Tie Life Condition Assessment and Tracking: More Information = Better Management

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PART 1: FIELD INSPECTION & EXPERIENCE
Aurora® 3D Tie Inspection

• Surface Condition
• Split
• Plate Cut
• Warped
• Broken

“This is great, but what about hollow ties?”
X-Ray Transmission vs Backscatter

Source

X-Rays

Target

Scatter Detector(s)

Transmission Detector
Aurora Xi® Inspection Platform

Combines 3D surface scan with X-Ray backscatter internal imaging

25 MPH continuous scanning
Aurora Xi® – Internal Defective Tie Cluster
Defective Tie Cluster – Field Inspection
Predominant Internal Failure Modes

Deep Splitting

Localized Hollowness

Uniform Density Loss
X-Ray Grading Scale

- Good
- Marginal
- Bad
- Failed
Texas Chainsaw Massacre/Experiment
More Destructive Testing (Failed Tie)

- Tie # 5570: Surface Score = 2.0, Internal Score = 4.0, Xi Score = 4.0
- Auditor could not determine hollowness upon inspection

- Image above left: Tie with white paint line to indicate where to cut
- Image above right: Cross section demonstrating sizable void in center of tie, top surface fell apart during cut
Observed High Degradation Rate

01/15/2016 – Surface Score 1.6, Internal Score 1.7 = Marginal Tie

11/10/2017 – Surface Score 1.8, Internal Score 3.7 = Failed Tie

22 Months Elapsed...Some Tie Replacement Occurred
Observed Low Degradation Rate

01/15/2016 – Surface Score 1.0, Internal Score 1.1 = **Good Tie**

11/10/2017 – Surface Score 1.1, Internal Score 1.4 = **Good Tie**

* 5 ties away from previous tie
Short Term Tie Condition Trending

• No context of service environment
• No history
Characterizing Full Tie Life History

- Initial condition
- Inspected condition over time
- Predicted end of service life
Aurora Surface & X-Ray Scans    01/14/2016

Rapid Tie Disintegration
Rapid Tie Disintegration

Picture taken 01/18/2017

Tie 1537

Tie 1538
Aurora Xi
- Tie Surface Condition
- Tie Internal Condition
- Plate & Fastener
- Track Curvature
- GPS Coordinates
  - Decay Zone
- Line & Milepost
- Proximity to:
  - Rail Joints
  - Switch, Crossing, Bridge

RR Added Information
- Tonnage
- Traffic Characteristics
- Gradient
- Track Geometry Condition
- Ballast Condition
- Last T&S Cycle
- Other Maintenance Activity
Tracking Tie Condition Over Life, Part 1

TIE IN TRACK

- Remove & Replace
- Depends on Local Conditions
- Keep in Track
PART 2: ECONOMIC INCENTIVES
• Crossties Magazine, October 2017:

<table>
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<tr>
<th>Type</th>
<th>Track</th>
<th>Switch</th>
<th>Bridge</th>
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<tbody>
<tr>
<td>Class I</td>
<td>15.85</td>
<td>0.51</td>
<td>0.15</td>
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<tr>
<td>Short Line*</td>
<td>5.26</td>
<td>0.74</td>
<td>0.44</td>
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<tr>
<td>Total</td>
<td>21.11</td>
<td>1.25</td>
<td>0.59</td>
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<tr>
<td>* extrapolated</td>
<td></td>
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<td>22.95</td>
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• 2017 RTA conference purchasing forum
  • Class I RRs continue to demand wood ties
  • One of highest capital spend categories is wood ties

• Recent issues with tie quality
Optimizing Tie Life Cycle – Replace Too Soon

- Exponential degradation over 30 years
- $150 initial value, $0 salvage value after 25 years

Replacement at 20 years is loss of $28.30 in remaining value.
For 2.5M tie program with 2% early replacement this is $1.42M
Optimizing Tie Life Cycle – Replace Too Late Neighbor Effects

If Tie #1 not supporting rail:
- Increased rail deflection
- Increased rail bending stress
- Increased rail seat forces on neighbor ties
- Increased neighbor tie degradation rate
- Increased bearing pressure on ballast

Fig. IV.9. Determination of rail-seat forces from the p(x)-curve

<table>
<thead>
<tr>
<th>Rail Seat Force</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
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<tbody>
<tr>
<td>Fn</td>
<td>6928</td>
<td>5865</td>
<td>3588</td>
<td>1863</td>
<td>759</td>
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<tr>
<td>% of Load</td>
<td>23.1</td>
<td>19.6</td>
<td>12</td>
<td>6.2</td>
<td>2.5</td>
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</tbody>
</table>

