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An ICRI task: Broken Rails, Risk and Safety

Eric Magel, Principal Engineer
Automotive and Surface Transportation

Outline

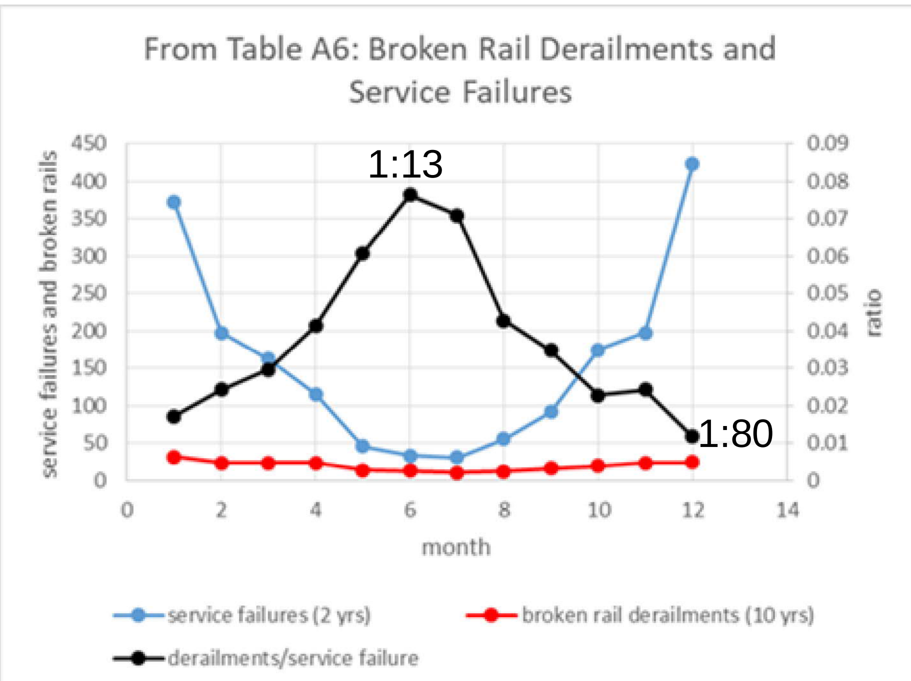
- Recent discussion re Broken rails and seasonality
- Could we model the problem – a stress vs strength approach
- Where do we go from here?
  - Develop a working team

→ ICRI Safety project

- Current Goal
  - Provide a methodology for quantifying the risk reduction or safety improvements associated with new technology or process adoptions.
    - This methodology should be generic
    - Would work with any safety issue
    - Will apply to WRI, RCF and Wear
  - Then work with VTI-Economics to cost that value.

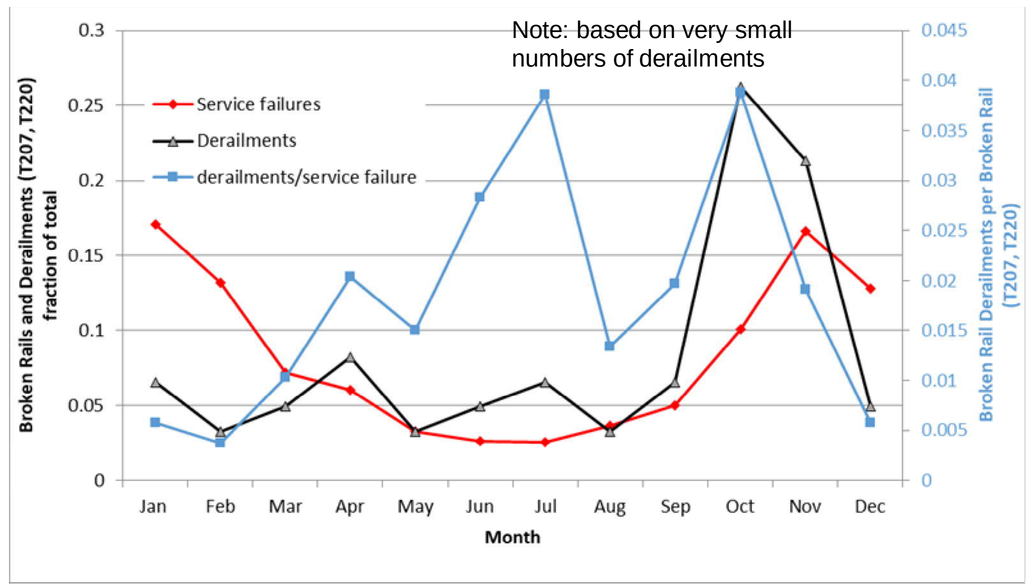
BR Derailments - Seasonality

from UIUC "SEASONAL EFFECT ON THE OPTIMIZATION OF RAIL DEFECT INSPECTION FREQUENCY“, ASME, 2013



- # of broken rail derailments DOES NOT vary directly with the number of broken rails

2004-2015



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ICRI-Broken Rails Group

65+ persons, online discussions via email

Cold Weather – tensile stresses

- M .Burstow
  - *a break from a rail foot or weld defect usually results in a single fracture of the rail.. a rail break from rolling contact fatigue is more likely to cause a break-up of the rail head making it much more likely to derail a train.*
- B. Kaempfer
  - *North America might have too many different climate conditions. Maybe, a certain region is more sensitive to such an effect than others?*
- N. Hooper
  - *May/June in northern countries is actually also bad for temperature effects. Really hot days and cold nights are a greater daily range. Track is shifting and adjusting.*
  - *Most pull-aparts occur during the first sustained cold snap as cracked joint bars and hidden rail defects reveal themselves*
- H. Harrison
  - Notes rail breaks in winter, especially in Canada exacerbated by shelled wheel impacts on rail in tension

Spring/summer: soft track, poor geometry

- C.Hogan

  …I would think the presence of mud holes/softer vertical support structure in warmer months that lead to increased vertical rail deflection/bending/bending strain under load…This may lead the next loaded wheel to depress this location to an even greater degree which in turn may increase poor vehicle dynamics and/or force the rails far enough apart that a wheel cannot pass over

- P. Baker

  The wet (track) bed, usually caused by poor or failing drainage… results in a short stretch of track with quite significant vertical deflections due to loss of support…these dips coupled with fatigue cracks can be a potential higher risk source of breakage.

- T. Pirvoaica

  In summer, railbreak + geometry error → increased probability of derailment?

- D. Fletcher

  Track in summer with compressive stress in the rails will have a greater tendency to shift laterally, especially if lateral bending strength is reduced by a break?

Warmer weather – compressive stresses

- A. Ekberg

In winter there is tension, thus the critical crack size is small... In summer the critical crack size is much larger meaning that as a rail break occurs the remaining crack …can cause additional fractures solely due to the rolling contact load.

Alternatively (mainly for weld cracks) the crack may have grown a longer distance than in wintertime along the rail before it branches to transverse fracture and detaches …a large section of the rail.

- C.J. Rasmussen

*…the tensile stresses in winter typically results in a more straight vertical and less critical rail break and that the **compression stresses in summer are more likely to make the cracks propagate in other directions**.*

- *C. Barkan*

Something to consider is whether the summer peak could be because a service failure in warm weather may be less likely to interrupt the track circuit and consequently reduces the ability to detect the break with the signal system.

