WHEEL Defect Prevention Research Consortium

Findings of the Wheel Defect Prevention Research Consortium

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Presentation

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- **The basics**
  - Who – are we?
  - What – is the goal?
  - Why – are we motivated?
  - How – do we approach the problem?
- **Findings**
  - Shelling vs. Spalling – Inspections of wheelsets
  - Spalling
  - Shelling
    - Rolling Contact Fatigue
    - Thermal Mechanical Shelling
- **Recommendations**
- **Ongoing work**

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Who?

- **WDPRC = Wheel Defect Prevention Research Consortium**
- **Government, Railroads, Private Car Owners, Suppliers**
  - American Electric Power
  - Amsted Rail (Griffin Wheel)
  - BNSF
  - CIT
  - Canadian Pacific Railway
  - CSX Transportation
  - Federal Railroad Administration
  - GATX
  - GE Rail
  - Holland Company
  - Norfolk Southern
  - New York Air Brake
  - Progress Rail
  - Standard Car Truck Co. (Anchor Brake Shoe, Zeftek)
  - Standard Steel
  - Sumitomo
  - TTCI
  - TTX
  - Union Tank Car
  - Union Pacific Railroad
  - Wabtec (Cardwell Westinghouse, Railroad Friction Products Corp.)

What?

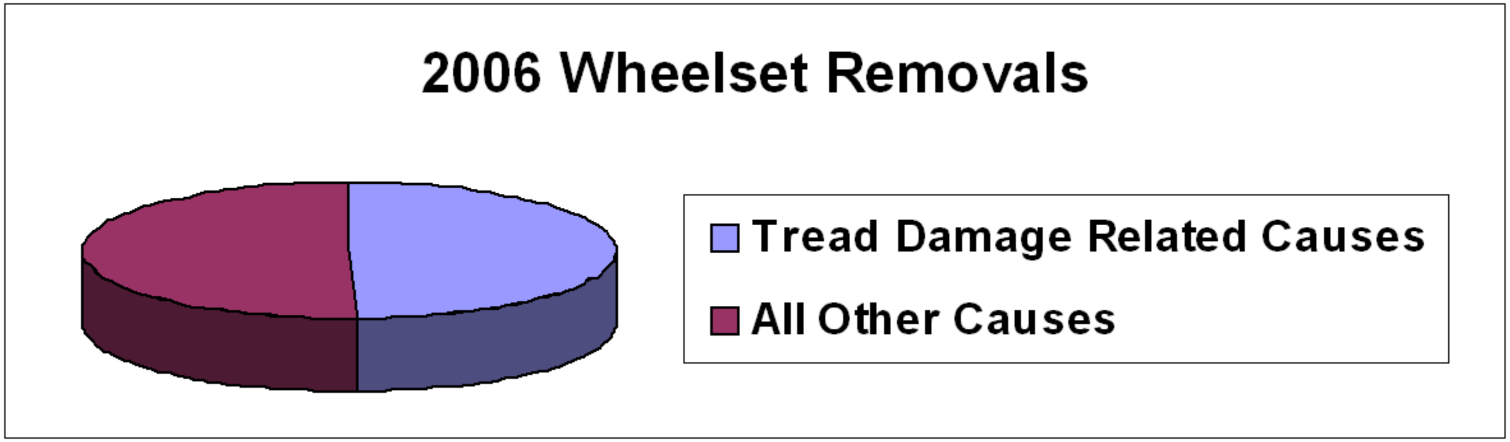
- Find root causes of wheel tread damage and identify remedies
- Two major categories of wheel tread damage:

- Slid flats and spalling:
  wheel sliding on rail creates enough heat to produce a metallurgical transformation and eventually produce a spall

- Fatigue and shelling:
  repeated cycling of stresses causes cracks to form and eventually produce a shell

Why?

- Tread damage → Impact loads → Damage to track and car
- Almost half of the 700,000 wheelsets changed out in 2006 were due to tread damage related causes (WMC 61, 65, 67, 75, and 78)
- Approximate cost in 2006: $350 million



How?

- **WDPRC utilizes diverse data sources to determine root cause**
  - Existing literature
  - Inspections
    - Damaged and undamaged wheelsets
    - Good and bad actor cars
  - Controlled condition testing
    - Air brake valves
    - Brake shoe force
    - Drag brake thermal testing
  - Analysis of data from wayside detectors
    - WILD (wheel impact load detector)
    - Wheel temperature
  - Computer simulation
    - Wheel sliding
    - Wheel fatigue

Findings: Shelling Vs Spalling

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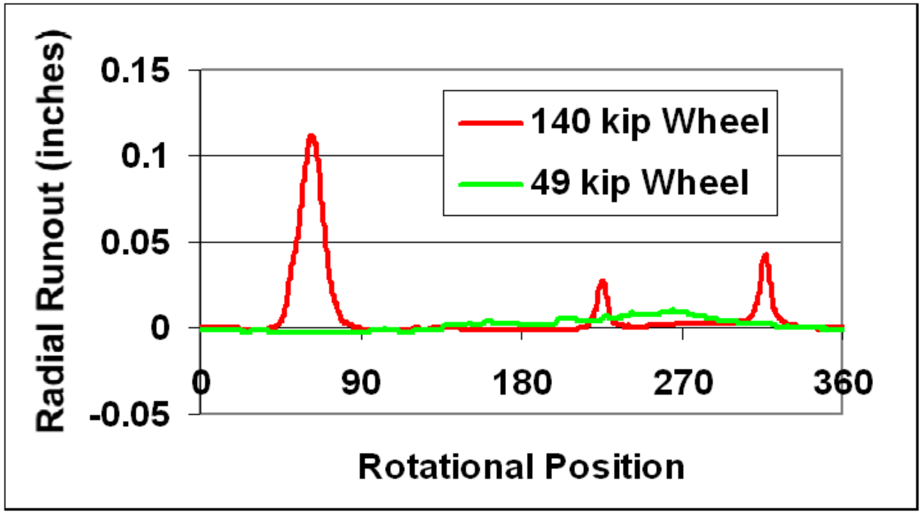
- 163 wheelsets inspected at three shops (WMC 11,61,64,65)
- Etchant applied, radial runout recorded, expert observation
- Type of damage tied to car type and service
  - Coal cars = shelling
  - Noncoal cars = mix of spalling and shelling (primarily spalling)
  - Intermodal = thermal mechanical shelling according to car owner



