Development of Faulting Prediction Models for Rigid Pavements Using LTPP Database

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Outline

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 faulting of JCP pavements using the LTPP database (www.datapave.com)

II. Review of Existing Models (1/2)

- SHRP-P-393

$$FAULTD = CESAL^{0.25} * \Big[0.0238 + 0.0006 * \left(\frac{JTSPACE}{10}\right)^2 + 0.0037 * \left(\frac{100}{KSTATIC}\right)^2 + 0.0039 * \left(\frac{AGE}{10}\right)^2 - 0.0037 * EDGESUP - 0.0218 * DOWEL$$

$$FAULTND = CESAL^{0.25} * \Big[-0.07575 + 0.0251 * \sqrt{AGE} + 0.0013 * \left(\frac{PRECIP}{10}\right)^2 + 0.0012 * \left(FI * \frac{PRECIP}{1000}\right) - 0.0378 * DRAIN\Big]$$

- AASHTO 1998

$$FAULTD = CESAL^{0.25} * [0.0628 - 0.0628 * C_d + 0.3673 * 10^{-8} * BSTRESS^2 + 0.4116 * 10^{-5} * JTSPACE^2 + 0.7466 * 10^{-9} * FI^2 * PRECIP^{0.5} - 0.009503 * BASE - 0.01917 * WIDENLANE + 0.0009217 * AGE]$$

$$FAULTND = CESAL^{0.25} * [0.2347 - 0.1516 * C_d - 0.00025 * h_{PCC}^2 / JTSPACE^{0.25} - 0.0115 * BASE + 0.7784 * 10^{-7} * FI^{1.5} * PRECIP^{0.25} - 0.002478 * DAYS90^{0.5} - 0.0415 * WIDENLANE]$$

II. Review of Existing Models (2/2)

- **The Proposed MEPDG (DG2002) (NCHRP 1-37A)**
  - **Faulting is determined in an incremental manner using more complex Axle Load Spectra (ALS) concept**

$$Fault_m = \sum_{i=1}^{m} \Delta Fault_i$$

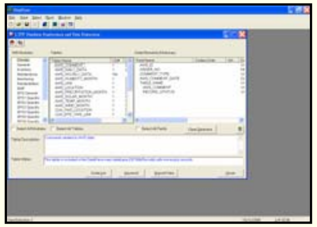
$$\Delta Fault_i = C_{34} * (FAULTMAX_{i-1} - Fault_{i-1})^2 * DE_i$$

$$FAULTMAX_i = FAULTMAX_0 + C_7 * \sum_{j=0}^{m} DE_j * Log\left(1 + C_5 * 5^{EROD}\right)^{C_6}$$

$$FAULTMAX_0 = C_{12} * \delta_{curling} * \left[Log\left(1 + C_5 * 5^{EROD}\right) * Log\left(\frac{P_{200} * WetDays}{P_s}\right)\right]^{C_6}$$

III. Database Preparation

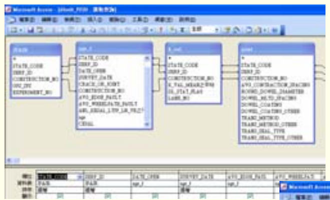
- LTPP GPS-3 (JPCP) & GPS-4 (JRCP)



DataPave 3.0

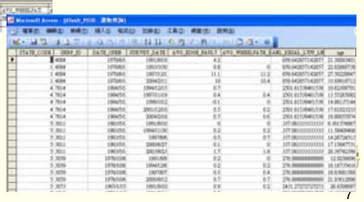
DataPave Online (Standard Release 18.0)

1. Retrieval of Required Data

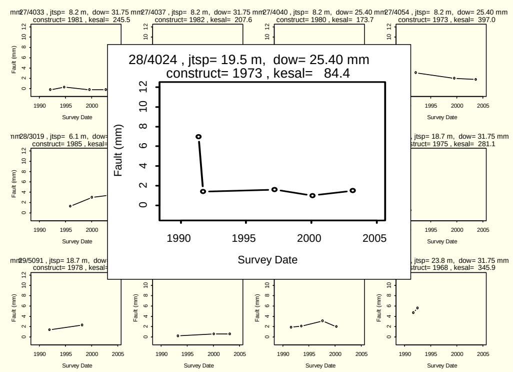


- IMS Modules(/Tables/Data Elements):
  - Climatic
  - General
  - Inventory
  - Maintenance
  - Monitoring
  - Rehabilitation
  - Testing
  - Traffic

