Relationships Between International Roughness Index and Present Serviceability Rating

BASHAR AL-OMARI AND MICHAEL I. DARTER

Relationships were developed between the international roughness index (IRI) and the present serviceability rating (PSR) for flexible, rigid, and composite pavement types. PSR is defined as the mean user panel rating for rideability on the conventional 0 to 5 scale. Relationships between IRI and PSR were developed for each pavement type for the states of Louisiana, Michigan, New Jersey, New Mexico, Ohio, and Indiana, and for all six states together. There were no significant differences between the models for different states and pavement types. The following nonlinear model that fits the boundary conditions is recommended: $PSR = 5 * e^{(-0.26 * IRI)}$ where IRI is in millimeters per meter or $PSR = 5 * e^{(-0.0041 * IRI)}$ where IRI is in inches per mile.

This paper documents relationships between the international roughness index (IRI) and the present serviceability rating (PSR) for pavement types included in the FHWA Highway Planning and Monitoring System (HPMS) data base. FHWA has requested that states report roughness data in the form of the IRI, which was developed by the World Bank in an effort to provide consistent data about roughness. The IRI is an objective and consistent measure of pavement condition that was chosen as the HPMS standard reference roughness index to provide more consistency between states. FHWA directed all states to report pavement roughness data by IRI for all paved rural arterials and urban freeways and expressways, including Interstates, beginning in 1989.

Currently, states are required to report both IRI and PSR to FHWA. The PSR ranges from 0 to 5 (very poor to very good) as defined in Figure 1 and includes a description of rideability, physical distress such as cracking, and rehabilitation needs. The PSR is determined by the states using this general definition but also by other methods. Another method is to first correlate some type of roughness measurement (using a state's equipment) with a mean user panel rating of rideability and then to use this correlation to obtain an estimate of PSR from the roughness index measurement on pavement sections. Another approach is to use a state's visual rating scheme, such as a scale between 0 and 100, and just divide ratings by 20 to estimate a value in the 0 to 5 range. The fact that various methods are used by states to estimate PSR makes consistency nationwide a very significant problem. The definition of PSR used in this report is that defined under NCHRP Project 1-23 (*1*) as subsequently described.

The PSR concept is important because it is built into the HPMS analytical software and is a vital part of the procedures used to estimate long-term pavement rehabilitation needs. The PSR is also a well-known indicator of pavement condition in the highway community. Not much is currently known about the IRI on the nation's highways, especially critical levels at which pavements should be rehabilitated.

Department of Civil Engineering, 1208 Newmark Civil Engineering Lab, 205 North Mathews Avenue, University of Illinois at Urbana-Champaign, Urbana, Ill. 61801.

RESEARCH OBJECTIVES

The primary objective of the first phase of this research was to develop a predictive model for PSR as a function of profile IRI that is applicable to flexible, rigid, and composite (asphalt over concrete) pavements. In the second phase of this study, additional data from the LTPP data base and other sources that included pavement distresses and IRI were analyzed to determine the relationships of key distress types to IRI and critical levels for rehabilitation. These results will be useful in the HPMS analytical process to achieve improved and consistent estimates of the future highway pavement rehabilitation needs in the United States.

PREVIOUS RESEARCH IN CORRELATING PROFILE TO PSR

The first major attempt to relate pavement profile to subjective highway user ratings of a highway was in 1958 by the AASHO Road Test research staff (*2*). The researchers found a reasonable correlation between longitudinal profile slope variance and PSR (mean panel rating). The following equations, which also include some physical distresses, were obtained (*2*):

- Asphalt concrete (flexible) pavements

$$PSR = 5.03 - 1.91 \log (1 + SV) - 1.38 (RD)^2 - 0.01 \sqrt{C + P} \qquad R^2 = 0.84,\ SEE = 0.38,\ n = 74 \qquad (1)$$

- Jointed concrete (rigid) pavements

$$PSR = 5.41 - 1.78 (1 + SV) - 0.09 \sqrt{C + P}$$

$$R^2 = 0.92,\ SEE = 0.32,\ n = 49 \qquad (2)$$

where

SV = slope variance over section from CHLOE profilometer,
RD = mean rut depth (in.),
C = cracking ($m^2/1000\ m^2$) (flexible),
= cracking ($m/305\ m^2$)(= 1 ft/1,000 ft^2) (rigid),

P = patching (m^2/1000 m^2),
SEE = standard error of estimate, and
n = number of sections.

