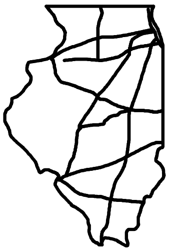
Development of Performance Prediction Models for Illinois Continuously Reinforced Concrete Pavements



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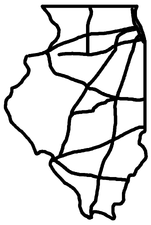
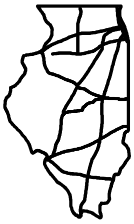
Objectives

- Provide IPFS Data retrieval
- guidelines
- Use of modern regression
- techniques
- Propose a new modeling
- approach
- Develop a CRCP performance
- prediction model
- Study the effect of different
- steel placement methode

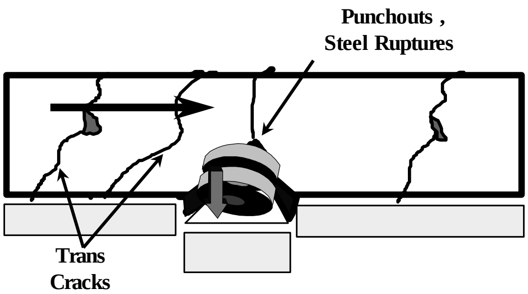


Illinois Interstate Highway system

- Illinois Pavement Feedback System
- (IPFS, 1977-91)
- 1.750 two-directional miles of
- multilane pavements
- Approximately 80 B originally
- constructed as CRCP
- 0.2 to 3.5 millions EASL/year,
- wet-freeze climate, poor subgrade

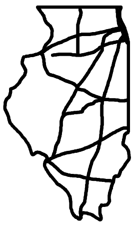


Localized Failures of CRCP



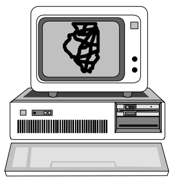
Challenges Facing IDOT

- Estimate major distress
- quentities for preventive design
- and rehab planning
- Study the effect of different
- steel placement methods: Tubes
- vs. Chairs



Data Preparation

- Implementation if IPFS DB
  - —Original design, Constr., Historical treffic, Distress, Condition, Maint & Rehab data
  - —1263 Interstate Sections
  - —IDOT Districts, Certral offices, & U of I have on-line access
- Old Vandalia, Illinois experimental study
- (0.3 to 1.0% steel)
- NOMAD2 databases ==> PC-SAS datasets



Design and Cilmatic Variables

- Must consider rehab history over time
  - Distress years: 1977. 79. 82. 85. 87. 89
  - Retrieve all distress data before any ACCL
- Steel reinforcement data
  - #5 & #6 bars before &after 1981
  - Chairs & Tubes construction before & after Sep. 1970
- Othe data
  - Drainage. base type. and environmental data

Traffic Calculation and Estimation

- IDOT traffic mape (ADT, SU, MU)
- Published once every 4 years
- Automatically estimate compound traffic (ADT, EASL) growth rates
  - By performing a huge array of reg. analysis (till latest 1987 data)
  - Estimate future traffic if necessary

Distress Quantities

- Zero or missing distresses
  - Unrecorded zero distresses or
  - Sections not actually surveyed
- D-cracked pavements
- Total failures

  FAIL=8.8 PATCH + PUNCH + MHPOT + NTCRK

  PATCH in %area (8 12 sq-ft/patch)

  others in #/mile
- Crack spacing to check distress data

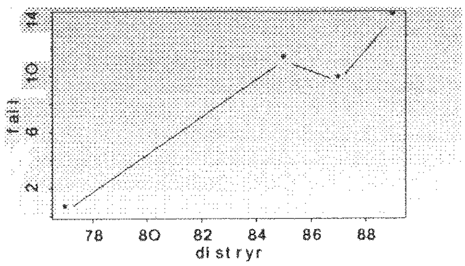
Additional Data

- Old Vandalia Experimental Study
  - Constructed in 1947-48 on US 40
  - Eight sections of 7-in and 8-in. CRCP
  - 0.3, 0.5, 0.7, 1.0% steel
- Carried 4.27 millions EASLs in 20 years
- Many failures in 0.3 and 0.5% steel in 7-in sections

Preiiminary Data Analysis

- Distress history and additional codes

55-N-43.21-50.38-N 9 CRCP, conyr=74



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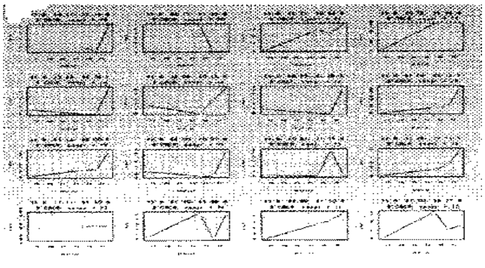
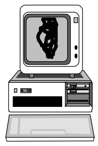
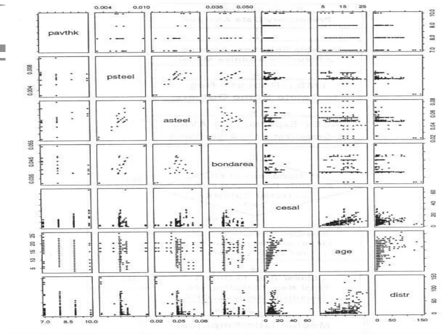
Distress History Along I-55



Preiiminary Data Analysis (Continue ..)



