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Rail Integrity Research at TTCI

Ananyo Banerjee, Ph.D.

Principal Investigator

ananyo_banerjee@aar.com

Presentation Outline

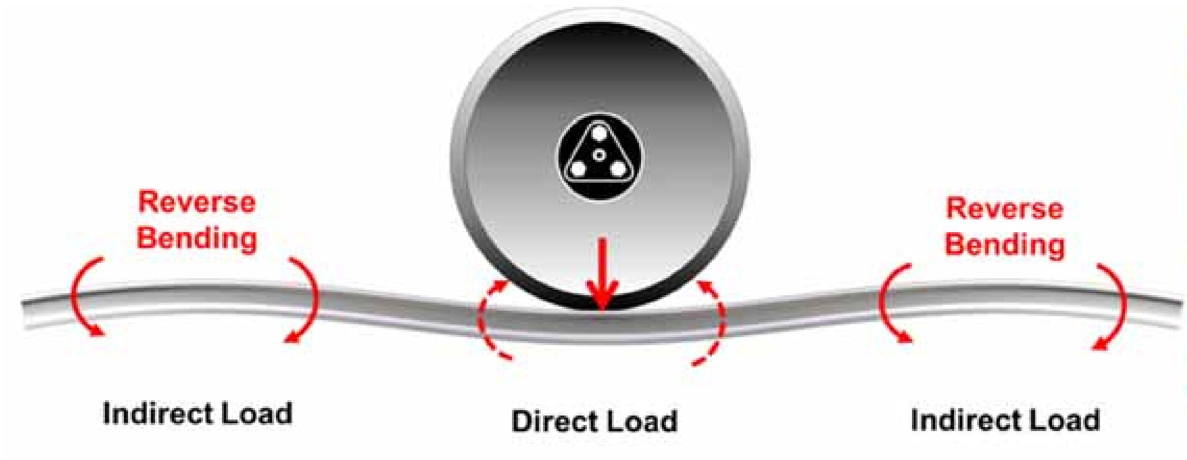
- Why study rail integrity?
- TTCI's RailGrow model
- Fatigue testing of rails under simulated wheel loads
- Residual stress analysis
- Rail defect prediction using machine learning
- Concluding remarks


Rail with transverse defect after fracture

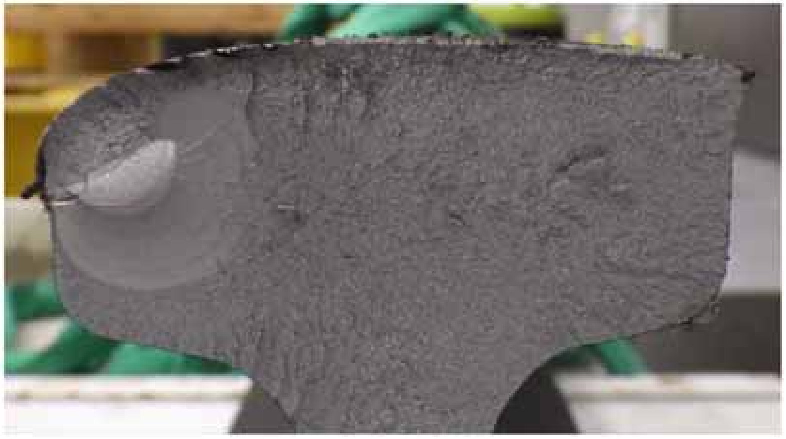
Why Study Rail Integrity?

- **Challenges**
  - Understanding how transverse defects (TDs) form and grow due to rail bending
  - Understanding how residual and thermal stresses affect TD growth rates
  - How different parameters influence probability of defect to form in a rail

