Truck Geometry: A New and Important Part of Wheel/Rail Assessment

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Outline

- What they are
- Where they are
- Measures….what's good, what's bad (fleet statistics)
- Previous work relating tracking position and angle of attack to rail force measurements
- Derailment examples…car and locomotive
- Current thresholds
- The future

Baseline: What are we about?

- What is the purpose of railroads?
  - "Capitalize upon the efficiency of rail transportation."
- What are our operational goals in pursuit of this purpose?
  - "Move trains safely and reliably."
- What is the purpose of Technology?
  - ***"Allow railroads to reach/exceed their operational goals."***

Derailment Cause Assessment

A modern ouija board plus planchette

1. Wheels come off rail.
2. Rail moves under wheels.
3. Sometimes rail cannot be found.
4. Field Investigation is challenging.
   - Parts hither and yon, do any look better or worse than any others in this new arrangement and landscape?
   - Area is cleared with haste and evidence is further disturbed or destroyed.
5. We assign cause.
   - What methods are used in this determination?

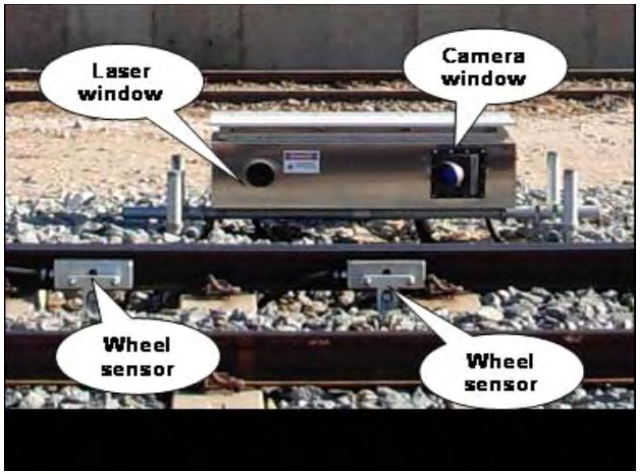
Root Cause Assessment

1. Cause assigned is what it is.
2. All available data is played back.
3. Track, Equipment, Wayside.
4. What were the pre-existing conditions? How did they conspire to cause the accident? What can we do differently?
5. There are elegant, easy to understand, and reliable tools that can help us answer these questions.

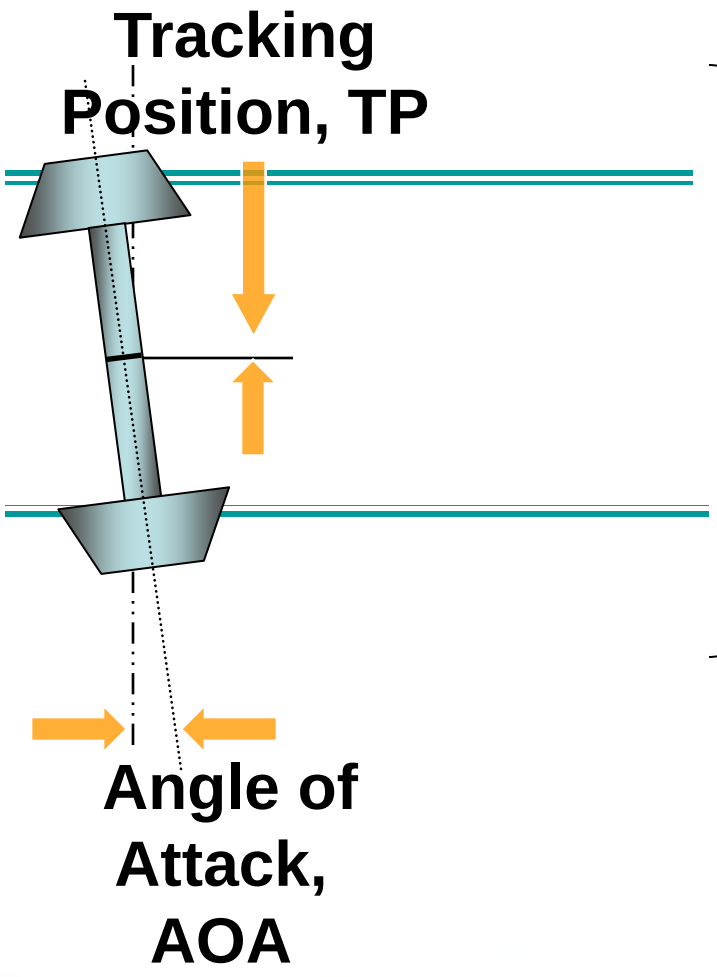
A simple dry magnetic pocket compass

Truck Geometry Inspection (TGI)

- A wayside device consisting of a laser and a camera.
- Mounted on TANGENT track.
- It draws a laser line on the wheel plate.
- It then compares the angle and position of this line to the track and determines wheel angle (angle of attack) and distance (tracking position) with respect to the gauge side of the rail.



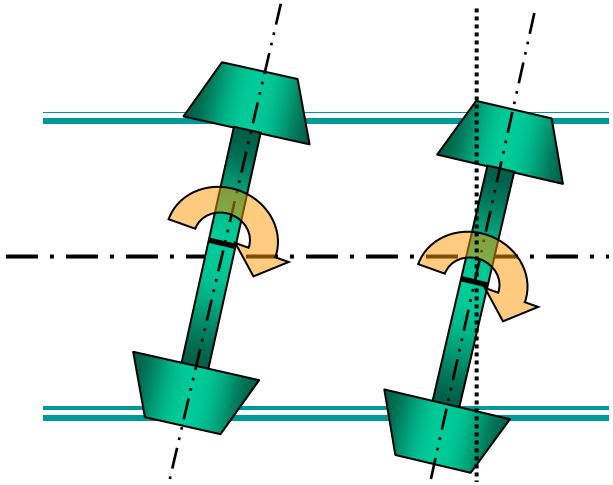
TGI Primary Measurements:



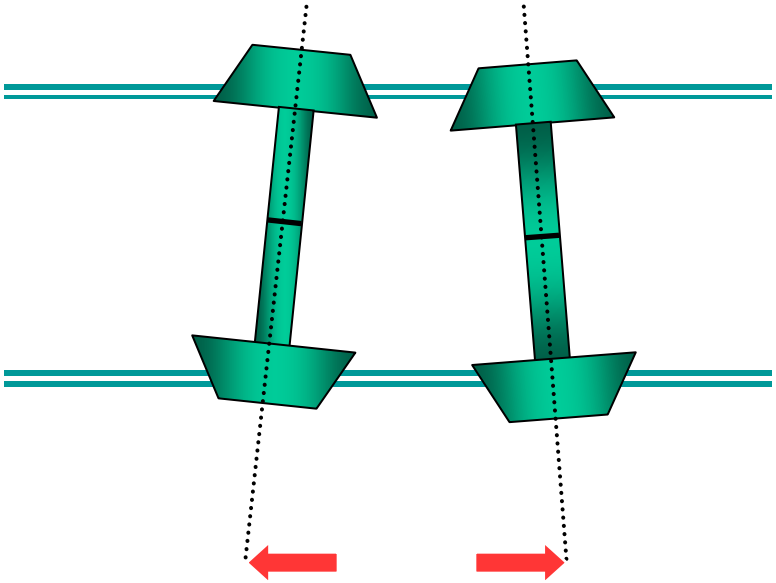
The Tracking Position and Angle of Attack of each wheel is determined and recorded.

Truck Measurements

Truck Rotation



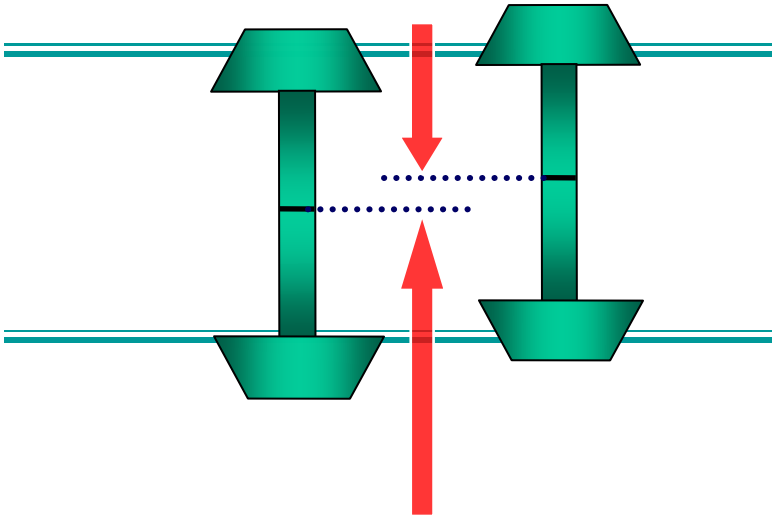
Interaxle Misalignment



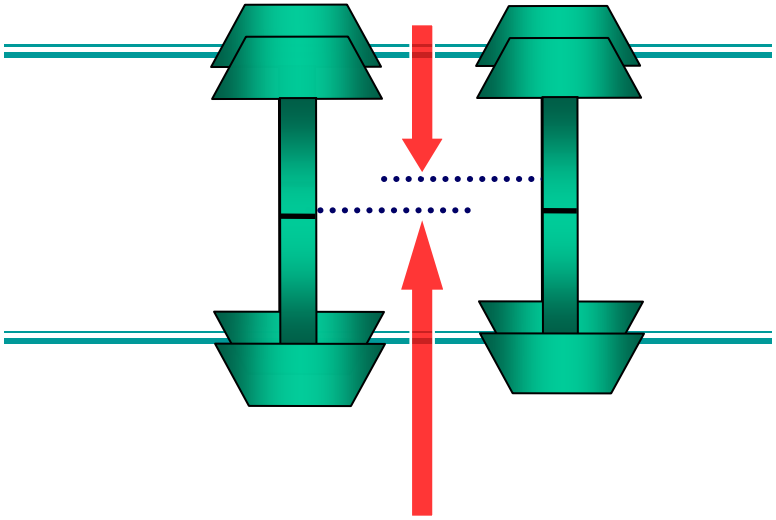
17.5mrad = 1 degree

Truck Measurements

Tracking Error (each wheel is flanging, but opposite rails)



Shift (both wheels flanging on same rail)