- *H. Harrison*

there will likely be greater compressive stresses in that June-July timeframe. So, if whatever fractures are progressing in that period reach a total break, the track circuits may not drop out reliably to stop following trains from passing.

Warmer weather – compressive stresses

- N. Hooper:
  - *You tend to have more of the other bending related defects in the summer months when the track modulus is lower (no longer frozen) like horizontal failures in the web/fillets and vertical splits. None of these defects alarm the CTC system because the rail base often stays intact as the upper rail fractures and the head falls off or the rail shatters under the train.*

European experience, horizontal cracks

- C.J. Rasmussen
  - Example from passenger train derailment in Denmark. Crack propagated horizontally along rail until a section broke off. Suggests that in winter the rail would have had a more vertical break
- N. Hooper
  - *This a 30-40 years ago problem. The issue is residual stress from rail straightening in the mill.*
  - *I still think a key to shatter is the residual stress from the rail manufacturing process.*
  - *I think if RR's looked at their defect types more in terms of survivable and fatal - see photos and then concentrated on those defects that the signal system wouldn't save them on that they would get better outcomes.*
- M. Richards
  - Difference in the fracture morphology summer vs winter? Some critical temperature dictates whether crack propagates vertically or becomes more influenced by internal/residual stresses?
- B. Kaempfer
  - *Can such a behaviour be found in other regions of the world, too? (e. g. European railways)*

R&D topics?

1. Is there evidence that greater resilience in summer, coupled with neutral or compressive thermal stress allowing the rail to accumulate greater damage before breaking?
   - Is the size of the TD recorded and could this be plotted against date of failure?
   - Is there more evidence of clusters in the summer?
2. Is there any evidence to suggest that cracks are more likely to propagate longitudinally in summer versus winter?
3. And even if so, what could we do with that knowledge?

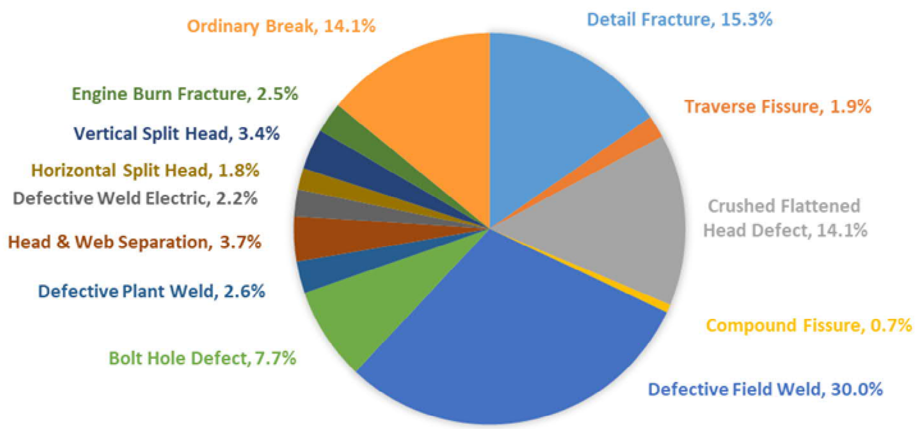
More, better data needed

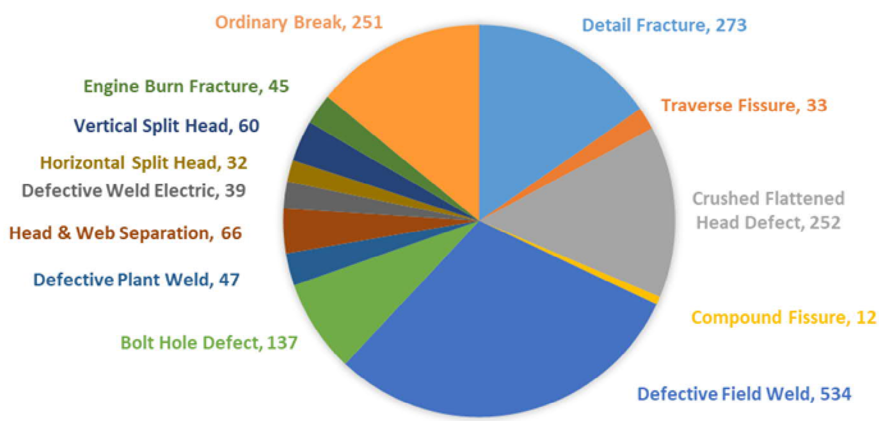
- G. Wolfe
  - statistical significance to the limited data we are seeing? Data being reviewed may no longer be relevant? Need a larger population of data from railways in climates with large seasonal temperature and moisture fluctuations
- D. Staplin

  Ideally, we should look at the broken rail derailment data for the summer months and see what type of fracture was involved and the circumstances surrounding *its occurrence. What we learn could then guide inspection policy.*
- J .Stanford
  - *While I questioned the data and relationships presented earlier there are a lot of unknowns within industry wide datasets which make it difficult to even guess what they represent sometimes and with no way to validate.*
  - BNSF data *"…a very consistent relationship between service failures and incidents regardless of seasonality*
- M .Burstow
  - *is there more detail to this data so that it can interrogated for the causes of rail break by time of year?*

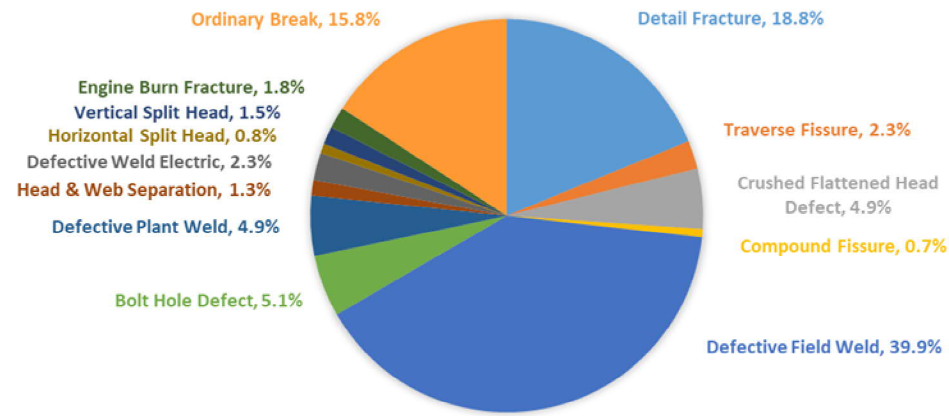
From: RSAC RIWG DATF Presentation, Nov 29, 2017, courtesy Robert Wilson, FRA