Rail is subjected to alternate bending moments



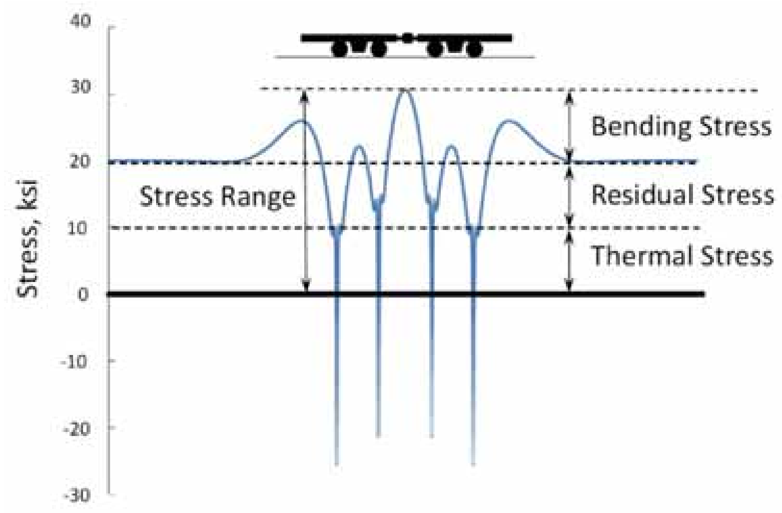
Worn rail with transverse defect at gage corner



Fracture Mechanics Model (RailGrow)

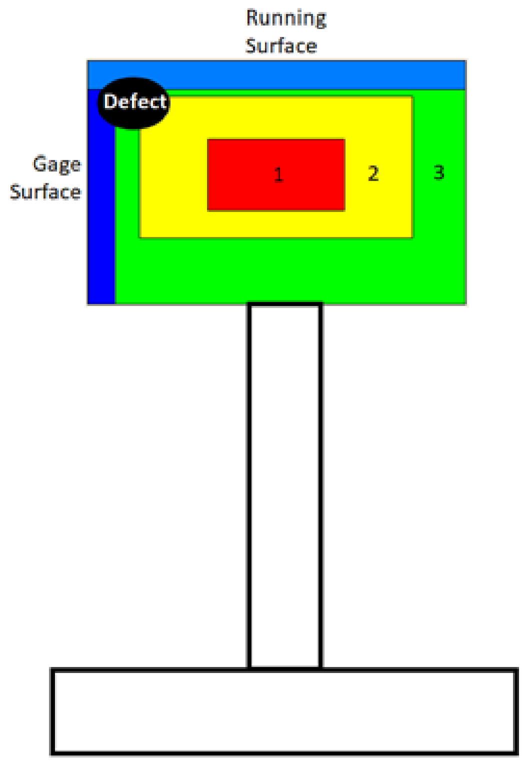
- **TD growth predicted as a function of million gross tons (MGT) to fracture**
  - Rail modeled as a continuous beam on an elastic foundation
  - Rail is subjected to:
    - Wheel loads (bending stresses)
    - Thermal stresses
    - Residual stresses

Combination of stresses experienced by a rail



The RailGrow Model

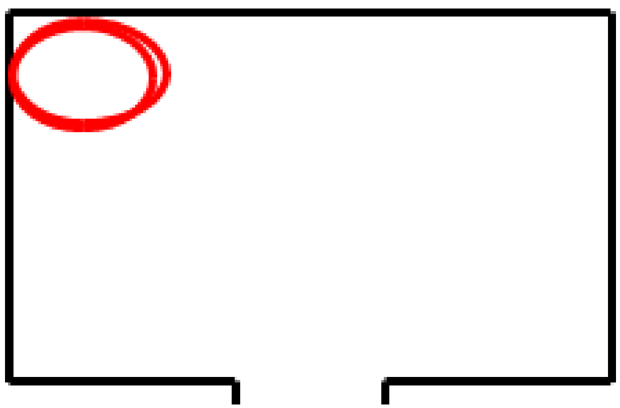
Simplified residual stress distribution modeled in RailGrow

