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# SIMPLIFIED PAVEMENT PERFORMANCE MODELS

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# Simplified Pavement Performance Models

Ying-Haur Lee[1], Alaeddin Mohseni, and Michael I. Darter

**ABSTRACT**

There exists a great need for simplified pavement performance models that can be used for various pavement management purposes for forecasting future pavement condition based on a minimal amount of data currently available. This paper summarizes the development of predictive models for five conventional pavement types: asphalt concrete (flexible), composite, jointed plain concrete, jointed reinforced concrete, and continuously reinforced concrete pavements. These models predict the present serviceability rating (PSR) based upon only knowledge of the pavement's age, cumulative equivalent single-axle loads, and a pavement structural parameter (structural number for flexible, overlay thickness for composite, and slab thickness for concrete pavements).

The models were developed based on data from several reliable and readily available databases in Illinois. A unique calibration technique was introduced and incorporated to the proposed models such that they can be used for performance prediction of both existing and new pavements. The models were then extended through the development of adjustment factors to various functional groups and climatic zones using data from the actual multi-year nationwide Highway Performance Monitoring System (HPMS) databases.

The accuracy of PSR prediction was tested for several thousand HPMS sections located

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throughout the U.S. using a user-friendly computer program (SIMPERF). The results appeared to be very reasonable in a large proportion of cases analyzed. However, these models are empirical and definitely not suitable for use in pavement design or for comparison of the performance of different pavement types.

## INTRODUCTION

There are many pavement management activities that require the prediction of future performance of pavements in a network. The determination of future pavement rehabilitation needs for a State highway network from which a multi-year plan for rehabilitation is an example. In fact, every agency that owns or is responsible for pavements and wishes to manage those facilities in a rational manner needs to be able to predict the future performance of their pavements.

However, collecting reliable inventory and monitoring data to develop predictive models for a large pavement network system is a formidable and very costly task. Many of these agencies do not have comprehensive databases that can provide a lot of data about each section in the network. Although this is improving through the development of pavement management systems, most agencies can only provide the current condition (in various forms), the current average daily traffic and percent trucks, type of pavement, and perhaps some design and rehabilitation history for their pavement sections. Thus, there is a great need for simplified pavement prediction models that only require a minimal amount of data that is likely to be available in the pavement management database.

The Federal Highway Administration (FHWA) must report to the Congress on a regular basis the long-term needs of the nation's highway system, and pavements represent the largest

component. This paper summarizes the development of predictive models and mean adjustment factors to be used in the Highway Performance Monitoring System (HPMS) [*1*] pavement performance simulation process.

## IDENTIFICATION OF PAVEMENT "GROUPS"

Item 28 of the HPMS data elements (pavement attributes) includes 15 different pavement types, which cover nearly all combinations of original construction and rehabilitation types. However, currently they are separated into only two main groups: flexible and rigid pavements in the HPMS pavement performance simulation process. The AASHTO flexible and rigid pavement equations are then used for pavement performance simulation. This procedure has some obvious deficiencies.

To more adequately represent a wide variety of different pavement attributes in the HPMS, the following five major conventional pavement types were considered:

- asphalt concrete (flexible or FLEX),
- composite (AC/PCC or COMP),
- jointed plain concrete (JPCP),
- jointed reinforced concrete (JRCP), and
- continuously reinforced concrete (CRCP) pavements.

Note that some pavement types including unimproved road, graded and drained, soil, grave, or stone, bricked, blocked, or other combinations in the HPMS were not considered in this study.

Nine different climatic zones (Item 68) based on Thornthwaite potential evapotranspiration and moisture index and their interaction [*1, 2*] were also considered in the "group" identification. This provides a fairly adequate consideration of the diverse climates and geographic areas that

exist across the U.S including any combination of wet, intermediate, and dry climates in freeze, freeze-thaw, and no freeze regions.

Item 9 of the data elements contains 12 different functional systems. After some analyses and discussion with the FHWA, they were condensed into two different major functional groups (FGROUP). Interstate highways and principal arterials were treated as one group. Minor arterials and all collectors were treated as the other group. This grouping was done to reflect expected differences in cross sections, drainage, and pavement performance.

The HPMS database was then divided into similar performance "groups," which were expected to have similar deterioration mechanisms and performance relationships. A given pavement "group" was defined having the same general **pavement type, functional group, and climatic zone** as previously described. It is assumed that pavements within the same group more or less follow the same performance pattern. Thus, predictive models need only be developed for a limited number of groups of conditions, as opposed to a large number of different types of pavement designs, functional systems, climatic regions, and rehabilitation types.

## DEVELOPMENT OF PERFORMANCE PREDICTION MODELS

After considerable review of different regression techniques, it was decided that nonlinear regression should not be used to develop predictive models for the HPMS due to the high possibility of having many potential errors in the database. Several trials using nonlinear regression produced unacceptable models largely due to including some bad data points in the analysis. Therefore, the following steps were adopted to develop predictive models:

1. A feasible general PSR loss model form was assumed including variables based on engineering knowledge and available databases.

