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PSI Models for Urban Highway Flexible Pavements in Jordan

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Abstract

Serviceability is the ability of a specific section of pavement to serve high speed, high volume, and mixed traffic in its existing condition. Serviceability is one of the methods to measure pavement behavior or performance at the time.

In this study, thirty-five pavement sections (with 1,200 ft length) for urban highways were selected. The data collected included the present serviceability rating (PSR), the slope variance (SV) representing roughness, and physical measurements of pavements distresses including: rutting, fatigue (alligator) cracking, potholes, linear cracking, patching, debonding, potholes, bumps & sags, and depressions. The PSR was determined based on ride quality using a scale from 0 to 5, where 0 represents the poorest rate and 5 is the best rate. It was measured by a panel of five engineers. Each engineer provided the rating independently of the others to avoid bias in PSR. In addition, the PSR was provided by a group of seven drivers (road users) of different types of trucks, buses, and passenger cars. This step was done to validate the results of the five-engineer panel.

A multiple regression experimental model was developed for the present serviceability index (PSI) of flexible pavements for urban highways in Jordan. It was found that potholes provided the most significant variable for computing PSI. Linear cracking and bumps and sags (combined as one variable) provided the second major variable for computing PSI. On the other hand, rut depth had the lowest effect on the variation of PSR.

Keywords: Flexible Pavements, Urban Highways, Serviceability, PSR, PSI, Performance, Distress, Slope Variance, Roughness.

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Background

Flexible pavements compose the majority of the pavement network in Jordan. All pavements for urban highways in Jordan are asphalt-surfaced pavements.

Flexible pavements of urban highways in Jordan experience structural and functional distresses as a result of several causes. Structural distresses including fatigue (alligator) cracking, rutting, linear cracking, depressions, swelling, and potholes are mainly caused by the heavily repeated traffic loadings, structural pavement defects, poor quality materials and design, improper pavement construction, and weak subgrade. On the other hand, functional distresses including bleeding, polished aggregate, and raveling are due to improper mixture design, poor quality aggregate and/or mixture, aging of asphalt, improper compaction, and repeated traffic loadings.

Pavements are typically evaluated by different methods. These methods include: (1) pavement roughness (ride-ability or ride quality), (2) pavement surface condition by distress survey, (3) pavement structural condition by deflection measurements, and (4) pavement functional and safety rating by skid resistance. Pavement roughness refers to irregularities in the pavement surface that affects the ride quality and the smoothness of the pavement.

The serviceability of flexible pavements provides a measure of their ability to serve traffic under existing conditions. And hence, it determines the present condition of the pavement and the maintenance and rehabilitation (M&R) needs and priorities. There are two ways that are commonly used to determine the serviceability of a highway pavement: (1) by using the present serviceability index (PSI), and (2) by using the roughness index.

Present serviceability is defined as the ability of a pavement section to serve mixed traffic with high speed and high volume in its existing condition (HRB, 1962). The Present Serviceability Rating (PSR) is the average of the ratings of road users of a pavement section using a scale from 0 to 5 (0 = very poor and 5 = very good). The mathematical relationship of pavement distresses and road profile (roughness) with PSR represents the Present Serviceability Index (PSI). The PSI equation is shown below (Huang, 2004):

$$PSI = 5.03 - 1.91\log\left(1 + \overline{SV}\right) - 0.01\left(C + P\right)^{0.5} - 1.38R\overline{D}^{2} \qquad (1)$$

Where: $\overline{SV}$ = mean of slope variance in the wheel paths, C = cracking (ft^2/1000 ft^2), P = patching (ft^2/1000 ft^2), and RD = mean rut depth (in).

The PSI was originally introduced and defined by the American Association of State Highway Officials (AASHO) Road Test (United Sates National Pavement Research Project) back in 1961 (HRB, 1961). The AASHO (currently AASHTO, American Association of State Highway and Transportation Officials) Road Test developed models for the PSI for both flexible and rigid pavements in the United States of America (USA) to be used in the AASHTO design procedures. These PSI models were based on pavement roughness and distress conditions. For flexible pavements, the distresses included rut depth, cracking, and patching, and for rigid pavements, they only included cracking and patching.