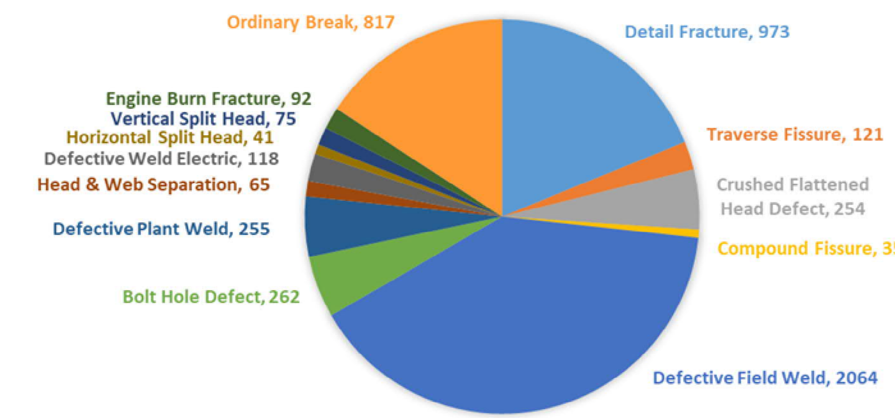
SUMMER SERVICE FAILURES (JUN-AUG, 2014 AND 2015)





WINTER SERVICE FAILURES (DEC-FEB, 2014-15 AND 2015-2016)

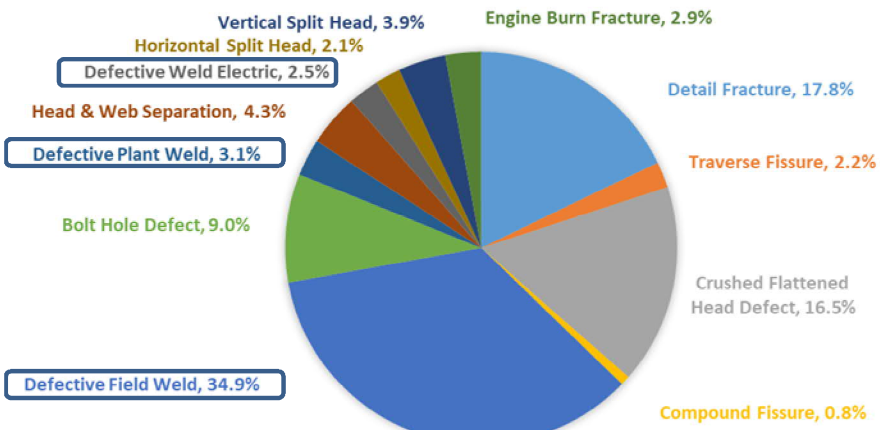




SUMMER SERVICE FAILURES (LESS ORDINARY BR (JUN-AUG, 2014 AND 2015)

Peter Mutton suggests need to look at weld failures

ER SERVICE FAILURES (LESS ORDINARY BREAKS) (DEC-FEB, 2014-15 AND 2015-2016)



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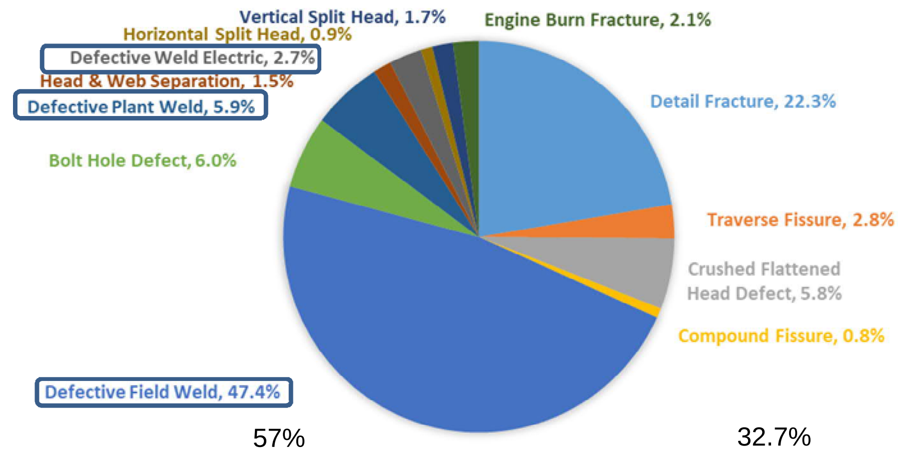

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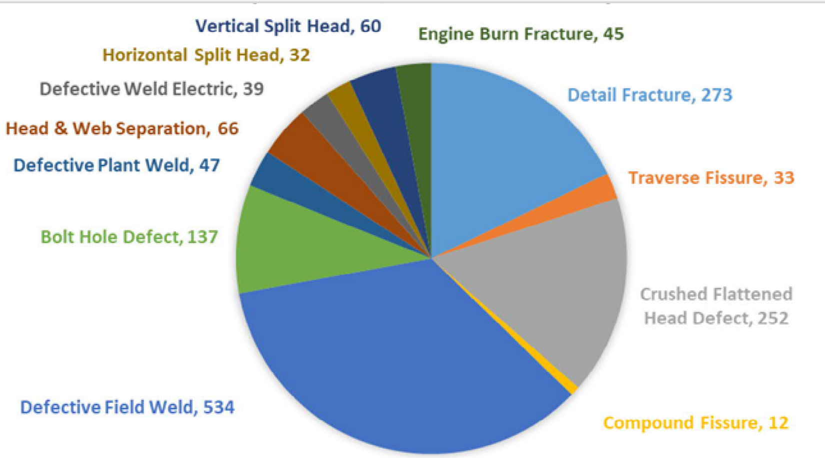
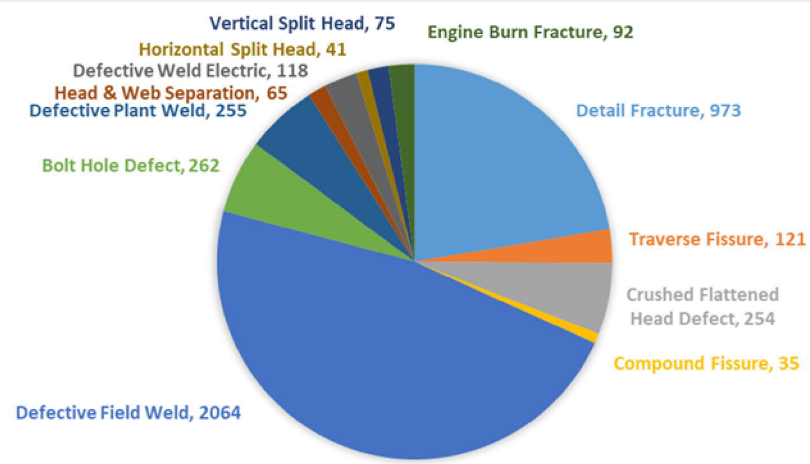
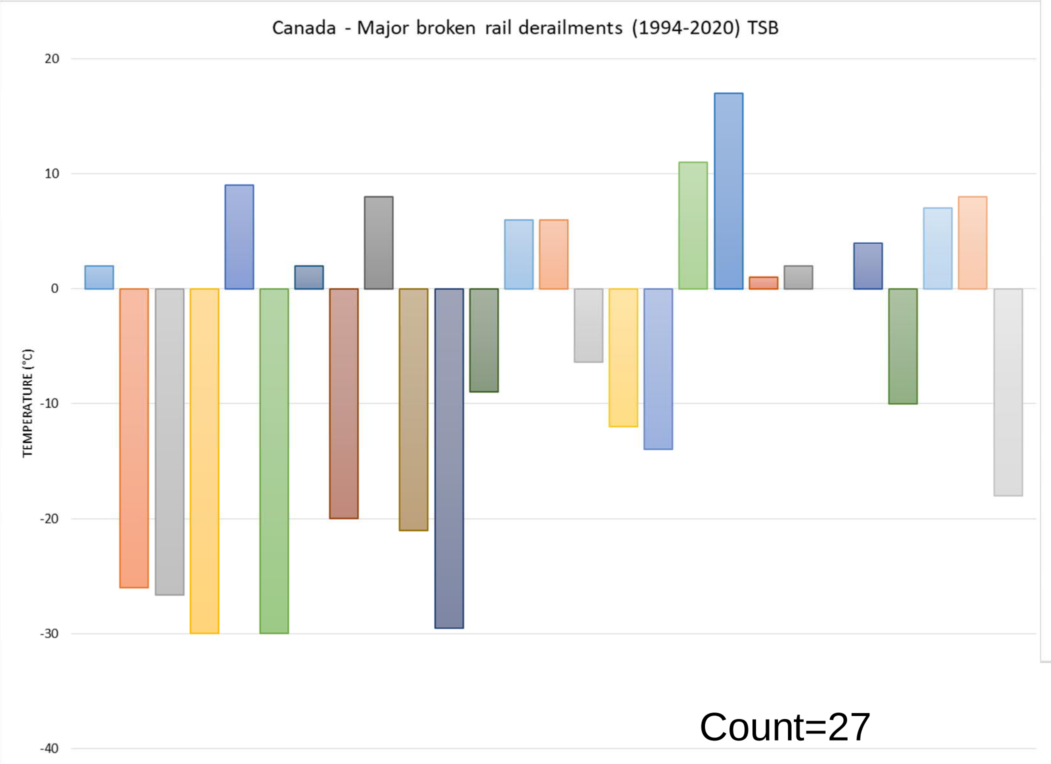




