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PRACTICAL PAVEMENT PERFORMANCE PREDICTION MODELS FOR INDIANA ROADS

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FINAL REPORT

PRACTICAL PAVEMENT PERFORMANCE PREDICTION MODELS FOR INDIANA ROADS

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I. INTRODUCTION

The Indiana Department of Transportation (INDOT) is increasingly committed to the Pavement Management System. For this reason, practical pavement performance prediction models with the least number of explanatory (independent) variables are required to predict the performance of various pavement types for future planning of rehabilitation or replacement. In Indiana, the two main pavement types are jointed concrete pavement (JCP) and bituminous pavement (BIT).

Desirable practical pavement performance prediction models should relate various pavement measurements, such as International Roughness Index (IRI), Pavement Serviceability Index (PSI), friction number and pavement condition rating to traffic (including trucks), pavement type and pavement age, if possible.

The Pavement Serviceability Index can be obtained from the International Roughness Index. The models were developed by the research study entitled [1] ***"Correlation of Pavement Serviceability Rating with International Roughness Index".*** These models have been implemented by the Roadway Management Division, INDOT, to obtain PSI values from the corresponding IRI values, since January 1993.

II. OBJECTIVE

The main objective of this experimental study is to obtain practical pavement performance prediction models for INDOT's pavement types. These models are needed for optimum planning of network pavement rehabilitation or replacement projects.

III. SCOPE

To address the major variables (i.e., age, traffic and pavement type), the design of this experimental study has at least one road section, approximately 1.6 km. (one mile) in length, for each combination of pavement type, traffic volume and age in the two environmental zones (i.e., north and south) of Indiana. To meet this condition, a total of ninety eight road sections were randomly selected from the available roads. Additional road sections were added progressively due to change in pavements and to obtain stronger statistical correlation.

IV. DATA COLLECTION

The following data were collected on the selected road test sections for this study:

(1) **IRI Data**
1993 by Research Division (INDOT).
1994-1996 by PaveTech*
1995-1996 by Research Division on selected 51 road sections.

(2) **Friction Number Data (FN)**
1993 -1996 by Research Division

(3) **Pavement Condition Rating (PCR)**
1994-1996 by PaveTech.

(4) **Average Annual Daily Traffic (AADT) and Average Daily Truck Traffic (ADTRK)**
1993-1995 by Roadway Management Division

(5) **Rutting Survey Data (RUT)**
1994-1996 by PaveTech

* PaveTech, Inc. $_{\text{T.M.}}$ of Norman, OK was contracted by INDOT to collect network wide pavement condition data during 1994 through 1996.

V. DATA ANALYSIS

The following steps were followed in the data analysis:

5.1 Conversion of the IRI to PSI:

The IRI values were converted to PSI using the following formula [1].

$$PSI = 9.0\, e^{(-0.008784 * IRI)}$$

Where IRI is in inches per mile.

5.2 Regression Models Search for PSI (IRI):

The IRI data (dependent variable) along with the independent variables were used for the regression models search in each year separately [2] to eliminate any systematic calibration errors of the IRI instrumentation on the IRI values. The independent variables used in the model search are average annual daily traffic (AADT), average daily truck traffic (ADTRK), pavement age in years (AGE), environmental zones and pavement types (PV). The following models only show those independent variables, which significantly contributed, to the best model obtained.

(1) *1993 IRI data by the Research Division (INDOT):*

The best model for PSI was obtained using only the independent variables AGE and PV [3]. The R^2 is equal to 0.23 and the standard error of the estimate (s) is equal to 0.9.

PSI = 3.7 - 0.03 * AGE - 0.7 *PV (1)

or

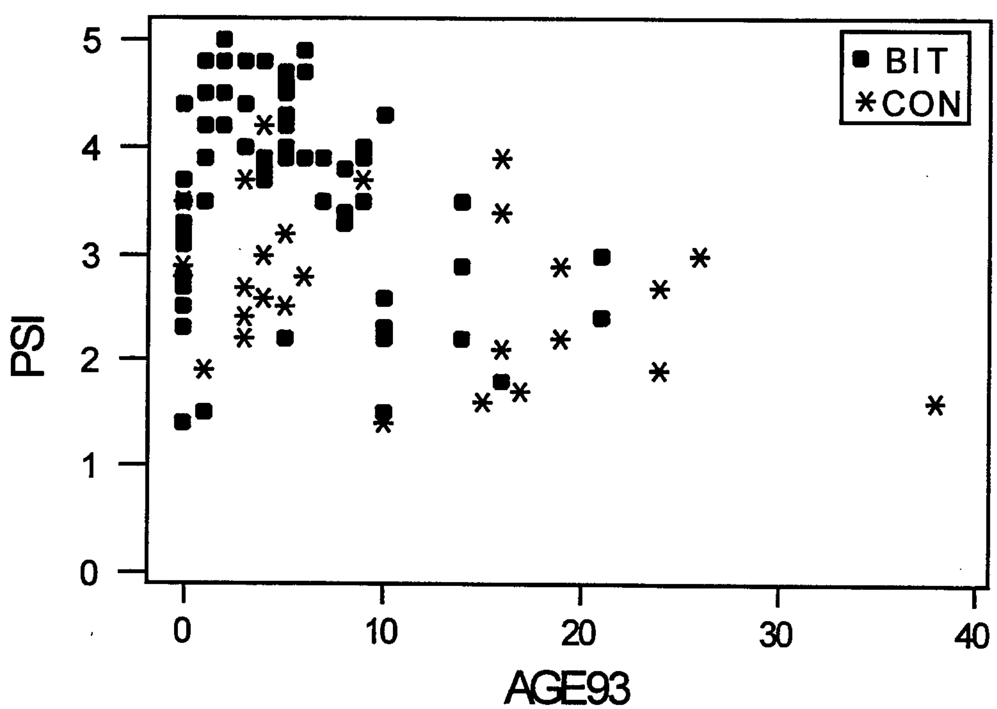
IRI = 1.65 + 0.019*AGE + 0.401*PV (s=0.53 and IRI is m/km) (2)

Where:

AGE= Year of the data collected - Year of the last surface
PV=1, for Concrete Pavements (CON).
PV=0, for Bituminous Pavements (BIT).
R^2 = The Correlation of Determination (i.e. the percent of information for PSI or IRI obtained from the independent variables AGE and PV).

