Complexity Challenges to the Discovery of Relationships in Eddy Current Non-destructive Test Data

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Outline

- Background Information
- Eddy Current Non-destructive Tests (NDT)
- Approach
- Algorithms
- Results
- Interpretation of Results
- Conclusions
- Future Research
- Questions

Background

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- Many commercial & military aircraft reached or exceeded original design life
  - *USAF aircraft 20-35+ years old*
  - *KC-135 (40 yrs. old) extended for 25 years*
  - *Civilian airlines Boeing 727 family – Introduced in 60's*
- Corrosion is a serious threat especially to older aircraft
  - *Significant increase in maintenance costs*
  - *Increasing concern about structural integrity*

Background

Aloha Flight 243

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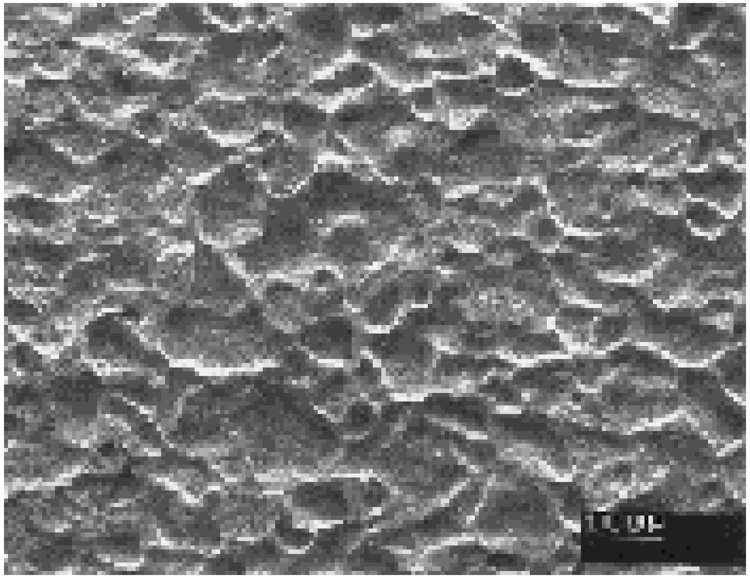
Relationship Hypothesis

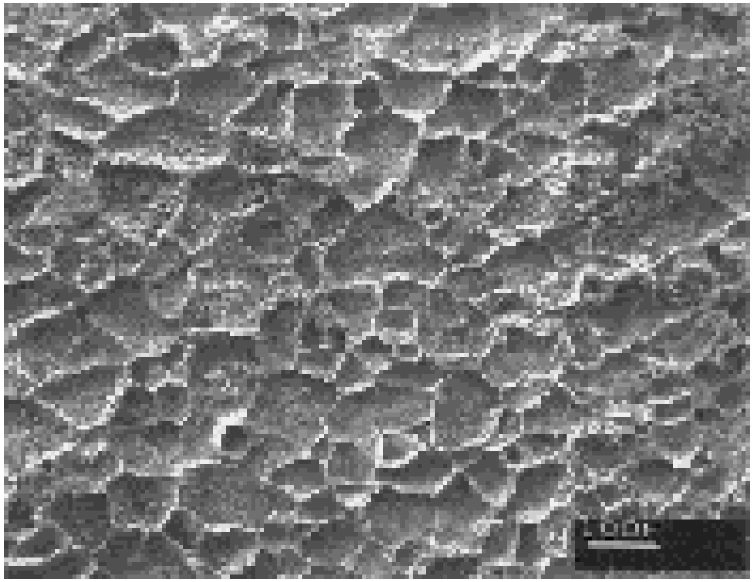
1 of 2

- Relationship between calibration specimen results & classifying corrosion on KC-135 parts
- Current artificial corrosion processes show similar characteristics as those found in naturally corroded lap joints

Relationship Hypothesis



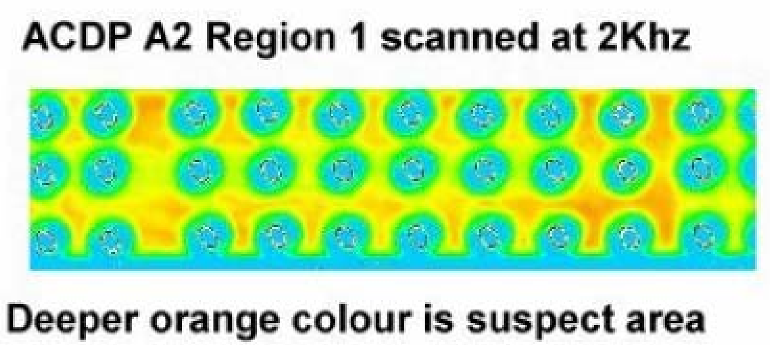
Natural Corrosion
(KC-135 Specimen)



Artificial Corrosion
(Calibration Specimen)

Eddy Current Non-destructive Tests

- Problems with current visual representation
  - *Requires considerable expertise to create and interpret*
  - *Need for visual clarity leads to data generalization, averaging, or overlooked points ~ accuracy?*
  - *Missed corrosion may cause a catastrophic accident*

