**Problem definition:**

- Increased tonnage and HAL will cause increased wear and tear on track structures
  - Track caused accident rate has increased since 1995
  - Substantial train delay due to maintenance & repair of special track work, bridge components, broken rails and welds
  - Rail base defects, rail weld defects and certain transverse rail defects masked by shells are difficult to detect.
  - Turnouts and crossing diamonds are the most costly and maintenance intensive elements of track structure. Insulated joints have become a significant problem.
Problem definition:

- Increased tonnage and HAL will cause increased wear and tear on track structures (Continued)
  - Bridges are the largest track asset. They have been identified as potential economic barriers to axle loads above 286K
  - Despite major improvements in rail performance, RCF resistant steels are needed for heavy haul operations
  - Field welds account for 1/3 of all rail defects on some RRs
AAR Engineering Research Program

- Track Integrity Monitoring
- Special Track Work
- Bridge Research
- Track Components
- Heavy Axle Loads/ FAST
Track Integrity – Improved Rail Flaw Detection

Objectives:
- Improve reliability and accuracy of rail defect detection systems

Major Tasks in 2003:
- Detector car evaluations at RDTF
- Facilitate development of advanced NDT technology
  - Laser-Air Hybrid Ultrasonic Testing (LAHUT) (Johns Hopkins University)
  - Low Frequency Eddy Current (LFEC)
- Cooperative efforts with FRA
  - Rail defect growth evaluation
  - Service failure characterization
**Track Integrity – Improved Rail Flaw Detection**

**Key findings:**

- The growth of various flaws are being monitored “in track,” at FAST
  - Monitoring provides “real” flaw growth data
  - Validation of fracture mechanics based models
  - Defect management tool to optimize rail inspection strategies

- **Service failure characterization**
  - Flaw orientation influences detection capability. Ex: 44% CHA defect
    - Flaw orientation at 90 degrees from perpendicular
    - Shelling reflects ultrasonic signal masking transverse defects (TDs)
Emerging Technologies for Rail Defect Detection

- Capacitive Air-Coupled Transducer
- LAHUT Proof of Concept Vertical Split Head Inspection
- Low Frequency Eddy Current
  - Targets TD’s and TD’s under shells
- Ultrasonic Testing
  - Targets head, web, and base defects using
    - Phased array technology
    - Laser technology
Track Integrity – Improved Rail Flaw Detection

Path Forward

◆ The LAHUT system is conceptually sound
◆ Make technology available to the railroad industry
◆ System requires further development such as:
  ◆ Optimize transducer setup for various defect types
  ◆ Field design for laser and optics
  ◆ Automated pattern recognition system

Laser to Air Coupled Ultrasonic Inspection

Remote/non-contact NDT method with demonstrated base inspection capability
Improved Rail Flaw Detection - Summary

- North American detector car evaluations show reliability in line with AREMA guidelines for detail fractures between the sizes of 10 to 30 percent CSHA.

- Characterization of service failures (i.e., missed flaws) assists in increasing detection reliability by providing a greater understanding of the inspection environment.

- Development of LAHUT and LFEC NDT systems are continuing to be pursued to increase the reliability of inspection for the total rail section (head, web, and base).
SRI 9: Special Track Work

Major Tasks in 2003

- Evaluation of existing insulated joint designs
- Testing of new design turnout prototype at FAST
- AAR Switch Point Evaluation
- Revenue Service Evaluation of Frog Running Surface Profile Designs
- Bainitic Steel Frog Revenue Service Tests
- Ramped Crossing Revenue Service Evaluation
- Flange Bearing Frog Revenue Service Evaluations
- Reduced Impact Foundation Design
- Bridge Joint Performance Analysis
- Special Track Work Component Evaluations
- Reports & TD’s: 7 issued in 2002, 4 in 2003
Insulated Joint Failure Modes (from examination of HAL joints)

- Resistance
- Debonding
- Thimbles
- Bar Insul.
- End Post
- Broken Bolts
- Bolt Hole Crack
- Loose Bolts
- Bar Crack