- Final database with Non-D e Cracked CRCP (586 data points)
- Correlation of Variables
  - —Matrix plots of important variables: Fail, thickness, %steel, AGE, CESAL
  - — Collinearity between AGE and CESAL
- Factor Space and Limitations
- Variability of the data



Proposed New Predictive Modeling Approach

Traditional Regression Techniques

Linear Reg ression

$y = {}_0 + {}_1x_1 + {}_2x_2 + \ldots + {}_{p-1}x_{p-1} + \varepsilon$

Nonlinear Regression

$y = F({}_0, {}_1, {}_2, \ldots, {}_{p-1}, x_1, x_2, x_{p-1}) + \varepsilon$

Minimize RSS( ) = $\sum r^2( )$

Modern Regression Techniques (in S-PLUS for Windows)

LMS, Robust Regression

(Least Median Squared Reg.)
for outlier detection by Rousseeuw, 1984

$$y = {}_0 + {}_1x_1 + {}_2x_2 + \ldots + {}_{p-1}x_{p-1} + \varepsilon$$

Minimize $RMS(\hat{}) = \underset{i=1}{\overset{n}{med}}\{r_i^2(\hat{})\}$

ACE, Expectation Algorithm

(Alternating Conditional Expectations)
for maximizing the R-square by Breiman and Friedman, 1985

$$\theta(y) = \phi_1(x_1) + \phi_2(x_2) + \ldots + \phi_p(x_p) + \varepsilon$$

Min $e^2(\theta, \phi_1, \ldots, \phi_p) = \frac{E[\theta(y) - \sum \phi_i(x_i)]^2}{E\,\theta^2(y)}$

Proposed New modeling Approach

- Conduct preliminary data analysis
- Assume a plausible additive model (variable selection)
- Apply Robust (LMS) Regression
- Apply Expectation & Stabilization algorithms

AVAS, Stabilization Algorithm

(Additivity and Variance Stabilization)
to improve the fit and achieve constant variance by Tibshiranl, 1987

$$\theta(y) = \phi_1(x_1) + \phi_2(x_2) + \ldots + \phi_p(x_p) + \varepsilon$$

To Achieve Two Goals :

$E[\theta(y)|x_1, x_2, \ldots, x_p] = \sum \phi_i(x_i)$

$VAR[\theta(y)|\sum \phi_i(x_i)] =$ Constant

Proposed New modeling Approach

- Check the goodness-of-the-fit, plausible functional fome, detected outliers
  (Repeat above steps if necessary)
- Apply traditional linear and nonlinear reg.and transformation techniques
- Obtain final reg. statistics and check sensitivity analysis (Repeat if necessary)

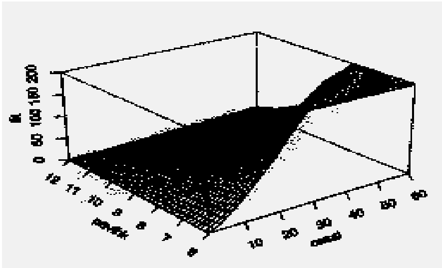
Proposed CRCP Performance Prediction Model

$$\ln(FAIL) = 6.8004 - 0.0334*PAVTHK^2 - 6.5858*PSTEEL + 1.2875*\ln(CESAL) - 1.1408*BAM - 0.9367*CAM - 0.8909*GRAN - 0.1258*CHAIRS$$

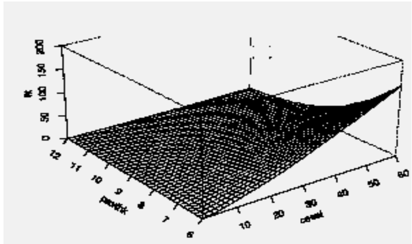
Statistics $R^2 = 0.44$, $SEE = 106$, $N = 408$

- Best among several dozen models developed
- Very high variations still present
- Demonstrated the proposed modeling approach

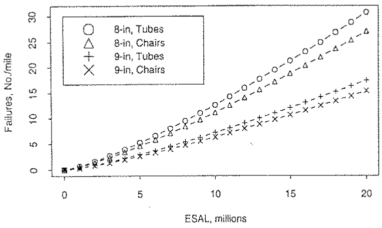
Sensitivity Analysis for Reinf. Content=0.5%



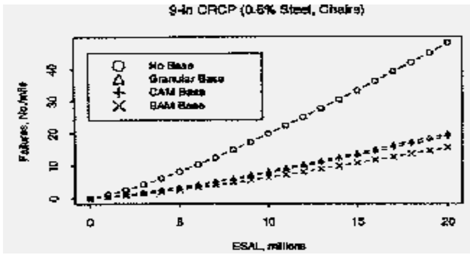
Sensitivity Analysis for Reinf. Content=0.7%



CRCP, 0.6% Steel, BAM Subbase



9-in. CRCP, 0.6% Steel, Chairs



Discussion

- In the proposed model;
  - The use of Chairs does result fewer total failures
  - However, the difference is not highly significant
- Previous research perfomed in Illinois on I-70 has shown:
  - The depth of reinforcing steel greatly effects the crack width, breakdownof cracks, and failures
  - Tube placement method would likely have a greater chance for more failures
- BAM base has the best overall performance
- CAM base has about the same effect as granular base

Conclusions

- Conducted the first attempt to use the in-service IPFS Database for research purpose
- Provided data retrievel guidelines
  - IPFS DB & old Vandalia experimental sections used
- Conducted a preliminary data analysis
  - For data cleaning
  - Assessing the variability of the data
  - Understanding the interrelationships among variables

Conclusions(continue...)

- Proposed a new predictive modeling approach
  - Using several modem regression techniques
- Developed a CRCP perfomance prediction
  - Failures=F(CEASL, Slab thickness, % Steel, Steel placement methods, Base Type)
- Conducted a sensitivity analysis
- The effect of various factore appeared to be very reasonable!

Recommendations

- Introduce more mechanistice variables
- Conduct a full-length survey (or at least 20-30 percent) to reduce data variability
- Improve the proposed predictive model
- Consider D eCracked Pavements

Acknowledgments

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