Pavement Rutting Prediction Model based on the Long Term Pavement Performance Data

ASMAIEL KODAN NAIEL and MUMTAZ A. USMEN

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

Various types of pavement deterioration can affect pavement performance, including rutting, which causes safety and service quality problems on the highways. Rutting, often referred to as permanent deformation of a pavement surface, causes longitudinal depressions creating channels in wheel paths. There are many in-service pavement performance databases, but the Long Term Pavement Performance database (LTTP) is the largest of its kind in the world. It encompasses data from four different climate zones in North America. Data on flexible pavements from only the dry freeze zone was included in the scope of the study reported herein. Regression analysis was performed to develop a rutting model. The proposed model indicates that the voids in the mineral aggregate (VMA) of hot mixed asphalt is the most important factor and the positive values of the regression coefficient of VMA implies that rut depth increases when VMA increases. The other important factors in this model are Marshall stiffness and freeze index. The negative values of the regression coefficients of Marshall stiffness and freeze index indicates that the rut depth will decrease when the Marshall stiffness and freeze index increase.

Keywords: Flexible pavement, pavement deterioration, pavement performance, pavement rutting, empirical model, the Long Term Pavement Performance (LTTP) database.

1 Introduction

Rutting, often referred to as permanent deformation of a flexible pavement surface, causes longitudinal depressions creating channels in wheel paths. This is effected by the consolidation or lateral movement of material due to traffic loads, inadequate compaction during construction, unstable mixture, and failure of the lower layers of the pavement (Miller and Bellinger, 2003).

Pavement rutting is observed on roads and streets, especially at high-stress locations such as intersections, grades, and locations where heavy vehicles stop, start, turn or climb steep grades (Flexible Pavement of Ohio, 2004). Indeed, rutting may endanger safety when it reaches critical depths.

There are many pavement deterioration prediction models, which have been developed using in- service pavement databases. The local agencies provide somewhat limited information about pavements, but the LTPP database is the largest pavement performance database in the world that provides extensive information about the pavements, which can help develop efficient performance prediction models.

The LTPP program encompasses field experiments and has more than 2400 in-service pavement test sections across the U.S. and Canada and aims to monitor pavement performance on these sections over a long time period.

In the late 1980's, the Transportation Research Board (TRB) and the Federal

Highway Administration (FHWA), in cooperation with the American Association of State Highway and Transportation Officials (AASHTO), initiated a study of the deterioration of the nation's highway and bridge infrastructure system to evaluate pavement performance and determine related factors. The study is described the Strategic Transportation Research Study (STRS) report published by TRB. It emphasized six research areas, one of which is the LTPP program (Elkins, et al., 2009).

Two types of experiments were conducted in the SHRP-LTPP program: the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS). The GPS test sections were on existing pavements, while the SPS sections were multiple test sections that had different experimental treatments (Elkins, et al., 2009).

In the LTPP program, there are four climate zones located in North America: wet freeze zone, dry freeze zone, wet no-freeze zone, and dry no-freeze zone. The study reported in this paper was undertaken to develop a pavement rutting prediction model for the dry freeze zone.

2 Background

Ashworth (2003) characterized the pavement rutting in terms of the following phenomena:

- Subsidence of the surface layer over yielding lower layers. The surface layer over weak lower layers subsides due to heavy and repeated traffic. The surface layer endeavors to conform to the shape of the lower layers.
- Loss of material from the wheel paths due to the progressive loss of particle aggregates of the surface layer. A combination of traffic and the environment causes this type of rutting.
- Plastic shear deformation of the asphalt mixtures near the pavement surface, a material failure of the asphalt concrete.

Deterioration of flexible pavement due to rutting is covered widely in the technical literature (Archilla and Madanat 2000, and Haddock, et al., 2005). Sousa, et al. (1991) emphasized that rutting may be affected by many factors, such as the traffic loads, characteristics of pavement materials, and environmental factors .

