Pavement Mechanistic-Empirical Design Climate Data Input for the State of Tennessee

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ABSTRACT

This paper presents the analysis of Pavement Mechanistic-Empirical Design (PMED) climate input data for the state of Tennessee. The climatic data source considered for the analysis is Modern-Era Retrospective Analysis for Research and Application (MERRA). First the sensitivity analysis using 2^k factorial design method, considering lower and higher extremes of each climatic input and water table, was conducted to determine the sensitivity of climatic inputs to pavement distress predictions. Then Virtual Weather stations (VWSs) were created, and their predicted performance was analyzed in comparison to the existing stations. On sensitivity analysis of the Enhanced Integrated Climatic Model (EICM) model, temperature was the most sensitive climatic input in PMED distress predictions, while humidity had no effect to pavement distress predictions. Performance evaluation of PMED VWSs indicated a significant difference in some of the predicted distresses when comparing PMED VWSs and MERRA stations at identical locations.

INTRODUCTION

Pavement design procedures have evolved through the years from the use of rule of thumb to empirical designs and currently, to mechanistic-empirical (M-E) design. Over the years, results from various pavement research activities have revealed factors that affect pavement longevity, material performance, and traffic characteristics. The AASHTO Guide for Design of Pavement Structures (1993), for instance, considered drainage factors in the design process, but other climatic related parameters were seldomly considered. This is among the reasons that led to Pavement M-E Design (PMED) method, which considers detailed design inputs in material characteristics, traffic loading, and climate (Khazanovich et. al. 2013; Oh et. al. 2006; NCHRP 2004).

The data input requirement in the PMED is large, hence it calls for a robust software to design the pavement and predict its performance. AASHTO developed a PMED software, AASHTOWare, to aid in the pavement design process, with three input levels. Level 1 data is of the highest quality but the hardest and most expensive to obtain as compared to other levels. In the absence of Level 1 data, Level 2, regional or statewide data, is recommended for use. Level 3 data are the default values and readily available in the software but has the lowest reliability level.

For this project, Modern-Era Retrospective Analysis for Research and Application (MERRA) was used for the evaluation of PMED VWSs. MERRA, developed by the National

Aeronautics and Space Administration (NASA), uses spatial stations that cover the whole state and provides continuous hourly weather data since 1985.

This project was conducted with an objective to evaluate the suitability of MERRA climate data source, among other inputs, to design pavements and predict distresses on selected pavement sections in Tennessee in order to establish regionwide (Level 2) climate data source for design of Tennessee pavements. Pavement sites with complete input data (pavement structure, traffic, and material) were selected as candidates for analysis, this included 48-hour count stations and LTPP sites in the state of Tennessee. PMED software was used to predict distresses predicted using the climatic data sources. A statistical analysis was utilized to evaluate the pavement performance of the selected sites using the two climatic data sources, and hence draw conclusions and recommendations.

LITERATURE REVIEW

This study evaluates the PMED climate inputs that will satisfactorily predict the performance of designed pavements in Tennessee. PMED software uses an Enhanced Integrated Climatic Model (EICM) to evaluate the influence of climatic conditions on pavement design. EICM allows pavement design to include the effects of air temperature, wind speed, precipitation, humidity, percent sunshine, and level/depth of water table (Khazanovich et. al. 2013). There have been numerous studies on climate data inputs on PMED software for pavement performance prediction (Ziedan 2017; Schwartz et. al. 2015; Guidotti 1976).

EICM is a one-dimensional program that uses hourly climatic data (HCD) to model and predict heat and moisture flow on the pavement layers and subgrade throughout the design life/years of service (Khazanovich et. al. 2013; Zapata & Houston 2008). The heat and moisture profiles directly impact distress development and the mechanistic properties of pavement materials. Furthermore, PMED software allows the pavement designer to select a weather station that best represents the location of pavement design. In cases where no weather station is available near the design site, the software allows interpolation of existing stations to create a Virtual Weather Station (VWS) at the design site. For better quality results, it is recommended to use more weather stations to create a VWS (NCHRP 2004).

