Rail integrity: what really matters, and what can be done about it?

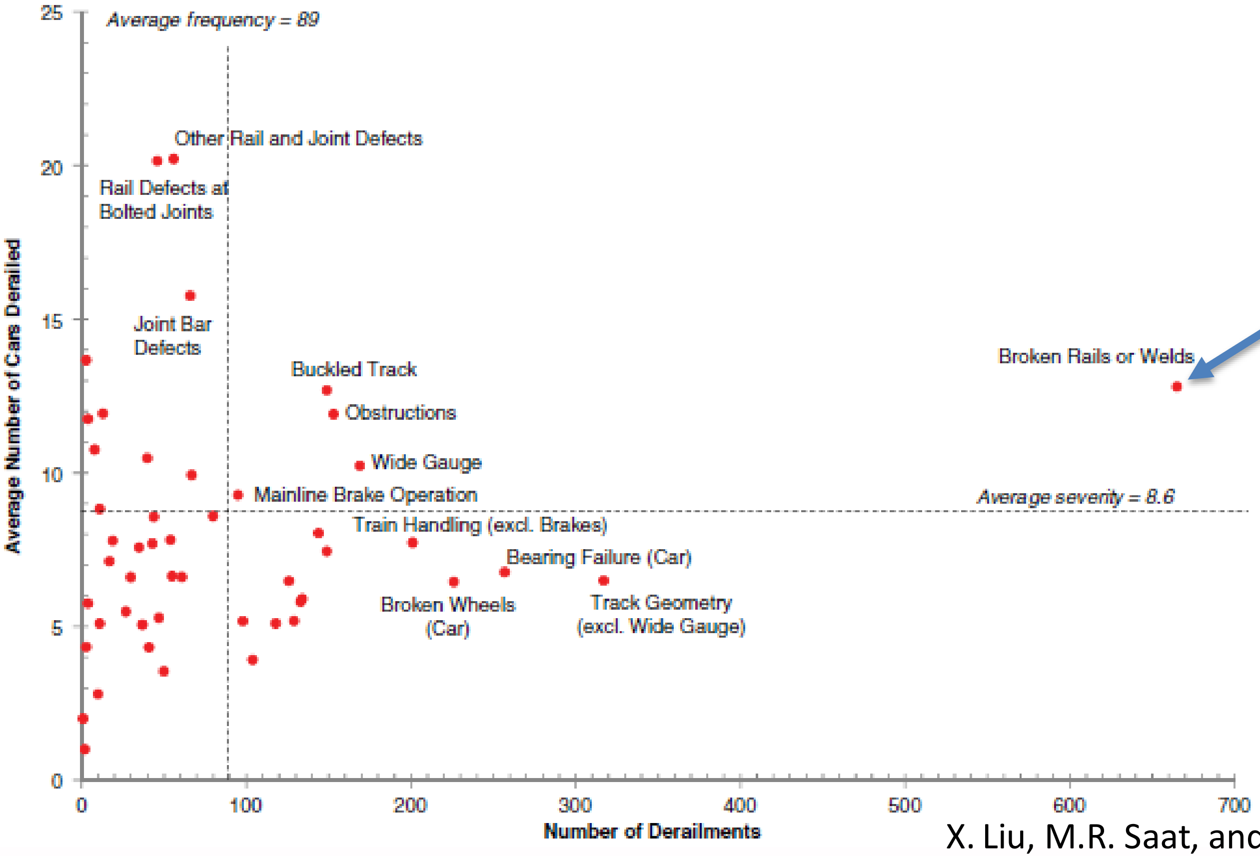
Don Eadie

Don Eadie Consulting and

Advanced Rail Management

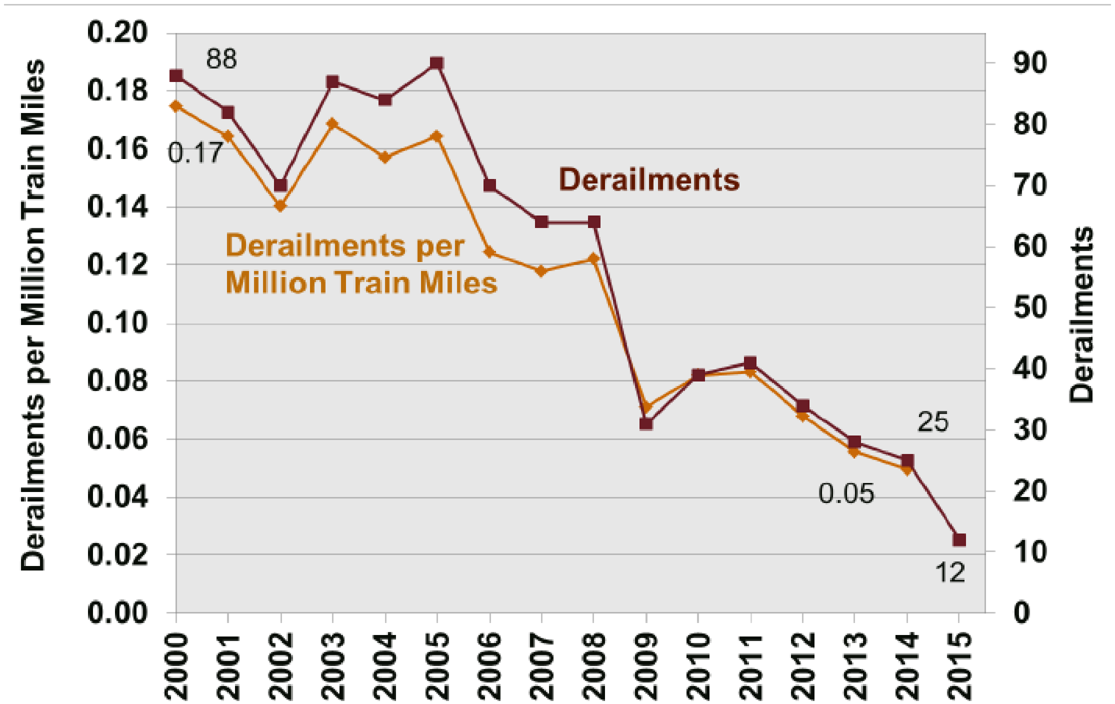
Overview

- Background
- Trends, impacts and major causes of broken rail derailments
- Deconstructing the process:
  - RCF generation → defect growth → ultimate fracture
- Modelling of rail failure and development of limits
- Driving rail break derailments down – where to focus?
- Performance targets
- Conclusions