Figure 1 shows the scatter plot of PSI by pavement type (BIT for bituminous and CON for concrete pavements), and AGE.

Figure 1 : PSI vs. AGE 1993 (Research)



(2) *1994 IRI Data by the PaveTech:*

The best model for PSI was obtained using only the independent variables AGE and PV. The R^2 is equal to 0.39 and the standard error of the estimate (s) is equal to 0.9.

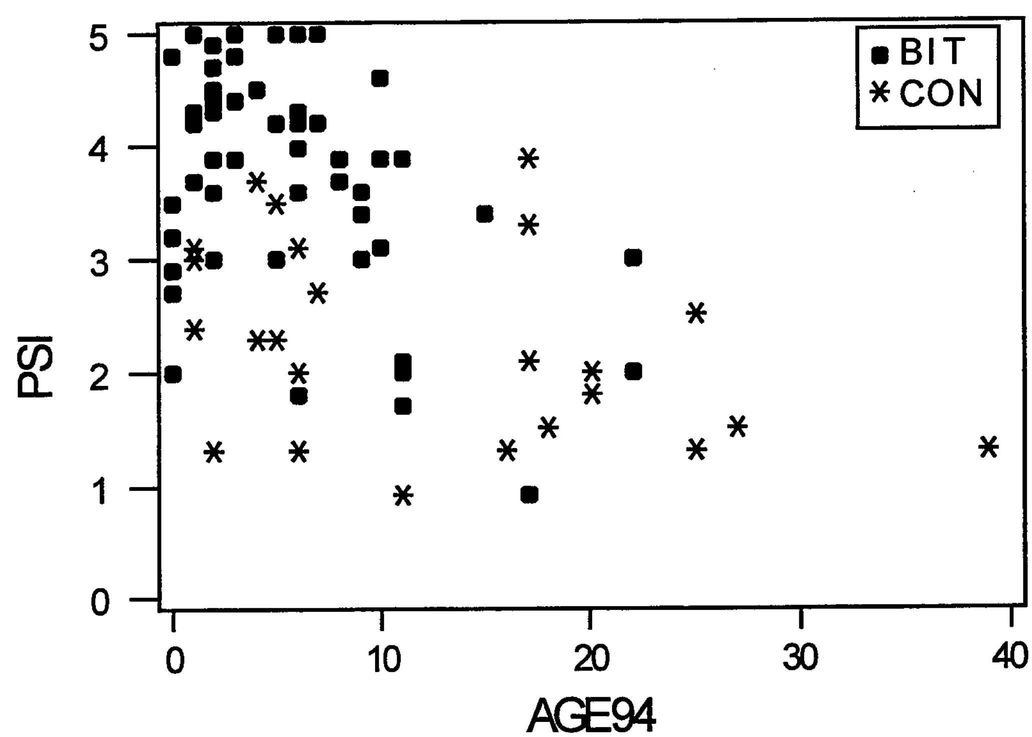
PSI = 3.98 - 0.0452*AGE - 1.19*PV (3)

or

IRI = 1.49 + 0.036*AGE + 0.667*PV (s=0.62 and IRI is m/km) (4)

Figure 2 shows the scatter plot of PSI by pavement type (BIT for bituminous and CON for concrete pavements), and AGE.

Figure 2: PSI vs. AGE 1994 (PaveTech)



(3) ***1995 IRI data by the PaveTech:***

The best model for PSI was obtained using only the independent variables AGE and PV. The R^2 is equal to 0.45 and the standard error of the estimate (s) is equal to 0.9.

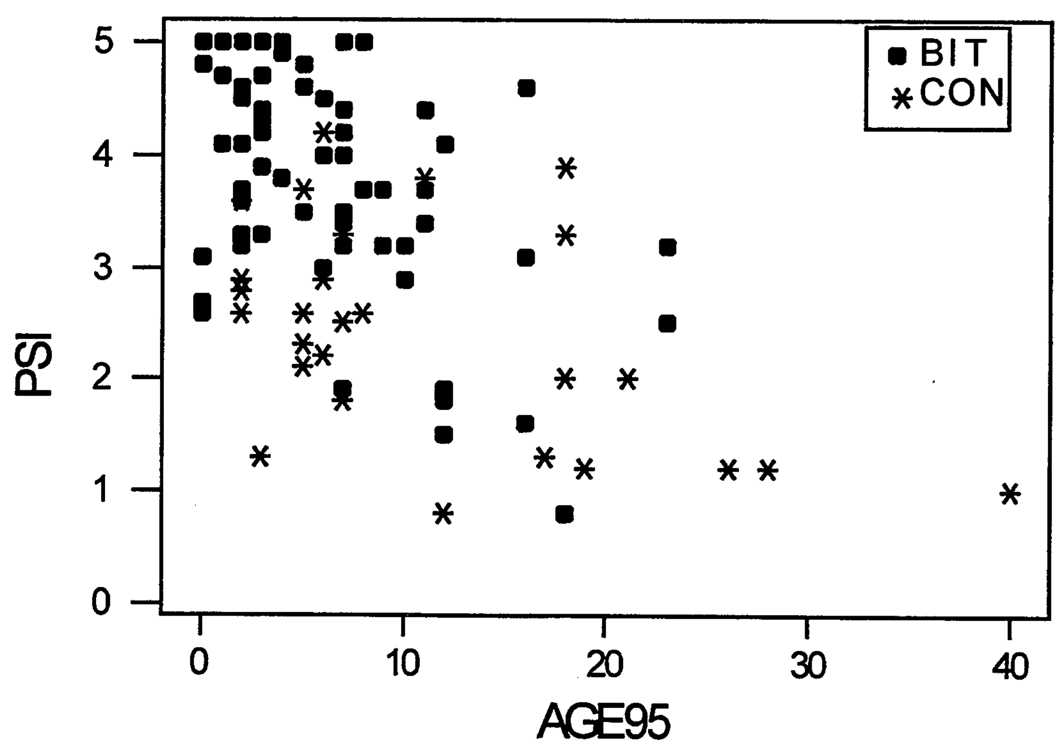
$$\mathbf{PSI = 4.2 - 0.07*AGE - 0.97*PV} \quad (5)$$

or

$$\mathbf{IRI = 1.309 + 0.053*AGE + 0.592*PV} \quad \text{(s=0.60 and IRI is m/km)} \quad (6)$$

Figure 3 shows the scatter plot of PSI by pavement type (BIT for bituminous and CON for concrete pavements), and AGE.