The most significant factor by far in each equation is the slope variance, which is calculated from the pavement longitudinal profile. The distress terms do not contribute much to the estimation of PSR and could have been left off without significant loss of accuracy.

Many other studies have been conducted since that time that relate various longitudinal profile statistics to highway user panel ratings. For example, a Purdue University study in 1964 provided several models showing slope variance and other roughness indicators correlating well with PSR without distress variables (*3*). Researchers from Texas completed a major study in 1968 into the relationship between profile characteristics and PSR (*4*). The World Bank sponsored a large research study in Brazil from 1976 to 1981 that resulted in the development of the IRI. Some correlations between IRI and PSR from various sources were given by Paterson (*5*) as shown in Figure 2 where a wide variation of relationships exists when different data sources from around the world are used. A nonlinear relationship between PSR and IRI that generally fits through the data set taken from Brazil, Texas, South Africa, and Pennsylvania is as follows:

$$\text{PSR} = 5 * e^{(-0.18*\text{IRI})} \tag{3}$$

where IRI is in meters per kilometer.

Another major study was conducted under NCHRP Project 1-23 by Janoff et al. (*1*) and Janoff (*6*) in the 1980s. The objective of NCHRP Project 1-23 (*1*) was to correlate mean user panel rideability ratings using the Figure 3 scale of selected pavement sections with objective parameters derived from the measured profile. The main experiment was conducted on 81 test sections in Ohio, including 25 asphalt concrete (AC), 22 portland cement concrete (PCC), and 34 composite (COMP) sections. The user panel included 36 Ohio Department of Transportation employees and laypersons driving in four K-cars of similar age who rated the pavement sections for rideability only on the same subjective scale (0 to 5) as that for the AASHO Road Test, and the mean panel rating (MPR) was computed for each section. Thus, the MPR was similar to the PSR as defined for the AASHO Road Test, but only rideability was rated.

Chapter IV
DRAFT

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Table IV-2

Pavement Condition Rating

(Use full range of values)

PSR & Verbal Rating	Description
5.0	
Very Good	Only new, superior (or nearly new) pavements are likely to be smooth enough and distress free (sufficiently free of cracks and patches) to qualify for this category. Most pavements constructed or resurfaced during the data year would normally be rated very good.
4.0	
Good	Pavements in this category, although not quite as smooth as those described above, give a first class ride and exhibit few, if any, visible signs of surface deterioration. Flexible pavements may be beginning to show evidence of rutting and fine random cracks. Rigid pavements may be beginning to show evidence of slight surface deterioration, such as minor cracks and spalling.
3.0	
Fair	The riding qualities of pavements in this category are noticeably inferior to those of new pavements, and may be barely tolerable for high speed traffic. Surface defects of flexible pavements may include rutting, map cracking, and extensive patching. Rigid pavements in this group may have a few joint failures, faulting and cracking, and some pumping.
2.0	
Poor	Pavements in this category have deteriorated to such an extent that they affect the speed of free-flow traffic. Flexible pavement may have large potholes and deep cracks. Distress includes ravelling, cracking, rutting, and occurs over 50 percent, or more, of the surface. Rigid pavement distress includes joint spalling, faulting, patching, cracking, scaling, and may include pumping and faulting.
1.0	
Very Poor	Pavements in this category are in an extremely deteriorated condition. The facility is passable only at reduced speeds, and with considerable ride discomfort. Large potholes and deep cracks exist. Distress occurs over 75 percent or more of the surface.
0.0	

FIGURE 1 PSR ranges from 0 to 5 based on a description of rideability, physical distress, and rehabilitation needs.

The results of the frequency study of Ohio and Florida data revealed that the total profile index (PI) in the band of frequencies from 0.125 to 0.630 cycles/ft was correlated with the MPR. The PI is defined as the root mean square of elevation for the profile. Relationships were developed to relate PI to the MPR for each pavement type and for all sections combined. A log transformation provided the best fit. Also, the PI and quarter car index were found to correlate well with the MPR.

The objectives of the second phase of NCHRP 1-23 were to expand the methodology developed in the first phase to more states and also to study the effects of region and vehicle size on panel rating and the effect of measuring one wheelpath instead of both wheelpaths in calculating the objective roughness index (*6*). An additional four states besides Ohio participated in this phase. AC, PCC, and COMP sections from New Jersey (46 sections), Michigan (68 sections), New Mexico (64 sections), and Louisiana (52 sections) were selected. Panel ratings and profile measurements were performed on each section.