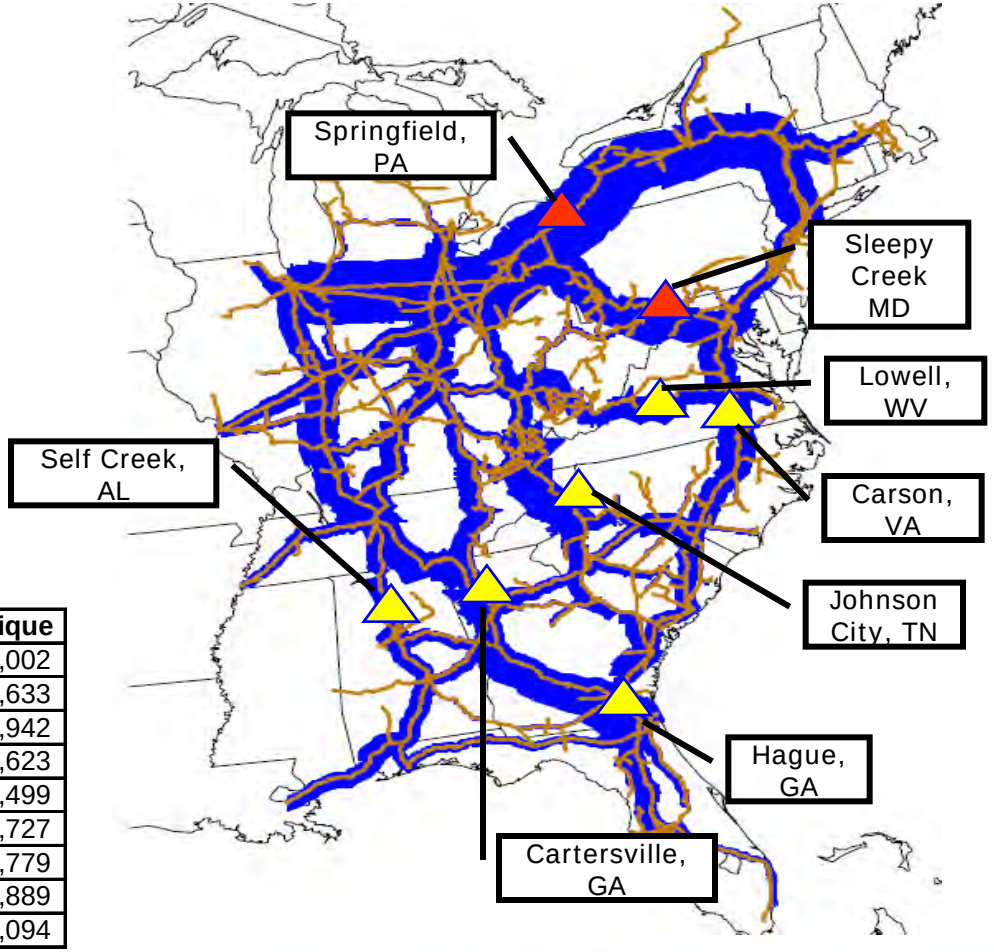


25.4 mm = 1 inch

TGI Site Locations

Single Track

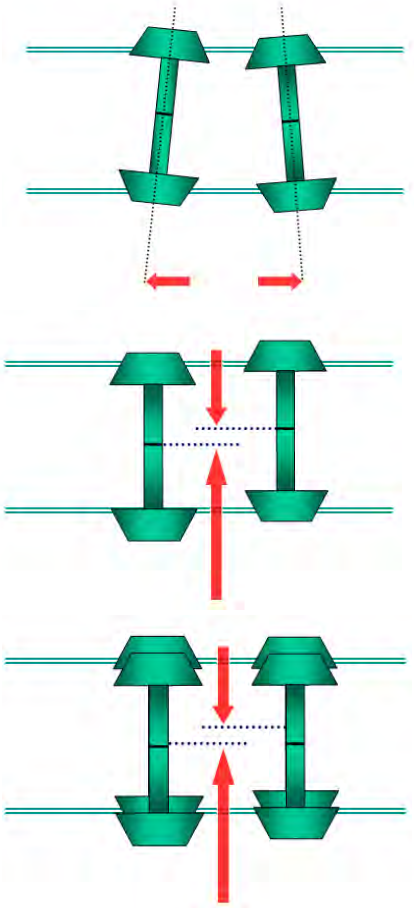
Double Track



Locations	MP	4 wk Unique	8 wk Unique	12 wk Unique
Springfield	QD 108.6	53,015	83,055	108,002
Hague	ANA611.0	45,524	70,142	90,633
Cartersville	0WA47.4	38,931	65,329	86,942
Sleepy Creek	BA 118.7	40,057	63,366	82,623
Self Creek	000371.8	32,538	52,145	68,499
Carson	A33.8	30,996	49,453	65,727
Lowell	CA345.1	17,243	24,567	30,779
Johnson City	Z125.5	16,221	22,310	26,889
Total Unique Cars		274,525	430,367	560,094

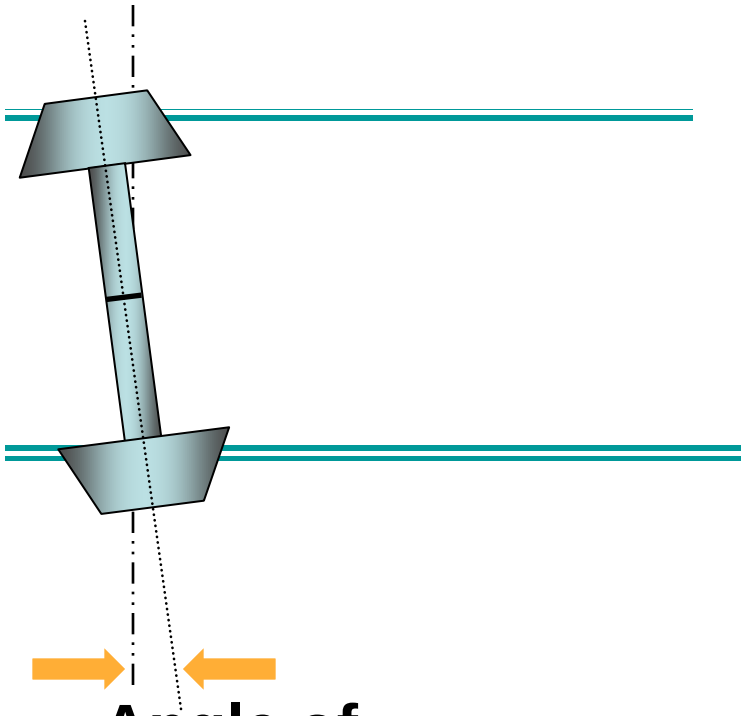
General Truck Statistics (March 2011, 1,042,450 car passes)

- Inter-Axle Misalignment (IAM):
  - Average: -0.03mrad
  - Std: 0.78mrad
  - Max: 13.60mrad
  - Min: -14.00mrad
- Tracking Error (TE):
  - Average: 0.2mm
  - Std: 8.1mm
  - Max: 39.0mm
  - Min: -38.0mm
- Shift:
  - Average: -0.05mm
  - Std: 3.74mm
  - Max: 18.98mm
  - Min: -19.80mm



Axle Angle Statistics (March 2011)

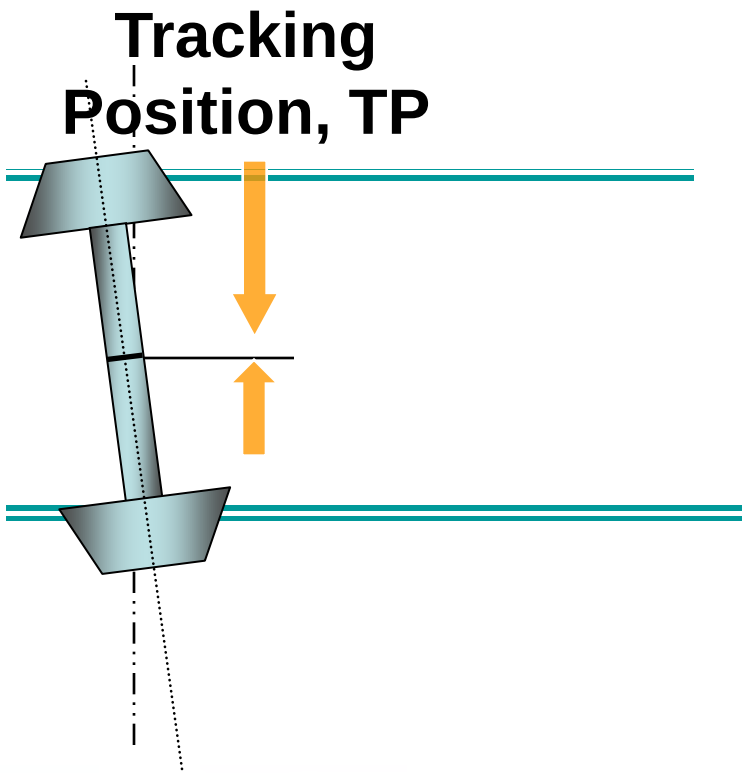
- Axle Angle: Lead
  - Average: -0.01mrad
  - Std: 0.53mrad
  - Max: 9.64mrad
  - Min: -10.05mrad
- Axle Angle: Trail
  - Average: 0.02mrad
  - Std: 0.49mrad
  - Max: 8.71mrad
  - Min: -9.40mrad



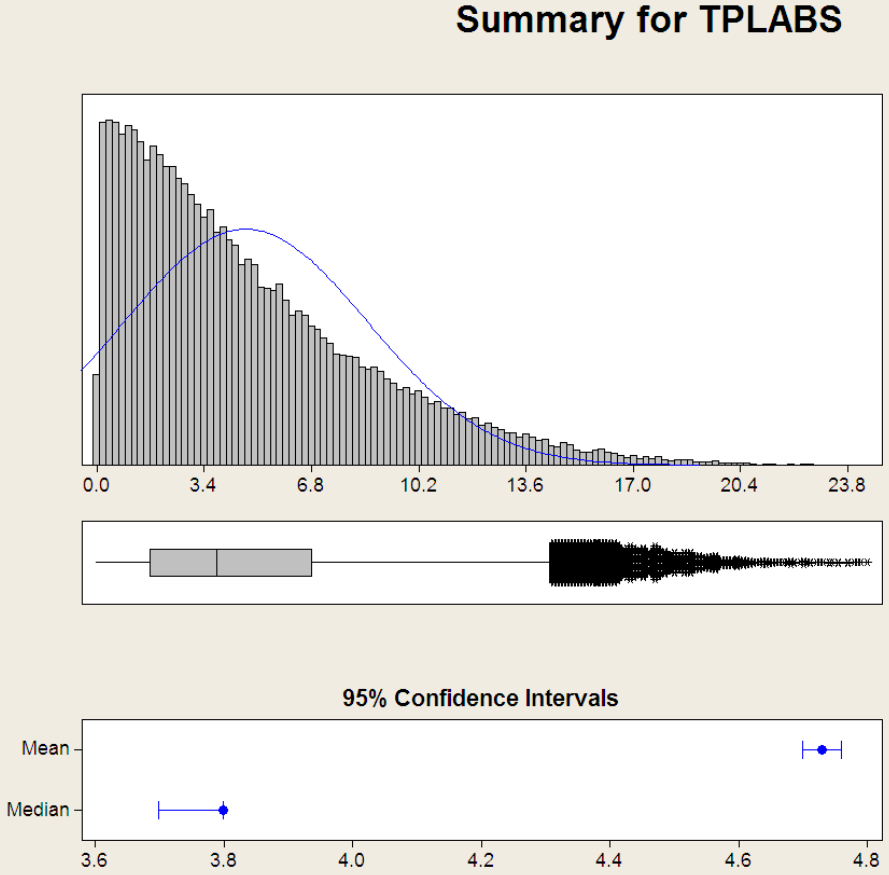
Angle of Attack, AOA

Axle Tracking Position Statistics (March 2011)

- Axle Position: Lead
  - Average: 0.06mm
  - Std: 6.05mm
  - Max: 22.64mm
  - Min: -24.38mm
- Axle Position: Trail
  - Average: -0.19mm
  - Std: 5.53mm
  - Max: 22.16mm
  - Min: -23.55mm



Descriptive Statistics for Car: Tracking Position, Absolute Value



Anderson-Darling Normality Test	
A-Squared	1618.19
P-Value <	0.005
Mean	4.7289
StDev	3.8603
Variance	14.9022
Skewness	1.13636
Kurtosis	1.07777
N	62699
Minimum	0.0000
1st Quartile	1.7000
Median	3.8000
3rd Quartile	6.8000
Maximum	24.4000
95% Confidence Interval for Mean	
4.6987	4.7591
95% Confidence Interval for Median	
3.7000	3.8000
95% Confidence Interval for StDev	
3.8391	3.8818