There are two types of pavement prediction models covered in the literature: mechanistic-empirical models and empirical models. The empirical model is based on statistical analysis of experimental data. In the mechanistic approach, the stresses and strains in a pavement structure influenced by physical factors such as traffic loads, traffic conditions and pavement layer material properties are explained by theory. Then the empirical models are used to link the stresses and strains to pavement failure.

Empirical pavement rut depth models developed by researchers such as Hicks and Finn (1970), Paterson (1987), Luo and Prozzi, (2008), have generated a concave curve of pavement rut depth. The concave shape of the rut suggests that there is a relationship to the cumulative number of traffic load repetitions (Archilla and Madanat 2000, Luo and Prozzi 2008).

3 Data Source

The LTPP database is extensive, and contains a large number of variables ranging from pavement type through material properties, traffic loads, climatic information and so on. Each individual data is associated with a given test section. This study used data from GPS-1 test sections that are comprised of asphalt concrete on granular base.

The completeness of the data in the GPS 1 test sections varies across sections. It was noted that not all data fields were filled and there were missing data.

The variables selected for rut depth modeling in the scope of this study are listed in

Table **1**, and discussed in the following sections.

Table 1: The model variables

Variable Name	Symbols	LTPP Field
Rut depth	R_D	MAX_MEAN_ DEPTH_1_8
Traffic loads	KESAL	ANL_KESAL_ LTPP_LN _YR
# of days > 32 C°	D> 32 C°	DAYS_ABOVE _32_C_YR
Freeze Index	FI	FREEZE_INDE X_YR
Total annual precipitation	TAP	TOTAL_ANN _PRECIP
Resilient modulus	M_R	RES_MOD_ AVE
Asphalt content in the mix	AC%	ASPHALT_ CONTENT_ MEAN
Air voids in the mix	VTM%	PCT_AIR_ VOIDS_MEAN
Voids in mineral aggregate	VMA	VOIDS_ MINERAL _AGGR
Marshall stiffness	MS	MARSHALL _STABILITY MARSHALL _FLOW
Structural number	SN	ESAL calculator software

3.1 *Pavement rut data*

Pavement rut depth (R_D) was used as the dependent variable to develop the pavement rutting model. Rutting data are stored in MON_T_PROF_ INDEX* tables in monitoring (MON) Module of the LTPP database.

3.2 *Traffic data*

The repetitions of heavy traffic loads accelerate rutting in pavement layers. The axle loads applied on roadbed will deteriorate the pavement structure during design life. It is difficult to account for each axle load, because traffic loads are variable. Consequently, in the AASHTO design method, multiple axles are converted to a standard axle load (80- KN ESAL, Equivalent Single Axle Load).

There are two types of traffic data: historical traffic data and monitored traffic data. Historical traffic data provide traffic data for each year from the original construction date to 1990, while the monitored traffic data are annual estimates provided by the participating highway agency or computed from raw data (Elkins, et al., 2009).

The field ANL_KESAL_LTPP_LN_YR in Table TRF_HIST_EST_ESAL of the LTPP database 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 of the LTPP database includes the annual estimates ESALs after 1990.

3.3 *Environmental data*

Environmental factors, such as temperature and precipitation have a significant effect on pavement rutting, especially when the surface layer is subjected to high temperature, or when subgrade layer is affected by seasonal climate variations.

Average annual precipitation (mm), average number of days above 32 °C, and freezing index (FI) were extracted from the climate module tables.

The field FREEZE_INDEX_YR in Table CLM_VWS_TEM_ANNUAL of the LTPP database includes the annual freezing indices of the test section. The number of days above 32 °C is stored in the field DAYS_ ABOVE_32_C_YR. Field TOTAL_ANN _PRECIP in the table CLM_VWS_PRECIP _ANNUAL of the LTPP database includes the annual precipitation information.

3.4 *Subgrade material stiffness*

Material stiffness is the ability of subgrade material to carry traffic loads. In this study, the resilient modulus (M_R) was used to characterize the subgrade material stiffness. M_R data was extracted from the Material Test module. The M_R field was saved as RES_MOD_AVE in TST_UG07_ SS07_ WKSHT _SUM table of the LTPP database.

