



室蘭工業大学

学術資源アーカイブ

Muroran Institute of Technology Academic Resources Archive



Development and Application of Predictor Model for Seasonal Variations in Skid Resistance (II) —Generalized Model—

メタデータ	言語: eng 出版者: 室蘭工業大学 公開日: 2014-03-04 キーワード (Ja): キーワード (En): 作成者: 斎藤, 和夫, HENRY, John J., BLACKBURN, Robert メールアドレス: 所属: 室蘭工業大学
URL	http://hdl.handle.net/10258/795

Development and Application of Predictor Model for Seasonal Variations in Skid Resistance (II) — Generalized Model —

Kazuo SAITO*, John J. HENRY** and Robert R. BLACKBURN***

Abstract

This paper describes some of the findings of a research program to develop and validate a model for predicting minimum pavement skid resistance values from measurements taken at any time during the testing season. The model was developed by obtaining frequent skid resistance measurements during a season in several geographical areas in the United States, namely Pennsylvania (1976–1980), North Carolina and Tennessee (1979–1980), Massachusetts (1978–1980), and Florida (1979–1980).

This model may be utilized to estimate the skid resistance at any time in the season from a measurement made during the same season, or to adjust skid resistance measurement made at any time during the season to the end-of-season level. To apply the model, the user should select the set of predictor coefficient values that pertains to the pavement type and geographical area of interest. The other information required is the average daily traffic (ADT), texture measurements (MTD and BPM) for each site, rainfall history, ambient temperature history in the vicinity of the site, and the date.

The model developed here was 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. Based on these results, it is concluded that the generalized model is an effective analytical tool for estimating seasonally adjusted values of skid resistance.

1. INTRODUCTION

It has been recognized that an important aspect of safe travel is the availability of adequate friction between vehicle tires and wet pavement surfaces. Over the years, this friction factor, commonly known as pavement skid resistance, has been measured in the field by various methods. The most widely used method in the United States is the measurement of the wet sliding friction between a full-scale test tire and the pavement, according to the ASTM E 274 Method of Test¹⁾. This method has been widely accepted because it is relatively straightforward and has an obvious connection with the problem it was designed to solve, namely, the skidding of vehicles on slippery roads.

-
- * Dr. Eng., Associate Professor of Civil Engineering, Muroran Institute of Technology, Muroran, Hokkaido, JAPAN
 - ** Sc. D., Professor of Mechanical Engineering and Director of the Pennsylvania Transportation Institute, the Pennsylvania State University, University Park, Pa. U.S.A.
 - *** M. S., Head of Engineering and Statistical Sciences Section, Midwest Research Institute, Kansas City, Mo. U.S.A.

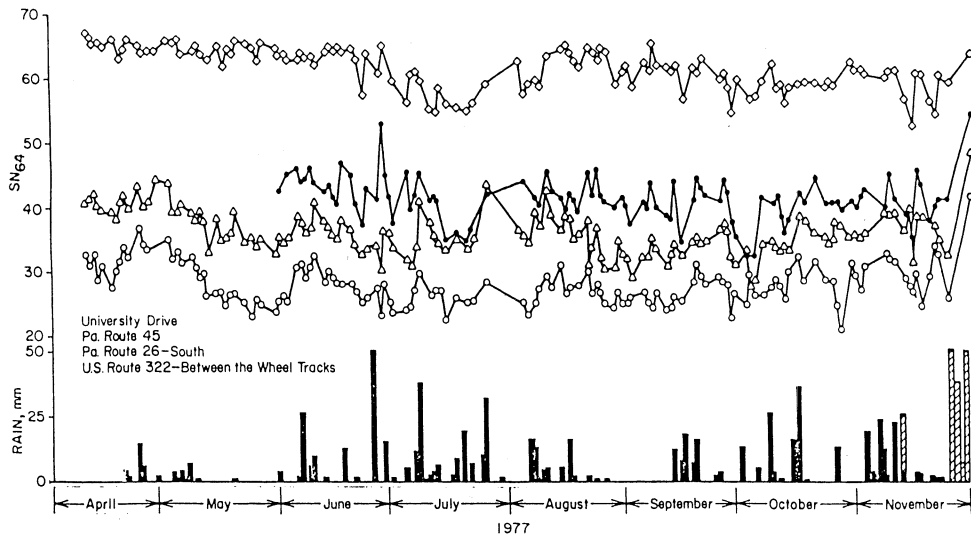


Figure 1. Skid Number (SN64) and Rainfall Data for the 1977 Test Season⁶⁾

In several skid-resistance surveys, repeated measurements on the same pavements have revealed significant variations over both long and short periods of time. Efforts to determine the trends of these variations have pointed to a seasonal cycle where the skid resistance value (skid number) generally decreases in the summer through fall and is rejuvenated in the winter months. Furthermore, skid numbers have been found to vary from week to week and even from day to day, particularly where weather conditions may vary significantly (see Figure 1).²⁾⁻⁶⁾

These variations in skid resistance make it impossible to determine the friction performance of a pavement from a single measurement. Not only it is difficult to specify minimum skid resistance value, much less enforce their maintenance, but it is also difficult to compare the skid resistance histories of different types of pavement.

Transportation departments require the identification of friction levels on their road systems in order to take corrective measures where needed and to evaluate surfacing materials and practices. The minimum friction level for a given pavement is normally the critical level to be determined, but it is not possible to survey all or most pavements during the short period of time when the friction level is expected to be at a minimum. Thus, analytical procedures are needed which provide a correction to the measured skid resistance for seasonal and short-term variations in test conditions.

The Federal Highway Administration (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 Transportation Institute (PTI) of the Pennsylvania State University to collect frequent skid-resistance measurements of pavements in various geographical areas of the United States and to develop predictor models to describe seasonal variations in skid resistance of pavement surfaces.

Two models for predicting seasonal variations in skid resistance have been developed in this research program. One is a mechanistic model based on hypothesized mechanisms of wear and polishing of the pavement texture. Development and application of this model was already reported.⁷⁾⁻⁸⁾ The other is a generalized model based on a purely statistical approach. This model was developed by obtaining frequent skid-resistance measurements during a season in several geographical areas. This model may be utilized to estimate the skid resistance at any time in the season from a measurement made during the same season, or to adjust skid-resistance measurement made at any time during the season to the end-of-season level. For the purpose of these estimates it is necessary only to know the length of time since the last rainfall, the 30-day temperature history from a nearby weather recording station, the average daily traffic, and a skid-resistance measurement and the date on which it was made. In this paper, the modeling approach used in the development of a generalized model and some applications of the model are described.

2. DATA BASE

The four geographical data sets were used in the development of the generalized predictor model and the associated predictor equations. These data pertain to sites in Pennsylvania, North Carolina and Tennessee, Massachusetts, and Florida. The data bases consisted of skid-resistance measurements taken at various speed, pavement-related data, weather-related data recorded at weather stations located near the test sites and the average daily traffic (ADT) count for each site.

(1) Pennsylvania Data

The Pennsylvania data base used for the modeling consisted of daily and monthly nonwinter data associated with six highway sites for each of five years (1976—1980) and data from 16 additional sites for each of two years (1979—1980).