- **Rail break derailments combine high frequency with high severity**

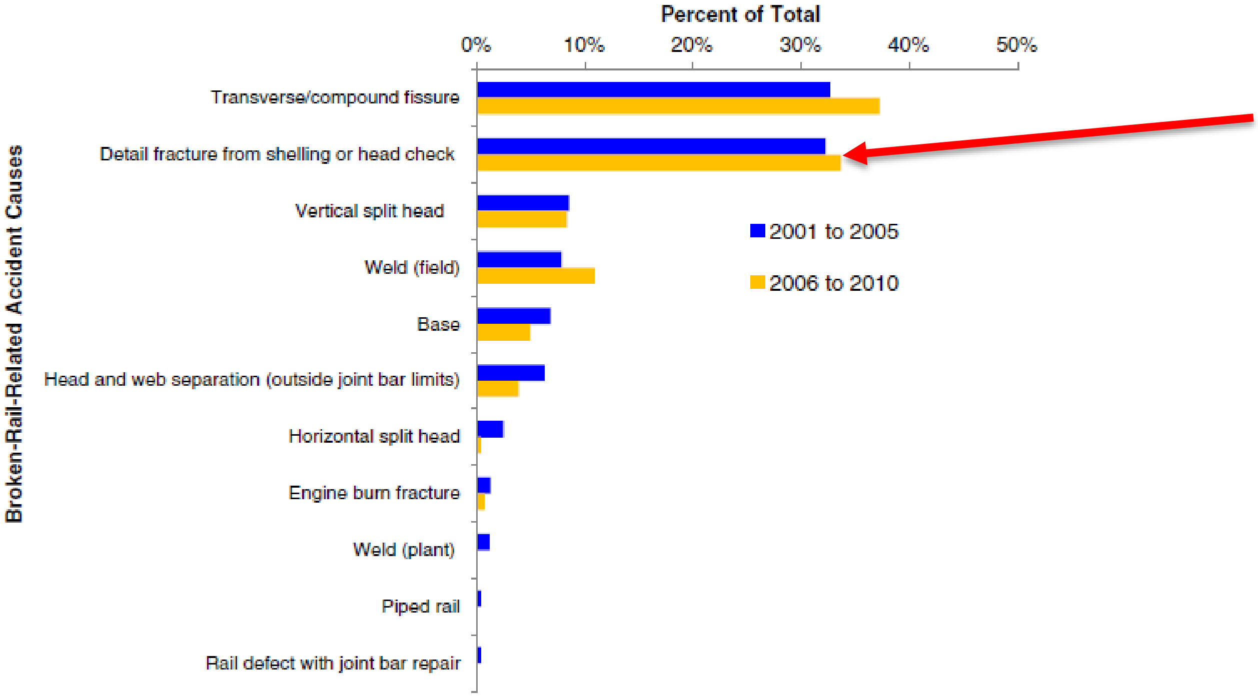
X. Liu, M.R. Saat, and C.P.L. Barkan, “*Analysis of Causes of Major Train Derailment and Their Effect on Accident Rates*”



Source: TTCI Analysis of FRA Train Accident Database, 2000-2014 data as of 1/11/2016. 2015 data is partial (through 11/30/2015) and was queried 2/17/2016. FRA Reported Class 1RR Main Track Accidents plus CP & CN US based RRs added. Filtered by JOINTCD=1; TYPRR=1, 1L, 1S; ACCTRK=1; and by the following CAUSE codes. Broken rail accident cause codes: T201, T202, T207, T208, T210-T212, T218, T220, T221

- But trends are in the right direction….

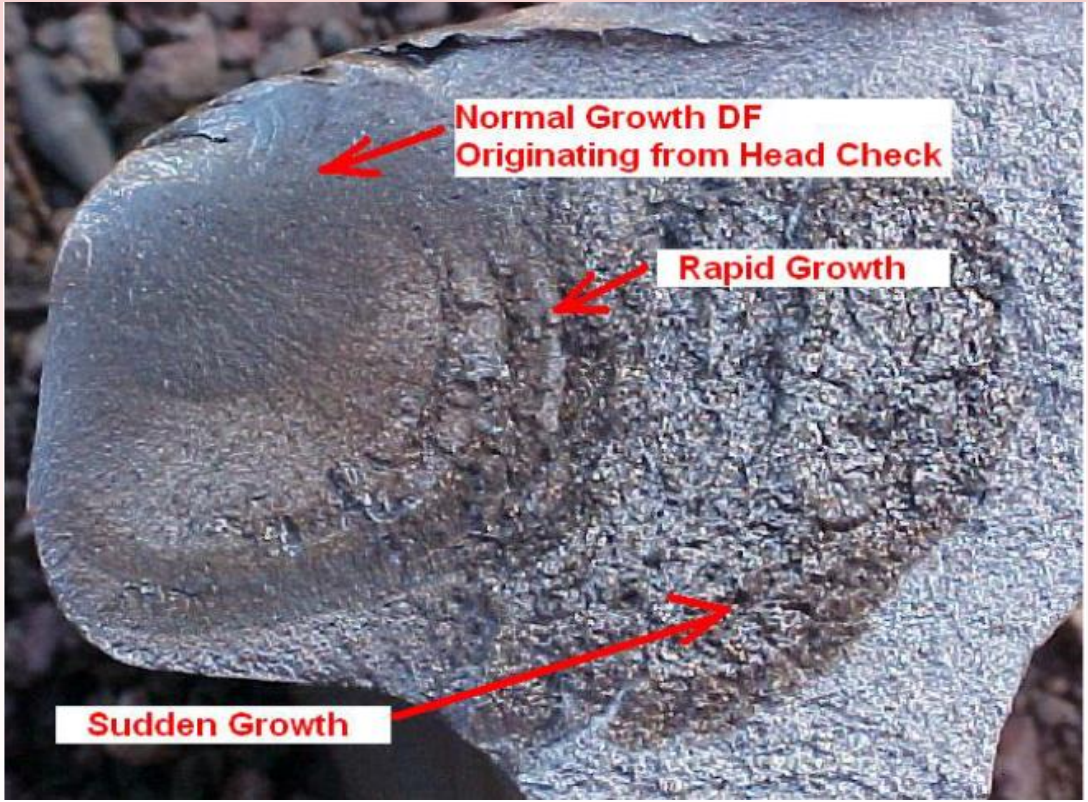
J. Stanford and M Roney, "*Understanding Rail Head Loss and Rail Integrity Interactions*", presentation to FRA Rail Integrity Working Group, February 23 2016



. Distribution of Class I railroad mainline freight train derailments by broken-rail-related accident causes, 2001–2010

- Detail fractures are a major cause of rail break derailments

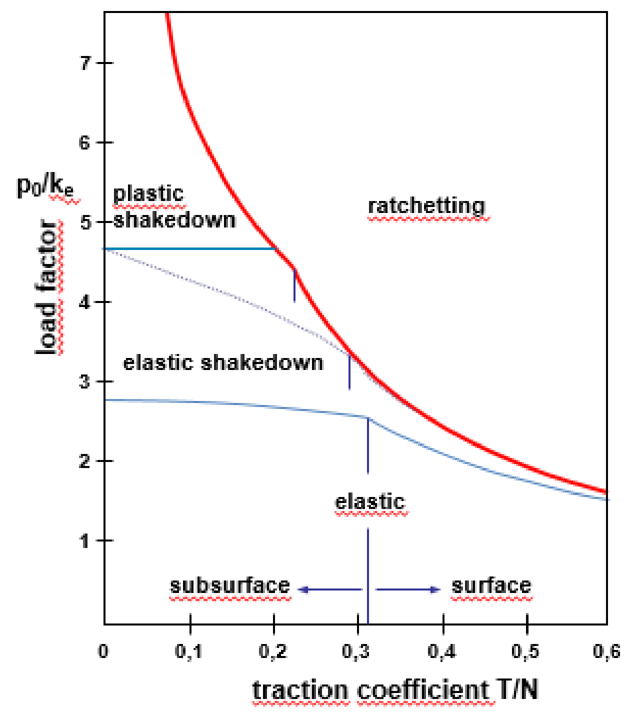
X. Liu, A. Lovett, T. Dick, M. Rapik and C.P. L. Barkan, “*Optimization of Ultrasonic Rail-Defect Inspection for Improving Railway Transportation Safety and Efficiency*