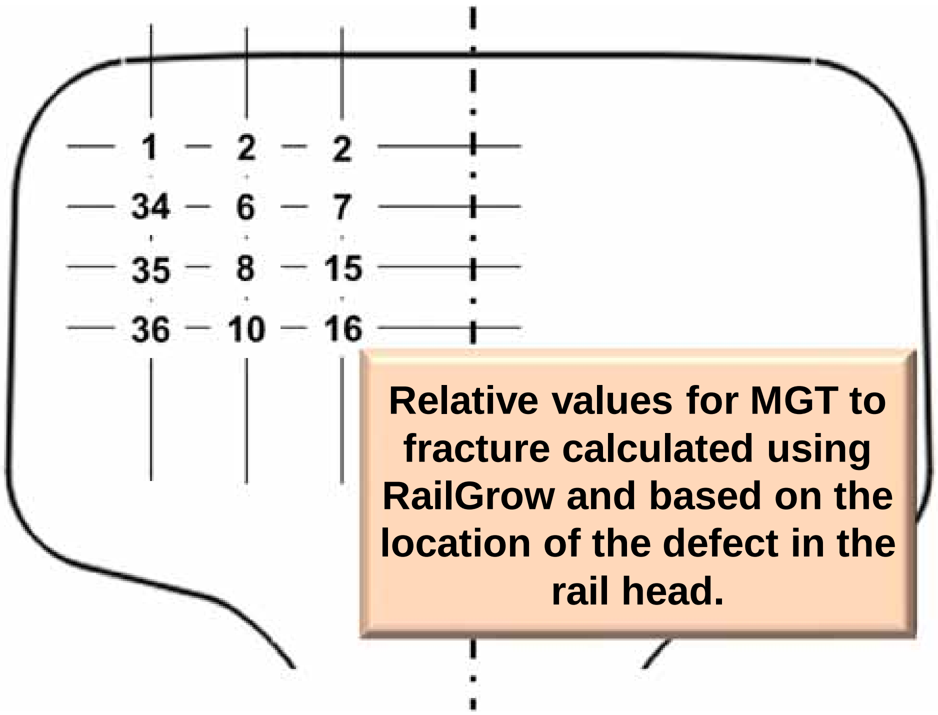


- **TD growth is affected by:**
  - Thermal stress (temperature deviation from neutral temperature)
  - Residual stress (single value vs. distribution)
  - Track modulus
  - Wheel loads (vertical and lateral)
  - Location and initial size of TD
  - Rail size (Example: 136RE)
  - Material properties of rail steels

TD Sensitivity

- **TD growth is sensitive to:**
  - Location in rail head
  - Residual stress distribution
  - Combination of above factors

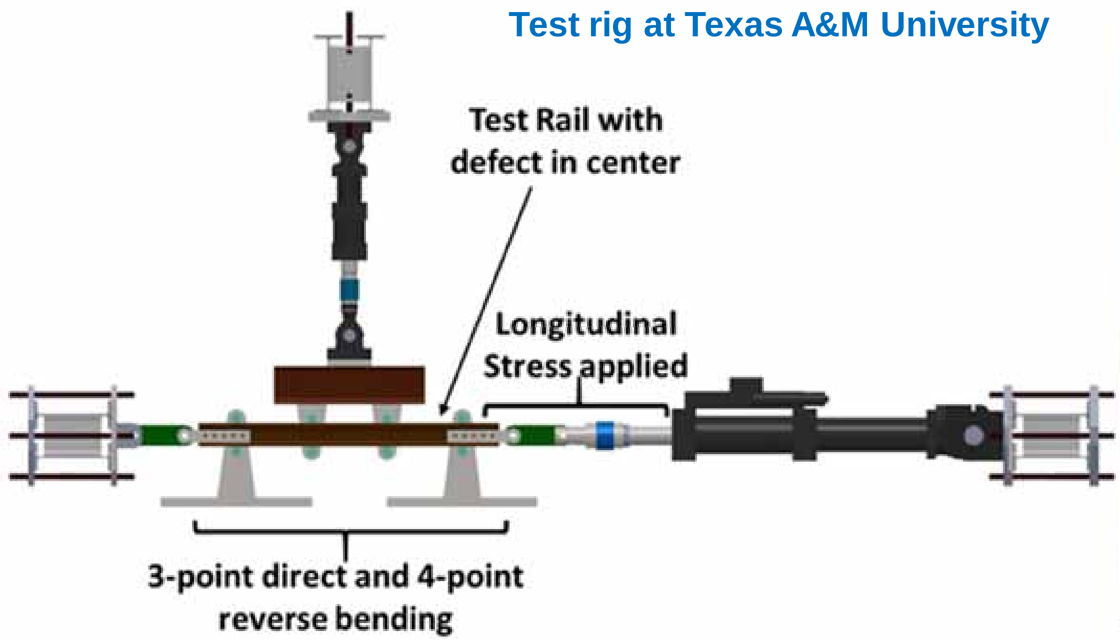




Testing of Rails Under Simulated Wheel Loads

- **Worn rails with detected TDs**
  - Simulated wheel loads applied with longitudinal stress

