness of the pavement means an increase in the pavement deterioration.
- The severity level of distress has a differential effect on the pavement roughness, and consequently, both severity and amount need to be considered to develop such models.
- The availability of the equipment is difficult so only the information of the distresses which are included in Equation 4 are enough to estimate of the pavement roughness.
- The results of this study can be usefully applied by the municipalities in preparing priority indicator for the budget and for developing techniques for effective maintenance programs.
- As a recommendation for future studies, development of prediction models for the International Roughness Index of rigid and composed pavement roadways is suggested.

References
[1] Mubarak, M 2014 Identification of pavement distress types and pavement condition evaluation based on network level inspection for Jazan City road network. The Journal of Engineering Research [TJER] 11(1): pp 44-54
[2] Shahin M Y, Pavement management for airports, roads, and parking lots. Vol. 501. 2005: Springer New York.
[3] Haas R and W R Hudson 1978 Pavement management systems
[4] Sayers M W 1986 The international road roughness experiment: Establishing correlation and a calibration standard for measurements
[5] Hudson W R 1981 Road roughness: its elements and measurement. Center for Transportation Research
[6] AASHTO, R43: 2015 Standard Practice for Quantifying Roughness of pavements
[7] ASTM, E867: Terminology Relating to Vehicle-Pavement Systems 2017
[8] Hall K and C Muñoz 1999 Estimation of present serviceability index from international roughness index. Transportation Research Record 1655(1): pp 93-99
[9] Al-Omari B and M I Darter 1994 Relationships between international roughness index and present serviceability rating. Transportation Research Record p 1435
[10] Du Y, et al., 2014 Measurement of international roughness index by using-axis accelerometers and GPS
[11] Sandra A K and A K Sarkar 2013 Development of a model for estimating International
Roughness Index from pavement distresses. *International Journal of Pavement Engineering* 14(8): pp 715-724

[12] Mactutis J A, S H Alavi and W C Ott 2000 Investigation of relationship between roughness and pavement surface distress based on WesTrack project. *Transportation research record.* 1699(1): pp 107-113

[13] Prasad J R et al. 2013 Development of relationship between roughness (IRI) and visible surface distresses: a study on PMGSY roads. *Procedia-Social and Behavioral Sciences* 104: pp 322-331

[14] ASTM, D6433: Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. 2017

[15] Hilal M M 2011 Prediction of permanent deformation models for asphalt pavements in hot climates. University of Baghdad, Iraq.