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DEVELOPMENT OF RUTTING PREDICTION MODELS FOR FLEXIBLE 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 rutting of flexible pavements using the LTPP database (www.datapave.com)

II. Review of Existing Models

- Mechanistic-Empirical Approach
  - allowable number of repetitions (N_d), cumulative rutting damage (D_d)

$$N_d = k_4(\varepsilon_c)^{-k_5} \qquad D_d = \sum_{i=1}^{k} \frac{n_i}{N_{di}} \le 1.0$$

Organization (Year)	k_4	k_5
AI (1982)	1.365×10^{-9}	4.477
Shell (1994)	6.15×10^{-7}	4.0
Indian model (1999)	2.56×10^{-8}	4.533
Mn/ROAD (2003)	7.0×10^{15}	3.909

- SHRP P-393
  - Rut Depth $= N^{B}10^{C}$

$B=b_o + b_1x_1 + b_2x_2 + \ldots\ldots + b_nx_n$

$C=c_o + c_1x_1 + c_2x_2 + \ldots\ldots + c_nx_n$

Parameters x_i	Unit	Regression Coefficients	
		b_i	c_i
(Intercept)	--	0.151	-0.00475
Log (HMAC percent passing #4 shieve)	Weight %	0	-0.596
Log (HMAC air content)	Voulme %	-0.0726	0
Log (base thickness)	in.	0	0.190
Subgrade (percent passing #200 shieve)	Weight %	0	0.00582
Freezing Index (FI)	Degree F-Days	$8.49*10^{-6}$	0
Log (AC thickness) × Log (base thickness)	in.	0	-0.161

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

$$RD = \sum_{i=1}^{k} \varepsilon_p^i h^i$$

$$\frac{\varepsilon_p}{\varepsilon_r} = k_1 * 10^{-3.4488} T^{1.5606} N^{0.479244}$$

$$k_1 = (C_1 + C_2 * depth) * 0.328196^{depth}$$

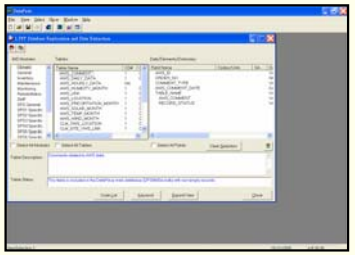
$$C_1 = -0.1039 * h_{ac}^2 + 2.4868 * h_{ac} - 17.342$$

$$C_2 = 0.0172 * h_{ac}^2 - 1.7331 * h_{ac} + 27.428$$

- **Rutting damage (RD) is determined in an incremental manner based on more complicated Axle Load Spectra (ALS) concept**

III. Database Preparation

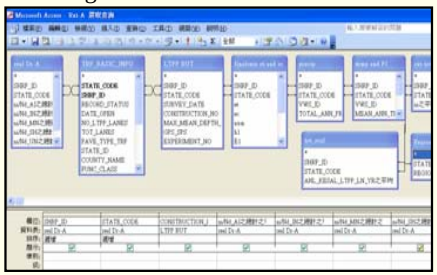
- LTPP GPS-1 (Granular Base), GPS-2 (Bound Base)



DataPave 3.0 → **DataPave Online (Standard Release 18.0)**

1. Retrieval of Required Data

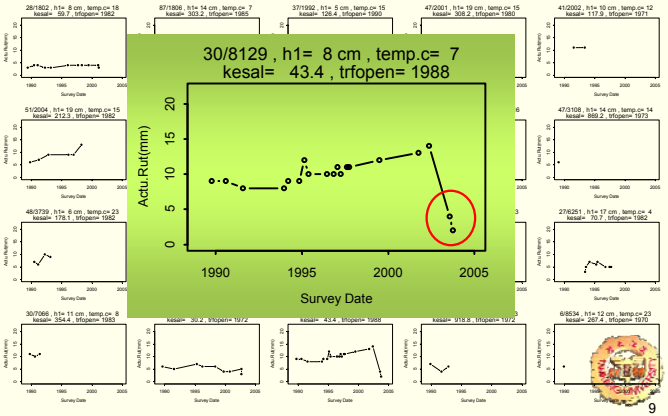
- IMS Modules(/Tables/Data Elements):
  - Climatic
  - General
  - Inventory
  - Maintenance
  - Monitoring
  - Rehabilitation
  - Testing
  - Traffic