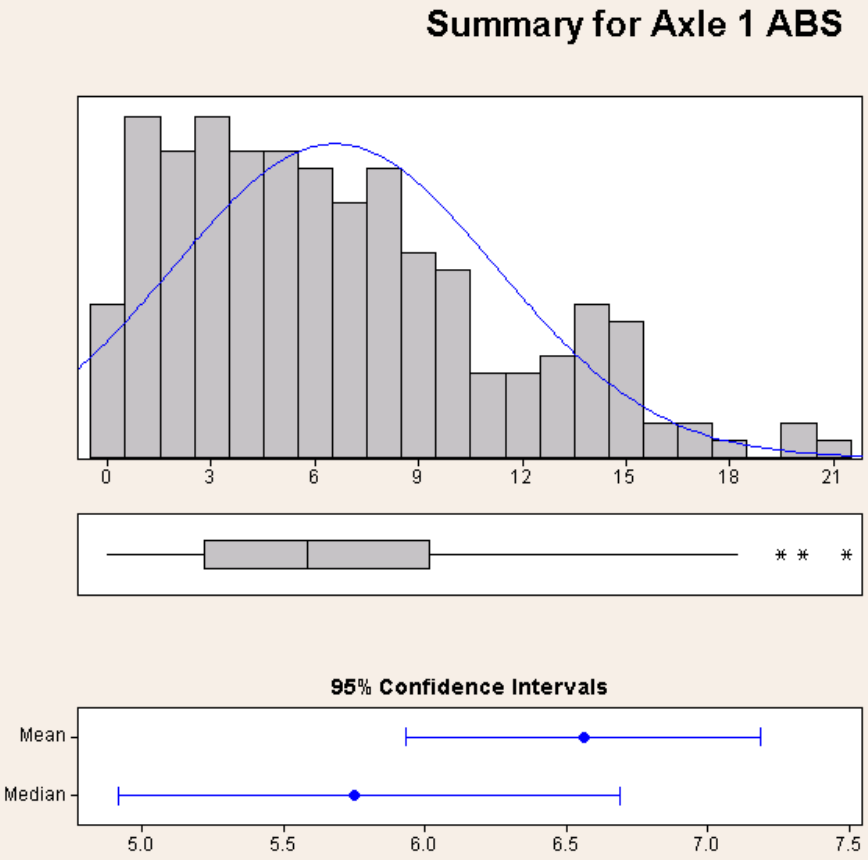
Above 20mm = AAR thin flange and dead wheel

In ABSOLUTE:

Median = 3.8mm

Mean = 4.7mm

Descriptive Statistics for Locomotive: Tracking Position, Absolute Value



Anderson-Darling Normality Test	
A-Squared	3.19
P-Value <	0.005
Mean	6.5606
StDev	4.6807
Variance	21.9087
Skewness	0.745469
Kurtosis	-0.038579
N	216
Minimum	0.0000
1st Quartile	2.8000
Median	5.7500
3rd Quartile	9.3000
Maximum	21.4000
95% Confidence Interval for Mean	
5.9329	7.1884
95% Confidence Interval for Median	
4.9109	6.6891
95% Confidence Interval for StDev	
4.2770	5.1692

Above 20mm = AAR thin flange and dead wheel

In ABSOLUTE:

Mean = 6.5mm

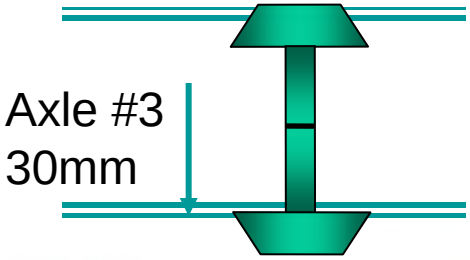
Median = 5.8mm

Extreme Tracking Position Example: Car "X"

- 30mm Tracking Position

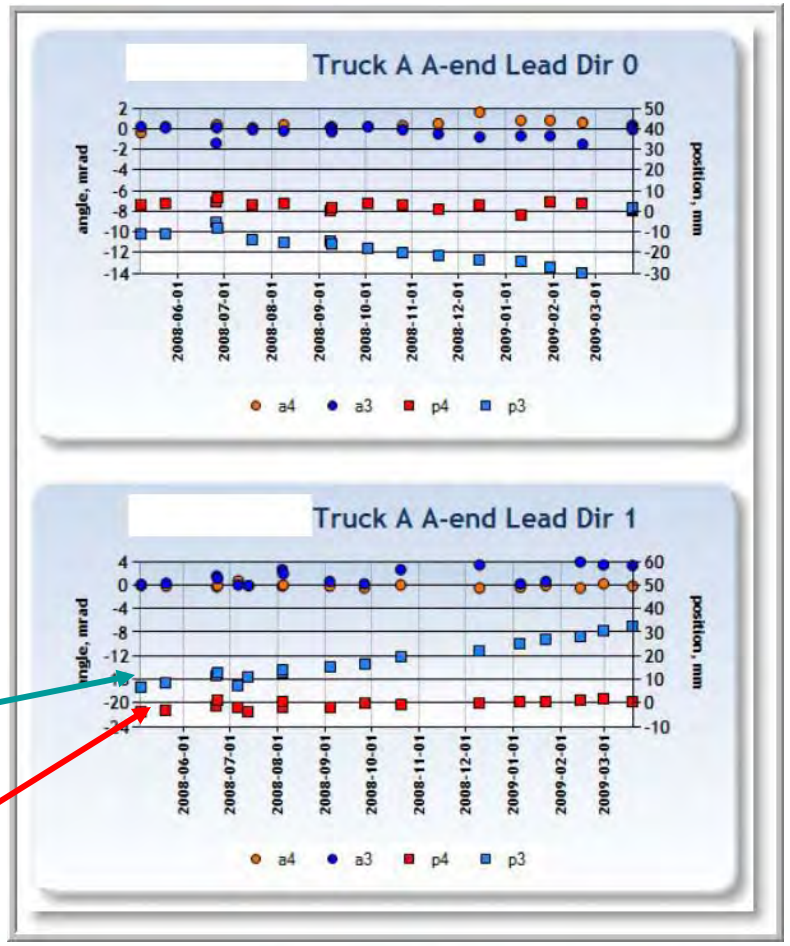
Extreme Tracking Position Example: Car "X"

- We see that that the #3 axle slowly walked it's way into the rail, while axle #4 stays centered.
  - Axle #3 starts with about an 8mm tracking position, and then gets progressively worse.
  - Doesn't matter which direction the car travels in, or which detector…they all show the same issue.



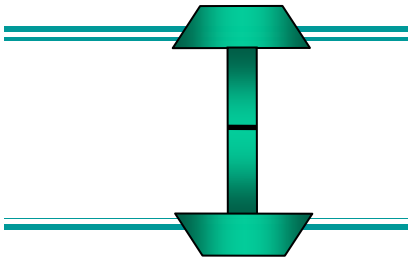
Axle #3

Axle #4



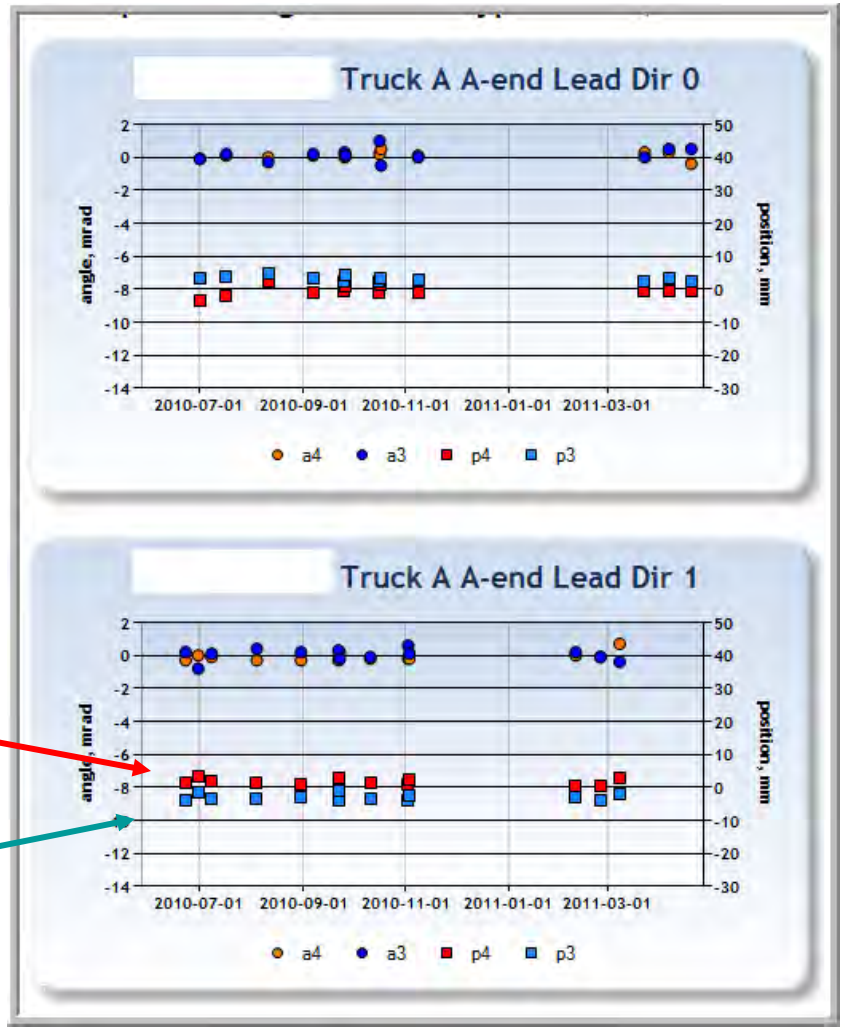
Remedial Action: Car "X"

- We replaced the #3 wheel set summer 2009.
- Car and A-truck inspected, no other issues noted.
- Car has been running well since then.
  - Lesson? Beware of asymmetrically worn wheels!



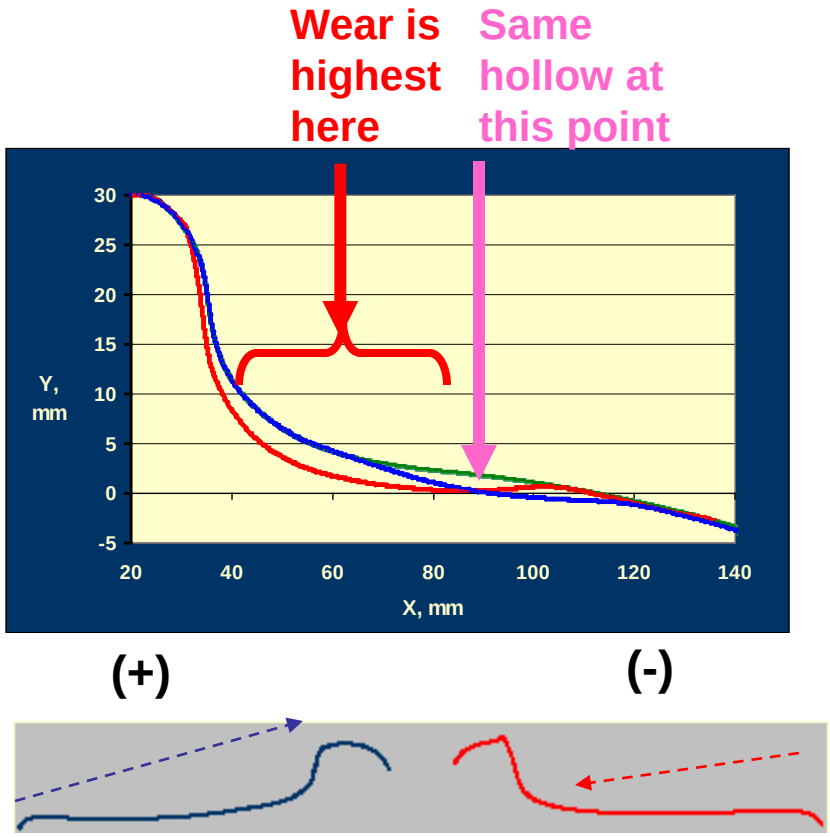
Axle #4

Axle #3



Asymmetry Effect: Wheel and Track

- Asymmetrical wheels:
  - Positive and negative cones
  - **Wear is most pronounced in flange root.**
  - In curves, negative cone will either conform to or want to boomerang out
  - Sharp flanging wheels may also cleave/climb switches.