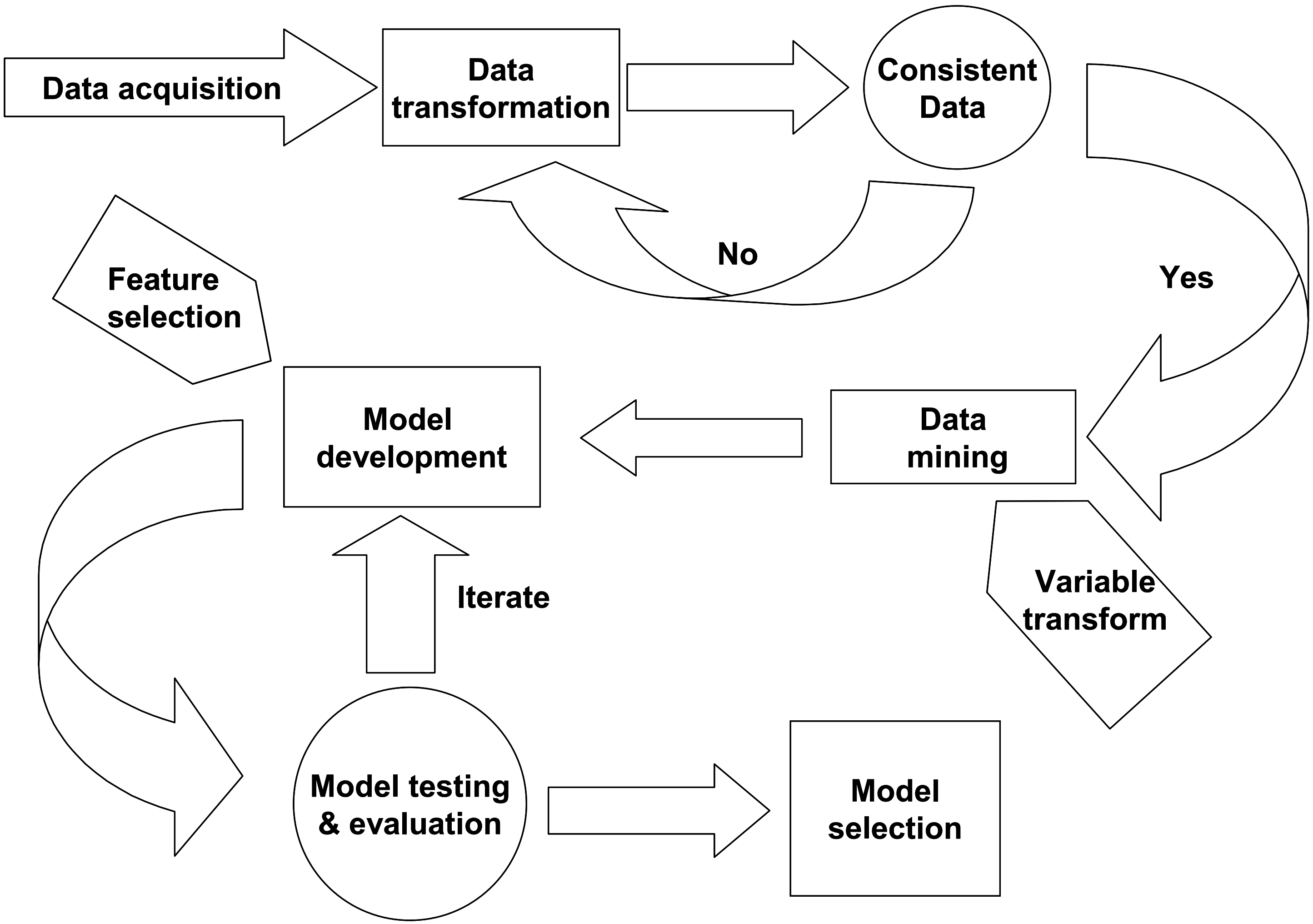


Approach
Outline

- Data acquisition
- Data transformation & consistency
- Model development & feature selection
- Model training & testing
- Model Evaluation
- Model Selection

Approach

Graphic



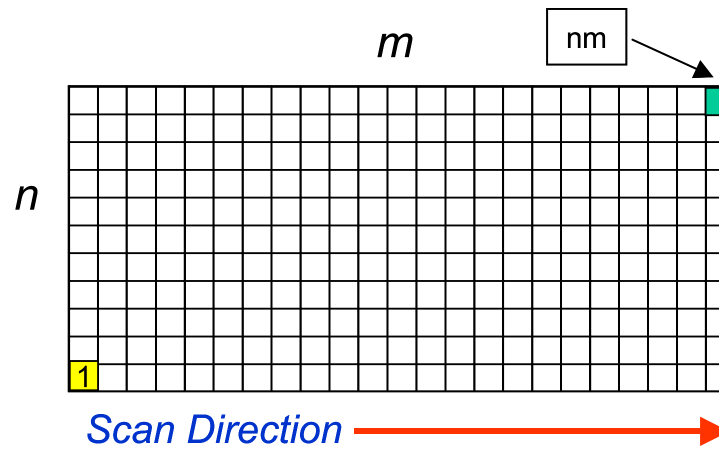
Approach

Data Acquisition

- Institute of Aerospace Research

National Research Council Canada Conseil national de recherches Canada

  - *Calibration specimens*
  - *Retired KC-135 specimens*



- Data

  - *Induced Voltage measurements from multi-frequency scans*
  - *Calibration specimen E1*

Approach

Data Transformation & Consistency

1 of 5

Eddy Current Specimen E1 data

– *4 different scan frequencies are the 4 predictor variables (5.5 kHz, 8 kHz, 17 kHz, & 30 kHz)*

– *Merged 4 scan frequency files into one file*

Approach

Data Transformation & Consistency

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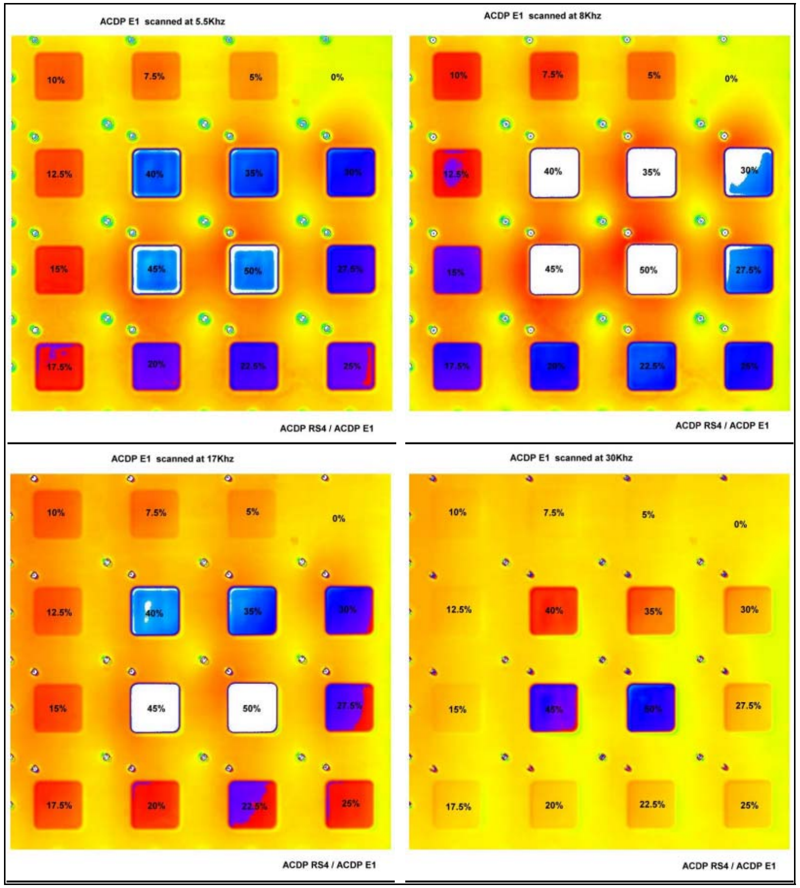
5.5 kHz

8 kHz



17 kHz

30 kHz

Approach

Data Transformation & Consistency

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Results from PicView Program

Starred areas show which picture is used to model specific loss area.

