Overview of Track Maintenance Planning

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Railroad Engineering and Maintenance

- Evolution of railroad track, and key components, paralleled by evolution in railroad engineering
- Early railroad engineering focused on “building” the railroad
  - Strong emphasis on construction techniques, bridge and tunnel engineering and route alignment engineering
- Modern railroad engineering focused on improved analytical tools, better designs, and improved maintenance procedures
  - Improve track structure’s strength and ability to carry heavy loads
  - To last longer and perform more efficiently
- Dependent of traffic type and characteristics
  - Axle load, Speed, Density of traffic
Purpose of Railroad Track Structure

• Support the loads of cars and locomotives
• Guide their movement
Function: Withstand and Distribute Loads
Pyramid of Bearing Stresses

- **Wheel/Rail Contact Stress**: ~100,000 psi/13.3 MPa
- **Rail Bending Stress**: <25,000 psi / 3.3 MPa
- **Tie Bearing Stress**: <200 psi/26.6 kPa
- **Ballast Bearing Stress**: <85 psi/11.3 kPa
- **Subgrade Bearing Stress**: <20 psi/2.6 kPa
Focus of Engineering Analysis

- Strength of the track and its components
  - Ability to resist catastrophic failure
- Ability to resist long term degradation or deterioration
  - Maintain geometric integrity
  - Reduce/control maintenance requirements over extended periods
    - Extend the life of track components
    - Reduce/control rate of track degradation
    - Identify/rectify problems before catastrophic failure
Railroad Engineering

• Current practice can be divided into two broad categories
  – Design based engineering
  – Maintenance based engineering

• Difference in focus and approach
  – Railroad design engineers primarily concerned with building new track
  – Railroad maintenance personnel being primarily concerned with maintaining existing track
    • Major focus today
Design Based Engineering:

- Design based engineering concerned with track systems, subsystems, or individual components
- “Standardized” tools presented by AREMA Manual for Railroad Engineering
- “Modern” railroad engineering starts with Beam On Elastic Foundation (BOEF) theory
  - Treats track structure as rail beam sitting on a continuous linear elastic foundation (k)
    - Representing the cross-ties, ballast and subgrade
  - Calculate rail stresses and deflections
  - Tie pressures
Beam on Elastic Foundation Model

\[ EI \frac{d^4 w(x)}{dx^4} + kw(x) = q(x) \]

\[ w(x) = \frac{P \beta}{2k} e^{-\beta x} \left[ \cos(\beta x) + \sin(\beta x) \right] \]

\[ M(x) = \frac{P}{4\beta} e^{-\beta x} \left[ \cos(\beta x) - \sin(\beta x) \right] \]
Maintenance Based Engineering

- Maintenance based engineering is concerned with existing track and how to optimize its performance
  - long term railroad environment
  - increasing loads
- Focus is usually on specific component or subsystems
  - Different focus for HAL freight and high speed passenger
- Engineering analyses and studies in conjunction with empirical development of maintenance practices
- Maintenance engineering focus of last 40 years
  - Under heavy axle load operations, rail represents highest maintenance and replacement cost area for track structure
  - Under high speed passenger operations; track geometry represents highest maintenance cost area
- Safety is a major area of concern
Railroad Load Environment

• Vertical Loadings
  – From railway vehicles
  – Basis for design engineering

• Lateral Loadings
  – From railway vehicles

• Longitudinal Loadings
  – From railway vehicles
  – From environment (temperature effects)
### Static Wheel Loads - Worldwide

<table>
<thead>
<tr>
<th>Axle Load</th>
<th>Gross Weight of Cars</th>
<th>Traffic Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonnes</td>
<td>Tons</td>
<td>kN</td>
</tr>
<tr>
<td>8</td>
<td>8.8</td>
<td>310</td>
</tr>
<tr>
<td>12</td>
<td>13.2</td>
<td>470</td>
</tr>
<tr>
<td>17</td>
<td>19</td>
<td>670</td>
</tr>
<tr>
<td>22.5</td>
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<td>880</td>
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<tr>
<td>25</td>
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<td>980</td>
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<tr>
<td>30</td>
<td>33</td>
<td>1170</td>
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<td>32.5</td>
<td>36</td>
<td>1270</td>
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<td>39</td>
<td>1400-</td>
</tr>
<tr>
<td>41</td>
<td>45</td>
<td>1600</td>
</tr>
</tbody>
</table>

Dynamic loads can be 3+ times static load
Current AAR dynamic wheel load limit is 90,000 lbs (400 kN)
Heavy Axle Load Freight Train
Heavy Axle Load Track Issues

• Design of track to allow for heavy axle loads
  – Minimum grades
    • Grades < 3%
  – Elevation
    • Issue for mixed passenger and freight traffic
  – High load/stress environment
    • Rapid degradation of track components
    • Potential for catastrophic failure/derailments

• Track maintenance
  – Focus on component degradation and failure
  – Needs for long lived components
  – Need for effective maintenance planning and management
High Speed Rail
High Speed Rail

• Speed has a major effect on loading and track system requirements
• “Very” High speed rail defined as speeds greater than 180 mph
  – Highest operating speeds 350 kph (210+mph)
• High speed rail is defined at 125 to 160 mph
  – FRA Class 8
  – Highest speed in US 150 mph (Amtrak NE Corridor)
• FRA Speed categories
  – Class 5 track with passenger train speeds up to 90 mph
  – Class 6 track operating at 90 to 110 mph
  – Class 7 track operating at 110-125 mph
  – Class 8 track operating at 125-160 mph
  – Class 9 track operating at 160-220 mph
High Speed Track Issues