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

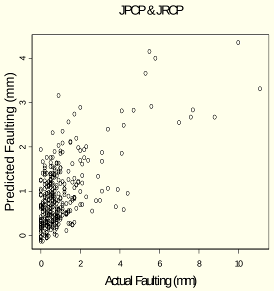


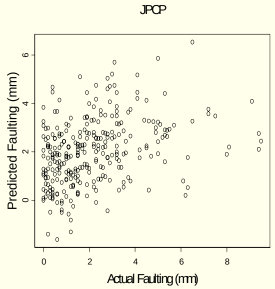
2. Graphical Representation and Data Cleaning



IV. Analysis of Existing Models(1/4)

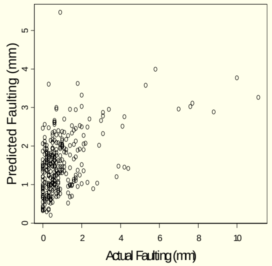
(a) SHRP-P-393 (dowelled) (b) SHRP-P-393 (nondowelled)

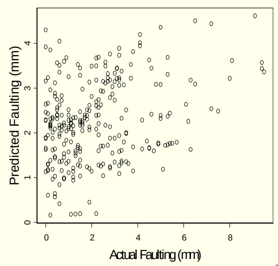




IV. Analysis of Existing Models(2/4)

(a) AASHTO 1998 (dowelled) (b) AASHTO 1998 (nondowelled)

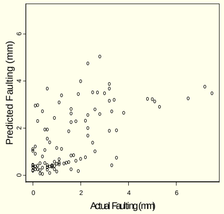


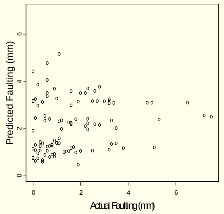


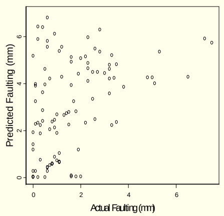
IV. Analysis of Existing Models(3/4)

Randomly selected 23 JPCP sections (n=98)

(a) SHRP-P-393 **(b) AASHTO 1998** **(c) DG2002**





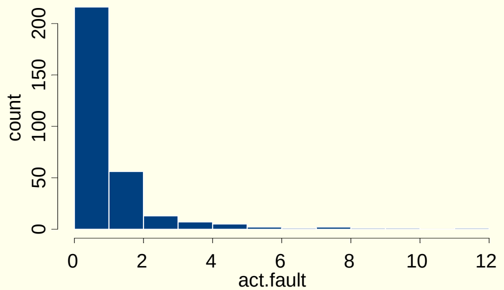


IV. Analysis of Existing Models(4/4)

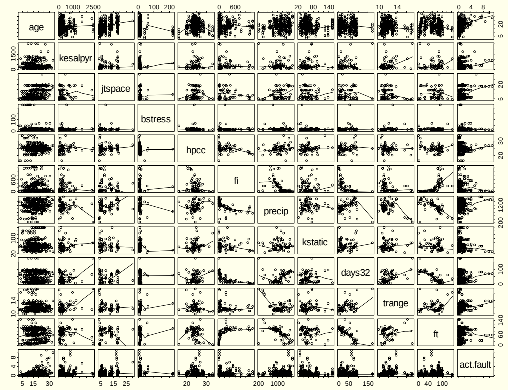
- Even though the use of an incremental approach and more complicated Axle Load Spectra (ALS) concept seems to be a logical approach, the integration of which with monthly or seasonal environmental factors such as humidity and temperature differentials often resulted in more variations in the predictions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