Figure 3 : PSI vs. AGE 1995 (PaveTech)



(4) ***1995 IRI data by Research Division (INDOT):***

The best model for PSI was obtained using only the independent variables AGE and PV. The R^2 is equal to 0.50 and the standard error of the estimate (**s**) is equal to 0.8.

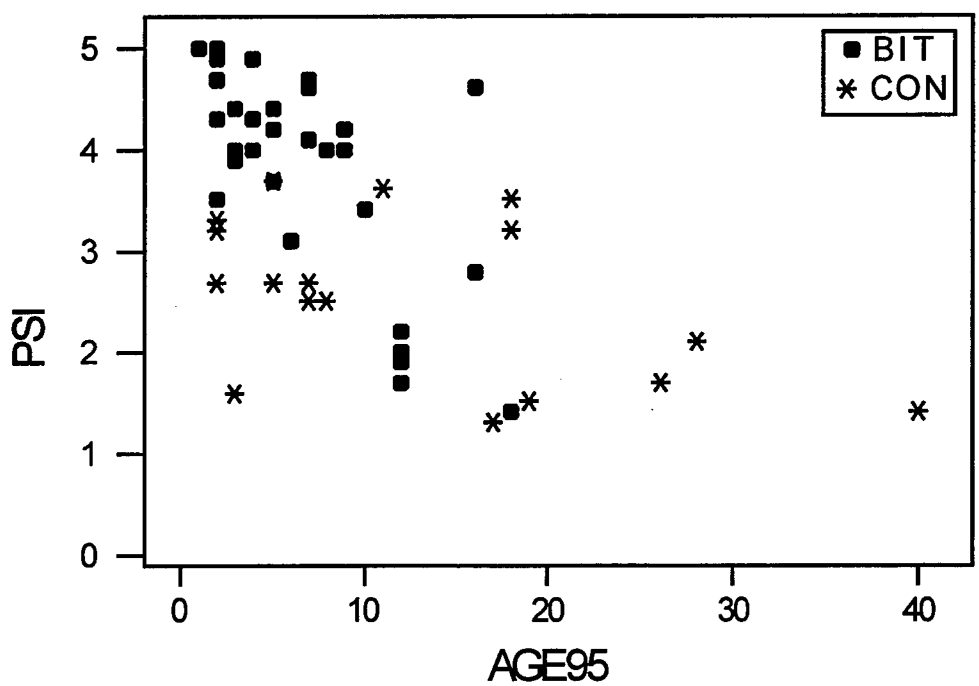
$$\mathbf{PSI = 4.3 - 0.07*AGE - 0.9*PV} \tag{7}$$

or

$$\mathbf{IRI = 1.317 + 0.047*AGE + 0.47*PV} \quad (\text{s=0.53 and IRI is m/km}) \tag{8}$$

Figure 4 shows the scatter plot of PSI by pavement type (BIT for bituminous and CON for concrete pavements), and AGE.

Figure 4: PSI vs. AGE 1995 (Research)



(5) ***1996 IRI data by the PaveTech:***

The best model for PSI was obtained using only the independent variables AGE and PV. The R^2 is equal to 0.51 and the standard error of the estimate (s) is equal to 1.0.

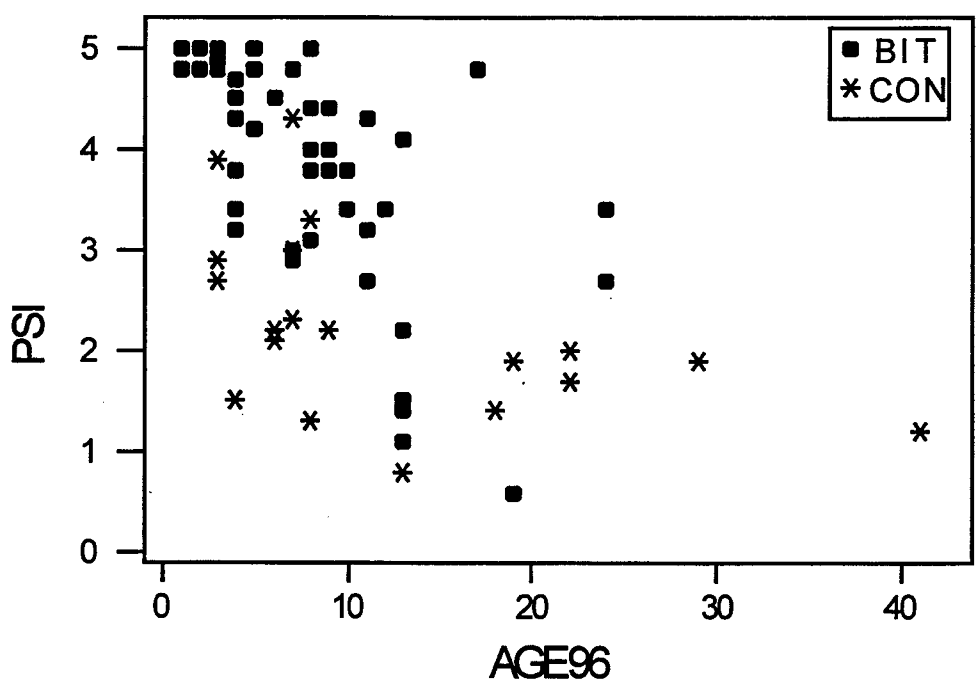
$$\mathbf{PSI = 4.6 - 0.086 * AGE - 1.3 * PV} \tag{9}$$

or

$$\mathbf{IRI = 1.170 + 0.057 * AGE + 0.755 * PV} \quad \text{(s=0.67 and IRI is m/km)} \tag{10}$$

Figure 5 shows the scatter plot of PSI by pavement type (BIT for bituminous and CON for concrete pavements), and AGE.