Findings: Shelling Vs. Spalling

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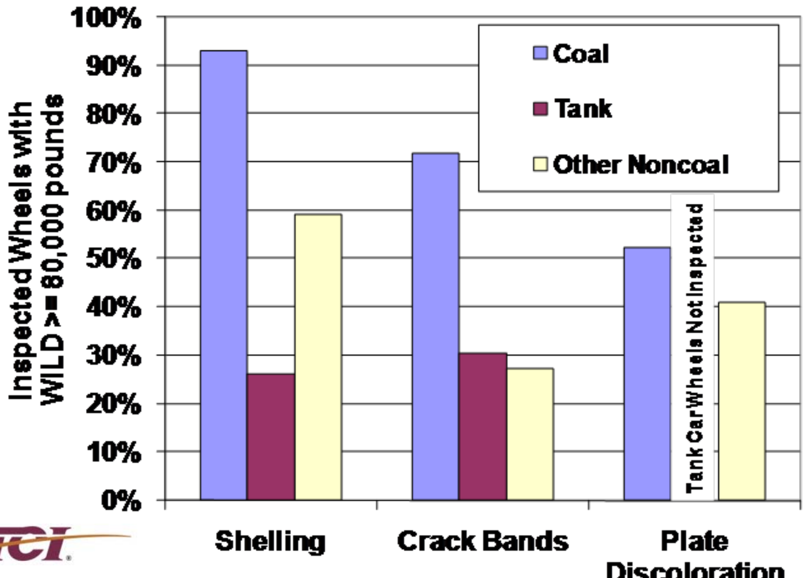
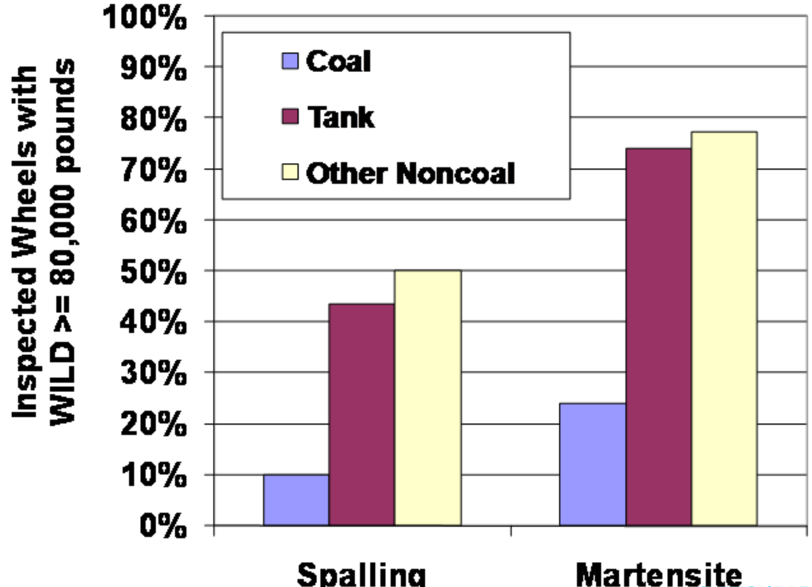
- **Based on CRB data, overall wheel tread damage problem is split about evenly between shells and spalls**
- **Noncondemnable defects found on many wheels removed for wear causes: tread damage more prevalent than repair records indicate**

Car Type	Sample Size	Shelling Found	Spalling Found
Coal Hoppers and Gondolas	71	93%	10%
Tank Cars	23	26%	44%
Covered Hoppers	12	42%	58%
Mill Gondolas	7	71%	43%





Findings: Spalling

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- **Literature Review**
  - Wheel slide tests show that the potential exists to create martensite on sliding wheels with almost any realistic combination of axle load, wheel slide duration, train speed, and wheel/rail adhesion level[1]
  - Maximum wheel slide contact patch temperatures are probably achieved within the first second of a constant velocity wheel slide[2]
  - Multiple authors note presence of spalling on one wheel with none on the mate
    - Different adhesion levels on each rail, such that one wheel reaches austenitizing temperature while the other does not[2]
    - Very short duration slide where one wheel stays in synchronous contact with the rail[3]
    - Different wear rates between wheels on same wheelset[4]

1) Jergeus, J., Odenmarck, C., Lunden, R., Sotkovski, P., Karlsson, B., and Gullers, P., "The Silinge Wheel Flat Experiments," Report F202, Department of Solid Mechanics, Chalmers University of Technology, Gothenburg, Sweden, 1997.
2) Sawley, K.J., and J.A. Rosser, "Tread Damage in Disc-Braked Wheels", 9th International Wheelset Congress, Montreal, Canada, Sept 1988.
3) Bartley, G.W., "A Practical View of Wheel Tread Shelling", 9th International Wheelset Congress, Montreal, Canada, Sept 1988.
4) Magel, E., and J. Kalousek, "Martensite and Contact Fatigue Initiated Wheel Defects", 12th International Wheelset Congress, Qingdao, China, Sept 1998.

