AN EXPERIMENTAL DESIGN BASED EVALUATION OF SENSITIVITIES OF MECHANISTIC – EMPIRICAL PAVEMENT DESIGN GUIDE (MEPDG) PREDICTIONS FOR ONTARIO'S LOCAL CALIBRATION

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ABSTRACT

A Mechanistic-Empirical Pavement Design Guide (MEPDG) was developed under NCHRP Project 1-37A to address the shortcomings of empirical pavement design methods. The MEPDG uses mechanistic-empirical models to analyze the impacts of traffic, climate, materials and pavement structure and to predict long term performances of pavement. The MEPDG software (AASHTOWare Pavement M-E) use a three-level hierarchical input scheme to predict pavement performance in terms of terminal International Roughness Index (IRI), Permanent Deformation , Total Cracking (Reflective and Alligator), Asphalt Concrete (AC) Thermal Fracture, AC Bottom-Up Fatigue Cracking, and AC Top-Down Fatigue Cracking. Different highway agencies are taking initiatives to adopt MEPDG based pavement design and performance prediction by calibrating the prediction models for their local conditions. However, these inputs with different levels of accuracy may have significant impact on performance prediction and thereby on accuracy of local calibration. This study focuses on the sensitivity of the input parameters of MEPDG distresses to identify the effect of the accuracy level of input parameters based on orthogonal experimental design. A local sensitivity analysis is carried out by using Ontario's default value and historical performance record of Ontario highway system. Sensitive input parameters are evaluated through a multiple regression analysis for respective distresses. It is found that terminal IRI is sensitive to initial IRI, initial permanent deformation, and milled thickness in asphalt layer; permanent deformation is sensitive to initial permanent deformation, subgrade resilient modulus, and traffic load; top down fatigue cracking is sensitive to AC effective binder content, and AC air voids. Based on the independent influence of these sensitive inputs, the requirement of accuracy level will be identified for MEPDG design.

Key Words: Performance Prediction, MEPDG, Sensitivity, Input Parameters

1. INTRODUCTION

A Mechanistic-Empirical Pavement Design Guide (MEPDG) was developed in the USA under NCHRP 1-37A in 2004 to address the shortcomings of empirical pavement design methods [1; 2].

This MEPDG approach is being adapted by the majority of highway agencies in North America, to incorporate all possible local factors for traffic, pavement materials and environmental conditions. MEPDG based distress prediction model incorporates local traffic, pavement materials and environmental conditions using the mechanistic empirical (M-E) models which will predict the distresses in a realistic way. Local calibration can further improve accurate prediction incorporating local conditions. The MEPDG distress models are developed by using Long Term Pavement Performance (LTPP) data which include pavement sections from many states in the USA and some provinces in Canada. These models are required to be adjusted for local conditions using local traffic, climate, material specification and construction activity. For calibration of the distress prediction models of Ontario highway systems, the historical pavement performance record from the Ministry of Transportation, Ontario (MTO) Pavement Management System (PMS-2) database, project specific information from the project documents and default values from the AASHTOWare Pavement M-E Design Interim Report' [3] are used are used as input parameters. The MEPDG based recent software, AASHTOWare Pavement M-E (version-2) allows input data at three level of accuracy. The local calibration guide [4] suggested using the same accuracy levels for future design. However, it would be ineffective to put effort for obtaining accuracy of level 1 for all input parameters. For this reason, a sensitivity analysis is essential to identify important input parameters which have significant impacts on MEPDG distresses.

Several sensitivity analyses have been conducted to address and understand the influential input parameters of the MEPDG process. NCHRP [5] analyzed five pavement types: new hot-mix asphalt (HMA), HMA over a stiff foundation, new jointed plain concrete pavement (JPCP), JPCP over a stiff foundation, and new continuously reinforced concrete pavement (CRCP). In this study a normalized sensitivity index was adopted as the quantitative metric. NCHRP [6] also carried out global sensitivity analyses for five pavement types under five climate conditions and three traffic levels. Retherford and McDonald [7] developed Gaussian process (GP) surrogate models for each relevant distress mode. The GP models were used for sensitivity analysis and design optimization. Graves and Mahboub [8] carried out a sampling-based global sensitivity analysis to identify influential variables of the parameters. Orobio and Zaniewski [9] conducted space-filling computer experiments with latin hypercube sampling, standardized regression coefficients, and Gaussian stochastic processes to categorize the relative importance of the material inputs in MEPDG for flexible pavement. Moya and Prozzi [10] conducted a case study of a pavement structure by considering several pavement design variables as random. Sensitivity of rutting and other distresses to input parameters (rutting sensitive to thin layer) are presented for different countries [11]. The impact of accuracy of traffic input parameters for forecasting traffic loads for pavement design are also analyzed [12]. MEPDG key input parameters (hot-mix asphalt, base nominal aggregate size, climate location, HMA thickness, AADTT, subgrade strength, truck traffic category, construction season, and binder grade are analyzed and impact on major distresses are discussed using local sensitivity [13]. Siraj et al [14] verified the accuracy of the predicted performance from the MEPDG software for the state of New Jersey for level 2 and level 3 inputs. Guclu et al. [15] carried out sensitivity for JPCP and the design input parameters were categorized as being most sensitive, moderately sensitive, or least sensitive in terms of their relative effect on distresses .Hall and Beam [16] assessed the relative sensitivity of the models used in the M-E design guide to inputs relating to portland cement concrete materials of JPCP.