The same analysis as before was performed on the data. The MPR versus the PI curve was similar for all states except New Mexico. The differences between the five states did not exceed 0.3 MPR. Therefore, it was concluded that the region did not have a significant effect on the ratings.

Data from New Jersey were used to compare the PI from one and two wheelpaths. It was concluded that data from either wheelpath could be used to estimate MPR with as much accuracy as data from both wheelpaths. In all cases the difference was lower than 0.15 MPR. In general, the right wheelpath showed slightly more roughness than the left wheelpath.

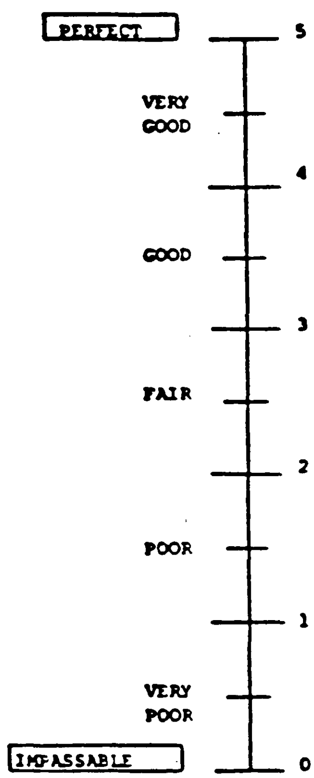


FIGURE 2 Approximate relationships between AASHO serviceability index, PSI, and QIm and IRI roughness scales, based on panel ratings from four sources (*5*).

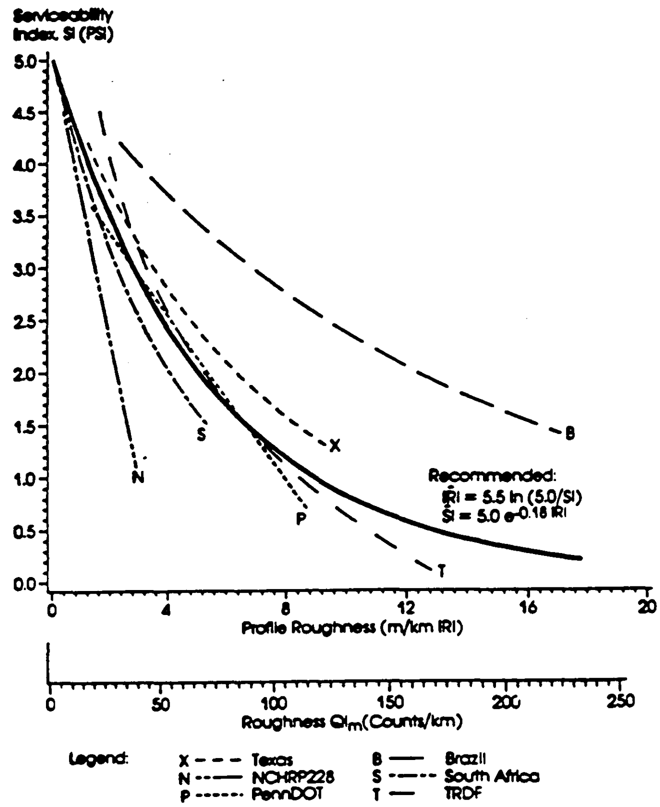


FIGURE 3 Weaver/AASHO scale used in NCHRP Project 1-23 to define PSR as mean panel rating.

A full-size car and a compact car were used to study the effect of vehicle size on the panel rating. No significant effect was observed. The effect of road class on the analysis was also determined. Data from New Jersey, Michigan, and New Mexico were classified by road class (Interstate/non-Interstate). No significant difference in the MPR-versus-PI relationship was observed between the two road classes for AC and PCC pavement types (the sample size for COMP was not sufficient) (*6*).