132RE rail
k = 3000 lb/in^2

PART 3: INITIAL CONDITIONS
Plant Tie Scanner Motivation

- Railroads spend about $2.4B/yr on ~23M crossties
- Human inspectors guess at the internal density and quality
- Transmission and/or scatter x-ray radiography can directly measure internal density and quality
• An untreated crosstie was mounted on a rotating pivot.  
  (*It’s easier to rotate the tie than rotating the heavy shielded X-ray tube.*)

• The crosstie was rolled through the fan beam to make transmission images.
Plant Tie Scanner – 2D and 3D

- One or more fan beams of x-rays illuminates the crosstie
- The surface is scanned and imaged
- 2D and 3D (CT) images are formed from transmitted and/or scattered x-rays
Perpendicular X-ray Perspectives

- Wood Density
- Splits
- Rot
- Other imperfections & variances

From Above through 7” of wood. (0deg)

From Side through 9” of wood. (90deg)
• Wood Density + Surface Characteristics $\rightarrow$ Species ID
• Treatment Penetration

Any color scale of raw/processed data is possible.

Gradient views and edge detection is also possible.
Tie Inspection at Production Plant

- **Scan Green Wood**
  - Surface Metrics
    - Species ID
    - Dimensions
    - Splits, bark seams, shake, etc.
  - Internal Metrics
    - Density variations
    - Rot, voids
    - Potentially a ‘moisture’ image

- **Scan Treated Wood**
  - Surface Metrics
  - Internal Metrics
    - New density
    - Treatment saturation
    - Treatment penetration depth

- **Attach all information to individual tie**
  - ID Tag
Tracking Tie Condition Over Life, Part 2

GREEN TIE

- Accept
- Reject

TREATED TIE

- Reject
- Industrial
- Secondary
- Main Line

TIE IN TRACK

- Remove & Replace
- Depends on Local Conditions
- Keep in Track
PART 3: END GOALS
Predicting End of Tie Life

Whole Tie Life Model

- Oak Tie - Good IC
- Oak Tie - Marginal IC
- Gum Tie - Good IC
- Gum Tie - Marginal IC

Tie Condition Score vs. Date

IC Oak = 2
IC Gum = 2
IC Oak = 1
IC Gum = 1


GREX - GEORGETOWN RAIL EQUIPMENT COMPANY
Executing Surgical Tie Replacement

- Tie Replacement Logic needed
- Tie Allotment/Budget constraints

Grade Threshold = 1105/mile

Replacement Logic = 1183/mile

Budget Constraint = 950/mile

- Automated Tie Marking System →
Tracking Tie Condition Over Life, Part 3

- **Green Tie**:
  - Reject: 4
  - Accept: 2

- **Treated Tie**:
  - Reject: 3
  - Industrial: 2
  - Secondary: 1
  - Main Line: 1

- **Tie in Track**:
  - Remove & Replace: 4
  - Depends on Local Conditions: 3
  - Keep in Track: 2

- **Removed Tie**:
  - Cogen: 4
  - Landscape: 3
  - Relay: 2
Building a Tie Life Cycle Model

- Inputs for track characteristics
- Determine attributes
  - Species
  - Size
- Determine initial condition
  - Density
  - Defects
- Measure condition in service over time
- Predict failure life/replacement threshold
- Replace the correct ties
• Large scale historical data for several North American railroads
  • Aurora – Laser Surface Scanning
    • 12 years of experience
    • 210,000 miles
    • 664 M ties scanned overall
  • Aurora Xi – Backscatter X-ray Inspection
    • 4 years of experience
    • 54,000 miles
    • 170 M ties scanned by X-ray
  • 550 TB raw data
• Repeated scanning
  • Locations scanned annually since 2012
  • Locations scanned 6+ times since 2014
Challenges

• ID Tag on new tie
  • Transfer tag to in-track service

• Tracking tie in service
  • Positive ID of same tie
  • Optimal evaluation conditions
    • Ballast, mud, etc.

• Logging accurate track properties
  • Tonnage
  • Environmental factors
  • Maintenance activity

• Dealing with Incomplete Data
• System for tracking asset over life of 20-50 years
• Volume of assets → **BIG DATA**
  • 1000 track miles is > 3M assets

• Data storage/retrieval
End Goals - The Future

• Complete first-of-a-kind bridge tie x-ray scanner.
• Combine data streams.
• Leverage true neural-net AI on combined data.
• Improve predictive capabilities and accuracy.
• Accomplish every task faster and more efficiently.
• Invent entirely new sensors for new measurements.