The objective of this study is to find the effect of input parameters on MEPDG distresses to identify the requirement of accuracy level for precise prediction and local calibration. For statistical validity of investigations, an experimental design based approach is used. Since, orthogonal design consists of uncorrelated or independent contrasts, economic run size and it ensures fairness in comparison, this method is considered for experimental design. A multiple linear regression model is also used for screening the input variables, which has the similar assumption of independent variables as of orthogonal design. The normalized values (dividing by maximum value of corresponding variable) of the variables of the regression model readily give the relative influences of different input parameters on MEPDG distresses.

2. ACCURACY LEVELS OF INPUT DATA

The input data required for the AASHTOWare Pavement M-E analysis are mainly of traffic, climate, and pavement structure along with materials' properties. This software allows input data at three level of accuracy (AASHTO 2014), as described below.

Level 1: Input parameters are the most accurate. Generally, site-specific and laboratory data or results of actual field testing are considered as level 1 input. For example, laboratory test values of dynamic modulus, and nonlinear resilient modulus are considered as level 1 for materials' properties. For traffic, site specific traffic data (AADTT, lane number, traffic growth factor etc.) are considered as level 1 input.

Level 2: Generally the input parameters estimated from mathematical correlations or regression equations, or the calculated from other site specific data are considered as level 2. For example, resilient modulus estimated from CBR values is considered as level 2 input.

Level 3: Input parameters are the least accurate. They are normally default values or based on best estimates. Generally, national level or regional level values are used.

The level of accuracy and required quality of the input parameters are recommended by AASHOTO guide for the local calibration of the MEPDG Guide (AASHTO 2010).The input data are mainly collected from the Ministry of Transportation, Ontario (MTO) Pavement Management System (PMS-2) database.

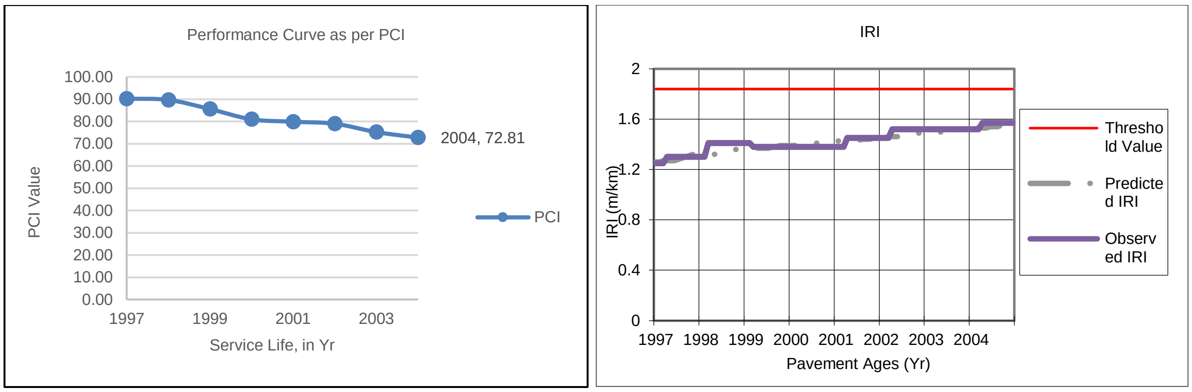
3. EXPERIMENTAL DESIGN

A sensitivity analysis will be conducted to investigate relative influences of input parameters. Generally, sensitivity analysis designs are categorized into three classes: screening methods, local sensitivity analysis and global sensitivity analysis [8].