RESEARCH APPROACH

A relationship is desired between IRI and the mean panel rating (PSR) over the range of conditions existing on freeways and expressways in urban areas and arterial highways in rural areas in the United States. After a comprehensive search of available data, the most comprehensive data were found in the NCHRP Project 1-23 data base (*1,6*) plus some additional similar data obtained from Indiana. The relationship between IRI and PSR (where PSR is defined as the mean highway user's panel rating) will be analyzed for five states obtained from the NCHRP Project 1-23 data base plus the sections in Indiana. The six states are Indiana (which did not separate COMP sections from AC sections), Louisiana, Michigan, New Jersey, New Mexico, and Ohio. The number of sections in each pavement type category and state is as follows:

State	*AC*	*COMP*	*PCC*	*Total*
Indiana	42	–	24	66
Louisiana	13	13	22	48
Michigan	19	21	27	67
New Mexico	39	13	10	62
New Jersey	15	10	21	46
Ohio	34	32	23	89
Total	120	89	127	378

IRI was computed using the measured profile data. The program used to calculate IRI was written in Quick BASIC using the procedure recommended by Sayers et al. (7). The right wheelpath profile was used in calculating IRI because it was found that there was no significant difference if the left wheelpath or the average of right and left wheelpath profiles were considered. The IRI values were calculated from the original profile data for all states except Indiana, where the already calculated IRI values were provided by the Indiana Department of Transportation. The sample interval used for profile measurement was 6 in. The mean panel rating was used as the PSR, as defined by Figure 3.

Development of PSR Versus IRI Models

Data for all six states were entered into a Statistical Analysis System (SAS) data set. These data include IRI, PSR, and pavement type for every pavement section in each state. Several linear and nonlinear models with various types of transformations were considered. The following nonlinear model was found to best fit the boundary conditions and the actual data:

$$\text{PSR} = 5 * e^{(a * \text{IRI})} \quad (4)$$

The logarithmic transformation was used in the actual regression:

$$\ln\left(\frac{\text{PSR}}{5}\right) = a * \text{IRI} \quad (5)$$

Regression analysis was conducted for all possible sets of data considering states and pavement types. The R^2 values obtained were very high (above 0.90) for all cases.

To provide a more realistic assessment of the accuracy of the relationship between PSR and IRI, the R^2 and standard error of the estimate (*SEE*) between the actual PSR values (dependent variable) and predicted PSR values (independent variable) were determined. These values are shown in Table 1 for each state and for each pavement type and in Table 2 for all states together for each pavement type.

As shown in Tables 1 and 2, most of the R^2 values are less than the 0.90 obtained for the transformed model. This occurs because the regression procedure works to minimize the error in the logarithm of PSR, not PSR directly.

In Figure 4 a plot of all state models shows that there is not much deviation between the predictions for each state, except the New Jersey model, which gives a somewhat higher prediction than the other states, especially for AC pavements.

Therefore, two analyses were conducted: one with and the other without the New Jersey sections, as shown in Table 2. The analysis without the New Jersey data gives higher R^2 values and lower *SEE* values than the analysis that includes the New Jersey sections (R^2 = 0.73 versus 0.68 for all pavement types).

Figure 5 shows the different models for each pavement type using combined data from all states. There is very little difference between these best-fit curves, indicating that for all practical purposes, the relationship between IRI and PSR is the same for all three pavement types. These results indicate that the model developed using all of the available data (excluding New Jersey

TABLE 1 Predictive Models for each State and Pavement Type

State	Pavement Type	Constant		R^2	SEE[2]
		a	SEE[1]		
IN	AC/COMP	-0.237800	0.005	0.92	0.244
	PCC	-0.327357	0.018	0.87	0.337
	ALL	-0.280107	0.010	0.88	0.329
LA	AC	-0.240457	0.015	0.80	0.337
	COMP	-0.296259	0.022	0.66	0.403
	PCC	-0.191240	0.007	0.84	0.221
	ALL	-0.224307	0.009	0.62	0.390
MI	AC	-0.258385	0.010	0.92	0.250
	COMP	-0.269314	0.012	0.86	0.337
	PCC	-0.273683	0.014	0.47	0.427
	ALL	-0.267337	0.007	0.79	0.356

State	Pavement Type	Constant		R^2	SEE
		a	SEE		
NJ	AC	-0.146167	0.007	0.84	0.222
	COMP	-0.206388	0.011	0.65	0.259
	PCC	-0.194998	0.010	0.69	0.345
	ALL	-0.182296	0.007	0.64	0.336
NM	AC	-0.291208	0.010	0.81	0.370
	COMP	-0.368312	0.021	0.80	0.267
	PCC	-0.320090	0.018	0.67	0.134
	ALL	-0.301952	0.008	0.79	0.348
OH	AC	-0.196603	0.008	0.79	0.302
	COMP	-0.304379	0.015	0.54	0.415
	PCC	-0.227174	0.010	0.72	0.278
	ALL	-0.228277	0.008	0.58	0.388

[1] Standard error of the estimate (for the constant a).