Sensitivity analysis. The sensitivity analysis in EICM provides a closer look at the effects and performance of the model at various climatic conditions. The sensitivity analysis gives the designer the awareness of the importance of quality of data used. Poor quality data, especially for the sensitive inputs, will eventually lead to poor pavement designs. Several studies have been performed on the EICM model to understand the performance of pavement sections under different climatic conditions. The studies also aimed at determining the level of sensitivity of each of the EICM inputs had in the design (Ahmed et. al. 2005; Tighe et. al. 2008; Saha et. al. 2014 and Yang et. al. 2017).

Most of the EICM sensitivity analysis studies reviewed indicated that predicted temperature and moisture content, variations were statistically significant (Ahmed et. al. 2005). Higher temperature values resulted to an increase in rutting predictions (Tighe et. al. 2008). Average annual temperature, and average temperature range were the most sensitive climatic data input parameters for both flexible, and rigid pavements affecting rutting, total rutting, and longitudinal cracking for flexible pavements and Jointed Plain Concrete Pavement slab cracking (Li et. al. 2013). Likewise, Temperature was the most sensitive climatic input followed by wind speed while relative humidity, precipitation showed, and percent sunshine showed less sensitivity to distress predictions (Yang et. al. 2017; Msechu et. al. 2020).

Performance of Virtual Weather Stations (VWSs). PMED software allows the user to create Virtual Weather Stations (VWSs) in instances where no weather station is available near the design/analysis site. The VWS is simply a product of interpolation of data from other existing weather stations (ARA 2004). The EICM model uses an inverse square ($1/R^2$) method in the interpolation to create VWSs. The inverse square method also referred to as the gravity model, creates VWS by using a weighing criterion. Weather stations closer to the point of VWS creation point are weighted more and hence contribute more to the values of the final data. (Schwartz et. al. 2015).

On the PMED VWSs creation tool, varying observations were reviewed. Comparing MERRA and NARR VWSs databases as the climate inputs, showed that MERRA could address climate effects on pavements much better than the NARR VWSs, since it predicted higher distress (Ziedan 2017). On other studies using VWSs was associated with a possibility of inaccuracies in some of the distress predictions, and VWS quality was stated to depend on the quality of the climatic stations used for their creation (Johanneck & Khazanovich 2010; Li et. al. 2010; Dzotepe & Ksaibati 2011; Li et. al. 2013). From this review, it can be concluded that the use of VWSs in pavement analysis and design can lead to inconsistent or unrealistic outputs. The use of VWSs should be carefully considered.

METHODOLOGY

To understand the EICM model, this research did a sensitivity analysis and assessment of virtual weather stations performance. The sensitivity analysis was performed to evaluate what climatic inputs (temperature, wind speed, percent sunshine, relative humidity, and water table depth) mostly affect the distress predictions. Virtual weather station (VWS) performance study was also carried out to confirm the suitability of PMED VWS creation tool for use in the analysis. All distress predictions used AASHTOWare PMED software version 2.5.5 and later repeated on version 2.6.0 and 2.6.1 due to the change of the previously top-down cracking model.

Sensitivity analysis of EICM. This analysis was performed to assess the sensitivity of climate inputs in distress prediction, using a full model 2^k factorial design approach. The 2^k factorial design considers maximum and minimum values of events/inputs when assessing their effect on the observed system (Msechu et. al. 2020). Climatic inputs/variables used for the analysis include temperature from 32ºF to 110ºF, wind speed from 0 to 60 miles/hour, percent sunshine from 0 to 100%, relative humidity from 0 to 100%, and water table depth from 0 to 100 ft. Precipitation was not included in the analysis due to the failure to replicate its high and low values in the AASHTOWare PMED software.

Using the five climate input variables as factors in the factorial design, a combination matrix with 32 (2^5) lines of high and low combinations was generated. Each combination in the matrix was used as a blueprint in creating 32 climatic files with 36.5 years of hourly climatic data. Example, the first climate file has low values for all climatic inputs, second has only temperature as a high input with others as low, and so on to 32nd climate file which has all high climate inputs. Each of these climatic files were used in the AASHTOWare PMED software as climatic stations in analyzing three LTPP flexible pavement sites shown in Table 1, LTPP sites were selected based on varying pavement structure and materials, and traffic conditions. Thirty-two (32) analyses per site were performed for each site using the 32 generated climatic stations. ANOVA (P value and F value) was used to assess the relationship between the climatic inputs and the distresses predicted. The distresses considered for analysis included asphalt concrete (AC) permanent deformation, total pavement permanent deformation, top-down cracking, bottom-up cracking, and terminal IRI.