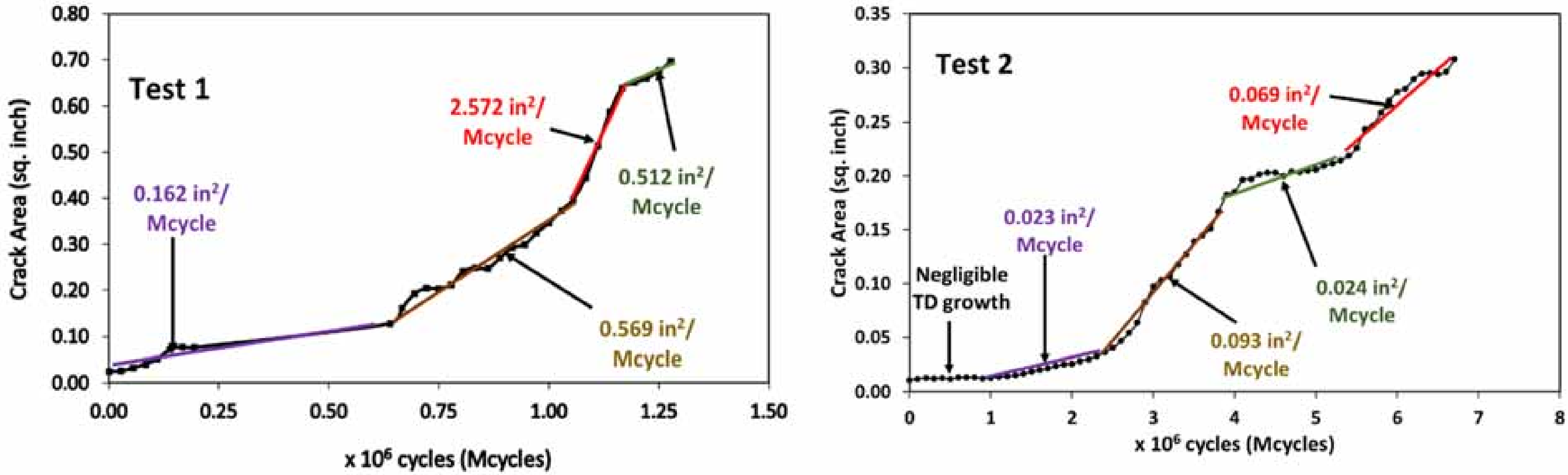
Test rig at Texas A&M University



Testing of Rails under Simulated Wheel Loads

- **TD growth rates are variable**
  - Same wheel loads and thermal stress applied for both tests

