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Development and Application of Predictor Model for Seasonal Variations in Skid Resistance (I)
—Mechanistic Model—

Kazuo SAITO* and John J. HENRY**

Abstract

This paper describes a part of the findings of a three-year research program to develop a basic mechanistic model to predict the seasonal and short-term variations in skid resistance as a function of environmental and traffic conditions. The model treats the seasonal and short-term variations separately. Data were analyzed from 21 test surfaces in State College, Pennsylvania. For the seasonal trend, an exponential curve was fitted to the skid number data for the asphalt pavements, while a linear relationship best fit the data for portland cement concrete surfaces. The coefficients of the resulting seanonal variation curves were fitted to pavement and traffic parameters to provide predictors for the long term effects. Significant predictors were found to be British Pendulum Numbers (*BPN*) and average daily traffic (*ADT*). Other predictors for pavement polishing are suggested in place of *BPN* to predict the rate of decrease in skid resistance over an annual cycle. After the data for seasonal variations were adjusted, the remaining short-term variations were regressed against rainfall, terperature, and macrotexture parameter. The short- term variations can be predicted by dry spell factor (*DSF*) and pavement temperature (T_P), but the introduction of the measured percent normalized gradient (*PNG*) was found to improve the regression.

The developed model wes applied for predicting the level of skid resistance at the end of the year (SN_{64F}) and for predicting the skid resistance at any day from a measurement taken on a different day. It is concluded that mechanistic model is effective predictor model for predicting those skid resistance.

1. INTRODUCTION

It is generally recognized that the skid resistance of pavement surfaces changes with time. Two decades ago, Giles and Sabey[1] reported that investigations on some British pavements revealed the existence of significant differences in skid resistance between summer and winter. They also presented data which showed that a strong relationship existed between seasonal variations in skid resistance and personal injury accidents.

During the past two decades, several transportation departments and other agencies in

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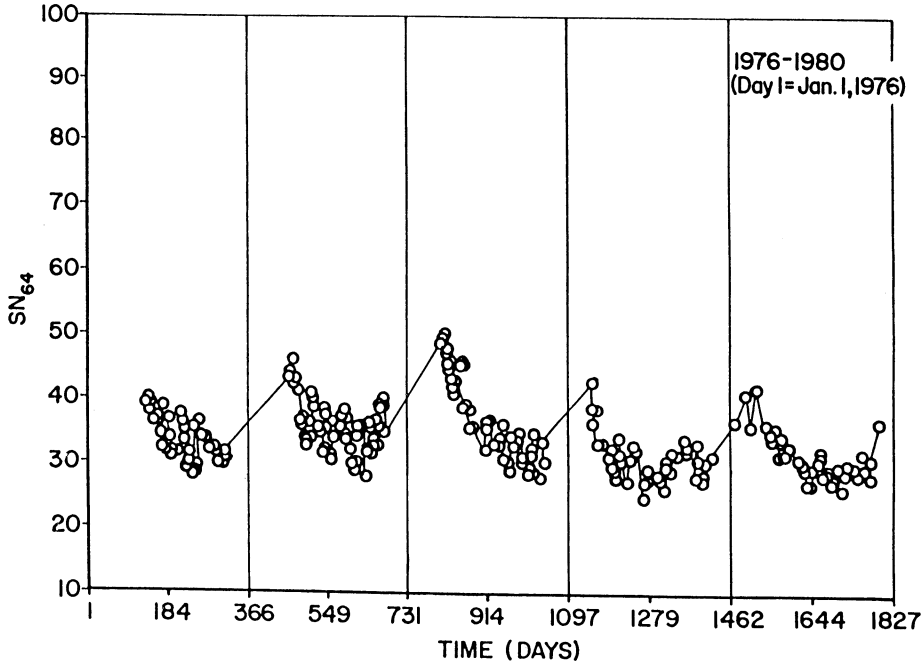

Figure. 1 Seasonal variation in skid resistance during five years (Dense-graded asphalt surface)

the United States have conducted extensive skid-resistance surveys. Skid-resistance measurements made on public highways in Pennsylvania and other states in accordance with ASTM E 274 Method of Test[2] exhibit seasonal and short-term variations,[3),4),5] but until last few years little attention was paid to seasonal variations in these measurements.

Until recently, the most comprehensively documented studies involving both seasonal and short-term skid-resistance variations were the ones undertaken by the Pennsylvania DOT.[4),5] The skid-resistance measurements made in these studies showed that, once a pavement surface had stabilized after being exposed to weather and traffic for one or two years, the surface exibited cyclic skid-resistance variations which tends to be higher in winter through spring than in summer through fall (see Figure 1). Superimposed on these annual cycles are short-term variations, seemingly the result of rainfall and other local weather conditions. Several other states have reported to the Federal Highway Administration (*FHWA*) of U. S. DOT their observations related to seasonal skid-resistance variations. Extreme seasonal variations as high as 30 skid numbers (*SN*) have been observed, with more typical variations in the range of 5 to 15. These observations were summarized by Rice.[6] Analyzing these large changes which occur rather systematically, Hegmon[7] concluded that there are real skid-resistance changes related to changing conditions.

