conduct local calibration. The Idaho Transportation Department (ITD) in cooperation with the University of Idaho developed a strategic plan that started back in 2009 to implement the mechanistic-empirical (ME) design approach using MEPDG software. The main focus of the implementation then was to establish a comprehensive material, traffic, and climatic database for the MEPDG. A series of research projects that covered various phases of development were conducted. Results are published in research reports RP193 (Bayomy et al. 2012), RP211A&B (Mallela et al. 2014) (Mallela et al. 2014), RP253 (Nassiri et al. 2017) and the latest one was RP268 (Bayomy et al. 2019), which was focused on the PCC calibration. This paper addresses the development of the local calibration factors for PCC rigid pavement performance models incorporated in the latest PMED software, version 2.5.3. However, the calibration was limited to the Jointed Plain Concrete Pavement (JPCP) since there was no sites available for the Continuous Reinforced Concrete Pavement (CRCP). Hence, this study refers only to the JPCP.

OBJECTIVES

The objectives of this study were:

- Verify the nationally-calibrated PMED distress models for rigid pavements using the AASHTOWare Pavement ME Design Software v2.5.3 to Idaho local conditions,
- Develop local calibration factors of the PMED performance models for rigid pavements in Idaho, and
- Validate the locally calibrated factors.

PREVIOUS STUDIES

This part of the study presents a review of the AASHTOWare Pavement ME Design (PMED) implementation efforts for rigid pavements conducted by different state DOTs. Several state transportation agencies have planned to implement mechanistic-empirical guide for their local conditions. However, few states have not yet developed plans for the implementation. According to a recent survey conducted by the AASTHTO Pavement ME National User Group, it was found that 14 states have already implemented the PMED for rigid pavements (Applied Pavement Technology, Inc 2017). The remaining states are involved in conducting the calibration and implementation of the PMED for rigid pavements within the coming five years.

For instance, among the implemented states that performed studies on local calibration for rigid pavements are Washington (Li et al. 2005), Ohio (Mallela et al. 2009), Utah (Darter et al. 2009), Oregon (Williams et al. 2013), Iowa (Ceylan et al. 2015), Virginia (Smith et al. 2015).

CALIBRATION METHOD

The calibration and validation of the performance models were conducted following the AASHTO Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide

(AASHTO 2010) and the Road Map for Implementing the AASHTO Pavement ME Design Software for the Idaho Transportation Department, ITD project RP211A (Mallela et al. 2014)

The term calibration here refers to the method to minimize the average differences between the measured and the predicted data. In that process, this study focused to eliminate bias and reduce the standard error of the estimate. Therefore, the precision of the performance models would improve. To validate the developed calibration factors, the process is tested on different pavement sites. A hypothesis test was checked to identify whether any significant differences existed between the predicted results and the measured data. In order to accomplish this, a paired t-test was conducted at 95% confidence interval ($\alpha = 0.05$) and the hypothesis test was performed. The hypothesis can be explained as follows:

- Null Hypothesis (H0): Mean measured distress or IRI = mean predicted distress or IRI.
- Alternative Hypothesis (HA): Mean measured distress or IRI ≠ mean predicted distress or IRI.

Bias is assessed based on P-value. Any value of P-value greater than 0.05 implies that there is no significant difference between the measured and predicted value, and the null hypothesis can be accepted. Therefore, the local calibration is not required and the globally calibrated coefficients are robust and yield reasonable predictions. Otherwise, P-value less than 0.05 indicates there are significant differences. As a result, reject the null hypothesis.

SELECTION of PAVEMENT SITES

The roadmap for PMED implementation in Idaho (Mallela et al. 2014) and the AASHTO guideline of local calibration (AASHTO 2010) recommended that pavement sites to be selected for calibration should have adequate design, construction and maintenance history and documented records of performance data. It is suggested that if available, the distress or IRI should represent at least 10-years of historical data. Based on these recommendations, a matrix for experimental design was developed as shown in Table 1.