Canada – TSB investigated broken rail derailments



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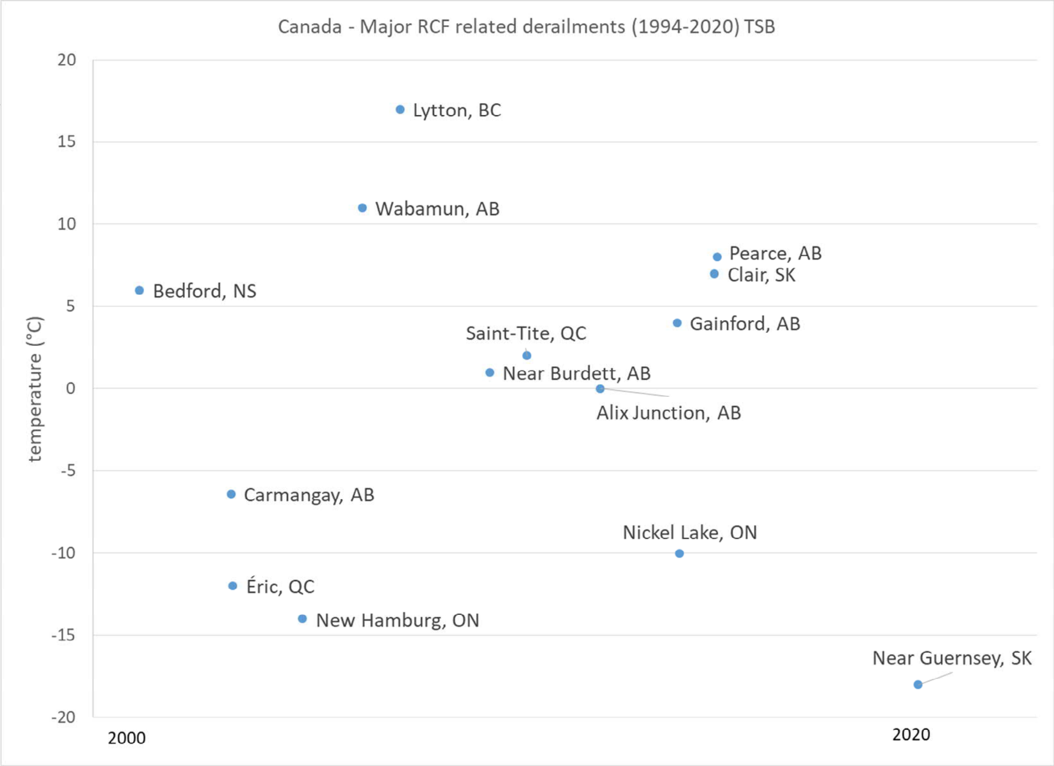

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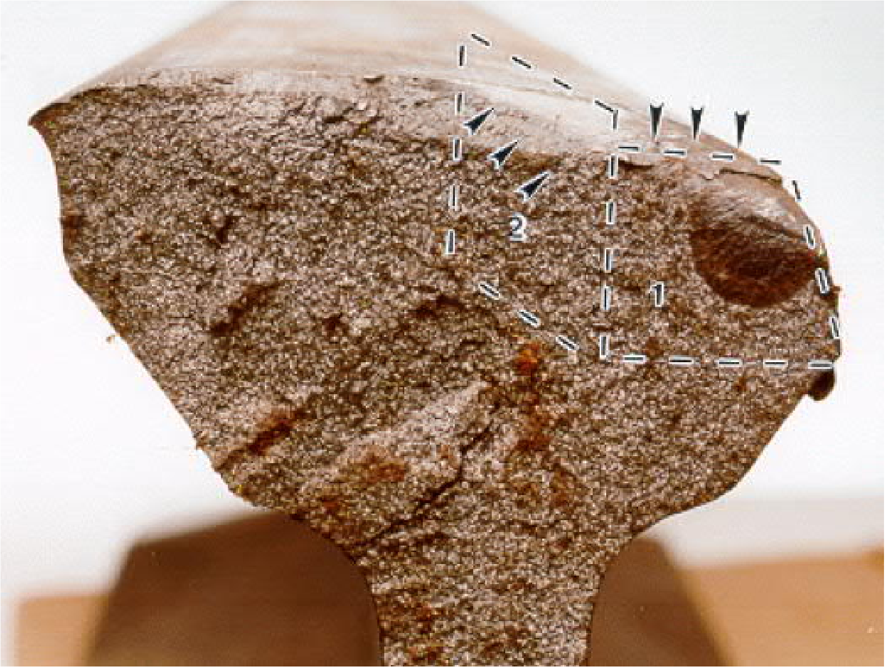
Photographs from TSB (Canadian Transportation Safety Board) Incident reports

TSB #R99M0046 1999-10-09 CN Bedford, Bedford, NS

- “origin of the initial fracture and the initiation of the downward progression was in the area of microcracks emanating from shelly damage on the rail head”. No photos