The daily data consisted of information collected during skid-resistance testing of the site surfaces and weather-related information assembled from weather records. The data derived from the daily skid-resistance testing included: date, various skid-test data such as SN₆₄, SN₄₈, SN₃₂, SN₁₆ which are the skid numbers measured at 64, 48, 32 and 16km/h respectively; and also air, tire,

and pavement temperatures recorded at the time of the skid test.

Texture measurements were made monthly at each site and included British Pendulum Number (BPN) and mean texture depth (MTD) as determined by the sand-patch technique.

General characteristics for each site were also available: type of pavement surface; pavement mix design; type and source of pavement aggregate; petrographic description; and ADT count for the facility.

(2) North Carolina and Tennessee Data

The North Carolina and Tennessee data base consisted of daily and occasional monthly data associated with 11 sites. The data span a 16-month period from July 1979 through October 1980. Skid-resistance measurements were conducted mainly at 64km/h. The weather data covered a two-year period (1979–1980) and included the same information as was recorded for the Pennsylvania sites.

Mean texture depth, BPN, and outflow meter measurements were made seven times at each site during the 16-month period. The texture depth measurements were made using the sand-patch technique.

(3) Massachusetts Data

The Massachusetts data base consisted of intermittently collected skid-resistance data from 3 highway sites and weather-related information assembled from weather records. These data covered a three-year (1978–1980) period. Other data available included: type of pavement aggregate; ADT count for the facility; and some fragmentary sand-patch and BPN measurements.

(4) Florida Data

The Florida data base consisted of daily and monthly data associated with six highway sites. The skid-resistance measurements were made mainly at 64km/h during an eight-month period (mid-July 1979 through mid-March 1980). The weather data covered a two-year period (1979–1980).

Texture measurements using the sand-patch technique were made eight times at each site. Other data available included: air and pavement temperatures at the time of test; pavement mix design code; type and source of pavement aggregate; and ADT count for the facility.

3. DEVELOPMENT OF GENERALIZED MODEL

(1) Statistical Modeling approaches

First, an overview is given of the modeling philosophy followed and the various modeling approaches tried. The primary goal of the modeling effort was to produce an equation, or model,

that reliably predicts pavement skid resistance. The predictive worth of such a model can be evaluated in a rigorous manner, but the construction of candidate models is based on analytical judgement.

The development of the generalized model was guided by the following modeling principles:

1. The model should be as simple as possible in mathematical form.
2. Ideally, the model should be amenable to standard statistical procedures, e. g., multiple regression analysis.
3. The model should be compatible with, or at least not incompatible with, known physical characteristics of the system.
4. The application of the model should be readily explainable to practicing engineers.
5. Subject to all these "simplicity" requirements, the model should nevertheless be quantitatively accurate enough to be of value.

The order in which data became available greatly influenced the development of the generalized model. The data base for the initial modeling efforts consisted essentially of daily, nonwinter data associated with six highway sites in the immediate area of State College, Pennsylvania for each of three years (1976, 1977, and 1978). The data base for these (original) six Pennsylvania sites was later extended over the period 1979—1980. Also, records for 16 additional Pennsylvania sites for these two years became available later for analysis along with texture data for all sites. Skid resistance, weather, and texture data were available subsequently from several other geographical areas of the United States, namely North Carolina and Tennessee (1979—1980), Massachusetts (1979—1980), and Florida (1979—1980).

Following this chronological flow of information, the statistical modeling approach can be summarized as follows:

1. Investigate various forms of the generalized model and develop one that best describes the seasonal variation in skid resistance for the six (original) Pennsylvania sites for the years 1976—1978.
2. Apply the best generalized model developed for the six sites to the same sites for the years 1979—1980, as well as to the additional 16 sites for the same time period.
3. Investigate the inclusion in the model of new independent variables and/or the removal of one or more independent variables already in the model.
4. Select a generalized model which is "best" in its capability to predict seasonal variation in skid resistance for Pennsylvania and, at the same time, is most suitable from an engineering point of view.

5. Compute predictor equations for other areas of the United States by using the best form of the generalized model.

(2) **Preliminary Modeling Approach**

Various responses were analyzed in the initial modeling efforts. The most extensive effort in both initial and subsequent stages was spent on modeling the seasonal variations in SN_{64} because of the general interest in this variable. Thus the discussion that follows concentrates on SN_{64} .

The first modeling approach consisted of passing a parabola in Julian calendar time, t_j .

$$SN_{64} = a_0 + a_1t_j + a_2t_j^2 \quad (1)$$

via regression analysis through each site-year of SN_{64} data for the six Pennsylvania sites. This preliminary step was taken in order to decide whether a "real" SN_{64} regression model was feasible, i. e., whether such parabolas reflect the general seasonal variation in SN_{64} . The examination of residuals from the parabolic curve fits also allowed decisions to be made about the daily variables as potential predictors. The examination of the parabolic residuals for autocorrelation determines, to a degree, the feasibility of regression analysis as a modeling technique.

Because of the relative uniformity of the percentage of replicate errors (an average replicate error of 3.9 percent was observed in the measurement of SN_{64}), logarithmic parabolas of the form

$$\ln SN_{64} = a_0 + a_1t_j + a_2t_j^2 \quad (2)$$

were also fitted to the SN_{64} data.

The parabolic fits, especially the logarithmic form, reasonably described the long-term variation of SN_{64} . The analysis also showed, generally speaking, that the quadratic term and higher-order polynomials often did not improve the fit of the model. Thus, it was decided that the mathematical form

$$\ln SN_{64} = a_0 + a_1t_j \quad (3)$$

could be used to describe the general seasonal patterns observed for each site-year. This form served empirically to remove the general seasonal patterns so that the importance of other factors could be examined.

A large number of regression analyses were examined in the development of a preliminary generalized model. The model that best described the seasonal variations in skid resistance for the six original Pennsylvania sites had the following form:

$$\ln SN_{64} = f(RF, T, T_{30}, T_{90}, t_j) \quad (4)$$

or

$$\ln SN_{64} = c_0 + c_1RF + c_2T + c_3T_{30} + c_4T_{90} + c_5t_j \quad (5)$$

RF is a rainfall function which exponentially smoothes rainfall amounts retrospectively and is

computed in the following manner for the i th day:

$$RF = 1/4M_i + 1/8M_{i-1} + 1/16M_{i-2} + 1/32M_{i-3} + \dots \quad (6)$$

where M_i is the rainfall (in mm) recorded for the i th day.

This RF was subsequently replaced by a dry spell factor, DSF, in later modeling efforts. T is the midrange of the daily maximum and minimum ambient air temperatures, T_{30} and T_{90} are 30- and 90-day exponentially lagged midrange ambient temperatures respectively, and t_j is a Julian calendar term. It was preferable to predict statistically the logarithm of SN_{64} rather than SN_{64} itself. Equivalently, SN_{64} is then predicted as a product of exponential terms (rather than as a sum of the linear terms).