In collaboration with ITD engineers, researchers were able to identify pavement sections that can represent the most valid and possible pavement conditions in Idaho road network and some road sections from the surrounding states. Pavement sections selected covered the cells marked with check mark (✓) in Table 1. A total number of 40 rigid pavement sections were identified. Figure 1 depicts the selected project sites from five different districts of Idaho and some sites from adjacent states. Even though the entire matrix was not filled, the selected number of sites were sufficient to cover the various types of JPCP across Idaho road network. It is to be noted here that the selected pavement sites from neighboring states represent same climatic zone and traffic pattern as Idaho local roads.

As per AASHTO local calibration guide, 80% of the pavement sites (32 sites) were randomly selected to develop the local calibration factors and the remaining 20% (8 sites) were set aside for the validation.

Table 1 Experimental Sampling Matrix for PCC Pavement Site Selection

JPCP Joints	Volume of Truck Traffic	Soil Type	PCC Pavement Base	
			Unbound Base	Stabilized Base
With Dowels	Low	Coarse Grained	✓	X
		Low Plasticity	X	X
		High Plasticity	✓	✓
	High	Coarse Grained	X	X
		Low Plasticity	X	✓
		High Plasticity	X	✓
Without Dowels	Low	Coarse Grained	X	X
		Low Plasticity	✓	✓
		High Plasticity	X	✓

✓ Indicates sites were available
X Indicates sites were not available

DATA COLLECTION

Based on the experience of the research team with the data available for in-service pavement sections in Idaho, level 1 ME input data was difficult to obtain for most of the required inputs. Thus, levels 2 and 3 input data were used when level 1 data was unavailable. ITD research project report RP193 (Bayomy et al. 2012) provided required traffic inputs at different input levels, where ITD research project RP253 (Nassiri et al. 2017) was the main source for the characterization of the PCC material properties at different hierarchical levels. The collected data for the calibration can be divided into two main categories, input data (e.g., traffic, pavement structure, layer properties) and performance data. Accumulating all collected data, this study developed a performance database for the selected rigid pavements. While running the software, missing inputs were considered following the Idaho PMED User Guide (Mallela et al. 2014). Anomalies and outliers were tried to identify following time series plot of each of the distress type.

Joint Faulting Model

Joint faulting is the cause of vertical pavement displacement across the joint as a result of pumping. Pumping occurs due to repeated loading of wheels, curling and warping (AASHTO 2008). Joint faulting may vary from joint to another. It is predicted in a month to month basis incremental method in the PMED. Detailed descriptions of the joint faulting model are documented in the AASHTO Manual of Practice (AASHTO 2015). There are eight calibration factors related to the joint faulting model such as C1, C2, C3, C4, C5, C6, C7 and C8 (see equations 5-20a to 5-24d in AASHTO 2015).

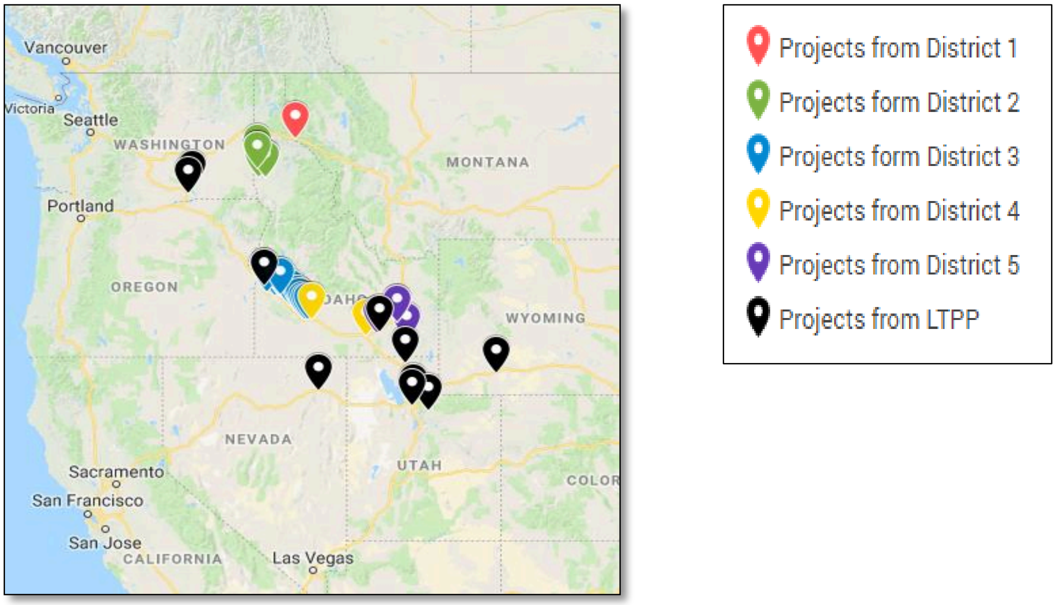


Figure 1. Selected rigid pavement sections.

