Case Study: Investigating a Rail Rollover Derailment

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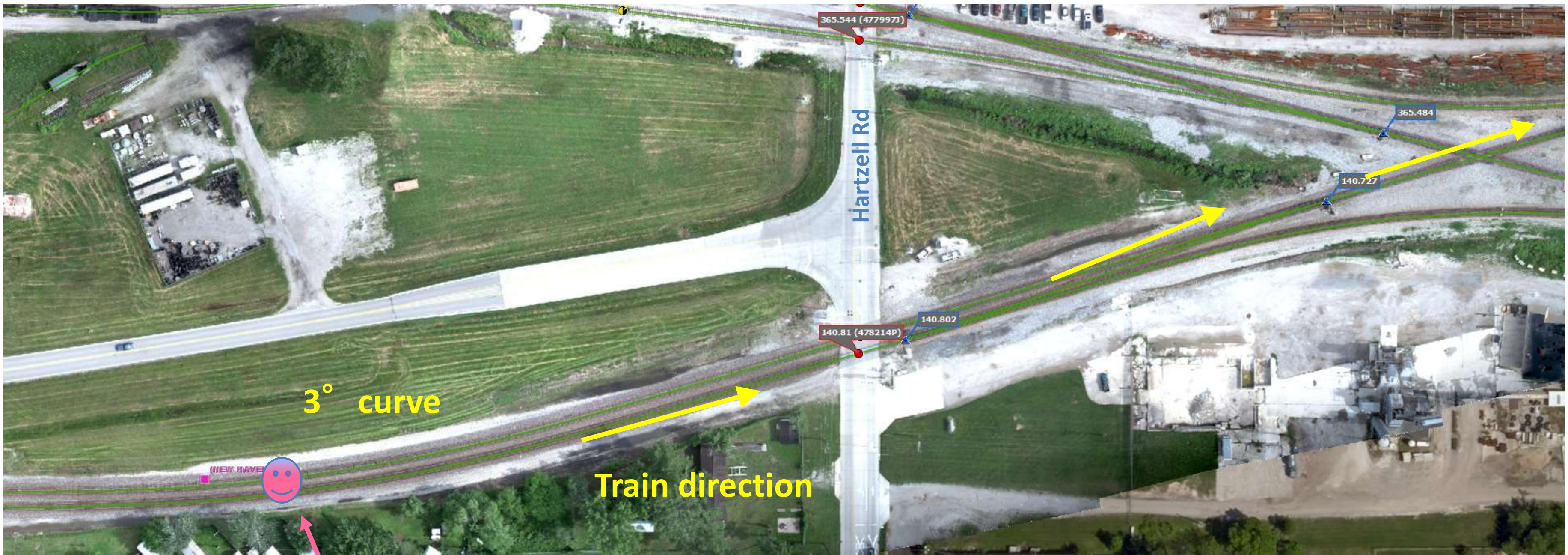
The set-up

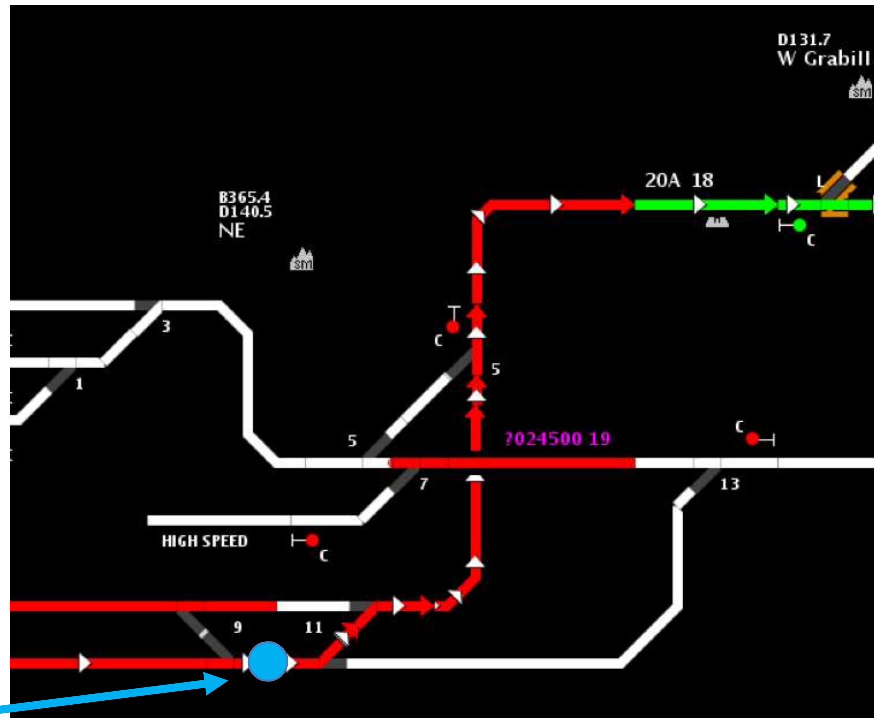
- CP NE, Ft Wayne, IN
- August 18, 2017
- Train 20A
  - 2 locomotives
  - 36 loads (88 double-stack platforms)
  - 5921 tons / 5894 feet
  - train was moving at 16 mph in notch 3
- 3.7° curve, 3” elevation
- Looking in direction of train movement at the POD

NS GIS image of derailment site



Camera location in slide 2

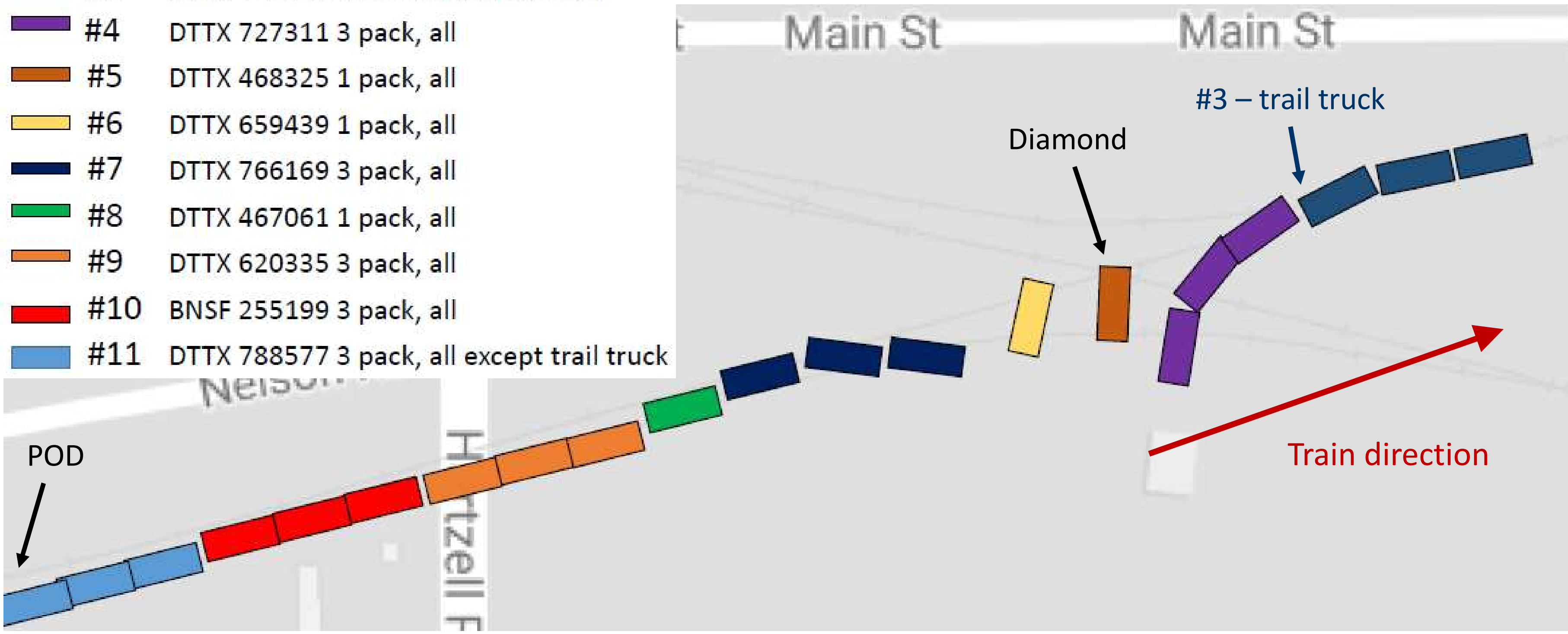
Dispatcher's screen showing train route



3.7° curve

Which cars derailed?

Position	Description
#3	DTTX 787816 3 pack, trail truck only
#4	DTTX 727311 3 pack, all
#5	DTTX 468325 1 pack, all
#6	DTTX 659439 1 pack, all
#7	DTTX 766169 3 pack, all
#8	DTTX 467061 1 pack, all
#9	DTTX 620335 3 pack, all
#10	BNSF 255199 3 pack, all
#11	DTTX 788577 3 pack, all except trail truck