More Findings: Spalling

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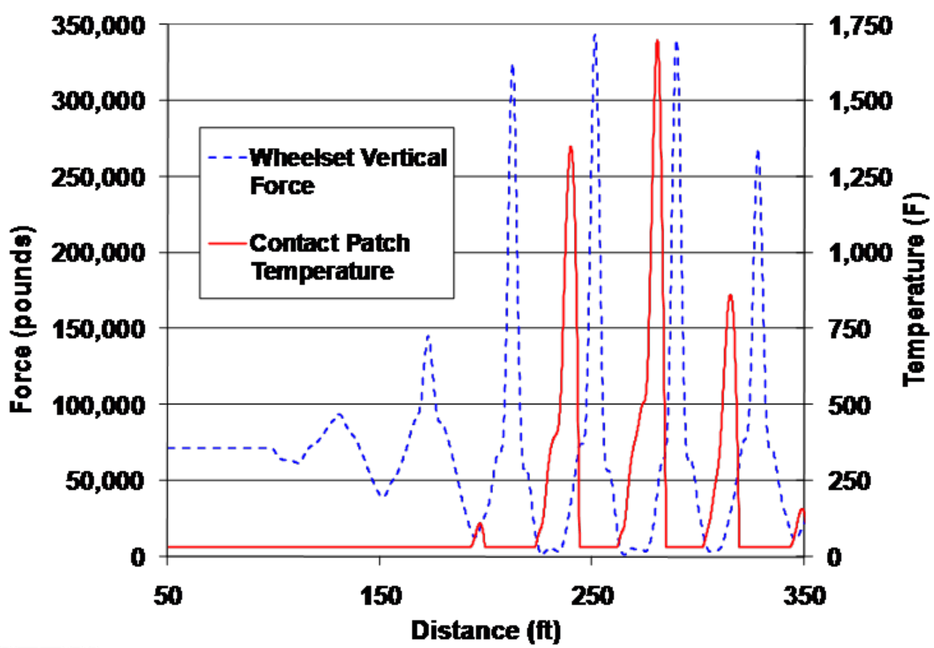
- **NUCARS®[1] simulations**
  - Traversing rough track designed to excite suspension bounce resonance
    - Brake retarding forces applied and wheelset rotational speeds calculated, contact patch temperatures estimated
    - Traversing rough track with brakes applied is probably not a major source of spalling for loaded cars
  - Empty cars (and especially those with malfunctioning E/L device) can slide wheels under heavy braking in low wheel/rail friction conditions regardless of track geometry. This may be a minor source of spalling



[1] NUCARS is a registered trademark of TTCI

More Findings: Spalling

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- **Movement of cars with handbrakes applied is a major source of wheel spalling**
  - Numerous analyses have been conducted in the past that show cars with truck mounted brakes have more tread damage to the wheels on the "B" end
  - WDPRC found 95% / 5% split in this case for a group of 294 tank cars
- **In 2007, WDPRC updated a training video about the importance of releasing handbrakes**
  - "Please Release Me…Let Me Roll"
  - Target audience is operating personnel
  - Free, downloadable version at www.aar.com/wdprc
  - Free DVD versions available to training organizations by emailing this presenter with a request and your mailing address
    - Scott_Cummings@ttci.aar.com

Background: Shelling - RCF & TMS

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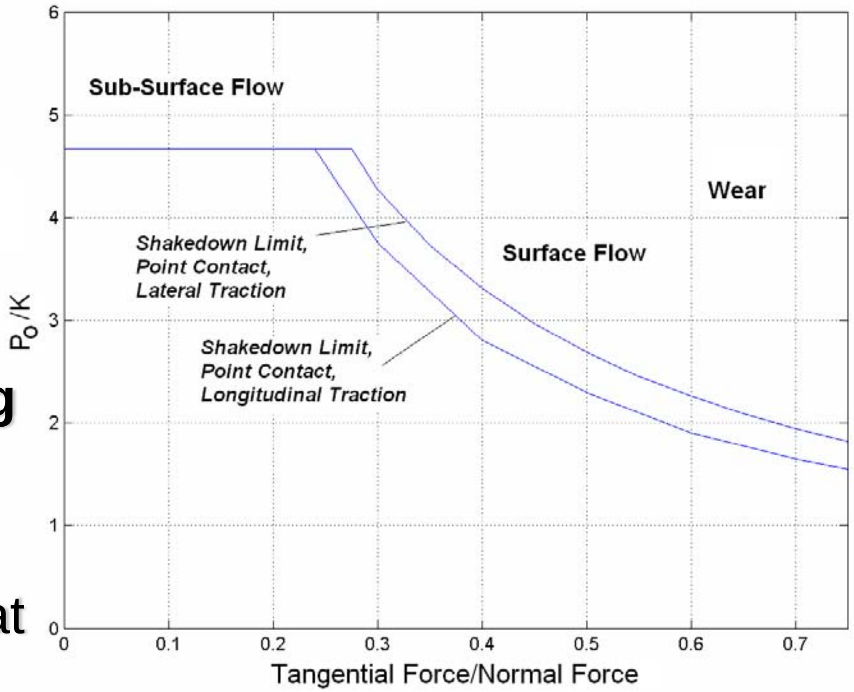
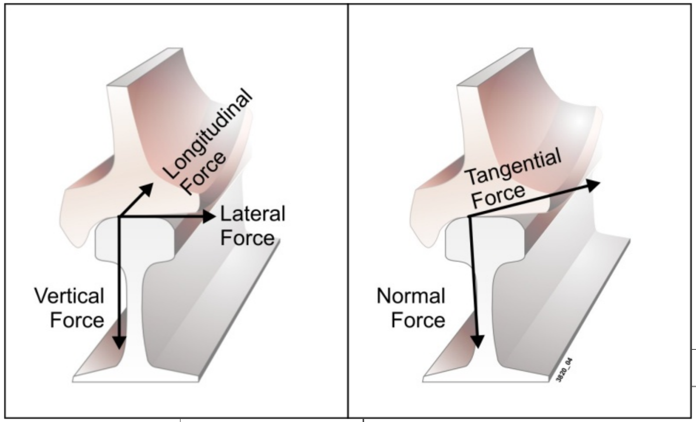
- **RCF = Rolling Contact Fatigue**
  - Many cycles of high stress (tangential forces)
  - Shakedown predicts RCF by relating
    - Ratio of tangential force to normal force (T/N)
    - Ratio of contact stress to shear yield strength (Po/K)
- **TMS = Thermal Mechanical Shelling**
  - Subset of shelling – requires hot wheels
  - Resistance to fatigue is reduced at high temperatures
    - Steel properties degrade
    - Beneficial compressive residual hoop stresses are relieved