Normal Growth DF
Originating from Head Check
Rapid Growth
Sudden Growth

Overall process for rail failure from RCF related defects

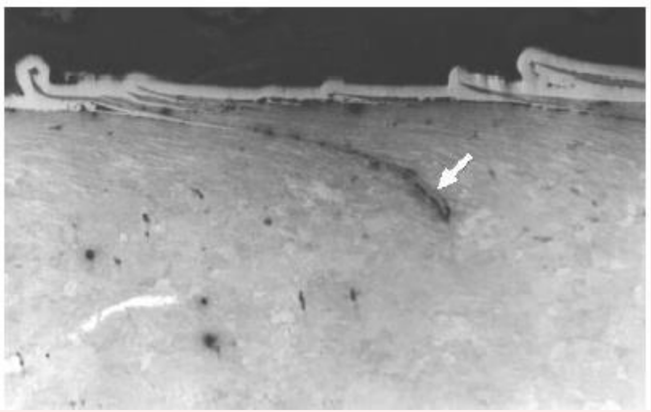
1. Initiation of Rail defects.
    - Surface initiation of surface RCF cracks
    - Growth of cracks into railhead
2. Growth of rail defect size
3. Critical failure of Rail

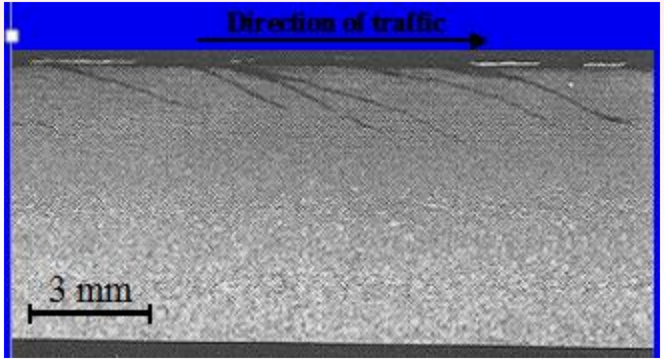
Crack Initiation and Growth



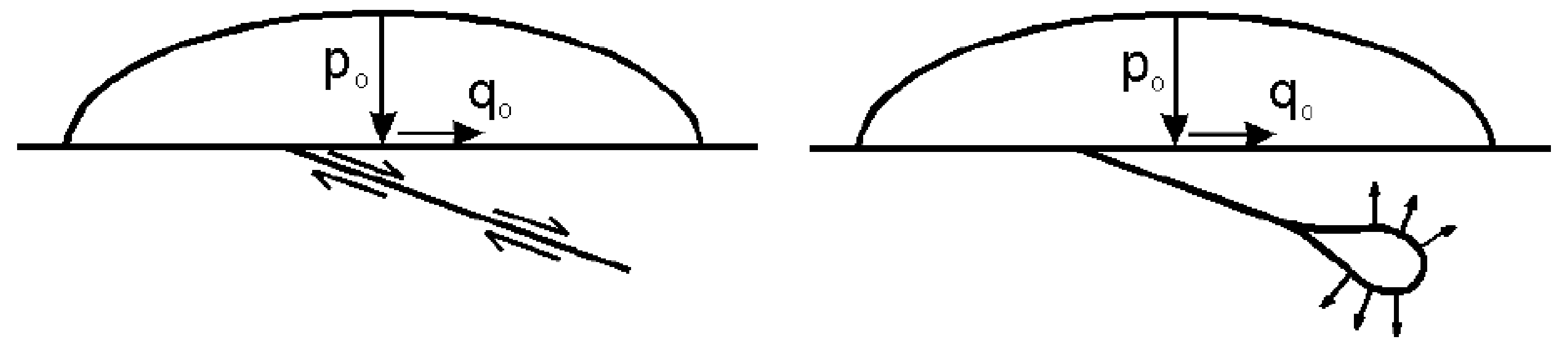
Shakedown diagram (Johnson)

Ratcheting caused by contact fatigue





Cracks can propagate by influence of liquids (water) by either reducing crack wall friction or hydraulic pressurization



Without water (and other liquids), crack growth would be mainly limited to rail surface

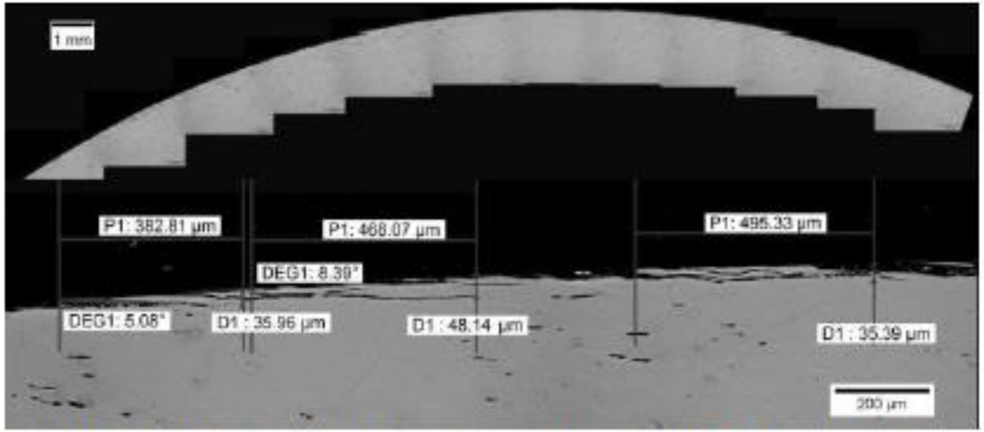


Figure 12: Test 2, Dry Baseline, 25000 Cycles

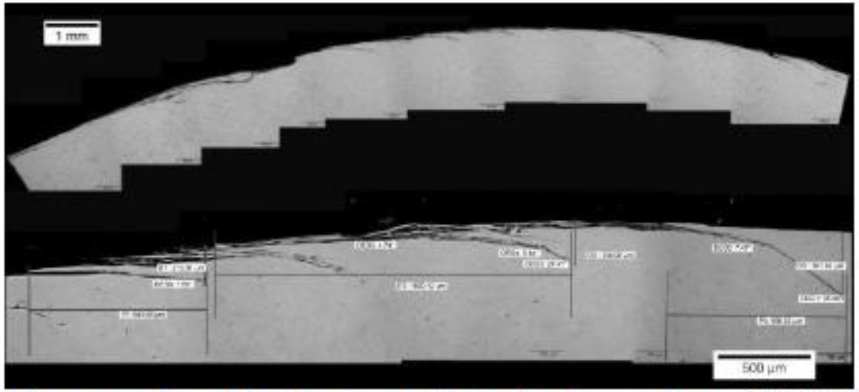
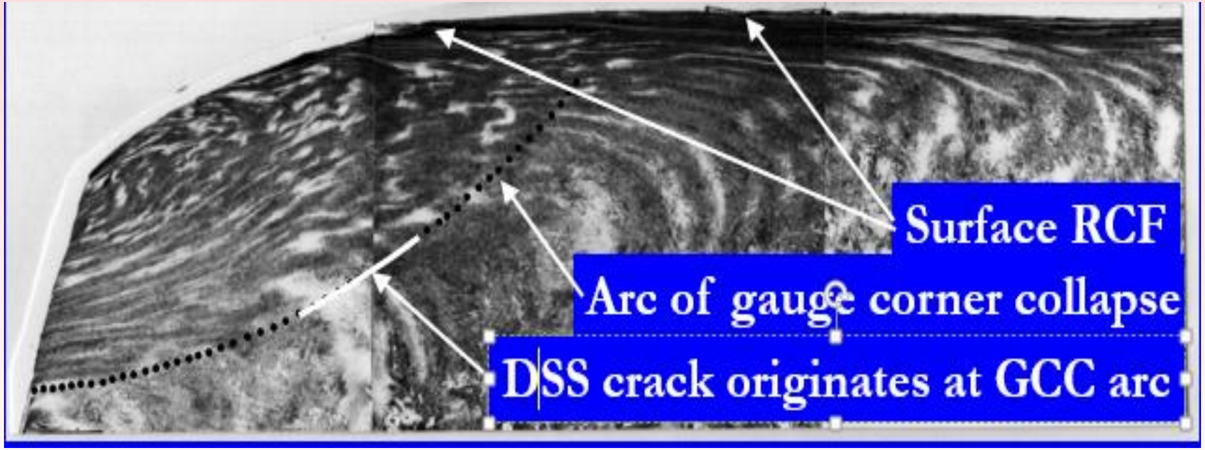