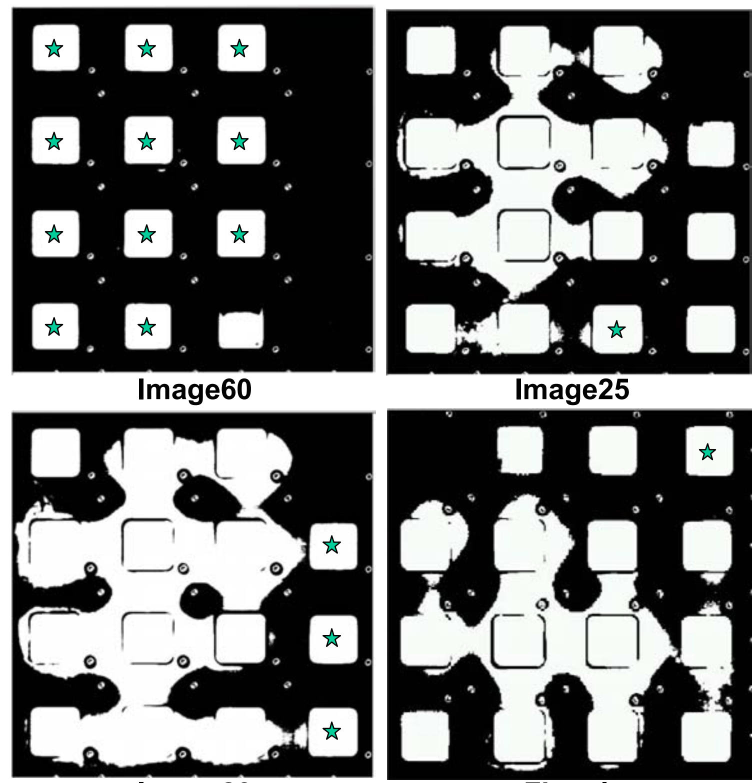

Image60 Image25

Image20 Finagle

Approach

Data Transformation & Consistency

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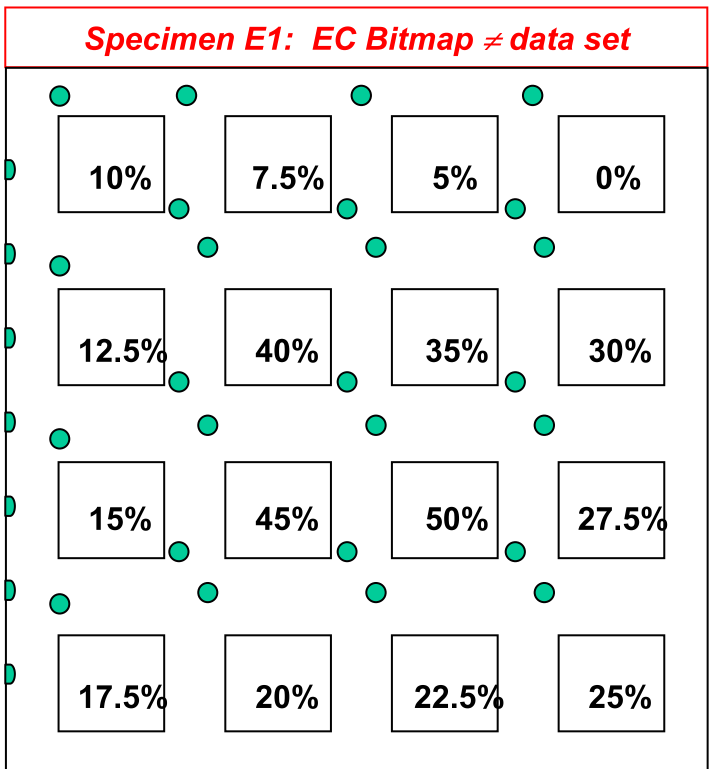
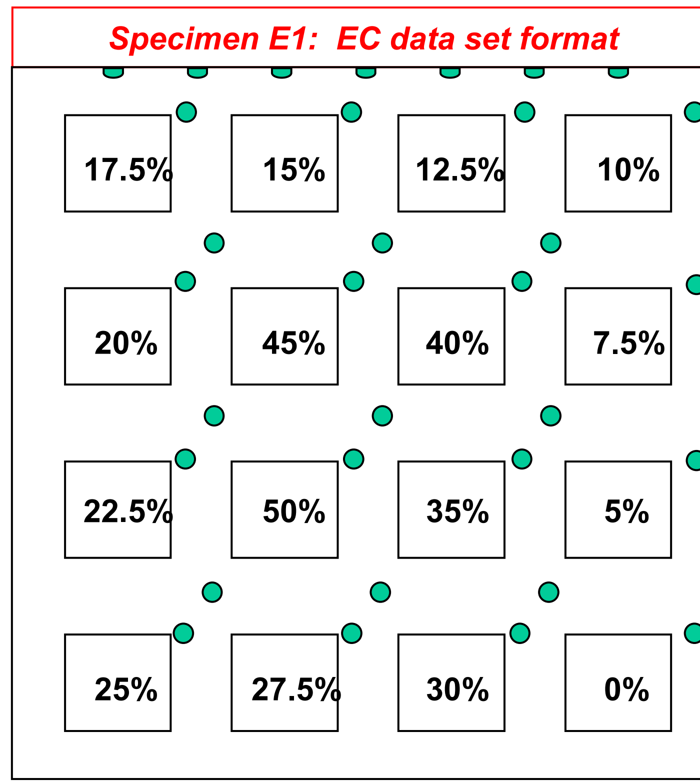
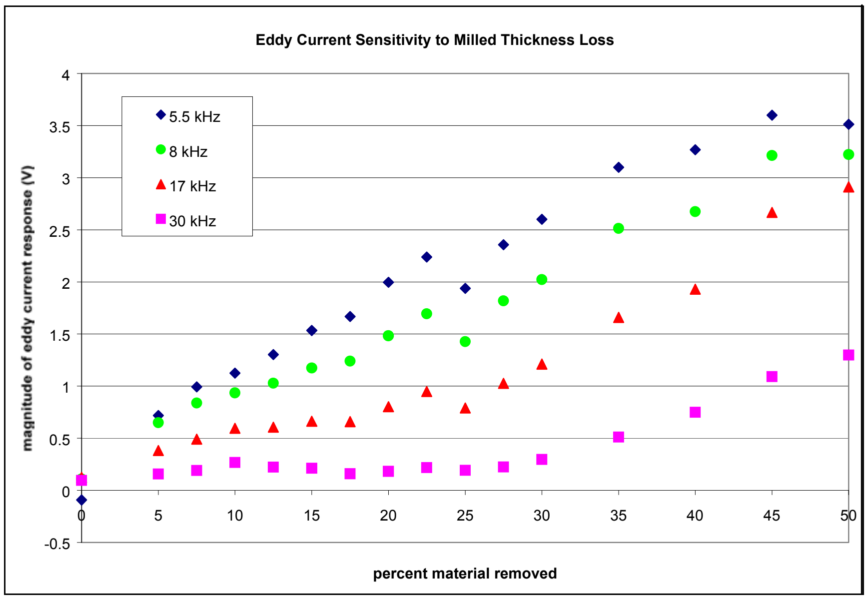