2. Least Median Squares (LMS, "robust") regression [*3, 4*] was performed to identify the potential outliers by using this assumed model form.
3. After screening out these possible outliers, traditional least squares (LS) regression was then used to obtain the regression coefficients and summary statistics.

Because it cannot be guaranteed *a priori* that the assumed functional form is valid, the analysis must proceed iteratively such that a more meaningful and reliable model can be developed. An alternating conditional expectations algorithm [*5*] was also applied to find other possible transformations of each explanatory variable to maximize the squared multiple correlation coefficient ($R^2$) for the next trial.

A new statistical package named S-PLUS which has been widely used by statisticians for data analysis [*6, 7, 8*] was selected due to the availability of these techniques. S-PLUS is very strong in its graphics, data exploration tools, and flexibility but weak in database management as compared to the most well-known and widely used SAS statistical package [*9*]. As a result, SAS was used primarily for data retrieval and data summary whereas S-PLUS was used for most of the modeling processes.

**Attempts to Develop Models Directly from the HPMS Database**

Five sets of the HPMS database in 1982, 1984, 1986, 1988, and 1989 were first retrieved from magnetic tapes [*1*] and downloaded to PC for further analyses. In order to obtain the needed history of the HPMS pavement performance, these data were then merged by their unique identification number, i.e., sample number (Item 24) and sample subdivision (Item 25).

Initially, major research efforts were focused on developing predictive models directly from the HPMS database using data from 1984 to 1989. Several different feasible model forms were

used to develop the performance prediction models. "Robust" regression successfully identified portions of the database as potential outliers which after deletion improved the regression dramatically. However, the regression models were still not adequate for implementation. This attempt was proved to be unsuccessful due to problems with the HPMS database, such as missing data, highly variable performance histories and apparent errors in many important data elements.

**Alternative Databases for Model Development**

Due to the difficulties in developing prediction models directly from the HPMS database, other accessible databases were considered for developing PSR prediction models for each of the five major pavement types. These include the pavement management database from the Illinois Department of Transportation, the Illinois portions of the NCHRP Project 1-19 database [*10*], the original AASHO Road Test data (DS 7322) [*11*], and some additional data from the extended Road Test (1962-1974) [*12, 13*].

The Illinois pavement management database contains detailed information about pavement inventories, materials, distress surveys, condition rating surveys, maintenance and rehabilitation records and traffic data. The most recent data (March, 1991) which contains 6 condition rating surveys in 1981, 1982, 1984, 1986, 1988, and 1990 were obtained to construct databases for CRCP and composite (COMP) pavements.

The NCHRP Project 1-19 database which contains some existing Illinois Interstate JRCP pavements and sections from the original and the extended AASHO Road Test for JRCP was used to construct JRCP database. The JPCP database was constructed from the original and the extended AASHO Road Test. The serviceability records of flexible pavements of the original

AASHO Road Test at 22-week (or 11-index-day) intervals were obtained to create the flexible pavement (FLEX) database.

**Proposed Predictive Model Form**

After considerable evaluations of different model forms including linear, logarithm, and other simplified forms, the following functional form was chosen to develop the proposed HPMS predictive models for all five major pavement types:

$$PSR = PSR_I - a * STR^b * AGE^c * CESAL^d \quad \textbf{(1)}$$

Where:

$PSR_I$ = initial value of PSR at construction (4.5 used in analysis);

STR = existing pavement structure: 1) structural number for flexible pavements; 2) total AC overlay thickness for composite pavements, inches; 3) slab thickness for concrete pavements, inches (1 inch = 25.4 mm);

AGE = age of the pavement since construction or major rehabilitation (overlay), years; and

CESAL = cumulative 18-kip ESAL applied to the pavement (in the heaviest traffic lane), millions.

The above nonlinear model form is also an implicit linear model since after transformation it becomes:

$$\log_{10}(PSR_I - PSR) = \log_{10}a + b * \log_{10}STR + c * \log_{10}AGE + d * \log_{10}CESAL \quad \textbf{(2)}$$

This nonlinear model form permits a realistic consideration of age, traffic, and pavement structure on the prediction of PSR. Subsequent model development showed that this equation form fits all of the pavement types reasonably well.

Note that currently structural number is reported as an indicator of pavement structure for both flexible and composite pavements in the HPMS database so that the AASHTO flexible equation could be used to predict future performance. However, composite pavements perform dramatically different from flexible pavements due to different failure modes. It is believed that the AC overlay thickness rather than the structural number or the underlying concrete slab thickness is the dominating factor in the performance of composite pavements. Thus, overlay thickness was used in the model development. The questionable determination of structural number for composite pavements is no longer needed in the HPMS database since no adequate guidelines are available.

**Summary of the Proposed Predictive Models**

The regression coefficients and summary statistics of each predictive model for all five major pavement types are summarized in Table 1. The standard error of estimates (SEE) as provided in the table is also a very good indicator of the accuracy of the prediction of the loss of PSR ($\Delta$PSR). The number of potential outliers identified and then excluded from the model are also indicated by parentheses in the table. For example, 31 out of total 553 data points were deleted from the flexible pavement model.