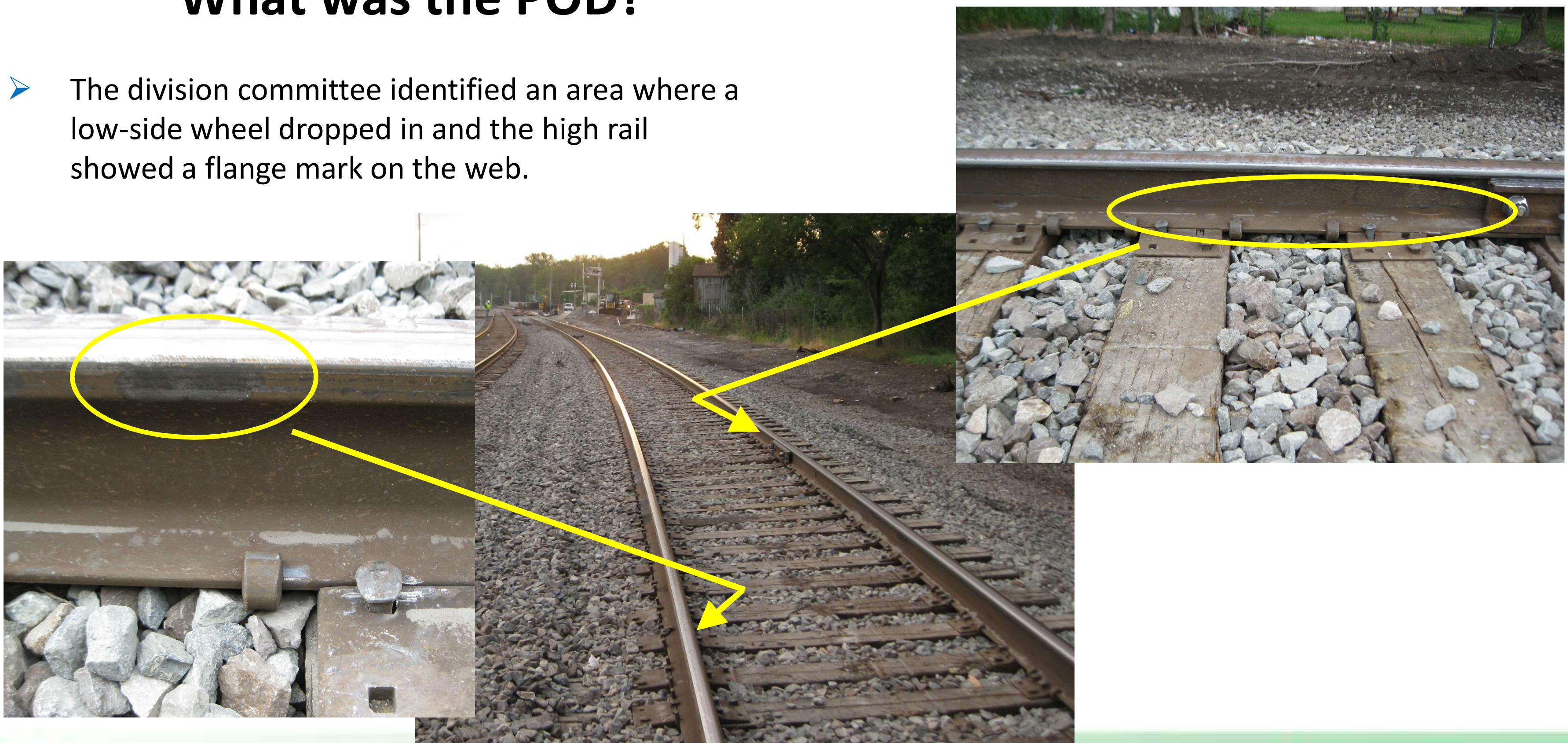


When looking for a derailment cause, what are the two most important questions?

1. What was the POD?
2. What was the first car to derail?

What was the POD?

- The division committee identified an area where a low-side wheel dropped in and the high rail showed a flange mark on the web.

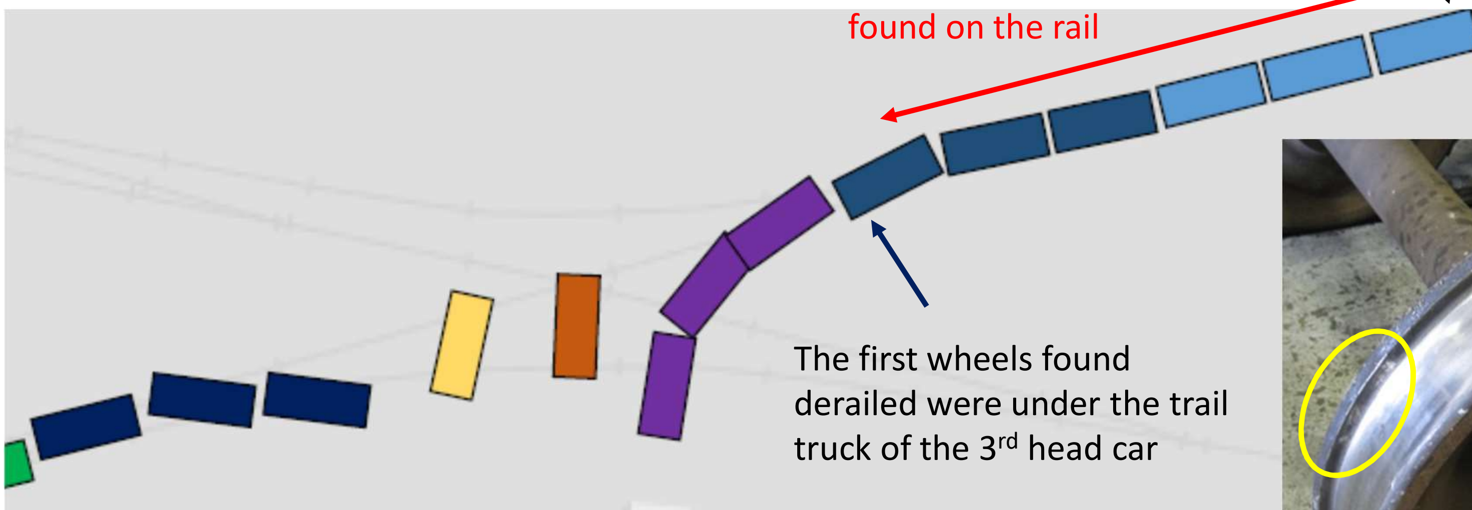


What was the first car to derail?

Mechanical identified the 2nd car / lead truck as the first to derail because of white marks on a wheel flange…and suggested that the car then rerailed itself!

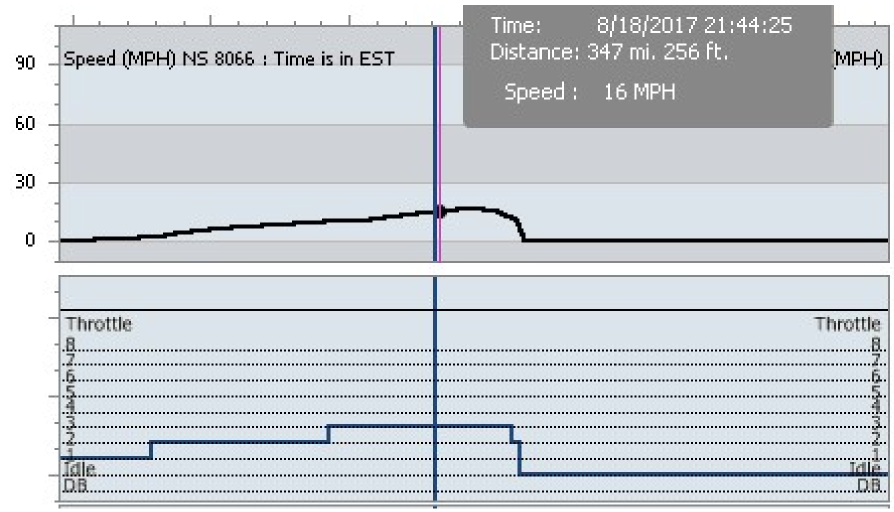
2nd head car added to sketch

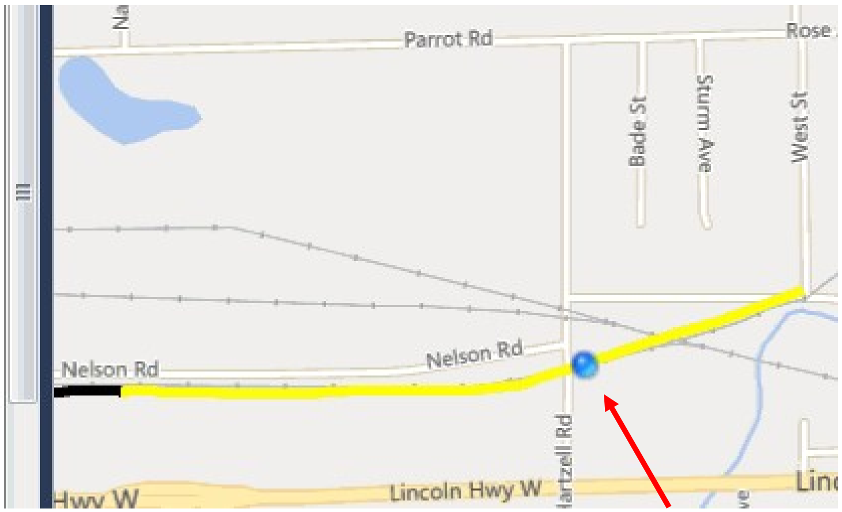
All of these wheels were found on the rail



The first wheels found derailed were under the trail truck of the 3rd head car

Transportation review – event recorder



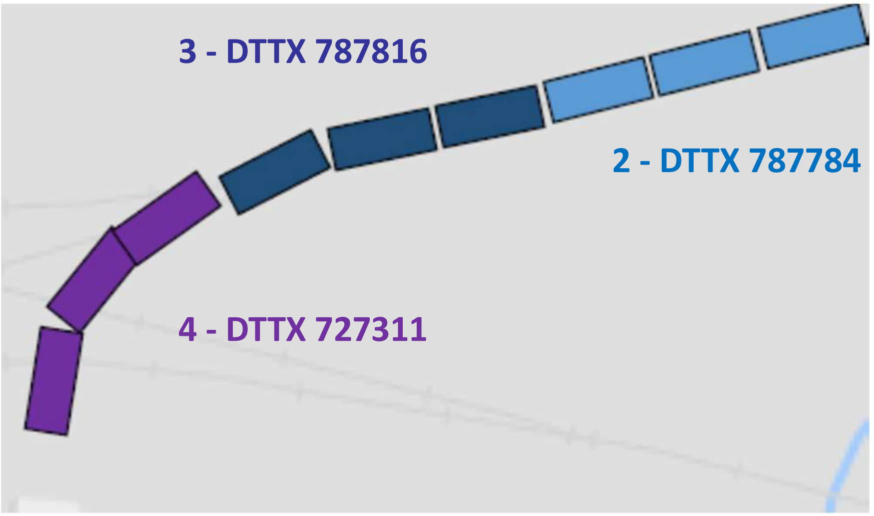


Lead loco

The cursor marks when the lead locomotive was just east of Hartzell Rd, speed was 16 mph and climbing gradually, and throttle was in notch 3.

The CHMM (crash-hardened memory module) includes a map display.

Mechanical review – car inspection



2nd head car, DTTX 787784, lead truck (the one thought to have derailed and then rerailed itself) inspected in car shop. No exceptions.

3rd head car DTTX 787816, trail truck inspected in car shop, wheels replaced due to minor derailment damage. No other exceptions.

4th head car DTTX 727311, all four trucks derailed, with severe damage to the wheels on the two intermediate (C and D) trucks. Car was not re-railed. A thorough inspection was not possible.

Track review – track geometry

Gage, alignment and crosslevel from the derailment track notes are shown as points.