The observed seasonal and short-term variations in skid resistance make it difficult to determine the skid resistance of pavement from a single measurements, to specify minimum skid resistance value for a given road surface in a given time and also to compare the skid resistance of different types of pavement. As a result, these variations make it difficult to establish a rational maintenance program in which skid resistance in one of the important factors. Thus, some analytical procedures are needed which provide a correction to the measured skid resistance for seasonal and short-term variations in test conditions.

The *FHWA* recognized the need for analytical means of interpreting skid-resistance data subjected to seasonal and short-term variations. In 1978, *FHWA* initiated a three-year research program with the Pennsylvania State University to collect frequent skid-resistance measurements of pavements in various areas of the United States and to develop predictor models to describe seasonal variations in skid resistance of pavement surfaces.

This paper describes the finding of a portion of this research program : the development of a basic mechanical model to predict the seasonal and short-term variations in skid resistance as a function of environmental and traffic conditions, and some applications of this developed model. The mechanistic model was based on the hypothesized mechanisms of wear and polishing of the pavement texture and on the data of 21 test pavements in Pennsylvania.

2. DATA BASE

The data base consisted of skid-resistance measurements taken at various speeds, pavement related data, weather data recorded at weather stations located near the test sites.

(1) **Test Sites**

Skid testing was performed on 21 test pavements in Pennsylvania between January and December, 1980. The 21 test sites represented a variety of aggregates and mix designs and included 16 asphalt pavements and 5 porotand cement concrete (*PCC*) pavements, which were subjected to a wide range of *ADT*. The pavement and traffic parameters for each site are listed in Table 1. The construction materials and locations ot the test sites have been fully described by Henry and Dahir.[8]

(2) **Skid-Resistance Test**

For the 21 test sites, the daily skid-resistance tests were made in the transient slip mode.[9] These tests provided SN_{64} data at 64 km/h (40 mph) according to the ASTM E 274 Method of Test, and also brake slip numbers at 16, 32, and 48 km/h (10, 20, and 30 mph) which can be used to approximate SN_{16}, SN_{32}, and SN_{48} respectively. Air, tire, and pavement temperatures were recorded at the time of each test.

(3) **Texture Measurements**

Monthly texture measurements made at each site included British Pendulum Number (*BPN*) according to ASTM E 303 Method of Test,[2] and mean texture depth (*MTD*)

Table 1. Pavement and fraffic parameters (1980)

Site No.	Type of* Pavement	Year of Construction	Type of Aggregate Coarse/Fine	SRL**	PNG(Ave.) h/km	BPN***	MTD*** mm	Total ADT
1	DG	1970	Limestone/NA	L	0.83	58.5	0.368	6630
2	PCC	1960	Limestone/Natural Sand	M	0.32	53.0	0.394	7700
3	PCC	1973	Limestone/Natural Sand	M	0.71	70.0	0.330	3640
4	DG	1972	Limestone/NA	M	0.84	62.5	0.330	3640
8	DG	1972	Limestone/Silica Sand	M	0.61	55.0	0.864	1820
9	DG	1972	Limestone/Silica Sand	M	0.69	69.5	0.622	1710
10	PCC	1973	Limestone/Silica Sand	L	0.77	72.0	0.292	1710
11	DG	1963	Limestone/NA	M	0.79	56.0	0.432	4490
12	DG	1970	Limestone/NA	G	0.63	60.0	0.648	4490
13	OG	1969	Limestone/NA	G	0.53	90.5	0.978	7920
14	PCC	1967	Limestone/NA	M	0.83	62.0	0.368	8770
15	OG	1969	Limestone/NA	E	0.53	86.5	1.194	7920
16	DG	1966	Limestone/Limestone	L	0.88	50.0	0.394	6500
17	DG	1961	Limestone/Limestone	–	0.67	53.5	0.775	800
18	PCC	1973	Limestone/NA	L	0.66	77.0	0.470	1200
19	DG	1968	Limestone/Silica Sand	L	0.81	54.0	0.508	7000
20	DG	1968	Limestone/Silica Sand	L	0.82	65.0	0.508	7000
21	OG	1969	Limestone/Silica Sand	M	0.68	64.0	1.029	2500
22	OG	1969	Gravel/Silica Sand	G	0.58	84.5	1.384	2500
24	DG	1963	Limestone/NA	M	0.83	54.0	0.432	4490
25	DG	1963	Gravel/NA	G	0.68	81.0	0.521	7920

* DG=Dense Graded PCC = Portland Cement Concrete OG = Open Graded
** SRL = Skid Resistance Level in Pennsylvania: L = Low M = Moderate H = High E = Excellent
***Average value of April and May

according to the sand-patch method described by ACPA.[10)]

(4) **Weather-Related Data**

The weather data available in the daily data base were obtained from Weather Station in University Park, Pennsylvania.