The statistics of the CRCP model are not very good as expected, since both "D-cracked" and "non D-cracked" pavements from the Illinois Interstate highways were all included in the database to develop this model. This model can be improved after more "D"-cracking information is collected in the HPMS database in the future.

To check the adequacy of each proposed model, the predicted $\Delta$PSR values were plotted against the actual values as shown in Figures 1 to 5. Several sensitivity analyses of the variables

included in each model were also performed and found to be very reasonable [*14*]. In general, the PSR curves of flexible pavement, composite pavement, and CRCP are in a concave-shape or have more rapid loss of PSR early. The PSR curves of JPCP and JRCP are in a convex-shape or have more rapid loss of PSR later.

## APPLICATION OF THE PROPOSED MODELS TO THE HPMS

### Calibration of the Models to Existing Pavement Conditions

Based on the proposed predictive models, a fixed family of curves could be developed for different pavement structures. Unfortunately, both age and cumulative ESALs are currently not available in the HPMS database. Therefore, it is necessary to obtain the best estimates of pavement's age and cumulative ESALs through knowledge of only the current annual ESALs and the current year condition of an existing pavement structure in the HPMS database.

Assume there exists a direct relationship between pavement's age and cumulative ESALs:

$$CESAL = AGE * ESALPYR \quad \textbf{(3)}$$

Where: ESALPYR = the current yearly ESAL, millions.

To locate the current year condition in a unique performance curve, the following calibration constants ($C_1$ and $C_2$) could be treated as the best estimates of pavement's age and cumulative ESALs, respectively:

$$C_1 = AGE = \left[ \frac{PSR_I - PSR1}{a * STR^b * ESALPYR^d} \right]^{\frac{1}{c+d}} \quad \textbf{(4)}$$

$$C_2 = CESAL = C_1 * ESALPYR \quad \textbf{(5)}$$

Where: PSR1 = the current year pavement condition.

Thus, the proposed models can be reformulated to the following form, which is a function of the current year condition, a pavement structure parameter, and the current annual ESALs of an existing pavement in the HPMS database:

$$PSR = PSR_1 - a * STR^b * (C_1 + \Delta YEAR)^c * (C_2 + \Delta ESAL)^d \quad \textbf{(6)}$$

Where:

ΔYEAR = change in age of the pavement, years; and

ΔESAL = change in cumulative ESALs, millions.

**Adjustment Factors for Different Pavement "Groups"**

In addition, adjustment factors (AFs) similar to the regional factor adopted in the 1972 AASHO Interim Guide [*15*] were introduced to adjust the rate of deterioration of PSR of the proposed models for different pavement "groups" in the HPMS database. The adjustment factor is defined as the ratio of the average rate of deterioration in a particular climatic zone and functional group to that determined by the proposed models:

Where:

$AF_j$ = adjustment factor in pavement "group" j;

$\Delta PSR_j$ and $PSR_j$ = actual ΔPSR and PSR values of existing pavements in "group" j, respectively; and

ΔPSR and PSR = predicted ΔPSR and PSR values of existing pavements determined by the proposed models, respectively.

An adjustment factor greater than 1.0 indicates that the actual rate of PSR loss is greater in that pavement "group" than the model based upon Illinois conditions would predict and vice versa. For example, the effects of adjustment factors of a flexible pavement with a structural number of 6 and traffic load of 0.5 million ESALs per year are illustrated in Figure 6.

***Determination of Mean Adjustment Factors***

Five sets of the HPMS database in 1982, 1984, 1986, 1988, and 1989 were received from the FHWA. However, it was decided not to use the 1982 database for determining adjustment factors after discussion with FHWA personnel. Any PSR value which increases over 0.5 or decreases greater than 0.75 per year were deleted to avoid retrieving sections which have been rehabilitated or had apparently deteriorated too fast to be believable. In addition, only the 3, 4, and 5-year PSR drops were retrieved because the PSR records may not be updated during a very short reporting cycle (1 or 2-year period).

A total of 85,533 data points were obtained from all five major pavement types, nine climatic zones, and two functional groups. Note that a few very large or very small AF values (1.7 percent of the data), which were outside the range of -10 to 10, were excluded from further consideration. The mean adjustment factors determined based upon different number of sections ranging from several thousand down to only one in a few cases are summarized in Table 2 [*14*]. Those mean values based on fewer than 25 data points and marked with an asterisk (*) in Table 2 should not be strongly considered.

The mean values vary widely across pavement types, climatic zones, and functional groups,

especially when they were determined based on only a few data points. In general, pavements in the south (less freeze-thaw and cold temperatures) showed a lower deterioration rate than those in norther climates. Also pavements in the western U.S. (dryer climate) showed a lower rate of deterioration than those in wetter climates in the east.

In addition, higher variation of the adjustment factors was observed for pavements in minor arterials and collectors. This may also be explained by the fact that the most important indicator of pavement structure (structural number or slab thickness) is not currently recorded in the HPMS database. Thus, default values for these pavement sections rated as heavy, medium, and light (Item 31) [*1*] were assigned to determine the adjustment factors.