RIGID PCC PAVEMENT PERFORMANCE MODELS

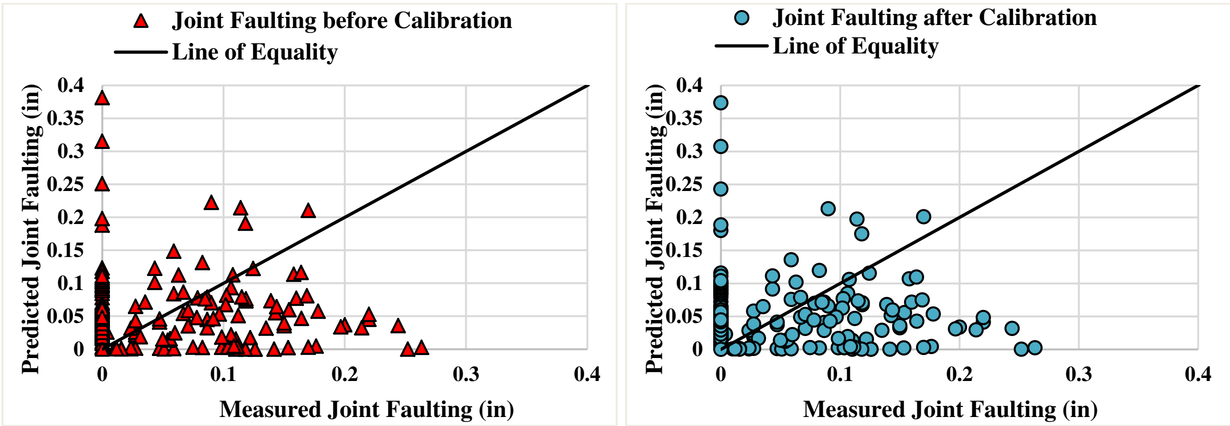
Calibration

To verify the faulting model, at first the AASHTOWare Pavement ME Design software was run with the national calibration factors. The verification results revealed that the null hypothesis at 95% confidence interval was failed to reject based on P-value > 0.05. Also, bias was found low. However, this study attempted to reduce the standard error further.

According to the AASHTO local calibration guide, only calibration parameter (C1) associated with the faulting model was considered to reduce both bias and standard error. After several trials, the simulation results provided lower bias close to almost zero and the standard error of the estimate was also reduced lower than 0.1 inch. The null hypothesis was still failed to reject. Table 2 presents the statistical summary results for the faulting model after adjusting the factor. Figure 2 shows the graphical representation of before and after calibration effort of the mean joint faulting model.

Table 2 Summary Results of the Joint Faulting Model Using National and Local Factors

Calibration Factor		**N**	**Bias**	**Standard Error**	**P-value (Paired t-test)**
National	C1 (**0.595**)	178	-0.725	0.1	0.285
Local	C1 (**0.516**)		0.002	0.09	0.499



(a) (b)

Figure 2. Predicted versus measured joint faulting (a) before calibration and (b) after calibration.

Validation

Six projects were run as a batch to validate the local calibration factor of the joint faulting model. The simulation results revealed lower bias and standard error of the estimate with the support of accepting the null hypothesis at 95% confidence interval. Table 3 lists the summary of the statistical results for the faulting model validation. Figure 3 shows a good agreement between the measured and predicted joint faulting data for the validation set.