The preliminary generalized model (5) was subsequently applied to two additional years of data (1979–1980) as they became available for the same six sites as well as for the 16 additional Pennsylvania sites. In this analysis, two new variables, DSF and T_p , were added to six variables included in model (5) to investigate the efficacy including in the preliminary generalized model new independent variables and/or the removal of one or more independent variables already in the model. T_p is the pavement surface temperature at the time of the skid test, and DSF is a dry spell factor. DSF is an exponentially increasing function dependent upon the number of days, up to seven, since the last significant rainfall, defined as

$$DSF = 1n(t_R + 1) \quad (7)$$

where t_R is the number of days since the last rainfall of 2.5 mm or more during one day (24h). Both DSF and T_p were included in the modeling because these factors were found to be more important in the mechanistic model.⁷⁾⁻⁸⁾

A large-scale multiple regression was performed using the data from the 22 Pennsylvania sites for the two-year period 1979–1980. Regression coefficients for each combination of variable and their associated R^2 value were calculated and compared. Here R^2 is a measure of the variability in the data explained or accounted for by the respective regression model. This quantity can be interpreted as a measure of the efficacy of the model in explaining SN_{64} variations.

The results of the individual regression analyses for nine models (combination of variables) and the respective R^2 values showed that the adequacy of the models varies considerably between asphalt and concrete sites. The two types of pavement were then considered separately, and average R^2 values were determined separately for the 7 portland cement concrete (PCC) sites and for the 15 asphalt sites. The models applied to the concrete sites yielded an average R^2 value of only 0.179, while an average R^2 value of 0.431 was obtained for the asphalt sites. This finding led to the conclusion that only the results obtained from the asphalt sites should be considered in the

selection of the "best" model. Table 1 shows the average R^2 values for nine models for asphalt sites in descending order. The followings can be drawn from Table 1 that:

- (1) On the average, substituting the rainfall function for a dry spell factor had a negligible effect on the regression results.
- (2) The improvement obtained when the T_{90} term (90-day exponentially lagged midrange temperature factor) is included is of little importance compared with the amount of additional weather information necessary to compute this factor.

Table 1. The Average R^2 Values for Nine Model (Asphalt, 15 Sites)

Model	Average R^2
$\ln SN_{64} = f(RF, T, T_{30}, T_{90}, t_j, t)$	0.460
$\ln SN_{64} = f(RF, T, T_{30}, T_{90}, t_j, t)$	0.457
$\ln SN_{64} = f(RF, T, T_{30}, t_j, t)$	0.450
$\ln SN_{64} = f(DSF, T, T_{30}, t_j, t)$	0.445
$\ln SN_{64} = f(RF, T_p, T_{30}, T_{90}, t_j, t)$	0.434
$\ln SN_{64} = f(DSF, T_p, T_{30}, T_{90}, t_j, t)$	0.431
$\ln SN_{64} = f(DSF, T_p, T_{30}, t_j, t)$	0.432
$\ln SN_{64} = f(DSF, T, t_j, t)$	0.406
$\ln SN_{64} = f(DSF, T_p, t_j, t)$	0.378

- (3) The substitution of the pavement temperature at the time of the test, T_p , for the daily midrange temperature, T , resulted in lower average R^2 values for the 15 asphalt sites.

In addition to these results, two other criteria for the "best" model were considered:

1. Simplicity of the model, i.e., a model with the fewest variables and therefore easiest to apply, but nevertheless accurate.
2. Comparability with the mechanistic model in terms of the variables used.

Therefore, the following model

$$\ln SN_{64} = f(DSF, T, T_{30}, t_j, t) \quad (8)$$

involving a dry spell factor, a midrange temperature, a 30-day exponentially lagged temperature, a Julian calendar time, and a long-term calendar time, was chosen as the best preliminary predictive model to describe the seasonal variation of SN_{64} for the Pennsylvania sites.

At this point in the development of the generalized model, it was judged that t , the long-term calendar time, was not the most appropriate choice. A more site-specific time measure seemed more appropriate, and therefore, pavement age measured in year, t_a , was chosen to represent the long-term time influence. The substitution of t_a for t also improved the fit of the model. For the 15 Pennsylvania asphalt sites (1979–1980 data), the R^2 improved from 0.075 to 0.188. For the seven Pennsylvania concrete sites (1978–1980 data), the R^2 value improved from 0.036 to 0.753. In the remaining of the model development, t_a was used exclusively to describe the long-term time measure.

(3) Description of the Generalized Model

Mathematically, the seasonal variations of SN_{64} can be predicted by a product of six exponential terms:

$$SN_{64} = e^{a_0} e^{a_1 DSF} e^{a_2 T} e^{a_3 T_{30}} e^{a_4 t_j} e^{a_5 t_a} \quad (9)$$

Alternatively, the natural logarithm of SN_{64} can be expressed as a linear combination of a constant plus five terms:

$$\ln SN_{64} = a_0 + a_1 DSF + a_2 T + a_3 T_{30} + a_4 t_j + a_5 t_a \quad (10)$$

where a 's are model coefficients; DSF, T , and T_{30} are weather-related variables; t_j is a Julian calendar time; and t_a is the pavement age. DSF is a spell factor defined in equation (7), where t_R is the number of days since the last rainfall of 2.5mm or more with an upper limit of seven days. Hence, $0 \leq t_R \leq 7$ and $0 \leq DSF \leq 2.075$.

The second term after the constant in (10) contains a measure of the ambient air temperature, T . It is the midrange of the daily maximum (T_U) and minimum (T_L) ambient air temperatures;

$$T = (T_U + T_L)/2$$

The third term contains a 30-day exponentially lagged temperature function. At any given day i , T_{30} is calculated iteratively as follows:

$$T_{30i} = \alpha T_i + \alpha (1 - \alpha) T_{i-1} + \alpha (1 - \alpha)^2 T_{i-2} + \dots \quad (11)$$

where T_i is the midrange temperature at day i and the constant α equals $1/30$. The term "lagged" temperature reflects the fact that the term T_{30} represents a historical temperature function with a turning point that lags approximately 30 days behind the current temperature. Theoretically, the smoothing equation (11) extends infinitely backwards in time, although in practice the numerical impact diminishes to a negligible magnitude in a finite number of terms.

The third and fourth exponential terms, t_j and t_a , are time terms that represent the short-term and long-term decays in skid resistance. The short-term calendar time, t_j , is the Julian calendar time and is expressed in days. The long-term calendar time, t_a , has been set equal to the pavement age of each site and is expressed in years.

The numerical values for the a 's are determined by stepwise multiple regression analysis. Equations (9) and (10) apply to a given site for several years, though different model parameter values are necessary to characterize different sites. When the model is applied to a site for a single year, the long-term function of time, t_a , is omitted since it would be a constant for that year.

(4) Summary of Model Results by Site for Pennsylvania

The generalized model expressed by equations (9) and (10) was developed for the six (original) Pennsylvania sites (1976–1978 data). It was then applied to 16 additional Pennsylvania sites (1979–1980 data). The adequacy of the model for each site-year combination was judged by the corresponding R^2 value. The goodness of fit of the predictive model varied from site to site for a given year and year to year for a given site. The predictive model was less powerful for the concrete

site than for the other five original sites (asphalt) for all five year. The R^2 values of the model averaged over the years 1976 to 1980 for six original sites are shown in Table 2.

The model produced very poor results when applied individually to the 1979 and 1980 data associated with concrete site. The extremely low R^2 values obtained for these two years contributed to the low average R^2 value for site 18.