• Design of track to allow for higher speed passenger traffic
  – Minimum curvature
    • Curves < 2 degrees (3000 foot radius)
  – High elevation (6 inches)/ unbalance (> 4’)
    • Issue for mixed passenger and freight traffic
  – Tight track geometry requirements
  – Uniform track support
  – Enhanced grade crossing protection

• Track maintenance
  – Focus on track geometry maintenance
  – Significant costs necessary to maintain track for mixed higher speed passenger and freight operations
Maintenance and Maintenance Planning

- Maintenance is primary focus of existing railway track
- Maintenance approaches
  - Interval based maintenance
    - Time
    - MGT
    - Mileage
  - Condition based maintenance
    - By component
    - By subsystem
      - Tie/fastener
    - Entire track
      - Used when train delay is critical issue
  - Scheduling and Planning key
Maintenance Planning Objectives

• What is in track now?
  – Data Base
  – Ongoing track inspection

• What will I need?
  – Next year (short term)
  – Two to Five years (medium term)
  – Five to Ten+ Years (long term)

• Maintenance Requirement Forecasting
  – Components (Rail, Ties, Ballast)/Dollars

• What should be done first?
  – Prioritization of needs
    • Adjust to changing budgets
  – Ability to Expand/Contract Budget
  – Decision making tools
Maintenance Planning Overview

• System Condition and Defects/Exceptions
• Rail
  – Rail Replacement Forecasting
    • Fatigue Life
    • Wear Life
  – Grinding Requirements/Planning
  – Rail Test Scheduling
• Ties
  – Replacement Analysis
  – Degradation/Forecasting
• Surfacing
  – Spot Maintenance Requirements
  – Forecasting Surfacing Cycles
• Track System Approach
  – Resource Allocation
Projected Wear on 5 Degree Curve

5 deg High Rail - Head Wear

5 deg High Rail - Head Wear Rates
Consolidated Rail Requirement Forecast

![Graph showing historical and forecasted rail requirements](image-url)
Projected Track Geometry Degradation

- Three track segments
  - Highly fouled (red)
  - Moderately fouled (yellow)
  - Relatively clean (green)
Data Analytics Based Geometry Forecasting Model

Cross-Tie Needs Forecast
Maintenance Planning Approaches

- Traditional ("old time railroading")
  - Visual inspection
    - Written reports from the field
  - Consolidation at headquarters and Verification
  - Determination of resource requirements

- Current
  - Extensive use of automated inspection systems
  - Continued use of visual inspection/tack inspectors
  - Analysis of exception reports
  - Use of early generation planning models

- Emerging
  - Increased reliance on automated inspection systems
  - Expanded analysis of data from inspection systems
    - Data Analytics/"Big Data"
  - New generation maintenance forecasting and planning models
  - Improved resource need forecasting and allocation
Currently Available Track Inspection Data

- Track Inspectors (visual)
- Track Geometry Cars
  - Manned
  - Autonomous
- Dynamic load measurements (e.g. VTI)
- Ride Quality (accelerometers)
- Ultrasonic Rail Test Cars (rail Defects)
- Rail Surface Condition Measurements/Corrugations
- Rail Profiles/ Wear (ORIAN, LaseRail, …)
- Tie Condition Data (e.g. Aurora)
- Ground Penetrating Radar based Ballast condition
- Track support/stiffness (M-Rail)
- Automated Turnout Inspection (e.g. ASIV)
Use of Data

• Inspection data can be analyzed and compared with past and future data
• Key issue is converting “lots of data” into “information”
  – Growing use of Data Analytics (“Big Data”)
• Develop degradation and forecasting models
• Develop relationship models between track components and systems
• Develop tools to help make maintenance more efficient
Use of Information

• Identify immediate maintenance needs
  – Short term maintenance
  – Safety focus
  – Extensive use of exception reports
    • Safety/maintenance thresholds
• Plan intermediate and long term maintenance requirements
  – Project track degradation
    • Develop track degradation models
  – Determine maintenance requirements
  – Develop maintenance plan
Elements of an Effective Maintenance Planning System

a) *Track Inspection Data* - both visual (subjective) and measured (objective). Track geometry, flaw detection and other inspection vehicles represent specific examples of the latter class of data.

b) *Track Data Base* - a consolidation of the track information, inspection data, maintenance history and other information into one central, accessible (computer) database.

c) *Track Deterioration Analyses* - relationships that predict the deterioration and/or failure of the key track components and subsystems, based on the information in (a) and (b).

d) *Maintenance Requirement Forecasts* - the resulting output of the track deterioration analyses applied to the track segments within the database.

e) *Policy and Controls* - guidelines that define the application of maintenance procedures to the individual maintenance requirements forecast above.

f) *Costs* - economic and financial constraints imposed upon maintenance activities.

g) *Maintenance Programs* - short-term and long-term work programs.
Summary

• Railroads are moving onto a new era of maintenance management and planning
• Increasing use of multiple inspection systems with a broad range of condition information
• Development of new generation of Data Analytic tools to convert data into useable information
• Degradation, forecasting and planning models will improve maintenance planning in the intermediate and long term
• Allow for improved maintenance practices and reduced costs