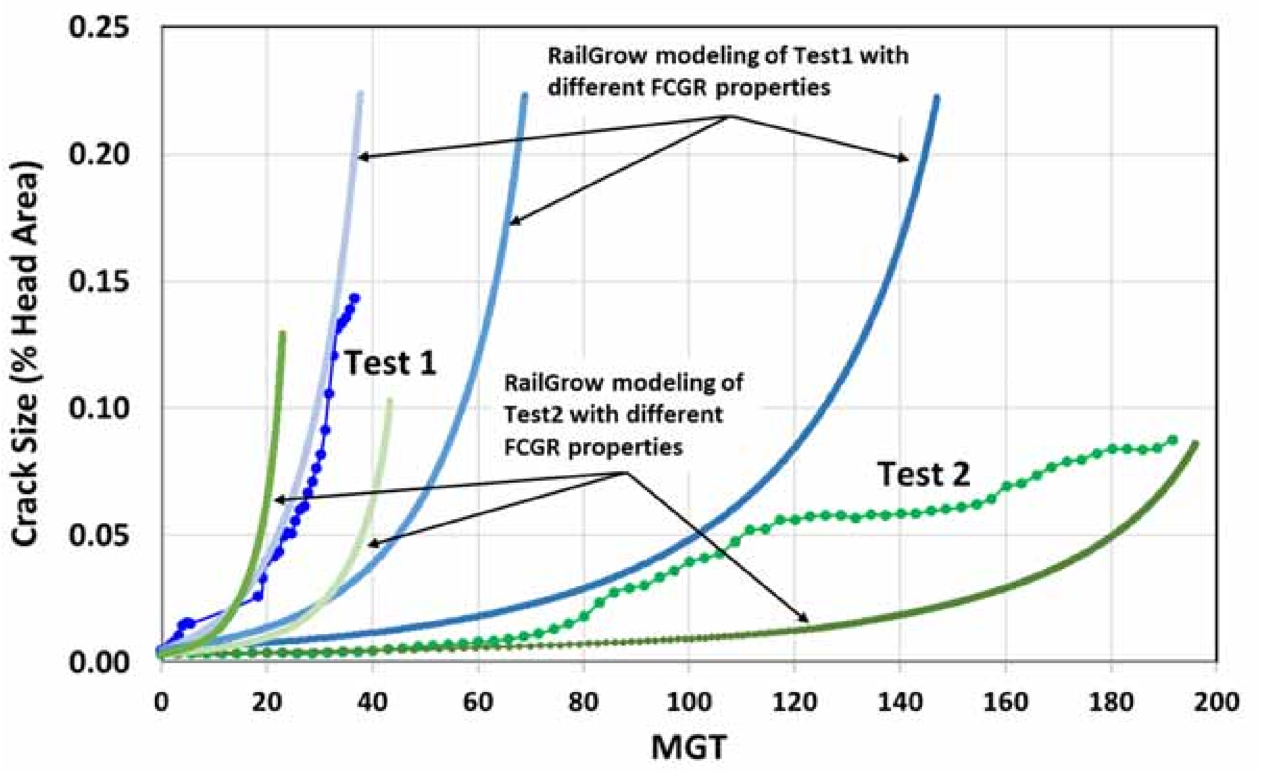
TD growth rate curves showing variable growth rates



Testing of Rails under Simulated Wheel Loads

- **Validating tests with RailGrow are influenced by:**
  - Residual stress
  - Fatigue crack growth rate (FCGR) properties of rail steels

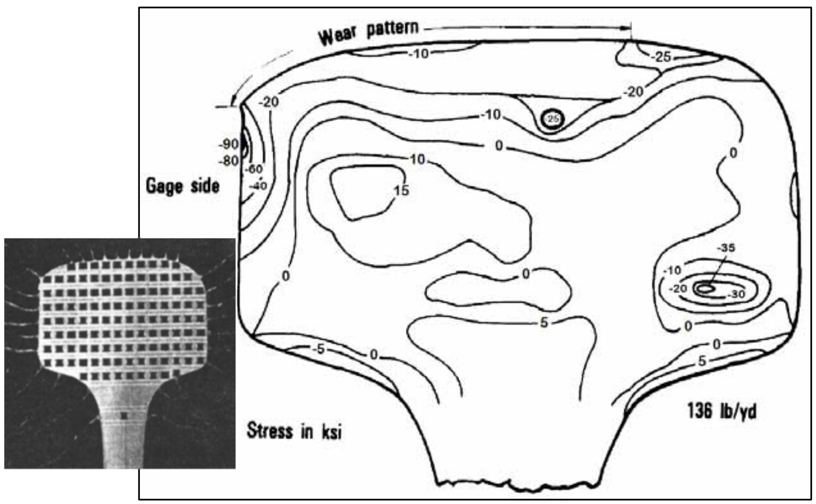
RailGrow predictions and rail test data comparison due to FCGR variation



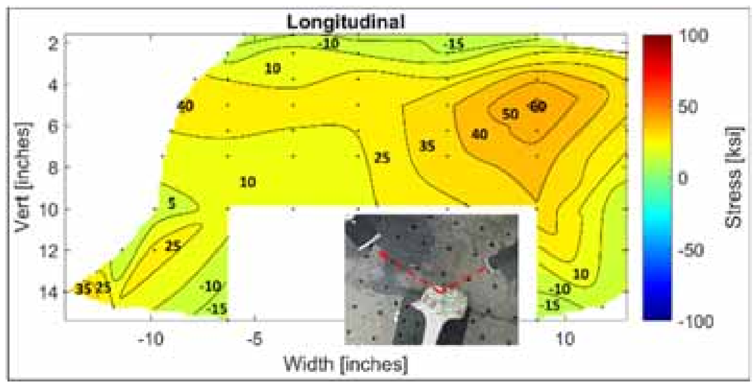
Residual Stress Analysis

- **Older methods included strain gages**
- **Newer methods provide stress maps without gauges**
  - Neutron diffraction, contour method