The relationship between pavement design and performance is crucial. The 1993 AASHTO design procedure is widely used at the current time to design flexible pavements. In this version of the design guide, the loss in serviceability or the change between the initial and terminal PSI values (□PSI) is one of the main design inputs. Therefore, PSI models are considered essential in the design of both flexible and rigid pavements.

The 2002 design guide was developed in the National Cooperative Highway Research Program (NCHRP) 1-37A (NCHRP, 2004) to include pavement response, material behavior nonlinearities, complexity in traffic loadings, and extreme environmental conditions. The 2002 mechanistic-empirical pavement design guide (MEPDG) allowed for pavement performance predictions including fatigue, rutting, and low-temperature cracking.

Objectives

The main objectives of this study were as follows:

1. To develop experimental model for the PSR of urban highway flexible pavements as a function of physical measurements of pavement distresses and roughness using multiple regression analysis. The model will be in the form of:

   $$PSI = \beta_0 + \beta_1 f(D_1) + \beta_2 f(D_2) + \beta_3 f(D_3) + \beta_4 f(D_4) + ... + \beta_n f(D_n)$$

   Where:

   β_0, β_1, β_2, β_3, β_4, …., and β_n are regression coefficients, and

   D_1, D_2, D_3, D_4, …., and D_n are types of distress measurements or slope variance.

2. To investigate the individual relationships between PSR and the different types of distresses as well as roughness of urban highway flexible pavements using multiple regression analysis.

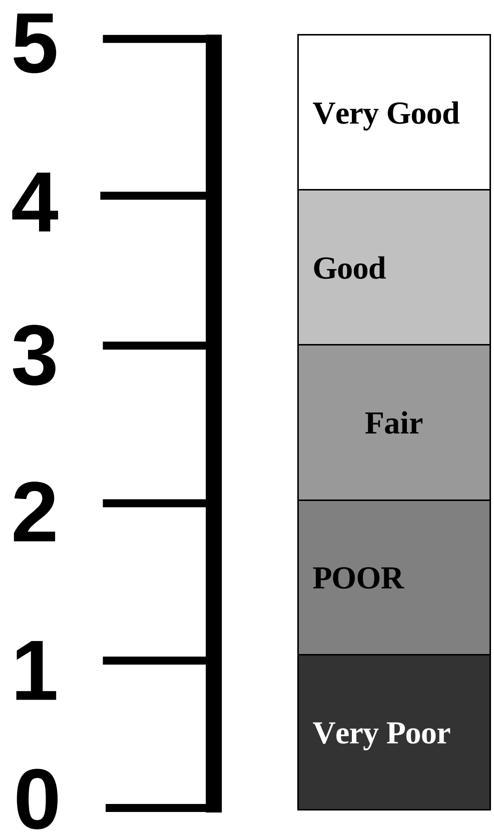
Methodology and Field Procedures

Highways Selection

Thirty-five urban highways were selected in this study covering a wide range of traffic loadings, environmental conditions, and geographical locations in Jordan. Pavement sections were all flexible ones. Each pavement section was 1,200 ft (366 m) in length and 10 ft (3.1 m) in width. Urban highways in Jordan are classified into two main classes: primary and secondary highways. The thirty-five urban highways selected in this study covered both highway classes: primary and secondary. Field procedures conducted in this study are detailed in the following sections.