[2] Standard error of the estimate in units of PSR.

Note: IRI in units of mm/m (1 mm/m = 1/63.36 in/mile)

TABLE 2 Predictive Models Developed for All States and for All States Except New Jersey

States	Pav. Type	Constant		R^2	SEE
		a	SEE		
All States	AC	-0.229945	0.005	0.76	0.383
	COMP	-0.276717	0.008	0.64	0.402
	PCC	-0.257445	0.008	0.62	0.442
	ALL	-0.248129	0.004	0.68	0.417
All States except NJ	AC	-0.239459	0.005	0.81	0.346
	COMP	-0.292981	0.008	0.70	0.383
	PCC	-0.271960	0.008	0.66	0.427
	ALL	-0.259708	0.004	0.73	0.393

Note: IRI in units of mm/m (1mm/m = 1/63.36 in/mile)

data) could be used for any of the pavement types without significant loss of accuracy for any pavement type. This equation is given in both metric and English units.

$$PSR = 5 * e^{(-0.26*IRI)} \quad (6)$$

where IRI is in millimeters per meter.

$$PSR = 5 * e^{(-0.0041*IRI)} \quad (7)$$

where IRI is in inches per mile.

For both Equations 6 and 7, $R^2 = 0.73$, $SEE = 0.39$ (units of PSR), $n = 332$ sections. A plot that shows this model with all the available data for PSR versus IRI is given in Figure 6.

These statistics compare favorably with those obtained from other studies, such as the AASHO Road Test where the R^2 values were 0.84 and 0.92 for AC and PCC pavements, respectively, and the *SEE* values were 0.38 and 0.32 units of PSR for AC and PCC pavements, respectively.

Most of the IRI/PSR data (especially for composite and PCC pavements) were observed over lower IRI and higher PSR ranges, as shown in Figure 6. This causes a weak definition of the relationship for higher IRI and lower PSR ranges, which results in a lower R^2 and higher *SEE* values for composite and PCC pavements.

CONCLUSIONS

The main conclusion of this research is that the mean panel rating of rideability can be predicted reasonably well from the IRI over a wide range of conditions across the United States for the three main types of existing pavements. Equation 7 or 8 is recommended for use in estimating PSR from IRI.

The following models may be used if it is desirable to consider each pavement type separately.

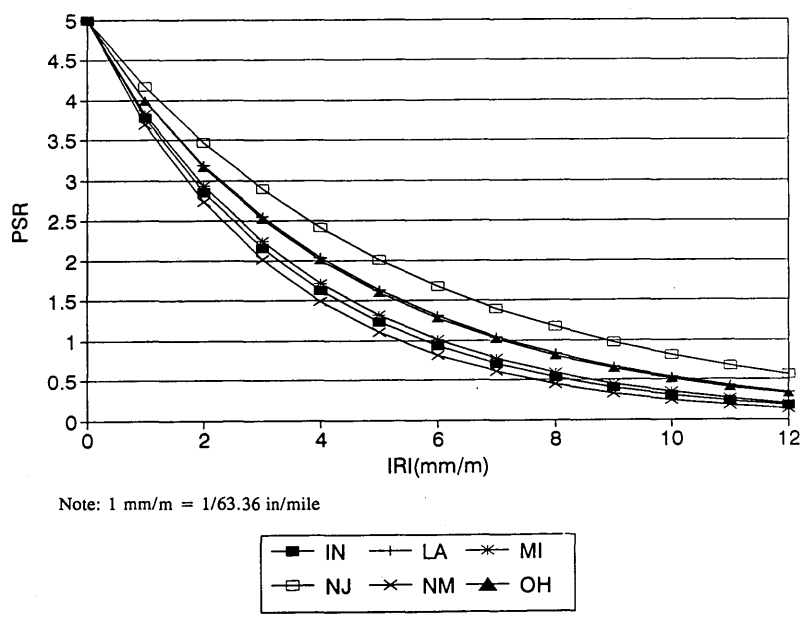
- *For AC pavements:*

$$PSR = 5 * e^{(-0.24*IRI)} \quad (8)$$

where IRI is in millimeters per meter,

$$PSR = 5 * e^{(-0.0038*IRI)} \quad (9)$$

where IRI is in inches per mile.