Table 1 Layer Description for LTPP Sites used in the Sensitivity Analysis

Layer	*LTPP Site 47-1028*	*LTPP Site 47-3108*	*LTPP Site 47-3104*
1	AC Surface (4.3 in.)	AC Surface (2.7 in.)	AC surface (1.3 in.)
2	AC Base (6.2 in.)	AC Base (5.5 in.)	Crushed stone base (8.7 in.)
3	AC Base (5.1 in.)	AC Base (6.1 in.)	Compacted subgrade A-6
4	Crushed stone base (3.8 in.)	Crushed stone base (6.1 in.)	
5	Compacted subgrade A-7-5	Compacted subgrade A-7-6	

EICM's Virtual Weather Stations (VWSs). To assess the performance of VWSs, the study used MERRA stations in and bordering the state of Tennessee (Msechu 2021). MERRA data was used because of its geographic coverage advantage. Figure 1 shows the distribution of forty-nine (49) MERRA climatic stations in the state of Tennessee. The stations are equally spaced, currently operating at 0.625º longitude by 0.5º latitude spatial resolution, which made the analysis easily adaptable.

The PMED software VWS creation tool was used to create the VWSs, where eight existing MERRA stations were used at each of the forty-nine (49) MERRA station locations shown on Figure 1. A total of forty-nine (49) VWSs were created at the same locations as the forty-nine (49) existing MERRA stations. Figure 2 shows the eight MERRA stations (in green) used to create a VWS at a yellow pin drop and an actual MERRA station in blue that is used for comparison to the created VWS.

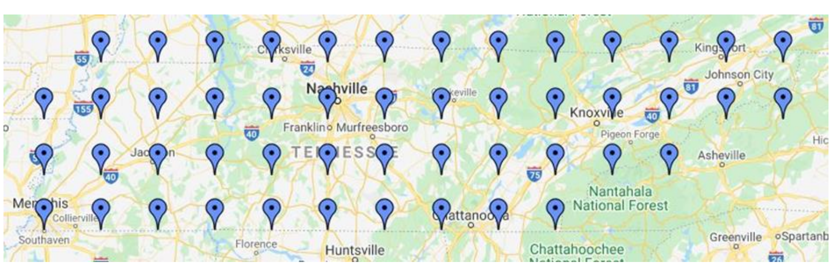

Figure 1 (a)

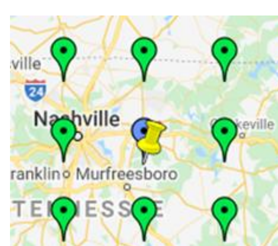

Figure 1 (b)

Figure 1(a) MERRA Stations for the State of Tennessee (b) Interpolation Methodology Scheme

The comparisons of the forty-nine (49) MERRA and forty-nine (49) PMED VWSs stations considered their climatic summary output values and their distress predictions. The climatic summaries comprised of the values of the climatic inputs for both MERRA and PMED VWS stations. For distress prediction, a total of five LTPP sites (Table 2) were used in comparing each of the forty-nine (49) MERRA and forty-nine (49) PMED VWS pairs at identical locations.

Table 2 Layer Description for LTPP Sites used on PMED VWS Analysis

Layer	*LTPP Site 47-C330*	*LTPP Site 47-3104*	*LTPP Site 47-3075*	*LTPP Site 47-0602*	*LTPP Site 47-B330*
1	AC Surface (5.3 in.)	AC surface (1.3 in.)	AC Surface (5.0 in.)	PCC Surface (8.9 in.)	AC Surface (1.8 in.)
2	AC Base (5.7 in.)	Crushed stone base (8.7 in.)	Crushed stone base (9.2 in.)	Chemical stabilized base (6.0 in.)	AC Base (3.2 in.)
3	Crushed stone subbase (6.0 in.)	Compacted subgrade A-4	Compacted subgrade A-4	Compacted subgrade A-4	Crushed stone subbase (9.2 in.)
4	Compacted subgrade A-6				Compacted subgrade A-5

The comparison of MERRA and PMED VWS data at a respective location utilized correlation analysis and hypothesis testing. For correlation analysis, the goodness of fit methods, coefficient of linear determination (R^2), and Standard Error of the Estimate (SEE) were used. For hypothesis testing, T-tests & Wilcoxon rank sum tests at a 95% confidence level were used for parametric and non-parametric data respectively. The hypothesis testing considered a null hypothesis stating, “There is No difference between MERRA and PMED VWS”, and an alternative hypothesis stated otherwise.