Figure 1. *Pavement Evaluation Form*

Jordan University of Science and Technology			
Department of Civil Engineering			
Transportation Section			
Pavement Evaluation			
Highway Name	Al-Hashemi Street	Rater Name	Riyada
Highway Class	Urban	Vehicle	Passenger Car
Section ID	1	Time	10:00 am
Pavement Type	Flexible	Date	April 2, 2008
Length of Section	1,200 ft	Rating	Good
Width of Section	10 ft		



	Yes	**No**	**Not Sure**
Is This Pavement Section Acceptable?		×	
Does Pavement Section Need Routine Maintenance?		×	
Does Highway Pavement Need Major Maintenance?	×		

PSR and Ride Quality

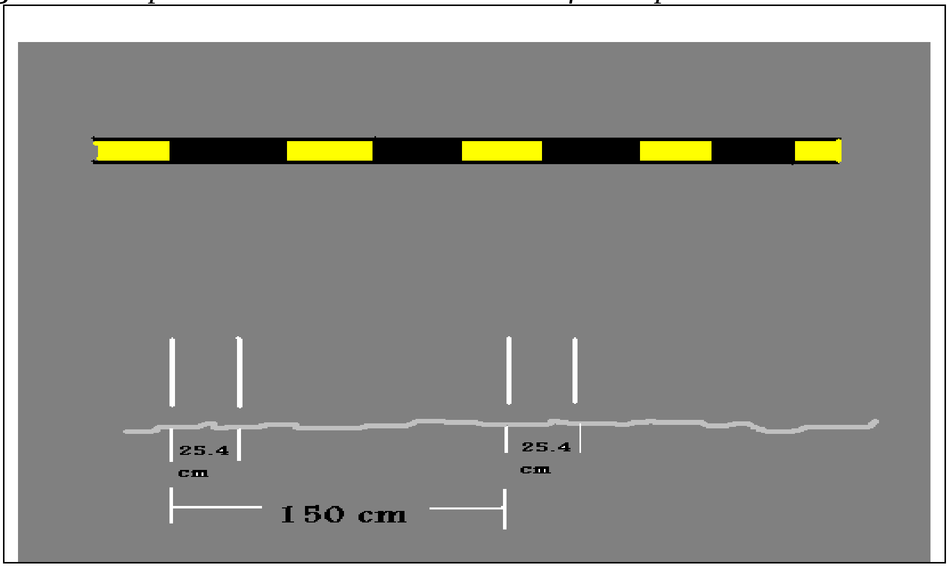
The present serviceability rating (PSR) was determined for each pavement section based on the ride quality over the section. It was measured by a panel of five engineers. Using the pavement evaluation form shown in Figure 1, each engineer provided the rating independently of the others to avoid bias in PSR determination. In addition, the PSR was provided by a group of seven drivers (road users) of single-unit trucks, semi-trailers, large trucks, buses, and passenger cars. This step was done to validate the results of the five-engineer panel. A significant linear correlation with a coefficient of determination of 0.86 was obtained between the PSR measures of the two sets (the panel of engineers and the group of road users). This result supported the validity of such subjective measure for the pavement condition.

Roughness / Slope Variance

Roughness for each pavement section on these highways was determined by measuring the slope variance (SV) along the wheel paths. Road profilometers were unavailable during the time period of the study, and hence, the slope variance was measured using the surveying level instrument and staff. The slopes were sampled at 1.5-m intervals over the entire length of the pavement section. Each slope was measured along 10-inch (25.4-cm) distance (Figure 2) by taking two level readings at the two ends. This was actually a tedious work to do. At the end, the data points for pavement sections were huge. A total number of 8,400 data points for slope measurements were taken (240 data points for each pavement section). The slope variance was computed using the following equation (Huang, 2004):

$$SV = \frac{\sum_{i=1}^{n} \left(S_i - \bar{S}\right)^2}{n-1} \qquad (2)$$

Figure 2. *Sample Intervals and Measurements for Slope Variance*



Where: SV = slope variance, S_i = ith slope, $\overline{S}$ = average of all slopes, and n = number of data points.