(5) **Pavement Polishing Data**

During July 1980 a series of tests was carried out on the 21 test sites using Penn State Reciprocating Pavement Polisher.[11)] Each pavement was subjected to 2000 polishing cycles using 0.05-mm silica abrasive, with measurements taken initially (BPN_0), after 500 cycles (BPN_{500}), and after 2000 cycles (BPN_{2000}). The results are listed in Table 2.

3. DEVELOPMENT OF MECHANISTIC MODEL

The mechanistic model based on the detailed pavement studies on surface property behavior over periods ranging three to five years, conducted at the Pennsylvania test sites. The observed seasonal variations in skid resistance from spring to fall were similar in all test sites, with a low skid number in the late fall that was brought to almost its original levels as the skid resistance was rejuvenated over the winter season. Short-term variations, seemingly due to rainfall and local weather conditions, were superimposed on this annual cycle.[12] These trends imply that it may be possible to develop an equation or model to predict the low skid numbers that generally occur in the fall, from a skid-resistance measurement taken at any time during the year.

Table 2. Results of polishing tests with the Penn State Reciprocating Pavement Polisher (July 1980)

Site No.	BPN_0	BPN_{500}	BPN_{2000}
1	59	60	59
2	68	75	64
3	74	79	70
4	58	68	64
7	68	70	71
8	56	51	50
9	71	66	69
10	70	72	75
11	67	68	66
12	87	82	73
13	89	85	87
14	73	68	66
15	87	85	81
16	70	62	56
17*	—	—	—
18	74	73	67
19	65	62	63
20	65	62	63
21	67	74	68
22	81	76	78
24	50	59	56
25	79	77	71

* This site has been resurfaced.

(1) **Description of the Mechanistic Model**

In this model, it is hypothesized that seasonal variations are due to a reduction in the microtexture as a result of polishing, and a reduction in the macrotexture as a result of the wear of the aggregate. The short term effects are attributed to contaminants that accumulate on the pavement,[13] and in some cases, to chemical reactions such as might occur between limestone aggregate and acid rain. The short-term effects, therefore, are modeled as causing short-term modifications to the microtexture.

The model utilizes the Penn State Model,[14] in which SN_0 is related to microtexture and PNG is related to macrotexture :

$$SN_V = SN_0 \ e^{-(PNG/100)V} \qquad (1)$$

where SN_V = skid number at velocity V (km/h)

SN_0 = skid number-speed intercept

PNG = percent normalized gradient defined as $-\dfrac{(100/SN_0)}{d(SN)/dv}$ and has unit of (h/km).

Or, for the skid resistance at 64 km/h :

$$SN_{64} = SN_0 \ e^{-0.64 \ PNG} \qquad (2)$$

The term SN_0 (microtexture) has both seasonal and short-term components (SN_{OL} and SN_{OR}), where the SN_{OR} is the residuals after curve-fitting a seasonal trend SN_{OR} . Thus, the value of SN_0 at any time can be expressed :

$$SN_0 = SN_{OL} + SN_{OR} \qquad (3)$$

The SN_0 deduced from data collected throughout the year typically exhibits seasonal variations as shown in Figures 2 and 3. Figure 2 shows the trend for a typical asphalt

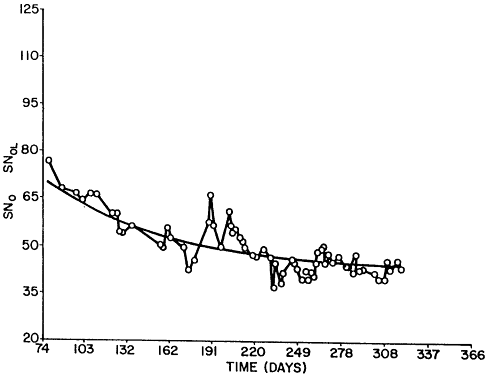

Figure. 2 SN_0 versus time for asphalt surface (Pennsylvania site 8, 1980)

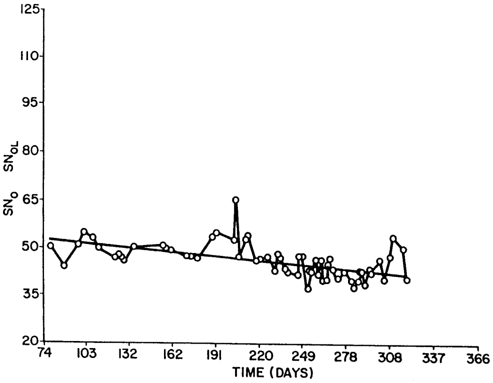

Figure. 3 SN_0 versus time for *PCC* surface (Pennsylvania site 2, 1980)

concrete surface. The seasonal trends for these cases can be considered to be exponential in nature, whereas the trends in the data for PCC surfaces (Figure 3) are linear.

