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DEVELOPMENT OF ROUGHNESS PREDICTION MODELS FOR RIGID PAVEMENTS USING LTPP DATABASE

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Outline

- I. Introduction
- II. Review of Existing Models
- III. Database Preparation
- IV. Analysis of Existing Models
- V. Development of Tentative Roughness Models
- VI. Conclusions

I. Introduction

Background and Objectives

- Predictive models used in pavement design, evaluation, rehabilitation, & management activities
- Evolves from purely empirical toward mechanistic-empirical approaches in the proposed MEPDG (DG2002)
- Focus on predicting roughness of rigid pavements using the LTPP database (www.datapave.com)

II. Review of Existing Models

- SHRP-P-393

Pavement Types	IRI Prediction Models
JPCP (Dowelled)	$IRI = 105.9236 + 159.1279 * AGE / KSTATIC + 2.1669 * JTSPACE - 7.1274 * THICK + 13.4955 * EDGESUP$ $Statistics: N = 21, R^2 = 0.548, SEE = 19.06$
JPCP (Non-Dowelled)	$IRI = 38.8523 + 12.8886 * CESAL + 0.2217 * FT + 1.4979 * PRECIP - 10.9625 * BASE - 13.6880 * SUBGRADE$ $Statistics: N = 28, R^2 = 0.644, SEE = 31.29$
JRCP	$IRI = -141.3723 + 0.8488 * AGE + 0.3469 * PRECIP + 1387.9594 / KSTATIC + 21.2432 * THICK + 15.0920 * EDGESUP$ $Statistics: N = 32, R^2 = 0.782, SEE = 9.86$
CRCP	$IRI = 262.0480 + 1.4706 * CESAL - 2.9432 * THICK - 232.2973 * PSTEEL - 29.7949 * WIDENED - 16.8235 * SUBGRADE$ $Statistics: N = 42, R^2 = 0.546, SEE = 17.1$

NCHRP Project 20-50(8/13)

Pavement Types	IRI Prediction Models
JPCP(Dowelled)	$IRI_t = 0.12284 + 0.94229(IRI_0) + 0.05009(Time) - 0.00733(Time \times f_t)$ Section effects standard deviation=0.26, SEE=0.11, No. Section=53
JPCP (Non-Dowelled)	$IRI_{Last} = -0.33172 + 1.15383(IRI_{First}) + 0.00436(KESAL/THICK) + 0.00418(\Delta Time \times MC_{Subg}) - 0.00178(\Delta Time \times TEMP)$ Section effects standard deviation=0.26, SEE=0.18, No. Section=63
JRCP	$Log_e(IRI_t) = -0.1875633 + 0.3967905(IRI_0) + 0.0000081(KESAL) + 0.0003266(Time \times MC) + 0.0000002(Time \times E_c)$ Section effects standard deviation=0.15, SEE=0.05, No. Section=52
CRCP (Wet-Freeze)	$IRI_t = -0.4963 + 0.0064(Wet.Days) + 0.0001(E_c / f_t) + 0.0054(SG200) + 0.0124(Time)$ Section effects standard deviation=0.44, SEE=0.08, No. Section=39
CRCP (Wet-Non-Freeze)	$IRI_t = 2.1952 + 0.0076(Days32) - 2.015(PSTEEL) + 0.0042(Time)$ Section effects standard deviation=0.35, SEE=0.08, No. Section=34

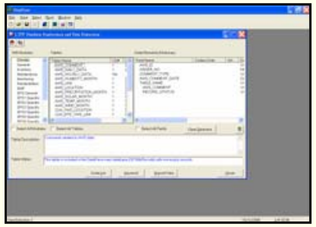
- **The Proposed MEPDG (DG2002) (NCHRP 1-37A)**

Pavement Types	IRI Prediction Models
JPCP	$IRI = IRI_I + C1 \times CRK + C2 \times SPALL + C3 \times TFAULT + C4 \times SF$ $C1 = 0.8203, C2 = 0.4417, C3 = 1.4929, C4 = 25.24$ Statistics: R^2=0.60, SEE=27.3, N=183 (Before Calibration)
CRCP	$IRI = IRI_I + C1 \times PO + C2 \times SF$ $C1 = 3.15, C2 = 28.35$ Statistics: R^2=0.60, SEE=14.6, N=94 (Before Calibration)