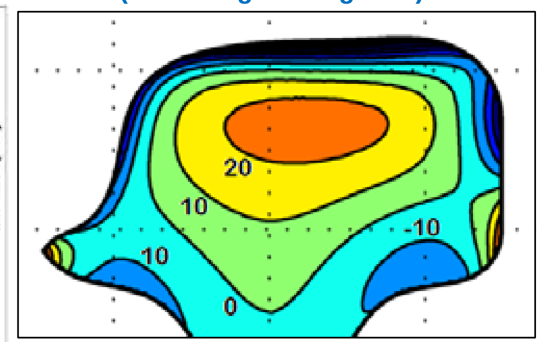
Strain gage method



Neutron Diffraction
(© Oak Ridge National Laboratory)



Contour Method
(© Hill Engineering LLC)



Neutron/X-ray Diffraction vs. Contour Method

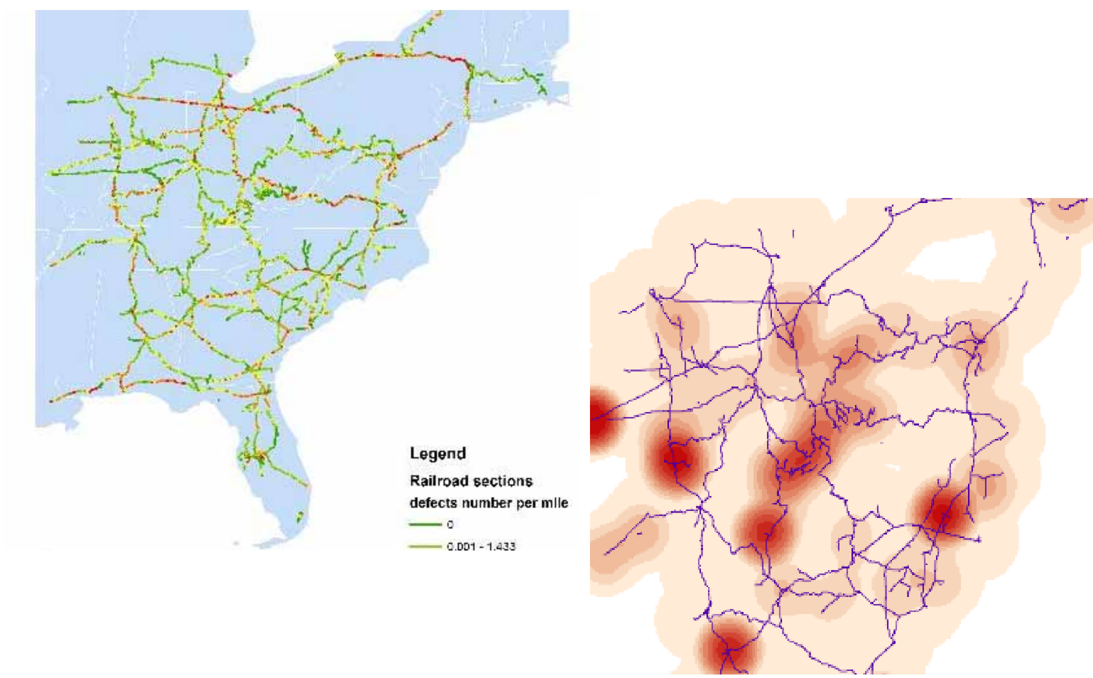
- **Contour Method**
  - Destructive method
  - Measures strains in longitudinal axis only
  - Provides stress map of entire cross-section
- **Neutron/X-ray Diffraction**
  - Non-destructive method
  - Measures strains in all 3 axes
  - Suitable for thin cross-sections or locations close to the surface

Precision metrology equipment measuring surface heights of rail cross section
(© Hill Engineering LLC)

Rail placed for Neutron Diffraction
(© Oak Ridge National Laboratory)