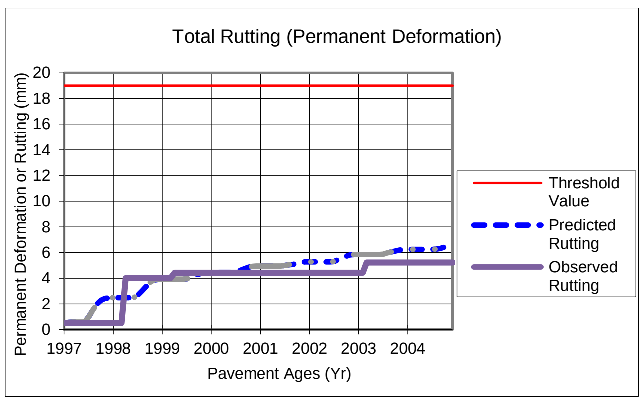
Screening method focuses on the hierarchical ranking according to importance of input factors, rather than providing change in quantity or impact on output. Local sensitivity focuses on the local impact of the input factors on the performance of output. This method is carried out by varying certain factor keeping other input factors as constant. Global sensitivity analysis is carried out varying the input parameter over the entire input parameters.

The input parameters may have the independent and/or combined effects on distress outputs. Since, the independent influence of an input parameter defines the accuracy level necessary for that input parameter, local sensitivity will be suitable the method. Local sensitivity will identify the requirement of higher level of accuracy which is significant step for local calibration especially for selecting the properties of local materials and traffic. Moreover, orthogonal based design will investigate independent influence since the experimental sets are independent. So, for the local calibration an orthogonal design based experimental method will be suitable for this study.

The base section (overlay design of highway section with a performance cycle of 8 years, three overlay layers, sub-base: granular A, base: granular B1, subgrade: sandy silt) is selected after analyzing the performances, if the predicted distresses were close to the observed performances. Figure 1 shows the performance curve for PCI, IRI and permanent deformation of the base case road section.



(a) (b)



(c)

Figure 1: (a) Performance Curve of Base Case as per PCI; (b) Comparison of Observed IRI to Predicted IRI; (c) Comparison of Observed to Predicted Permanent Deformation

For each input parameter, specific ranges from the base case are selected based on the nature of the input parameters. The ranges are selected mainly based on the historical performance record (existing condition, traffic information, subgrade type, layer thickness etc.) of pavement sections from the MTO-PMS-2; Ontario's default parameters (axle per truck; axle load spectra; and default materials properties for specific AC, base and subgrade etc.) from the 'Ontario's Default Parameters for AASHTOWare Pavement M-E Design- Interim Report' [3], and soil properties and specifications from the Pavement Asset Design and Management Guide (PADMG) [17]. Table 1 summarizes the range of change in input values that are considered for the analysis.

Table 1: Summary of the Ranges of Input Parameters

Input Category	Input Parameters	Change in Input Parameters Comparing to Base Value	Remarks
Existing Condition	Initial IRI	-40% to + 40%	Considering the target value (1.9 m/km for freeways and 2.3 m/km for Arterials) of IRI for Ontario, the range of change in initial IRI of base case is selected. A total of 9 levels are considered from -40% to +40% with 10% increment.
	Initial Permanent Deformation	-50% to + 50%	Considering the target value of Permanent deformation of 19 mm for Ontario, the range of change in existing permanent deformation of base case is selected. A total of 11 levels are considered from -50% to +50% with 10% increment.
	Milled Thickness	40 mm to maximum 100 mm	From the historical record, 40 mm to 100 mm milled thickness are found. The ranges are selected from 40 mm to 100 mm with increment of 20 mm. A total of 4 levels are considered.
Traffic	Annual Average Daily Truck Traffic (AADTT)	-50% to + 50%	From the historical record of AADTT of all road sections, the ranges are selected from 700 to 2109 with increment of 10%. A total of 11 levels are considered.
	Percent Truck in Design Lane	-25% to + 11%	From the default value of percent of truck in design lane based on the number of lanes in one direction and AADT in both direction, the ranges are selected from 60% to 100% with increment of 10%. A total of 9 levels are considered.
	Traffic Growth Factor	-50% to + 50%	From the annual historical record of AADT, the compound growth factors are calculated for all road sections. The ranges are selected from 1.65% to 4.94% with increment of 10% which are -50% to +50% of base case value. A total of 11 levels are considered.
	Operational Speed	-40% to + 40%	Considering the speed limit of highways, the ranges are selected from min 60 km to max 140 km with increment of 10% which are -40% to +40% of base case value. A total of 9 levels are considered.
	Axle per Truck	Default Value of Southern Ontario, Northern Ontario and Ontario 2006	Default value of Southern Ontario, Northern Ontario and Ontario 2006 value are considered as 3 independent variables with level 1.
	Truck Traffic Class (TTC)	TTC type 1 to 17	Types of TTC are defined based on 17 combination of %bus, % single trailer truck, and % multi trailer truck. Each type is considered as an independent variable with level of 1.
	Axle Load Spectra	Default Value of Southern Ontario, Northern Ontario, Ontario 2006 and Software Default Value	Based on default value of Southern Ontario, Northern Ontario and Ontario 2006 value. In addition, software default value is considered and a total of 4 independent variables each with single level are considered.
Climate	Water Table Depth	-60% to + 60%	Based on Ontario default value of 6.1 m, ranges are selected from 2.44 to 9.76 m. A total of 7 levels are considered from -60% to +60% with a 20% increment.