For asphalt surfaces, the seasonal component is well described by an exponential relationship at any time t when a measurement is made.

$$SN_{OL} = SN_{OF} + \Delta SN_0 \ e^{-t/\tau} \tag{4}$$

while for PCC surfaces, a linear relationship better fits the observations :

$$SN_{OL} = SN_{OF} + \frac{\Delta SN_0}{\tau}(\tau - t) \tag{5}$$

where

SN_{OF} = the level of SN_o after the pavement is fully polished. SN_{OF} is independent of both seasonal and short-term variations.

$\triangle SN_0$ = the polish susceptibility of the aggregate (an aggregate property).

τ = the polishing rate of the aggregate, a combination of aggregate property and *ADT*.

At any time t when a measurement of SN_{64} is made, equations (2), (3), and (4) combine for asphalt pavement surfaces to yield

$$SN_{64} = (SN_{OR} + SN_{OF} + \Delta SN_0 e^{-t/\tau}) e^{-0.64 \cdot PNG} \tag{6}$$

The level of skid resistance at the end of the season (SN_{64F}) can be written, noting that the mean of the residuals SN_{OR} is zero :

$$SN_{64F} = SN_{OF} \ e^{-0.64PNG} \tag{7}$$

Substituting equation (7) into equation (6) to eliminate SN_{OF}, and rearranging, produces a relationship that can be used to predict the level of skid resistance at the end of the year (SN_{64F}) from a measurement taken at any time during the season (SN_{64}) :

$$SN_{64F} = SN_{64} - (SN_{OR} + \Delta SN_0\ e^{-t/\tau})e^{-0.64\ PNG} \qquad (8)$$

For Pcc surfaces,

$$SN_{64F} = SN_{64} - (\ SN_{OR} + \frac{\Delta SN_0}{\tau}(\ \tau - t\ ))\ e^{-0.64\ PNG} \qquad (9)$$

The short-term component SN_{OR} in equation (3) can be described by variables related to weather and texture in the form of the following linear model :

$$SN_{OR} = a_0 + a_1X_1 + a_2X_2 + \cdots\cdots + a_nX_n \qquad (10)$$

where

a_i = coefficient determined by multiple regression

X_i = variables related to weather and texture

(2) **Fitting of Seasonal Relationship**

For each site, data were averaged for each month and these averaged SN_0 were assigned at the middle of each month. Next, the seasonal variations of mothly averaged SN_0 were fitted according to the shifted model instead of equation (4), since the highest recorded values of SN_0 at all sites were observed in mid-March (t=74 Jullian days) :

$$SN_{OL} = SN_{OF} + \Delta SN_0\ e^{-(t-74)/\tau} \qquad (11)$$

Figure 4 graphically shows the basic concept of this model. The procedure to fit the data is to vary τ which is treated as an independent variable and regress the data to produce values of SN_{OF} and $\triangle SN_0$ for each value of τ.

For PCC surfaces, the following linear model was applied to yield the average value of SN_{OF} and the rate of decrease, $\triangle SN_0/\tau$, where τ is fixed at 275 Jullian days (mid-

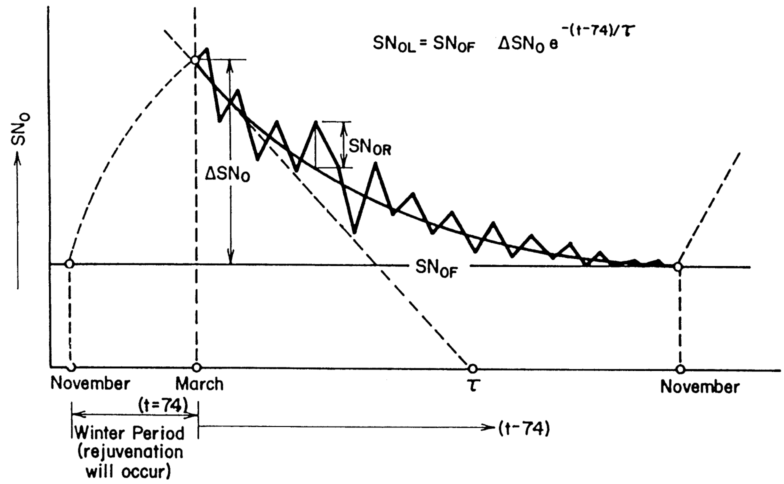

Figure. 4 The basic concept of mechanistic model

Table 3. Parameters of model for seasonal variations in skid resistance (1980)