Figure 13: Test 3, 4000 Cycles Dry, 21000 Cycles Water

C Hardwick, R. Lewis, D.I. Fletcher, and R Stock, *"THE EFFECTS OF FRICTION MANAGEMENT MATERIALS ON RAIL WITH PRE EXISTING RCF SURFACE DAMAGE" IHHA 2015*



- Residual stresses are a major influence in crack and defect propagation

- Residual stresses near the rail surface are COMPRESSIVE therefore will tend to retard crack growth

Phase 2: Defect has now grown outside the influence of contact forces. Growth driven by rail longitudinal stresses

Longitudinal stress

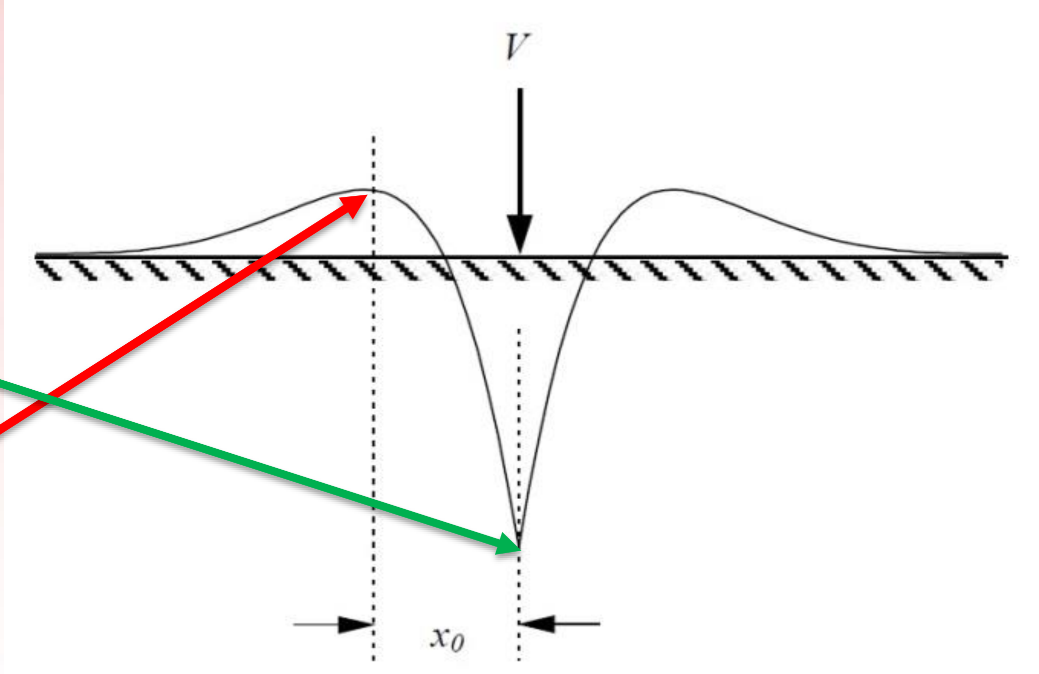
Thermal Stress

$$\sigma_{\infty} = \sigma_R + \sigma_T + M_G(a).\sigma_B$$

Residual stress (rail manufacturing)

Bending stress

Bending stresses



- Maximum bending moment occurs directly under the load
  - Generates compressive stress with less likelihood of crack defect propagation

- Maximum tensile bending occurs away from point of load application (reverse bending)

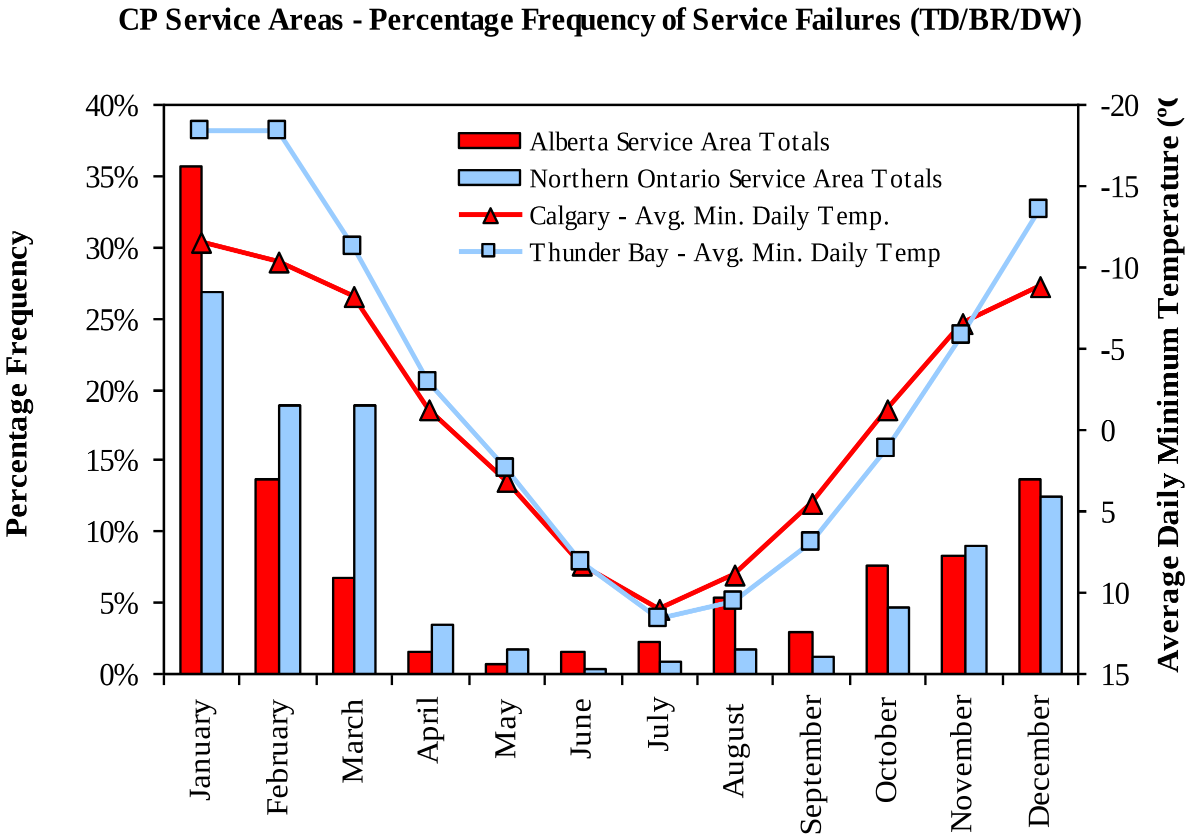
Thermal stresses in continuously welded rail