TSB #R02C0013 2002-03-03 CP Aldersyde, Carmangay, AB -6.4°

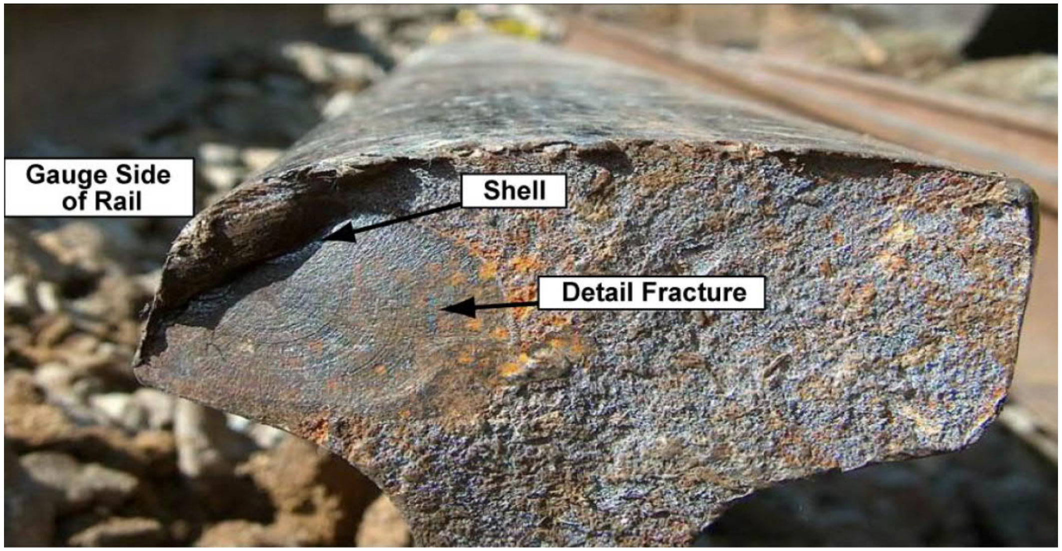


TSB #R02Q0021 2002-03-18 QNS&L Wancouna, Éric, QC

TSB #R04S0001 2004-01-08 VIA Guelph, New Hamburg, ON

- *The north rail broke under the lead locomotive, causing the three trailing passenger coaches to derail. The rail fracture initiated from a transverse defect in the head of the north rail. The defect originated from manganese sulphide inclusions that were present in the rail at time of manufacture.*

TSB #R05E0059 2005-08-03 CN Edson Wabamun, AB



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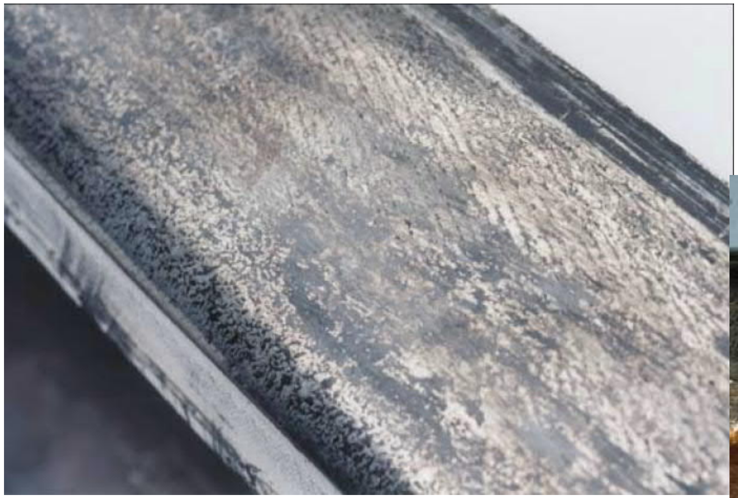
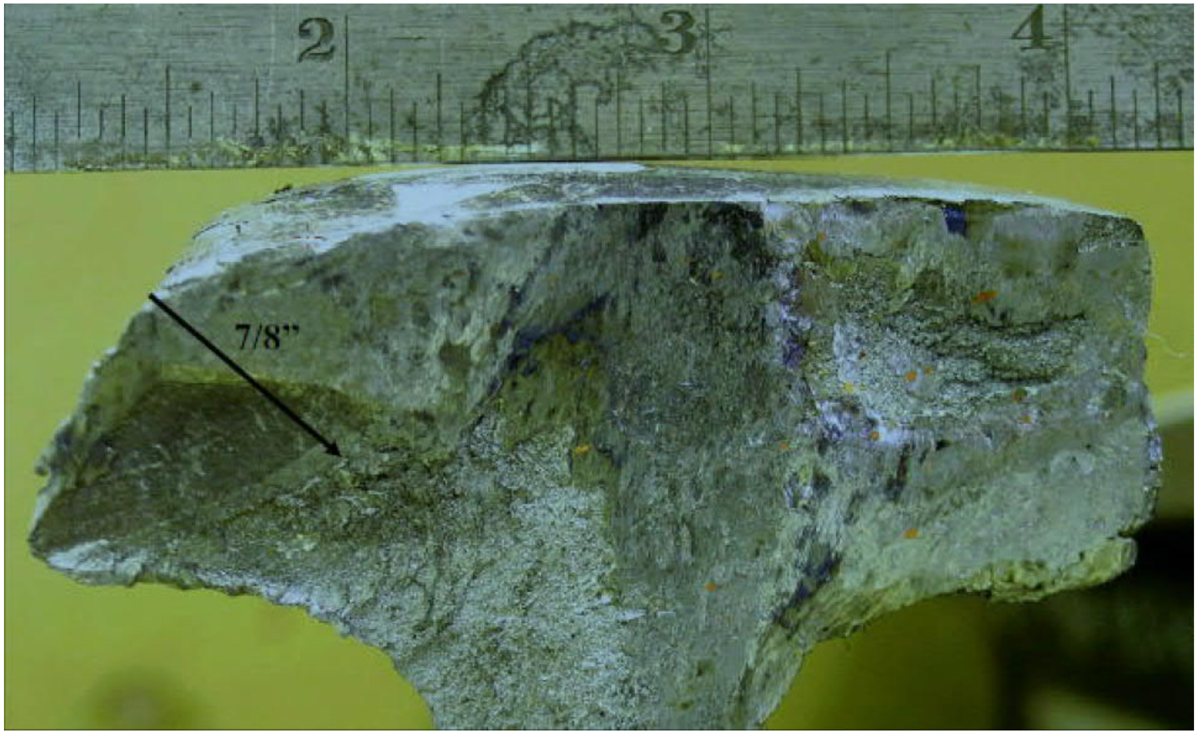
TSB #R06C0104 2006-07-31 CP Ashcroft, Lytton, BC



TSB #R08C0164 2008-11-30 CP Taber, Near Burdett, AB



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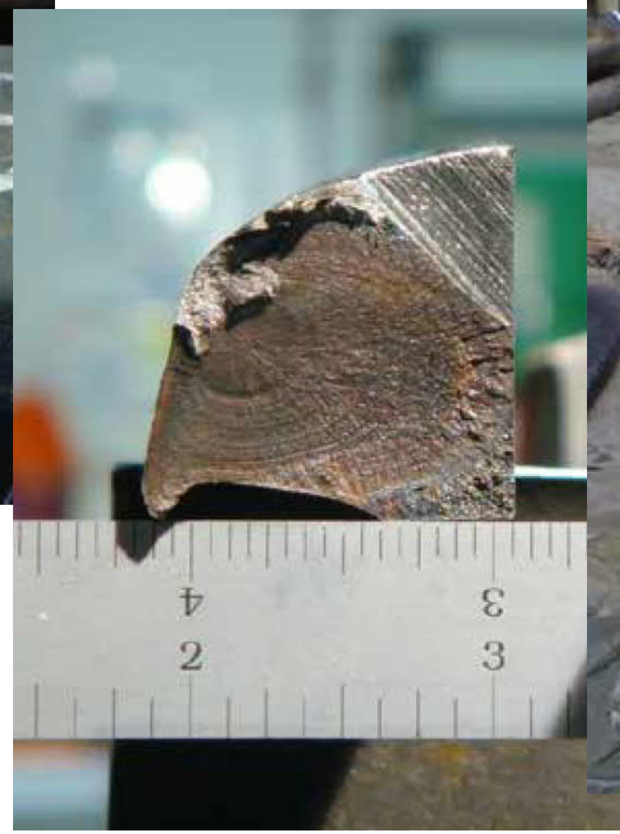
TSB #R09Q0047, 2009-11-21 CN Lac-St.Jean Saint-Tite, QC