Input Category	Input Parameters	Change in Input Parameters Comparing to Base Value	Remarks
AC Layer and Properties	Top Layer Thickness	-49% to + 50%	Considering the minimum thickness requirement of the software of 25.4 mm and historical record of average overlay top layer thickness, the range is selected from 25.4 mm to 75 mm. A total of 11 levels ranging -49% to +50% of base case with an increment of 10%, are considered.
	Unit Weight	-23% to +3%	Based on Ontario default value of volumetric properties of AC, the ranges are selected from 1940 to 2596 KG/M3. A total of 6 levels are considered from -23% to +3%.
	Effective Binder Content	-59.7% to +20%	Based on Ontario default value of volumetric properties of AC, effective binder content ranges upto 14.88 %. A total of 5 levels are considered from -59.7% to +20% of base value 12.70%.
	Air Voids	-40% to +60%	Based on Ontario default value of volumetric properties of AC for selected sections, air voids range from 2.4% to 5%. A total of 6 levels are considered from -40% to +60% of base value 4%.
	Reference Temperature	-30% to +23%	Ontario default value of reference temperature is 21.1 degree Celsius However, reference temperature is varied from -30% to 23% of 21.1 degree Celsius. A total of 5 levels are considered.
	Thermal Conductivity	-30% to +120%	Ontario default value of thermal conductivity 1.16 watt/meter-Kelvin. However, a total of 6 levels are considered ranging from -30 to +120% of 1.16 watt/meter-Kelvin.
	Heat Capacity	-40% to +40%	Ontario default value of heat capacity is 963 joule/kg-Kelvin. However, a total of 5 levels are considered ranging from -40% to +40% of 963 joule/kg-Kelvin.
	Asphalt Binder Penetration Grade	Software default value: 40-50, and 60-70; Southern Ontario: 85-100; NE Ontario: 120-150; and NW Ontario: 200-300	Default value for Southern Ontario is 85-100; for NE Ontario is 120-150; for NW Ontario is 200-300. In addition, 40-50 and 60-70 are also considered. A total of 5 subcategories are considered as independent variables with level of 1.
Base Layer and Materials	Base Layer Thickness	-40% to +40%	Minimum thickness of base layer for Ontario is 150 mm. Maximum range is considered based on the existing layer thickness of road sections. AASHTO has also guidelines for minimum base layer based on Equivalent Single Axle Load (ESAL). These AASHTO recommended value is also considered here. A total of 9 levels are considered ranging from -40% to +40% of base value 150 mm.
	Resilient Modulus of Base Layer	-60% to +60%	Based on the MR values for types of base materials, the range from 100 MPa to 400 MPa is selected and a total of 7 levels are considered.
Subgrade Materials	Resilient Modulus of Subgrade Soil	-40% to +40%	Based on the corresponding resilient modulus of available subgrade soil types, the range from 25 MPa to 40 MPa is selected. A total of 7 levels are considered for the selected range of -40% to +40% of 35 MPa base value with a increment of 10%.

After observing the effects on specific distresses of all input parameters, a total of 46 independent variables (including sub-categories of TTC, axle load spectra, and Asphalt binder penetration grade as independent variables) are considered for the analysis. The levels of the parameter values are found to be different for each independent input variable since the ranges of the levels are different. Finally, an experimental design is used to identify a total of 171 experimental sets considering 46 independent variables. The variables are normalized so that the results can be compared readily.

4. RESULT ANALYSIS

For these experiments, distresses are predicted by using the AASHTOWare Pavement M-E. The predicted values of each distress are compared to the corresponding target values of failure which are shown in Table 2. The rate of changes in output distresses are compared. The rate of changes in output distresses are plotted for 46 input parameters to compare to each other. For example, Table 3 shows the changes in distresses due to change in AADTT, and Figure 2 shows the changes in the major sensitive distresses for changes in AC top layer thickness. Finally, changes in all output distresses for change in input parameters are summarized in Table 4.

Table 2: MEPDG Outputs Distresses and Target Value of Failure in Ontario

Distress Type	Target Value for Freeway	Target Value for Arterial
Terminal IRI (m/km)	1.9	2.3
Permanent Deformation - Total Pavement (mm)	19	19
Total Cracking (Reflective + Alligator) (percent)	100	100
AC Thermal Fracture (m/km)	190	190
AC Bottom-Up Fatigue Cracking (percent)	10	20
AC Top-Down Fatigue Cracking (m/km)	380	380
Permanent Deformation - AC only (mm)	6	6

After comparing the range of change in output distresses with respect to range of change in input parameters, the input parameters that have individual substantial effects on distresses are screened and listed in Table 5.