Also, the contribution of the model to explaining the variation observed in $\ln SN_{64}$ for these two years is not statistically significant. Such inadequacy of the model was not

Table 2. The R^2 Values of the Model Averaged Over the Years 1976-1980 for Six Original Sites

Site	Type	\bar{R}^2
16	Asphalt	0.539
17	Asphalt	0.673
19	Asphalt	0.640
21	Asphalt	0.707
22	Asphalt	0.514
18	Concrete	0.179

found for any of the site-year combinations of the five original asphalt sites.

Another inconsistency was found when the model was applied to the additional 16 Pennsylvania sites. The R^2 values of the model averaged over the ten asphalt sites more than doubled from 1979 to 1980, whereas the R^2 values averaged over the six concrete sites decreased by a small amount from 1979 to 1980. For the ten asphalt sites, $\bar{R}^2 = 0.224$ in 1979 and 0.558 in 1980. For the six concrete sites, $\bar{R}^2 = 0.357$ in 1979 and 0.299 in 1980. In general, the model produced poorer results for the 16 additional sites when applied to the 1979 data than when applied to the 1980 data. This lack of fit was more evident for the asphalt sites than for concrete sites.

The following conclusions were drawn from these results:

- (1) the model cannot be applied uniformly to combinations of asphalt and concrete sites;
- (2) the model does not account for site-to-site and year-to-year variations; and
- (3) the model needs to be applied to combined sites and years for a specific geographical area in order to reduce the number of sets of models required for a given area.

(5) Need for Introducing Additional Site-Specific Terms in the Model

In general, the model coefficients developed for a given site in a specific area of the United States would be applicable only to sites with similar weather and site characteristics. Thus, to minimize the number of sets of model coefficients needed to describe sites within an area, it is necessary to pool data from many sites in an area. On the other hand, combining the data for all sites in an area and ignoring the "site effect" would result in a considerable loss of predictive power of the composite model. Therefore, model parameters that distinguish between pavements in the same environment, and classification by pavement type must be incorporated into the modeling. Thus, the following model was investigated:

$$\ln SN_{64} = a_0 + a_1 DSF + a_2 T + a_3 T_{30} + a_4 t_j + a_5 t_a + a_6 ADT + a_7 MTD + a_8 BPN \quad (12)$$

or, alternatively,

$$SN_{64} = e^{a_0} e^{a_1 DSF} e^{a_2 T} e^{a_3 T_{30}} e^{a_4 t_j} e^{a_5 t_a} e^{a_6 ADT} e^{a_7 MTD} e^{a_8 BPN} \quad (13)$$

where the variables DSF, T, T₃₀, t_j, t_a, are as defined in (10), and ADT = average daily traffic in the lane tested, MTD = macrotexture term (sand-patch texture depth), and BPN = microtexture term. Each site was classified as either concrete (C) or asphalt (A). A further subdivision of the asphalt pavement group into dense-graded and open-graded bituminous pavements was not carried out, because of the small size of the subgroups.

(6) Model Results by Geographical Area

The specific predictive equations for the generalized model in (13) were determined from the data for the 22 sites in Pennsylvania, the 6 sites in Florida, the 3 sites in Massachusetts, and the 11 sites in North Carolina and Tennessee. Both pavement types, asphalt and concrete, were considered separately and together, i.e., the generalized model was applied to the total data set. Within each of three groups, three models were used to calculate the coefficient values and R² values: the model without the BPN factor; the model without MTD factor; and the model with both factors.

The values of the model coefficients were accepted only if the contribution of the corresponding factor in explaining the variation observed in lnSN₆₄ is significant at the 90 percent confidence level.

The model results for Pennsylvania sites showed that the model without the BPN factor gives rather poor R² value for the asphalt sites (R² = 0.56) and for all sites together (R² = 0.47); whereas for the concrete sites, the model yields a satisfactory R² value of 0.76. Including BPN in the model (without MTD) improved the fit of the model by such as 54 percent for the asphalt sites (R² = 0.86) and by 77 percent for all sites together (R² = 0.83). For the concrete sites, R² value improved only from 0.76 to 0.80. Including both factors, MTD and BPN, in the model brought little or no improvement over the model with BPN only.

The standard error, Se, of the dependent variable lnSN₆₄ shows the same behavior for the different models. Including BPN in the model but not MTD decreased the error by a considerable amount, while the inclusion of both BPN and MTD showed little or no reduction over the error obtained from the model with BPN only.

The best predictor models for explaining seasonal variations in the skid resistance of Pennsylvania sites are those that have incorporated ADT, BPN, and pavement type. The best predictor model for asphalt sites is the one determined for the 15 sites (1,945 observations) for the 1979–1980 period as follows:

$$SN_{64} = e^{a_0} e^{a_1 DSF} e^{a_2 T_{30}} e^{a_3 t_j} e^{a_4 t_a} e^{a_5 ADT} e^{a_6 BPN} \quad (14a)$$

where $a_0 = 2.933$ $a_1 = -0.0397$ $a_3 = -0.00033$ $a_4 = -0.00034$

$$a_5 = -0.0143 \quad a_6 = -0.000034 \quad a_8 = 0.0196$$

and $R^2 = 0.86$

The best predictor model for concrete sites is the one determined for the 7 concrete sites (926 observations) for the 1979—1980 period as follows:

$$SN_{64} = e^{a_0} e^{a_1 DSF} e^{a_2 T} e^{a_3 T^{30}} e^{a_5 a} e^{a_6 ADT} e^{a_8 BPN} \tag{14b}$$

where $a_0 = 2.747 \quad a_1 = -0.0222 \quad a_2 = -0.0015 \quad a_3 = 0.0011$

$$a_5 = -0.0159 \quad a_6 = -0.000008 \quad a_8 = 0.018$$

and $R^2 = 0.80$

Table 3. Model Coefficients for Various Geographical Areas

Geographical Area	Pavement Type	a ₀	a ₁	a ₂	a ₃	a ₄	a ₅	a ₆	a ₇	a ₈	R ²
Pennsylvania	Asphalt	2.933	-0.0397	0.0	-0.00033	-0.00034	-0.0143	-0.000034	**	0.0196	0.86
	Concrete	2.747	-0.0222	-0.0015	0.0011	0.0	-0.0159	-0.000008	-	0.018	0.80
Florida	Asphalt	4.106	-0.0125	-0.0007	0.0017	-0.00035	-0.0670	-0.000012	-0.0058	-	0.79
	Concrete	----- No Data Available -----									
Massachusetts	Asphalt	----- Generalized Model Investigated was Inadequate -----									
	Concrete	----- No Data Available -----									
North Carolina/ Tennessee	Asphalt	3.065	-0.0097	0.0	0.0	-0.00043	-0.0151	0.000031	-	0.0138	0.91
	Concrete	1.728	-0.0288	0.0	-0.0028	-0.00018	0.0	0.0	0.0	-	0.69

*These R² values reflect the goodness of fit of the model for the geographical areas for which the model has been developed and are only an indicator of how well the model might work in future applications.
 **A blank indicates that term was excluded from the model.