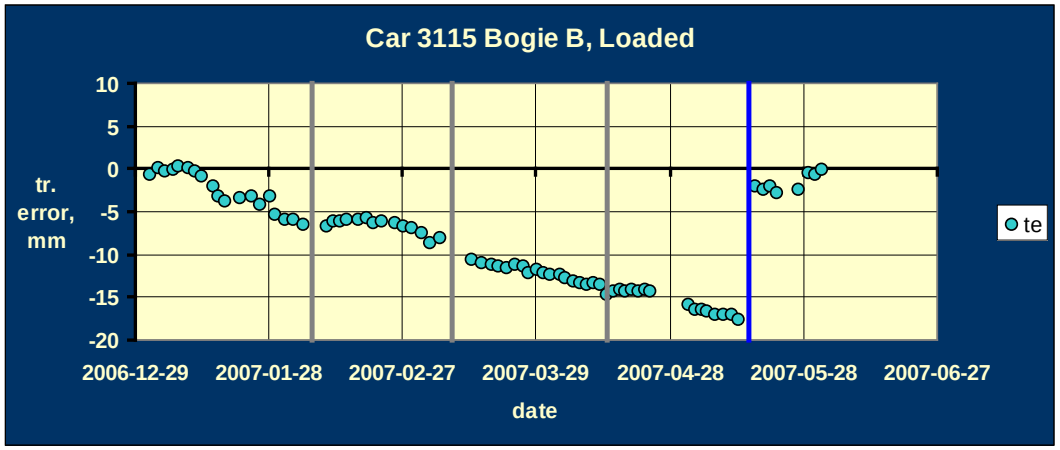


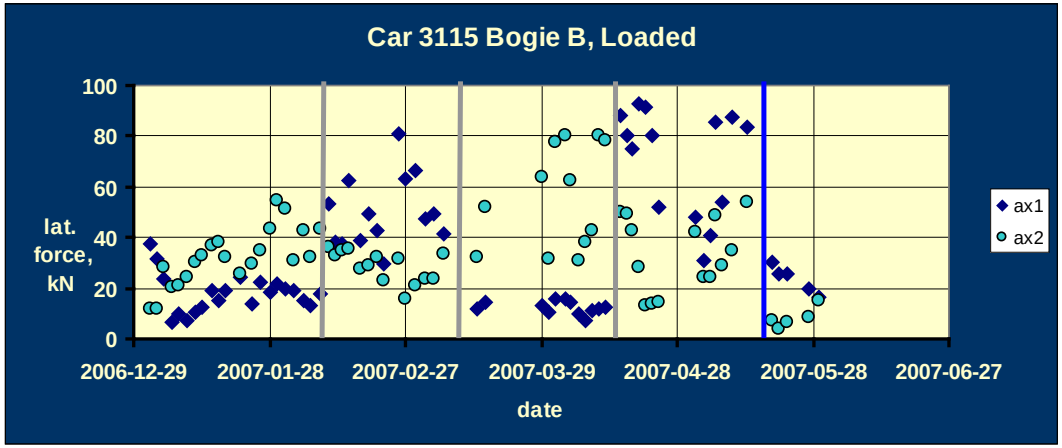
Wheel with 8mm Tracking Position

Mean = 4.7mm

Median = 3.8mm

Tracking Error & Lateral Force



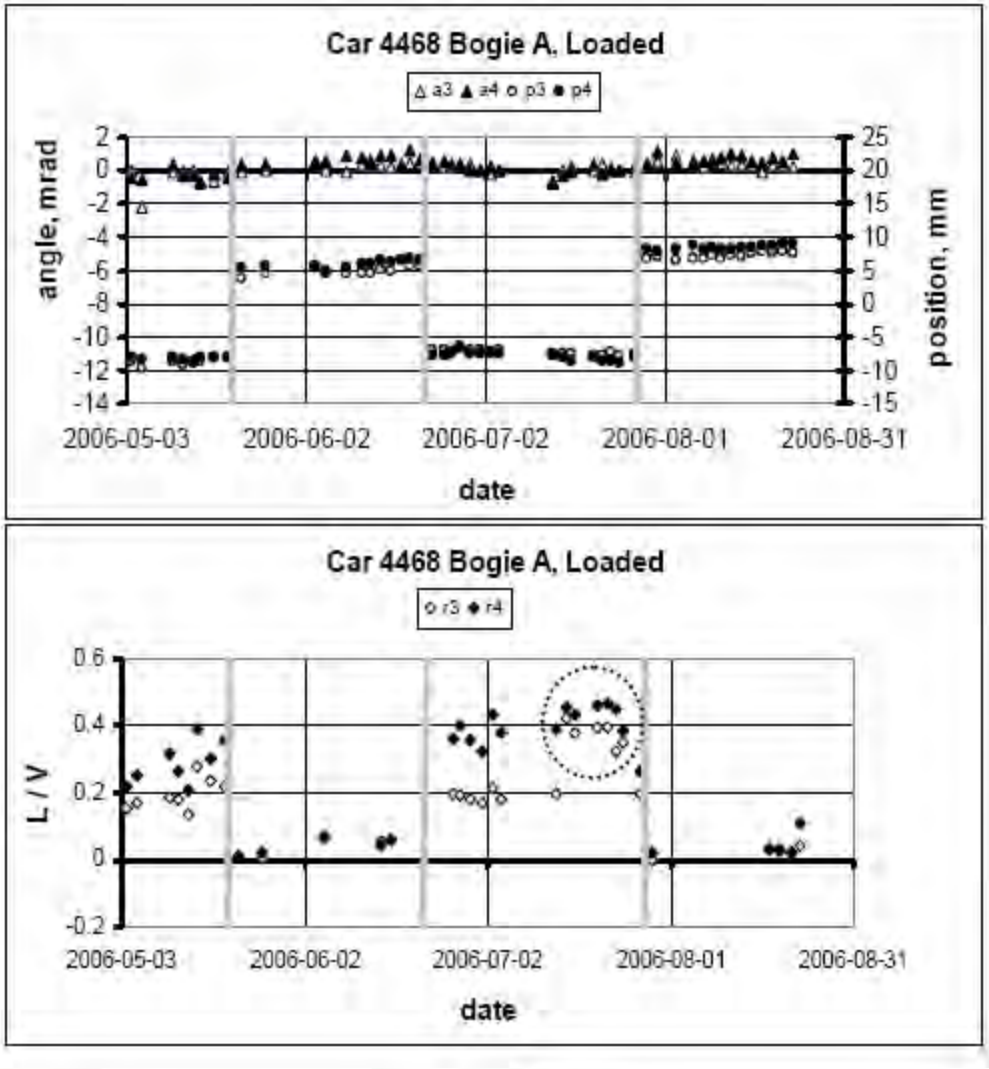


- Loaded 286 car wheel weight = 35.75kips vertical load.
- 100kN = 22.5kips.
- TE at 18mm = 20kips
- Each wheel only 8-9mm Tp.
- Gauge Restraint Designated Track is tested at lateral of 3.2kips.

Curve R270M

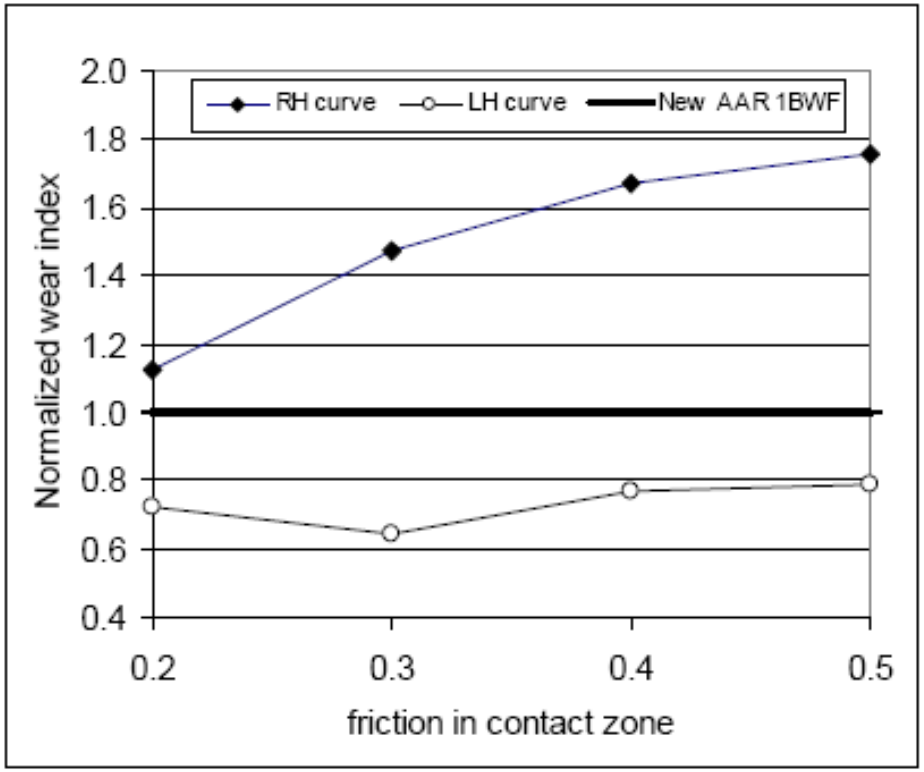
Shift and L/V

- Shift here is **only 7mm**…
- L/V ~ 0.5 in R270M curve
- If we assume a 35kip static load, about 18kips, or 80kN!



QCM Wear Index

- Vampire model conducted at Centre for Surface Transportation Technology
- 20mm TE with two wheels (10mm each)
- Curve R=350M (about 5 degree)
- Remember….Tp 20mm = AAR condemnable, these are only Tp 10mm each in opposite direction!



From previous work: Sirois, Gerard; Izbinsky, Grigory

20mm Tracking Error = $2,733.00/year?

- Assume 135 kip wheel equivalent.
- Only 6” impact zone…
  - $376/year fuel.
  - $2,131/year in track, tie, switch.
  - $226 in eqpt. (wheel)
  - No delay cost.