Data Sources for Distress Prediction. Different types of data were obtained from different sources as required for PMED pavement distress prediction. Data needed for PMED analysis includes traffic volumes, traffic adjustment factors, materials inputs, pavement profile/structure, and water table depth. Local Calibration factors for distress prediction models (Level 2) used in this research were obtained from the research conducted by the University of Tennessee Knoxville. The calibrated distress models included alligator cracking (bottom-up), longitudinal cracking (top-down), and rutting (Gong et. al. 2017). Top-down calibration factors were not adopted for this research because the latest PMED software version 2.6.1 used in this research had a new top-down prediction model that was not locally calibrated, hence default values were used for this model.

Level 2 traffic volume adjustment factors used in this research were obtained from research by conducted the University of Tennessee at Chattanooga. A linear traffic growth rate of 1.34 % was adopted for the state of Tennessee (Onyango et. al. 2019). Level 2 material properties and pavement profiles were obtained from LTPP InfoPave website and as provided by TDOT staff. In the case of missing data, the PMED default (Level 3) data were used.

The climatic data used in this research were obtained from three major sources: NARR climatic data was downloaded from the AASHTOWare Pavement ME Design official website. MERRA climatic data files were downloaded from the LTPP InfoPave website special for PMED analysis. Water table depth values (ft), considered as Level 3 data, were obtained from the National Water Information System, Mapper, which is an interactive USGS website that enables selection of existing test locations for ground water tables and other water related information.

RESULTS AND DISCUSSION

Results and discussion are presented here as per methodology described above. First the sensitivity analysis of EICM using 2^k factorial design was used to generate 32 climatic data files with high and low climatic inputs. Three LTPP sites were used in the sensitivity analysis to evaluate the sensitivity of predicted distresses to climatic inputs using the 32 climatic data files. Secondly, PMED VWS tool was used to create VWSs climatic data files using MERRA climatic data stations available in the state of Tennessee. Both MERRA and PMED VWSs climatic data files at the same location were used to predict pavement distresses. The comparison of the predicted distresses in general indicated that distresses predicted using PMED VWSs were significantly different from those predicted using MERRA climatic files at the same locations.

EICM Sensitivity Analysis. The 2^k factorial design was conducted to determine the sensitivity of climatic inputs on distress predictions using three LTPP sites (Figure 2). Since the design considered five ($k = 5$) climatic inputs, 32 (2^5) climatic files were generated with combinations of high and low values. The generated climatic files had a total length of 36.5 years of hourly climatic data, which was trimmed to match the NARR climatic data file length. All generated climatic files were then used in the PMED software as climatic input files to evaluate the distress predictions of the three LTPP sites (Table 1).

From the analysis, it was observed that all predicted distresses showed sensitivity to temperature changes. Thermal cracking was affected by temperature inputs only, other climatic inputs showed negligible effect. Wind speed inputs affected most of the distress predictions (second to air temperature). Permanent deformation and bottom-up cracking were affected by wind speed on all three sites. Variation of water table depth mostly affected total pavement rutting and terminal IRI, for all sites, which reflects subgrade failure due to excessive presence of water. LTPP site 47- 3104 was the most sensitive to water table depth input affecting total pavement rutting and terminal IRI predictions. This outcome is likely due to site 47-3104 having a thin AC surface layer and crushed stone base on an existing subgrade, which makes the structure more exposed to water table fluctuation effects. Relative humidity showed a negligible influence on all distress prediction results.

Various distresses showed sensitivity to a combination effect of the climatic inputs. The following is a summary of the interacting climatic inputs and the distresses common to the three LTPP sites. Temperature and wind speed affected AC permanent deformation, bottom-up, and top-down cracking. Temperature and water table depth affected terminal IRI, total pavement permanent deformation, and top-down cracking. Temperature and percent sunshine affected bottom-up cracking. Wind speed and percent sunshine affected AC permanent deformation.

From the sensitivity analysis, it was determined that temperature is the most sensitive climatic input, followed by wind speed. Relative humidity had a negligible effect on pavement distress predictions. The findings agree with other researchers (Ahmed et. al. 2005; Tighe et. al. 2008; Li et. al. 2013; Yang et. al. 2017).