Figure 5: PSI vs. AGE 1996 (PaveTech)



(6) ***1996 IRI data by Research Division (INDOT):***

The best model for PSI was obtained using only the independent variables AGE and PV. The R^2 is equal to 0.42 and the standard error of the estimate (s) is equal to 0.8.

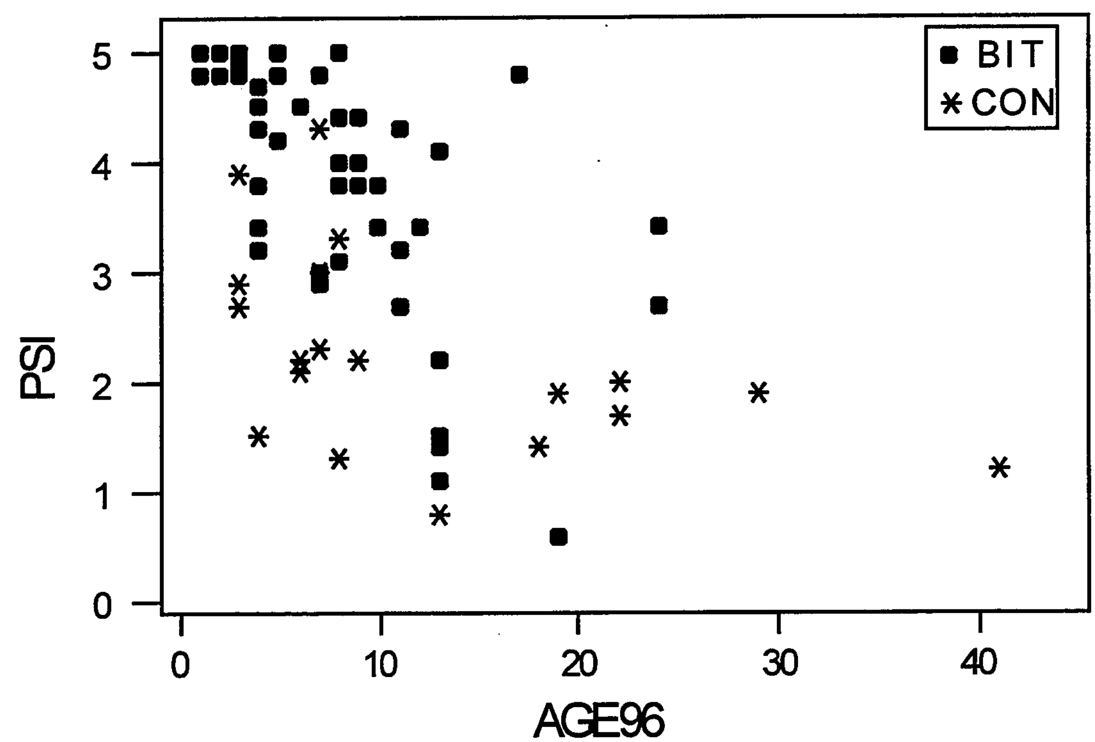
PSI = 4.1 - 0.07*AGE - 0.38*PV (11)

or

IRI = 1.374 + 0.053*AGE + 0.131*PV (s=0.55 and IRI is m/km) (12)

Figure 6 shows the scatter plot of PSI by pavement type (BIT for bituminous and CON for concrete pavements), and AGE.

Figure 6: PSI vs. AGE 1996 (Research)



(7) *1996 IRI data by PaveTech on the entire Interstate Freeway System:*

This data was added to the original proposed data. The best model for PSI was obtained using only the independent variables AGE, AADT and PV. The R^2 is equal to 0.7 and the standard error of the estimate (s) is equal to 0.25.

$$\mathbf{PSI = 4.7 - 0.065*AGE - 0.000006*AADT - 0.46*PV} \qquad (13)$$

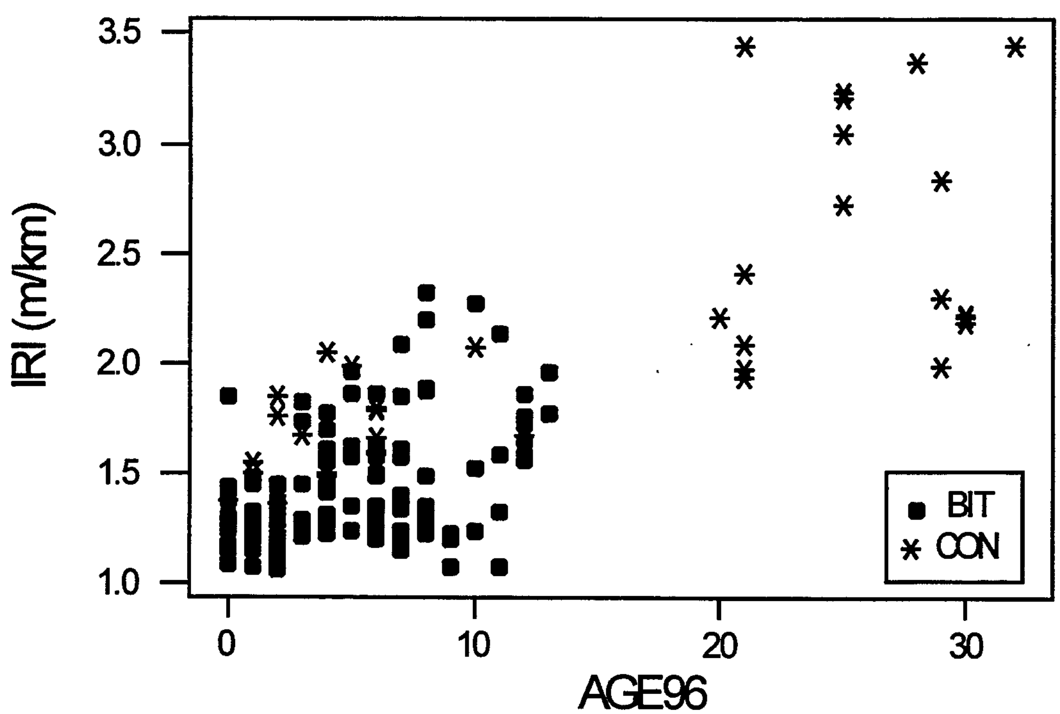
or

$$\mathbf{IRI = 1.08 + 0.0405*AGE + 0.0000035*AADT + 0.23*PV} \qquad (s=0.25) \qquad (14)$$