TSB #R11C0118 2011-10-21 CN Three Hills Alix Junction, AB

TSB #R13E0142 2013-10-19 CN Edson, Gainford, AB

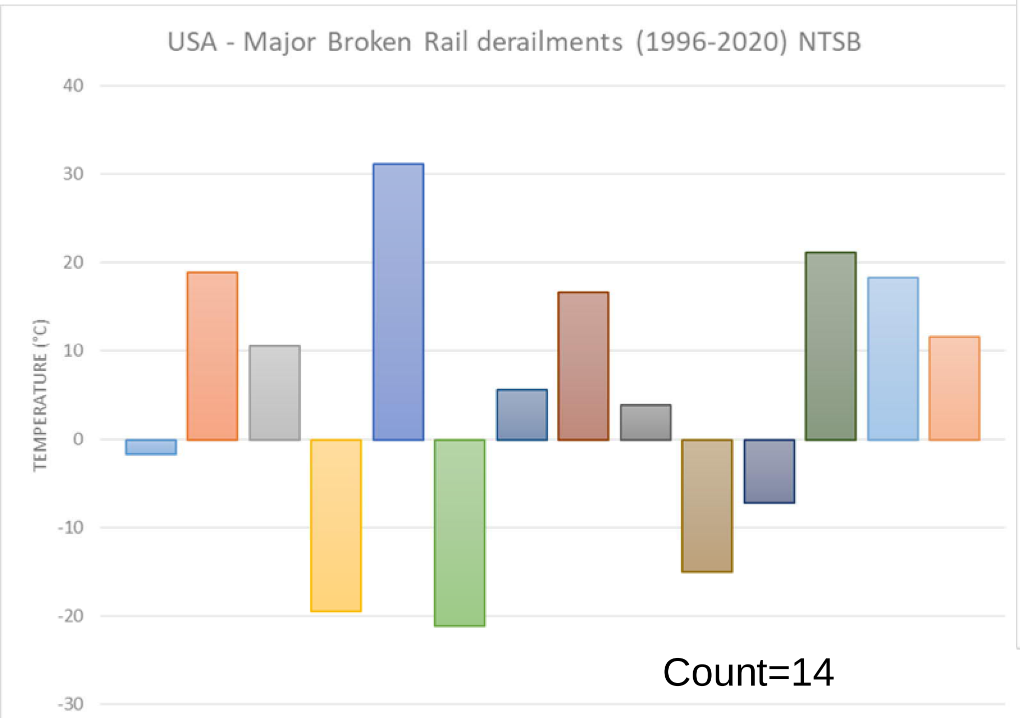


TSB #R14W0256 2014-10-07 CP Margo Clair, SK

TSB #R14C0114 2014-11-06 CP Crowsnest Pearce, AB

USA – NTSB investigated broken rail derailments

None since late 2015



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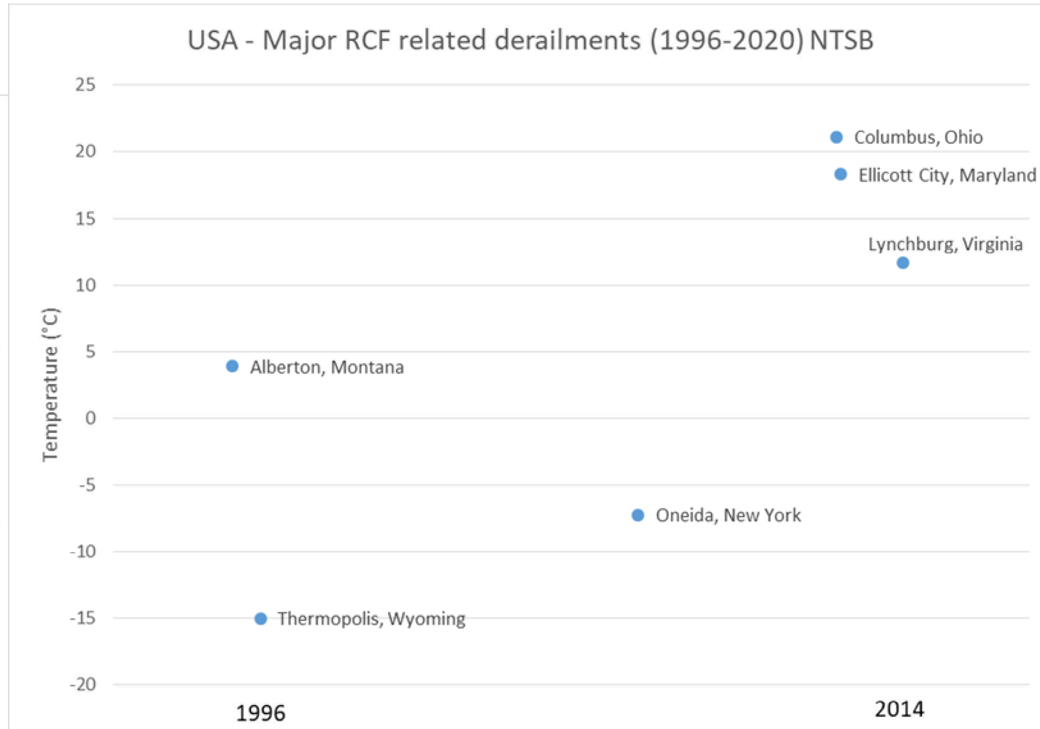