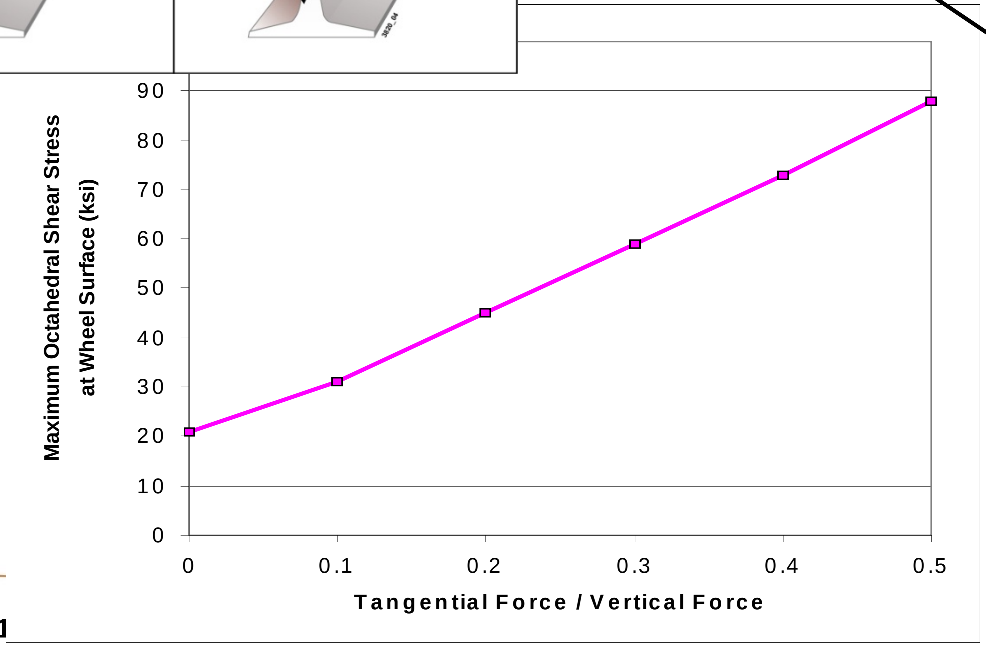
- Loaded car P_o/K ~ 3, therefore RCF @ T/N ~ 0.375
- T/N limited by wheel/rail COF
- Typical COF values 0.35 to 0.55



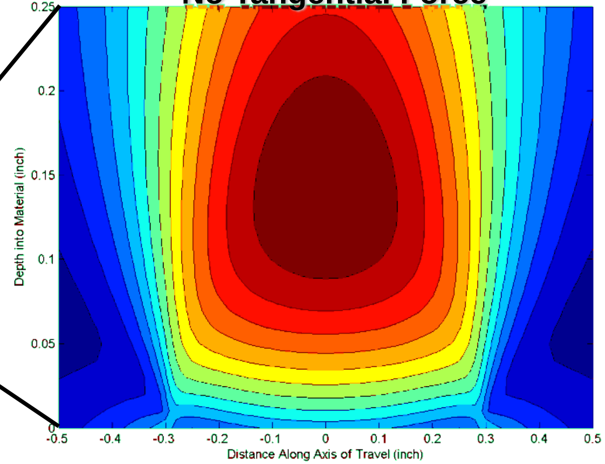
Background: Shelling - RCF

- **Wheel/rail tangential forces are important to the stress near the tread surface where cracks initiate and propagate**
  - Tangential forces move the stress closer to the tread surface

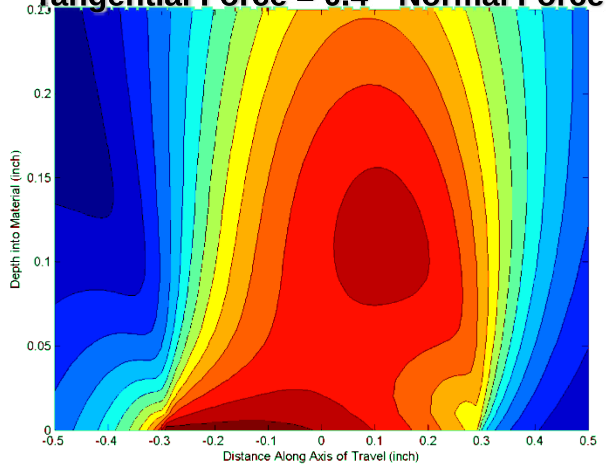




No Tangential Force



Tangential Force = 0.4 * Normal Force



Findings: Shelling (RCF)

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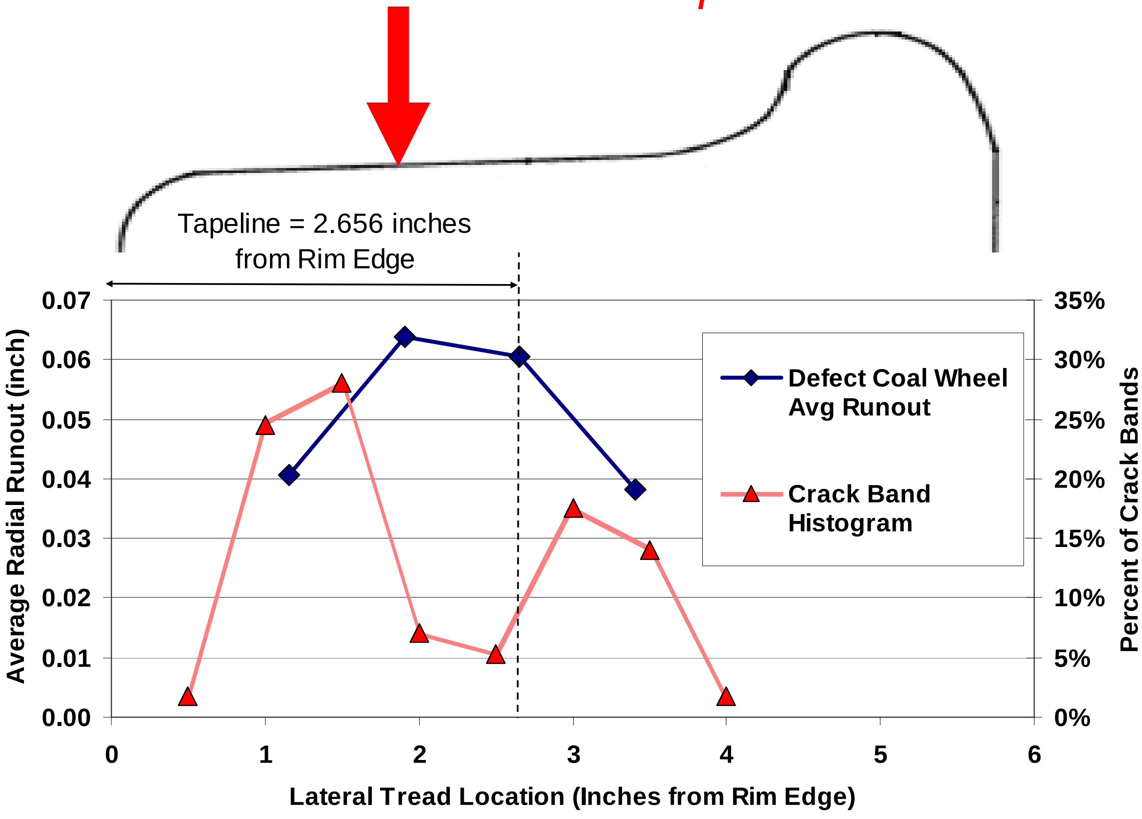
- Most RCF damage occurs on the low rail wheel of the wheelset in the lead position of the truck during curve negotiation of a loaded car. Finding supported by:
  - Wheelset inspections
  - Revenue service Instrumented Wheelset data
  - NUCARS modeling
  - WILD data analysis