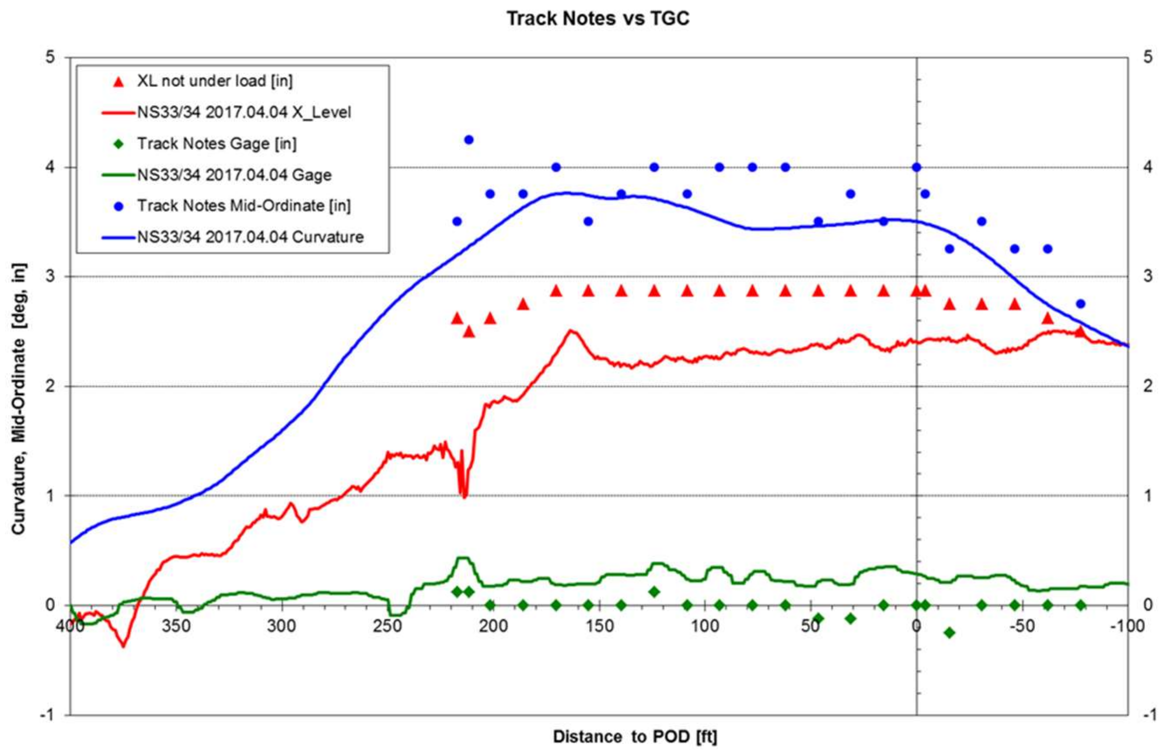
Same parameters from April 4, 2017 track geometry car test are shown as lines.

Curvature – left axis

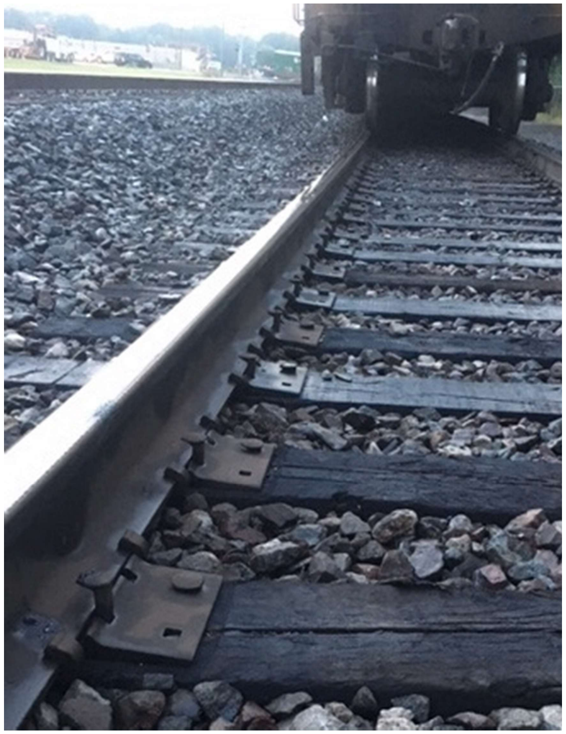
X-level and gage – right axis

"0" on horizontal axis marks the POD.

Conclusion: line, surface and gage all good!



Track review – conditions before POD



Wheelset is under trail truck of last derailed car.

Low rail on left

High rail on right

Note raised spikes on both rails

Video taken by Division Engineer

Observations

- High rail - spikes lifted for a short distance prior to POD.
- Low rail - spikes lifted for a longer distance prior to POD.

Track review – wheel / rail contact

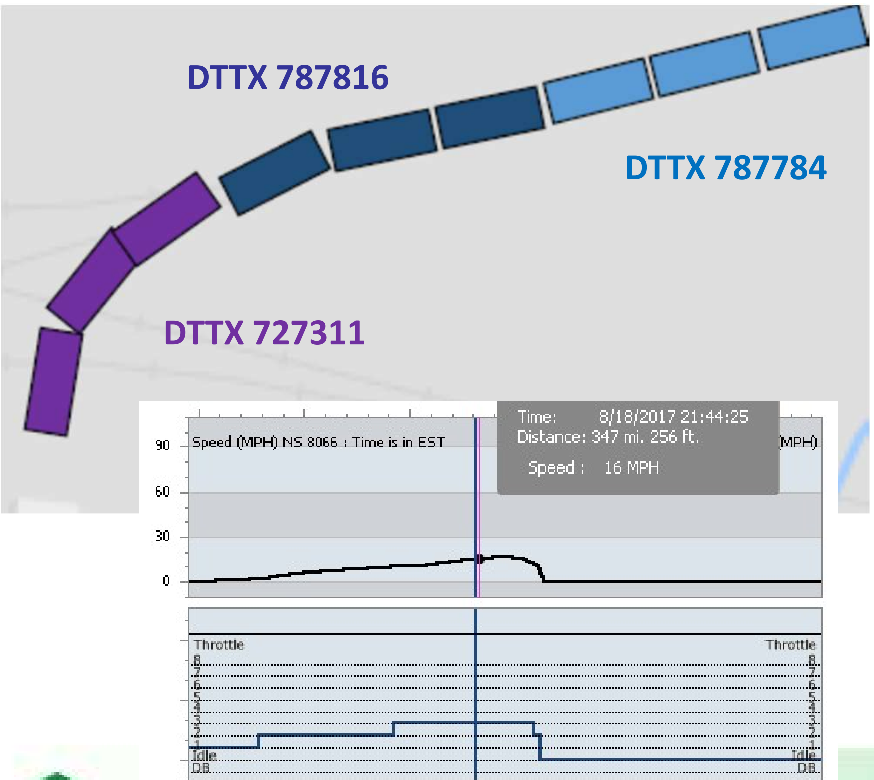
Three unusual conditions were noted on the <u>low rail</u> prior to the POD:

1. Left - scuff marks on field side of the head
2. Middle - wheel flange contact on the gage face
3. Right - evidence that rail had been canting out under load

The division committee's initial assessment

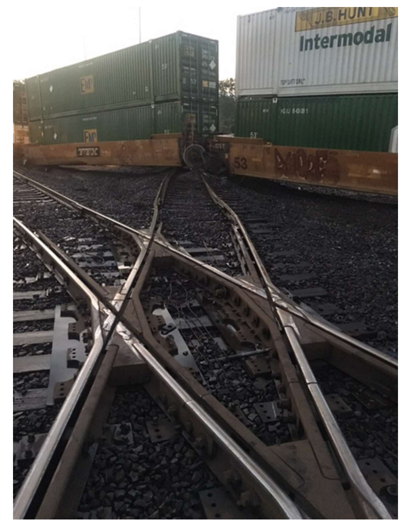
- Train handling
  - Steady draft, accelerating at 16 mph in throttle notch 3. Speed slowed to 10 mph as train was dragged down by derailed cars, then emergency brake application. Train handling determined not to be a factor.
- Mechanical
  - Identified lead truck of 2nd car as first to derail. Other than wheel damage due to derailment, no mechanical defects were noted on 2nd, 3rd or 4th head cars.
- Track
  - No exceptions to alignment (3.7° curve), elevation (consistent 2-7/8"), or gage (consistent 56-3/4").
  - No exceptions to low rail (136# installed 2016) or high rail (worn 132# installed 1978).
  - Circumstances involved low rail canting out and high rail rolling over.
  - Unusual marks on low rail – scuff marks, flange contact on gage face & dynamic cant.

So what happened?



<u>What is a key piece of evidence?</u>

4th head car DTTX 727311, all four trucks derailed, with severe damage to the wheels under the two intermediate (C and D) trucks.



Why did the division identify the 2nd car / lead truck?

- Conclusion: This truck did not derail

Suspect: 2nd head car, lead truck

R1 showed several white marks on the flange. During a car shop inspection, however, no evidence was found on the tread or flange tip that indicated that the wheel had been on the ground.

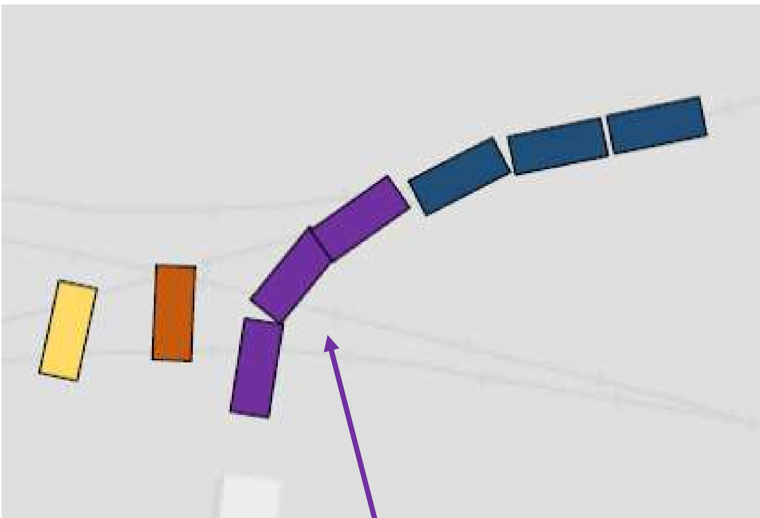
None of the other wheel treads or flanges showed evidence of derailment damage.

Let's take a look at the 1st derailed car – DTTX 787816

The first derailed wheels were under the trail truck of the 3rd car.

These wheels show some flange contact with the ground, but not enough to have been the first to derail (they would have run over 2 turnouts and a diamond).

How about the 2nd derailed car – DTTX 727311?



Wheels under all 4 trucks derailed

The B (lead) and C platforms shown. Between them is the C truck. The D truck and the A platform were separated by the derailment.

What did the wheels under B truck look like?

L1 and R1 show minimal damage

L2 and R2 also show minimal damage

What did the wheels under C truck look like?

L3 and R3.

Bottom (left to right): L4, close-up of L4 flange, R4, and close-up of R4 tread (note asphalt deposit from Hartzell Rd crossing).

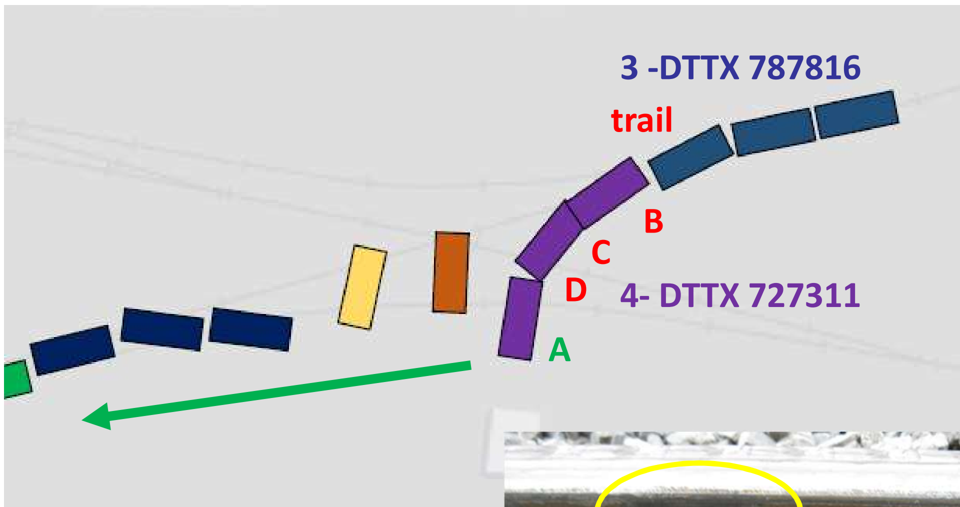
What did the wheels under D truck look like?