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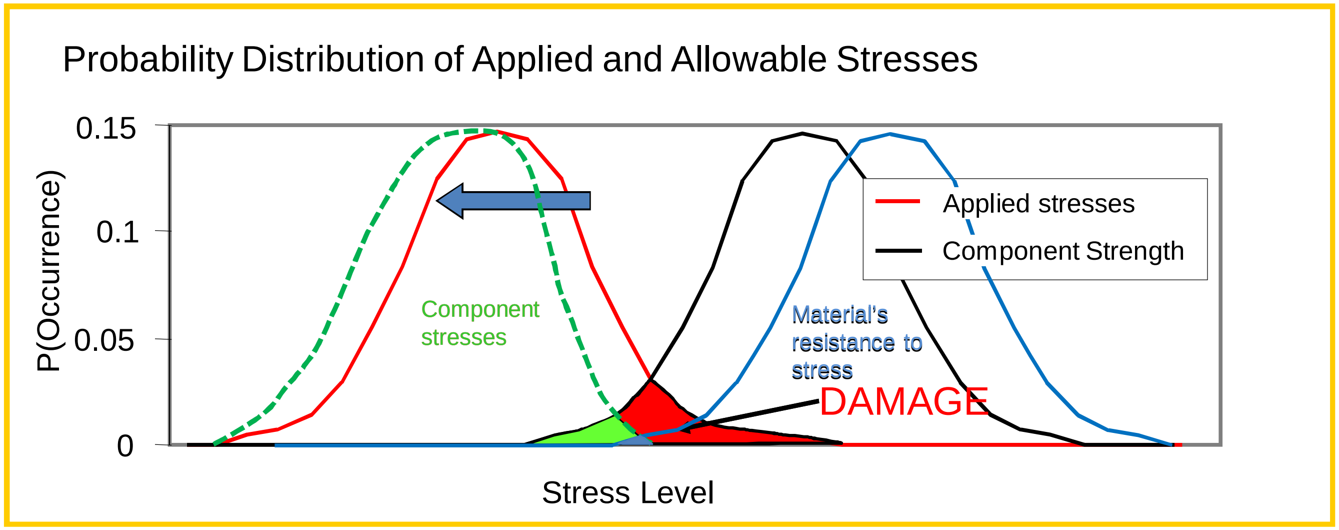
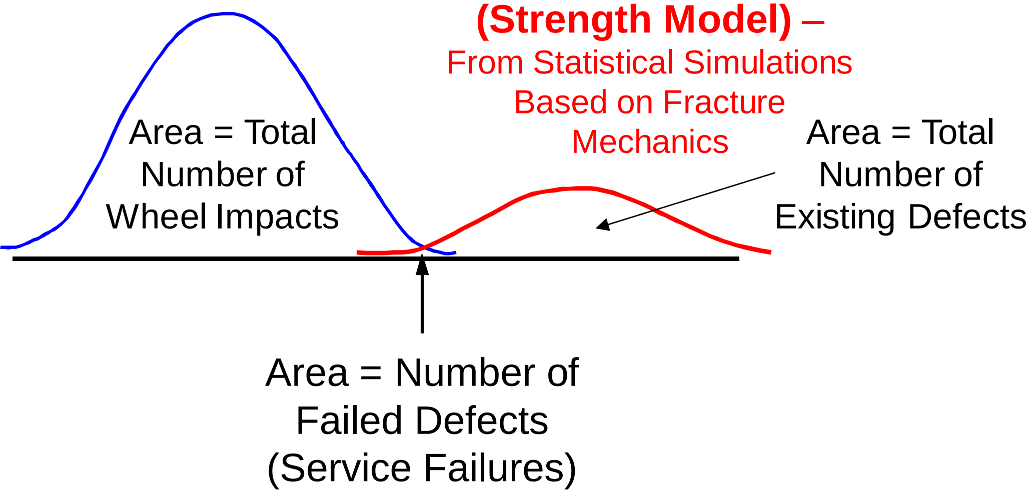
Stress vs Strength



Stress-Strength concept – THAW model

Train Force (Stress Model) –
From WILD Data

Track Strength (Strength Model) –
From Statistical Simulations Based on Fracture Mechanics



Random parameter inputs

- Defect size (%Head Area)
- Head loss due to wear
- Neutral temperature
- Residual stress severity
- Foundation stiffness
- Ambient temperature
- Rail type

$$P_{allow} = f(l, k_v)\left[\frac{K_{IC}}{\frac{2}{\pi}M_1 M_S M_G\sqrt{\pi a}} - \frac{\sigma_R + \sigma_T}{M_G}\right]$$

- Defect location and configuration

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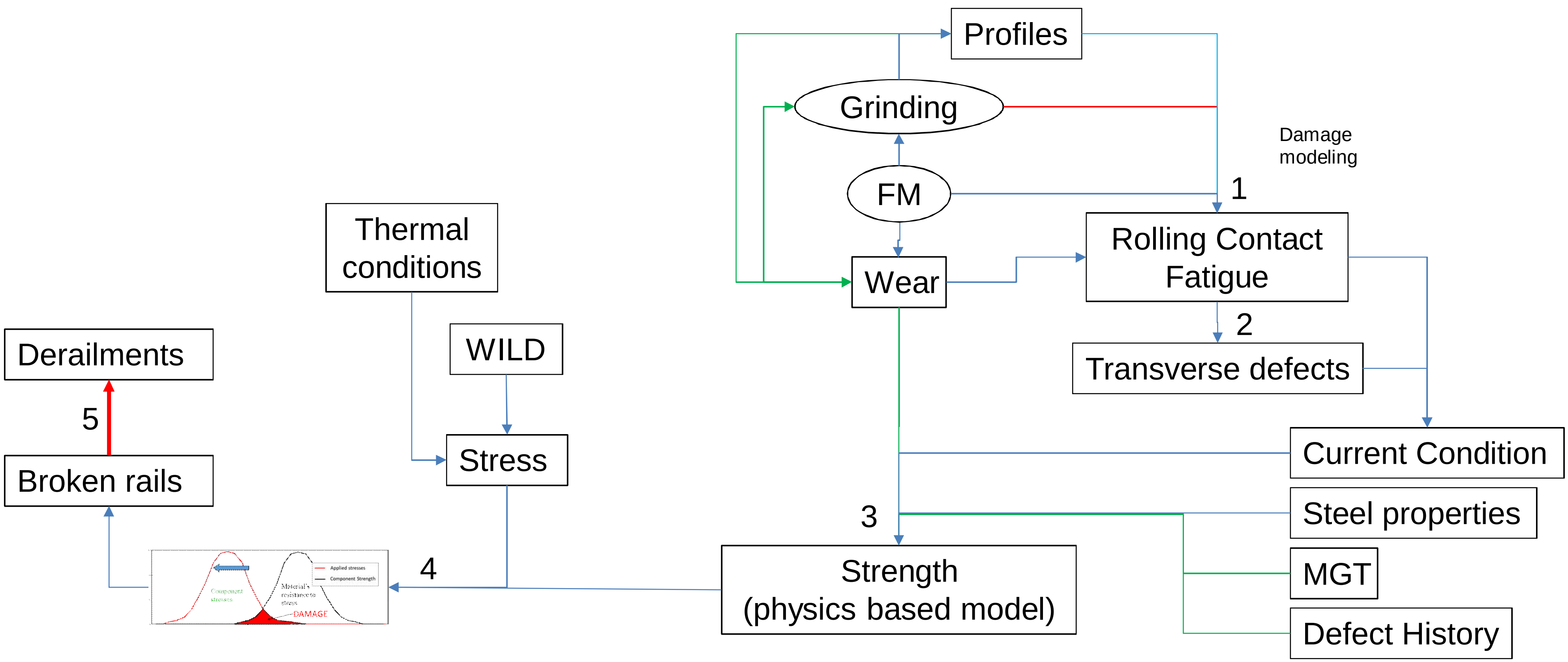
Stress-Strength Approach to Modeling Broken Rails



1: Impact of Rail Grinding on RCF

- Freight railroads generally chase shape, not RCF, unless have SSC
- Transit/passenger rail chase RCF
- Outstanding questions:
  - How soon should new rail be ground?
  - Is mill scale grinding really necessary?
  - What happens with residual cracks – is it ok to leave cracks behind?
  - Is there any evidence that coarse grinding can initiate RCF?