Asphalt Surface: $SN_{OL}=SN_{OF}+\varDelta SN_0 e^{-(t-74)/\tau}$

Site No.	τ	$\varDelta SN_0$	SN_{OF}	R^2
1	190	22.8	44.2	0.765
4	160	26.5	47.9	0.848
8	80	28.6	43.1	0.919
9	40	28.0	64.9	0.672
11	110	19.4	44.2	0.787
12	210	32.5	46.9	0.795
13	160	26.6	78.4	0.926
15	210	31.0	77.0	0.939
16	170	14.8	34.3	0.656
17	130	26.4	40.0	0.750
19	140	19.9	44.2	0.844
20	90	23.1	57.6	0.893
21	150	26.2	40.4	0.767
22	170	32.5	66.7	0.866
24	190	20.4	39.6	0.720
25	210	25.3	69.4	0.963

PCC Surface: $SN_{OL}=SN_{OF}+\frac{\varDelta SN_0}{\tau}(\tau-t+74)$

Site No.	τ	$\varDelta SN_0$	SN_{OF}	R^2
2	275	12.4	40.5	0.544
3	275	11.5	66.7	0.546
10	275	8.2	77.8	0.512
14	275	9.6	60.6	0.597
18	275	5.4	73.0	0.323

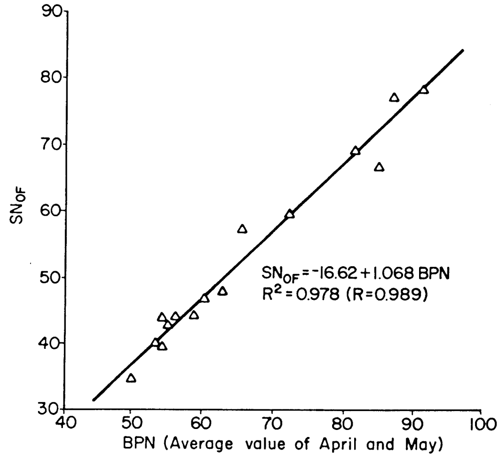

Figure. 5 Relationship between SN_{OF} and *BPN* for asphalt pavement surface

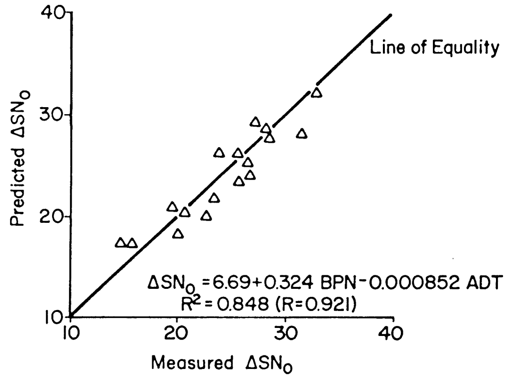

Figure. 6 Prediction of ΔSN_0 from *BPN* and *ADT* for asphalt pavement surface

December) :

$$SN_{OL}=SN_{OF}+\frac{\varDelta SN_0}{\tau}(\tau-t+74) \tag{12}$$

The results of the fitting of the seasonal relationship for all surfaces are summarized in Table 3.

(3) **Prediction of Seasonal Parameters**

After the values of the parameters SN_{OF}, $\triangle SN_0$, and τ were obtained from measured data, methods for predicting these values were attempted.

1) Prediction of SN_{OF}

SN_{OF} is a measure of the microtexture of the pavement after removal of the seasonal and short-term effects. Thus, it seemed likely that a microtexture parameter could be used to predict SN_{OF}. Monthly measurements of *BPN* were available for each of the test pavements. A linear regression of SN_{OF} versus *BPN*, which is the average value of measurements early in the season (April and May), for asphalt surfaces (see Figure 5) yields

$$SN_{OF} = -16.32 + 1.068\, BPN \qquad (R = 0.989) \tag{13}$$

A regression for PCC surfaces yields

$$SN_{OF} = -32.83 + 1.445\, BPN \qquad (R = 0.938) \tag{14}$$

Although the number of observations is not large, linear regression yields significantly high correlations.

2) Prediction of ΔSN_0

ΔSN_0 is a measure of the rejuvenation of skid resistance (see Figure 3) that occurs during the winter months as a result of the depolishing effects of winter conditions[5] and also a measure of the polishing susceptibility of the aggregate by traffic. Therefore, *BPN* and *ADT* seemed likely parameter to be used as predictors. A linear regression of ΔSN_0 versus *BPN* and *ADT* for asphalt surfaces (see Figure 6) yields

$$\Delta SN_0 = 6.69 + 0.324 BPN - 0.000852 ADT \qquad (R = 0.921) \tag{15}$$

For *PCC* surfaces :

$$\Delta SN_0 = 29.51 - 0.289 BPN - 0.000171 ADT \qquad (R = 0.796) \tag{16}$$

The results indicate that the dipolishing of the pavement as a result of winter deicing chemicals is offset by the mechanical polishing that occurs with moderate traffic volumes in case of Pennsylvania test sites. The mechanical aspects of pavement rejuvenation become important when the winter use of studded tires is considered.