Car Repair Savings Calculations

KIP Level	FUEL(L1/L2/L3/L4)	TRACK (L1/L2/L3/L4)	EQPT (L1/L2/L3/L4)	DELAY (L3/L4)	DELAY (L1 /L2)	Total
80	$121.00	$800.00	$67.00	$ 700.00	$0	$1,688
90	$121.00	$800.00	$67.00	$ 700.00	$0	$1,688
100	$180.00	$1,069.00	$95.00	$ 700.00	$0	$2,044
110	$194.00	$1,377.00	$131.00	$ 700.00	$0	$2,402
120	$276.00	$1,731.00	$174.00	$ 700.00	$0	$2,881
130	$376.00	$2,131.00	$226.00	$ 700.00	$0	$3,433
140	$497.00	$2,577.00	$289.00	$ 700.00	$0	$4,063
150	$637.00	$3,071.00	$363.00	$ 700.00	$0	$4,771
160	$798.00	$3,614.00	$450.00	$ 700.00	$0	$5,562
170	$798.00	$3,614.00	$450.00	$ 700.00	$0	$5,562
180	$798.00	$3,614.00	$450.00	$ 700.00	$0	$5,562
TE	$376.00	$2,131.00	$226.00	N/A	N/A	$2,733.00
IAM	2*TE	2*TE	2*TE	N/A	N/A	$5,466.00
ROT	2*TE	2*TE	2*TE	N/A	N/A	$5,466.00
SHIFT	2*TE	2*TE	2*TE	N/A	N/A	$5,466.00
ABD				$700/repair		$ 700.00

IAM Inter Axle Miss Alignment
TE Tracking Error
ROT Rotation Error
ABD Acoustic Bearing Detectoe
* Only Pattern Codes - 2130 and 2430

For FUEL $ * 2

Notes:

Assumes savings are enjoyed for the year repaired ONLY.
WILD savings are 33% of calculated savings from TTCi/MIT (6" impact zone vice field calculated 18")
Geometry savings assume a 6" effective wheel circumference
Geometry savings are a heuristic that has been accepted by TTCi Economist Tom Guinns, and are considered extremely conservative.
Fuel savings based on $2/gallon

Only 600 repairs a year = $1.6M USD

Bradenton Derailment: 11/28/2010

FIRST INVOLVED CAR	
Initial and Number	ALPHA 1234
Position	2
Car Type	R670
Loaded	Y
Weight	130
Verified with Consist	N
End of Car Derailed	B end /wheel 1,2 (car)
First Wheel Derailed	Right 1
First Wheel Action	Drop in
Distance (ft)	185
Special Track Feature	Turnout or crossover

T205 Derailment… Structure failed allowing B-end (R1) to fall inside the track.

8mph/10mph track

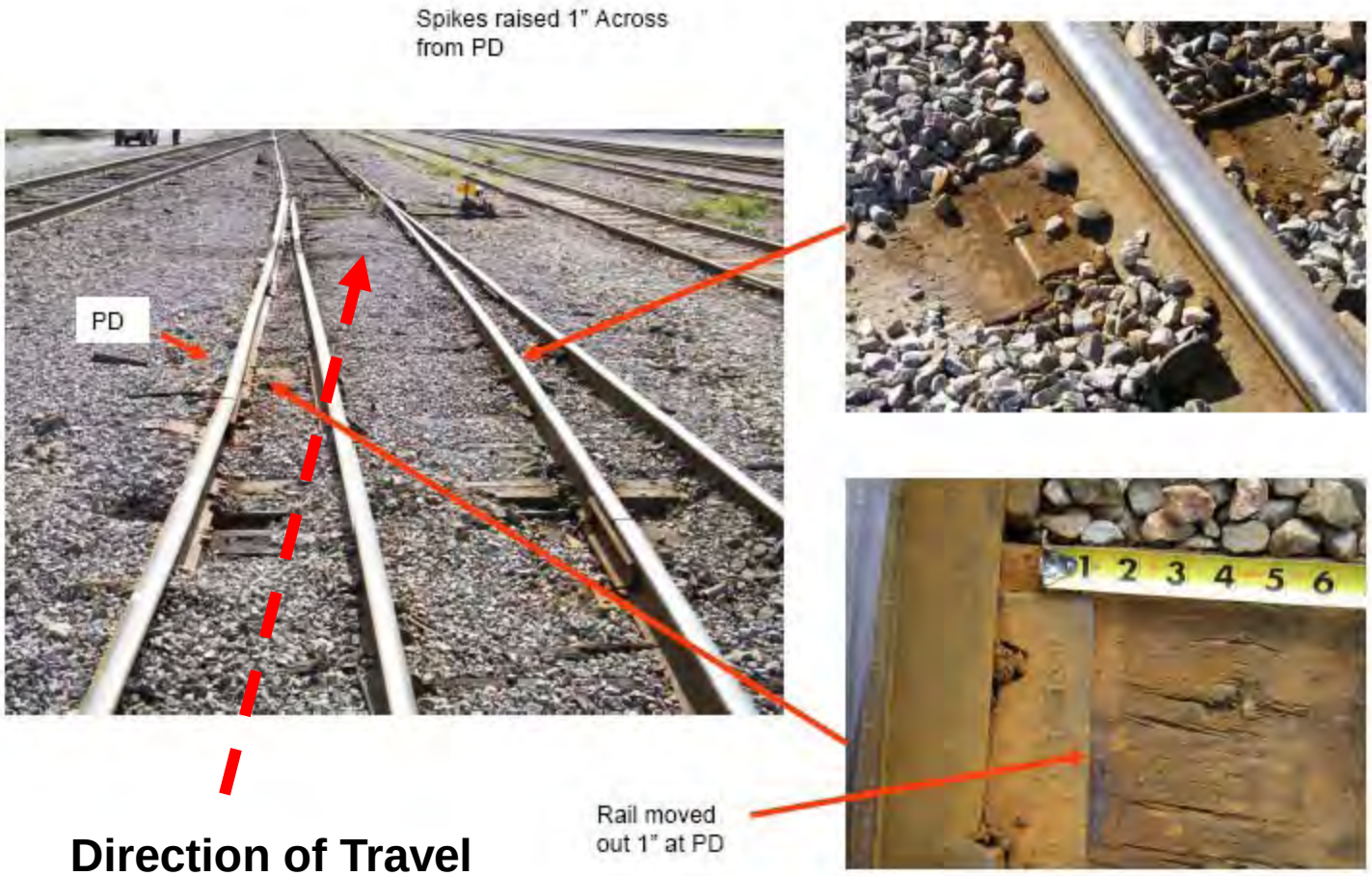
Engineering noted wheels were asymmetrically worn.

However, wheel was not AAR condemnable…..

TRAIN ACCIDENT CAUSE CODES	
Primary Cause	T205 Defective or missing crossties
Contributing Cause	

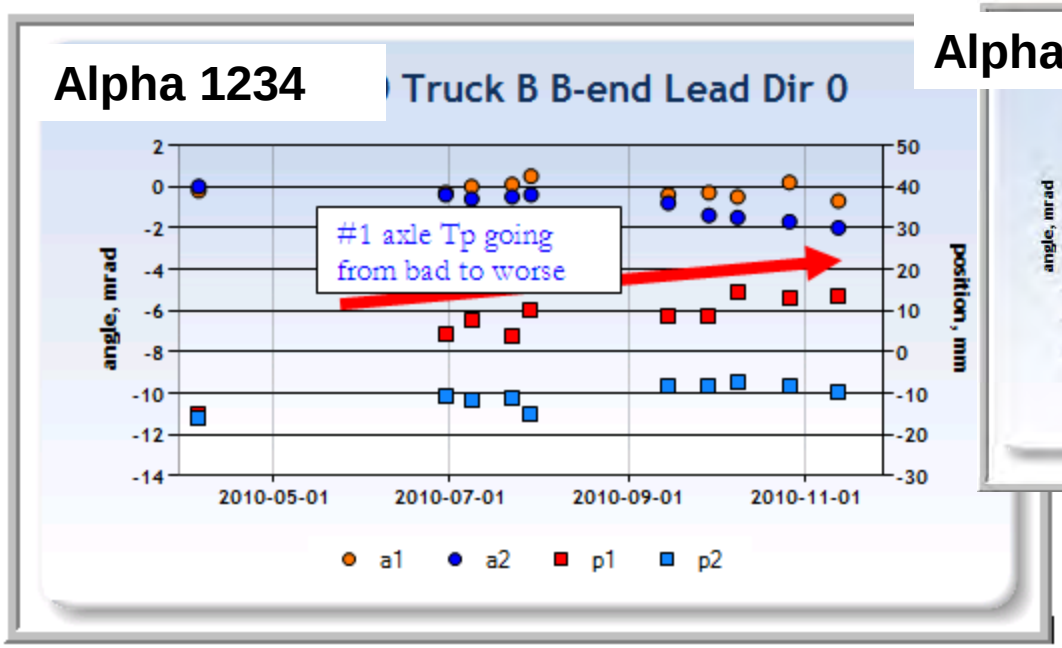
REMARKS
O70527 WAS PULLING THE LONG TRACK TO CLASSIFY CARS FOR OUTBOUND JUICE TRAIN. AS O70527 TRAVERSED THE SECTION OF TRACK BETWEEN THE SWITCH AT THE LONG TRACK AND OLD MAIN THE TRACK STRUCTURE FAILED DROPPING THE CARS INSIDE THE GAUGE.

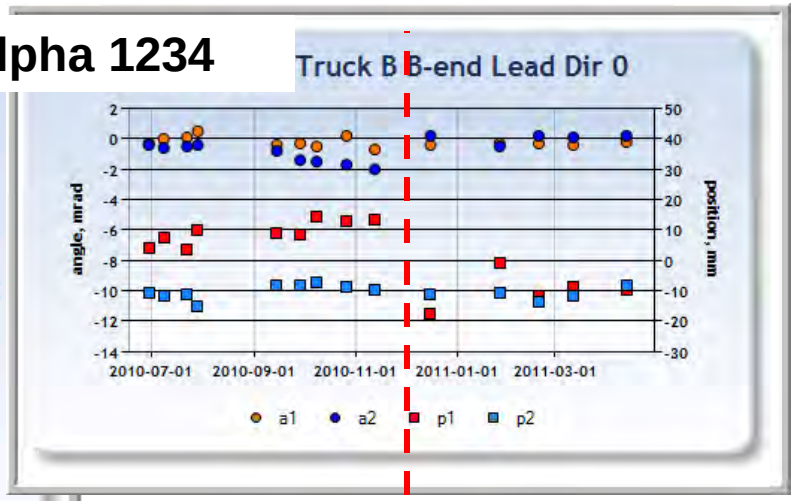
Bradenton Derailment



“ALPHA 1234” Axle 1 Flipped?

B-end leading, axle 1 around 13mm Tp…not condemnable…not a screamer.

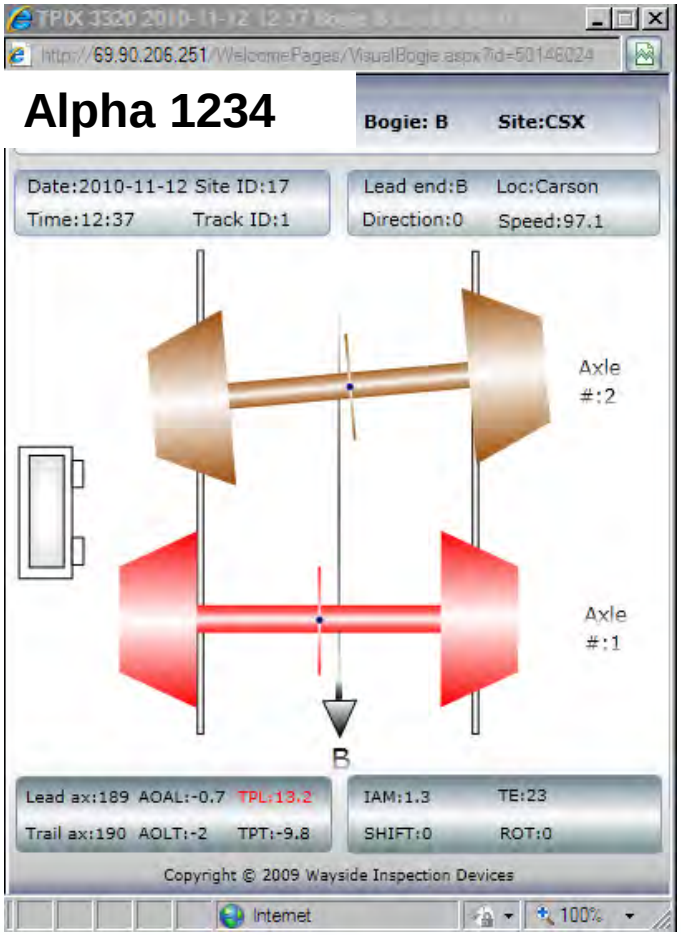




#1 wheel swapped?!