Where IRI is in (m/km),

Figure 7 shows the scatter plot of PSI by pavement type (BIT for bituminous and CON for concrete pavements), and AGE.

Figure 7: IRI vs. AGE 1996 Interstate System



(8) *Discussion of Results*

A good correlation could not be obtained between IRI (corresponding PSI) and the other independent variables of AADT, ADTRK, AGE, PV, etc. The test sections were randomly selected from various roads of variable cross section, layers, and structural foundation. This variability may account for the poor correlation. In addition, there must be other independent variables that would increase the correlation between the dependent variable and the model. However, using the additional data obtained on the Interstate System in 1996, a good performance prediction model, eq.(14), was obtained. This equation has R^2 of **0.7.**

Since no good correlation was found on non-interstate highways, INDOT can use the eq. (14) for roughly estimating deterioration on the entire system. This should be reasonable approximation, especially for higher type pavements, since the same mixtures and design standards are used as on the interstate system.

5.3 Calibration of the IRI systems by Research Division and PaveTech

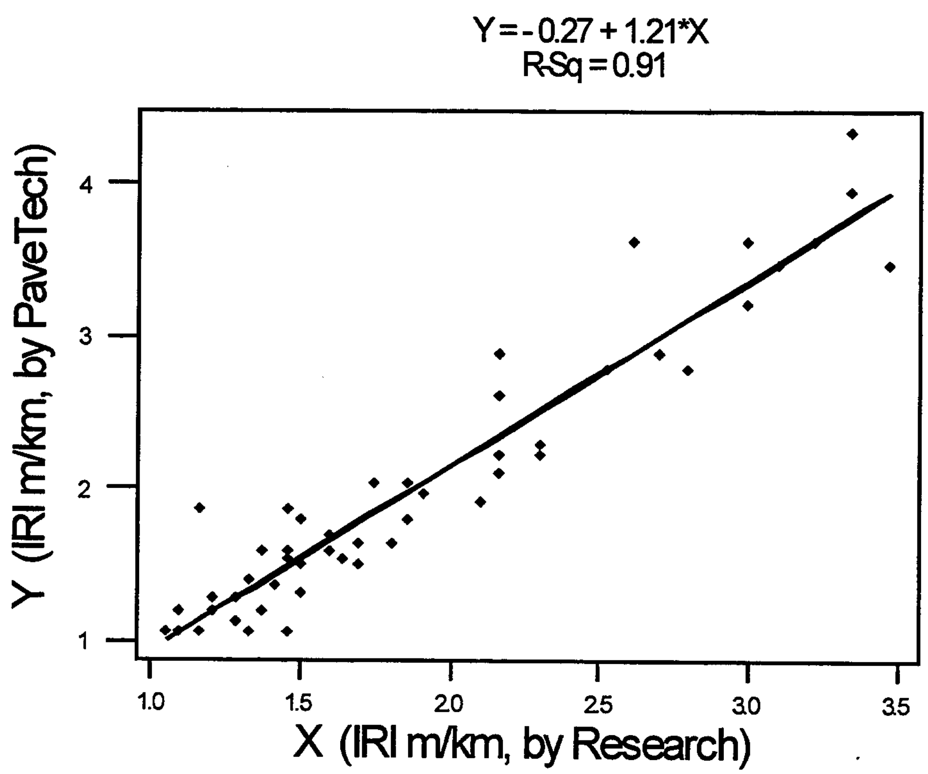
(1) ***Introduction*:**

The INDOT Division of Research has maintained a laser based roughness measurement van for research purpose over the years. To fulfill the needs of the Pavement Management System, PaveTech was contracted to collect system wide pavement conditions including IRI values. This research study gave the opportunity to correlate the PaveTech data collection system with the Research Division IRI system. Initial correlations were made in an independent study in 1994 to verify the PaveTech data and with this opportunity additional verification could be made. The following analyses shows the results.

(2) ***Using 1995 IRI data:***

The 1995 IRI data on the selected 51 test sections were used to obtain a regression model between the Research IRI and PaveTech IRI systems. The model on figure 8 was obtained.