L5 & R5.

Note asymmetric wear – each axle has a wheel with a worn flange and hollow tread, and a wheel with a full flange and normal tread.

L6, close-up of L6 flange & R6.

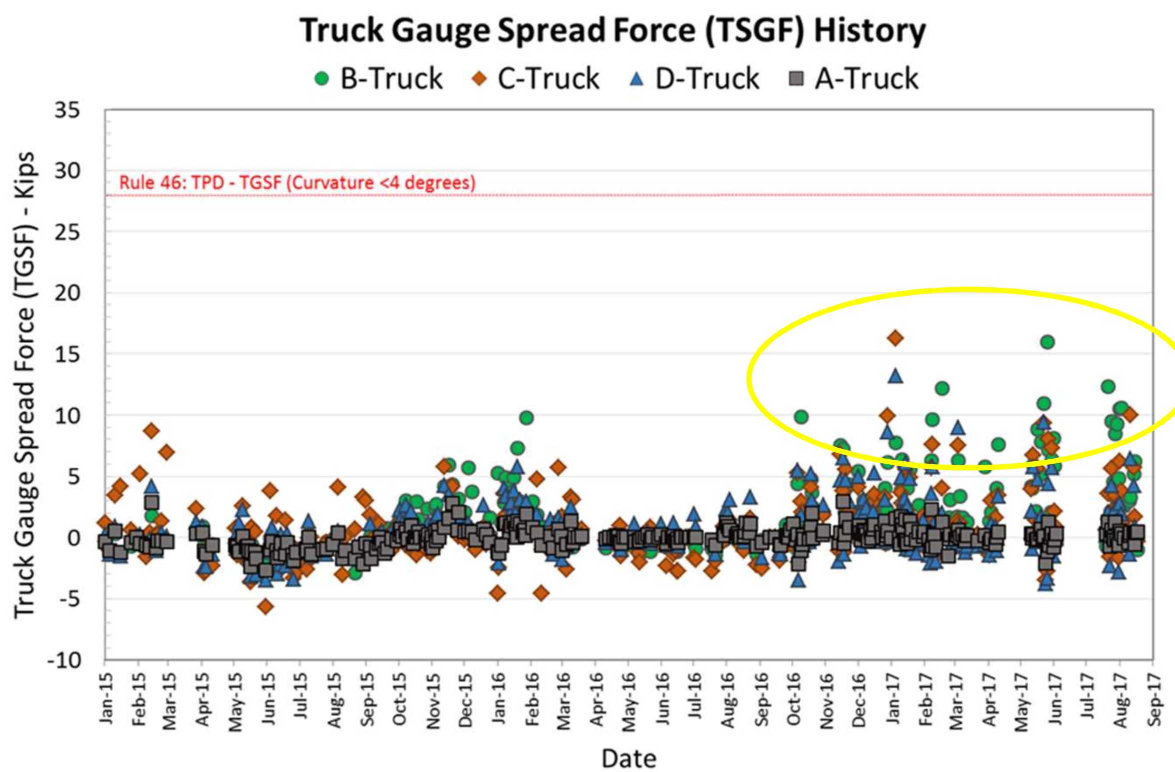
Explanation of the derailment (and answers to our two questions)



Based on the significant damage to wheelsets 4 and 6, and only slightly less damage to wheelsets 3 and 5, we concluded that:

1. The two intermediate trucks (**C** and **D**) under the 3rd car **DTTX 727311** were the first to derail, as a result of rolled rail.
2. These derailed trucks subsequently pulled off the lead (**B**) truck, which then pulled off the **trail** truck of the 2nd car (**DTTX 787816**).
3. All following trucks derailed due to the rolled rail.
4. The POD was identified where the 1st low-side wheel dropped in.

WILD data for DTTX 727311



Gage-spreading force = sum of lateral wheel forces.

B and C trucks, and to some extent D truck, became elevated on a sustained basis in late 2016.

This plot does not differentiate by leading end or load/empty status.

Marks on the rail (1)

The field side of the low rail showed a series of scuff marks from beginning of curve to the POD

What wheel characteristic is likely to cause this type of scuff mark?

Marks on the rail (2)

The low rail gage face showed evidence of wheel flange contact from the beginning of the curve to the POD.


Entrance to curve, 350 ft. before POD

Station 16

Station 6

In order for wheel flanges to contact this low rail gage face, the rail must be canted out!

Marks on the rail (3)

The low rail showed evidence of dynamic cant from beginning of the curve to the POD.

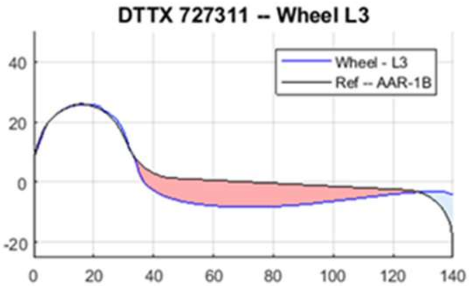
Derailment Station 16
(15' – 6" spacing)

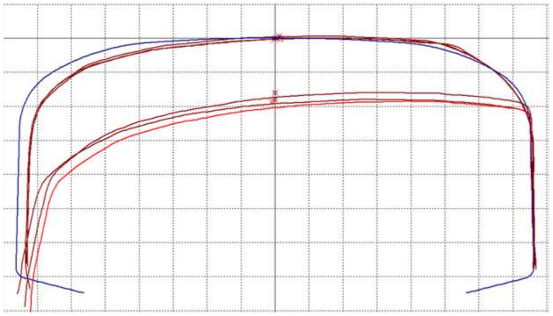
Station 14

Station 11

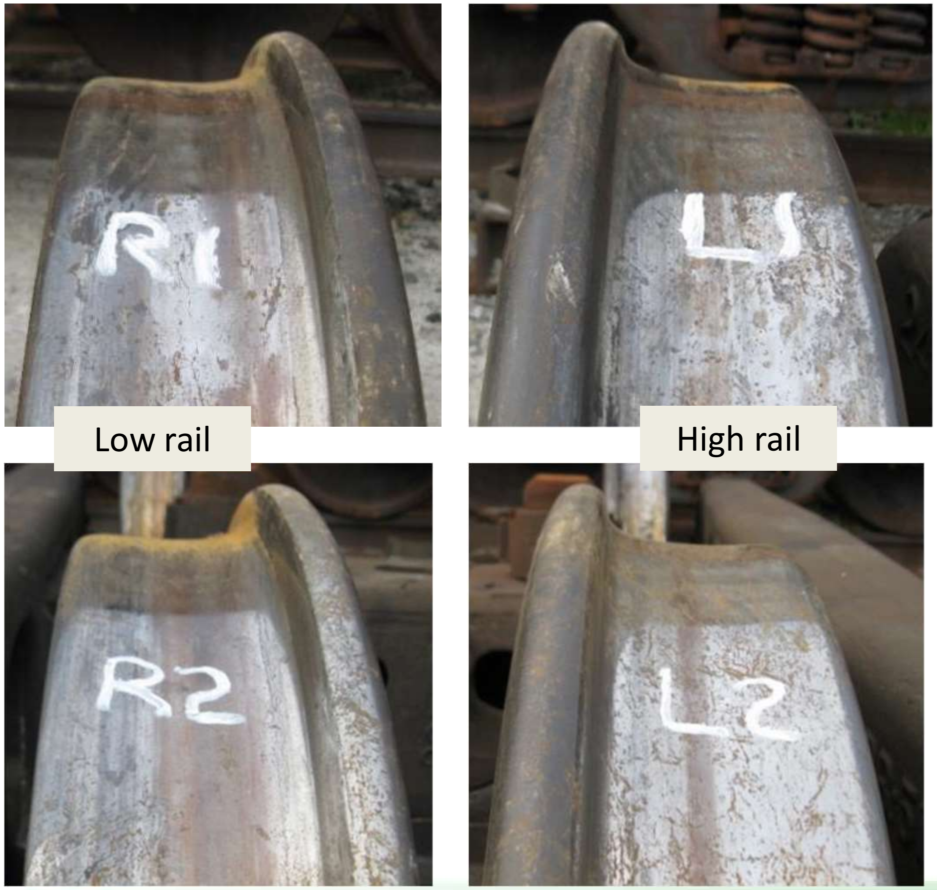
Station 6

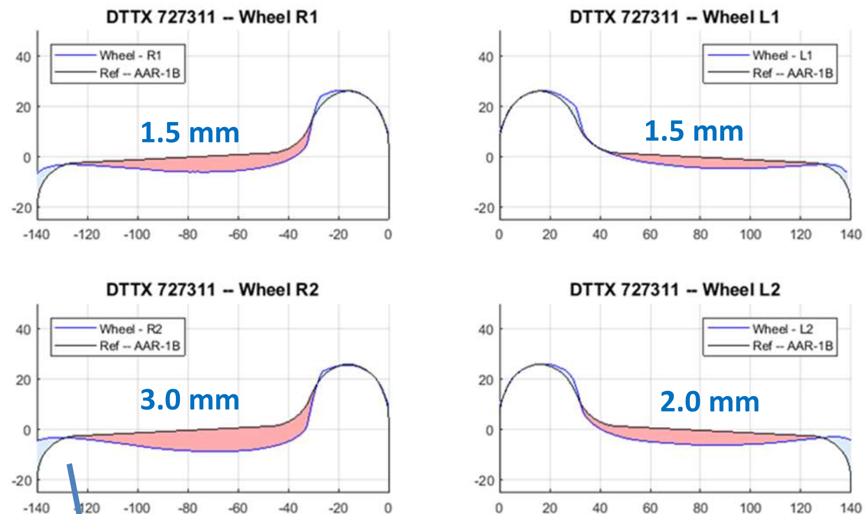
Let’s take a closer look at wheel profiles from B, C and D trucks, and then rail profiles