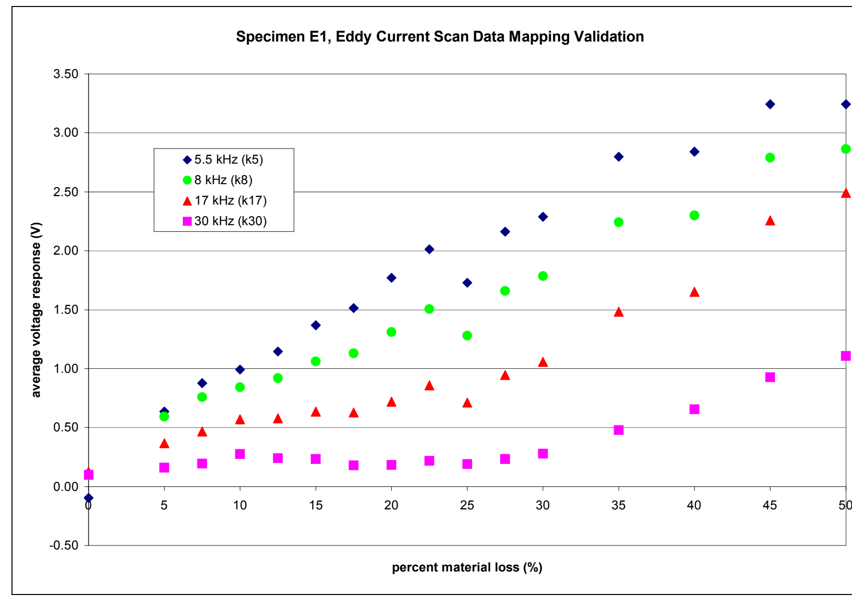


Approach

Data Transformation & Consistency



Graph from original study



Graph resulting from data transformation

Approach

Model Development & Feature Selection

- Eddy Current
  - Four predictors and one response variable
  - Looked at histograms of variables to categorize the observation’s distribution
  - Used scaling and transformations of predictors
- Feature Selection (E.G., regression)
  - Stepwise, Forward, Backward selection
  - Maximum R^2_{adj}, Mallows CP

Approach

Model Training & Testing

- Calibration specimen data used for training ~ Eddy Current specimen E1
- Training and Test data configuration (in general)
  - – 75% training (120,456 observations)
  - – 25% test (40,152 observations)

Approach

Model Training Evaluation

- Akaike Information Criterion
- Schwartz Criterion
- Coefficient of multiple determination (R^2)
- Adjusted R^2
- Mallows Cp
- Mean Absolute Error
- Mean Squared Error

Approach

Model Selection

Selection of best modeling methodology based on root mean squared error calculation on test set

$$\sqrt{MSE_{TESTSET}} = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(y_j - \bar{y}\right)^2}$$

Algorithms

Multiple Regression

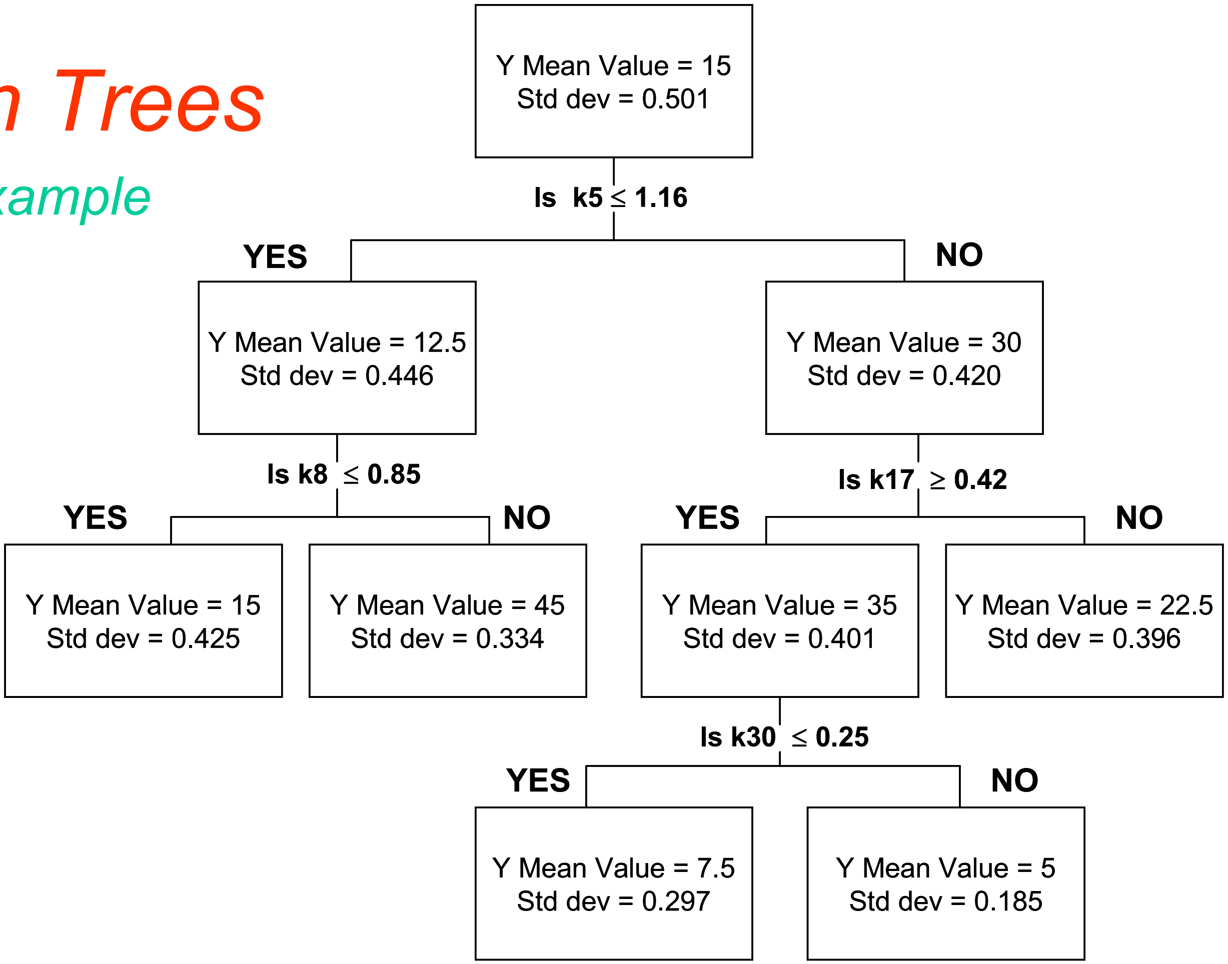
$$Y_i = \beta_0 + \beta_1 X_{i,1} + \beta_2 X_{i,2} + \ldots + \beta_{p-1} X_{i,p-1} + \varepsilon_i$$