Pavement Distresses

In this study, physical measurements of distresses on the selected pavement sections were conducted. Pavement distresses included: rutting, fatigue (alligator) cracking, potholes, linear (longitudinal and transverse) cracking, patching, debonding, potholes, bumps & sags, and depressions. From this point on, these distresses will be given the following symbols:

Rut Depth = RD, Alligator Cracking = AC, Linear Cracking = LC, Patching = P, Debonding = DB,Potholes = PH, Bumps and Sags = B&S, and Depressions = D.

Alligator (fatigue) cracking, patching, debonding, and depressions were all measured by surface area (m^2). Linear (longitudinal and transverse) cracking and bumps and sags were measured by length (m). Potholes were measured by number. On the other hand, rutting was measured by rut depth across the rutting area in the wheel path using a straightedge. Several rut depth measurements were taken across the straightedge and the mean rut depth was then computed. Rut depths were measured at 5-m intervals along the rutting area in the wheel paths of the pavement section. The overall average of all rut depth means was at the end calculated to represent the mean rut depth of the pavement section. While some of these distresses were observed to exist on the surveyed pavements at relatively quite good quantities, other distresses, however, existed at a lower rate including debonding and depressions. Distresses that did not exist or existed in the pavement sections at a minimum rate and were less likely to affect the PSR were not considered in the study. Figure 3 shows significant distresses considered in this study.

Figure 3. *Significant Pavement Distresses Considered in the Study*

(a) High Severity Fatigue Cracking **(b) Potholes**

(c) Medium Severity Fatigue Cracking

(d) Linear Cracking

(e) Patching

(f) Rutting

The dependent variable in this study was PSR (present serviceability rating) that represented the present serviceability index (PSI), and the independent variables were: SV = slope variance (10^{-6}), RD = rut depth (m), AC = alligator cracking (m^2), LC = linear cracking (m), P = patching (m^2), DB = debonding (m^2), PH = potholes (number), B&S = bumps and sags (m), and D = depressions (m^2). To develop experimental models between the dependent variables and the seven independent variables, the least squares method in a multiple regression analysis was therefore used. PSI was formulated as follows:

$$PSI = \beta_0 + \beta_1 f(SV) + \beta_2 f(RD) + \beta_3 f(AC) + \beta_4 f(LC) + \beta_5 f(P) + \beta_6 f(DB) + \beta_7 f(PH) + \beta_8 f(B\&S) + \beta_9 f(D) \tag{3}$$

Where: β_1, β_2, β_3, β_4, β_5, β_6, β_7, β_8, and β_9 are regression coefficients.

Results, Analysis, and Modeling

Selection of Proper Functions

Prior to regression analysis, the function (*f*) for each independent variable was selected carefully based on the relationship between each independent variable and PSR separately. Sometimes, combined variables were used as one independent variable to obtain the best results in terms of the function that best described the relationship between the PSR (the dependent variable) and the independent variables. For instance, Figure 4 shows the scatter diagram for the PSR value plotted against RD; and Figure 5, on the other hand, illustrates the relationship between the PSR value and PH.

