# Flexible Pavement Rutting Prediction Model for Wet Freeze Zone

ASMAIEL KODAN A.NAIEL Ph.D. and MUMTAZ USMEN Ph.D., P.E

*Department of Civil Engineering, Sebha University, Brack Alshati, Libya*
*Department of Civil and Environmental Engineering, Wayne State University, Detroit, Michigan, USA*
*E-mail:* naiel1440@yahoo.com
*E-mail*: musmen@eng.wayne.edu

Pavement distress is an indication of pavement layer deterioration. There are many types of deteriorations; however, rutting, defined as the permanent deformation forming longitudinal surface depressions in the wheel paths, is one of the most important kind of distress that affect the safety and the ride quality of flexible pavement. The main objective of this study was to develop an empirical pavement rutting model for the wet freeze zone, which is one of the four long term pavement performance (LTPP) climate zones, to predict the depth of pavement rutting on granular bases. Using the LTPP database, the study aimed at a better understanding of the pavement rutting phenomena and the factors that may affect pavement rutting. Multiple regression analysis was performed to develop a flexible pavement rutting model. The proposed model was developed based on the relationship between the response variable rut depth, and predictor variables of traffic loads, structural number, Marshall stiffness, air voids in the total mix, and voids in the mineral aggregate. It was found that traffic loads was the predominant factor that have a significant effect on pavement rutting, which agrees with the existing literature, as well as engineering knowledge and practice. Following the traffic loads, structural number was the most significant secondary factor, followed by percent of voids in the total mix, voids in the mineral aggregate, and Marshall stiffness.

*Keywords*: Traffic loads, Flexible pavement, pavement rutting, empirical model, Environmental factors, the Long Term Pavement Performance program.

## 1 Introduction

Pavement performance relates to the ability of a pavement to acceptably serve road users over time. Serviceability is a measure of the ability of a pavement to serve the traffic that passes over it. Combining both definitions will lead to the understanding that pavement performance can be viewed as the integration of serviceability over time (Yoder, E. J., and Witczak, M. W. 1975).

The evaluation of pavement performance is an essential element of pavement design, rehabilitation, maintenance, and management. It includes evaluating pavement distress, roughness, friction, and structure (Huang 2004).

Pavement distress is an indication of pavement layer deterioration. Environmental conditions, traffic loads, and pavement material properties are the principle factors that affect flexible pavement performance. Various types of pavement deterioration can adversely affect pavement serviceability, including rutting, which causes safety and service quality problems on the road. Rutting is manifested as the permanent deformation of a pavement surface causing longitudinal depressions within pavement layers.

Forecasting future deterioration of pavements through consideration of various factors is a crucial aspect of a pavement management system. Pavement condition surveys provide the most important data (in-service pavement data) for forecasting the future deterioration of a pavement through models that predict pavement conditions throughout the life of a pavement.

There are many pavement deterioration prediction models, which have been developed using in- service pavement databases. The list includes models known as Federal Highway Administration (FHWA), Accelerated Loading Facility (ALF), Long Term Pavement Performance Program (LTPP), United States Army Corps of Engineers (USACOE), Cold Regions Research and Engineering Laboratory (CRREL), and AASHTO Road Test (Naiel 2010).

There are also many data sources available in different states, which have been developed in those states. The data collected by the states is different from state to state. Therefore, the data collected in different states will have a large variation in quantity and quality. On the other hand, the LTPP database, which has been developed under controlled and uniform conditions, provides very large amounts of data for four climate zones covering all of the states. These zones are wet freeze, dry freeze, wet no freeze and dry no freeze areas in North America. The models developed based on these data could be used in a wide range of states or in other countries over the world that have regions with climates similar to these zones.

Two types of experiments were conducted in the SHRP-LTPP program; the General Pavement Studies (GPS), which is the test sections that have used existing pavements; and the Specific Pavement Studies (SPS), which is the test sections that have different experimental treatments (Rowshan 1998). There are around 2400 test sections of the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS) in the U.S and Canada (Elkins et al. 2009).

## 2 Background

Flexible pavement rutting is the accumulation of the plastic flow in the surface layer or in other layers (Cebon 1993).