Considered polynomial, interaction, and transformed terms

Algorithms

Regression Trees

Least Squares example



Algorithms

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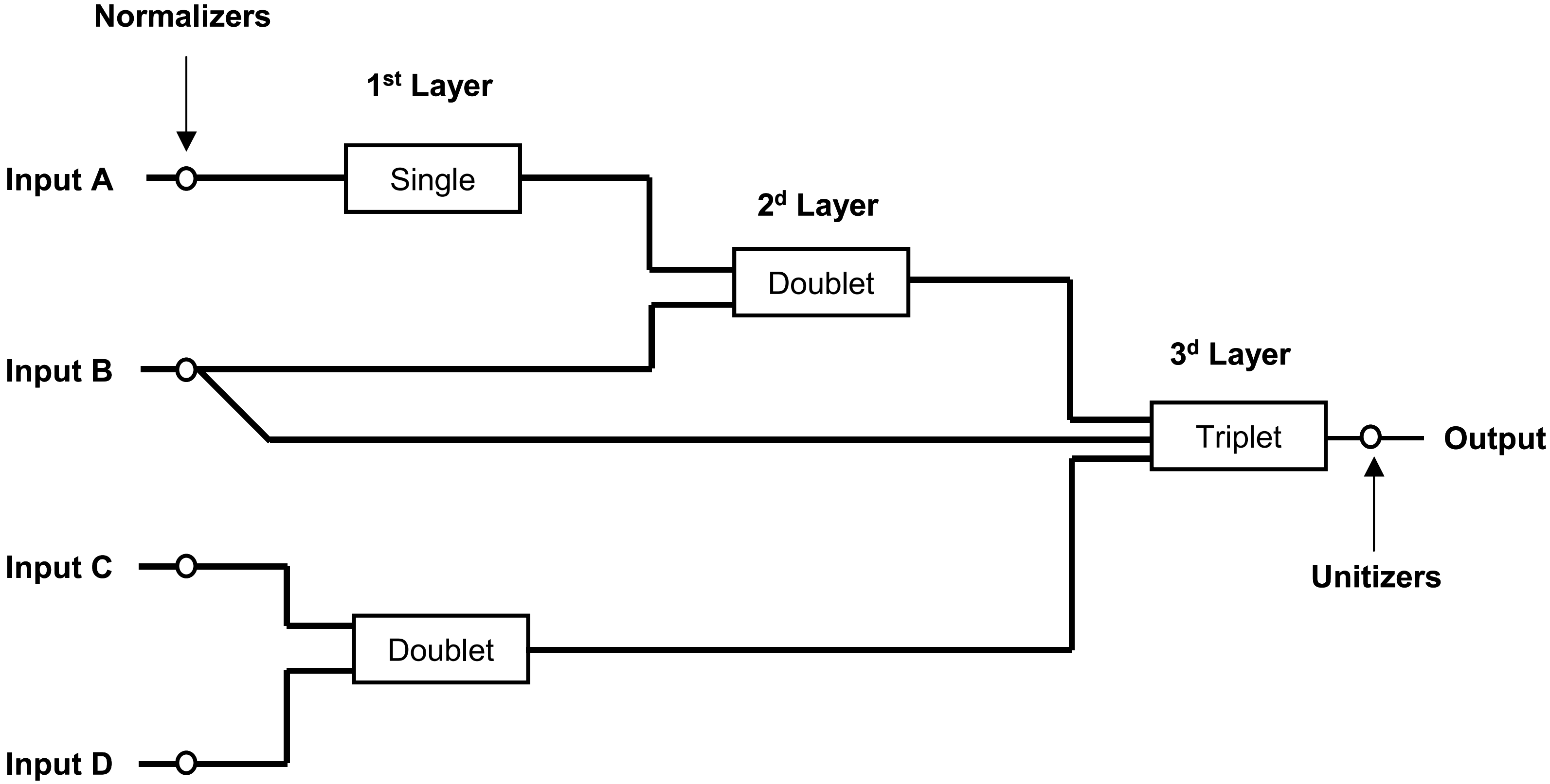
Polynomial Networks