"ALPHA 1234" B-Truck Prior to Derailment

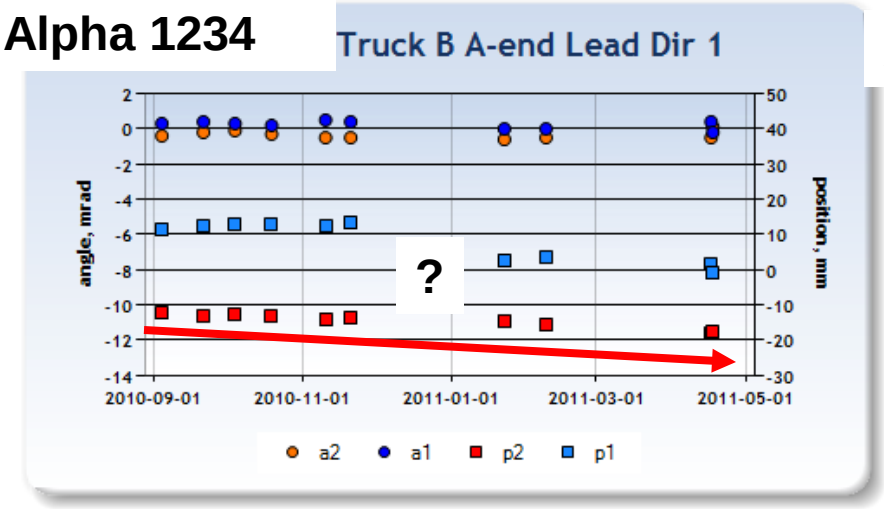
- B-End leading, we see high Tracking Error and some dragging and rotation of the #2 axle.
- B-end leading, this truck wants to steer right.
- If forced into a shallow left hand curve…what will it do?
  - # 2 wheel will plow into the low rail..
  - #1 wheel with inverted wheel cone wants to push out the high rail.
  - Isn't that how the track reacted?



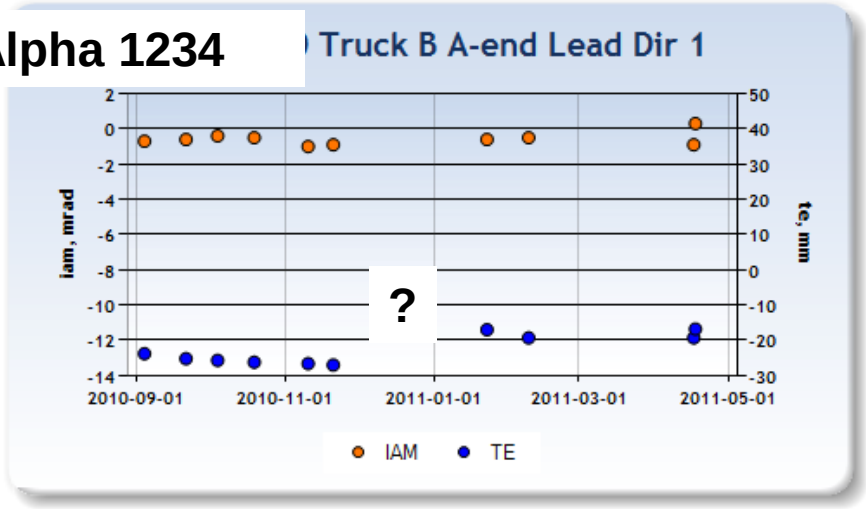
"ALPHA 1234" #2 Axle

- #2 axle is nearly condemnable now…

Alpha 1234



Alpha 1234



- Was it bad at 12mm? 13mm? When?

Tennesse City Derailment: 9/14/2010

FIRST INVOLVED CAR	
Initial and Number	BRAVO 9876
Position	20
Car Type	S635
Loaded	Y
Weight	120
Verified with Consist	N
End of Car Derailed	C end (car)
First Wheel Derailed	Left 7
First Wheel Action	Unknown
Distance (ft)	961
Special Track Feature	Turnout or crossover

T314 Derailment…
Switch point worn or broken.

“3 engines and 19 articulated cars made it over the switch when L7 of the 20th car derailed.”

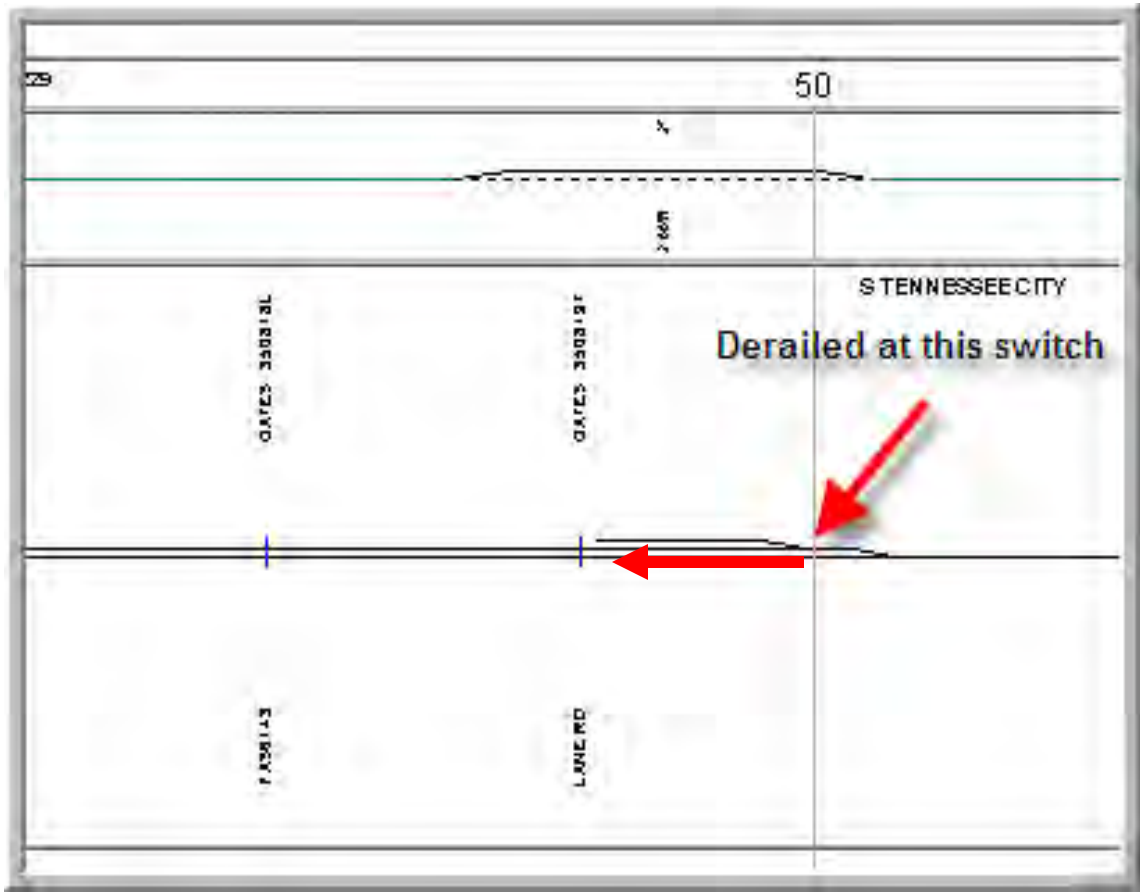
Engineering noted wheels were asymmetrically worn.

However wheel was not AAR condemnable…

TRAIN ACCIDENT CAUSE CODES		
Primary Cause	T314	Switch point worn or broken
Contributing Cause		

REMARKS
Q12514 WAS LINED TO GO INTO THE SIDING. 3 ENGINES AND 19 ARTICULATED CARS MADE IT OVER THE HOUSE TRACK SWITCH WHEN L7 ON THE 20TH CAR DERAILED. 2 CARS DERAILED.

Tennesse City Derailment

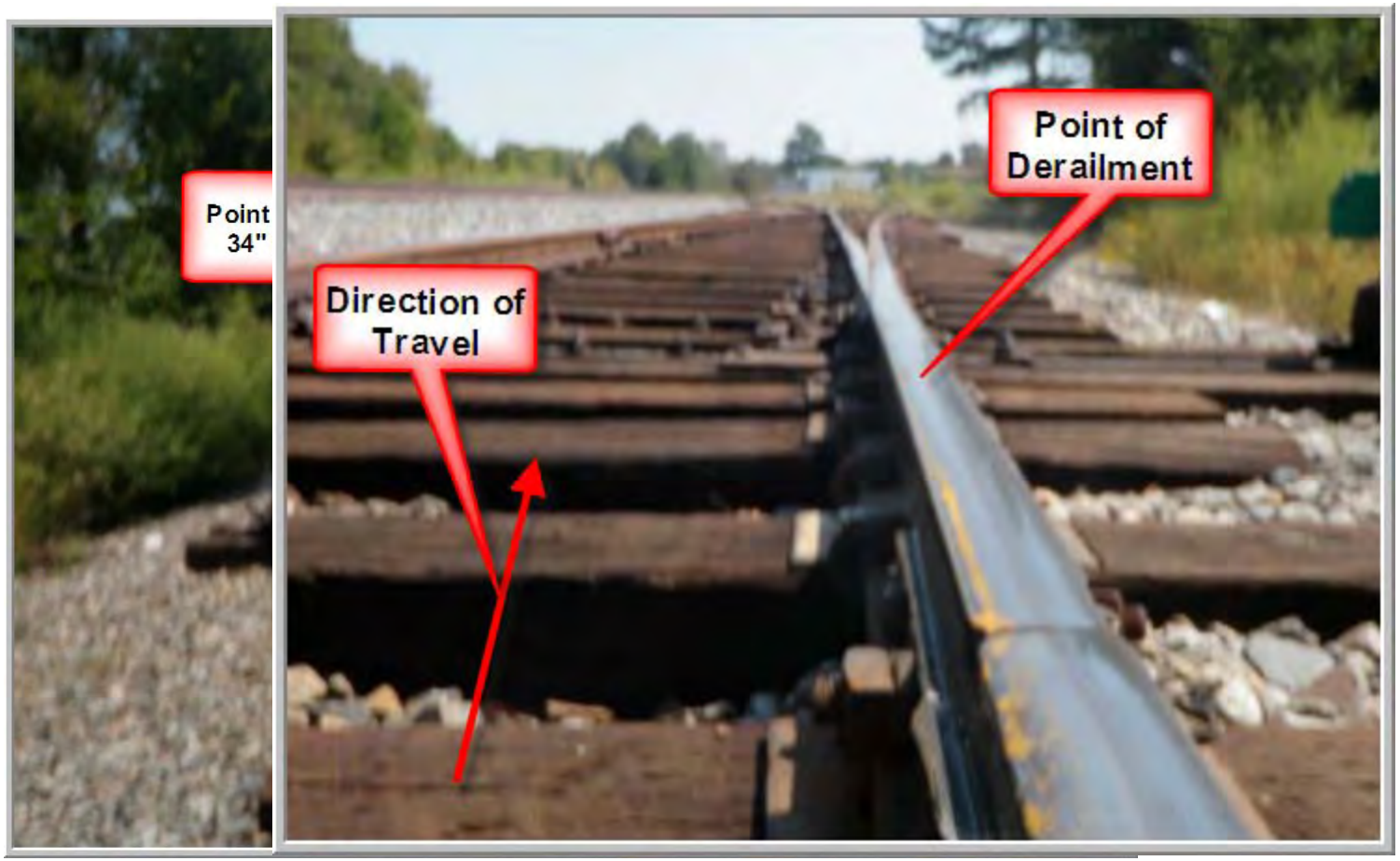


Train traversing **left hand** curve in siding…climbed point of House Track switch.
2 degree left hand curve, 8mph.