V. Development of Tentative Faulting Models

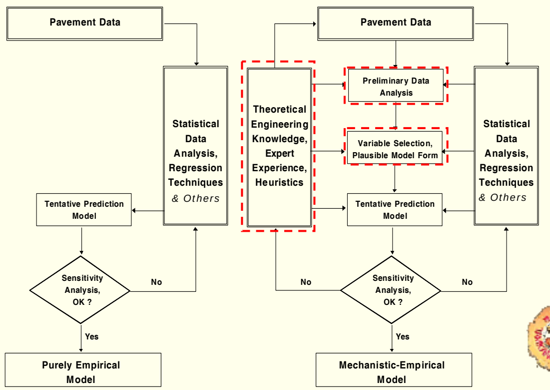
1. Preliminary Analysis (Univariate Data Analysis)



2. Bivariate and Multivariate Analysis (scatter plot matrix with lowess smoother)



3. Model Development Using Purely Empirical or Mechanistic-Empirical Concept (Lee, 1993)



4. Preliminary Models Using Poisson Regression

- 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 and Poisson distribution were adopted

- Generalized Linear Model (GLM)

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

Distribution	Link Function	Variance
Normal/Gaussian	μ	1
Binomial	$\log(\mu/(1-\mu))$	$\mu(1-\mu)/n$
Poisson	$\log(\mu)$	μ
Gamma	$1/\mu$	μ^2
Inverse Normal/Gaussian	$1/\mu^2$	μ^3
Quasi	$g(\mu)$	$V(\mu)$

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 Poisson distribution, and quasi-likelihood estimation method, i.e., quasi(link="log", var = "mu")

6. Tentatively Proposed Models

$$FaultD = \exp[1.982 + 0.8413 * \sqrt{age} - 6.094 * \frac{1}{\sqrt{kesalpyr}} - 1.899 * \frac{1}{\sqrt{bstress}}$$
$$+ 0.05487 * \sqrt{precip} - 0.5103 * basetype - 0.3309 * stype - 22.35 * \frac{1}{\sqrt{trange}}]$$

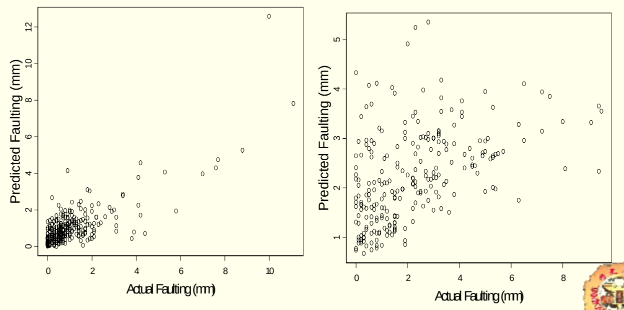
Statistics: $N = 305, R^2 = 0.6039, SEE = 0.9122$

$$FaultND = \exp[1.775 - 3.129 * \frac{1}{\sqrt{age}} + 0.01487 * \sqrt{kesalpyr} - 8.267 * \frac{1}{jtspace}$$
$$+ 0.0004246 * precip + 5.530 * \frac{1}{\sqrt{kstatic}} - 0.4735 * basetype + 0.005457 * ft]$$

Statistics : $N = 243, R^2 = 0.2154, SEE = 1.778$

7. Goodness of the Proposed Models

(a) Dowelled (b) Nondowelled



VI. Concluding Remarks (1/2)

- Even though the use of an incremental approach and more complicated Axle Load Spectra (ALS) concept as recommended by the MEPDG 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
- Existing models for faulting predictions are inadequate using LTPP Database

VI. Concluding Remarks (2/2)

- Relatively skewed distribution was identified, indicating that normality assumption is inappropriate
- GLM and GAM along with Poisson distribution assumption and quasi-likelihood estimation method were adopted
- By eliminating insignificant and inappropriate parameters repeatedly, the resulting model only includes age, kesalpyr, bstress, precip, basetype, stype, trange, jtspace, kstatic, and ft for predicting joint faulting
- Conducted goodness of fit and sensitivity analysis study
- Further improvements are possible and recommended

Questions?

THANKS FOR YOUR ATTENTION