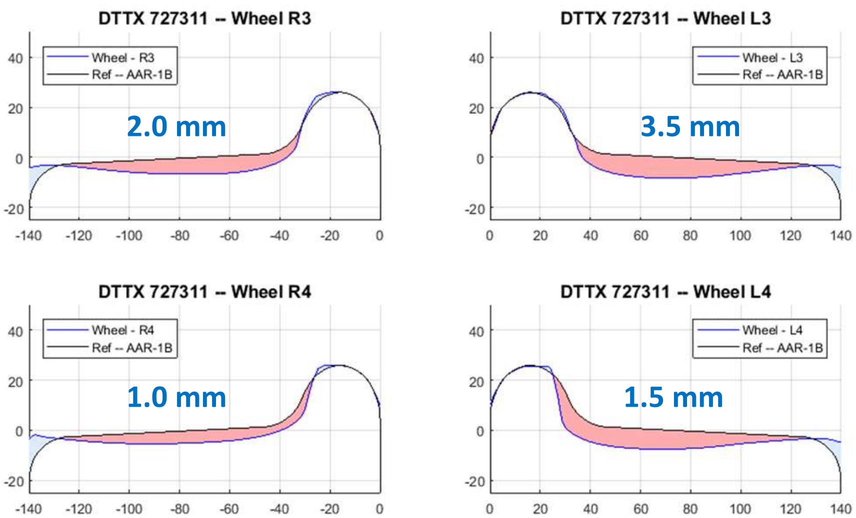


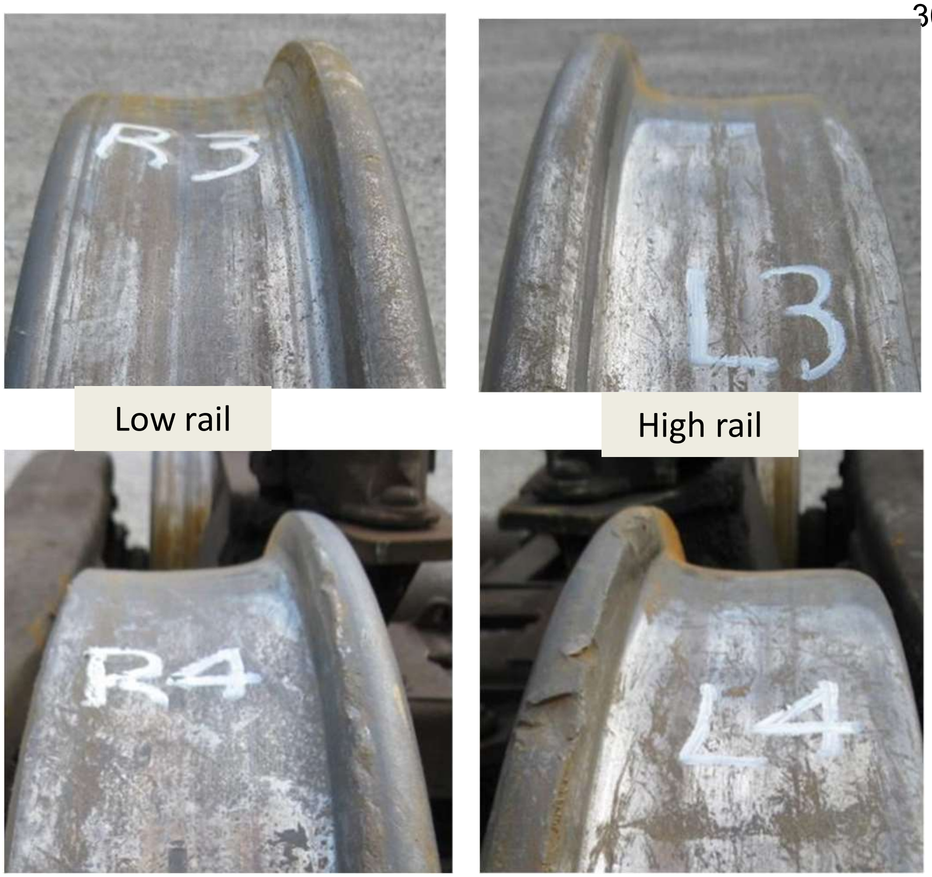
Wheel profiles B truck



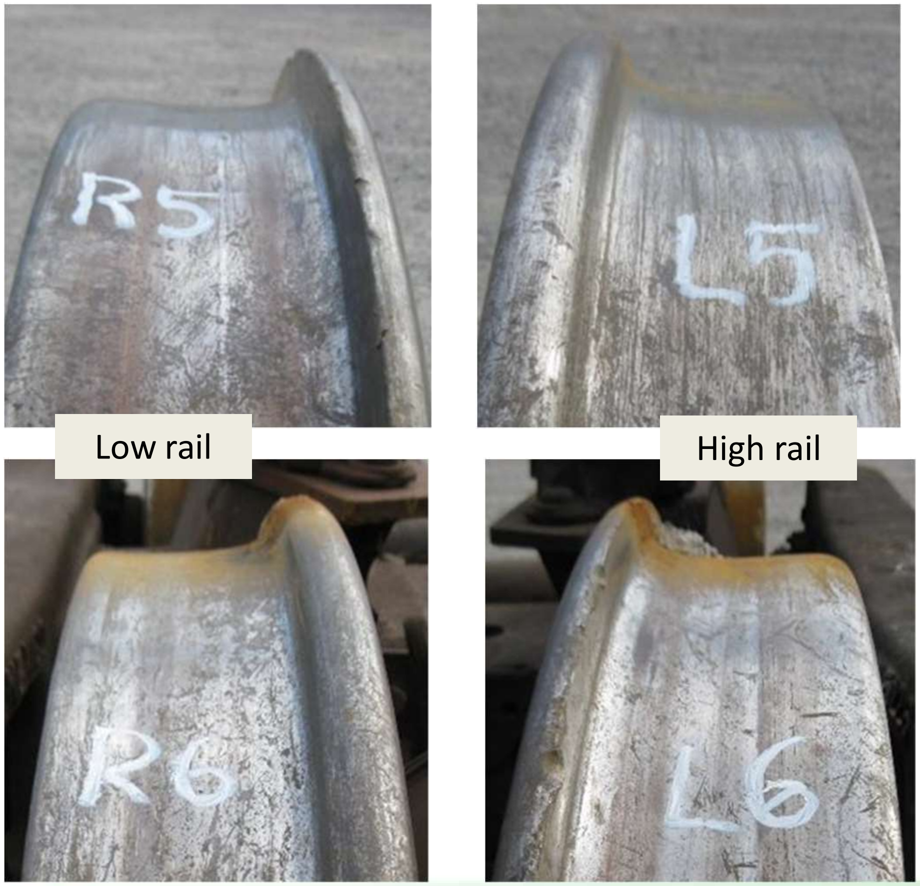


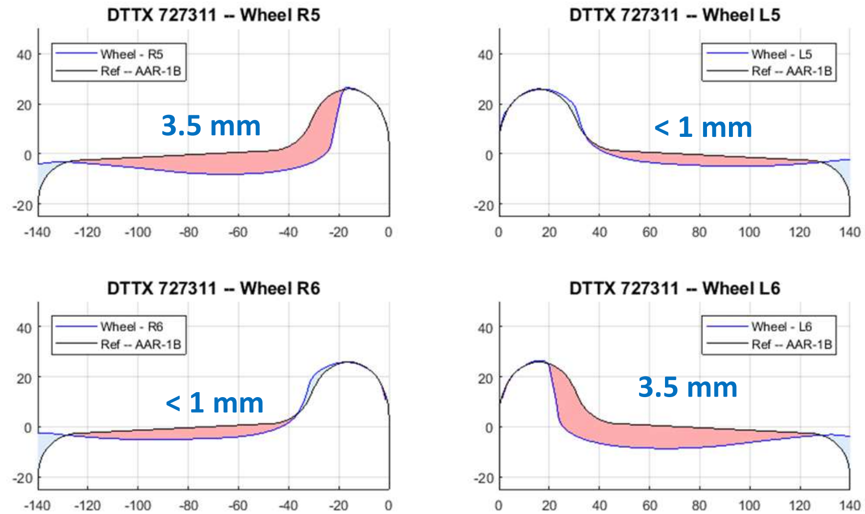
Wheel profiles C truck



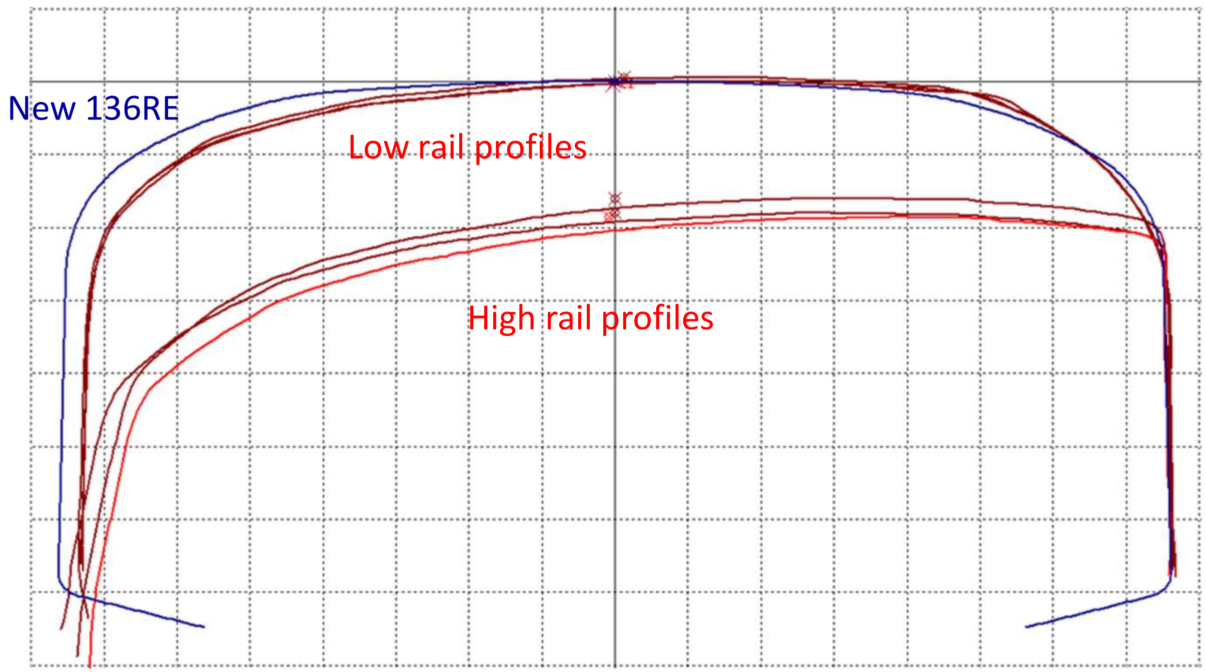


Wheel profiles D truck





Rail profiles



High and low rail profiles from 3 locations in the full body.

The blue line is new 136RE.

How do we evaluate a high rail profile?