Finally, multiple linear regression analysis is carried out for each distress separately. In the regression model only statistically significant effects (with the hypothesis of *t statistics > 1.96)* are considered. The experimental design is rearranged with only the inputs that have significant effects and multiple regression is carried out again for rearranged sample. In this way, significant sensitive input parameters are found. The parameters are ranked based on the higher value of coefficients. Finally, sensitive input parameters for each distress are summarized in Table 6.

Table 3: Changes in Distress for respective Change in AADTT

Change in Input AADTT		**Change in Output Distresses**											
AADTT changed by %	**Changed AADTT**	**Terminal IRI (m/km)**	**Change in Terminal IRI (%)**	**Permanent Deformation - Total pavement (mm)**	**Change in Permanent Deformation Total (%)**	**Total Cracking (Reflective + Alligator) (%)**	**AC Thermal Fracture (m/km)**	**Change in AC Thermal Fracture (%)**	**AC Bottom-Up Fatigue Cracking (%)**	**AC Top-Down Fatigue Cracking (m/km)**	**Change in AC Top-Down Fatigue Cracking (%)**	**Permanent Deformation - AC only (mm)**	**Change in Permanent Deformation - AC only (%)**
-50%	703	1.52	-2.56%	5.12	-21.59%	28.32	14.64	0.00%	0	0.01	-66.67%	1.75	-31.37%
-40.%	844	1.53	-1.92%	5.46	-16.39%	28.32	14.64	0.00%	0	0.02	-33.33%	1.93	-24.31%
-30%	984	1.54	-1.28%	5.76	-11.79%	28.32	14.64	0.00%	0	0.02	-33.33%	2.10	-17.65%
-20%	1125	1.54	-1.28%	6.04	-7.50%	28.32	14.64	0.00%	0	0.02	-33.33%	2.26	-11.37%
-10%	1265	1.55	-0.64%	6.29	-3.68%	28.32	14.64	0.00%	0	0.03	0.00%	2.41	-5.49%
Base	1406	1.56	0.00%	6.53	0.00%	28.32	14.64	0.00%	0	0.03	0.00%	2.55	0.00%
10.00%	1547	1.56	0.00%	6.76	3.52%	28.32	14.64	0.00%	0	0.04	33.33%	2.68	5.10%
20.00%	1687	1.57	0.64%	6.97	6.74%	28.32	14.64	0.00%	0	0.04	33.33%	2.81	10.20%
30.00%	1828	1.57	0.64%	7.17	9.80%	28.32	14.64	0.00%	0	0.05	66.67%	2.93	14.90%
40.00%	1968	1.58	1.28%	7.35	12.56%	28.32	14.64	0.00%	0	0.06	100.00%	3.05	19.61%
50.00%	2109	1.58	1.28%	7.53	15.31%	28.32	14.64	0.00%	0	0.06	100.00%	3.16	23.92%