Algorithms

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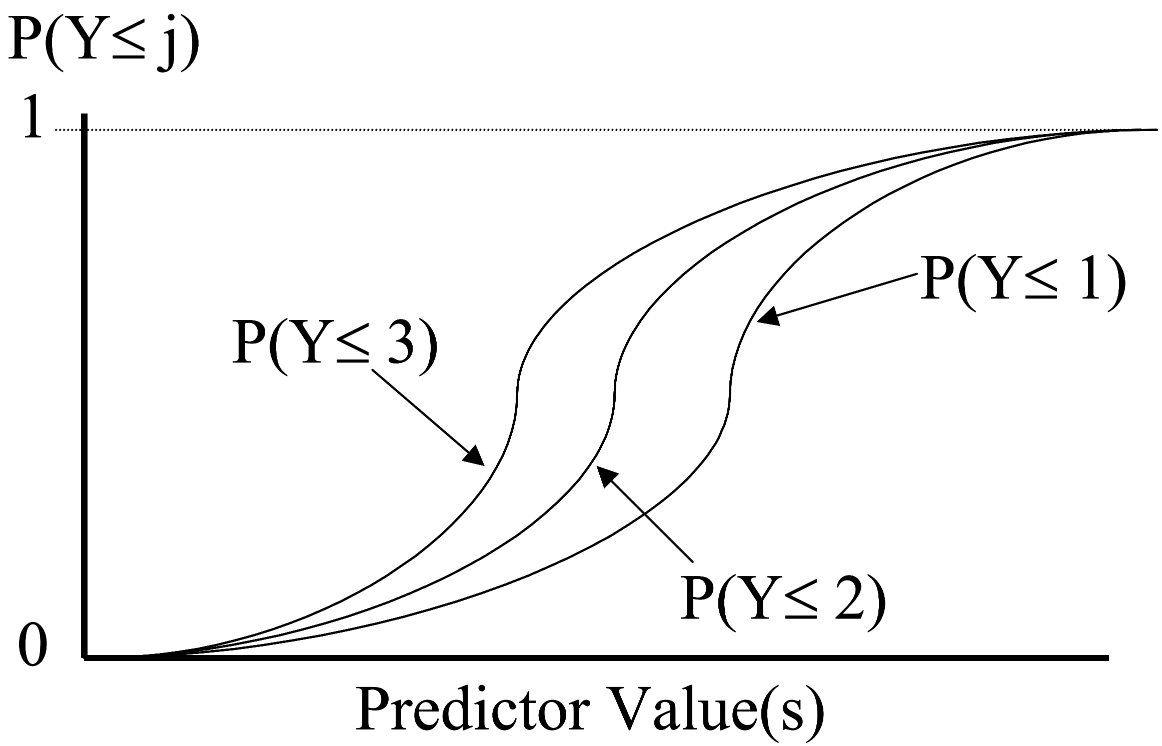
Ordinal Logistic Regression



Results

Multiple Regression

- The more complex the model, the better it did with both training and test datasets
- Best model incorporated transformed 4th order polynomial and interaction terms
- Problem ~ Heteroscedasticity

  (non-constant variance)

Results

Regression Trees

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- Program limitations for data size
  - 60,000 observation training dataset
  - 60,000 observation test dataset
- Least squares tree tested 2611 trees
- Least absolute deviation tested 172 trees

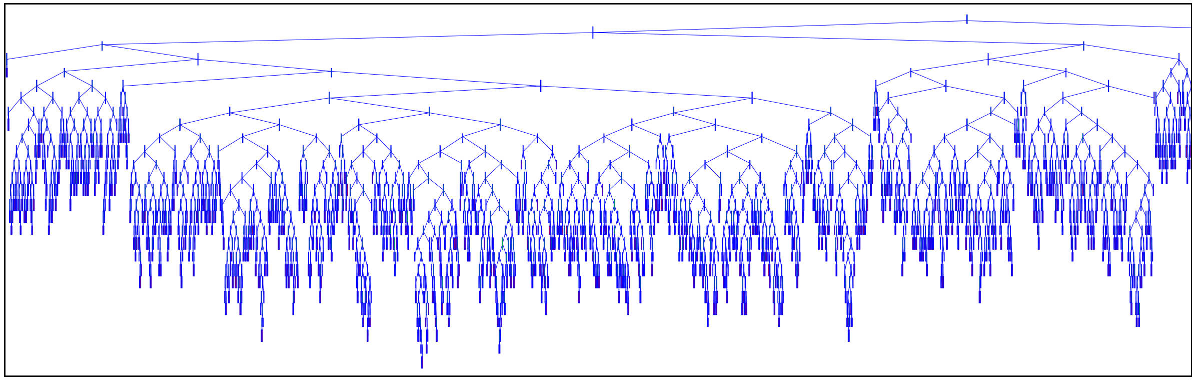
Results

Regression Trees

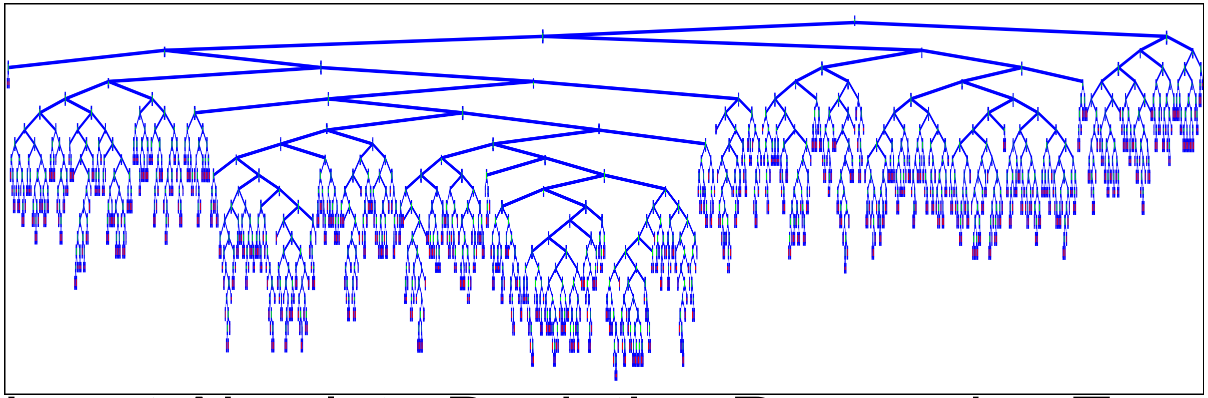
- Least absolute deviation regression tree was the best
  - Fewer nodes 819 vs. 1857
  - Smaller Complexity value: –1.0 vs 37.6
  - Smaller Root MSE for test set