Values for the predictive parameters of the model were computed for other three geographical areas in the same manner for the Pennsylvania sites. The best predictor models and associated coefficients for the various geographical areas are summarized in Table 3. Some of the coefficients in the tabulation were set equal zero. These zero values denote that the contributions of the associated factors toward explaining the variations observed in $\ln SN_{64}$ is not significant at the 90 percent confidence limit.

4. APPLICATION OF THE GENERALIZED MODEL

To apply the generalized model, the user should select the set of predictor coefficient values from Table 3 that pertains to the pavement type and geographical area of interest. The other information required is the average daily traffic (ADT), rainfall history, ambient temperature history in the vicinity of the site, and the date. When a prediction of SN_{64} on a particular day is required,

texture measurements (MTD and BPN) are needed, but when a year-end level or a prediction on day k based on a measurement on day j is desired, texture data are not needed, as shown below. The generalized model with an appropriate set of predictor coefficients can be used in several ways to furnish quantities of interest to the user.

(1) **Prediction of SN₆₄ on a Particular Day**

As an example, consider the following data for Pennsylvania site 19 on June 11, 1980 ($t_j = 163$):

- DSF = 0.693
- T = 48 (°F)
- T₃₀ = 40 (°F)
- t_a = 19 (years)
- ADT = 7000 (vehicles per day)
- MTD = 0.51 (mm)
- PBN = 54

The generalized model predicts, for June 11, 1980:

$$\begin{aligned} SN_{64} &= e^{2.933} e^{0.0397(.693)} e^{0(.48)} e^{-0.00033(.40)} e^{-0.00034(.163)} e^{-0.0143(.19)} e^{-0.000034(.7000)} e^{0(.51)} e^{0.0196(.54)} \\ &= 29.5 \end{aligned}$$

The skid number actually measured on June 11, 1980 was 30.2.

(2) **Prediction of Year-End Level of Skid Resistance, SN_{64F}**

The generalized model can be used to adjust, for seasonal variations, the skid-resistance measurement taken at any time of the year. A method to predict the level of skid resistance at the end of the year (SN_{64F}) from a measurement taken at any time (day j) during the season (SN_{64j}) had been developed for the Pennsylvania sites from the generalized model.

The generalized model recommended for the Pennsylvania sites contains only the annual average BPN as a site-specific variable and is expressed in the form:

$$SN_{64j} = e^{a_0} e^{a_1 DSF} e^{a_2 T} e^{a_3 T_{30}} e^{a_4 t_j} e^{a_5 t_a} e^{a_6 ADT} e^{a_8 BPN} \tag{15}$$

where SN_{64j} = skid resistance measured on day j.

For the application of the generalized model to the Pennsylvania sites, the BPN term in equation (15) was replaced by another site-specific variable, SN_{64F} (the observed final skid-resistance level), to yield the following form of the generalized model:

$$SN_{64j} = e^{a_0} e^{a_1 DSF} e^{a_2 T} e^{a_3 T_{30}} e^{a_4 t_j} e^{a_5 t_a} e^{a_6 ADT} e^{a_9 SN_{64F}} \tag{16}$$

The values of the coefficients in equation (16) have been determined from the observed data, so that the adjusted skid number can be predicted mathematically by a linear relationship produced by taking the natural logarithm of SN_{64j} in equation (16) and rearranging:

$$SN_{64F} = \frac{1}{(-a_0)} (a_0 + a_1 DSF + a_2 T + a_3 T_{30} + a_4 t_j + a_5 t_a + a_6 ADT + \ln SN_{64j}) \quad (17)$$

In this analysis, the 1979 and 1980 data values of SN_{64F} (listed in Table 4), which were calculated from the terminal values of SN_{OF} and PNG by equation (18) shown in the previous paper⁸⁾, were used with the weather-related data.

$$SN_{64F} = SN_{OF} e^{-0.6PNG} \quad (18)$$

where SN_{OF} = the level of SN_0 after the pavement is fully polished. SN_{OF} is independent of both seasonal and short-term variations. SN_0 = skid number-speed intercept and is related to microtexture. PNG = percent normalized gradient and related to macrotexture.

The coefficients that resulted are shown in Table 5 for each pavement type.

For this application, the adjusted level of skid resistance (SN_{64F}) was predicted for asphalt pavements from each observation during the 1980 test season. As an example, consider again Pennsylvania site 19. From the observed value of skid resistance on June 11, 1980, the model predicts the year-end level using equation (17)

Table 4. SN_{64F} Values Calculated from SN_{OF} in the Mechanistic Model for 1979 and 1980 (Pennsylvania Sites)

Site No.	Type of Pavement*	SN_{64F}	
		1979	1980
1	OG	21.3	26.1
2	PCC	31.9	24.0
3	PCC	49.7	42.4
4	OG	22.7	27.9
7	PCC	48.8	45.8
8	PCC	29.3	29.1
9	OG	36.7	41.8
10	PCC	52.3	47.6
11	OG	21.1	26.7
12	OG	34.3	31.3
13	OG	57.7	55.8
14	PCC	42.5	35.7
15	OG	53.9	55.0
16	OG	20.4	19.5
17	OG	27.5	26.1
18	PCC	40.8	48.0
19	OG	26.4	26.3
20	OG	32.5	34.1
21	OG	27.3	26.1
22	OG	54.1	46.0
24	OG	18.5	23.4
25	OG	42.9	45.1

*OG = dense-graded asphalt; OG = open-graded asphalt; PCC = portland cement concrete.

Table 5. Values of Model Coefficients for Each Pavement Type (Pennsylvania Sites, 1979 and 1980)

Pavement Type	a_0	a_1 (DSF)	a_2 (T)	a_3 (T_{30})	a_4 (t_j)	a_5 (t_a)	a_6 (ADT)	a_9 (SN_{64F})	R^2
Asphalt	3.124	-0.0371	0.0	-0.0028	-0.00047	-0.0041	0.0	0.0244	0.85
Concrete	4.264	-0.0195	-0.0019	0.0013	0.0	-0.0440	0.0	-0.0028	0.73
All Sites	3.186	-0.0286	-0.0015	0.00063	-0.00056	-0.0045	-0.000020	0.0204	0.75

with the data from the example in previous section (2) and with $SN_{64j}=30.2$ as follows:

$$SN_{64F} = \frac{1}{-0.0244} \{3.124 - 0.0371 (.693) + 0(48) + 0.0028(40) - 0.00047(163) - 0.0041(19) + 0(7000) - 1n(30.2)\} = 23.6$$

The value of the year-end level observed for site 19 in 1980 was 26.3.