Figure 4. *Relationship Between RD and PSR*

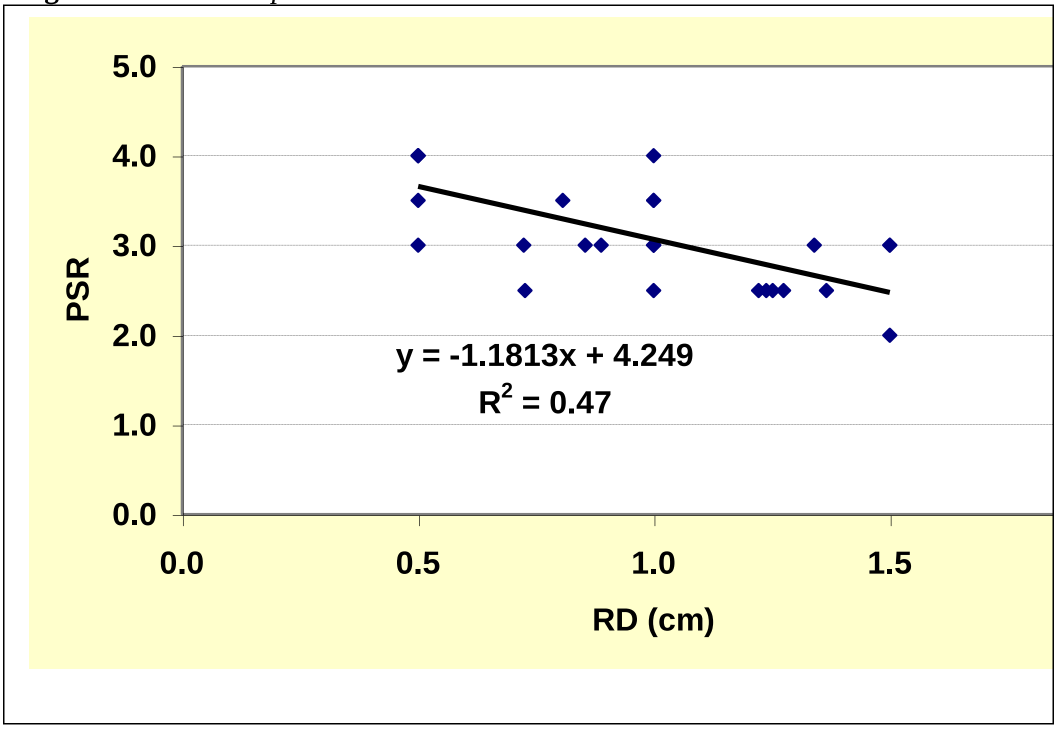
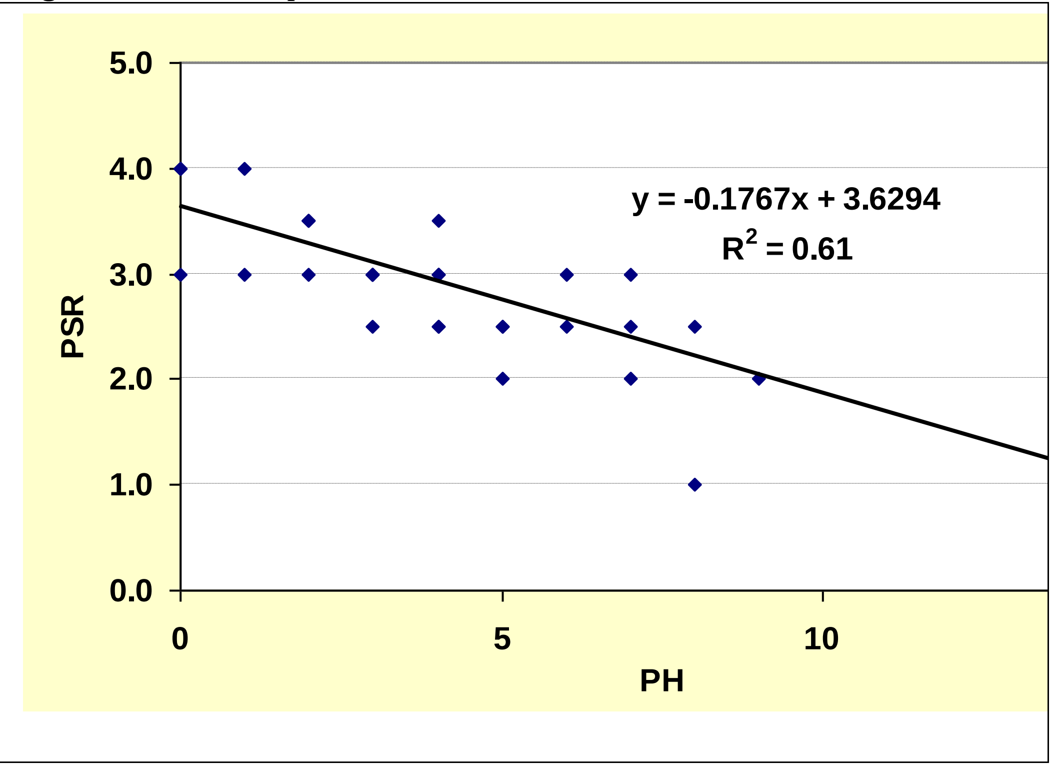