Results

Regression Trees



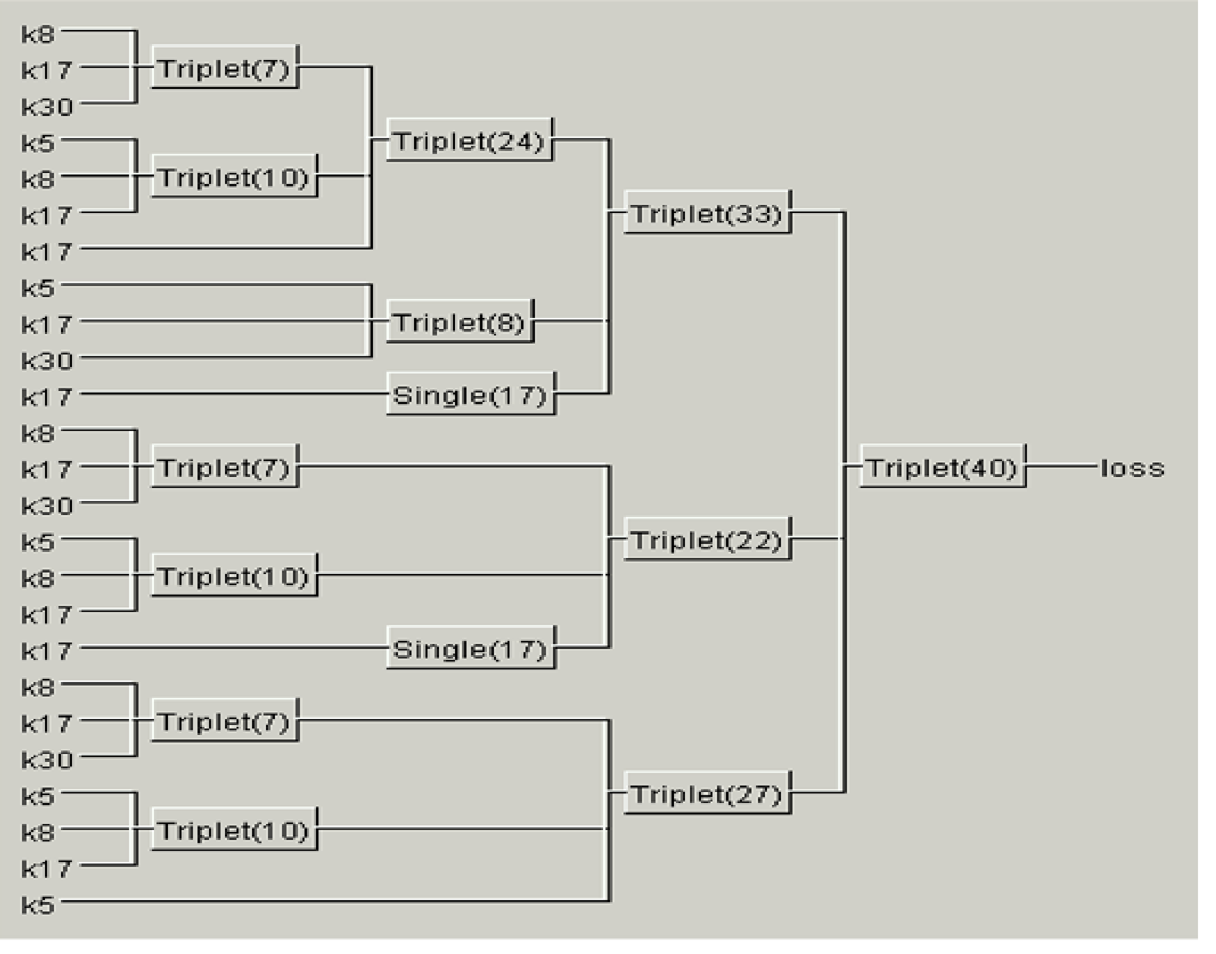
Least Squares Regression Tree



Least Absolute Deviation Regression Tree

Results

Polynomial Networks



Results

Ordinal Logistic Regression

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- The more complex the model, the better it did with both training and test datasets
- Best model incorporated transformed 4th order polynomial and interaction terms

Results

Model Selection

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Overall Model Comparision by Test Set		
Model	***RT MSE***	***VAR***
Multiple Regression Model 8	5.388	29.030
Logistic Regression Model 8	5.610	31.468
Polynomial Network	4.872	23.739
LAD Regression Tree	***0.566***	0.320