Table 6. Comparison of Measured SN_{64} , Adjusted SN_{64F} , and Observed SN_{64F} for Asphalt Pavement Surfaces (Pennsylvania Sites, 1980)

Site No.	Measured SN_{64}					Adjusted SN_{64F}					Observed*
	Mean	S.D.	Max.	Min.	Max.-Min.	Mean	S.D.	Max.	Min.	Max.-Min.	SN_{64F}
1	31.05	4.31	46.20	25.80	20.40	24.71	3.79	35.44	17.94	17.50	26.07
4	33.54	3.82	42.60	26.80	15.80	27.62	3.48	36.78	20.00	16.78	27.91
8	33.03	5.11	50.00	27.00	23.00	26.82	4.39	38.34	18.88	19.46	29.12
9	43.23	3.76	53.40	35.80	17.60	38.13	2.97	44.95	30.57	14.38	41.80
11	30.30	3.62	42.60	24.60	18.00	25.05	3.74	34.86	17.79	17.07	26.70
12	43.18	3.55	51.00	35.00	16.00	38.44	2.49	43.27	31.08	12.19	31.31
13	65.77	2.95	73.00	60.20	12.80	55.25	1.99	60.30	51.58	8.72	55.80
15	68.70	2.97	76.00	62.80	13.20	57.01	2.34	63.25	53.10	10.15	55.03
16	22.32	2.61	32.60	18.70	13.90	12.05	3.42	21.82	5.38	16.44	19.51
17	36.41	5.50	47.20	26.00	21.20	30.24	4.73	37.83	20.05	17.78	26.07
19	29.75	2.60	36.80	25.60	11.20	23.72	2.42	30.21	19.67	10.54	26.28
20	36.75	2.91	46.00	31.50	14.50	32.28	2.40	38.56	27.21	11.35	34.11
21	35.34	3.37	43.80	31.20	12.60	29.28	2.40	33.50	26.01	7.49	26.12
22	59.13	3.02	67.00	52.50	14.50	50.57	1.66	53.98	46.86	7.12	45.98
24	28.62	3.46	40.80	24.40	16.40	22.63	3.47	31.52	17.66	13.86	23.36
25	54.40	3.16	64.40	49.60	14.80	47.28	1.82	51.70	43.65	8.05	45.06

*Observed SN_{64F} was determined from observed SN_{64} and PNG by using equation (21).

The results of applying the model in this way was shown in Table 6, where the mean, standard deviation, and range of the observed SN_{64} and the mean, standard deviation, and the range of predicted final skid-resistance level (SN_{64F}) can be compared. In most cases, both the range of the observed data and the standard deviations were reduced by the application of the model. The average standard deviation for the observed SN_{64} data is 3.55, which is reduced to a standard deviation of the adjusted SN_{64F} of 2.95.

In Figure 2, good agreement is shown between the observed SN_{64F} and the average of the daily predicted values of SN_{64F} . When applied to the portland cement concrete sites, however, the model was not successful. The reason for this may be the different behavior noted in the skid-resistance histories for the PCC sites as well as the relatively small number of PCC sites (5) compared with the number of asphalt sites (16).

Furthermore, it has been shown that there is very good agreement between SN_{64F} estimated by the generalized model and SN_{64F} estimated by the mechanistic model which was already presented in the previous paper, as shown in Figure 3.

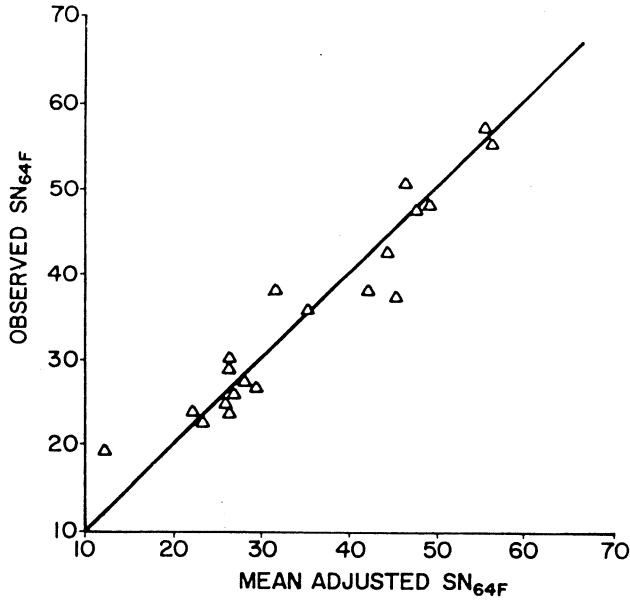


Figure 2. Comparison of Observed SN_{64F} and Adjusted SN_{64F} Obtained by Using the Generalized Model for Asphalt Pavement Surfaces (Pennsylvania Sites, 1980)

(3) Estimation of Skid Resistance at Any Time from Measurement on Another Day

A third application of the generalized model is to estimate the skid number at any time from a measurement on another day using the model developed in the previous section (2). For asphalt pavement surfaces, the skid number on day j (SN_{64j}) can be predicted in the form:

$$SN_{64j} = e^{a_0} e^{a_1 DSF_j} e^{a_3 T_{30j}} e^{a_4 t_j} e^{a_5 ADT} e^{a_9 SN_{64F}} \quad (19a)$$

The skid number on another day (k) can be predicted in the form:

$$SN_{64k} = e^{a_0} e^{a_1 DSF_k} e^{a_3 T_{30k}} e^{a_4 t_k} e^{a_5 ADT} e^{a_9 SN_{64F}} \quad (19b)$$

where the regression coefficients are given in Table 5, and noting that the value of a_2 is zero for this application. The ratio of SN_{64k} to SN_{64j} is then formed:

$$\frac{SN_{64k}}{SN_{64j}} = e^{a_1(DSF_k - DSF_j)} e^{a_3(T_{30k} - T_{30j})} e^{a_4(t_k - t_j)} \quad (20)$$

Thus the relationship to estimate the level of skid resistance at day k from a measurement taken at day j is formed:

$$SN_{64k} = SN_{64j} \{ e^{a_1(DSF_k - DSF_j)} e^{a_3(T_{30k} - T_{30j})} e^{a_4(t_k - t_j)} \} \quad (21)$$

As an example of the application, the skid resistance on April 17, 1980 ($t_k = 108$) can be estimated from the June 11, 1980 ($t_j = 163$) data. In addition to the data for June 11, as given in the

example in previous section (1) and (2), the following data for April 17 must be obtained from weather records:

$$DSF_k = 1.099$$

$$T_k = 32$$

$$T_{30k} = 27.9$$

Inserting these data and the data listed in section (1) for day j, the model (21) provides the following estimate for skid resistance on April 17 :

$$SN_{64k} = 30.2 \left\{ e^{-0.0371(1.099 - .693)} e^{0(32 - 48)} e^{-0.0028(27.93 - 40.06)} e^{-0.00047(108 - 163)} \right\} = 31.6$$

The skid number measured on April

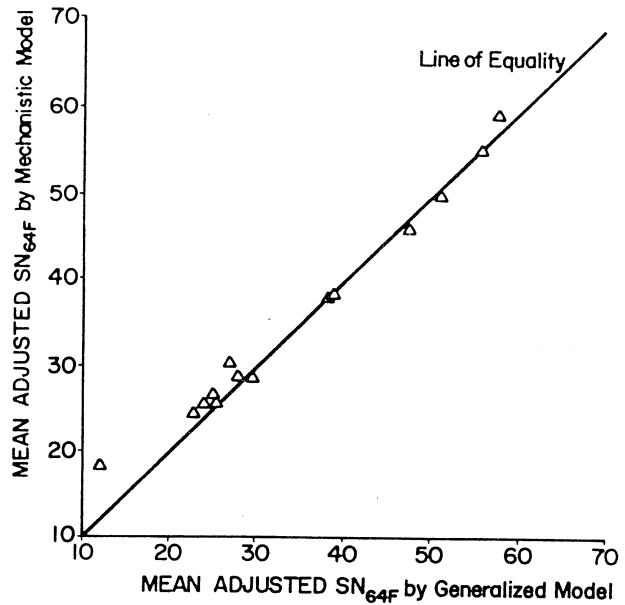


Figure 3. Comparison of Adjusted SN_{64F} Obtained by the Generalized Model and Adjusted SN_{64F} Obtained by the Mechanistic Model for Asphalt Pavement Surfaces (Pennsylvania Sites, 1980)