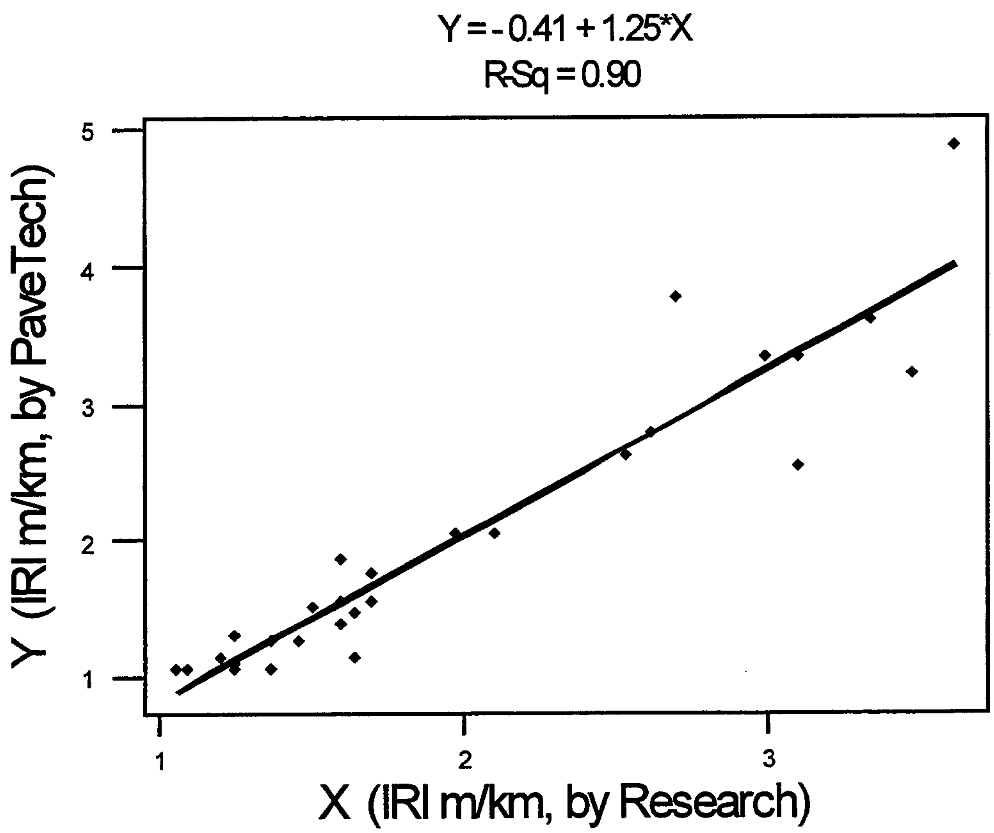
Figure 8: 1995 Calibration of IRI systems



(3) ***Using 1996 IRI data***

The 1996 IRI data on the selected 51 test sections were used to obtain a regression model between the Research IRI and PaveTech IRI systems and the model on figure 9 was obtained.

Figure 9: 1996 Calibration of IRI systems



The regression equations between Research and PaveTech IRI systems indicates that both systems correlates with each other identically in 1995 and 1996 with statistically sound R^2 is equal to **0.9** or more. For this reason no further calibration analysis was needed between the IRI systems. It should also be noted that the two data sets were collected at different times and most probably were not obtained along the same wheel path within test sections.

5.4 Regression Models Search for PCR, RUT and Friction Number :

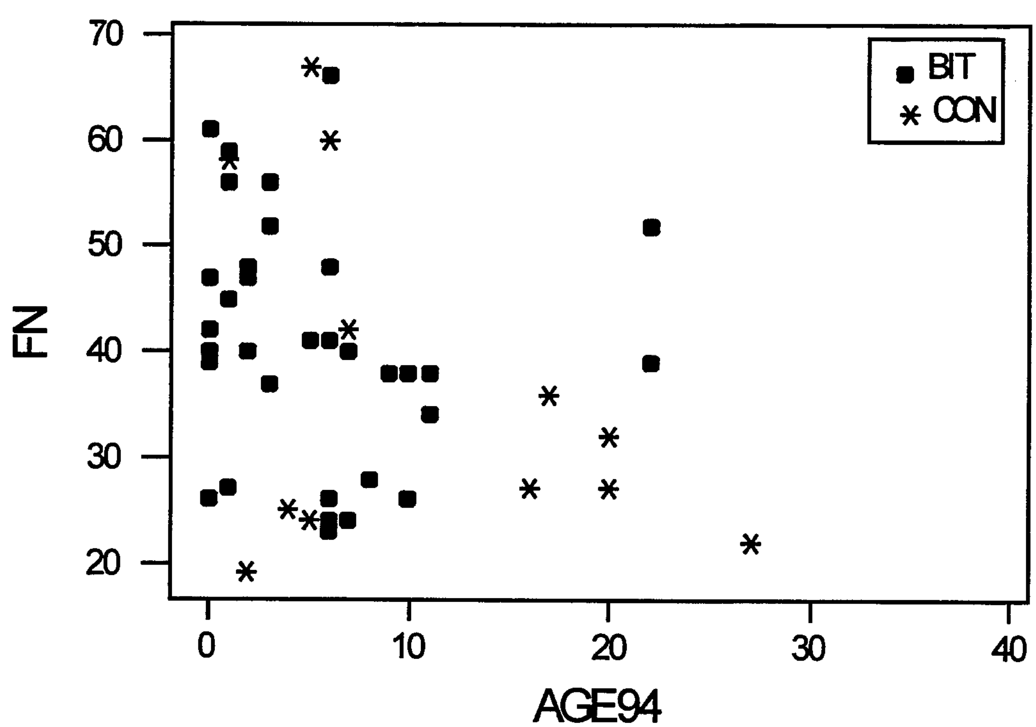
(1) *Friction Number (FN) 1994 obtained by Research Division:*

The best model for Friction Number (FN) was obtained using only the independent variables AGE and AADT. The R^2 is equal to 0.19 and the standard error of the estimate (s) is equal to 9.8.

$$\mathbf{FN = 46.8 - 0.00152 * AADT - 0.5 * AGE} \quad (15)$$

Figure 10 shows the scatter plot of FN vs. AGE by pavement types.