Rail Defect Prediction Model- Reasons for Development

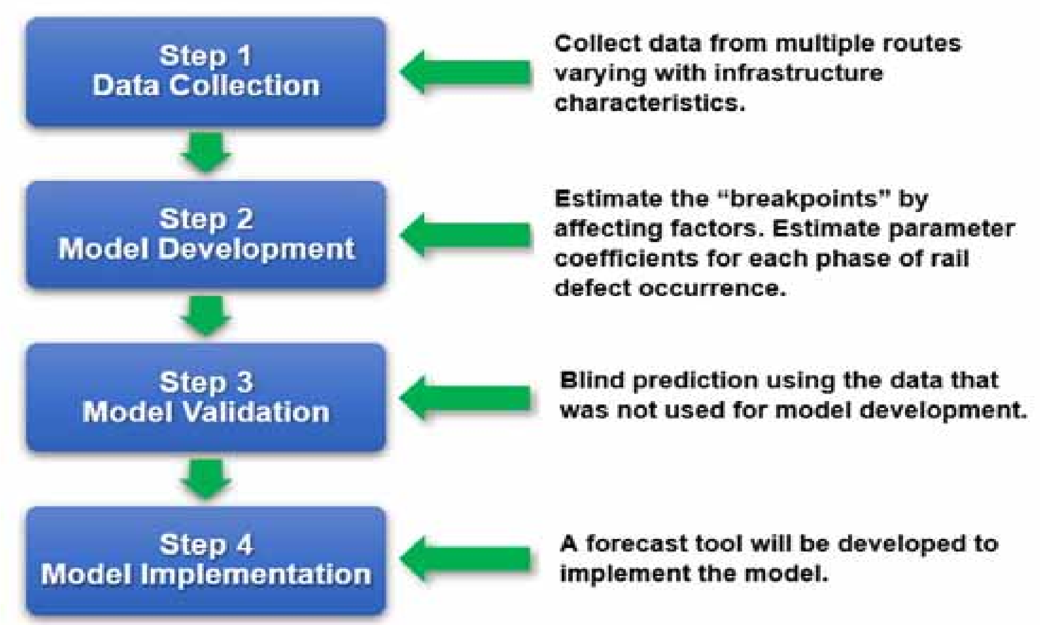
- **Probability of rail defect**
  - Is it high in specific sub-divisions?
  - How maintenance strategy needs to be changed?
  - Which operational parameters need to be changed?



Hypothetical mock-up of risk screening on the network

Rail Defect Prediction Model- Steps

- **Probability depends on**
  - Defect history
  - Track characteristics
  - Operational information
  - Maintenance activity
    - rail grinding
    - ballast cleaning
- **4-step procedure of model development**



Four-step process in developing a rail defect statistical prediction model

Rail Defect Prediction Model- Inputs and Output

- **Model Inputs can be changed to see trend of output value**
- **Output is a probability value between 0 and 1**

PREDICT

The Estimated Probability of Rail Fatigue Defects is

0.4865

Output of the model

Input	Input Range	Default Value
Rail age (years)	0-80	24
Segment length (miles)	0-10	0.25
Annual traffic density (MGT)	0-100	20
Annual number of car passes (in thousands)	0-700	250
Maximum allowed speed (mph)	0-60	35
Curve (degrees)	0-20	0 for tangent; 3 for curved track
Grade (percent)	0-4	0.4
Rail position	Tangent rail, high rail, low rail	Tangent rail
Rail size (lbs./yard)	0-155	132
Number of turnouts per mile	0-2	0.5
Rail quality index	New rail, re-laid rail	New rail
Number of ballast cleaning per year	0-2	0
Number of grinding passes per year	0-4	1
Number of prior defects (all types) per mile per year	0-10	0.3
Number of prior vehicle track interaction (VTI) exceptions per mile per year	0-15	0.5
Number of prior track geometry defects per mile per year	0-10	2

Inputs for the prediction model

Concluding Remarks

- **RailGrow model uses fracture mechanics to predict TD growth rate as a function of tonnage**
- **TD growth is sensitive to location and residual stress distribution**
- **Testing rails with defects under simulated loads show variable TD growth rates**
- **Methods of analyzing residual stresses provide insight to TD growth rate variability; each method has its pros and cons**
- **Rail defect prediction model uses various parameters based on historical big data to give probability of defect formation**

THANK YOU