Different mechanisms may be responsible for flexible pavement rutting (Sousa, J., and Weissman, S 1994). The deformation causes the pavement material to rise adjacent due to the accumulation of the material in between the side of the wheel paths caused by movement of material under the wheels; however, for well compacted pavements, the stress in the asphalt pavement shear layer is the primary mechanism of rutting (Bahuguna, et al., 2006). Figure 1 shows the flexible pavement surface deformation induced by traffic loads.

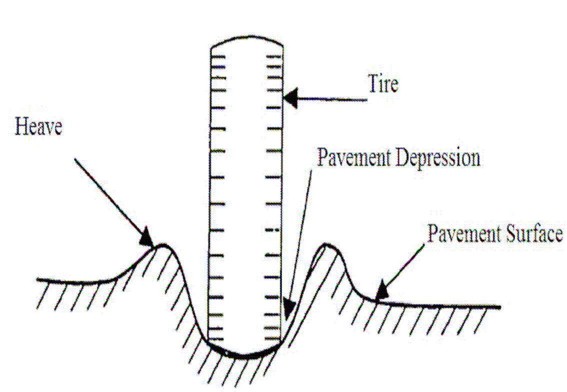


Figure 2-5: Pavement surface deformation, (Archilla 2000)

MTC (1986) classified pavement rutting into three categories based on severity (magnitude of depression): 1- Low: less than 1 in (13 to 25 mm), 2- Medium: between 1 and 2in (25 to 5o mm), and 3- High: equal to or greater than 2 in (> 50 mm).

Dawley, et al. (1990) classified flexible pavement rutting into three types based on the causes of rutting. These are as follows:

- Wear ruts: The main cause of this type of flexible pavement rutting is the progressive loss of particle aggregates of the surface layer, and other factors such as environmental and traffic loads.
- The rut instability: The main cause of this type of flexible pavement rutting is lateral displacement of material of layers.
- Structural rutting: The structural rutting is due to the permanent vertical deformation in lower layers.

In recent years, several models have been developed to forecast the rutting of flexible pavements. However, all developed models are not universally accepted (Xiao 2006).

The most significant rutting models found in the literature are those by Thompson and Nauman and by Archilla and Madanat (Naiel, 2010).

Thompson and Nauman developed the following equation to calculate the pavement rut rate.

$$R_R = RD/N = A/NB \quad (1)$$

where: $R_R$ is rutting rate, RD is rut depth (in), N is the number of repeated load applications, and A and B are terms developed from field calibration data.

Archilla and Madanat developed a model based on data from the AASHO Road Test using rut depth instead of rutting rate as used by Thompson and Nauman. The form of the model is

$$RD_{it}=\beta_{i10}+a_i.N^{bi}{}_{it} \quad (2)$$

where $RD_{it}$ is rut depth (mm) for section i at time t; βi10 is rut depth immediately after construction for pavement section I; ai and bi are a function of the characteristics of pavement I, such as layer thickness, gradation, etc, and Nit is a variable representing the cumulative number of load repetitions applied to pavement section I up to time of period t.

The literature indicates that various studies have been carried out focusing on factors affecting pavement rutting, including traffic loading, pavement material properties, pavement layer thickness, and environmental effects. Statistical analysis was performed where pavement rutting was used as the dependent variable and the factors that affect the pavement rutting were used as independent variables. Rut depth was most widely used as the rutting indicator (Wang 2003).

## 3 Data Source

As mentioned previously, there are many in-service pavement performance databases including LTPP. The LTPP database was used in this study because it is the largest pavement performance data base, and is accessible to researchers.

There are many types of errors leading to outliers in data, but measurement errors and data entry errors, mechanical and technical errors, and incomplete historical data are the most important errors. Therefore, descriptive analysis was used to identify the missing values in the data. The graphical description, Scatter-Plot and Box Plot methods were used to identify any outliers in the raw data.

The main objective of this study was to develop an empirical model to forecast the rutting depth of flexible pavements on granular base sections (GPS-1 test sections) in the LTTP wet freeze zone. There are several factors (independent variables), internal and external, to consider, which may influence the development of pavement rutting.

### *3.1 Response Variable*

Pavement rut depth was used as the dependent variable to develop the pavement rutting model. Rutting data are stored in the MON_T_PROF_INDEX* tables in MON Module of the LTPP data.