- **Site Factor** $SF = AGE\,(1 + 0.556 * FI)\,(1 + P200) * 10^{-6}$
- **No prediction model was proposed for JRCP pavements**
- **Key distress is determined in an incremental manner using more complex Axle Load Spectra (ALS) concept**

III. Database Preparation

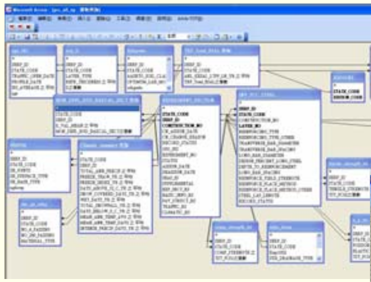
- LTPP GPS-3 (JPCP), GPS-4 (JRCP), & GPS-5 (CRCP)



DataPave 3.0

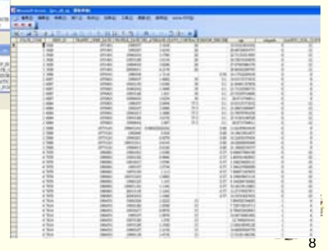
DataPave Online (Standard Release 18.0)

1. Retrieval of Required Data

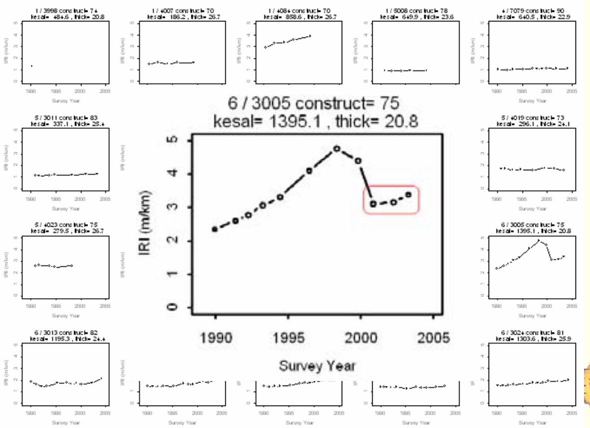


- IMS Modules(/Tables/Data Elements):
  - Climatic
  - General
  - Inventory
  - Maintenance
  - Monitoring
  - Rehabilitation
  - Testing
  - Traffic

Existing models 10~15 items,
DG2002 45~50 items

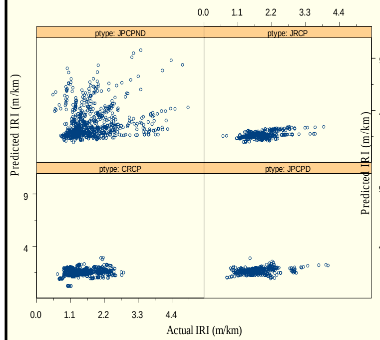


2. Graphical Representation & Data Cleaning

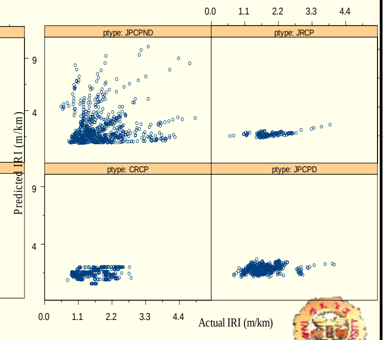


IV. Analysis of Existing Models

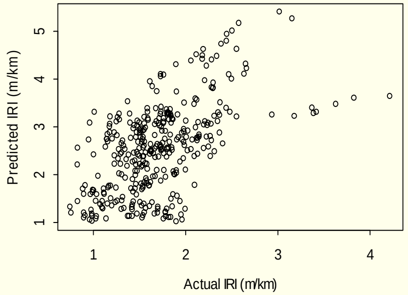
- SHRP P-393



- NCHRP Project 20-50(8/13)