$$\sigma_T = E\alpha\Delta T$$

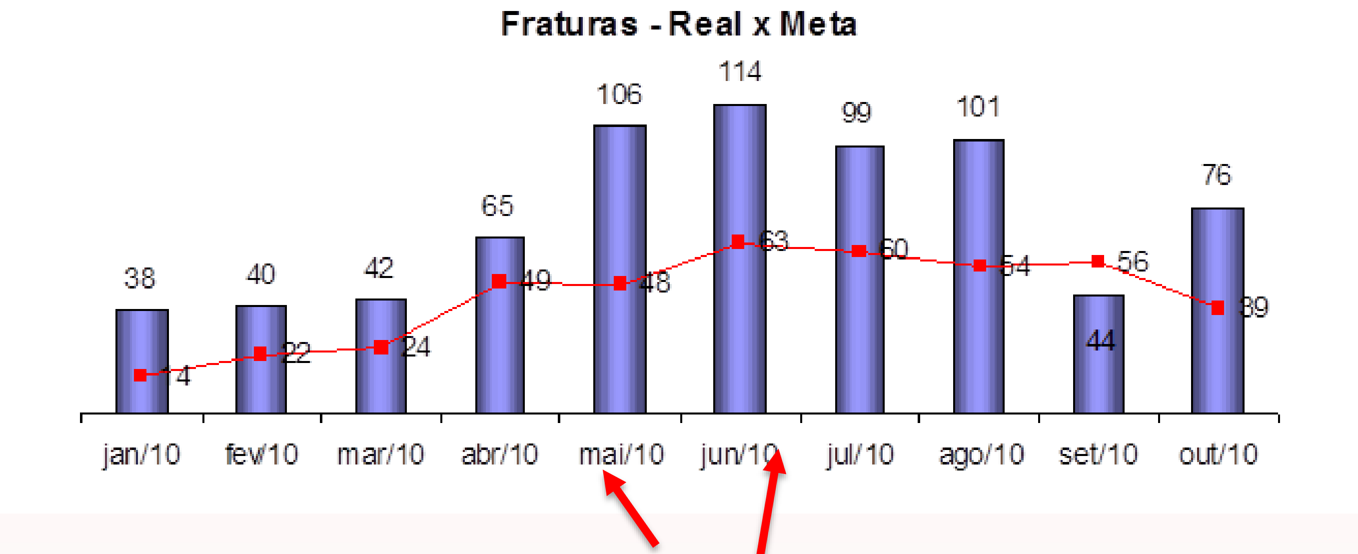
$\Delta\mathrm{T} = \text{difference between in service temp. and stress free (neutral) temp.}$

α = coefficient of thermal expansion of rail steel

E = Modulus of Elasticity

CP Service Areas - Percentage Frequency of Service Failures (TD/BR/DW)
Percentage Frequency
40%
35%
30%
25%
20%
15%
10%
5%
0%
Alberta Service Area Totals
Northern Ontario Service Area Totals
Calgary - Avg. Min. Daily Temp.
Thunder Bay - Avg. Min. Daily Temp
-20
-15
-10
-5
0
5
10
15
Average Daily Minimum Temperature (°
January
February
March
April
May
June
July
August
September
October
November
December

Rail Break seasonality in southern Brazil



Winter

Average summer low temp 48-52F

Data courtesy of Leonardo Soares, RUMO

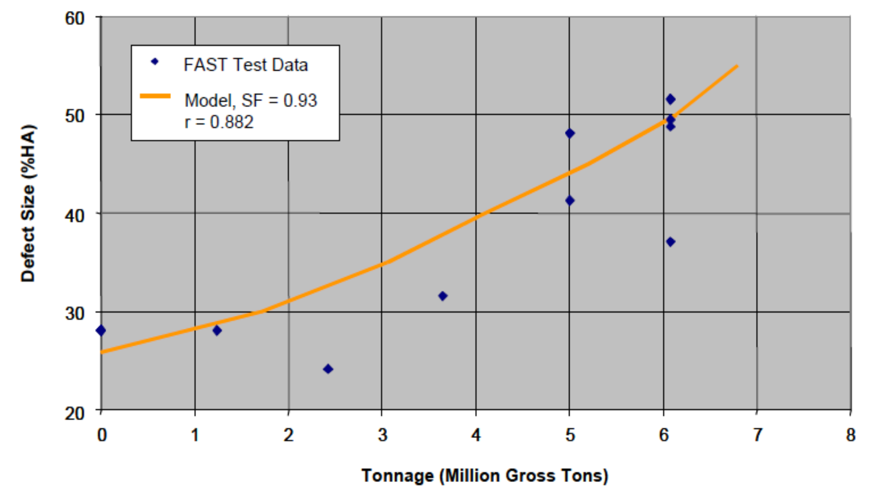
Phase 3: Rail Failure

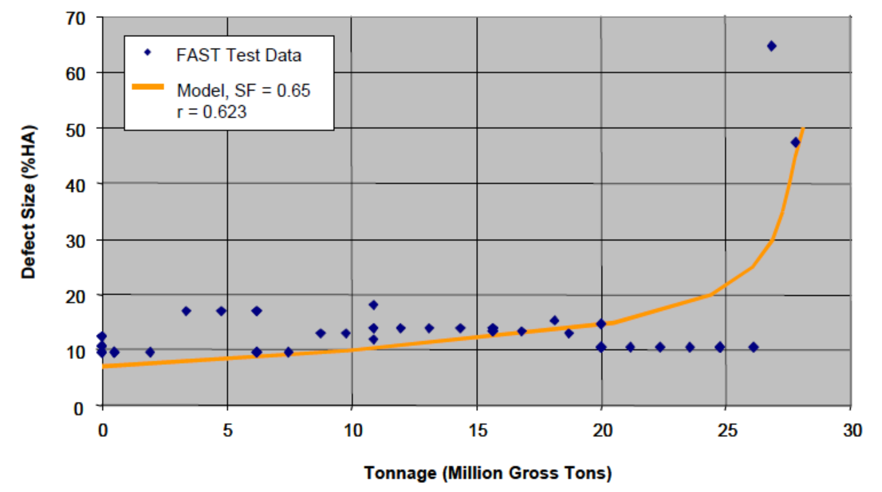
- Defects grow to a critical size
- Fracture in response to *dynamically applied loads*
  - At average loads if cracks allowed to grow to large size
  - At smaller size when high dynamic loads e.g. from wheel flats
- Low temperature (high delta T) leads to high tensile longitudinal stress