Table 3 Summary Results for the Joint Faulting Model Validation

Calibration Factor	N	Bias, $e_{r(mean)}$	Standard Error, S_e	P-value (Paired t-test)
C1 (**0.516**)	33	-0.214	0.078	0.32

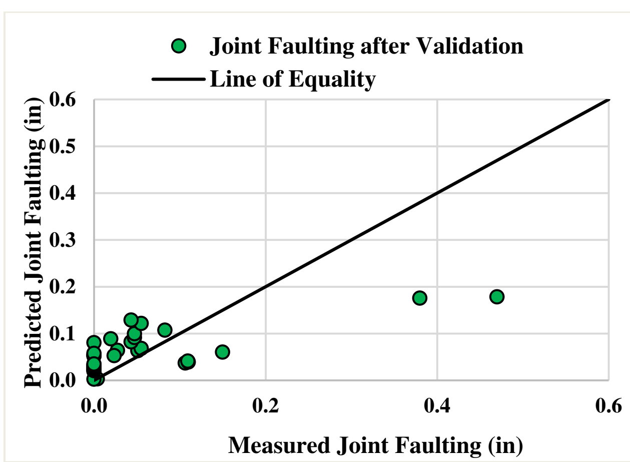


Figure 3. Validation of the calibrated joint faulting model.

Transverse Slab Cracking Model

Transverse cracking is considered as one of the prominent distresses that occur in rigid pavements. It appears as straight cracks that spread-out normal to the centerline of the pavement. Such cracks are initiated either at the top or bottom of the pavement and propagates on the other direction. Transverse slab cracking depends on traffic loading, climate condition, material characteristics, and design criteria (NCHRP 2004). Detailed descriptions of the transverse slab cracking model are documented in the AASHTO Manual of Practice (AASHTO 2015). There are four calibration factors related to the transverse cracking model such as C1, C2, C4 and C5 (see equations 5-16 to 5-18 in AASHTO 2015).

Calibration

Using the national calibration factors, the transverse cracking model verification for Idaho local conditions revealed that the null hypothesis was rejected with a significant amount of bias and standard error of the estimate. Therefore, local calibration was necessary.

Local calibration guide recommends to adjust C1 or C4 – term for the transverse cracking model in order to reduce bias as per the AASHTO local calibration guide. After several trials for different sets of C1, the optimized value provided lower bias. Although after adjusting C1, the standard error of the estimate was found in the reasonable range; further adjustment was tried considering the recommended calibration factors C2 and C5. However, changing C2 and C5 terms, the validation was not accepted in terms of the null hypothesis because there was a poor correlation between the measured and the predicted cracking. Therefore, in this case, reducing bias was recommended only without going further to reduce the standard error. Hence, only C1 was optimized in this study. The statistical summary results for the transverse cracking model after local calibration are presented in Table 4. Figure 4 shows the transverse cracking before and after the calibration effort.

Validation

Validation of transverse cracking model could not be achieved as most of the projects that were selected for validation have little to no cracking.

Table 4 Summary Results of the Transverse Cracking Model Using National and Local Factors

Calibration Factor		**N**	**Bias**	**Standard Error**	**P-value (Paired t-test)**
National	C1 (**2**)	196	-767.6	18.9	0.002
Local	C1 (**2.366**)		-69.02	7.6	0.258

JPCP IRI Prediction Model

The International Roughness Index (IRI) is a parameter describes the smoothness and ride quality of a pavement. It is dependent on the other two type of distress prediction models alongside with site factor and spalling. Detailed descriptions of the IRI model are documented in the AASHTO Manual of Practice (AASHTO 2015).