Table 7. Prediction of Skid Resistance (SN) on Day k from the Measurement Taken at Day j by Use of the Generalized Model (Pennsylvania Sites, 1980)

Date		Site 4			Site 11			Site 16		
Day j	Day k	Measured	Predicted	Dif.	Measured	Predicted	Dif.	Measured	Predicted	Dif.
8/18/80		32.0	-	-	27.6	-	-	20.6	-	-
	5/02/80	37.0	34.6	2.4	-	-	-	25.2	22.2	3.0
	5/05/80	39.2	33.3	5.9	32.6	28.8	3.8	22.7	21.5	1.2
	5/07/80	35.0	33.3	1.7	31.6	28.7	2.9	22.0	21.4	0.6
	5/08/80	35.6	34.5	1.1	30.8	29.7	1.1	21.4	22.2	-0.8
	5/15/80	38.0	34.9	3.1	32.8	30.1	2.9	24.0	22.5	1.5
8/21/80		32.2	-	-	30.2	-	-	20.4	-	-
	5/02/80	37.0	36.7	0.3	-	-	-	25.2	23.2	2.0
	5/05/80	39.2	35.4	3.8	32.6	33.2	-0.6	22.7	22.4	0.3
	5/07/80	35.0	35.3	-0.3	31.6	33.1	-1.5	22.0	22.4	-0.4
	5/08/80	35.6	36.6	-1.0	30.8	34.3	-3.5	21.4	23.2	-1.8
	5/15/80	38.0	37.0	1.0	32.8	34.7	-1.9	24.0	23.5	0.5
8/25/80		33.4	-	-	26.4	-	-	20.7	-	-
	5/02/80	37.0	37.9	-0.9	-	-	-	25.2	23.5	1.7
	5/05/80	39.2	36.6	2.6	32.6	28.9	3.7	22.7	22.7	0.0
	5/07/80	35.0	36.5	-1.5	31.6	28.8	2.8	22.0	22.6	-0.6
	5/08/80	35.6	37.8	-2.2	30.8	29.9	-0.9	21.4	23.4	-2.0
	5/15/80	38.0	38.3	-0.3	32.8	30.2	2.6	24.0	23.7	0.3

17 was 33.8.

The results of applying equation (21) in this way to some of the Pennsylvania sites are shown in

Table 7. In this case, three days (j) in August were used, and the skid resistance for five days (k) in May was estimated for asphalt pavement surfaces. The results show good agreement between measured SN_{64} and predicted SN_{64} for each site. Therefore, it can be concluded that the generalized model can be used to estimate the skid resistance at any day in the past from a measurement made at a later date. In this form the model can be used in the investigation of accidents. The model similarly could be used to predict skid resistance at a future date given an assumption about weather conditions (T_{30} and DSF) for that date.

5. CONCLUSIONS

The following conclusions were drawn from the analysis of the generalized model:

(1) An effective and relatively simple generalized model for estimating SN_{64} of a site has been constructed. The use of the model requires a set of coefficients and knowledge of the age of the pavement; the average daily traffic count for the site; an annual estimate of the BPN value or the mean texture depth for the site as determined by the sand-patch technique; the rainfall and ambient air temperature histories in the vicinity of the site; and the date.

(2) The goodness of fit of the model for a regional set of highway sites was improved by adding ADT and a measure of surface texture (as determined by BPN and sand-patch mean texture depth) as factors to the model and by determining the predictor parameters separately for asphalt and concrete pavements. The improvement was greater when BPN was added than when mean texture depth was included.

(3) Highly satisfactory predictive coefficients for the model were developed separately for asphalt and concrete sites in Pennsylvania and in the North Carolina/Tennessee area and for asphalt sites in Florida. Less than satisfactory predictive coefficients were developed for asphalt sites in Massachusetts. The goodness of fit of the model as measured by the R^2 values for the highway sites in the three areas, excluding Massachusetts, ranged from a low of 0.69 to a high of 0.91.

(4) Relatively large differences between geographical areas can be seen in the model coefficients.

(5) Since it is a multiple regression equation, the generalized model can be used directly to establish future SN_{64} values or future SN_{64} mean values for a given site.

(6) The equation 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}) have been developed for the Pennsylvania sites. In the generalized model, the equation takes the form:

$$SN_{64F} = \frac{1}{-a_9} (a_0 + a_1DSF + a_2T + a_3T_{30} + a_4t_j + a_5t_a + a_6ADT - \ln SN_{64})$$

where the model coefficients for the Pennsylvania sites are those given in Table 5 .

(7) The results of the application of this model to the 1980 data for Pennsylvania sites have been shown in Table 6 . Based on these results, it is concluded that the generalized model is effective predictor model for estimating seasonally adjusted values of SN_{64} . Furthermore, it has been shown that there is very good agreement between SN_{64F} estimated by the generalized model and SN_{64F} estimated by the mechanistic model, as shown in Figure 3 .

(8) Further application of the generalized model has been made to predict the skid resistance at any day from a measurement taken on a different day. The relationship to predict the level of skid resistance at day k from a measurement taken at any day j has been developed from the generalized model for Pennsylvania asphalt sites in the form:

$$SN_{64k} = SN_{64j} \{e^{a_1(DSF_k - DSF_j)} e^{a_3(T_{30k} - T_{30j})} e^{a_4(t_k - t_j)}\}$$

where the model coefficients are those given in Table 5 .

(9) The results of the application of this equation to the 1980 data from some Pennsylvania asphalt pavement sites was shown in Table 7 . The average differences between measured and predicted SN_{64k} for all Pennsylvania asphalt pavement sites are given in Table 8 . It can be seen that the mechanistic model produces better predictions, less variation, than those produced by the generalized model.

Table 8. Average Differences Between Measured and Predicted SN_{64k} for All Pennsylvania Asphalt Pavement Sites

(10) All the predictions considered above must be compared with the possible variations in SN_{64} measurements resulting from measurement errors and other sources error. Meyer, Hegmon, and Gillespie⁹⁾ have reported number of

Day j	Generalized Model		Mechanistic Model		Number of Observations
	Average	Std. Dev.	Average	Std. Dev.	
8/18/80	2.3	2.89	1.1	2.56	61
8/21/80	-0.7	3.52	-0.4	2.51	62
8/25/80	1.4	2.99	0.2	2.09	47

factors responsible for errors in locked-wheel skid-resistance tests and have calculated the average error band associated with each type of error. These factors include:

- Speed holding $\pm 1.5 SN$
- Pavement variability, lateral $\pm 4 SN$
- Pavement variability, longitudinal $\pm 2 SN$
- Dynamic wheel-load change $\pm 1 SN$

Data evaluation by operator ± 3 SN

Compared with these errors, the differences between measured and estimated SN_{64} , as shown in Table 8, and the predicted SN_{64F} , as shown in Tables 6 and 7, are less than the expected variations in SN_{64} measurements resulting from measurement errors and other sources of error.