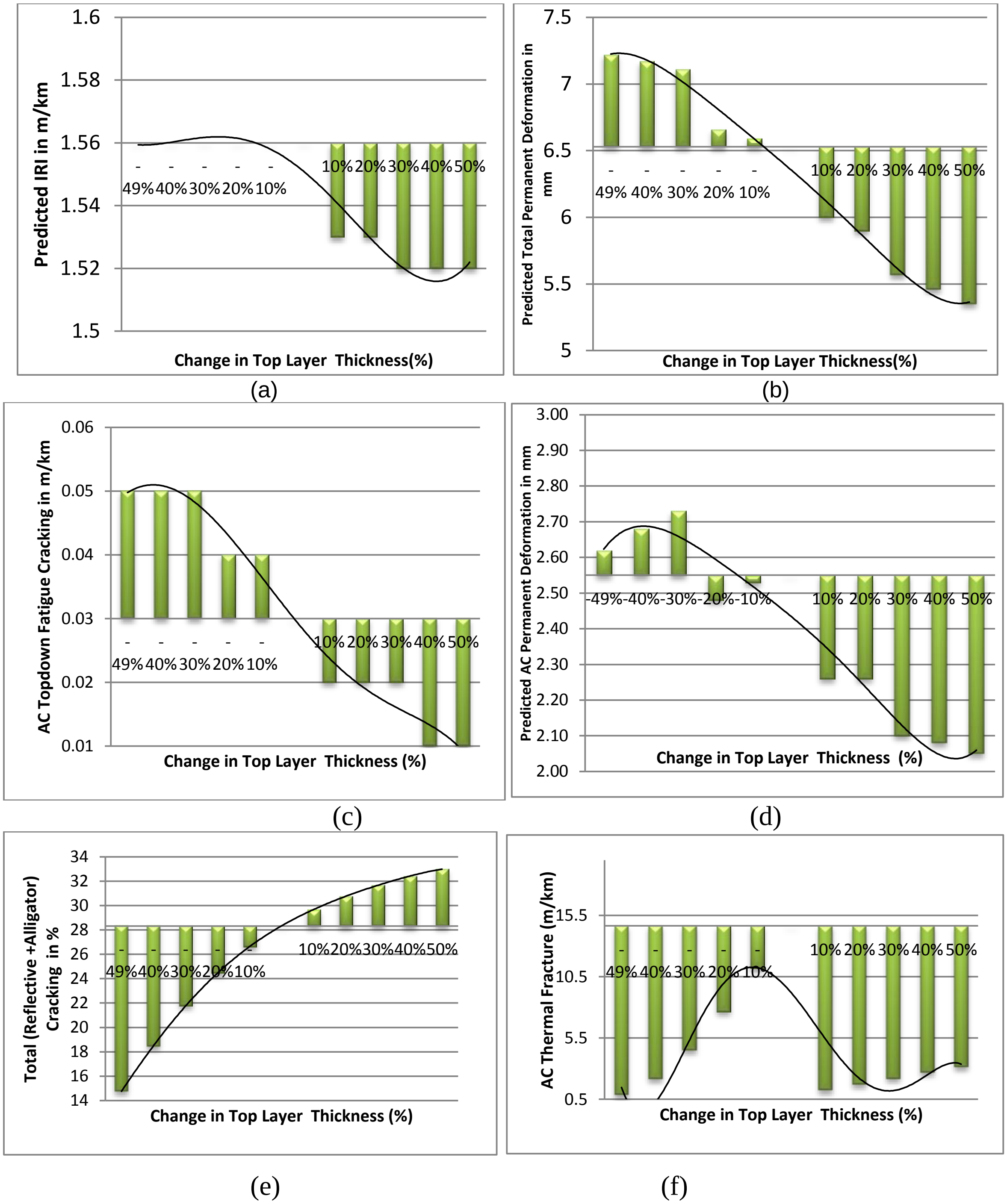


Figure 2: Sensitivity of (a) Terminal IRI; (b) Total Permanent Deformation (c) AC Top down Fatigue Cracking; (d) AC Permanent Deformation, (e) Total (Reflective +Alligator) Cracking, (f) AC Thermal Fracture, with Respect to Top Layer Thickness

Table 4: Summary of Changes in MEPDG Distresses for Change in Major Input Parameters

Input Parameters	**Change in Input Parameters Comparing to Base Value**	**Change in Output Distresses**						
		Terminal IRI	**Total Permanent Deformation**	**AC Permanent Deformation**	**Total Cracking (Reflective + Alligator)**	**AC Thermal Fracture**	**AC bottom-up fatigue cracking**	**AC top-down fatigue cracking**
Initial IRI	-40% to + 40%	-32% to + 32%	0% to + 15%	0% to + 15%	0%	0%	0%	0%
Initial Permanent Deformation	-50% to + 50%	+4.5% to -2.56%	+48% to - 22%	+7% to -5.5%	0%	0%	0%	0%
Milled Thickness	40 mm to maximum 100 mm	+0.64% to +1.28%	+7% to +15%	+11% to +26%	0%	0%	0%	0%
AADTT	-50% to + 50%	-2.56% to +1.28%	-22% to +15%	-31% to +24%	0%	0%	0%	-66% to +100%
Percent Truck in Design Lane	-25% to + 11%	-1.28% to +0%	-9% to +4%	-14% to +5%	0%	0%	0%	-33% to +33%
Traffic Growth Factor	-50% to + 50%	-0.64% to +0%	-2% to +2%	-3% to +3%	0%	0%	0%	0% to +33%
Operational Speed	-40% to + 40%	+0.64% to -0.64%	+0.64% to - 3.83%	+8.6% to -5.5%	0%	0%	0%	33% to +0%
Axle per Truck	3 Types	0%	+0.15% to 0.31%	+0% to -1.81%	0%	0%	0%	0%
Truck Traffic Class (TTC)	TTC type 1 to 17	-0.64% to -3.21%	-1.23% to - 27.57%	Varies from - 1.26% to - 26.27%; for Type 3 +0.98%; for Type 5 1.96%	0%	0%	0%	-33% to - 66%
Axle Load Spectra	4 Types	-0.64% to + 0.64%	-0.92% to +5.51%	1.18% to -7.06%	0%	0%	0%	+33% to 0%
Water Table Depth	-60% to + 60%	0%	0%	0%	0%	0%	0%	0%
Top Layer Thickness	-49% to + 50%	0.0% to - 2.56%	10.57% to - 18.07%	-23% to -94%	-48% to +17%	2.75% to -19.6%	0%	+66% to - 66%
Unit Weight	-23% to +3%	0%	0.92% to - 0.15%	+2.35% to - 0.39%	0%	+44% to -6.32%	0%	0%
Effective Binder Content	-59.7% to +20%	14.74% to - 0.64%	-9.04% to +1.53%	-12.16% to +1.96%	0%	+2512% to -74%, failure found for -40% to -59.7% change in input	0%	+1633.33% to -33.33%; values are lower than the failure criteria 380 m/km