Tennesse City Derailment

Train traversing left hand curve in siding….and derailed House Track switch.

Tennesse City Derailment



Train traversing left hand curve in siding….and derailed at a spur switch.

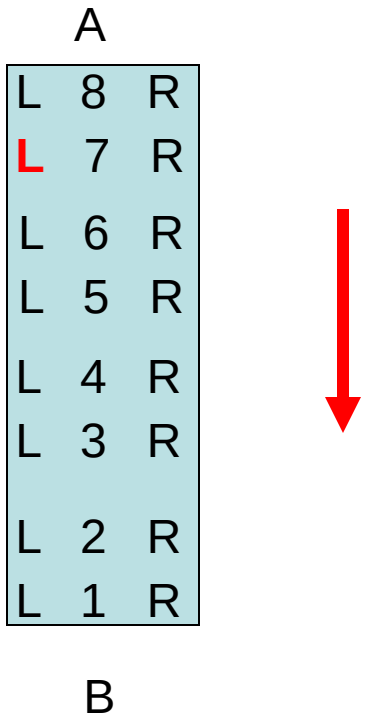
Tennesse City Derailment

Offending Switch Point

Principle Car: “BRAVO 9876”

- This is a four-truck car: B end leading…
  - 1&2 = B truck
  - 3&4 = C truck
  - 5&6 = D truck
  - 7&8 = A truck.

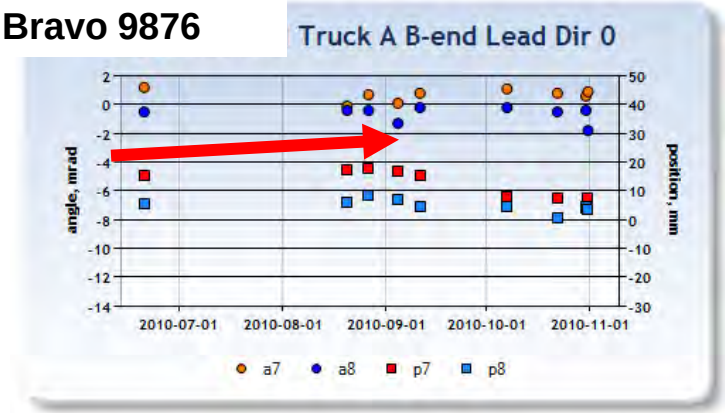
L7 was first wheel off!



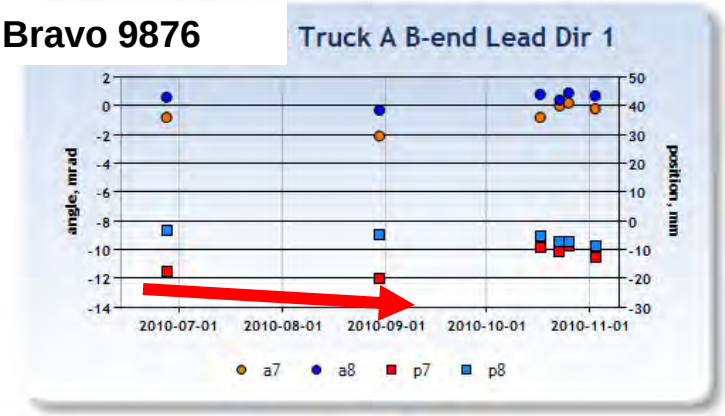
Principle Car: “BRAVO 9876”

- Axle 7 running around 15-18mm Tp prior to derailment B end leading. Truck wants to steer RIGHT!

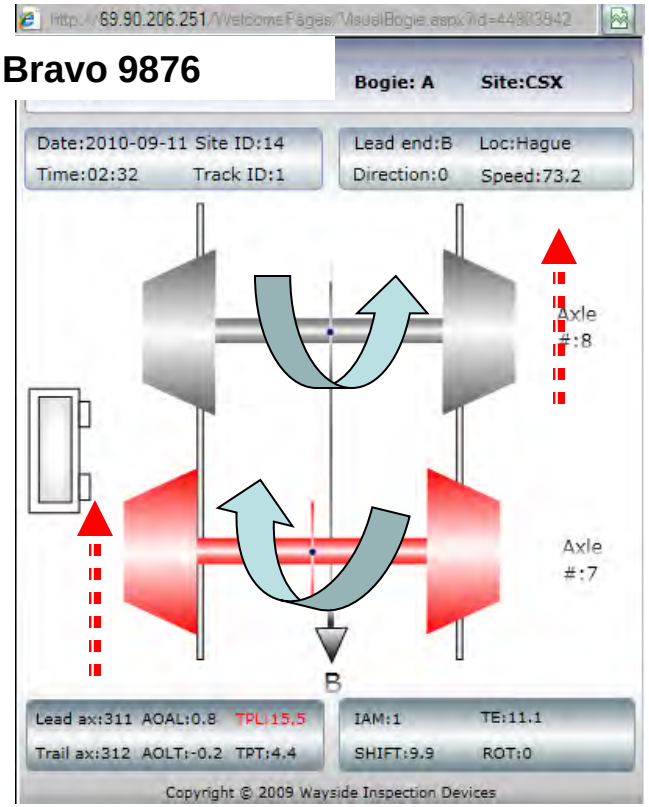
Bravo 9876



Bravo 9876

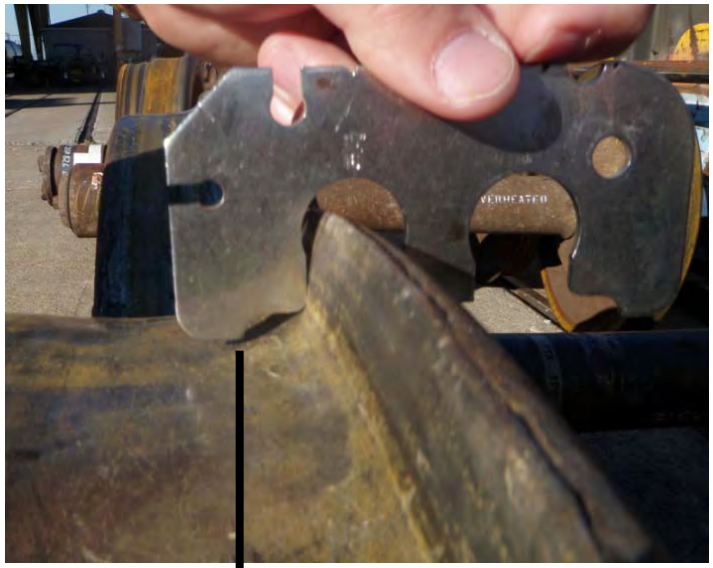


Bravo 9876



BRAVO 9876 Axle 7, Left Side

BRAVO 9876 Axle 7, Right Side



L7

R7

Root wear may have kept wheel from failing.

Bravo 9876

- L7 flange not condemnable.
  - Tracking at 18mm…3rd quartile is 6.8mm
- L7 = 3.5mm hollow…not condemnable.
- Field measured 3 tape size DELTA on #7 at the tape line…but wear at the root was probably more severe than this indicates
- Not condemnable = “not car caused.”

Parma Ohio, 3/24/2011

CAUSING CAR	
Initial and Number	CSXT 920462
Position	23
Car Type	M150
Loaded	N
Weight	50
Verified with Consist	N
End of Car Derailed	B end /wheel 1,2 (car)
First Wheel Derailed	Left 2
First Wheel Action	Climb
Distance (ft)	4114
Special Track Feature	Crossing diamond

47 in 50

23rd car

First Report: Rail Rolled and tore…broken rail?

Cause Code: E40C Side bearing clearance insufficient.

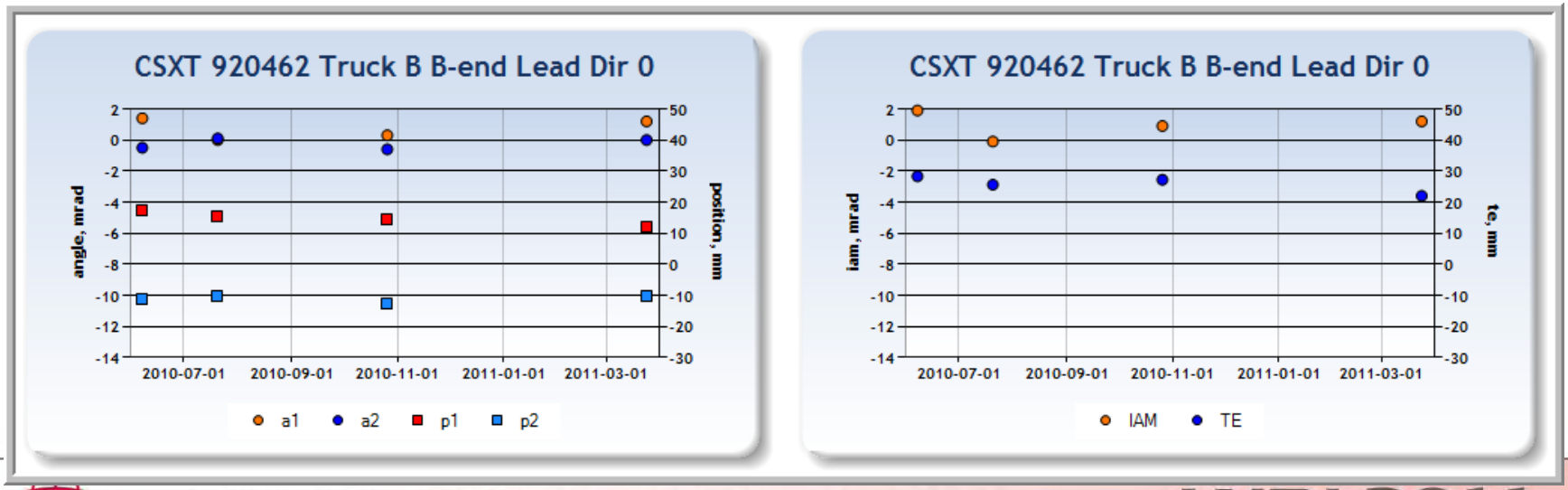
Parma Ohio, 3/24/2011

1) 0535. Cleveland Short Line Sub, MP QDS 17, Parma, OH. W01413 reported T.I.E. and investigation revealed 11 cars derailed. No PIs, no hazmat. All cars are part of empty rail train. Corman arrived 1000. **Equip. $ 62,000. Track $ 24,500. Signals $ 7,000.** Trains to be rerouted on NS between Berea and Cleveland Lake Front. #2 Track ok'd for 10 mph at 1400. Expect #1 Track to be repaired 2200. UPS trains route via NS/Berea to Cleveland and reverse.