Note: 1 mm/m = 1/63.36 in/mile

FIGURE 4 PSR versus IRI for all pavement types (models developed for each state).

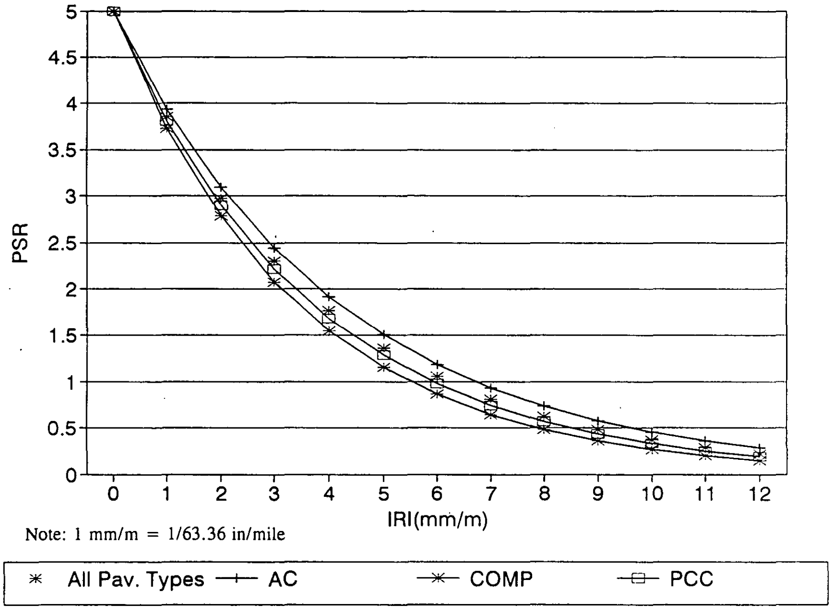


FIGURE 5 PSR versus IRI for each pavement type using data from all states.

- *For COMP pavements:*

$$PSR = 5 * e^{(-0.293 * IRI)} \quad (10)$$

where IRI is in millimeters per meter, or

$$PSR = 5 * e^{(-.0046 * IRI)} \quad (11)$$

where IRI is in inches per mile.

- *For PCC pavements:*

$$PSR = 5 * e^{(-0.272 * IRI)} \quad (12)$$

where IRI is in millimeters per meter, or

$$PSR = 5 * e^{(-0.0043 * IRI)} \quad (13)$$

where IRI is in inches per mile.

Because the maximum deviation of the predicted PSR value by any of these equations for each pavement type from that predicted by the overall model was not more than about 0.25 PSR units, it is recommended to use one model for all pavement types.

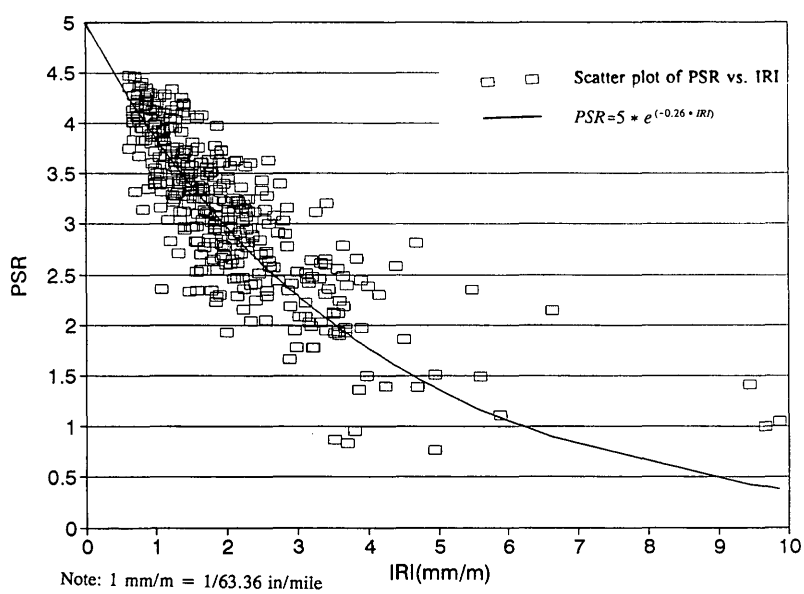


FIGURE 6 Plot showing recommended model with all data.

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