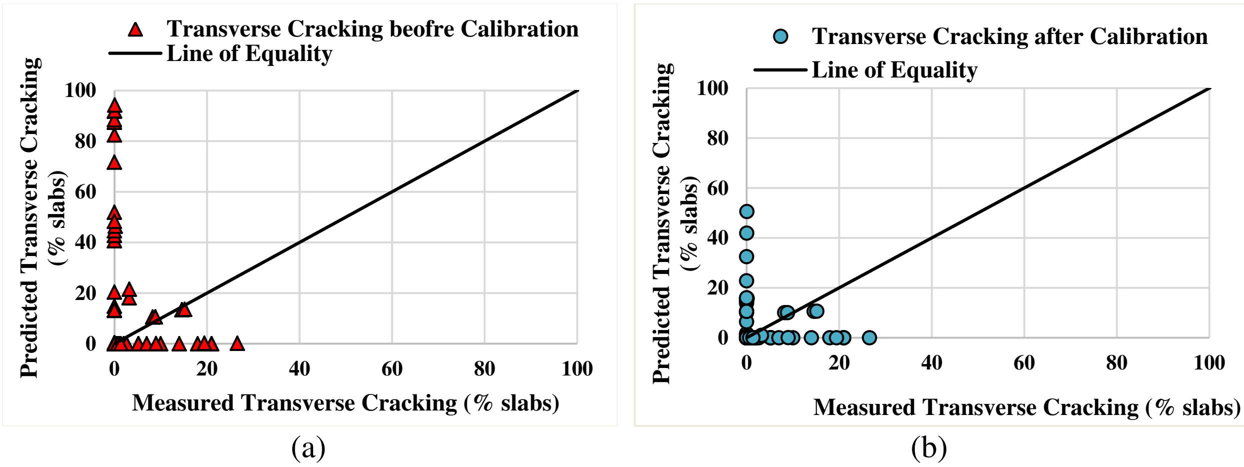


Figure 4. Predicted versus measured transverse cracking (a) before calibration and (b) after calibration.

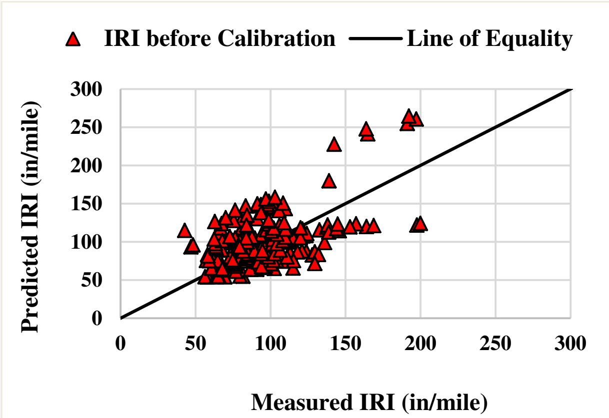
Calibration

The verification of the IRI model with the national calibration factors showed significant amount of bias and standard error of the estimate. Also, the P-value was found lower than 0.05, which implied to reject the null hypothesis at 95% confidence interval. Hence, local calibration was attempted to reduce bias and standard error.

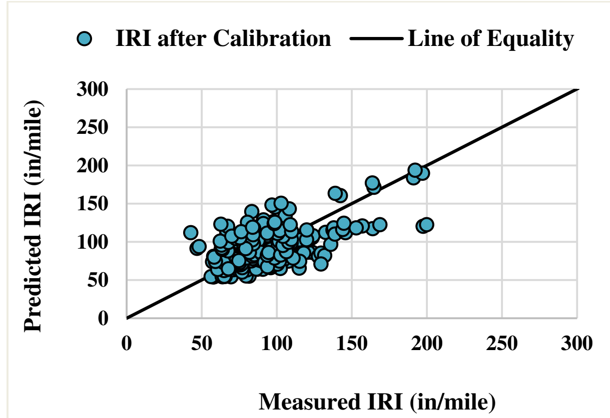
In order to reduce the significant amount of bias and the standard error of the estimate, the calibration factors J4 and J1 were adjusted, respectively. After several trials for J4, bias significantly reduced from -1233.6 to 0.2. Also, the adjustment for J1 reduced the standard error of the estimate. Table 5 presents the summary statistical results for the IRI model after local calibration. Figure 5 illustrates before and after calibration effort of the IRI model. It can be observed that the data points got relatively clustered around the line of equality after the local calibration.

Table 5 Summary Results of the IRI Model Using National and Local Factors

Calibration Factors		**N**	**Bias**	**Standard Error**	**P-value (Paired t-test)**
National	J1 (**0.8203**)	213	-1233.6	31.1	0.003
	J4 (**25.24**)				
Local	J1 (**0.845**)		0.2	25.3	0.5
	J4 (**28.24**)				



(a)



(b)

Figure 5 Predicted versus measured IRI (a) before calibration and (b) after calibration

Validation

The validation effort of the IRI model also supported calibration results. Validation of the IRI model showed comparatively lower standard error and the null hypothesis was failed to reject at 95% confidence interval. Table 6 highlights the summary results for the IRI model after validation. Figure 6 shows the validation plot of the predicted versus measured IRI.