MODELLING OF RAIL STRENGTH AND CALCULATION OF WEAR AND OTHER LIMITS

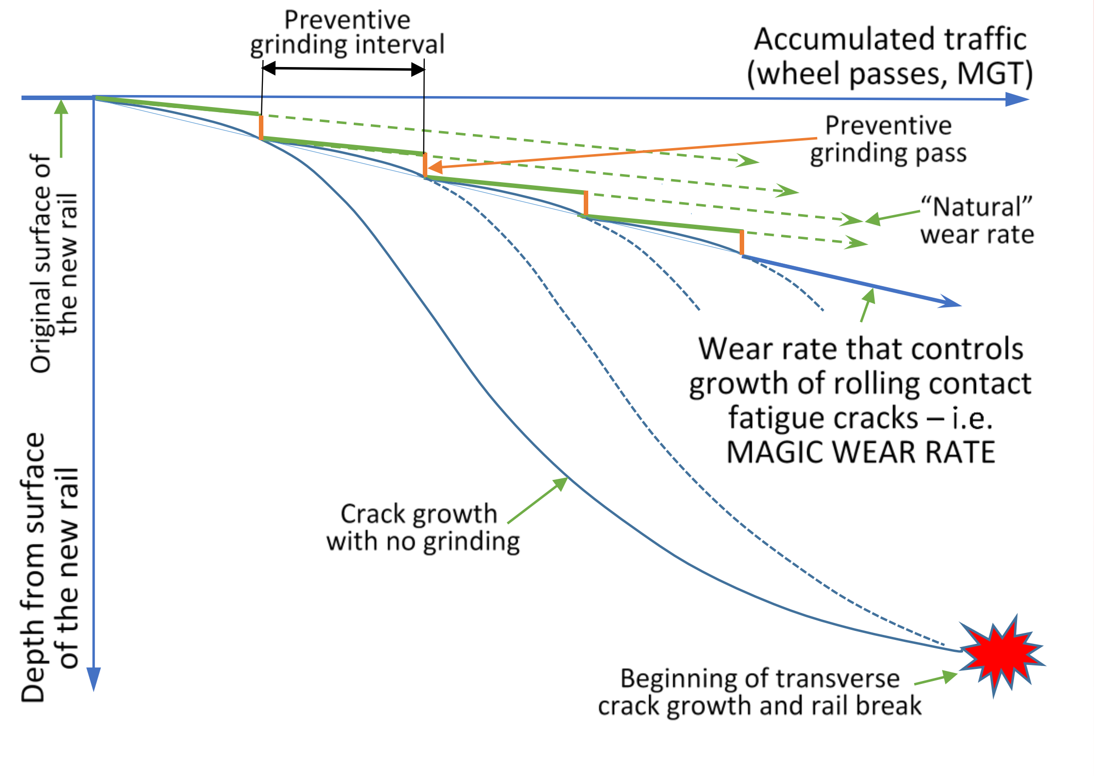
- Volpe Centre: Orringer, Jeong et al
  - Mainly based on fracture mechanics
  - Modelling of defect growth rates and safe rail wear limits based on target inspection interval
- Igwemezie:
  - Linear finite element analysis (FEA) complemented by cold chamber hammer drop testing
  - Highly influential in setting rail wear limits on Class 1s
- Mutton et al
  - Fracture mechanics plus FEA and multi-body dynamics.
- Ekberg et al:
  - Linear elastic fracture mechanics to calculate **wheel impact load limits**

Defect growth rates: the great unknown variable - can be modelled successfully but only by (retrospectively) adjusting residual stress intensity factor





WHAT CAN BE DONE TO ACCELERATE REDUCTION IN RAIL BREAK DERAILMENTS?



Mitigate initiation and growth of RCF

1. ***Grinding***

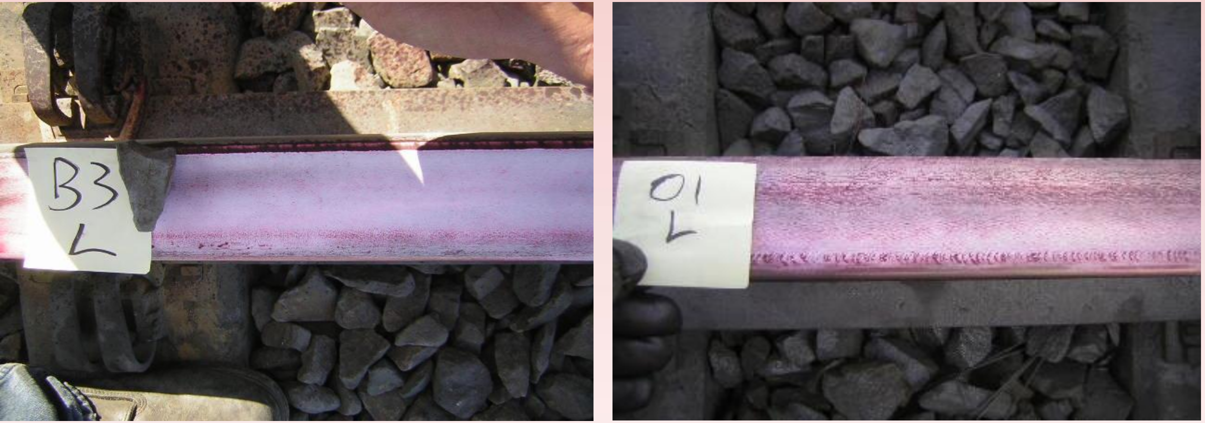
E. Magel, *"Rolling Contact Fatigue: A Comprehensive Review"*, DOT/FRA/ORD-11/24

Enhanced grinding for rail defect / rail break reduction?

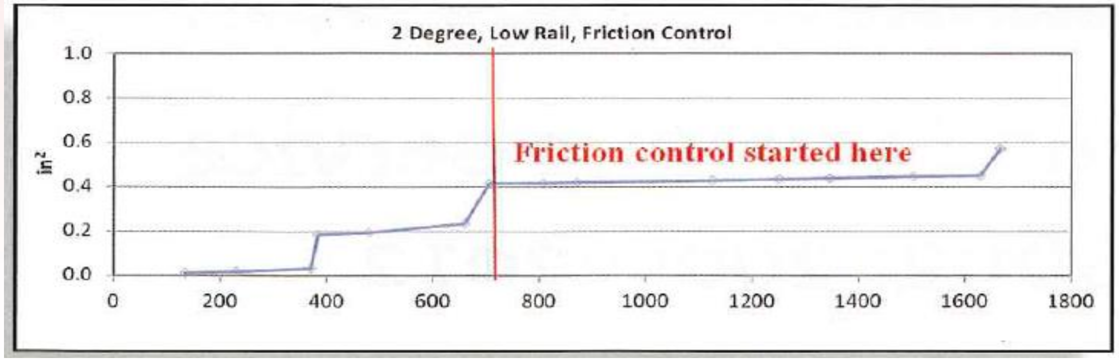
- How to determine the magic wear rate? (ICRI)
- Are Class 1s truly in a preventative grinding mode and able to achieve the magic wear rate?
  - 25 MGT in curves, 70 MGT in tangent
  - Sufficient metal removal to prevent crack growth into the rail head
  - Grinding budgets set to maximize economic rail life – consider economics of grinding for defect minimization / rail breaks?
- New measurement technologies (eddy current, magnetic induction) to better understand crack removal effectiveness

Eddy current measurements

Mitigate initiation and growth of RCF



Low rail in sharp curve A) TOR-FM, B) Control (GF only)



2. ***Friction Management***

- Reduce traction forces and prevent ratcheting

Mitigate initiation and growth of RCF:
3 **Improved rail quality**

1. Residual stress specifications?
    1. Deeper compressive residual stress zone (1/2” into rail?)
    2. Reduce tensile residual stresses - mitigate Phase 2 Defect Growth

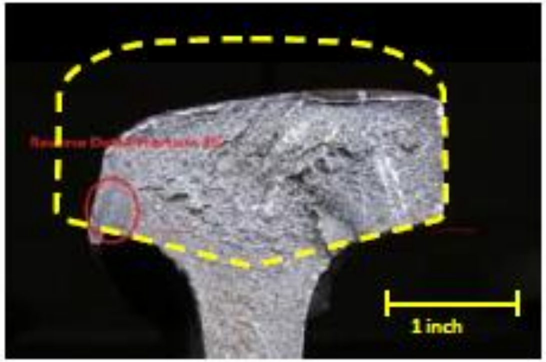
2. Fracture toughness specs? (especially at cold temperatures)