Largest average runout is outboard of the tapeline



Shelling Progression Photos

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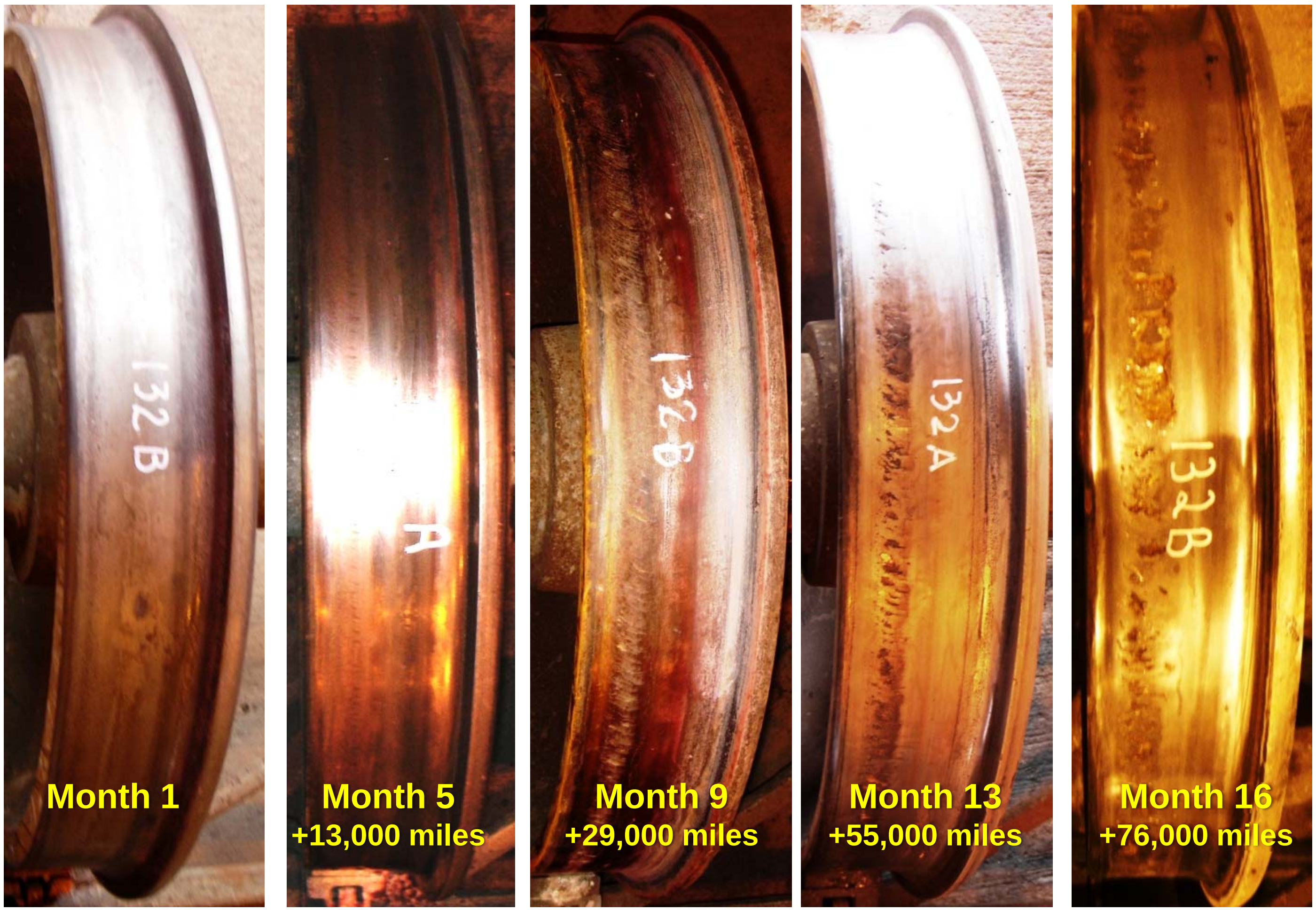
- **Photos show wheel shells developing as follows:**
  1. Crack band appears outboard of tapeline
  2. Cracks join to form shells
  3. Shells grow inboard toward tapeline where contact with rail occurs on more regular basis



More Findings: Shelling (RCF)