OCCURRENCE

DEFECTS
Analysis of Failed Joints

Thimble – Cracked with Rust

Bar Insulation – Worn and Rubbing with Rail
Background:

- The special loading conditions of frogs (i.e. high impacts) cause track degradation.
- TTCI analysis suggests that adding damping to the crossing will lower maximum dynamic loads.
- Modeling suggests optimal properties to lower dynamic loads (~300 lb/in/sec/tie).
- Hammer tests show that track damping is below optimal (~50 lb/in/sec/tie).
Predicted Optimal Damping

EFFECT OF TRACK DAMPING AT FLANGEWAY GAPS
LOADED 100-TON HOPPER CAR

SPEED=50 mph  90-DEGREE CROSSING DIAMOND

MAXIMUM WHEEL LOAD (lbs)

DIAMOND FOUNDATION DAMPING (lbs/in/sec/tie/rail)
Comparison of Measured Track Damping with Optimal Damping

- Concretes, Good Ballast
- Concretes, Ballast Mat
- Concretes, Undertie Pad
- Woods, Poor Ballast
- Woods, Subgrade Improvements
Frog Running Surface Profile Design

- Longitudinal & Cross section profile frogs
  - Designed to reduce impacts from non-conformal wheel profiles
  - Designed to reduce contact stresses, metal flow grinding

- Revenue Service & FAST results after 150 - 200 MGT:
  - Reduced maintenance
  - Wider wheel/rail contact band
  - 1 weld repair at 110 MGT
  - Reduced point deformation
  - Wings showing RCF & flow
Frog Running Surface Profiles
Profile frogs in Revenue Service

- UP Laramie, WY
  - Mixed Freight
- BNSF Bragdon, CO
  - Unit coal, Mixed Freight
SRI 9: Special Track Work

Summary

◆ Ready to Implement
  ● FBF diamonds
  ● Frog running surface profiles
  ● Bainitic steel for high angle diamonds

◆ Under Development
  ● Next generation TO for FAST
  ● Damped foundations
  ● Guard rail designs
  ● Bridge (Rail) joints
  ● Tampable switch
  ● Insulated joints
SRI#10A Steel Bridges

Objective:

◆ Develop guidelines to extend the life of existing steel bridges, to better assess capacity, and to prioritize maintenance and replacements

Deliverables:

◆ CWR Effects on Long Steel Bridges
◆ Capacity Assessment of Steel Bridges for HAL Lateral Forces
◆ HAL Effects on Welded Steel Bridges
  ● Ultrasonic Impact Treatment (UIT) Technique
  ● Acoustic Emission Monitoring of Crack Growth
CWR Issues on Long Bridges

- CWR broken rail force ~ 1000 kips long. force into bridge
- Rail joints often used with CWR on long bridges to minimize rail forces into bridge
- Bridge rail joint at FAST increased rate of crack growth
- Rail anchoring if no joints, to minimize buckling potential
- Tradeoffs: Cost of joints, joint maintenance, and bridge impact damage vs. broken / buckled rails, bridge and deck damage

![CWR Issues on Long Bridges](image)

**Crack Growth Rate Comparison**

<table>
<thead>
<tr>
<th>Crack Growth Rate Comparison</th>
<th>Before Joint</th>
<th>Joint Installed</th>
<th>After Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Inches/MI)</td>
<td>0.005</td>
<td>0.025</td>
<td>0.03</td>
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</tbody>
</table>
Steel Bridge Lateral Forces

- Current design guidelines date to 1936, HAL equipment ~1986.
  - No existing rating guidelines
- HAL rev. svc. loads similar to AREMA
- Capacity assessment HAL lateral forces
  - Stronger new designs
  - Appropriate rating guidelines to prioritize bridge maintenance

Western US Coal Line
Lead Axle Net Lateral Force
Distribution: Normal

Centrifugal Force and Wind

Ballast Deck
Ultrasonic Impact Treatment of Welds in Girders

- Can UIT prevent cracking at welds?
- Initial application showed 7 ksi reduction in residual stress (nominal live load stress: 9ksi)
- Long term monitoring ongoing at FAST