The adjustment factors as given in Table 2 obviously have very strong impact on the pavement performance prediction. They were also evaluated for several thousand HPMS sections using a user-friendly PC program (SIMPERF). The overall results showed that the use of either very high or very low adjustment factors produced unreasonable future service lives of HPMS pavement sections. A recommended adjustment factor ranging from approximately 0.4 to 1.5 is believed to provide reasonable PSR predictions. Many of the mean values that fall outside of this range are the result of a small sample size, and thus would be expected to be highly variable.

Table 3 provides the recommended mean adjustment factors for use as defaults in the HPMS analytical process. The mean values were recommended, unless the value fell outside of this range. For those lower than 0.4 or higher than 1.5, the value was assigned to that cell. The only exception to these rules was for CRCP in minor arterials and collectors, where a value of 1.0 was assigned for wet and intermediate zones and a value of 0.5 was for dry zones.

Currently, the recommended adjustment factors along with the proposed predictive models are implemented in the SIMPERF program for pavement performance and subsequent

rehabilitation simulations. The recommended adjustment factors are user-modifiable and can be easily adjusted to more accurately reflect the performance of any given pavement type if desired.

***Further Discussions***

An adjustment factor represents the ratio of the PSR loss of a section of highway to the model predicted PSR loss for that section. There are many reasons for differences in performance which are not climate related including different subgrades, materials, construction quality, designs (such as joint design) and maintenance. The adjustment factors should be compared only within a pavement type since each predictive PSR model was based on a different database. Comparisons between different pavement types is not meaningful.

The predictive models were developed based on field data from regular in-service pavement sections, which included maintenance (except the AASHO Road Test pavements). Heavy maintenance could prevent pavements from deteriorating to very low serviceability levels. All of the proposed models show that the rate of deterioration decreases as PSR decreases, which reflects the impact of maintenance when the pavement conditions get worse.

The FLEX model was developed based upon the original AASHO Road Test data only. The mean adjustment factor for wet-freeze zone is 0.59 based upon 5685 data points for Interstate highways and principal arterials. This indicates that the pavements in the HPMS database in the same climatic zone have performed better than the pavements at the AASHO Road Test. In general, the mean values decrease going from a wet to a dry climatic zone which means that flexible pavements in dryer climates show a lower rate of loss of PSR. The Interstate highways and principal arterials have lower adjustment factors and thus perform better than the minor

arterials and collectors.

In addition, the adjustment factors for the FLEX model were computed for two major functional groups and for levels of average daily traffic (ADT) greater than and less than 6,000 vehicles. Even when similar traffic levels were considered the Interstate highways and principal arterials still exhibited lower adjustment factors than the other group. Also, within the same functional group, the ADT level did not appear to cause a consistent difference in the adjustment factors. These results may indicate that some physical difference, such as improved drainage or construction quality for the Interstate highways and primary arterials, results in a lower rate of deterioration for the same traffic level.

The COMP model was based upon the in-service Illinois Interstate highway pavements. In the wet-freeze climate, the mean adjustment factor is close to 1.0, indicating that on average other pavements in this zone are performing similarly. As with flexible pavements, the adjustment factor decreases with a drier climate and increases with the lower functional group.

The JPCP model was based upon the AASHO Road Test data plus a few sections that were left in-service on I-80 for 14 years. The mean adjustment factor for wet-freeze zone is 0.56 based upon 946 data points for Interstate highways and principal arterials. This indicates that the pavements in the HPMS database in this climate zone have performed better than the JPCP at the AASHO Road Test. The mean values generally show a decrease going from a wet to a dry climatic zone which means that JPCP in dryer climates show a lower rate of loss of PSR. A previous study showed that JPCP located in the dry-nonfreeze climate performed much better than that in a wet-freeze climate [*10*].

The JRCP model was based upon the AASHO Road Test data plus many sections from regular Illinois Interstate highways. The mean adjustment factor for wet-freeze zone is 0.87 based upon 2149 data points for Interstate highways and principal arterials. This indicates that the

pavements in the HPMS database in this climate zone have performed about the same as the combined AASHO Road Test and Illinois Interstate highways. The mean values show a wide range of results over different climatic zones. However, the number of data points from many of the JRCP sections are very limited which has caused some wide ranging results.

The CRCP model was based upon many sections from regular Illinois Interstate highways. The mean adjustment factor for the wet-freeze zone is 0.57 based upon 462 data points for Interstate highways and principal arterials. This indicates that the pavements in the HPMS database throughout this climate zone have performed better than the Illinois Interstate highways. This may be due to the large amount of "D" cracking in the Illinois CRCP pavements. The values show a wide range of results over different climatic zones. However, the number of data points from many of the CRCP sections are very limited which has caused some wide ranging results.

**Summary of the Proposed HPMS Performance Prediction**

The proposed HPMS performance prediction equations for both existing and new pavements in pavement "group" j based upon only knowledge of a given pavement structure, current year condition, and current yearly ESALs are summarized as follows:

$$PSR_j = PSR_I - AF_j * \left[ a * STR^b * (C_{1j} + \Delta YEAR)^c * (C_{2j} + \Delta ESAL)^d \right] \quad \textbf{(8)}$$

$$C_{1j} = AGE_j = \left[ \frac{PSR_I - PSR1}{AF_j * \langle a * STR^b * ESALPYR^d \rangle} \right]^{\frac{1}{c+d}} \quad \textbf{(9)}$$

$$C_{2j} = CESAL_j = C_{1j} * ESALPYR \quad \textbf{(10)}$$

The calibration constants ($C_{1j}$ and $C_{2j}$) can be treated the best estimates of current pavement age ($AGE_j$) and current cumulative ESALs ($CESAL_j$) for any existing pavement in "group" j.