Using the three LTPP sections with varying layer thicknesses, materials, and traffic conditions have shown that different pavement sections can be affected differently by climatic inputs. For example, the LTTP 47-3104 structure was mostly affected by water table depth inputs than the other two sites because of its layer structure (AC surface layer on crushed stone base and subgrade). From this observation, and the general climatic input sensitivity analysis, it is recommended for transportation agencies to carefully select climatic data files and depth of water table data for design and analysis since they have an influence on the pavement performance.

Performance of Virtual Weather Stations (VWSs). The comparative analysis of PMED created VWSs and MERRA climatic data files, was performed to evaluate the performance of PMED VWS creation tool. Eight MERRA stations were used to create a PMED VWS and generate climatic summaries at same location with an existing MERRA station. Forty-nine (49) PMED VWSs and forty-nine (49) MERRA climatic files were generated and used in the analysis. The comparative analysis performed included the climatic summaries and distresses predicted using the two climatic datasets on five LTPP sections.

Comparative Analysis of MERRA and VWSs Climatic Summaries. To check the viability of PMED generated VWSs it was thus important to compare these values to those of known stations (MERRA) at similar locations. A correlation analysis using R^2 compared the climatic summary output data of PMED VWSs and MERRA stations. Table 3 shows that mean annual precipitation values and mean annual number of freeze/thaw cycle values had a weak correlation. While mean annual air temperature, freezing index and number of wet days had a moderate correlation. The Standard Error of the Estimate (SEE) values showed freezing index, mean annual number of freeze/thaw cycles, and number of wet days with relatively higher values indicating a higher difference between PMED VWSs and MERRA climatic data sources. This is an indication that a difference in climatic data outputs can arise when VWSs created by the PMED software are used.

Table 3 Climatic Summaries Correlation and Hypothesis Testing

Climatic Summary	*R^2*	*SEE*	*P-value*
Mean annual air temperature (°F)	0.654 (Moderate)	1.6252	0.3373
Mean annual precipitation (in)	0.0554 (Very weak)	1.5751	0.5224
Freezing Index (°F - days)	0.6172 (Moderate)	50.2992	0.2111
Mean annual number of freeze/thaw cycles	0.5416 (Weak)	7.3403	0.0005**
Number of wet days	0.6912 (Moderate)	6.4962	2.2e-16**

*NOTE: ** refers to a 0.05 level of significance*

On hypothesis testing, it was observed that the climatic values from PMED VWSs created at identical location as MERRA stations had a significant difference ($p < 0.05$) on two out of the five climatic summary outputs. Even those that had no significant difference ($p > 0.05$) the correlations were moderate or weak (Table 3). Since eight existing MERRA stations were used to create a PMED VWS at the same location with an existing MERRA station (Figure 2), the expectation was, the created VWSs would produce statistically significant data with very strong or perfect correlation for all its outputs. Therefore, it was concluded from this study that PMED VWS creation tool does not in all cases create climatic summary outputs that are close to actual values (MERRA) at identical locations. This observation is crucial and important since the PMED software uses climatic summary outputs in pavement design and analysis. Further effects of these findings are explored when comparing the pavement distresses predicted using these climatic files.

Comparative Analysis of Predicted Distresses. Forty-nine (49) climatic data files from both MERRA and PMED VWSs were used in pavement distress predictions and their results were compared. Five LTPP pavement sections were used in this analysis, four flexible pavements, and one rigid pavement (Table 2). Correlation analysis (SEE and R^2) and hypothesis tests (T-test and Wilcoxon rank sum test) were used in the analysis of the predicted pavement distress outputs. For each LTPP pavement section, a total of ninety-eight (98) distress prediction runs were made with forty-nine (49) runs from each MERRA and PMED VWS stations at identical locations. To understand the normality of data, Q-Q plots were used as a tool on all predicted distress data sets.