### *3.2 Explanatory Variables*

Based on the structure, availability and limitations of the LTPP data, on previous studies using the LTPP data, and on engineering judgment, it is difficult to capture and address all the factors that affect rutting. Therefore, the main quantitative variables that were selected in the models are temperature, traffic loads, pavement strength, structural number (SN), resilient modulus (MR), asphalt content, voids in the mineral aggregate (VMA), voids in the total mix (VTM), Marshall stability, and Marshall flow. These factors are listed in Table 1.

Table 1: Variables of the rutting model

| Variable Name | LTPP-Field | LTPP Table |
|---|---|---|
| Traffic loads (KESAL) | ANL_KESAL_LTPP_LN _YR | TRF_HIST_EST_ESAL &TRF_MON_EST_ESAL |
| SN | ESAL calculator software | ESAL calculator software |
| VTM (%) | PCT_AIR_VOIDS_MEAN | INV_PMA_ORIG_MIX |
| VMA (%) | VOIDS_MINERAL_AGGR | INV_PMA_ORIG_MIX |
| $M_R$ | RES_MOD_AVE | TST_UG07_SS07_WKSHT_SUM |
| Asphalt content (AC %) | ASPHALT_CONTENT_MEAN | INV_PMA_ORIG_MIX |
| Marshall stiffness (MS) | MARSHALL_STABILITY | INV_PMA_ORIG_MIX |
| | MARSHALL_FLOW | INV_PMA_ORIG_MIX |
| Total annual precipitation (TAP) | TOTAL_ANN_PRECIP | CLM_VWS_PRECIP_ANNUAL |
| #of days > 32 °C | DAYS_ABOVE_32_C_YR | CLM_VWS_TEMP_ANNUAL |
| Freeze Index (FI) | FREEZE_INDEX_YR | CLM_VWS_TEMP_ANNUAL |

The table contains the name of the variables that were selected to develop the prediction model, field name, and its LTPP table name.

Traffic loads which are the repetitions of heavy traffic loads accelerate elastic deformation in layers of roadbeds, and cause permanent deformation. Therefore, the effect of traffic loads should be considered in the design process. According to AASHTO (1993), pavement rutting is directly related to the magnitude and frequency of the applied truck loading. The field ANL_KESAL_ LTPP_LN_YR in Table TRF_HIST_EST _ESAL includes the annual ESAL estimates from the original construction date to 1990. In addition, the field ANL_KESAL_ LTPP_LN_YR in Table TRF_MON_EST_ ESAL includes the annual estimates ESALs after 1990.

Pavement structural strength is the ability of the road structure to carry the significantly increasing traffic loads and distribute the vertical deformation to the lowest layer during the design life. This will prevent the rapid failure of the road structure.

The AASHTO method of pavement design uses the structural number SN, which depends on the thickness and type of surface, base, and subbase layers, and serves as a measure of pavement structural strength. The structural number data are not included in the LTPP data because it is not a value that could be directly measured in the laboratory. The SN values were derived from ESAL calculator software (Naiel 2010).

The air voids in the total mix and excessive amount of the asphalt content in the total mix (AC) are the properties of asphalt mixtures that may most affect pavement rutting (Brown, E., and Cross, S. 1989). Therefore, VTM and asphalt content were selected as independent variables in the development process of the models. Data of air voids and asphalt content in the pavement mixture are included in the fields PCT_AIR_ VOIDS_MEAN and ASPHALT_CONTENT _MEAN respectively. These fields are located in INV_PMA_ORIG_MIX in Inventory Module tables.

VMA is the percentage of voids in the compacted asphalt mixture. Roberts, et al. (1996) defined and explained VMA as the intergranular void space that exists between the aggregate particles, which are occupied by asphalt and air in a compacted asphalt mixture. The VMA data in the LTPP data is included in the field VOIDS_MINERAL_AGGR that saved in INV_PMA_ORIG_MIX Table.

Material stiffness is the ability of subgrade material to carry and distribute the repetition of traffic loads throughout the design life; therefore, the higher the subgrade material stiffness, the lower the pavement rut. California Bearing Ratio (CBR), resistance value (R- Value), and MR are the most common characterizations of subgrade stiffness (WAPA, 2002). In this study, the resilient modulus was used as characterization of subgrade material stiffness. Subgrade material resilient modulus data was extracted from the Material Test module. The resilient modulus field was saved as RES_MOD_AVE in TST_UG07_ SS07_ WKSHT _SUM table.