In order to predict the future performance of an existing pavement, proper coefficients based on major pavement type, climatic zone, and functional group are first selected, i.e., $AF_j$, $\log_{10}a$, b, c, and d (Table 1 and Table 3). $C_{1j}$ and $C_{2j}$ based on known STR, PSR1, ESALPYR, and these coefficients are then determined. Thus, the future performance can be estimated for different future ΔESAL and ΔYEAR using equation (8).

**Numerical Example**

Consider a high type flexible pavement classified as a rural major collector and located in climatic zone 1. This pavement has a structural number of 5.0 and its current condition is 3.5 in 1991. The current yearly ESAL is 0.2 million ESALs/YR with an average compounded future yearly ESAL growth rate of 6 percent.

The coefficients of the proposed model for flexible pavements (as given in Table 1) are: $\log_{10}a$ = 1.1550, b = -1.8720, c = 0.3449, and d = 0.3385. The adjustment factor for pavements from rural major collectors in climatic zone 1 (as given in Table 3) is: $AF_j$ = 0.81. Thus, the best estimates of current pavement age ($C_{1j}$) and current cumulative ESALs ($C_{2j}$) using equations (9) and (10) are: $C_{1j}$= 5.007 years and $C_{2j}$ = 5.007 * 0.2 = 1.001 million ESALs.

Therefore, the following equation can be used to predict the future performance of this pavement:

$$PSR_j = 4.5 - 0.81 * 10^{1.1550} * 5.0^{-1.8720} * (5.007 + \Delta YEAR)^{0.3499} * (1.001 + \Delta ESAL)^{0.3385} \quad \textbf{(11)}$$

The future traffic year's change in ESAL (ΔESAL) based on a compound yearly ESAL growth

rate (ESALGRW) can be calculated by:

$$\Delta ESAL = \frac{ESALPYR * (1 + ESALGRW) * \left[ (1 + ESALGRW)^{\Delta YEAR} - 1 \right]}{ESALGRW} \quad \textbf{(12)}$$

or in this case,

$$\Delta ESAL = \frac{0.2 * (1 + 0.06) * \left[ (1 + 0.06)^{\Delta YEAR} - 1 \right]}{0.06} \quad \textbf{(13)}$$

## CONCLUSIONS

The proposed models predict the present serviceability rating (PSR) based upon only knowledge of the pavement's age since construction, cumulative equivalent single-axle loads (ESAL), and a pavement structural parameter (structural number for flexible, overlay thickness for composite, and slab thickness for concrete pavements). The models were developed for five major pavement types (FLEX, COMP, JPCP, JRCP, and CRCP) based upon data from the original and the extended AASHO Road Test, the NCHRP Project 1-19 (COPES), and the Illinois pavement feedback system databases.

A unique calibration technique was introduced and incorporated to the proposed models such that they can be used for performance prediction of both existing and new pavements. For an existing pavement, the predictive model is calibrated to its current condition and then projected into the future, which also greatly reduces the prediction error. Mean adjustment factors were also determined using the actual multi-year nationwide HPMS pavement performance data and engineering judgement to extend these models to other climatic zones and functional groups.

The reasonableness of PSR predictions was tested for several thousand HPMS sections located throughout the U.S. based on the researchers' past experience in pavement performance using

the SIMPERF program. The results appeared to be reasonable in a large proportion of cases analyzed using the recommended adjustment factors. The mean adjustment factors can be easily adjusted by individual states or the FHWA based on more reliable pavement performance data in a given state or climatic area as desired.

It is also noted that there are many other factors that affect the performance of these pavements that are not reflected in these simplified models. Thus, these models should be used only to predict the future performance of existing pavements. They are definitely not appropriate for use in pavement design or for comparison of the performance of different pavement types.

Within this context, it is believed that the predictive models and adjustment factors for other geographic and climatic areas and functional groups are approximate but reasonable for the purposes intended. There is no doubt that these models represent far more realistic predictions than what currently exists in the HPMS analytical process. The predictive models and adjustment factors can also be improved over time if additional data items are added to the HPMS.

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**Table 1** - Summary of the Proposed Predictive Models

| | Models | | | | |
|---|---|---|---|---|---|
| | FLEX | COMP | JPCP | JRCP | CRCP |
| $\log_{10}a$ | 1.1550 | -0.4185 | 0.5104 | 1.7241 | 0.7900 |
| b | -1.8720 | -0.1458 | -1.7701 | -2.7359 | -1.3121 |
| c | 0.3499 | 0.5732 | 1.0713 | 0.3800 | 0.1849 |
| d | 0.3385 | 0.1431 | 0.2493 | 0.6212 | 0.2634 |
| $R^2$ | 0.52 | 0.58 | 0.79 | 0.57 | 0.37 |
| SEE | 0.45 | 0.38 | 0.26 | 0.40 | 0.31 |
| N | 522 (31) | 509 (0) | 117 (3) | 254 (21) | 1204 (65) |

Note:

1. $\log_{10}a$, b, c, and d are regression coefficients.
2. $R^2$ = coefficient of determination, SEE = standard error of estimates, N = number of observations included in the models (the number of potential outliers excluded is given in parentheses).