Input Parameters	Change in Input Parameters Comparing to Base Value	Change in Output Distresses						
		Terminal IRI	Total Permanent Deformation	AC Permanent Deformation	Total Cracking (Reflective + Alligator)	AC Thermal Fracture	AC bottom-up fatigue cracking	AC top-down fatigue cracking
Air Voids	-40% to +60%	-0.64% to +5.13%	-1.53% to +3.68%	-2.35% to +4.71%	0%	140% for -40% change in input; varies -19.19% to 836.75%for -20% to +60% of input change	0%	-66.67% to +666.67%; the values are lower than failure criteria of 380m/km
Reference Temperature	-30% to +23%	0%	0%	0%	0%	0%	0%	0%
Thermal Conductivity	-30% to +120%	-0.64% to 0%	-2.30% to +3.83%	-3.92% to +7.06%	0%	-18.24% to +18.78%	0%	0% to +33.33%
Heat Capacity	-40% to +40%	+0.64% to -0.64%	+1.53% to -1.53%	+3.53% to -3.53%	0%	+89.48% to -48.77%	0%	0%
Asphalt Binder Penetration Grade	5 types	+8.33% to 0%	-7.50% to +10.41%	-12.16% to +18.04%	0% to +0.35%	+1495% to -100%; Failure found for 40-50 and 60-70;	0%	0%
Base Layer Thickness	-40% to +40%	0% to -0.64%	4.29% to -1.07%	-4.71% to +1.57%	0%	+17.96% to +3.42%	0%	0%
Resilient Modulus of Base Layer	-60% to +60%	+0.64% to -0.64%	+6.28% to -3.52%	-3.14% to +1.57%	0%	0%	0%	+33.33% to 0%
Resilient Modulus of Subgrade Soil	-40% to +40%	+2.56% to -1.28%	+29.86% to -12.40%	-2.35% to -1.18%	0%	0%	0%	0% to +33.33%

Table 5: Summary of Sensitive Input Parameters as per Range of Change in Output Distresses

Output Distress	Sensitive Input Parameters as per Change in Output Distresses
Terminal IRI	1. Initial IRI, 2. Initial Permanent Deformation, 3 Milled Thickness, 4. Percent of Truck in Design Lane, 5. AADTT, 6. Traffic Growth Factor, 7. Operational Speed, 8. Axle per Truck, 9. TTC, 10. Axle Load Spectra, 11. AC Effective Binder Content, Air Voids, AC Top Layer Thickness
Total Permanent Deformation	1. Initial Permanent Deformation, 2. Subgrade Resilient Modulus, 3. TTC, 4. AADTT, 5. AC Top Layer Thickness, 6. Asphalt Binder Penetration Grade, 7. Milled Thickness, Initial IRI, 8. Percent Truck in Design Lane, 9. % Effective Binder Content, 10. Resilient Modulus of Base Layer, 11. Base Layer Thickness, 13. Operational Speed
AC Permanent Deformation	1. AC Top Layer Thickness, 2.AADTT, 3. TTC Class, 4. Percent Truck in Design Lane, 5. Milled Thickness, 6. Initial IRI, 7. Effective Binder Content, 8. Binder Penetration Grade, 9. Operational Speed, 10. Axle Load Spectra, 11. AC Thermal Conductivity, 12. Initial Permanent Deformation, 13. Air Voids, 14. Base Layer Thickness, 15 AC Heat Capacity

Output Distress	Sensitive Input Parameters as per Change in Output Distresses
Total Cracking (Reflective + Alligator)	1. AC Top Layer Thickness, 2. Asphalt Binder Penetration Grade.
AC Thermal Fracture	1. Effective Binder Content, 2. AC Binder Penetration Grade, 3. AC Air Voids, 4. AC Heat Capacity, 5. AC Unit wt, 6. AC Top Layer Thickness, 7. AC Thermal Conductivity, 8. Base Thickness
AC Top-Down Fatigue Cracking	1. Effective Binder Content, 2.AC Air Voids, 3. AADTT, 4. TTC, AC Top Layer Thickness; 5. Percent Truck in Design Lane, 6. Subgrade Resilient Modulus, 7. AC Thermal Conductivity, Traffic Growth Factor, Axle Load Spectra, and Resilient Modulus of Base Layer