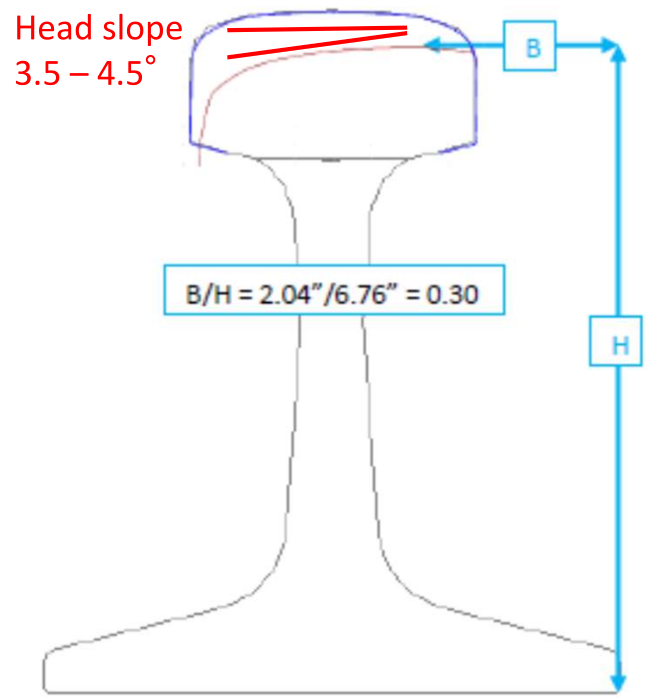
We look at two geometric measurements:

- B/H (base/height) ratio, which is the base extension divided by rail height
- Head slope, which is defined by a line through two points ½" either side of centerline

On NS, our thresholds for concern are:

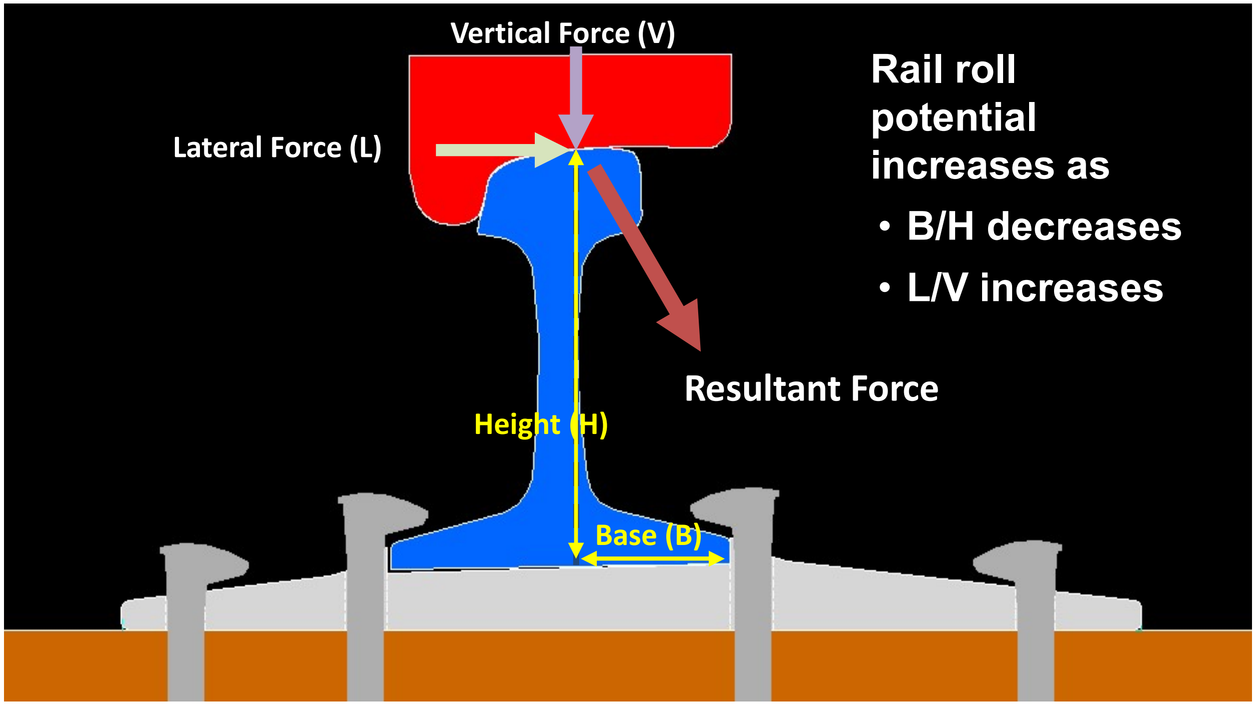
- B/H < 0.35
- Head slope > 5°

Actual wheel contact location is influenced by B/H, head slope, rail cant and wheel profile.



High rail profile from near POD

Can a high rail profile contribute to rail rollover?

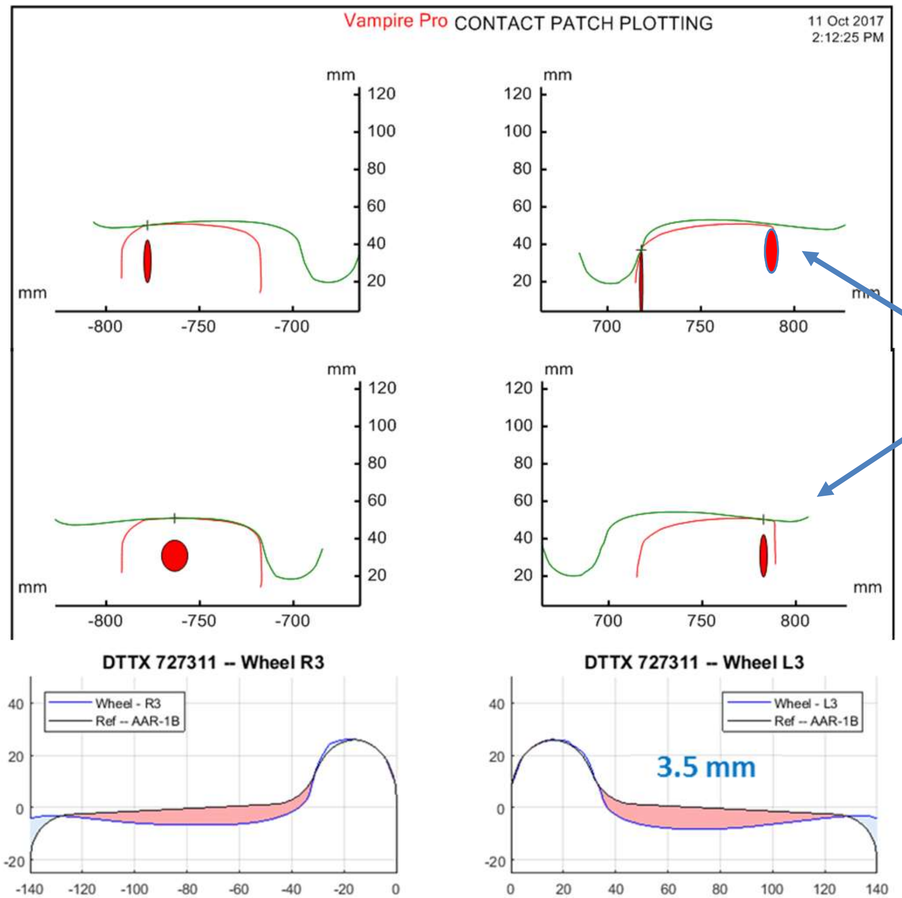


When the resultant force is directed beyond the base, the rail will tend to roll, absent the hold-down strength of gage spikes and torsional resistance of the rail.

A lower B/H moves the resultant force closer to the field edge.

A B/H ratio 0.30 means that the truckside L/V ratio need only exceed 0.30 to initiate rail roll!

VAMPIRE wheel/rail contact plots – C truck, R3 – L3 wheels

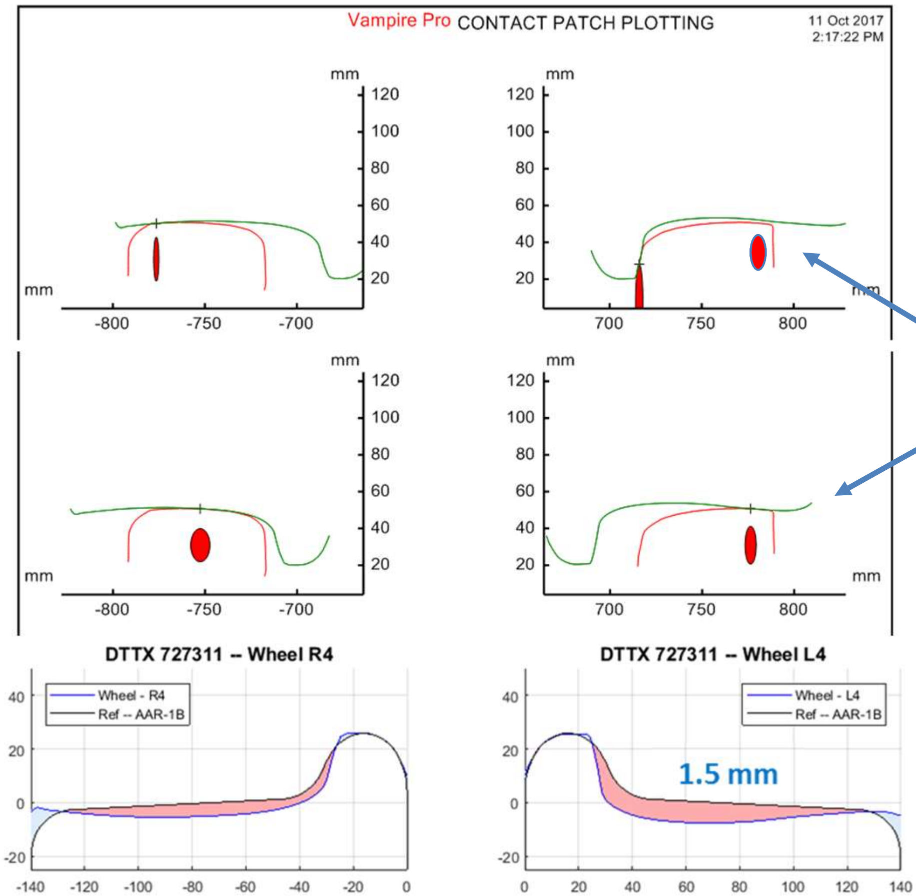


In all tracking positions – from high rail flanging to low rail flanging, the L3 always contacts the field edge of the high. (Field side contact is typical of tread-hollow wheels.)