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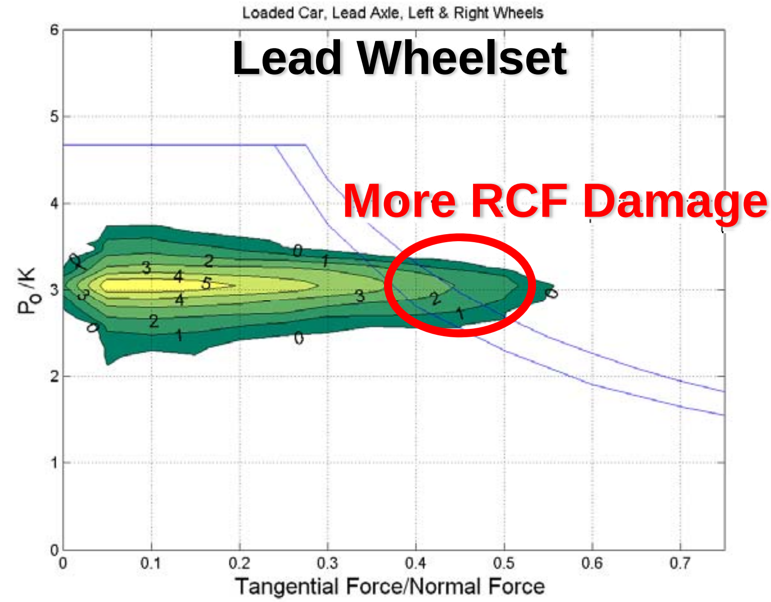
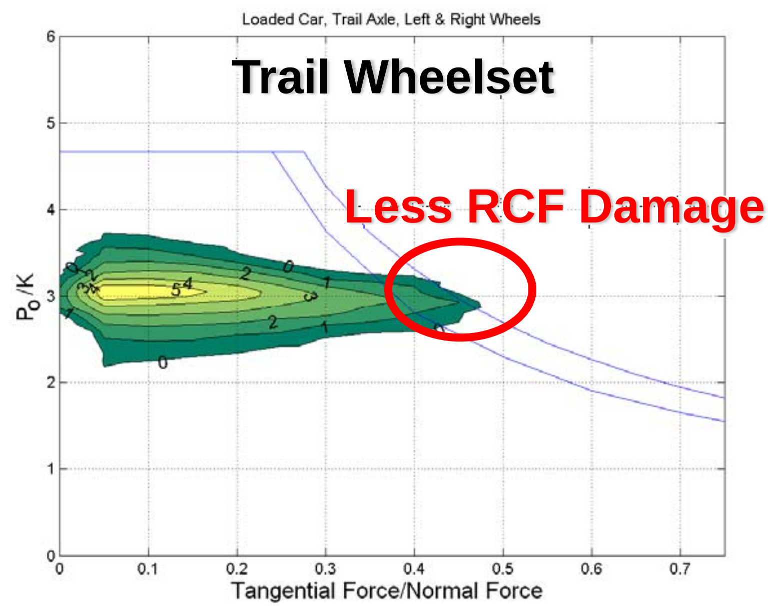
- **Potential to reduce RCF with minor changes to track & operating conditions**
  - Data analyzed from instrumented wheelsets installed in a loaded coal car: 1,500 miles in revenue service
  - Total distance traveled with predicted RCF damage: < 1 mile
  - Most curves of 4 degrees or tighter caused some predicted RCF
  - 4 specific locations accounted for half of ***predicted*** RCF damage
  - Train typically operated below curve balance speed when RCF was predicted





More Findings: Shelling (RCF)

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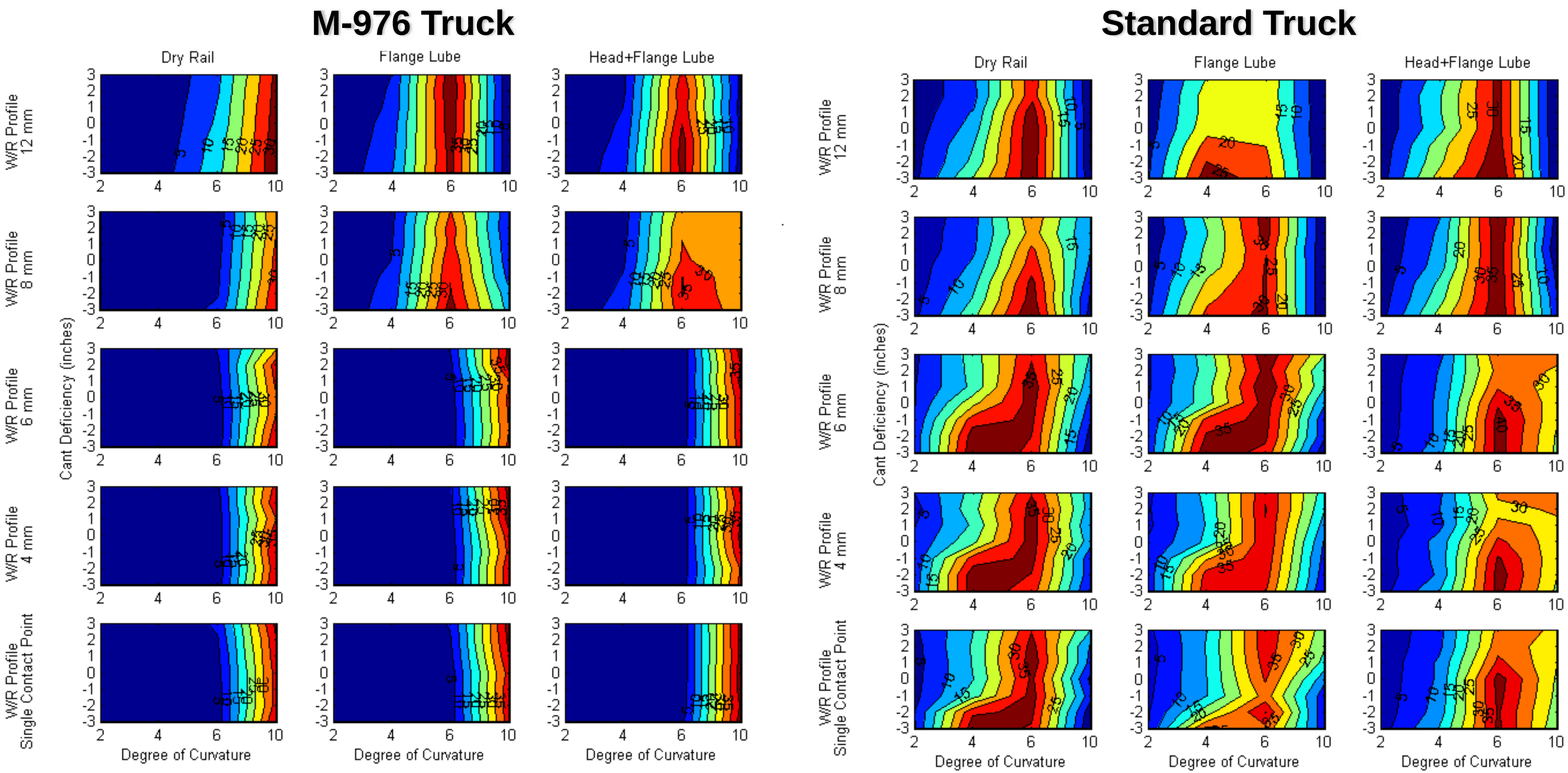
- **Potential to reduce RCF with improved trucks**
  - NUCARS modeling of many condition combinations shows truck type to be important factor (red = RCF, blue = no RCF)