Figure 10 : FN vs. AGE 1994



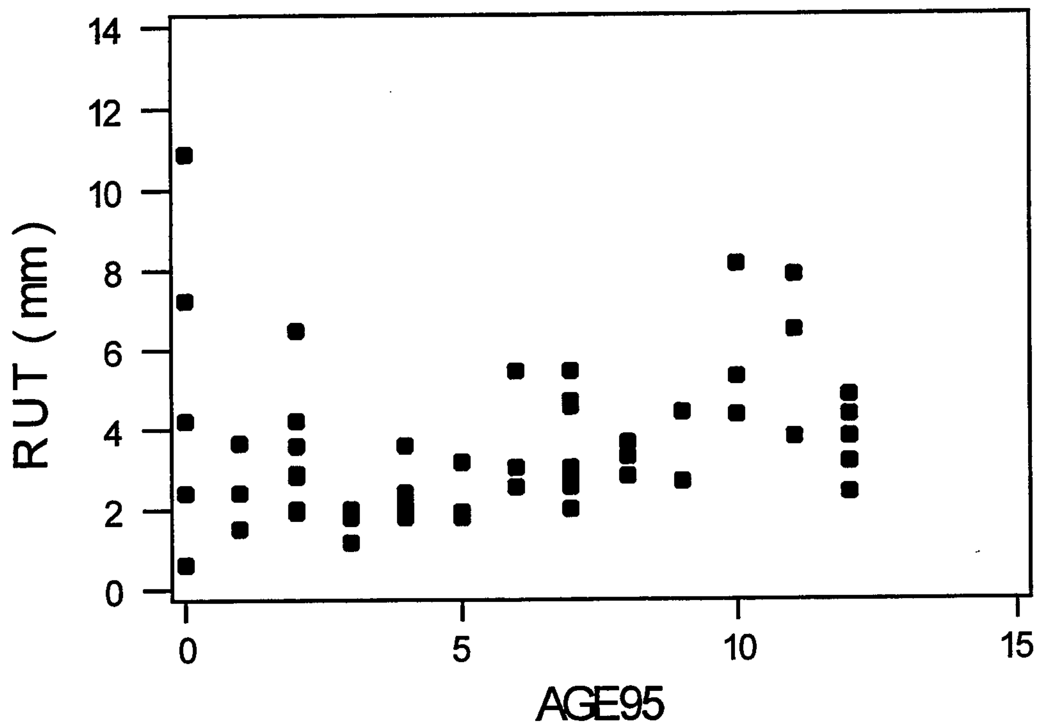
(2) ***Rut Depth (RUT) 1995 by PaveTech:***

The best model for RUT (in mm.) was obtained using only the independent variable AGE. The R^2 is equal to 0.29 and the standard error of the estimate (s) is equal to 2.21.

$$\mathbf{RUT = 2.24 + 0.26 * AGE} \quad (16)$$

Figure 11 shows the scatter plot of RUT vs. AGE for bituminous pavements.

Figure 11: RUT vs. AGE 1995



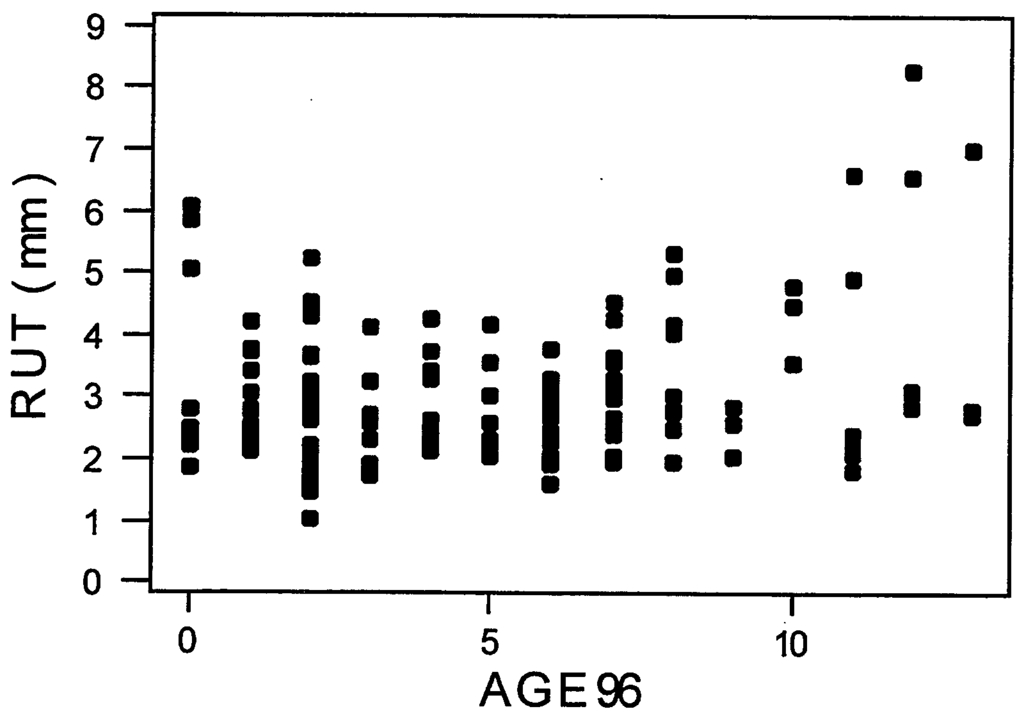
(3) ***Rut Depth (RUT) 1996 on Entire Interstate Freeway System by PaveTech:***

The best model for RUT (in mm.) was obtained using only the independent variable AGE. The R^2 is equal to 0.12 and the standard error of the estimate (s) is equal to 1.21

$$\mathbf{RUT = 2.73 + 0.01*AGE^2} \tag{17}$$

Figure 12 shows the scatter plot of RUT vs. AGE for bituminous pavements.