3. Rail cleanliness specs introduced in late 1980s led to significant improvements – time for further improvements?

Mitigate Defect Growth rates (Phase 2) – control rail longitudinal stresses

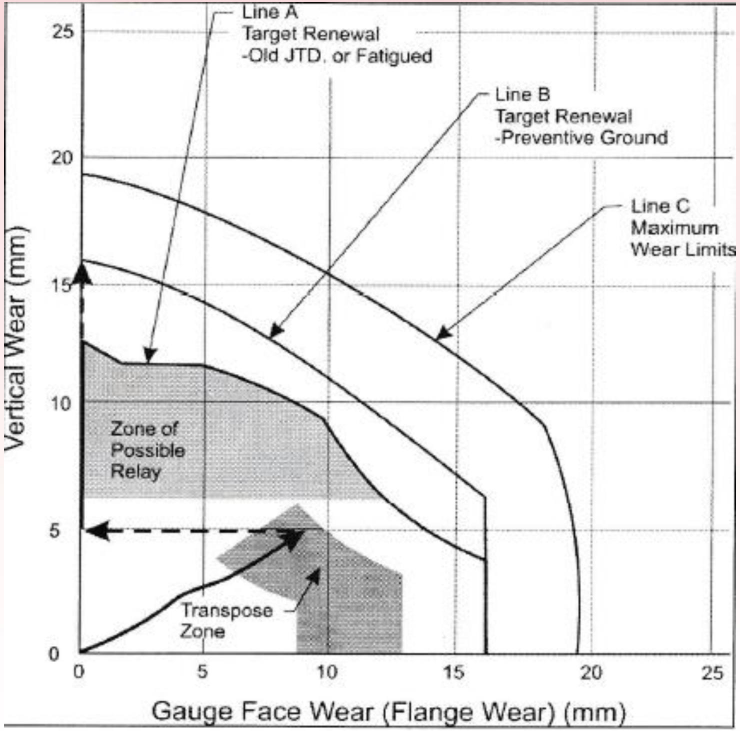
- Rail tensile longitudinal stresses: primarily introduced by roller straightening
- Thermal longitudinal stress:
  - Rail is laid at high stress free (“neutral”) temperature to minimize potential for sun kinks
  - Although track will naturally try to destress, cold weather may still lead to very high temperature differentials (ΔT) and consequent thermal stress in the rail

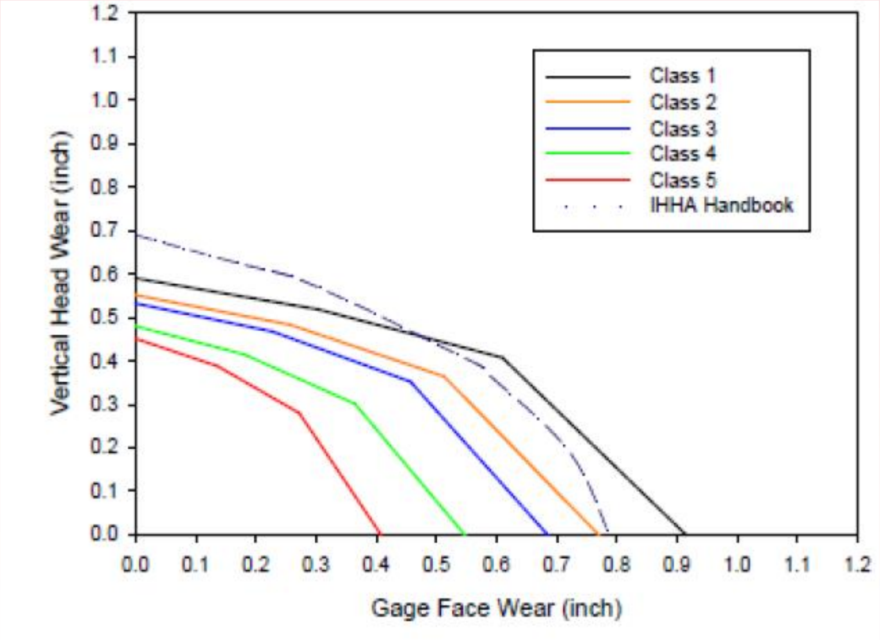
RAIL WEAR EFFECTS AND LIMITS



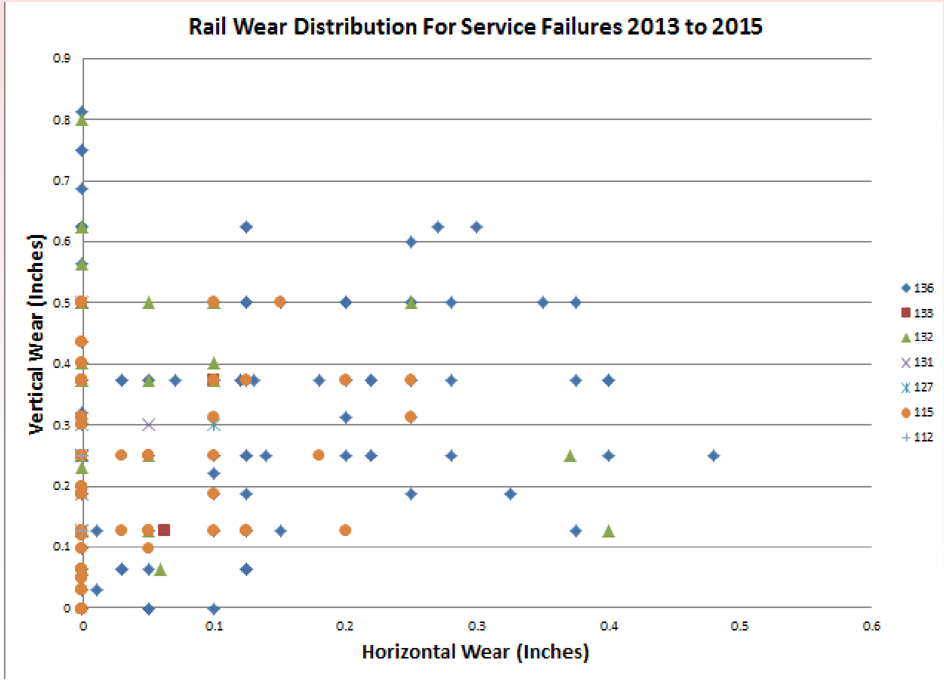
NTSB Docket No. DCA14FR008

- Worn rail affects rail strength due to:
  - Corresponding reduction in moment of inertia
  - Increased lateral and vertical bending
  - Increased peak magnitude of tensile longitudinal bending stresses


Line A
Target Renewal
-Old JTD, or Fatigued
Line B
Target Renewal
-Preventive Ground
Line C
Maximum
Wear Limits
Zone of
Possible
Relay
Transpose
Zone
Vertical Wear (mm)
0
5
10
15
20
25
Gauge Face Wear (Flange Wear) (mm)
0
5
10
15
20
25