Findings: Shelling (TMS)

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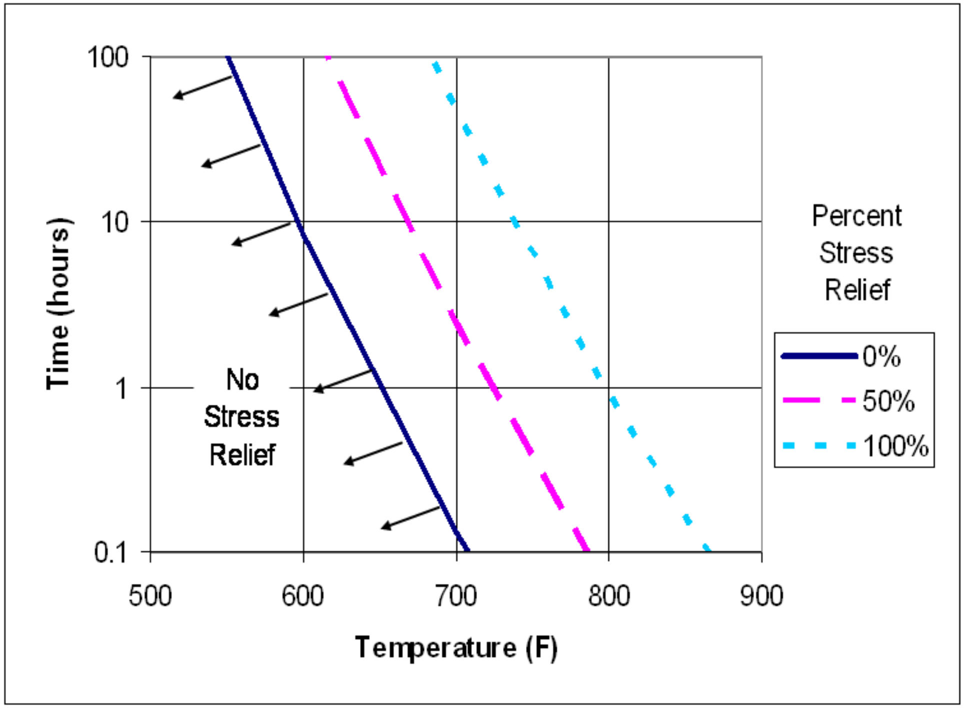
- **Maximum acceptable operating tread temperature to avoid TMS is approximately 600°F**
  - Applying Larson-Miller equation to existing data allows time / temperature / % stress relief relationship
  - Sines fatigue calculation shows that wheels are far more prone to shelling in the absence of compressive residual stress
  - Short duration exposure allows higher temperatures
  - Wheels with properly functioning brake systems do not typically reach 600°F
    - Ex: 50 Hp for 30 minutes would produce 600°F[1]



1) Stone, D.H., D.G. Blaine, and G.F. Carpenter. 1994. "Effect of High Horsepower Grade Braking on AAR High Friction Composition Shoes." *Proceedings of 86th Annual Convention and Technical Conference of the Air Brake Association*. Chicago, IL. pp. 113-135.

More Findings: Shelling (TMS)

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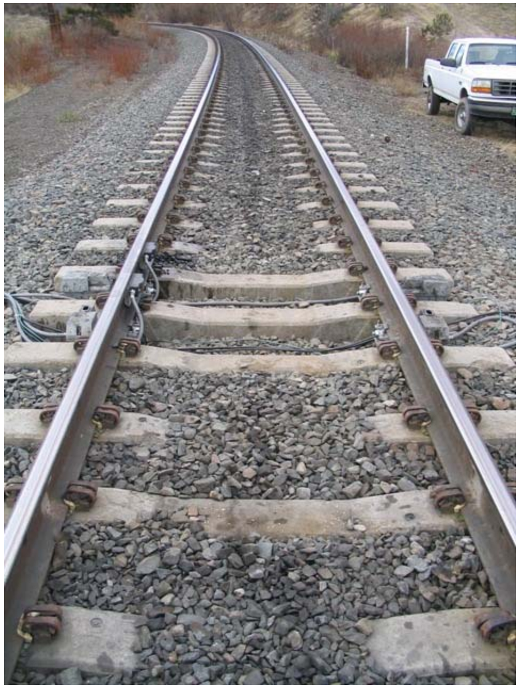
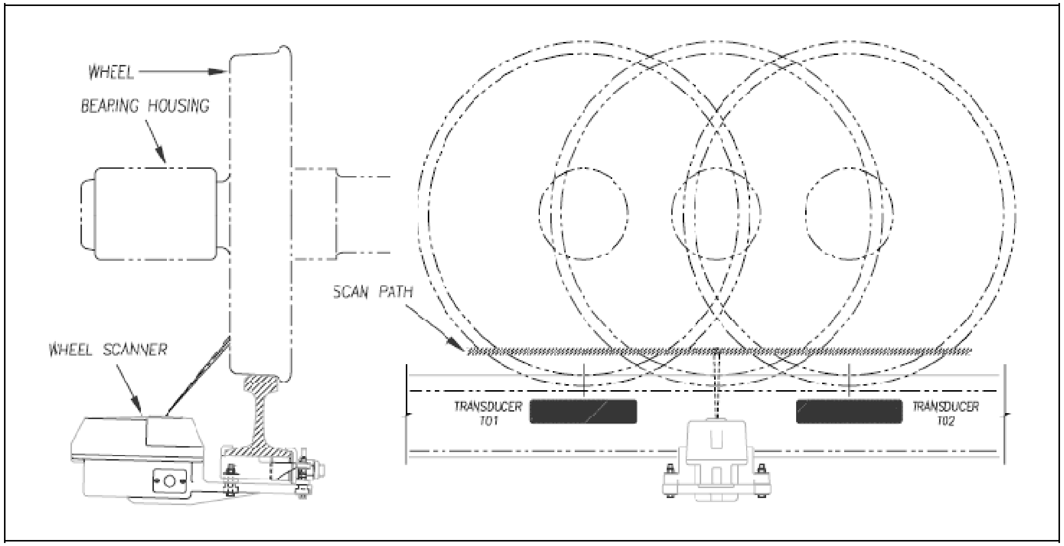
- **Wheel temperature variations lead to hot wheels**
  - Data from a single wheel temperature detector installed near bottom of hill – 1,575 trains analyzed, over 600,000 wheelsets
  - Temperature variations found <u>between trains</u>
    - 15 trains accounted for more than 20% of the descending cars with hot wheels
      - Train handling can affect wheel temperature ⟶ shelling