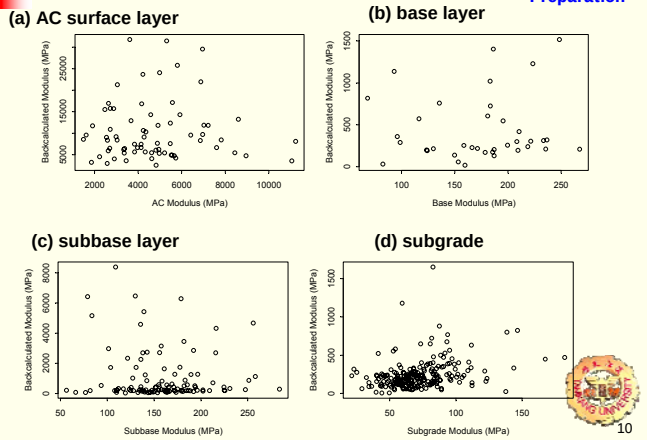
Microsoft Access

Existing models 10~15 items, DG2002 45~50 items
Batch BISAR Program Runs: compressive strain on top of subgrade

2. Graphical Representation & Data Cleaning

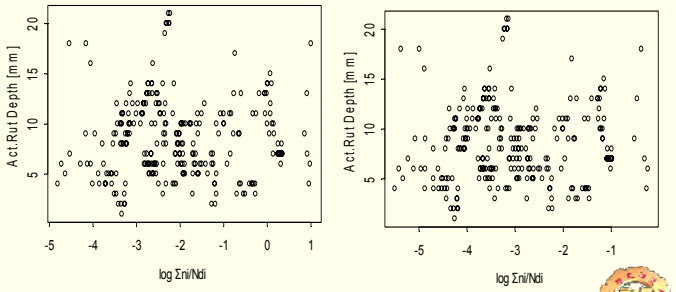


3. Comparison of Lab Tested vs. MODCOMP4 Backcalculated Layer Moduli (MPa)

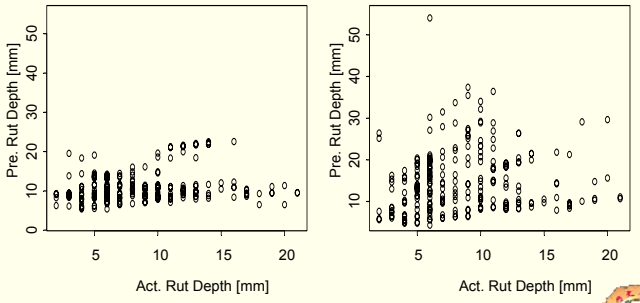


IV. Analysis of Existing Models

- AI model
- Shell Oil Model



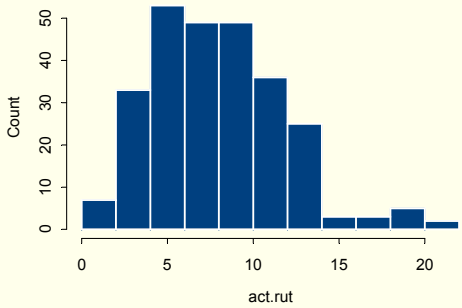
- SHRP P-393
- MEPDG (DG2002)



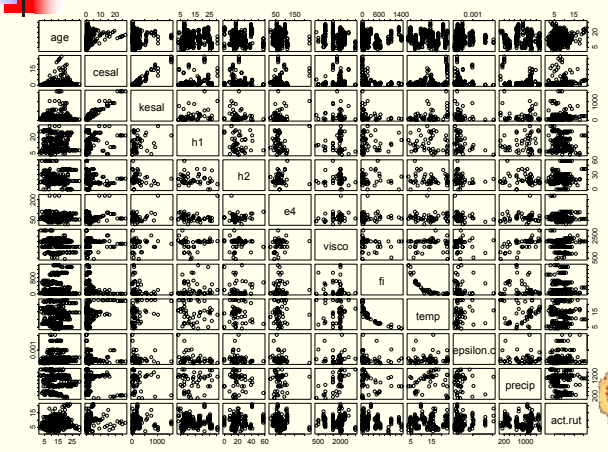
- Even though the use of an incremental approach and more complicated Axle Load Spectra (ALS) concept seems to be a logical approach, the integration of which with monthly or seasonal environmental factors such as humidity and temperature differentials often resulted in more variations in the predictions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