Consequences of this type of contact:

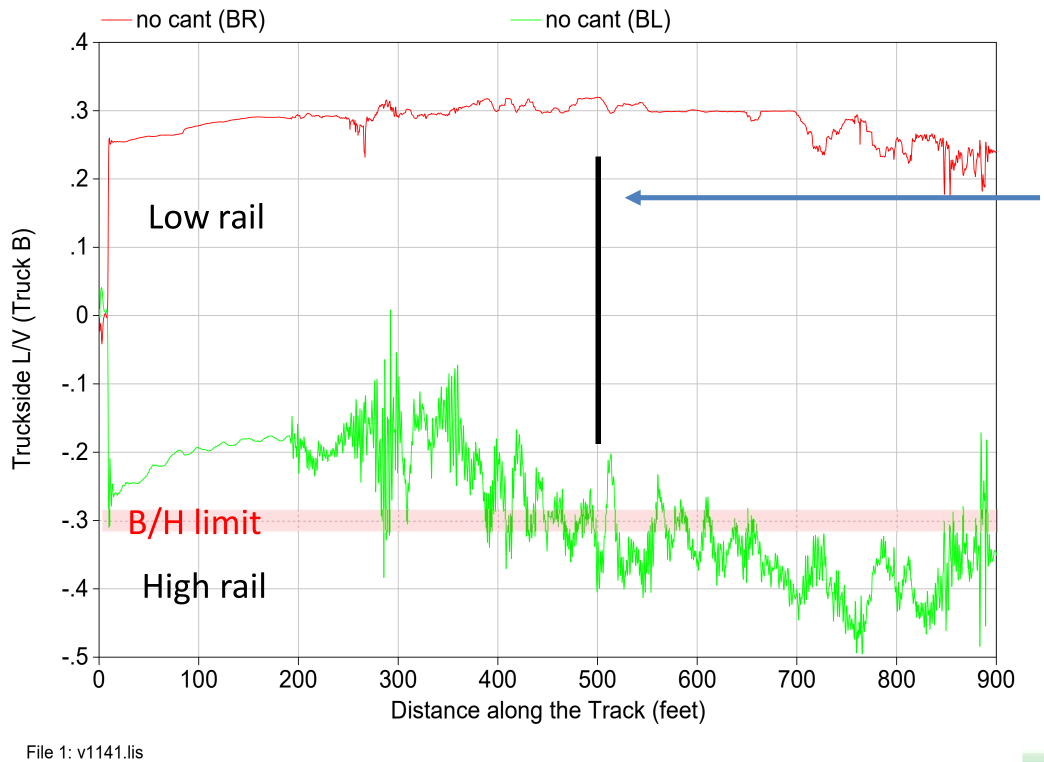
- high gage-spreading forces
- low B/H rail stability

VAMPIRE wheel/rail contact plots – C truck, R4 – L4 wheels



Like the L3, the L4 wheel always contacts the high rail on the field edge, no matter what the tracking position.

VAMPIRE truckside L/V ratios for B truck



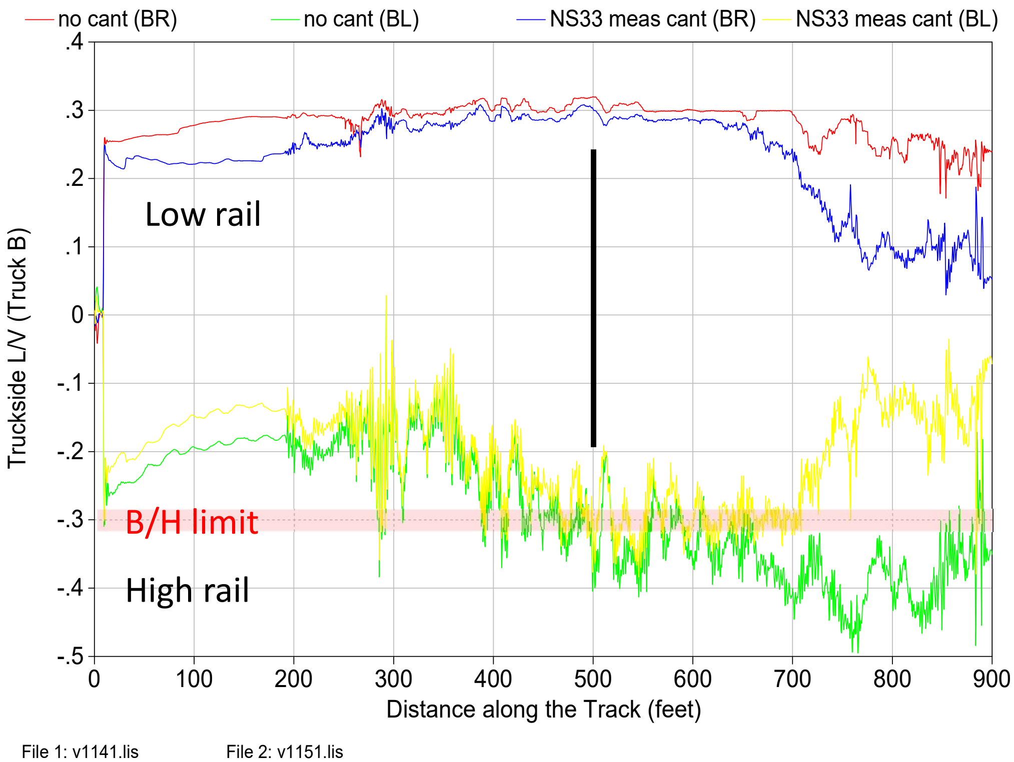
Truckside L/V ratios are shown *as a function of cant*; red & green = no cant.

POD located at 500 feet

High rail L/V reaches 0.40 in the vicinity of the POD. But the rail hasn't rolled over yet!

How do we know? Minimal damage to the B truck wheels

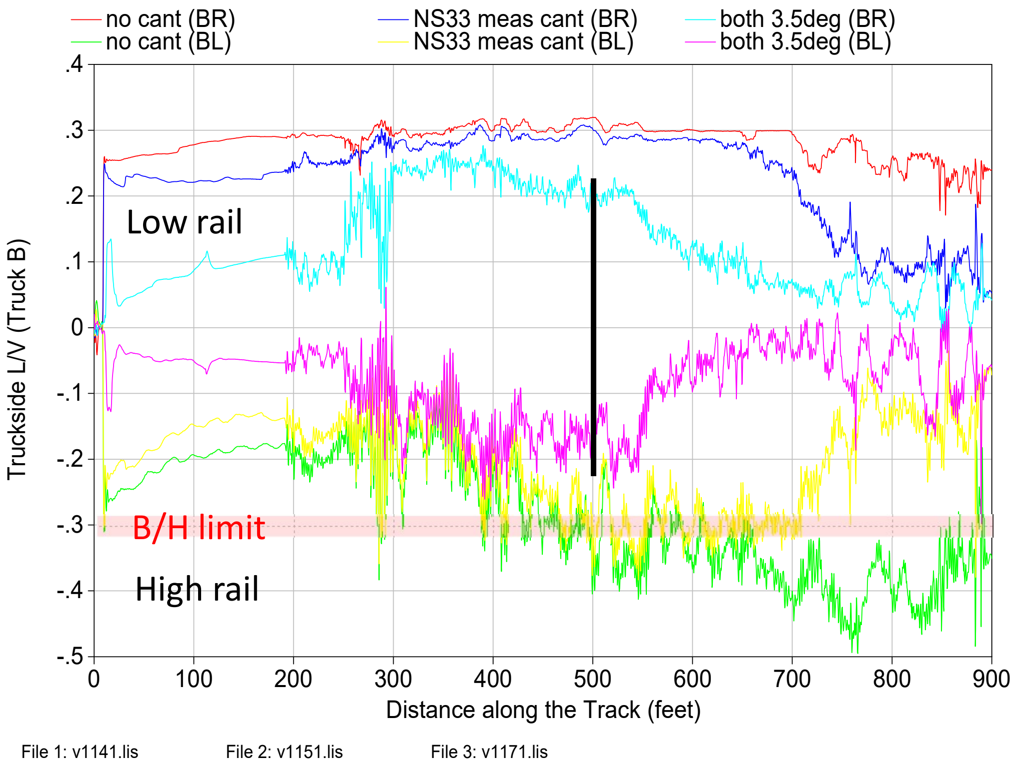
VAMPIRE truckside L/V ratios for B truck



Truckside L/V ratios are shown *as a function of cant*: blue & yellow = cant from April 2017 geometry car test (0.5° high rail, 1.0° low rail).

POD located at 500 feet.

VAMPIRE truckside L/V ratios for B truck



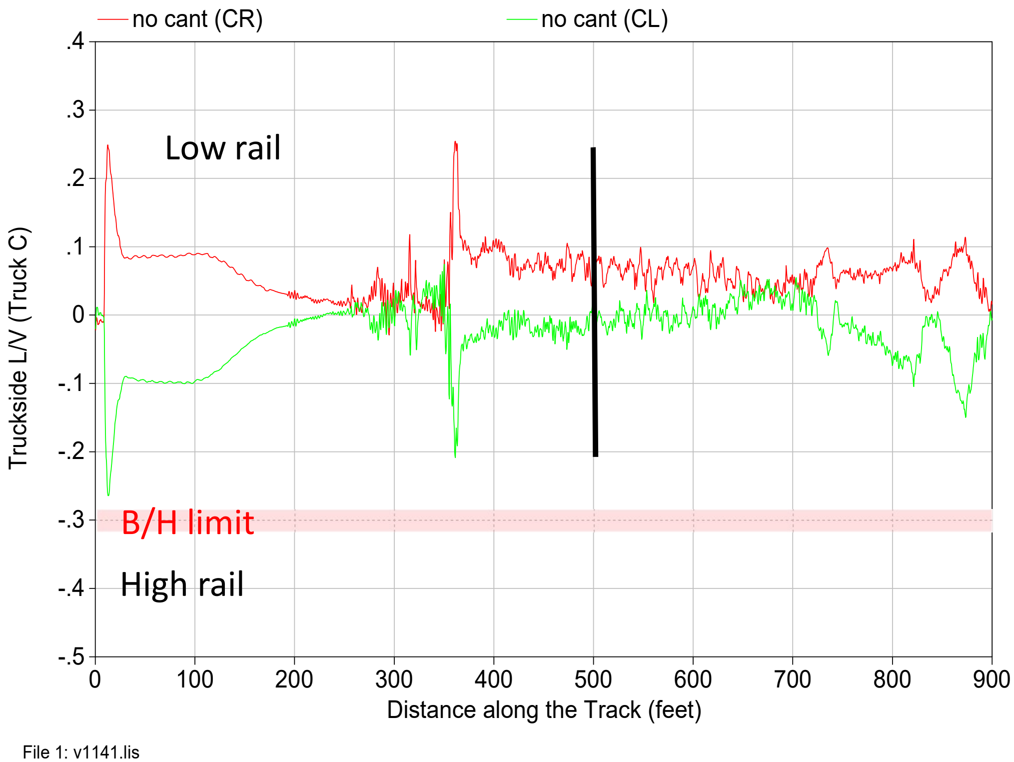
Truckside L/V ratios are shown *as a function of cant*: cyan & pink = 3.5° cant (the amount indicated by spike lift).

POD located at 500 feet.

As cant increases, truckside L/V decreases.

There would likely be no derailment if B truck were the only consideration.