Data are available for five of the asphalt pavements in Pennsylvania, for a period of three consecutive winters. In the winter of the second year (1978-1979), the use of studded tires was prohibited. Table 4 shows that ΔSN_0 is consistently greater for the two winters during which studded tires were used. Specifically, ΔSN_0 is greatest for the first winter, during which studded tires were used by a large number of motorists. It is also greater for the third winter, during which studded tires were used by a relatively small number of motorists because it was uncertain untill late November the use of studs would be permitted. These results seem to support the theory that a significant factor in winter rejuvenation of the surface texture is the mechanical interaction between tire and pavement.

Table 4. ΔSN_0 for six asphalt pavement site over three consecutive winters

Site No.	ΔSN_0		
	1977-1978	1978-1979	1979-1980
16	28.0	14.0	14.8
17	31.7	24.9	26.4
19	36.3	23.2	19.9
20	27.3	22.4	23.1
21	30.3	21.5	26.2
22	37.8	15.3	32.5

3) Prediction of τ

The time constant τ is associated with the rate of decrease in skid resistance over an annual cycle and with the polishing rate of an aggregate. Again, *BPN* and*ADT* appear to be usefull parameters for prediction. A linear regression of the data, however, yields a poor, though significant, correlation. The resulting relationship for asphalt pavement sites is

$$\tau = 56.3 + 0.972BPN + 0.00721ADT \qquad (R = 0.713) \tag{17}$$

The introduction of polishing parameter BPN_{2000} instead of *BPN* is found to significantly improve the prediction of τ, yielding for Pennsylvania sites (see Figure 7) :

$$\tau = -22.6 + 0.00933ADT + 2.120BPN_{2000} \qquad (R = 0.875) \tag{18}$$

where BPN_{2000} is reasure of the polish susceptibility of the aggregate, and is the value of *BPN* after 2000 cycles of polishing with 0.05mm (50-m) silica abrasive on the Penn State Reciprocating Pavement Polisher.

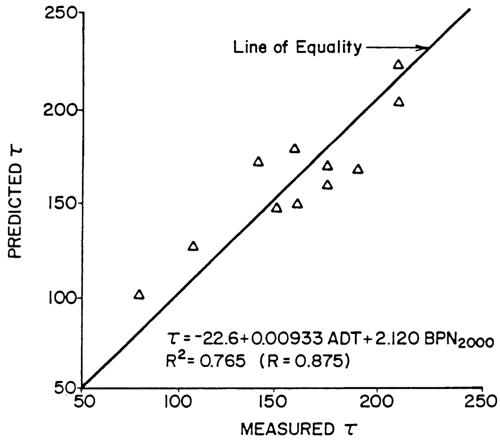

Figure. 7 Prediction of τ from *ADT* and BPN_{2000} for asphalt pavement surface

(4) **Prediction of Short-Term Residuals**

The seasonal variation in skid resistance are assumed to be a function of pavement aggregate properties and traffic density. The short-term residuals, however, are a result of rainfall effects, temperature effects, and errors in skid-resistance reasurements. The largest source of measurement errors is the variation in the lateral placement of the test tire. Hill and Henry[15] discussed these three factors on the basis of the 1979 data from 21 test pavements in Pennsylvania. A multiple regression of SN_{OR} versus dry spell factor (*DSF*) and pavement temperature (T_p) was performed. The resulting regression equation was

$$SN_{OR} = 3.79 - 1.17\ DSF - 0.104\ T_p \tag{19}$$

where

$DSF = ln(t_R + 1)$, where t_R = the number of days since the last rainfall of 2.5 mm or more, with an upper limit of 7 days. Hence, $0 \leqq t_R \leqq 7$.

T_p= pavement temperature at the time of test, measured continuously in the wheel path not being tested.

The coefficient of this regression was $r = 0.35$. The result thus not yield a good prediction of short-term residuals.

To improve the model, the parameter PNG was introduced, which can be deduced from skid-test data by using equation (1) or predicted from a macrotexture measurement.[14] A multiple regression was performed for the 1980 data. For asphalt pavement surfaces, the regression equation is ;

$$SN_{OR} = -9.971 - 2.654DSF + 0.057\,T_p + 7.811PNG \qquad (R=0.522) \qquad (20)$$

and for PCC surfaces, the regression equation is

$$SN_{OR} = -11.464 - 1.049DSF + 0.0005\,T_p + 10.934PNG \qquad (R=0.436) \qquad (21)$$

4. APPLICATION OF MECHANISTIC MODEL

The application of the mechanistic model requires the measurement of skid number-gradients. It may be possible to replace gradient measurement by a texture measurement[14] or surrogate texture measurements such as blank and ribbed tire data at a single speed.[16] Also required are a measure of the the BPN of the aggregate early in the season (April and May), before significant polishing take place, and a measure of the BPN of the aggregate after polishing with the Penn State Reciprocating Pavement Polisher or a similar device (BPN_{2000}). Other data needed are ADT, dry spell factor (DSF), and pavement temperature (T_p), which are all easily measured.