Table 6 Summary Results for the IRI Model Validation

Calibration Factors	**N**	**Bias, $e_{r(mean)}$**	**Standard Error, S_e**	**P-value (Paired t-test)**
J1 (**0.845**)	59	-11.55	21.04	0.485
J4 (**28.24**)				

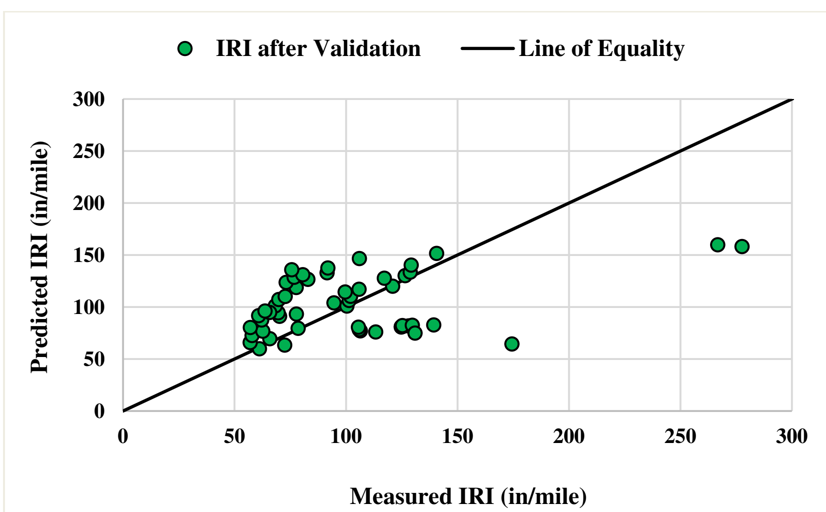


Figure 6. Validation of the calibrated JPCP IRI model.

SUMMARY AND CONCLUSIONS

The main goal of this research was to determine the calibration factors for JPCP prediction models for Idaho local conditions. ITD's current practice of maintaining records of construction history (as built structures) was sufficient to provide traffic, layers' thicknesses, and material properties inputs. A total number of 40 rigid pavement sections were selected for this study to improve the PMED models' prediction accuracy through local calibration in Idaho. The AASHTOWare Pavement ME Design Software version 2.5.3 was utilized for this calibration effort. All required inputs were collected at different hierarchical levels from ITD records and previous research projects RP193 (Bayomy et al. 2012) and RP253 (Nassiri et al. 2017). In this study, which was conducted under RP268 (Bayomy et al. 2019), the JPCP prediction models were calibrated to improve prediction accuracy. Results showed that overall the local calibration factors reduced bias and standard error of the estimate. Among them the IRI model seemed to be the most promising and the transverse cracking was the least. This statement was also supported through validation. Table 7 highlights the developed calibration factors in Idaho for the JPCP performance models incorporated in the PMED software, v2.5.3.

Table 7 Summary of Calibration Factors before and after Local Calibration for Rigid Pavements in Idaho

Performance Model	Calibration Parameters	National Factors (as per PMED V2.5.3)	Local Factors for Idaho
Joint Faulting	C1	0.595	**0.516**
Transverse Slab Cracking	C1	2	**2.366**
IRI	J1	0.8203	**0.845**
	J4	25.24	**28.24**

RECOMMENDATIONS

- The JPCP faulting and IRI performance models have good prediction with the field data. However, the JPCP transverse cracking showed poor correlation. Thus, further calibration for this model is recommended in the future once more data points are acquired.
- It is expected that the JPCP performance models would be nationally re-calibrated in near future considering the MERRA climate database. Therefore, it is recommended to verify these developed factors, and if needed, conduct further calibration.
- If at all possible, it is recommended that the pavement distress survey in the Idaho Transportation Asset Management System (TAMS) follow the LTPP distress manual to be consistent with the PMED reporting units. This will assist the distress data survey a great deal.
- Further refinement of the ITD traffic database is recommended to include more recent data from the WIM stations across the state. This will provide more accurate measurements of traffic counts and classifications.

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