Figure 5. *Relationship Between PH and PSR*



Based upon the previous results, the final formulation of the PSI was as shown in the following equation:

$$PSI = \beta_0 + \beta_1\left(\frac{1}{SV}\right) + \beta_2(RD) + \beta_3(AC+P)^{0.25} + \beta_4\left(LC + \sqrt{B\,\&\,S}\right) + \beta_5(PH) \qquad (4)$$

Due to the fact that debonding and depressions existed at a lower rate in some of the pavements sections and did not exist in others, it was found that their effect on the variation of the PSR was inconsiderable and the relationship between each of these two distresses and the PSR was insignificant.

Development of Multiple-Regression Model for PSI

Multiple regression analysis was conducted using STATISTICA software version 6.0 (2001) to determine the regression coefficients *β1, β2, β3, β4, and β5*. Also a stepwise regression analysis was conducted to determine the best independent variables affecting the PSR variation and the variables that have minimum or insignificant effect on PSR. A finding similar to that found earlier was obtained for debonding and depressions with regards to their correlation with the PSR. In other words, the effect of each of these two variables on PSR variation was insignificant.

The experimental model developed for PSI is shown in the following equation:

$$PSI = 4.1248 + 4.5156\left(\frac{1}{SV}\right) - 0.4339(RD) - 0.2592(AC + P)^{0.25} - 0.1024\left(LC + \sqrt{B\,\&\,S}\right) - 0.0969(PH) \quad (5)$$

The coefficient of determination (R^2) for this model is 0.72. The analysis of variance (ANOVA) and the inter-correlation matrix between variables for this model are shown in Table 1.

Table 1. *ANOVA and Inter-Correlation Matrix for PSI Model*

ANOVA					
Source of Variance	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean of Squares (MS)	F-Value	Significance F
Regression	5	12.178	2.436	15.003	2.706E-07
Residual	29	4.708	0.162		
Total	34	16.886			

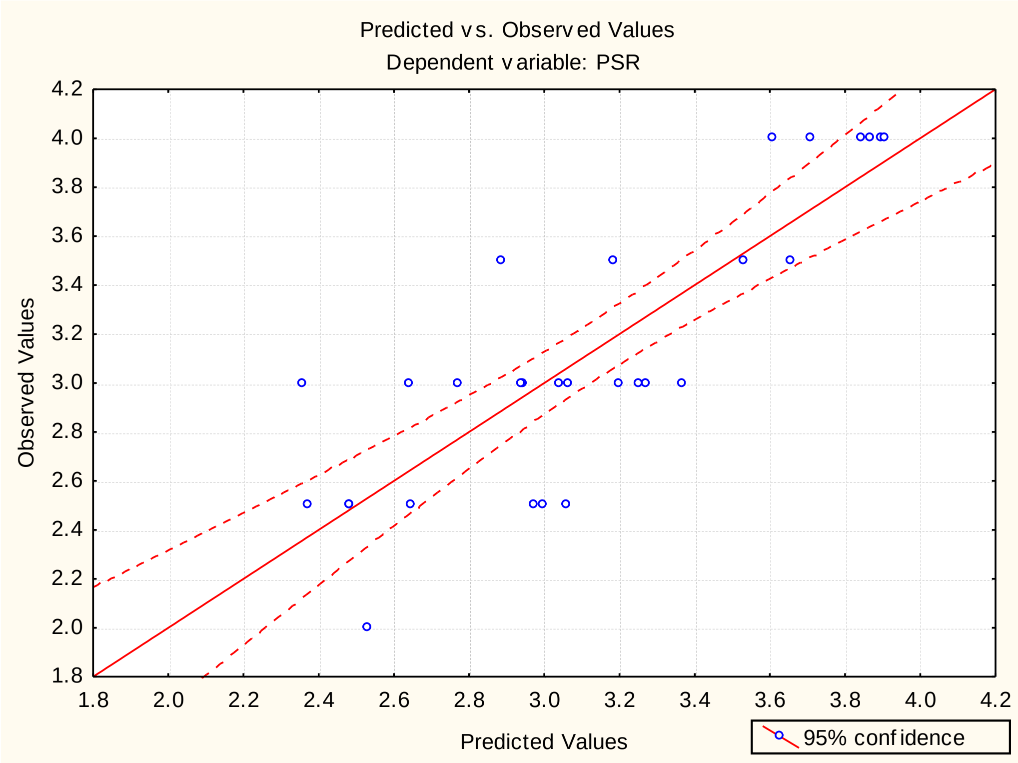
Inter-Correlation Matrix						
Variable	PSR	1/SV	RD	$(AC+P)^{0.25}$	Log $(LC+(B+S)^{0.5})$	PH
PSR	1					
1/SV	0.2420	1				
RD	0.1049	-0.0047	1			
$(AC+P)^{0.25}$	-0.6851	-0.1687	0.1599	1		
Log $(LC+(B+S)^{0.5})$	-0.7498	-0.3113	-0.0959	0.6003	1	
PH	-0.7806	-0.3512	-0.1445	0.6079	0.7375	1