Marshall stiffness (MS) estimates load deformation characteristics of the mixture, and indicates the material resistance to pavement rutting (Asphalt Institute 2001). A mixture with high Marshall stiffness is a stiffer mixture, and is resistant to pavement rutting (Abukhettala 2006). Marshal stability and Marshall flow data in the LTPP program is included in Marshall_Stability and Marshall_Flow fields. These fields are saved in INV_PMA_ORIG_MIX table.

Asphalt binder is sensitive to temperature which makes the mixture stiffer during the winter season and softer during the summer season. For this reason, the pavement rutting risk will decrease during the winter season and will increase during the summer season (Archilla 2000). The moisture also has a significant effect on pavement layers. For example, existence of moisture would affect the material of base layer, which will lead to pavement rutting. In this study, average annual precipitation (mm), average number of days above 32 $^{o}$C, and freezing index (FI) were extracted from the climate module tables. The field FREEZE_INDEX_YR in Table CLM_VWS_TEM_ANNUAL includes the annual freezing indices of the test section. The number of days above 90 $^{o}$F (32 C$^{o}$) is stored in the field DAYS_ABOVE_32_C _YR. Field TOTAL_ANN_PRECIP in table CLM_VWS_ PRECIP_ ANNUAL includes the annual precipitation information.

## 4 Processing and Evaluation of Data

Generally, the quality of the LTPP data varied from section to section. Therefore, the rutting data at each section was examined to identify any abnormal data. Section-by-section study, descriptive statistical analysis, and scatter-plot test were performed to evaluate the quality of the rutting data. After the validation of the data, modeling work was initiated.

## 5 Model Formulation

The next step that follows in the data validation is the model formulation. In this step multiple regression analysis was performed to develop pavement rutting models for the wet freeze zones.

A total of 69 sections were selected in this zone to be analyzed. The stepwise regression analysis was performed at the 0.05 significance level to develop the prediction model. The results of the regression analysis are shown in Table 2, Table 3, and Table 4.

Table 2: Model summary

| R | $R^2$ | Adjusted $R^2$ | St. Error of Estimate |
|---|---|---|---|
| 0.774 | .60 | 0.568 | 0.30505 |

Table 3: ANOVA table

| Model | SS | df | MS | F | Sig. |
|---|---|---|---|---|---|
| Reg | 8.78 | 5 | 1.75 | 18.87 | 0.000 |
| Res | 5.86 | 63 | 0.09 | | |
| Total | 14.6 | 68 | | | |

Table 4: Model coefficients

| Model | Unstandardized Coefficients | | t | Sig |
|---|---|---|---|---|
| | Reg Coeff | Std. Error | | |
| Constant | 1.659 | 0.489 | 3.390 | 0.001 |
| LN_KESAL | 0.131 | 0.050 | 2.637 | 0.011 |
| SN | -0.084 | 0.031 | -2.709 | 0.009 |
| VTM | 0.061 | 0.021 | 2.875 | 0.005 |
| VMA | 0.055 | 0.022 | 2.471 | 0.016 |
| MS | -0.004 | 0.001 | -3.882 | 0.000 |

The model can be expressed by the following regression equation:

$$\text{Ln RD} = 1.659 + 0.131 \text{ Ln KESAL} - 0.084 \text{ SN} + 0.061 \text{ VTM} + 0.055 \text{ VMA} - 0.004 \text{ MS} \quad (3)$$

The model includes rut depth as response variable and traffic loads, SN, VTM, VMA, and MS as the predictor variables.

## 6 Validation of Model

The model validation is the final step in model development. Parameter estimates (regression coefficients), t-test, determination coefficient, and standard error of estimate were used to validate the models. These statistical measures are important indicators to illustrate that the developed models are suitable to predict pavement rutting.

### *6.1 Multiple Determination Coefficient*

The determination coefficient of this model is (0.60) which means that 60% of the variance in the rut depth can be associated with the variance in traffic loads, SN, VTM, , and MS.

### *6.2 Standard Error of Estimate*

The model summary table indicates that the standard error of estimate (SEE) is 0.30505 which consider small and significant. Therefore, the small value of the SEE means less error in estimating the relationship in the model. The larger the correlation between rut depth and independent variables, the greater is the accuracy of prediction.