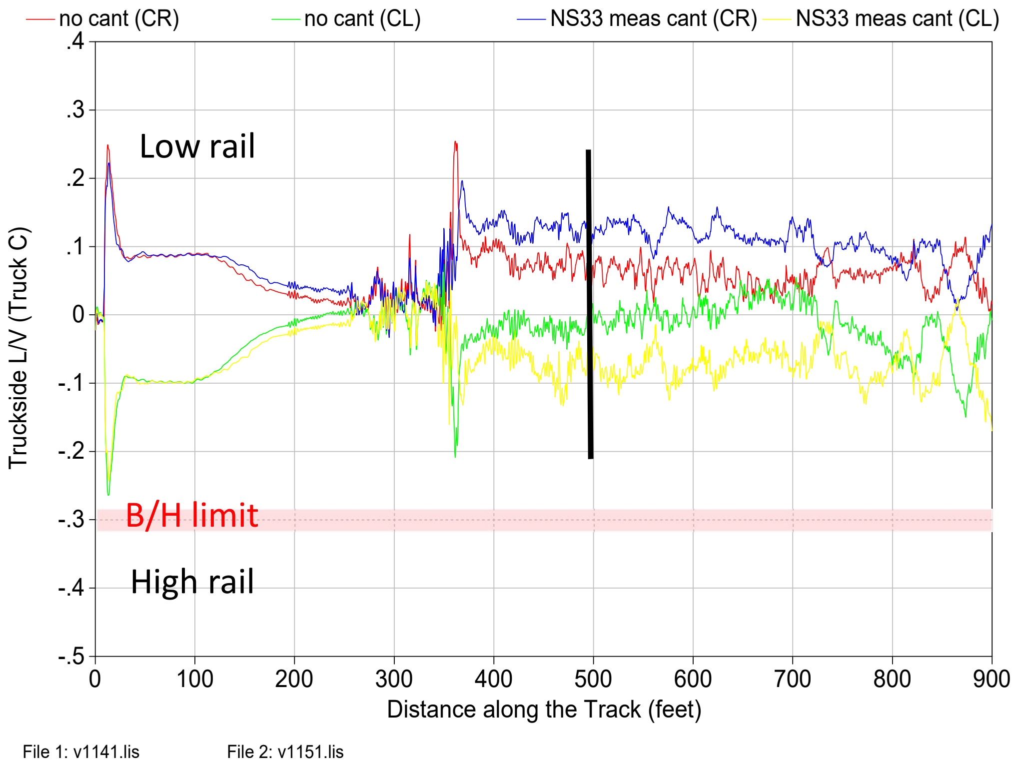
VAMPIRE truckside L/V ratios for C truck



Truckside L/V ratios are shown *as a function of cant*: red & green = no cant.

POD located at 500 feet

VAMPIRE truckside L/V ratios for C truck

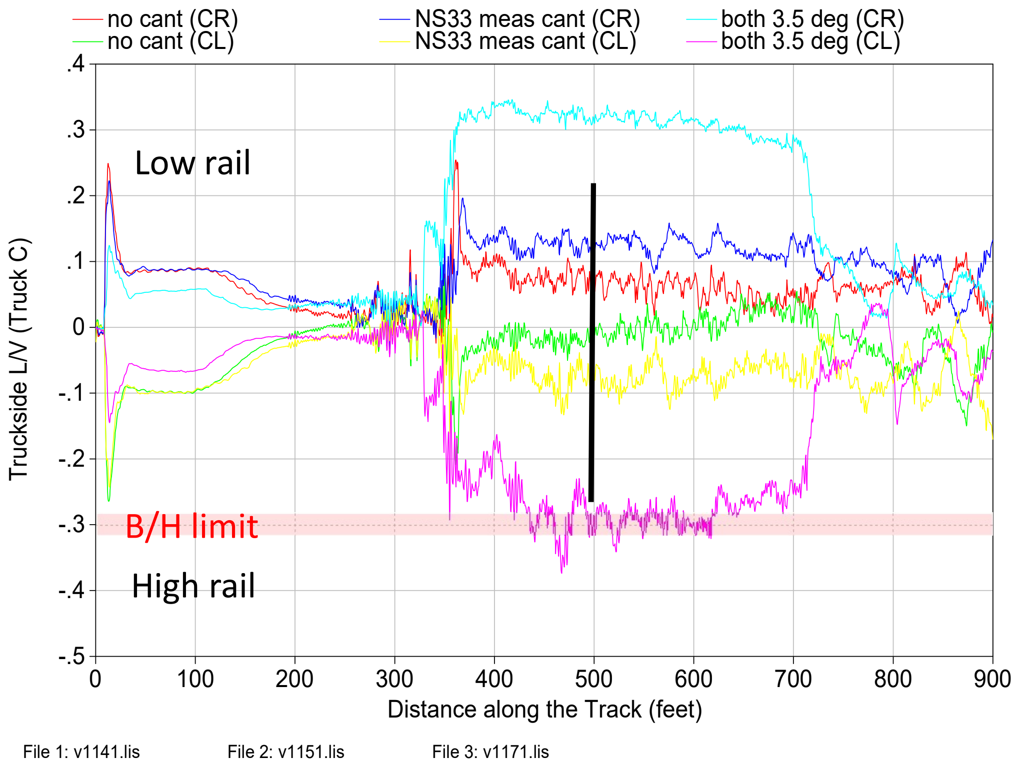


Truckside L/V ratios are shown *as a function of cant*: blue & yellow = cant from April 2017 geometry car test (0.5° high rail, 1.0° low rail).

POD located at 500 feet.

As cant increases, truckside L/V also increases.

VAMPIRE truckside L/V ratios for C truck



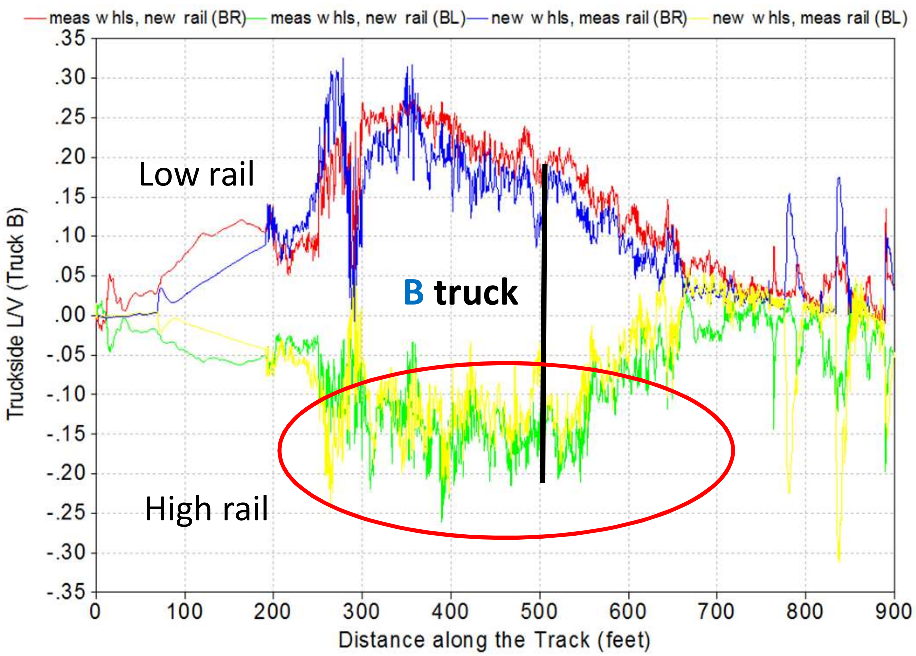
Truckside L/V ratios are shown *as a function of cant*: cyan & pink =3.5° cant (the amount indicated by spike lift).

POD located at 500 feet.

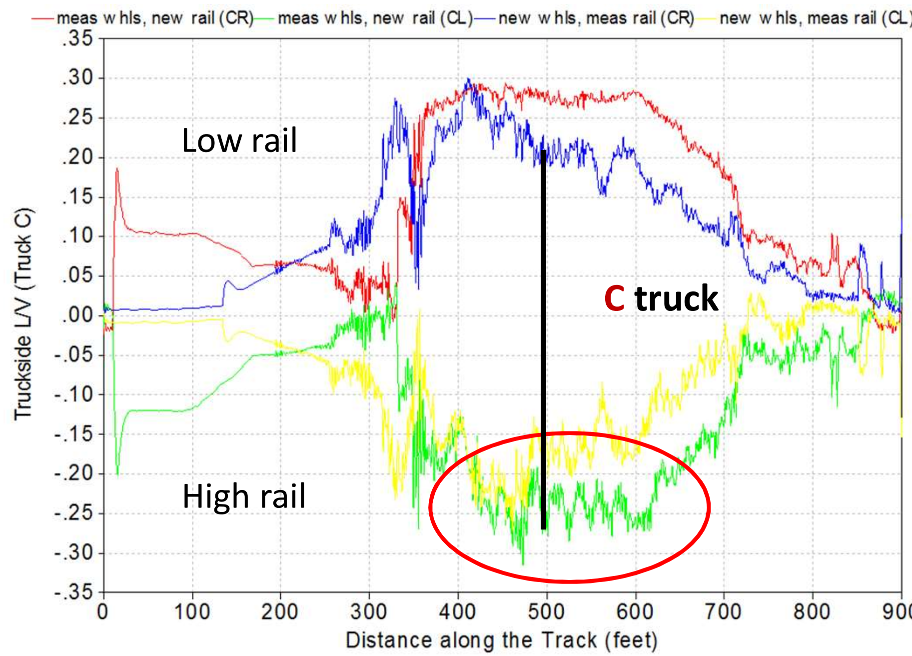
As cant increases, truckside L/V also increases, reaching an high rail L/V close to 0.35. This is self-driving behavior - as cant increases, B/H diminishes.

Conclusion: B truck initiated significant high rail cant, and C truck rolled the high rail over.

Which had greater impact – worn rail or worn wheels?



L/V's for worn wheels on new rail (red/green) **are approx. equal to** new wheels on worn rail (blue/yellow).



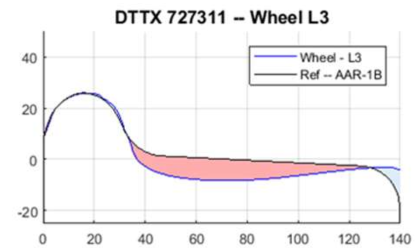
L/V's for **worn wheels on new rail** (red/green) **are greater** than for new wheels on worn rail (blue/yellow).

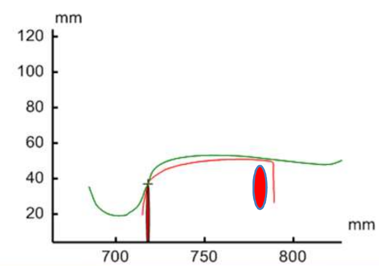
Derailment cause

Based on the truckside L/V ratios predicted by our VAMPIRE simulations:

“High rail rolled out under lead and intermediate trucks of loaded articulated doublestack DTTX 727311 account significantly hollow (but non-defective) wheel profiles operating on a high rail in a 3.5° curve with moderate head slope and low B/H.”

FRA Cause Code: E65C Worn Tread





What is unique about multi-platform doublestack cars?

Elevated truckside L/V's under an articulated intermediate truck are particularly dangerous because there is no adjacent truck applying a vertical load to hold down the rail.

Questions?