Acoustic Emission Monitoring of Fatigue Crack Growth

- Long term monitoring at FAST has helped accumulate 700 MGT on bridge with major crack in tension flange
- AE shows major crack is not growing noticeably
- Lack of growth confirmed with recent X-ray and ultrasonic inspections
- AE provides early warning for remedial action
Steel Bridge Summary

- **HAL Lateral Forces**
  - Final statistical analysis work in progress

- **CWR Issues**
  - Test plan in progress for rev. svc. bridge test
  - Awaiting new bridge joint for FAST testing

- **Welded Bridge Issues**
  - Monitoring of UIT long term performance ongoing
  - AE testing continuing on FAST steel bridge
  - Looking for good field demo site for AE installation
Objective:

- Maximize service life, reduce maintenance, and reduce HAL-related problems with concrete railroad bridges

Deliverables:

- Install concrete bridge at FAST
- Tie & ballast performance on concrete bridge decks
- Shear crack issues on concrete bridge spans
FAST Concrete Bridge Plans

Conventional and State-of-the-Art Bridges

16' UP New Standard Slab
42' CN High Performance Box Girders
30' UP New Standard Box Girders

High Tonnage Loop

Existing Steel Bridge Location
Proposed Concrete Bridge Location
Key Donations

- UP to donate 2 state-of-the-art spans
- CN to donate High Performance Concrete span
- Rinker Materials to donate 2 conventional spans
- CP to design caps and foundations
- CSX and NS to donate piles
- UP to drive piles
- BNSF to assist with general construction
- Rinker Materials to donate caps and backwalls
- Waterproofing suppliers to apply waterproofing
SRI#11A Advanced Rail Steels

Objective:

◆ Develop and/or demonstrate advanced rail steels giving lower life-cycle costs than current rail steels

Significance of Rail Research:

◆ The AAR/TTCI bainitic steel research program begun in mid 1980s spurred advances in the field of rail metallurgy
  ● Three manufacturers currently investigating bainitic rail

◆ Rail Expenditures:
  ● $17.4 billion expenditures on rail and other track materials in the last ten years
  ● Rail breaks are the most common cause of track-related derailments totaling $142 million in track and equipment repairs over the last three years
Program Information and Issues

- J6 Bainitic Rail
  - Exceptional rolling contact fatigue performance
  - Mixed wear performance
  - Special track work performance exceptional
  - Welding and 141AB section performance issues

- Current Research Course
  - Perform research to allow welding and manufacture of 141AB J6 rail

- Alternative Course of Action
  - Investigate ultra high carbon steel (UHCS) for use as rail with 1.3 to 2.1% carbon [≥430-500 HB]
    - This will accelerate current manufacturer trend to higher carbon
  - Continue UIUC research to optimize rail metallurgy
SRI#11B Improved Rail Welding

Objective:
- Develop and test improved techniques, materials, installation, and maintenance procedures to enhance the reliability and utility of rail welds

Techniques:
- Minimize the number of thermite welds in track
- Alternative rail welding methods with enhanced performance
- Improve the performance of current thermite welds
- Development of timely laboratory evaluation technique for rail welds
Rail Welding Key Findings

◆ Wide-Gap Welds
  ● Laboratory test results consistent with 1-inch weld
  ◆ Fatigue performance superior to 1-inch
  ● WGW usage implemented by UP and BNSF

◆ Gas-Pressure Welding
  ● Laboratory results equal or superior to flash-butt
  ● In-track GPW equipment currently being developed in Japan and China
Rail Welding Key Findings

- **Thermite Weld Improvements**
  - UIUC thermite weld FEA research – preliminary results
    - Variability in thermite reaction (heat output) may be controlling factor
  - Utilization of WGW for compromised joints
    - 1-inch comp joints no longer allowed in UK

- **Fatigue testing of rail welds**
  - Better replicates service conditions
  - Provides timely data
    - 2 million cycles in 10 days
  - Large database accumulated