3.5 *Pavement structural strength*

Pavement structural strength is the ability of the roadbed layers to carry the repeated traffic loads as well as distribute the vertical deformation to the lowest layer. In this study, the structural number (SN) was selected as the measure of pavement load carrying capacity. The SN values were derived from ESAL calculator software, which is available online at the LTPP products online.

3.6 *Air voids and asphalt content data*

The air voids content in the total mix (VTM) and excessive amount of asphalt content (AC) have a significant effect on pavement rutting. Mixtures perform well when there is an adequate percentage of VTA and AC.

Data of VTM and AC 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 of the LTPP database.

3.7 *Voids in the Mineral Aggregate*

The VMA is the percentage of voids in the compacted asphalt mixture. A mixture with excessive VMA will have low mixture stability.

VMA data in the LTPP data is included in the field VOIDS_MINERAL_ AGGR that is saved in INV_PMA_ORIG _MIX table of the LTPP database.

3.8 *Marshall stiffness*

Marshall stiffness (MS), which is calculated as Marshall stability divided by Marshall flow, estimates the load deformation characteristics of the mixture. A mixture with high MS is a stiffer mixture, and is resistant to pavement rutting. Marshall stability and Marshall flow are saved in the INV_PMA_ ORIG_MIX table of the LTPP database.

4 *Data Validation*

There are many types of errors leading to anomalous data and outliers in data, but measurement errors and data entry errors, mechanical and technical errors, and incomplete historical data are the most important deficiencies.

Descriptive analysis was used to identify the missing values in the data. Graphical procedures encompassing scatter-plot and box plot methods were used to identify any anomalous or outlier data. After the validation of the data, modeling work was initiated.

5 The Proposed Model

With pavement rut depth selected as the dependent variable, ESAL, FI, ATP, D> 32 °C, M_R, SN, AC%, VTM%, VMA%, and MS were established as independent variables. From the dry freeze zone, 35 test sections containing rut depth information were selected to develop the model.

5.1 *Model Formulation*

The model was developed by using stepwise regression analysis at the 0.05 significance level. The results are shown in Table 2 and Table 3.

The degrees of freedom are provided in the df column; the sum of squares are provided in the SS column, and the mean square terms are provided in the MS column.

Table 2: ANOVA for dry freeze zone

Mod-el	SS	df	MS	F	Sig.
Reg	3.77	3	1.25	27.8	.000
Res	1.40	31	0.04		
Total	5.17	34			

Table 3: Coefficients for dry freeze zone

Model	Reg Coeff	t	Sig.	
Inter	2.075	5.479	.000	R^2=
VMA	.059	2.582	.015	.729
MS	-.004	-7.490	.000	SSE=
FI	-.00028	-4.148	.000	.21261

The F test shows that the model is statistically significant at the 0.05 significance level. The proposed model has a high R^2 (0.729), and small and significant standard error of estimate (0.21261).

The positive regression coefficient of VMA indicates that the rut depth will increase when the VMA increases, which agrees with engineering knowledge and practice. The negative regression coefficient of MS and FI indicates that the rut depth will decrease when these variables increase, as expected. The t-test significance values show that the regression coefficients of VMA, MS, and FI are significant at the 0.05 significance level.

There is a general belief that the traffic loads have a significant effect on pavement rutting. Based on this premise, many researchers consider that it is important to include traffic loads in the model even if it is not statistically significant. Consequently, the traffic loads variable was added to analysis. Table 4 and

Table **5** show the results of the model that include traffic loads as one of the independent variables.