Southern Technologies Corporation. July 2004. “SmartScanIS User’s Guide for Union Pacific,” EUD-2004194-PV, pp 137.

TTCI

More Findings: Shelling (TMS)

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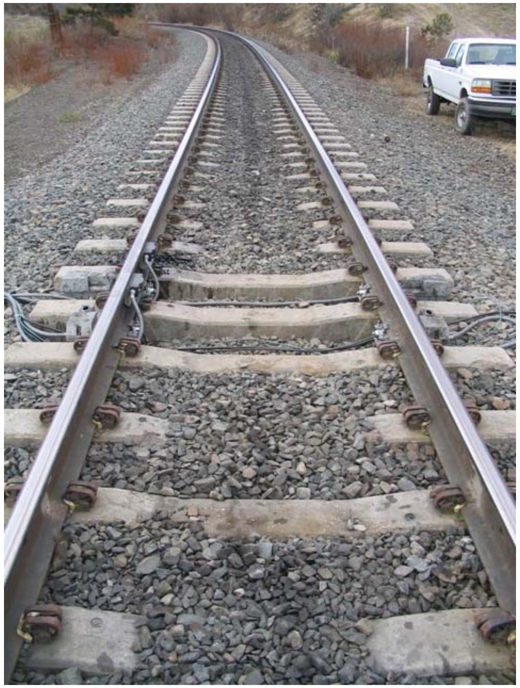
- **Wheel temperature variations lead to hot wheels**
  - Data from a single wheel temperature detector installed near bottom of hill – 1,575 trains analyzed, over 600,000 wheelsets
  - Temperature variations found <u>within cars</u> and <u>between cars</u>
    - 76% of the descending cars with a wheel temperature greater than 500°F had only a single wheel above this level
    - While the wheels in these cars are generally at higher temperatures than the wheels of other cars in the train, there were large temperature differences between individual wheel locations
  - Repeated hot wheel behavior was found on
    - 37% of the descending cars with hot wheels
    - 20% of individual hot wheel locations



More Findings: Shelling (TMS)

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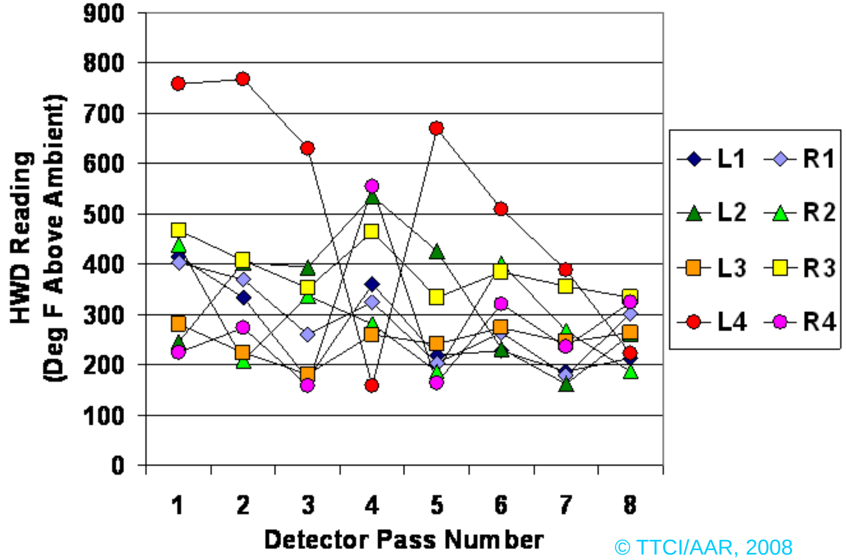
- **The cause of hot wheel behavior within cars and between cars is difficult to identify**
  - Inspection shortly after passing temperature detector
    - 1 car found with handbrake applied, all wheels hot
    - No cause found for 14 other cars inspected
  - Detailed inspection/teardown/brake test
    - Good and bad actor cars selected based on multiple wheel temperature readings
    - Found one bad actor car with valve leaking air into brake cylinder
    - The selection of bad and good actor cars based on wheel temperatures correlated well with wheelset replacements
      - Bad actors had twice as many replacements



Recommendations

- **Abridged list of WDPRC recommendations**
  - Increase adherence to handbrake release policies to reduce wheel spalling
    - Utilize “Please Release Me…Let Me Roll” in training programs
  - Identify problem RCF curves and investigate
    - Rail profiles
    - Superelevation
    - Rail COF
  - Reduce wheel/rail tangential forces during curve negotiation
    - Use trucks with high warp resistance and low axle steering resistance
  - Minimize use of train brake by maximizing use of dynamic brake, especially in regions with heavy grades to obtain the minimum average wheel temperature per train

WDPRC On-Going Work

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- **Focus on implementing recommendations**
  - Proposed changes to single car test (AAR S-486) with evidence to support
  - Distribute and promote “Please Release Me…Let Me Roll”
  - Determine current state of industry with respect to dynamic brake training and usage
    - Possibly assist with industry standard training material
  - Identify specific problem RCF curves
    - Determine why worse than other curves (profile, COF, geometry)?
    - Recommend specific course of action to correct
  - Determine economics related to truck maintenance
    - Wheel savings could pay for improved truck maintenance
    - Recommend optimal ton-mileage for reconditioning
  - Additional investigation into sources of wheel temperature variations within cars and between cars