Interpretation of Results

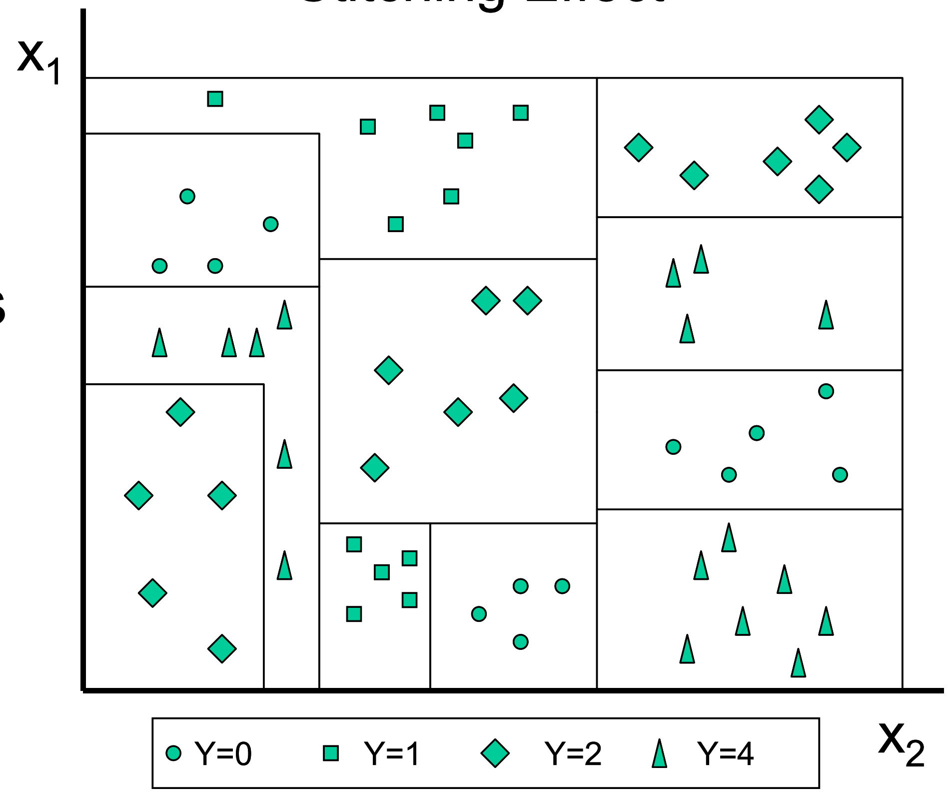
More Complex = Better Model

Dataset requires
complex parametric models

Or

Non-parametric models

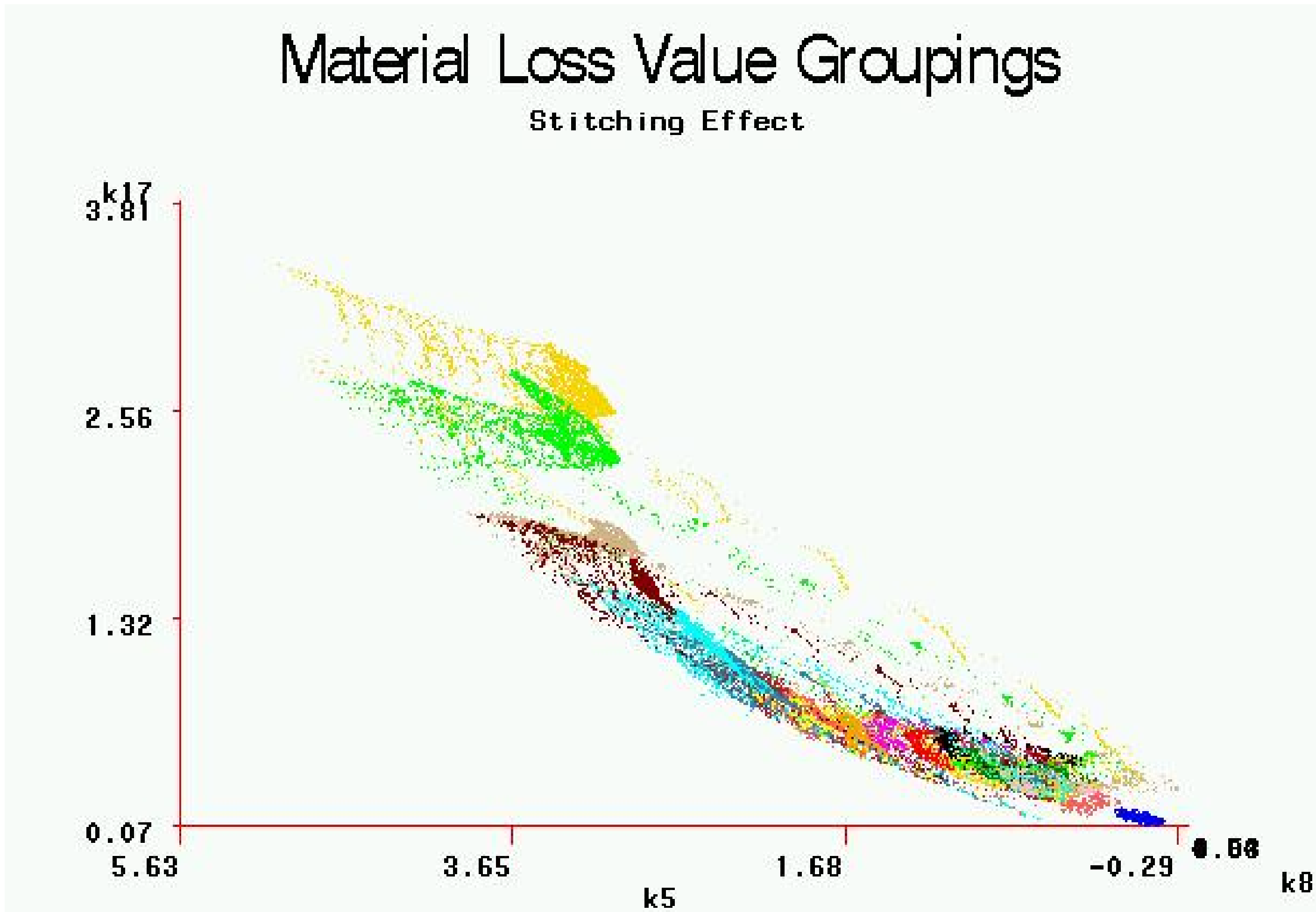
Stitching Effect



Interpretation of Results

More Complex = Better Model

STITCHING EFFECT



Interpretation of Results

Why LAD RT does well

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LAD regression tree does well because:

- Robust in presence of heteroscedasticity
- Partitioning provides for improved accuracy
- Uses “stitching” to capture nonlinearities

Conclusions
1 of 2

Maintenance Operations

- *Showed that an algorithm can be developed to assist operators in maintenance decisions*
- *Showed how to transform and clean the eddy current data for analysis*
- *Provided a basis for choosing among competing algorithms for actual implementation*

Conclusions
2 of 2

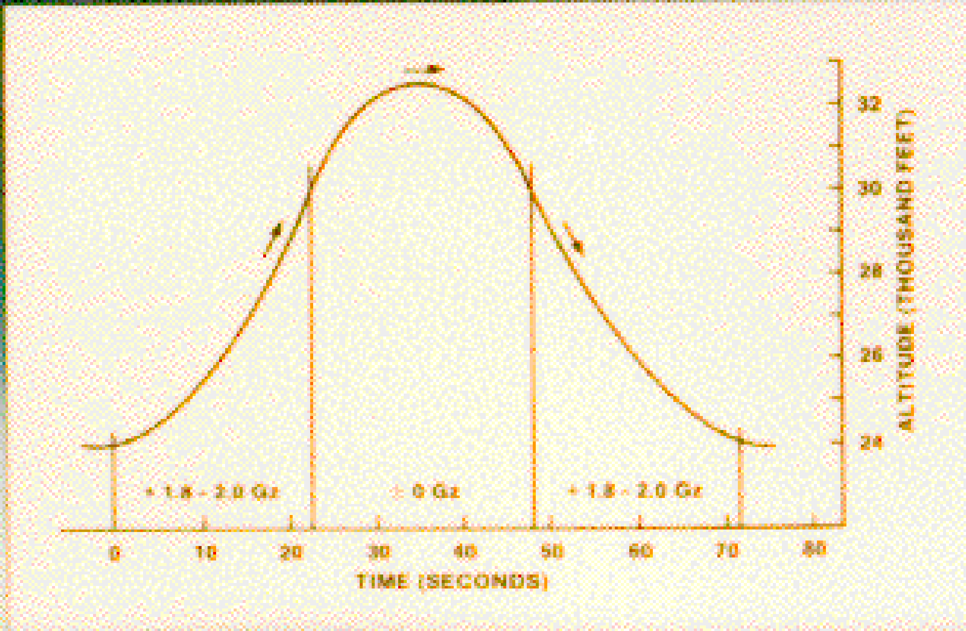
Methodological

- *Provided a formal approach for comparing different data mining techniques on real corrosion data*
- *Showed that real data sets can produce highly complex relationships (contrast with Ockham's razor) and that models can be found to handle these complexities*
- *Demonstrated the power of tree-based methods to treat nonlinearities in the data through "stitching", which was formerly thought to be a disadvantage*

Future Research

- Classification algorithms
- If time-lapse available ~ time series analysis
- Spatial models (correlation between corrosion areas)
- Other non-parametric techniques
- Application of a "known" naturally corroded specimen as test dataset

Questions ?



NASA's "Vomit Comet"