**Table 2** - Mean Adjustment Factors Directly Generated from SAS Program

| | PTYPE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FLEX | | COMP | | JPCP | | JRCP | | CRCP | |
| | FGROUP | | FGROUP | | FGROUP | | FGROUP | | FGROUP | |
| | INT/-OPA | MA/C-OL | INT/-OPA | MA/C-OL | INT/-OPA | MA/C-OL | INT/-OPA | MA/C-OL | INT/-OPA | MA/C-OL |
| | AF | AF | AF | AF | AF | AF | AF | AF | AF | AF |
| | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN |
| ZONE | | | | | | | | | | |
| 1. Wet; Freeze | 0.59 | 0.81 | 1.04 | 1.11 | 0.56 | 0.99 | 0.87 | 2.27 | 0.57 | -0.18* |
| 2. Wet; Freeze-Thaw | 0.37 | 0.85 | 1.13 | 1.07 | 0.33 | 0.64 | 1.25 | 1.46 | 0.39 | 2.12* |
| 3. Wet; No Freeze | 0.44 | 0.69 | 0.78 | 0.31 | 0.60 | 0.55 | 0.57 | 0.97 | 1.08 | 1.74* |
| 4. Intermediate; Freeze | 0.27 | 0.49 | 0.55 | 1.15 | 0.46 | 0.52 | 0.23 | 0.12* | 0.94 | 0.00* |
| 5. Intermediate; Freeze-Thaw | 0.52 | 0.71 | 0.26 | 0.64* | 0.66 | 1.61* | 2.09 | 1.00* | 1.10* | 1.56* |
| 6. Intermediate; No Freeze | 0.43 | 0.65 | 0.71 | 0.87 | 0.27 | 1.34 | 1.71 | 2.61 | 2.02 | . |
| 7. Dry; Freeze | 0.22 | 0.43 | 0.76* | 2.53* | 0.79 | 0.79 | 0.22 | 0.00* | 0.17 | . |
| 8. Dry; Freeze-Thaw | 0.32 | 0.39 | -0.44* | 0.00* | 1.80 | . | 0.49* | 0.00* | -0.13 | . |
| 9. Dry; No Freeze | 0.38 | 0.79 | 0.26 | . | 0.22 | 0.66* | -0.30* | 2.10* | 0.45* | . |

Note:
1. FGROUP := functional groupings
2. INT/OPA := Interstate highways and other principal arterials, FGROUP=1
3. MA/COL := minor arterials and collectors, FGROUP=2
4. * := mean AFs based on 25 data points or less
5. . := data unavailable

**Table 3** - Recommended Mean Adjustment Factors for Different Pavement "Groups"

| | PTYPE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FLEX | | COMP | | JPCP | | JRCP | | CRCP | |
| | FGROUP | | FGROUP | | FGROUP | | FGROUP | | FGROUP | |
| | INT/-OPA | MA/C-OL | INT/-OPA | MA/C-OL | INT/-OPA | MA/C-OL | INT/-OPA | MA/C-OL | INT/-OPA | MA/C-OL |
| | AF | AF | AF | AF | AF | AF | AF | AF | AF | AF |
| | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN |
| ZONE | | | | | | | | | | |
| 1. Wet; Freeze | 0.59 | 0.81 | 1.04 | 1.11 | 0.56 | 0.99 | 0.87 | 1.50 | 0.57 | 1.00 |
| 2. Wet; Freeze-Thaw | 0.40 | 0.85 | 1.13 | 1.07 | 0.40 | 0.64 | 1.25 | 1.46 | 0.40 | 1.00 |
| 3. Wet; No Freeze | 0.44 | 0.69 | 0.78 | 0.40 | 0.60 | 0.55 | 0.57 | 0.97 | 1.08 | 1.00 |
| 4. Intermediate; Freeze | 0.40 | 0.49 | 0.55 | 1.15 | 0.46 | 0.52 | 0.40 | 0.40 | 0.94 | 1.00 |
| 5. Intermediate; Freeze-Thaw | 0.52 | 0.71 | 0.40 | 0.64 | 0.66 | 1.50 | 1.50 | 1.00 | 1.10 | 1.00 |
| 6. Intermediate; No Freeze | 0.43 | 0.65 | 0.71 | 0.87 | 0.40 | 1.34 | 1.50 | 1.50 | 1.50 | 1.00 |
| 7. Dry; Freeze | 0.40 | 0.43 | 0.76 | 1.50 | 0.79 | 0.79 | 0.40 | 0.40 | 0.40 | 0.50 |
| 8. Dry; Freeze-Thaw | 0.40 | 0.40 | 0.40 | 0.40 | 1.50 | 0.40 | 0.49 | 0.40 | 0.40 | 0.50 |
| 9. Dry; No Freeze | 0.40 | 0.79 | 0.40 | 0.40 | 0.40 | 0.66 | 0.40 | 1.50 | 0.45 | 0.50 |