For the rigid pavement section (LTPP site 47-602), general information as per Table 2, normality testing using Q-Q plots showed varying results on the predicted distresses. Terminal IRI followed a normal distribution while mean joint faulting, and JPCP transverse cracking did not follow a normal distribution. T-test was performed for the parametric terminal IRI pair, and Wilcoxon Rank Sum test was performed for both non-parametric mean joint faulting, and JPCP transverse cracking pairs. From the correlation analysis on distresses predicted using the MERRA and PMED VWSs climatic data files, all the three predicted distresses on a rigid pavement section showed a very weak correlation (R^2 values less than 0.5), which signifies a variation of values from the two compared groups (Table 4).

Hypothesis testing showed a significant difference when comparing MERRA, and PMED VWSs JPCP transverse cracking outputs (Table 4). From these results it can be concluded by accepting the alternative hypothesis that states, “there is a difference between MERRA, and PMED VWSs predicted JPCP transverse cracking outputs.” Terminal IRI and mean joint faulting had no significant difference between MERRA and PMED VWSs climate file inputs, at a 95% confidence level. This indicates that the use of PMED VWSs on rigid pavements in distress prediction has potential of producing results that are different from actual or expected results.

Table 4 Rigid Pavement Analysis

Climatic Summary	*R^2*	*SEE*	*P-value*
Terminal IRI	0.0791 (Very weak)	12.6702	0.0915
Mean joint faulting	0.0933 (Very weak)	0.0198	0.1935
JPCP transverse cracking	0.3781 (Very weak)	4.3480	0.0009**

*NOTE: ** refers to a 0.05 level of significance*

Flexible pavement analysis used four LTPP sites for distress prediction. Table 4 provides general information for each site, which form part of the inputs used in the PMED software for pavement distress predictions. For each of the four LTPP sites, six (6) distresses predicted using PMED VWSs, and MERRA climatic data files were used for the comparison. The six distresses included terminal IRI, total pavement permanent deformation, bottom-up cracking, thermal cracking, top-down cracking, and AC only permanent deformation.

Correlation analysis was used to understand the relationship (correlation) between the pavement distresses predicted using the MERRA and PMED VWSs climatic files. From the correlation analysis, a preliminary understanding of the compared data can be established.

Since MERRA and PMED VWS climatic data files were derived from identical locations, it was expected that the results will be statistically significant and have a very strong or perfect correlation. However, the correlation coefficient (R^2) results (Table 5 and Table 6) varied widely from perfect to very weak correlation for the six distresses. LTPP 47-3075 had very weak correlation for all six predicted distresses except one (top-down cracking). LTPP 47-3104 had three distresses with perfect correlation, however, thermal cracking and terminal IRI had very weak correlation and total pavement permanent deformation had weak correlation (Table 5). LTPP sites 47-B330 and 47-C3104 distresses had moderate to very weak correlation except for site 47-B330 which had one distress (top-down cracking) with perfect correlation (Table 6).

Table 5 Flexible Pavement Correlation Analysis for LTPP Sites 47-3075 and 47-3104

	LTPP 47-3075		*LTPP 47-3104*	
Climatic Summary	R^2	SEE	R^2	SEE
Terminal IRI	0.4347 (Very weak)	4.4922	0.2651 (Very weak)	3.6465
Permanent deformation – total pavement	0.2564 (Very weak)	0.0075	0.5146 (Weak)	0.0043
Bottom-up cracking	0.2270 (Very weak)	0.0107	1 (Perfect)	0
Thermal cracking	0.4878 (Very weak)	590.758	0.3411 (Very weak)	470.55
Top-down cracking	1(Perfect)	0	1 (Perfect)	0
Permanent deformation – AC only	0.2950 (Very weak)	0.0052	1 (Perfect)	0

From the correlation analysis the preliminary understanding of the predicted output groups has been established where a very weak correlation hinted the probability of existence of a large difference on predicted distresses, and on the other end, perfect correlation hinted identical predicted outputs (which was expected). To confirm the extent of the differences, hypothesis testing was conducted (Table 7). T-test was used for the data sets that followed a normal distribution, and Wilcoxson rank sum test was used for the non-parametric (not normally distributed) dataset.

As shown in Table 7 the predicted distresses, a significant difference ($p > 0.05$) was observed on AC permanent deformation prediction on three of the four LTPP sites (47-3075, 47-B330, and C330), LTPP 47-3075 bottom-up cracking, and LTPP 47-C330 total pavement permanent deformation values. The rest of the predicted results were statistically significant.