ACKNOWLEDGEMENTS

This paper is based on research program sponsored by the U.S. Department of Transportation in cooperation with the Federal Highway Administration under Contract No. DOT-FH-11-9474. Kazuo Saito, one of the authors, had joined in this research program for a year (1981–1982) as a visiting professor of the Pennsylvania State University. Personnel from FHWA and the Pennsylvania Transportation Institute of Pennsylvania State University have assisted in the research. Valuable assistance was contributed by FHWA engineers, Mr. H.C. Huckins and Dr. R.R. Hegmon.

The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the U.S. Department of Transportation or the Federal Highway Administration.

(Received May 21, 1985)

REFERENCES

- 1) American Society for Testing and Materials. 1980 Annual Book of ASTM Standards, Part 15, Paving, Bituminous Materials; Traveled Surface Characteristics, 1980.
- 2) Rice, J. M.: Seasonal Variations in Pavement Skid Resistance. Public Roads, Vol. 40, No. 4 (March 1977), pp. 160–166.
- 3) Dahir, S. H., Henry, J. J., and Meyer, W. E.: Seasonal Skid Resistance Variations. Final Report, Research Project No. 75–10, Pennsylvania Department of Transportation, 1979.
- 4) Dahir, S. H. and Meyer, W. E.: Bituminous Pavement Polishing. Final Report. Pennsylvania Department of Transportation, 1974.
- 5) Dry, D. R., Henry, J. J., and Dahir, S. H.: Seasonal Skid Resistance Variations. Interim Report, Report No. FHWA-PA-75-10(2). Pennsylvania Department of Transportation, 1977
- 6) Dahir, S. H. and Henry, J. J.: Seasonal and Short-Term Variations in Skid Resistance. Transportation Research Record 715 (1979), pp. 69–76.
- 7) Kazuo Saito and Henry, J. J.: Mechanistic Model for Predicting Seasonal Variations in Skid Resistance. Transportation Research Record 946 (1984), pp. 29–38.
- 8) Kazuo Saito and Henry, J. J.: Development and Application of Predictor Model for Seasonal Variations in Skid Resistance (I). Memoirs of the Muroran Institute of Technology (Science and Engineering), Vol. 34 (1984), pp. 25–39.
- 9) Meyer, W. E., Hegmon, R. R., and Gillespie, T. D.: Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques. National Cooperative Highway Research Program Report 151, Transportation Research Board, 1974.

APPENDIX

Measurement Required For Seasonal Adjustment of Skid Resistance

The two models developed in this research require similar inputs to describe weather and long-term conditions. The mechanistic model also requires aggregate properties which are not yet well identified. Four types of inputs are required, assuming that a measurement of skid resistance has been made on a particular day:

1. Observations made at the time and location of the skid-resistance measurement.
2. Data available from weather records at an NOAA weather reporting station, ideally located on more than 5 to 10 miles from the location of the pavement site.
3. Pavement history including age of wearing course, ADT, and pavement type.
4. Aggregate properties and texture measurements.

In the conduct of research, measurements were made which were not used in the final predictor models, either because the models were not sensitive to these measurements or because the measurements were themselves highly correlated with other measurements used in the models.

The measurements used in the mechanistic model are given in Table A-1, and those used in the generalized model are given in Table A-2. All the measurements performed in the course of the research, many of which were not used in the model, are listed in Table A-3.

The mechanistic and generalized models require similar types of data; however, the mechanistic model requires BPN measurements taken before and after polishing with the Penn State Reciprocating Pavement Polisher or a similar device. The mechanistic model also requires skid resistance-speed data in order to calculate the percent normalized gradient. The generalized model uses texture data (MTD and/or BPN) rather than observations of skid resistance as inputs; however, equations (16) and (20), developed to apply the

Table A-1 Measurements Required by the Generalized Model

Observations made at time of test (on Julian calendar day, t)
1. Skid-resistance measurements (ASTM E 274): SN_{64}
2. Weather station data
A. Maximum and minimum temperature for a period of 30 days prior to date of test and on date of test. (To calculate T and T_{30} using equation (11)).
B. Rainfall: Total precipitation per day for at least 7 days prior to the date of test. (To calculate dry spell factor, DSF, by equation (7)).
3. Pavement data
A. Average daily traffic in lane tested (ADT)
B. Pavement surface age in years since last resurfacing (t_a)
C. Pavement type — PCC, dense graded, open graded
4. Texture data (optional)*
A. Sand-patch mean texture depth (MTD)
B. British pendulum number (BPN)

* These need not be measured to apply the predictor model if the model is being used to predict SN_{64F} or to predict the skid resistance on a day other than on which the measurement was made.

generalized model, are based on skid-resistance measurements rather than texture data. The resulting generalized models thus utilize readily available data.

Table A— 2 Measurements Required by the Mechanistic Model

-
1. Observations made at time of test (on Julian Calendar day, t)
 - A. Skid resistance measurements (ASTM E 274)
 1. SN_{64}
 2. SN_{48} , SN_{80} (or percent normalized gradient, PNG)
 - B. Pavement temperature- T_p
 2. Weather station data
 - A. Rainfall: Total precipitation per day for at least 7 day prior to date of test. (To calculate dry spell factor, DSF, by equation (7)).
 3. Pavement data
 - A. Average daily traffic in lane tested (ADT)
 - B. Pavement type — PCC, dense graded, open graded
 4. Aggregate and texture data
 - A. British Pendulum Number (BPN)(ASTM E 303)
 - B. BPN_{2000} : BPN after 2000 cycles of polishing
-

Table A— 3 Measurements Made During the Course of the Research

-
1. Frequent tests on pavements
 - A. Skid-resistance measurements (ASTM E 274)
 1. SN_{64}
 2. SN_{48} , SN_{80} (or SN_0 , PNG)
 3. SN_{48}^B , SN_{80}^B (or SN_0^B , PNG^B) — brank tire tests
 - B. Temperature obsevatons
 1. Pavement temperature (T_p)
 2. Air temperature (T_a)
 3. Water temperature (T_w)
 4. Tire temperature (T_t)
 2. Weather station data
 - A. Maximum and minimum daily temperature (NOAA Station)
 - B. Temperature at 8 : 00 a.m. standard time (NOAA Station)
 - C. Relative humidity (NOAA Station)
 - D. Cloud cover (NOAA Station)
 - E. Wind direction and speed (NOAA Station)
 - F. Precipitation (total per day) (NOAA Station)
 - G. Rainfall rate during test season (tilting bucket at local site)

3. Pavement data
 - A. Pavement type
 - B. Aggregate source
 - C. Mix design
 - D. Construction date
 - E. Average daily traffic (including traffic classification)
 4. Texture measurements (monthly)
 - A. BPN (ASTM E 303)
 - B. Sand-patch mean texture depth (ACPA Method)
 - C. Microtexture profiles
 - D. Macrottexture profiles
 - E. Stereo photographs (ASTM E 559)
 - F. BPN after polishing with the reciprocating pavement polisher
-