It can be concluded from this table that, for urban highway flexible pavements, PH provided the major correlation variable for predicting PSI followed by LC+(B&S) and (AC+P), respectively. On the other hand, RD provided the least significant correlation variable for computing PSI. The occurrence of rutting in urban highway pavements is not as frequent as in rural highway pavements due to the fact that these pavements do not experience high volume of truck traffic or heavy loadings as the case in rural pavements. As a matter of fact, some urban pavements do not receive any truck or heavy traffic at all particularly those located in downtown or central business district (CBD) areas. Accordingly, the effect of rutting on the variation of PSR was the lowest.

On the other hand, although these pavements do not suffer from heavily repeated traffic loadings, the poor drainage systems and the improper cross slopes for the highway pavements in urban areas result in saturated base and saturated subgrade in some cases; the case that accelerates the occurrence of fatigue cracking. Moreover, the thickness of the asphalt layer for urban highway pavements is mostly insufficient, which also leads to high pavement susceptibility to fatigue cracking.

Figure 6 below shows the model-predicted PSI values plotted against the field-measured values. It is obvious from this figure that at 95 percent confidence interval, there was relatively good match between the predicted values and measured values. In other words, the PSI model provided a good correlation between the PSR and the independent variables including the slope variance and pavement distresses.

Figure 6. *PSI Model-Predicted Values versus Field-Measured*



Conclusions

The following conclusions were drawn based upon the results of this study:

1. A statistical multiple-regression model was developed for the PSI of urban highway flexible pavements as a function of pavement distresses and slope variance. The PSR values can be determined directly from this model.
2. The PSI model developed in this study was a function of the following independent variables: 1/SV, RD, (AC+P), LC+(B&S), and PH.
3. The PSI model developed had a coefficient of determination (R^2) of 0.72.

4. The relationship between the PSR and the SV was power, which indicates that the PSR decreases in power order as the SV increases, and after that, the variations in SV values no longer affects the PSR values.
5. At 95 percent confidence interval, the PSI model-predicted values compared well with the PSR field-measured values. In other words, the PSI model provided a good correlation between the PSR or ride quality and the independent variables including the slope variance and pavement distresses.
6. It was found that PH provided the major correlation variable for computing PSI followed by LC+(B&S) and (AC+P), respectively. On the other hand, RD was found to be the least correlation variable for computing PSI.

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