Table 6 Flexible Pavement Correlation Analysis for LTPP Sites 47-B330 and 47-C330

	LTPP 47-B330		*LTPP 47-C330*	
Climatic Summary	R^2	SEE	R^2	SEE
Terminal IRI	0.5961 (Weak)	4.4367	0.7145 (Moderate)	3.9435
Permanent deformation – total pavement	0.3023 (Very weak)	0.0076	0.2884 (Very weak)	0.0124
Bottom-up cracking	1.0e-10 (Very weak)	1.1e-15	0.1858 (Very weak)	2.0924
Thermal cracking	0.6228 (Moderate)	588.26	0.7068 (Moderate)	584.4
Top-down cracking	1 (Perfect)	1	0.1066 (Very weak)	0.0058
Permanent deformation – AC only	0.2782 (Very weak)	0.4717	0.3210 (Very weak)	0.0107

Table 7 Flexible Pavement Hypothesis Test P-Value Results for all Sites

Pavement Distresses	*LTPP 47-3075*	*LTPP 47-3104*	*LTPP 47-B330*	*LTPP 47-C330*
Terminal IRI	0.6544	0.6089	0.7304	0.4139
Permanent deformation – total pavement	0.0619	0.4038	0.0851	0.0234**
Bottom-up cracking	0.0329**	1	1	0.1404
Thermal cracking	0.2192	0.2698	0.2983	0.6162
Top-down cracking	1	1	1	0.4969
Permanent deformation – AC only	0.0306**	1	0.0235**	0.0445**

*NOTE: ** refers to a 0.05 level of significance*

Observing Tables 5 to 7, not all very weak correlated distresses had a significant difference on predicted distresses comparing MERRA and PMED VWSs (a low R^2 value may not necessarily lead to a small p-value) however, all distresses determined to have a significant difference, had very weak correlation. Significantly different distresses explains that PMED VWSs and MERRA did not produce the same output on the respective distresses as expected.

From these observations, it is recommended that the VWS function on PMED software be used with caution, knowing that the created station may contain errors, until the PMED VWS creation model is modified or updated. Instead, a single nearby NARR or MERRA weather station may be used. More results analysis and discussion can be obtained from the project final report (Onyango et. al. 2022).

CONCLUSION AND RECOMMENDATION

This paper evaluates the climatic data inputs for the state of Tennessee. The sensitivity of PMED EICM model and the PMED VWSs creation tool were analyzed. Sensitivity analysis used climatic files created using the 2^k factorial analysis and the PMED VWSs tool used MERRA climatic files to generate VWSs climatic files. However, the distresses predicted in this study were not compared to measured distresses on those sites due to unavailability of measured distresses on the respective sites. Therefore, the correlation and hypothesis testing of predicted distresses using generated climatic data sources was used. The latest PMED version 2.6.1, used during the research had an updated thermal cracking model (fracture model), which is not calibrated to suit Tennessee local design conditions. Therefore, thermal cracking predictions used default model calibration values available on the PMED software. From this study the following were observed:

1. PMED VWS did not create climatic data files and distress predictions that were similar to MERRA data files and distress predictions at the same locations as expected to ascertain the null hypothesis in all cases. Therefore, it was determined that using the PMED VWS may lead to erroneous results and faulty pavement design.
2. Virtual weather stations generated with the PMED software showed a significant difference on some distresses and some climatic data files when compared to existing MERRA stations at the same location.
3. Sensitivity analysis showed that PMED predicted distresses were mostly sensitive to temperature climatic input values than other climatic inputs, followed by wind speed. The depth of the water table is most sensitive in shallow pavement structures with a granular or unbound base course.
4. From the research findings it can be concluded that temperature, and wind speed are the climatic inputs that mostly affect pavement performance. On the other hand, depth of water table affects mostly pavements with unbound base layer. Therefore, careful consideration of climatic inputs is recommended by obtaining climatic files that represents the design site as close as possible, to minimize pavement failures and improve their performance.

Moreover, this study may benefit pavement design engineers on climate data selection. As it was revealed that the NARR VWS creation tool may result to erroneous VWS climate data, pavement engineers should consider using the nearest available weather station (NARR or MERRA) for climate data and avoid creating virtual weather stations unless the current VWS model is updated. Likewise, the depth of water table depth need to be carefully considered when designing and analyzing pavements using PMED software, as they have shown to be a sensitive input to predicted distresses, especially on pavements with unbound bases.

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