Table 4: ANOVA for the model that include ESAL - dry freeze zone

Model	SS	df	MS	F	Sig
Reg	3.791	4	.948	20.57	.000
Res	1.382	30	.046		
Total	5.173	34			

Table 5: Coefficients for the model that include ESAL - dry freeze zone

Model	Reg Coeff	t	Sig.	
Inter	1.878	3.842	.001	R2=
VMA	0.063	2.639	.013	.733
LN_K ESAL	0.028	0.648	.522	SSE= .2146
MS	-0.004	-6.954	.000	
FI	- .00029	-4.160	.000	

5.2 *Model Validation*

The modified model is formulated as follows:

$$\text{Ln } R_D = 1.878 + 0.063\,(\text{VMA}) + 0.028\,(\text{Ln KESAL}) - 0.004\,(\text{MS}) - 0.00029\,(\text{FI}) \qquad (1)$$

The F-test shows that the developed model is statistically significant at the 0.05 significance level. The R^2 of this model is (0.733), a high determination coefficient, which means that 73.3 % of the variance in the rut depth can be associated with the variance in the independent variables. The standard error of estimate (SEE) is considered small and significant (0.21462), with less error in estimating the dependent and independent variable relationship. The signs of the regression coefficients and their explanations remain unchanged.

Generally, any parameter estimate of any independent variable that has insignificant value of t-test should be eliminated from the model. Nevertheless, traffic loads has a relatively small t-test significance value; so, it should be included in the model due to its significant effect on pavement rutting. The t-test significance values show that the regression coefficient of VMA, MS, and FI are significant at the 0.05 significance level.

5.3 *Sensitivity analysis*

Analysis of both of the proposed models indicates that the models are statistically significant. However, the modified model was mathematically investigated to identify the effect of the addition of traffic loads. The sensitivity analysis results with and without traffic loads are tabulated in Table 6. From this table it is clearly seen that the R square value increases only by a small amount, indicating that the accuracy of the model does not necessarily improve much by adding the traffic loads into it. Also, the rut depth will be slightly less if the traffic loads is included in the model, which shows that, imposing this physical factor on the model actually makes the rut depth prediction less conservative.

Table 6: Sensitivity Analysis for proposed models

Model	Ln Rut (mm)	Rut (mm)	R^2
Without KESAL	2.08	8.00	0.729
With KESAL	2.06	7.88	0.733

6 Conclusions

Based on the findings of this study, we offer the following conclusions:

- The VMA has the highest effect on pavement rutting in the dry freeze zone. Increasing VMA and traffic loads will increase the pavement rut depth. MS and FI have a reducing effect on pavement rutting. These findings are in agreement with those of previous researchers.
- Imposing traffic loads on the model does not improve accuracy by much and makes the prediction less conservative. This has not been addressed by previous researchers to a great extent. Therefore, further studies should be conducted on the effect of traffic loads on pavement rutting.

References

Archilla, A., and Madanat, S., Development of a pavement rutting model from experimental data. *Journal of Transportation Engineering*, 126, 291, 2000.

Ashworth, L., Factors affecting rutting potential of Superpave asphalt mixtures in New Brunswick. M.Sc.E., The University of New Brunswick, Canada, 2003.

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

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, 2009.

Flexible Pavement of Ohio, Preventing and Correcting Rutting in Asphalt Pavement, 2004.

Haddock, J., White, T., PE, M., Hand, A., and Fang, H., Determining layer contributions to rutting by surface profile analysis, *Journal of Transportation Engineering*, 131, 131- 139, February, 2005.

Hicks, R. G., and Finn, F. N., Analysis of Results from the Dynamic Measurements Program on the San Diego Test Road, *Association of Asphalt Paving Technologists Proc* 153-185 1970.

Luo, R., and Prozzi, J. A., Development of a Pavement Rutting Model from Long-Term Pavement Performance Data. *87th Annual Meeting of Transportation Research Board* Washington DC, 2008.

Miller, J., and Bellinger, W., Distress identification manual for the long-term pavement performance program (Fourth Revised Edition). Rep. FHWA-RD-03-031, Office of Infrastructure Research and Development, Federal Highway Administration, Mclean, VA, 2003.

Paterson, W. D. O., *Road Deterioration and Maintenance Effects: Models for Planning and Management*, Johns Hopkins University Press, Baltimore and London 1987.

Sousa, J., Craus, J., and Monismith, C., Summary report on permanent deformation in asphalt concrete. *Institute of Transportation Studies, University of California,* Berkeley, California, 1991.