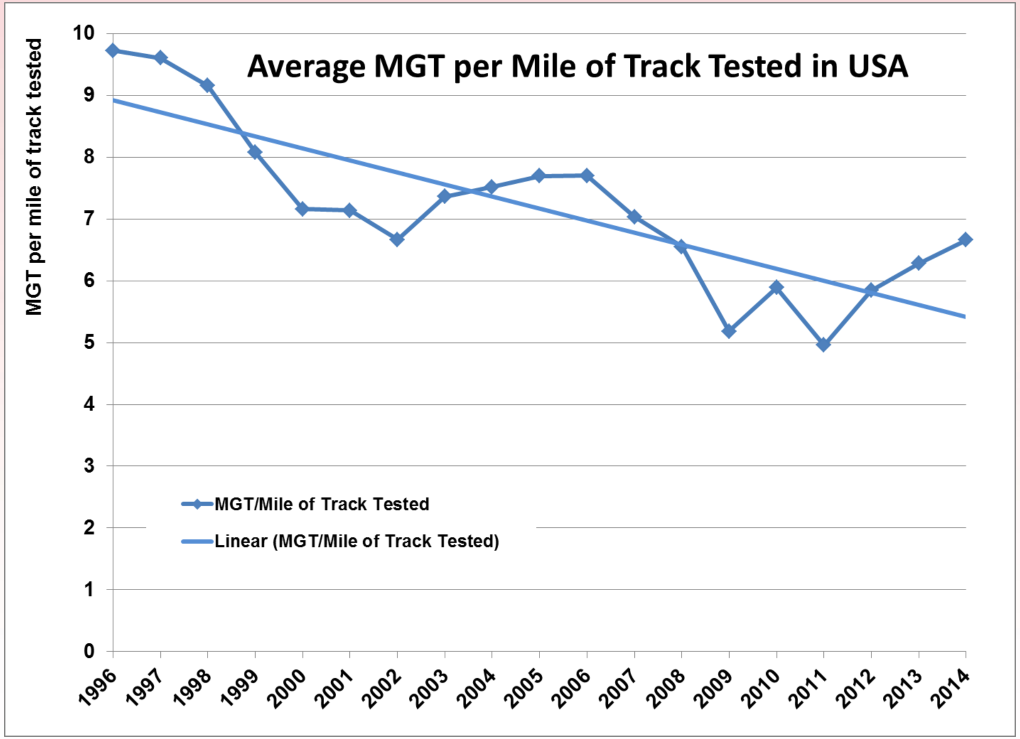

Class 1
Class 2
Class 3
Class 4
Class 5
IHHA Handbook
Vertical Head Wear (inch)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Gage Face Wear (inch)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2

Data from a Class 1 on head loss for rails with service failures shows no apparent relationship between head loss and rail fracture



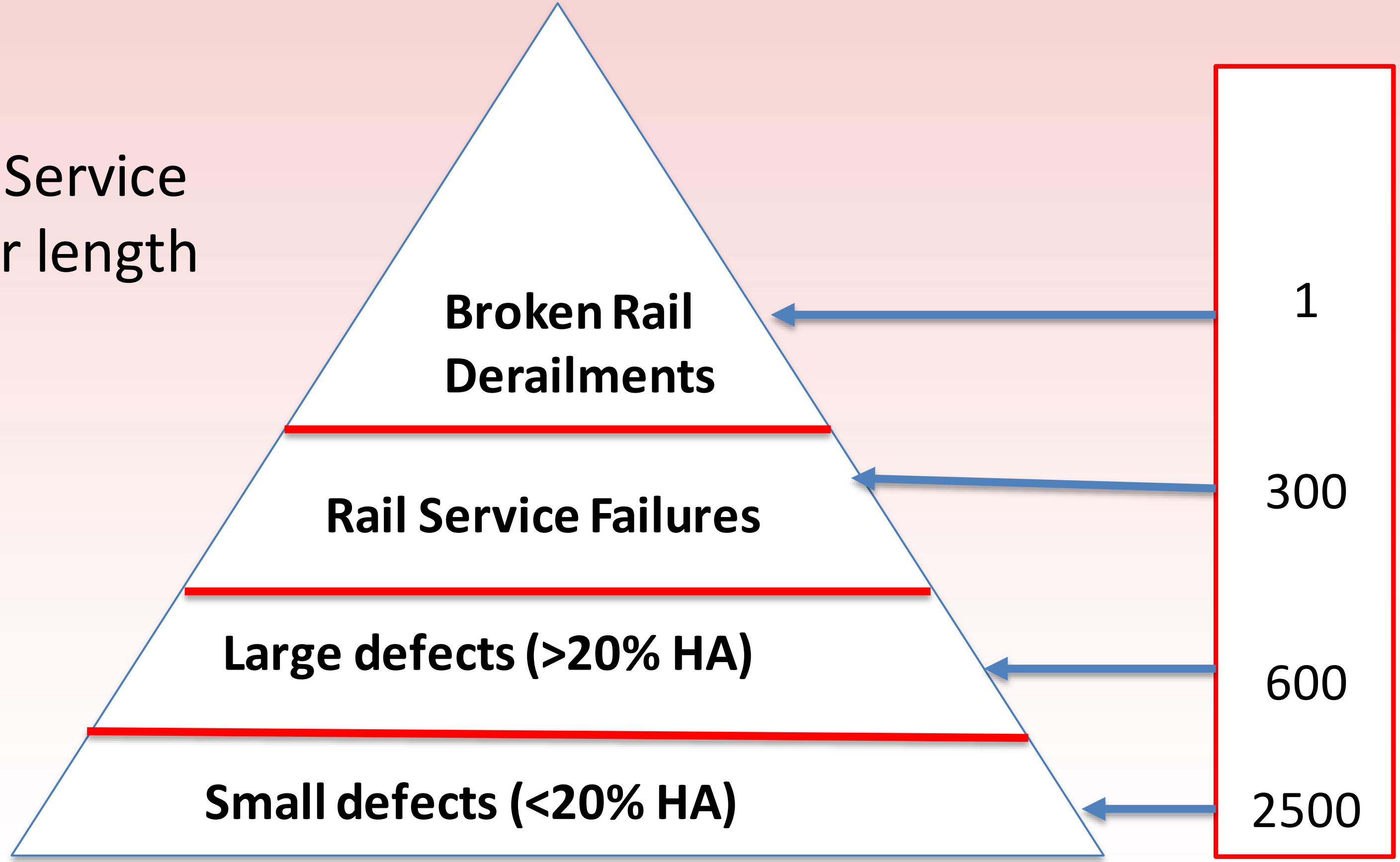
DEFECT TESTING

Ultrasonic testing is the main tool to mitigate risk of defects: trend has been to increased testing frequency



SETTING TARGETS THAT WILL HELP TO REDUCE RAIL BREAK DERAILMENTS

- Target Rail Service Failures per length of track?



Broken Rail Derailments

Rail Service Failures

Large defects (>20% HA)

Small defects (<20% HA)

1

300

600

2500

Conclusions

- Rail break derailments are relatively common and severe in impact
  - Risk to industry in reactive regulatory response to public / social media responses
  - Need to be proactive in showing positive responses
- Positive trend likely due to improved rail metallurgy, grinding, friction management and more frequent ultrasonic testing
- For accelerated reduction:
  - Focus on RCF prevention through ongoing improvements in crack growth mitigation (grinding, FM)
  - Consider rail residual stresses – deeper residual stress, less tensile stress. Fracture toughness specs
  - More attention to rail thermal stresses esp in transition into winter – destress
  - Reduce worst wheel impact loads especially in winter
- Many areas of uncertainty and new knowledge needs

- Reverse detail fracture
- **5% of head area!**

Acknowledgements

- Mike Roney, Eric Magel, Joe Kalousek, Peter Mutton, Richard Stock, Anders Ekberg, Jens Nielsen, Mark Richards and many others…..
- Work by David Jeong and co-workers at Volpe centre
- Work by Gord English (Transys)
- Gordon Bachinsky

Thank you