Table 6: Input Parameters as per Sensitivity Ranking for MEPDG Distresses

Distress	Input Parameter as per Sensitivity Ranking
Terminal IRI	1. Initial IRI, 2. AC Air Voids, 3. AC Binder Penetration Grade, 4. Milled Thickness, 4. AC Top Layer Thickness, 5. Initial Permanent Deformation, 6. AC Effective Binder Content
Total Permanent Deformation	1. Initial Permanent Deformation, 2. Subgrade Resilient Modulus, 3. AADTT, 4. AC Top Layer Thickness, 5. Percent Truck in Design Lane, 6.TTC, 7. Milled Thickness
AC Permanent Deformation	1. Percent Truck in Design Lane, 2.AC Top Layer Thickness, 3. TTC, 4. Milled Thickness, 5. Initial Permanent Deformation, 6. AC Binder Penetration Grade
Total Cracking (Reflective + Alligator)	AC Top Layer Thickness
AC Thermal Fracture	1. Effective Binder Content, 2. AC Binder Penetration Grade, 3. AC Air Voids
AC Top-Down Fatigue Cracking	1. AC Effective Binder Content, 2. AC Air Voids, 3. AADTT, 4. AC Top Layer Thickness

5. CONCLUSIONS

This study is mainly focused on the identification of individual effects of independent input parameters on MEPDG distresses. The relative influence of input parameters are required to identify the requirements of high level of accuracy of inputs for precise prediction and calibration of MEPDG distresses.

For statistical validity of investigations, an orthogonal experimental design based approach is used. Orthogonal design is considered as the results are used for estimating a multiple linear regression model. Since Local sensitivity focuses on the local impact of the input factors on the performance of output, this process is carried out by varying certain input keeping other input parameters constant. Based on a wide range of changes in output distresses with respect to range of change in input parameters, the input parameters with individual substantial effects on distresses are listed. The relative influences of different input parameters are found from the normalized values of the variables of the regression model of each MEPDG distress. To identify statistically significant sensitive parameters, multiple linear regression analysis is carried out. Sensitive input parameters are screened and ranked with the hypothesis of *t statistics > 1.96;* and the higher value of coefficients respectively.

Finally, it is found that terminal IRI is sensitive to initial IRI, AC air voids, AC binder penetration grade, and milled thickness. Total permanent deformation is sensitive to initial permanent deformation, subgrade resilient modulus, AADTT, AC top layer thickness, percent truck in design lane, TTC, and milled thickness. Permanent deformation in AC layer is sensitive to percent truck in design lane, AC top layer thickness, TTC, milled thickness, initial permanent deformation, and AC binder penetration grade. For total cracking (reflective + alligator), sensitivity of only AC top layer thickness is proven to be statistically significant. Sensitivity of effective binder content, AC binder penetration grade, and AC Air Voids are proven to be statistically significant for AC Thermal Fracture. Similarly, AC Top-Down Fatigue Cracking is found to be significant sensitive to AC effective binder content, AC air voids, AADTT, and AC top layer thickness. However, no sensitive input parameters are found for AC Bottom-Up Fatigue Cracking for the experimental sample. Therefore, further investigation is required for AC Bottom-Up Fatigue Cracking.

Based on these identified sensitive input parameters, the accuracy level of major inputs of specific distress are to be improved for realistic prediction and precise local calibration of MEPDG distresses. The flexibility ranges of input parameters can also be selected based on this sensitivity analysis for economic pavement design and future research.

The effort for obtaining high accuracy level of only sensitive input parameters rather than all input parameters will be more efficient and economical. Laboratory tests of pavement sections can be carried out for the specific properties only. For example, only AC air voids, AC binder penetration grade, top layer thickness and AC effective binder contents are to be investigated to get level 1 accuracy for precise prediction of terminal IRI. Similarly, subgrade resilient modulus are to be investigated for prediction of permanent deformation. Vehicles' surveys for specific AADT, percent truck in design lane, TTC type are to be conducted for prediction of permanent deformation. Since from the analysis specific sensitive input properties are found for respective distresses, it will be more efficient to get higher accuracy level of these properties through laboratory tests or investigations. Future pavement design will also be efficient and economic based on the higher accuracy level of the specific inputs. The local calibration will be precise, realistic and efficient. Therefore, future prediction of distresses will be improved which will ensure efficient future pavement management systems.

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