Note:
1. FGROUP := functional groupings
2. INT/OPA := Interstate highways and other principal arterials, FGROUP=1
3. MA/COL := minor arterials and collectors, FGROUP=2

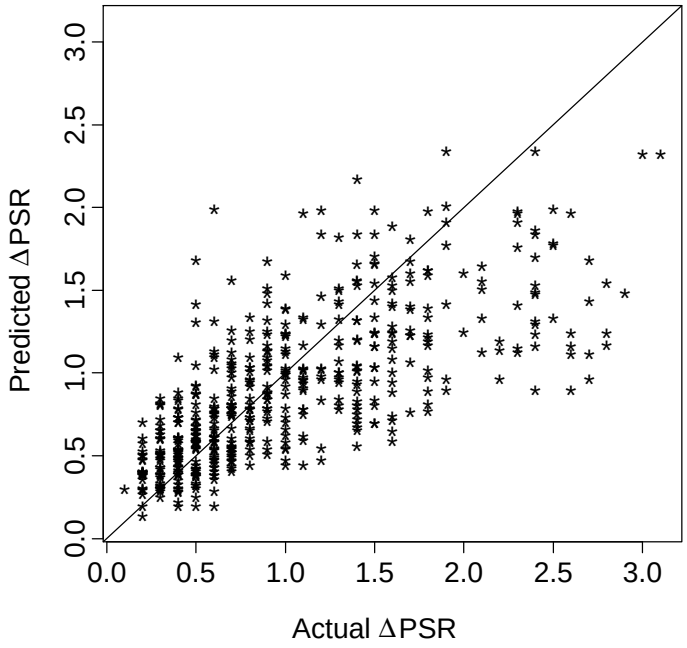


**Figure 1** - FLEX Model: Predicted versus Actual ΔPSR

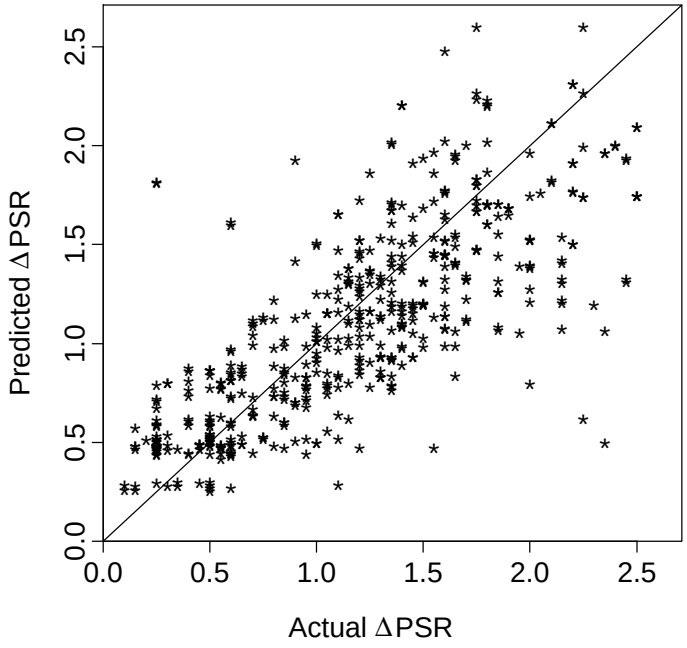


**Figure 2** - COMP Model: Predicted versus Actual ΔPSR

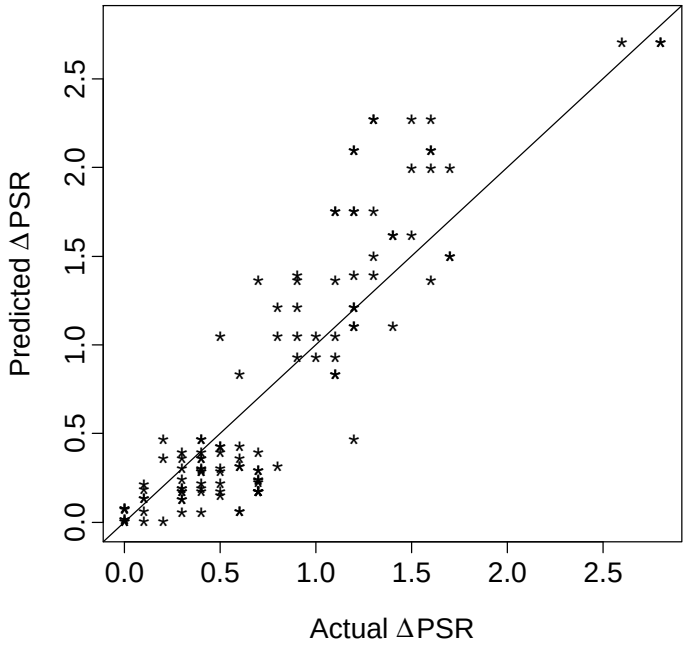