(1) **Prediction of the Adjusted Level of Skid Resistance**

Equations (20) and (21) can be used with equations (8) and (9) to determine the value of SN_{64F} after adjustment for seasonal and short-term effects. The models that can be used to predict the level of skid resistance at the end of the year (SN_{64F}) for a measurement taken at any time during the season (SN_{64}) are for asphalt pavement surfaces :

$$SN_{64F} = SN_{64} - (\Delta SN_0 e^{-(t-74)/\tau} - 9.971 - 2.654DSF + 0.05\,T_p + 7.811PNG)e^{-0.64PNG} \qquad (22)$$

and for PCC surfaces :

$$SN_{64F} = SN_{64} - (\frac{\Delta SN_0}{\tau}(\tau - t + 74) - 11.464 - 1.049DSF + 0.0005\,T_p + 10.934PNG)e^{-0.64PNG} \qquad (23)$$

Figure 8 shows the adjusted SN_{64F} values compared with the original data for asphalt surface. Similar results were obtained for all of the other sites. Ideally, SN_{64F} should be constant with time after all the seasonal and short-term effects have been accounted for. The comparatively low coefficients obviously limit the ability of regression equations (20) and (21) to smooth the data for short-term variations. Figure 9 shows the comparision of

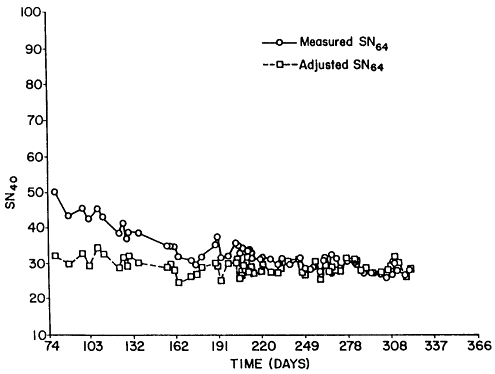

Figure. 8 Comparison of measured and adjusted SN_{64} for asphalt pavement surface (site 8, 1980)

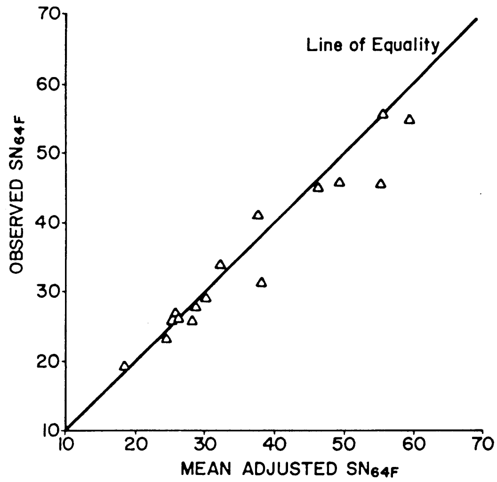

Figure. 9 Comparison of observed SN_{64F} and adjusted SN_{64F} obtained using the mechanistic model

observed SN_{64F} values which are determined from the terminal values of SN_{OF} and the average of the adjusted daily values of SN_{64F}. There is a good agreement between both values.

It is concluded that the mechanistic model developed in this study is an effective predictor model for estimating seasonally adjusted values of SN_{64F}. Further improvement in the correlation between the short-term residuals SN_{OR} and the weather-related parameters would improve the ability of the predictor model to smooth the data for short-term variations.

(2) **Estimation of Skid Resistance at Any Time from a Measurement Taken on Another Day**

The mechanistic model also can be used to estimate the skid number at any time from the measurement made on another day. For asphalt pavement surfaces, the seasonally adjusted level of skid resistance at day $j(SN_{64Fj})$can be predicted from equation (22) by using the related data on day j :

$$SN_{64Fj}=SN_{64j}-(SN_0e^{-(t_j-74)/\tau}-9.971-2.654DSF_j+0.057T_{pj}+7.811PNG_j)e^{-0.64PNG_j} \tag{24}$$

Similarly, the seasonally adjusted level of skid resistance at day k (SN_{64Fk}) can be predicted from the following equation :

$$SN_{64Fk}=SN64_k-(SN_0e^{-(t_k-74)/\tau}-9.971-2.654DSF_k+0.057T_{pk}+7.811PNG_k)e^{-0.64PNG_k} \tag{25}$$

The value of SN_{64} is theoretically equal. Taking the ratio of SN_{64Fk} to SN_{64Fj} and

Table 5. Prediction of skid resistance (*SN*) on day *k* from a measurement taken on day *j* by use of the mechanistic model (1980)