Figure 12 : RUT vs. AGE 1996 Interstate System



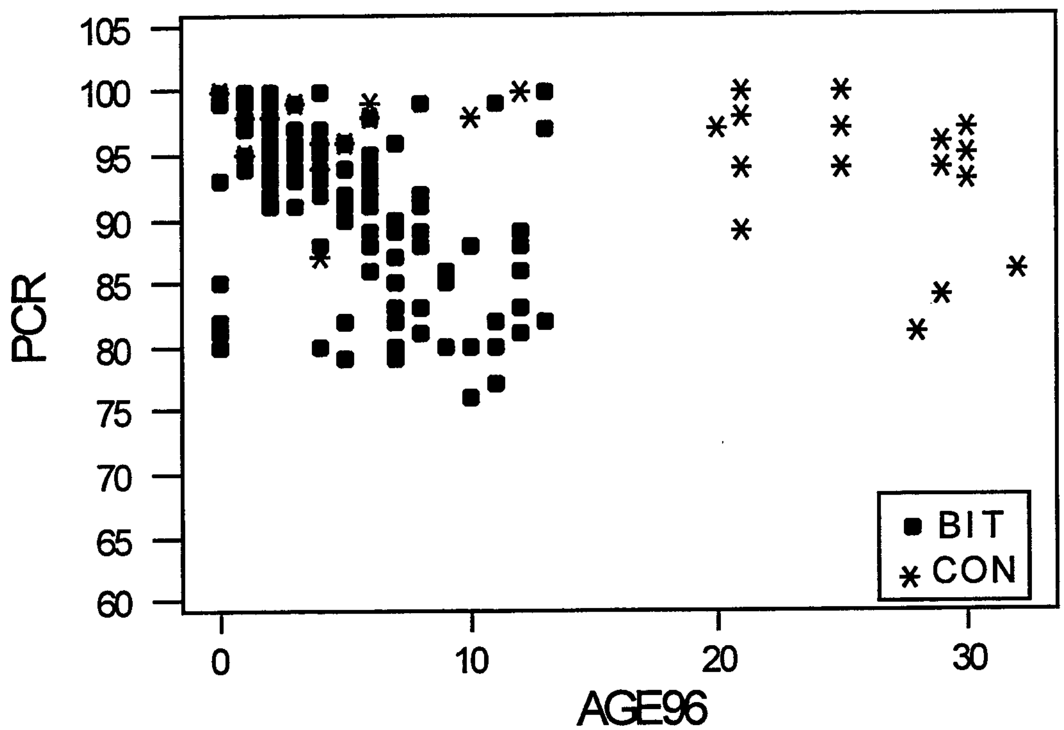
(4) ***PCR 1996 on Entire Interstate Freeway System by PaveTech:***

The best model for PCR was obtained using only the independent variables AGE and PV. The R^2 is equal to 0.22 and the standard error of the estimate (s) is equal to 6.

$$\mathbf{PCR = 94 - 0.42*AGE + 8*PV} \tag{18}$$

Figure 13 shows the scatter plot of PCR vs. AGE by PV

Figure 13: PCR vs AGE 1996 Interstate System



(5) ***Discussion of Results:***

RUT, FN and PCR could not be statistically correlated to the independent variables, AADT, ADTRK, PV and AGE. The RUT measurements are very small and show no significant variation over the time during this study. This indicates that rutting of bituminous pavement is not as significant problem as it was in the past. For this reason, these response-dependent variables (i.e. FN, RUT and PCR) can't be used to obtain pavement performance prediction models. However, FN values should be used for safety purposes in conjunction with an acceptable pavement performance model (s).

5.5 Correlation of the pavements indexes, IRI/PSI with FN, RUT and PCR.

The coefficients of correlation (Pearson) between IRI/PSI and the other response variables (pavement measurements) FN, PCR and RUT were obtained and the results were listed in Table 1 with 95 % confidence limits for the coefficient of correlation in parenthesis. If the confidence interval includes zero (0), this indicates that the coefficient of correlation is not significant at α=**0.05 significance** level.

Table 1. IRI/PSI CORRELATIONS (PEARSON)

VARIABLES	IRI/PSI TEST SECTIONS 1994	1995	1996	IRI/PSI INTERSTATES 1996
FN	***-0.24*** (-0.5 to +0.1)	***0.23*** (-0.1 to +0.5)	***0.48*** (+0.3 to +0.7)	-
PCR	***0.34*** (+0.1 to +0.5)	***0.23*** (+0.0 to +0.4)	***0.35*** (+0.1 to +0.6)	***0.14*** (0.0 to +0.3)
RUT	***-0.34*** (-0.6 to -0.1)	***-0.49*** (-0.7 to -0.3)	***-0.13*** (-0.5 to +0.1)	***-0.40*** (-0.5 to -0.3)

The coefficient of correlation between IRI/PSI and PCR was found to be somewhat statistically significant for the data obtained in 1994 and 1996 on the test sections. There should have been statistically good correlation between IRI and PCR but the PCR data obtained for this study did not correlate well with the IRI. The coefficients of correlation between IRI/PSI and RUT are somewhat significant except for 1996 data on the test sections. The coefficient of correlation between IRI/PSI and FN was found to be somewhat statistically significant only for the data obtained in 1996.

VI. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were made on the basis of this study:

(1) The International Roughness Index (IRI in m/km), for pavement performance prediction model, can be predicted from the independent variables, AADT, AGE and PV using the following model, eq. (14).

$$\mathbf{IRI = 1.08 + 0.04*AGE + 0.0000035*AADT + 0.23*PV}$$

From this equation, one could obtain 70 (R^2 =0.70) percent information about IRI (PSI) from AGE, AADT and PV for INDOT's roads.

(2) Statistically sound pavement performance prediction models for FN, RUT and PCR could not be obtained. However, the very low correlation of determination in eq. (17) indicates that rutting is not affected by accumulated traffic on the Indiana Freeway System.

(3) The friction number (FN) and RUT are recommended to be used in association with the pavement performance prediction model, eq.(14), as safety indexes.

(4) The collection of the PCR data is not necessary for pavement performance prediction modeling, however good PCR data may be used in association with the pavement performance prediction model, eq. (14), as an index of structural integrity.

(5) The IRI system used by the Research Division and the one used by PaveTech yielded statistically identical results.

(6) The above mentioned pavement performance prediction model should be periodically checked and refined, as more data are available.

(7) The data from the road test sections, which were randomly selected for this study, did not yield statistically strong pavement performance prediction models more probably due to non-uniform construction and foundation of the test sections.

(8) Improved recording of pavement cross sections is needed to provide more statistically acceptable results.

(9) Improved quality control of all data collection is needed.

VII. IMPLEMENTATION

Based on this research study, the following implementation steps are recommended:

(1) The Roadway Management Division will implement the findings of the study.

(2) The pavement performance prediction model, eq. (14), will be used for INDOT's entire road system. When new sound data is available, the model, eq. (14) should be refined.

(3) The yearly or latest available FN and RUT numbers will be used in conjunction with the pavement performance prediction model.

VIII. REFERENCES

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