**Figure 3** - JPCP Model: Predicted versus Actual ΔPSR

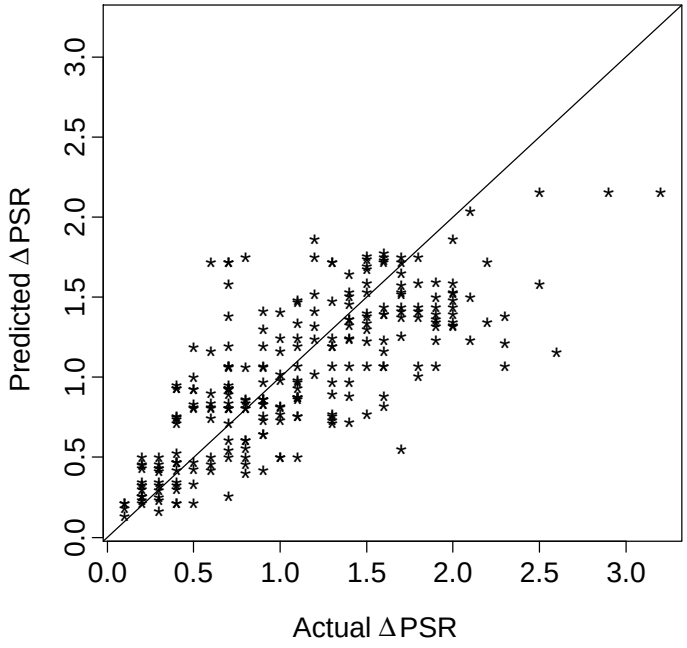


**Figure 4** - JRCP Model: Predicted versus Actual ΔPSR

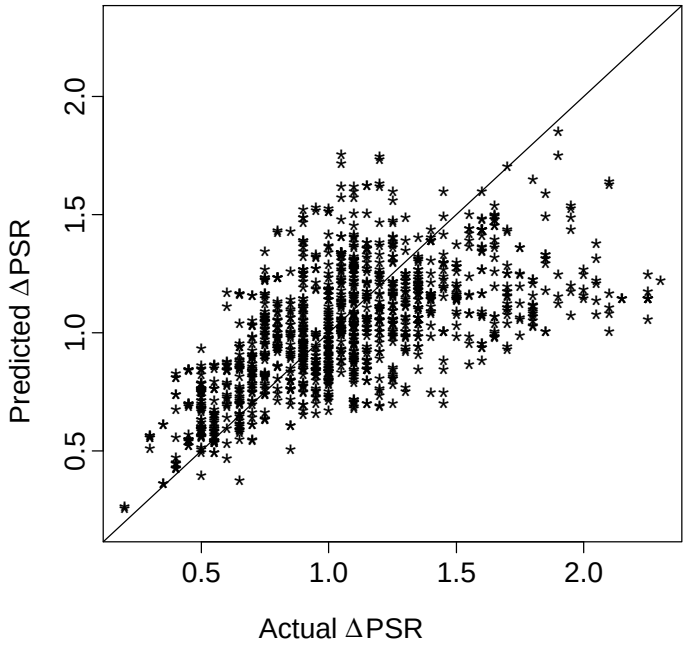


**Figure 5** - CRCP Model: Predicted versus Actual ΔPSR

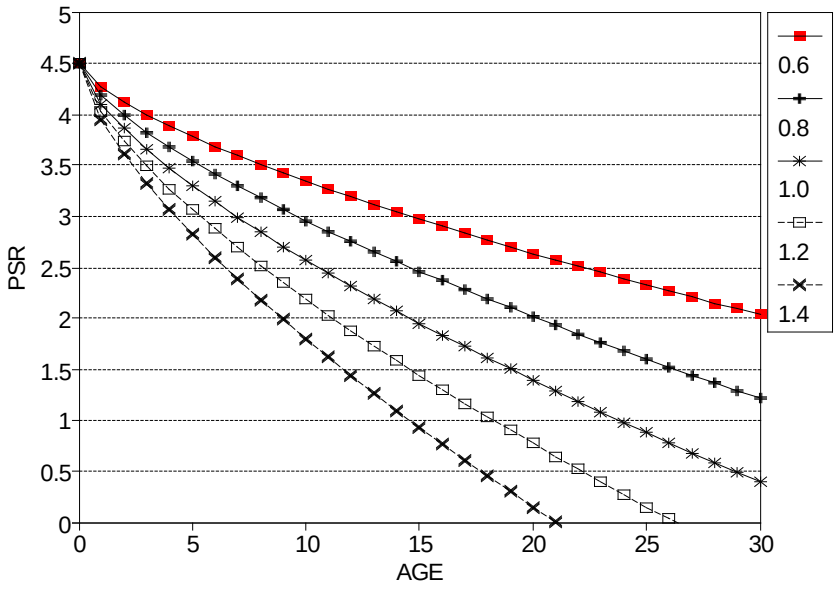


**Figure 6** - Effects of Adjustment Factors on Pavement Performance

**(7) (7) (7) (7) (7)**