Spalling, shelling, corrugation (untestable rail)

2: Impact of Friction Modifiers on RCF

- It is generally accepted that rail FM, by reducing excessive shear forces, reduces RCF.
- Also can significantly impact wear – Magic Wear Rate impact?
- Models now available to quantify this

3: Relationship between RCF and UT

- ICRI Survey undertaken 2018 asking for examples of untestable rail
  - MRS, BNSF, CP, LUL responded
  - Clearly deep RCF at crown of rail
  - None were GCC
  - Is that a flaw in the concept - untestable rails are not necessarily prone to breakage?

  - D. Szablewski reported on this at 18JUN20
  - Where to go from here?

Improving Testing Capabilities?

Reliably Detected*	Not Reliably Detected
Detail Fracture	Engine Burn Fracture
Transverse Defect	Crushed Head
Horizontal Split Head	Broken Base
Vertical Split Head	Rail End Weld Fracture
Piped Rail	Welded Engine Burn Fracture
Bolt Hole Break	
Head and Web Separation	
Weld	
Plain Break	

From A. Zarembski, "Characterization of Broken Rail Risk for Freight and Passenger Railway Operations, AREMA 2005

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4: Strength model

- Material properties - known
- MGT - known
- Defect history - known
- Current condition – mostly measureable

- Must be combined to provide some assessment of the local “strength” or at least the relative resistance to breakage

5: Derailment modeling

- Broken Rails
  - Clusters
  - Poor fastening
  - High local forces (e.g. track geometry perturbations)
  - Crossings, switches, bridges

- But which broken rails lead to derailment?
  - Multiple fractures, large breaks
  - Seasonality?
  - Other geometry or speed factors?

ICRI – Next Steps?

- Are there any **good** data sets related to derailments?
- Workshop with the BrokenRails group:
  - Determine if proposed model is sufficiently comprehensive
  - Literature reviews / gap analysis on each of the 5 model elements
  - Identify an appropriately sized project for the ICRI to tackle:
    - Is relevant
    - Is within our capabilities/expertise
    - Can expect to make substantial progress within 2-3 years.
  - Perhaps start with a risk matrix exercise?

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ICRI BrokenRails

Please contact

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An ICRI task: Risk and Safety

National Research Council Canada   Conseil national de recherches Canada

Canada

Risk Mapping

SAFETY RISK		Severity/Consequence				
Probability		Catastrophic	Hazardous	Major	Minor	Negligible
		A	B	C	D	E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely improbable	1	1A	1B	1C	1D	1E

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Risk

Frequency

- Generally from historical data
- Often (very) low frequency events
- Can get statistics that span the industry, but can that be applied to a specific railroad?

Consequence

- Sometimes straightforward
  - Direct Costs
- Can be Difficult
  - Environmental damage
  - Cost of life
  - Indirect Impacts

Consequence?

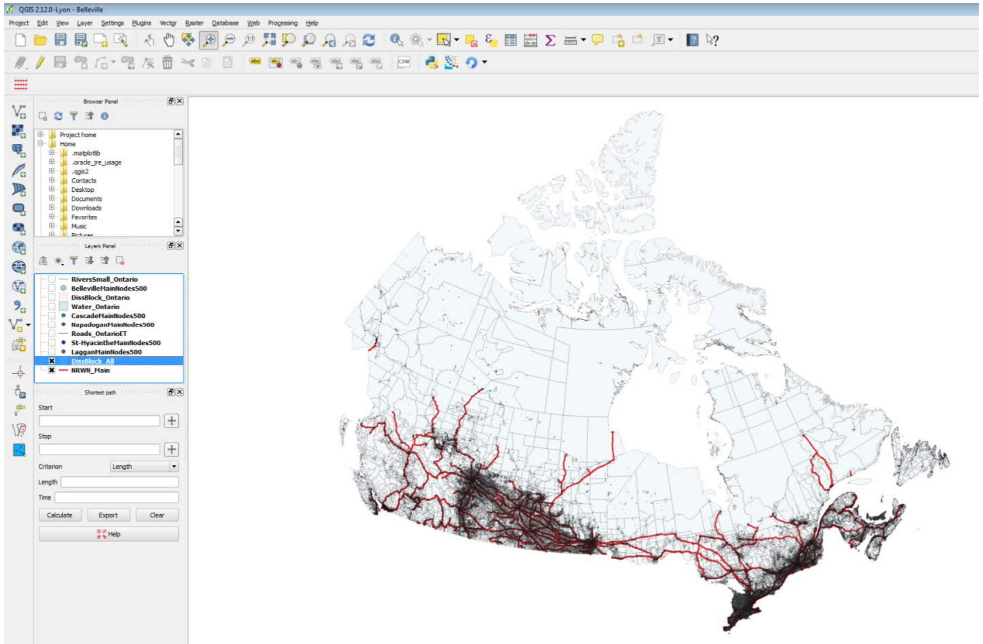
Guernsey, Saskatchewan 2020

Ellicott City, Maryland, 2012

Columbus, Ohio, 2012

Consequence: Route Analysis with GIS

- With a route mapped in GIS, a count of various attributes can be done.
- Large array of attributes are available
- Use GIS to collect estimates of proximity of a routes to many items of interest:
  - Population
  - Environment
  - Schools, hospitals, roads, factories….



Frequency/probability: Challenges

- Relatively little data for the low frequency, high consequence events
  - A transit agency might have less than a handful of mainline wheel-climb derailments in a decade.
- There can be large uncertainties and variabilities in the data used to develop the risk assessment.

Expected service failures per mile per is expressed as

$$E_{SF} = \frac{100e^{u}}{4\left(1+e^{u}\right)} \quad (1)$$

$$U = Z^{*} + C_1S + C_2R + C_3A + C_4T + C_5L + C_6I + C_7G + C_8B \quad (2)$$

where

E_{SF} = expected number of service failures per mile per year on a specific segment

Z^{*} = adjusted model constant

S = rail weight (in pounds per yard)

R = rail type (1 if welded, 0 if bolted)

A = rail age (in years)

T = annual traffic (in million gross tons)

L = weight of car (in tons)

I = presence of an ultrasonic defect in the last three years (1 if present, 0 otherwise)

G = presence of a geometric defect in the last three years (1 if present, 0 otherwise)

B = presence of a bridge within 200 feet of segment (1 if present, 0 otherwise)

$C_1, C_2, C_3, \ldots, C_8$ = coefficients

Schafer, II, D.H. (2008). "Effect of Train Length on Railroad Accidents and a Quantitative Analysis of Factors Affecting Broken Rails." MS. Thesis, University of Illinois at Urbana-Champaign.

Predictive models

- Often based on historical data
- Need continual updating to account for remediations
- How to account for new technologies, processes, investments/upgrades?

- For examples:
  - Adopting an improved rail steel? Previous model had no such factoring
  - If we employed top of rail friction management, what would be the impact on safety?

Other examples

- Improved track geometry
- Improved track modulus transitions
- Better, more consistent welding
- Optimizing super-elevation
- Rail grinding to remove RCF
- RCF limits (e.g. using electromagnetic systems)
- Improved rail profiles and their management
- Better RNT management