### *6.3 Parameter Estimation*

In parameter estimation, the regression coefficient illustrates the effect of the independent variables on pavement rutting.

The positive sign of traffic loads regression coefficient (+0.131) indicates that the rut depth will increase with increasing traffic loads, which are concurrent with engineering practice. The negative value of SN (-0.084) indicates that the rut depth will decrease when SN increases, which also agrees with engineering knowledge and practice. The equation shows that there is a positive correlation between VTM and rut depth (+0.061), which means the rut depth will increase when the air voids increase, which is as expected as well. The positive value of VMA (+0.055) indicates that the excessive amount of VMA will lead to increase rut depth, which again agrees with engineering practice. The negative value of MS (-0.004), which is expected, indicates that the rut depth decreases when the MS increases.

### *6.4 t-test*

Any parameter estimate of an independent variable that has insignificant t-test value should be eliminated from the model. The values of the t-test for the model indicate that the parameter estimates are statistically significant at the 0.05 significance level.

## 7. Conclusions

The following conclusions can be drawn from this study:

- Traffic loads is the predominant factor that have a significant effect in pavement rutting which agree with existing literature and engineering knowledge and practice.
- Structural number is the most significant secondary factor.
- The percent of voids in the total mix, voids in the mineral aggregate, and Marshall stiffness also has a significant effect in pavement rutting.

## References


AASHTO. *AASHTO Guide For Design Of Pavement Structures* . American Association of State Highway and Transportation Officials., 1993.

Abukhettala, M. E. *The Relationship between Marshall Stability, Flow and Rutting of the New Malaysian Hot-Mix Asphalt Mixtures.* PhD, Universiti Teknologi Malaysia, Johor, Malaysia., 2006.

Archilla, A. R. *Development of Rutting Progression Models by Combining Data from Multiple Sources.* Ph.D., University of California, Berkeley, California USA, 2000.

Asphalt Institute. *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types.* Asphalt Institute, 2001.

Bahuguna, S., Panoskaltsis, V., and Papoulia, K. "Identification and Modeling of Permanent

Deformation of Asphalt Pavements." *Journal of Engineering Mechanics*, 2006: 231-239.

Brown, E., and Cross, S. *A Study Of In-Place Rutting Of Asphalt Pavements."* . Report No. 89-2, NCAT , 1989.

Cebon, D. *Interaction Between Heavy Vehicles And Roads.* Cambridge, UK, 1993.

Dawley, C., Hogewiede, B., and Anderson, K. "Mitigation Of Instability Rutting Of Asphalt Concrete Pavements In Lethbridge, Alberta, Canada." *Association of Asphalt Paving Technologists*, 1990: 481-508.

Elkins, G. E., Schmalzer, P., Thompson, T., Simpson, A. and Ostrom, B. *Long-Term Pavement Performance information Management System: Pavement Performance Database User Reference Guide.* McLean, VA: Highway Research Center, 2009.

Huang, Y. *Pavement Design and Analysis.* Upper Saddle River, NJ: Pearson/Prentice, 2004.

MTC. *Pavement Condition Index Distress Identification Manual for Asphalt and Surface Treatment Pavements.* Oakland, CA: Metropolitan Transportation Commission, 1986.

Naiel, A. K. *Flexible Pavement Rut Depth Modeling for Different Climate Zones.* PhD,. Wayne State University. Detroit, Michigan, 2010.

Roberts, F., Kandhal, P., Brown, E., Lee, D., and Kennedy, T. *Hot Mix Asphalt Materials, Mixture Design, and Construction.* NAPA Education Found, Lanham, Maryland., 1996.

Rowshan, S. *Performance Prediction Models Based on Roughness in Asphalt Concrete Bavements.* Ph.D., University of Maryland College Park, Maryland, United States, 1998.

Sousa, J., and Weissman, S. "Modeling Permanent Deformation of Asphalt Aggregate Mixes." *Association of Asphalt Paving Technologists*, 1994: 224-257.

Wang, Y. *Predicting flexible pavement deterioration for pavement management systems.* Ph.D., University of Kentucky, Lexington, Kentucky, 2003.

Xiao, S. *Investigation Of Performance Parameters For Hot-Mix Asphalt.* Ph.D., Purdue University, United States -- Indiana., 2006.

Yoder, E. J., and Witczak, M. W. *Principles of pavement design.* New York.: Wiley, 1975.