V. Development of Tentative Rutting Models

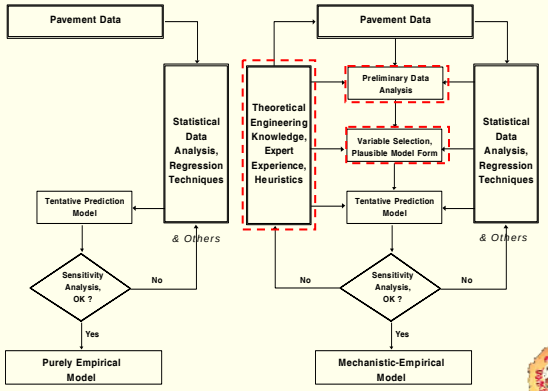
1. Preliminary Analysis (Univariate Data Analysis)



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 several distributions was adopted $g(E(Y \mid x)) = g(\mu) = \beta_0 + \sum_{i=1}^{p} \beta_i x_i = \eta(x)$
- The quasi family with the same link and variance functions from Poisson family was found to be the best choice

5. Improved Models Using Additional Modern Regression Techniques

General Predictive Modeling Procedures:

- Generalized Additive Models (GAM)

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

- 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

$$Rut = \exp[-0.99 + 0.137 * \sqrt{age} + 0.322 * \log(kesal) + 0.38 * \log(1 + fi) + 0.352 * \sqrt{temp} + 0.083 * (epsilon.c * 1000)^2]$$

$$\text{Statistics}: R^2 = 0.155, \text{SEE} = 3.568, \text{N} = 265$$

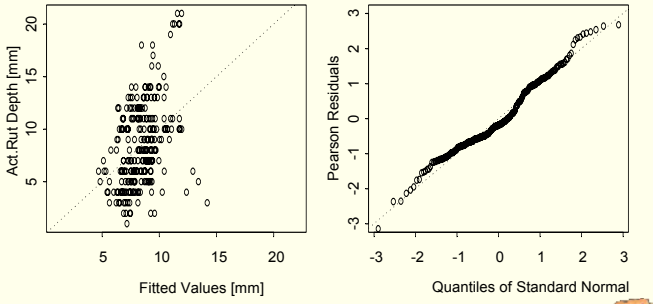
$$(Rut)_{wet} = \exp[-1.489 + 0.25 * \sqrt{age} + 0.6 * \log(kesal) + 0.24 * \log(1 + fi) + 0.256 * \sqrt{temp} + 0.288 * (epsilon.c * 1000)^2]$$

$$\text{Statistics}: R^2 = 0.338, \text{SEE} = 3.401, \text{N} = 194$$

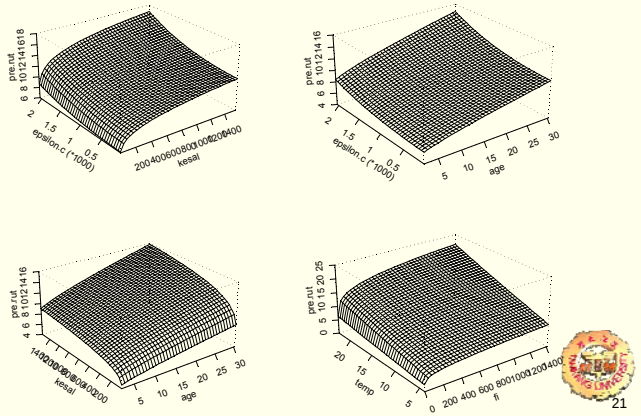
$$(Rut)_{nonfreeze} = \exp[0.253 + 0.065 * \sqrt{age} + 0.486 * \log(kesal) + 0.187 * \log(1 + fi) + 0.06 * \sqrt{temp} + 0.288 * (epsilon.c * 1000)^2]$$

$$\text{Statistics}: R^2 = 0.282, \text{SEE} = 3.193, \text{N} = 124$$

7. Goodness of Fit of the Proposed Models



7. Sensitivity Analysis of the Proposed Models



VI. Conclusions

- Existing rutting models are inadequate using LTPP Database
- 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
- GLM, GAM, & quasi-likelihood estimation method were adopted (Poisson family was found to be the best choice)
- By eliminating insignificant and inappropriate parameters repeatedly, the resulting model includes kesalpyr, age, temp, critical compressive strain, and FI for predicting AC rutting
- Conducted goodness of fit and sensitivity analysis study
- Further improvements are possible and recommended