Date		Site 4				Site 11				Site 16			
Day *j*	Day *k*	*PNG*	Measured	Predicted	Dif.	*PNG*	Measured	Predicted	Dif.	*PNG*	Measured	Predicted	Dif.
8/18/80		1.35	32.0	–	–	1.29	27.6	–	–	1.58	20.6	–	–
	5/02/80		37.0	35.9	1.1		–	–	–		25.2	23.2	2.0
	5/05/80		39.2	35.9	3.3		32.6	31.4	1.2		22.7	23.4	−0.7
	5/07/80		35.0	35.0	0.0		31.6	30.4	1.2		22.0	22.5	−0.5
	5/08/80		35.6	34.6	1.0		30.8	29.9	0.9		21.4	22.1	−0.7
	5/15/80		38.0	35.5	2.5		32.8	31.1	1.7		24.0	22.9	1.1
8/21/80		1.29	32.2	–	–	1.23	30.2	–	–	1.41	20.4	–	–
	5/02/80		37.0	36.8	0.2		–	–	–		25.2	23.9	1.3
	5/05/80		39.2	36.9	2.3		32.6	34.8	−2.2		22.7	24.0	−1.3
	5/07/80		35.0	35.9	−0.9		31.6	33.7	−2.1		22.0	23.1	−1.1
	5/08/80		35.6	35.5	0.1		30.8	33.2	−2.4		21.4	22.6	−1.2
	5/15/80		38.0	36.4	1.6		32.8	34.5	−1.7		24.0	23.5	−0.5
8/25/80		1.18	33.4	–	–	1.19	26.4	–	–	1.46	20.7	–	–
	5/02/80		37.0	38.7	−1.7		–	–	–		25.2	24.2	1.0
	5/05/80		39.2	38.7	0.5		32.6	31.3	1.3		22.7	24.3	−1.6
	5/07/80		35.0	37.7	2.7		31.6	30.2	1.4		22.0	23.5	−1.5
	5/08/80		35.6	37.3	1.7		30.8	29.7	1.1		21.4	22.9	−1.5
	5/15/80		38.0	38.2	0.2		32.8	31.0	1.8		24.0	23.8	0.2

assuming that *PNG* is the same on day *j* and *k* (which is reasonable given the traffic levels on the Pennsylvania sites), produces a relationship that can be used to predict the level of skid resistance on day *k* from a measurement taken on day *j* :

$$SN_{64k} = SN_{64j} - (SN_0 e^{74/\tau}(e^{-t_j/\tau} - e^{-t_k/\tau}) - 2.654(DSF_j - DSF_k) + 0.057(T_{pj} - T_{pk})e^{-0.64PNG_j} \qquad (26)$$

The equation for Pcc surfaces can be formed similarly by using equation(23)

$$SN_{64k} = SN_{64j} - \frac{\Delta SN_0}{\tau}(t_j - t_k) - 1.049(DSF_j - DSF_k) + 0.0005(T_{pj} - T_{pk})e^{-0.64PNG_j} \qquad (27)$$

Some results of applying these equations are given in Table 5. In this case, Three days (*j*) in August were used, and the skid resistance on five days (*k*) in May were estimated for asphalt surfaces. The results show that there is a good agreement between measured SN_{64k} and predicted SN_{64k} for each site. Therefore, it is concluded that the mechanistic model can be used to predict the skid resistance at any day either in the future or in the past on the basis of measurement taken at any other time.

5. CONCLUSIONS

The following conclusions can be drawn from the development of mechanistic model and its applications :

(1) Based on some observations about seasonal variations in skid resistance, an effective and simple mechanistic model that treats the seasonal and short-term variations separately has been developed. In this model, it is hypothesized that seasonal variation is due to a reduction in the microtexture and the macrotexture as a result of the polishing and wear of the aggregate.

(2) It was found that the level of skid resistance at the beginning of the spring is a function of surface microtexture as measred by *BPN*, average daily traffic volume (*ADT*), and mechanical effects such as the roughening of the surface by studded tires in winter.

(3) The level of SN_0 after the long- and short-term effects have been removed, SN_{OF}, can be predicted by the average *BPN* obtained over a number of tests made in April and May.

(4) The rate of decrease, τ, in skid resistance due to polishing of the aggregate can be adequately predicted by *ADT*, and by BPN_{2000} data obtained using the Penn State Reciprocating Pavement Polisher. Other polishing devices also may be usefull in providing data to predict τ, but suitable relationship would have to be developed.

(5) The short-term variations (SN_{OR}) can be predicted by the dry spell factor (*DSF*), pavement temperature (T_p) and macrotexture parameter PNG, but futher study is needed to improve the prediction of SN_{OR}.

(6) Based on the result of an application of this model to the 1980 data, it is concluded that the mechanistic model is effective predictor model for estimating seasonally adjusted values of SN_{64}.

(7) Further application of this model have been made to predict the skid resistance at any day from a measurement taken on a different day. Based on this result, it is concluded that the mechanistic model can be used to predict the skid resistance at any day either in the future or in the past on the basis of measurement taken at any other day.

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