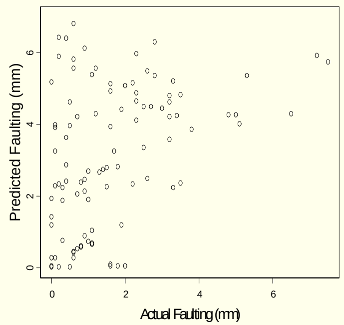


- **The Proposed MEPDG (DG2002) (NCHRP 1-37A)**

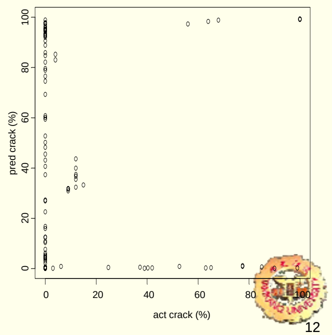


- Since the adequacy of IRI predictions is heavily relied on the accuracy of distress predictions, knowledge of initial IRI, and site factor adjustment, further study on clarifying this discrepancy is warranted.

- Faulting (DG2002)
  - Randomly selected 23 JPCP sections (n=98)



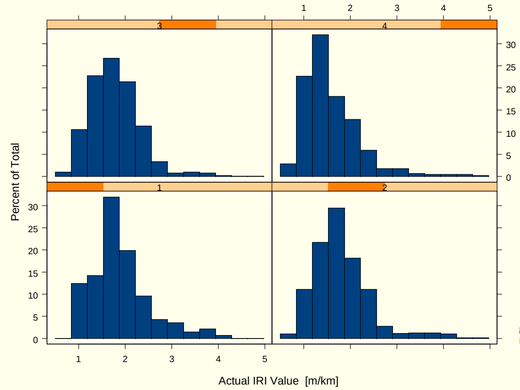
- Trans. Cracking (DG2002)
  - Randomly selected 22 JPCP sections (n=102)



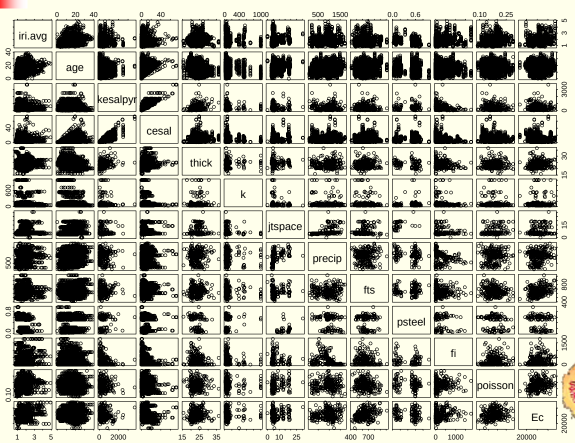
- Even though the use of an incremental approach and more complicated Axle Load Spectra (ALS) concept seems to be a logical approach, the integration of which with monthly or seasonal environmental factors such as humidity and temperature differentials often resulted in more variations in the predictions of joint faulting due to many uncertainties involved

V. Development of Tentative Roughness Models

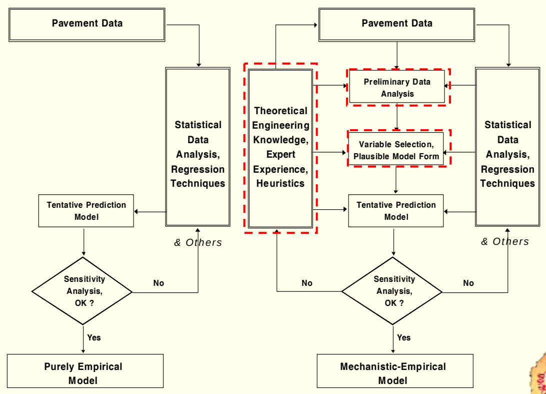
1. Preliminary Analysis (Univariate Data Analysis)



2. Bivariate and Multivariate Analysis



3. Model Development Using Purely Empirical or Mechanistic-Empirical Concept



(Ref: Lee, 1993)

4. Preliminary Models Using GLM

- Exploratory data analysis has indicated that the normality assumption with random errors and constant variance using conventional regression techniques might not be appropriate
- Without assuming the error distribution of the response variable, generalized linear model (GLM) along with quasi-likelihood estimation method was adopted

$$g(E(Y \mid x)) = g(\mu) = \beta_0 + \sum_{i=1}^{p} \beta_i x_i = \eta(x)$$

5. Improved Models Using Additional Modern Regression Techniques

General Predictive Modeling Procedures:

- Generalized Additive Models (GAM)

$$g(E(Y \mid x)) = g(\mu) = \alpha + \sum_{i=1}^{p} f_i(x_i) = \eta(x) \qquad \mathrm{var}(Y) = \phi V(\mu)$$

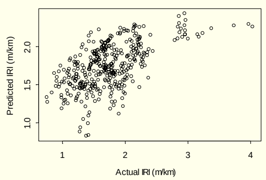
- Box-Cox (1964) Power Transformation
- Striving to find a monotonic power transformation function with reasonable physical interpretations
- Fitting a tentative GLM model using quasi-likelihood estimation method, i.e., quasi(link="log", var = "mu")

6. Tentative Prediction Models

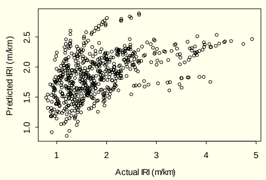
Pavement Types	IRI Prediction Models
JPCP (Dowelled)	$IRI = 0.4712 + 0.01733*age + 267.7*\frac{1}{kstat^2} + 5.736*\frac{1}{jtspace^2} + 0.1668*\log_{10}(cesal) + 0.0004158*precip + 0.1004*bt - 0.1809*subgrade + 0.2473*widened$ Statistics: R^2=0.35, SEE=0.41, N=380
JPCP (Non-Dowelled)	$IRI = 0.3701 + 0.2758*\sqrt{age} + 5.5953*\frac{1}{kstat} - 8.3323*\frac{1}{jtspace^2} - 304.1814*\frac{1}{thick^2} + 0.0529*FT^2 + 0.2985*\log_{10} precip$ Statistics: R^2=0.231, SEE=0.681, N=605
JRCP	$IRI = -0.554 + 0.1978*\sqrt{age} + 168.3167*\frac{1}{kstat^2} + 0.0021*jtspace^{1.5} + 0.0015*thick^2 + 0.3166*\frac{precip}{1000} - 0.528*\log_{10}(1+psteel) + 0.431*\mathrm{edgesup} + 0.0837*subgrade$ Statistics: R^2=0.4, SEE=0.34, N=416
CRCP	$IRI = 1.9568 + 0.1158*\sqrt{age} - 112.3738*\frac{1}{thick^2} - 0.2423\log_{10}(cesal) + 0.0001*FT^{1.5} + 0.4333*\log_{10} precip - 2.3863*\sqrt{psteel} + 0.1046*subgrade - 0.183*widened$ Statistics: R^2=0.14, SEE=0.44, N=537

7. Goodness of the Proposed Models

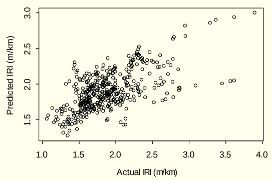
(a) JPCP (dowelled)



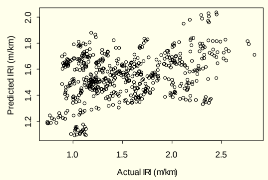
(b) JPCP (non-dowelled)



(c) JRCP



(d) CRCP



VI. Conclusions

- The results of existing IRI model predictions from SHRP P-393 and NCHRP 20-50(8/13) were not very favorable
- For some unknown reasons, the MEPDG software could not be executed for several randomly selected sections
- Even though the IRI prediction accuracy of the MEPDG (DG2002) appeared to be reasonable, the results of a similar study for the prediction of joint faulting and transverse cracking was found to be inadequate
- Since the adequacy of IRI predictions is heavily relied on the accuracy of distress predictions, knowledge of initial IRI, and site factor adjustment, further study on clarifying this discrepancy is warranted

- GLM, GAM, & quasi-likelihood estimation method were adopted
- By eliminating insignificant and inappropriate parameters repeatedly, the resulting model includes age, kstatic, jtspace, cesal, precip, bt, subgrade, widened, thick, FT, psteel, and edgesup for predicting IRI
- Conducted goodness of fit and sensitivity analysis study
  - However, large variability was still observable in the models, especially for the JPCP (non-dowelled) and CRCP predictions
  - the effect of slab thickness does not agree with general perceptions that the increase in slab thickness will result in the decrease in roughness
  - One possible explanation can be that initial roughness may be higher for thicker pavements due to construction problems
- Further improvements are possible and recommended

Questions?

THANKS FOR YOUR ATTENTION