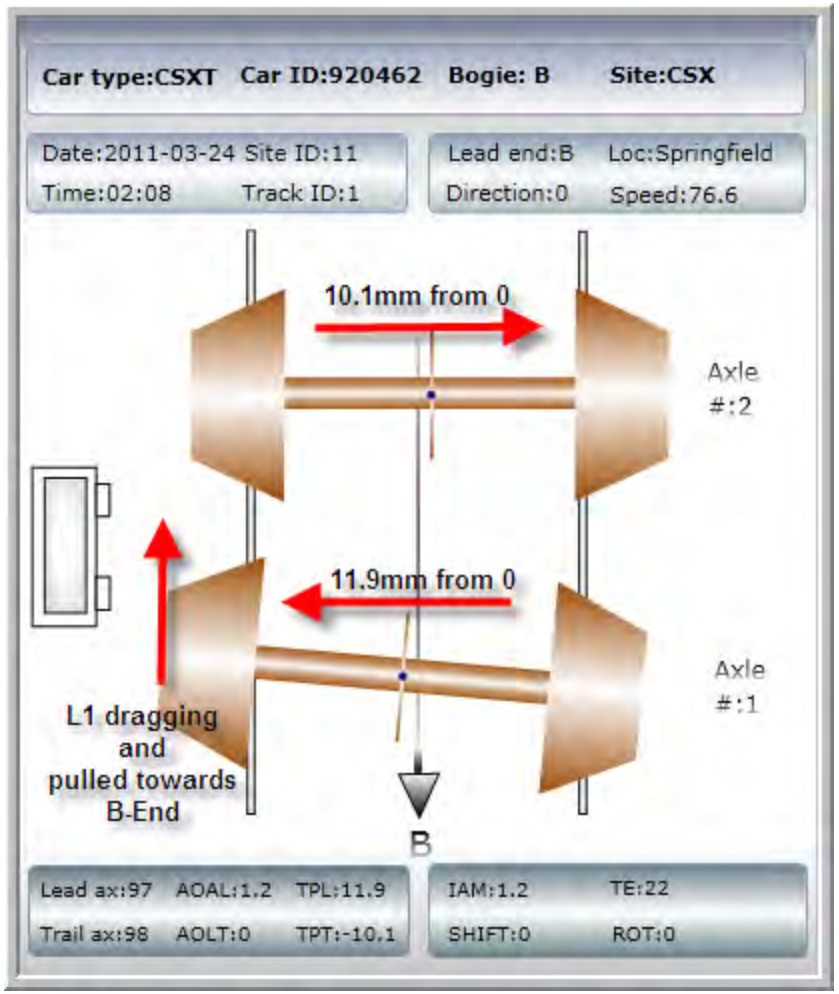
Parma Ohio, 3/24/2011

B-Truck B-End Leading Performance, last 365 days

- Tracking Position for these axles is above 10mm in opposite directions (10mm is > 2x the mean of 4.7mm or median of 3.8mm).
  - Wheels are not condemnable for thin flange until consistently > 20mm.
- Tracking Error is 22mm or more (worse 1%)
- Axle 1 is rotated, likely flange drag on left side is pulling L1 wheel towards the A-end.



CSXT 920462, 3/24/2011



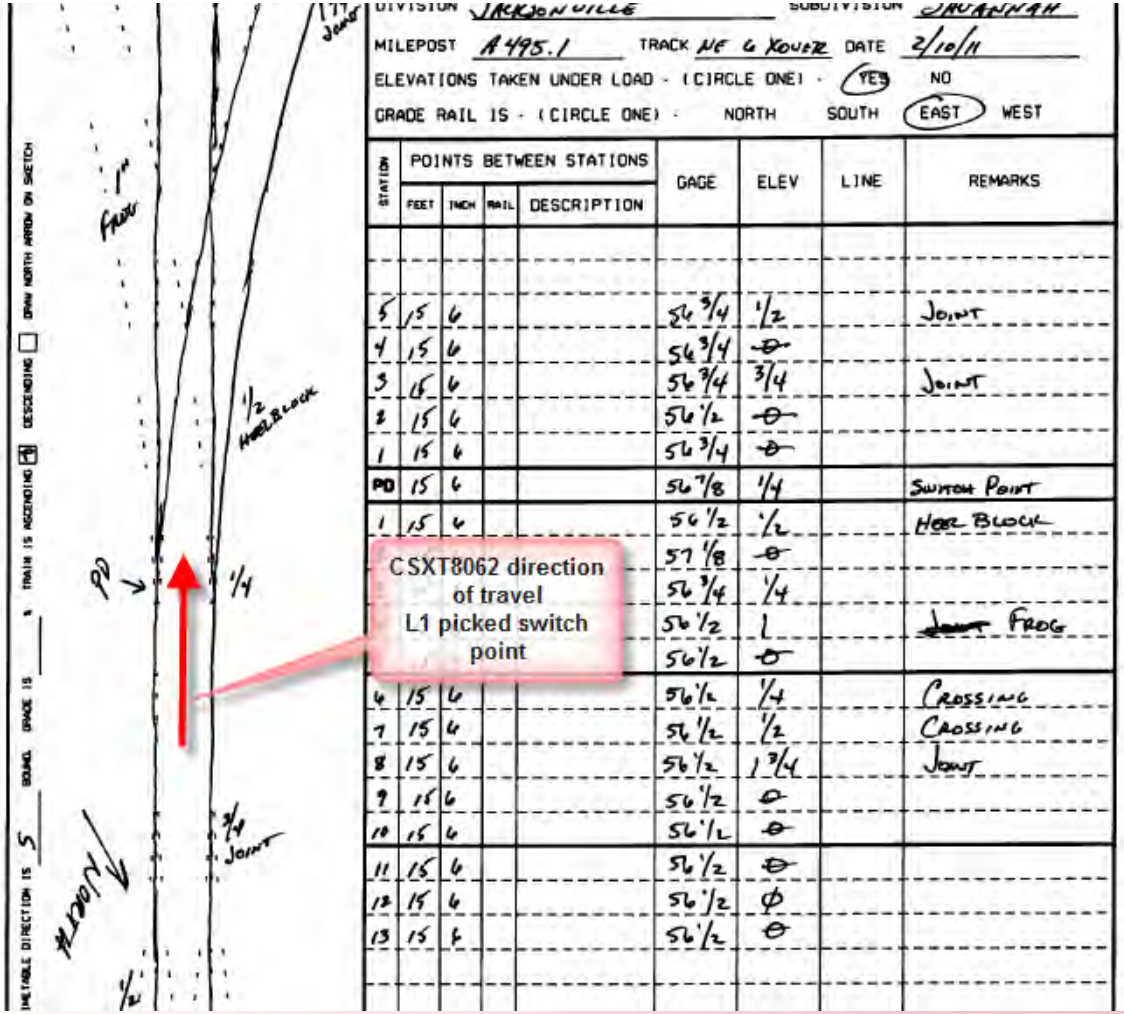
Car wants to steer to the right with B-End leading….

Locomotive CSXT 8062

- Locomotive derailed on a switch at Savannah on 2/8/2011. Switch was written up as cause.
- Team noted high and sharp flange on the principle wheel, L1.
- TBOGi data for wheel tracking position (Tp) was collected and examined.
- L1 was identified as having highest Tp and increasing over time
- Locomotive sent to Waycross Heavy Repair (WHR) for truck inspection

Locomotive CSXT 8062

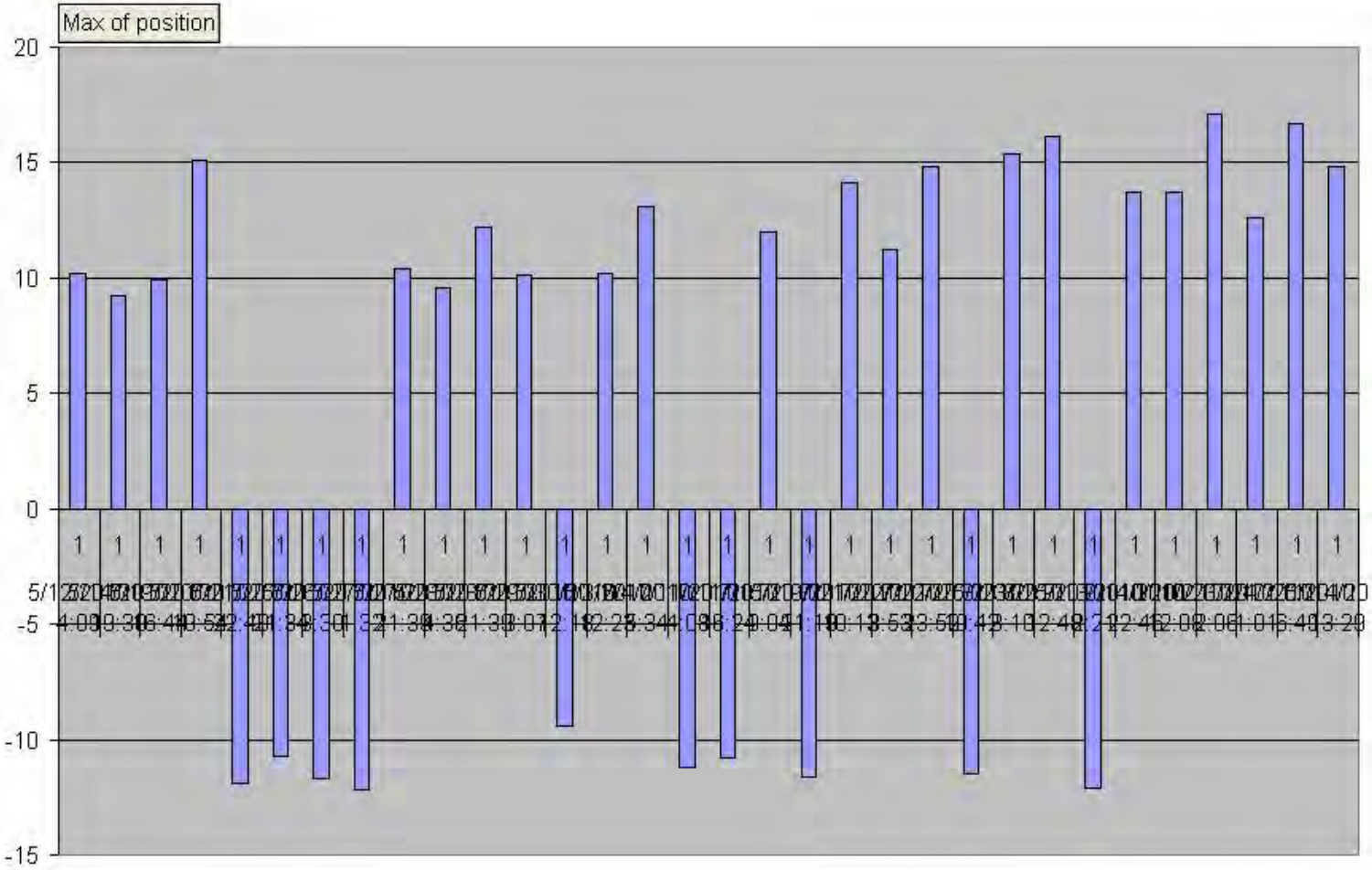
Savannah Derailment



Savannah Derailment

- Switch Point: Shows deformation

TGI 8062 Axle 1 Tp



Wheel Measurements TM1 and TM6

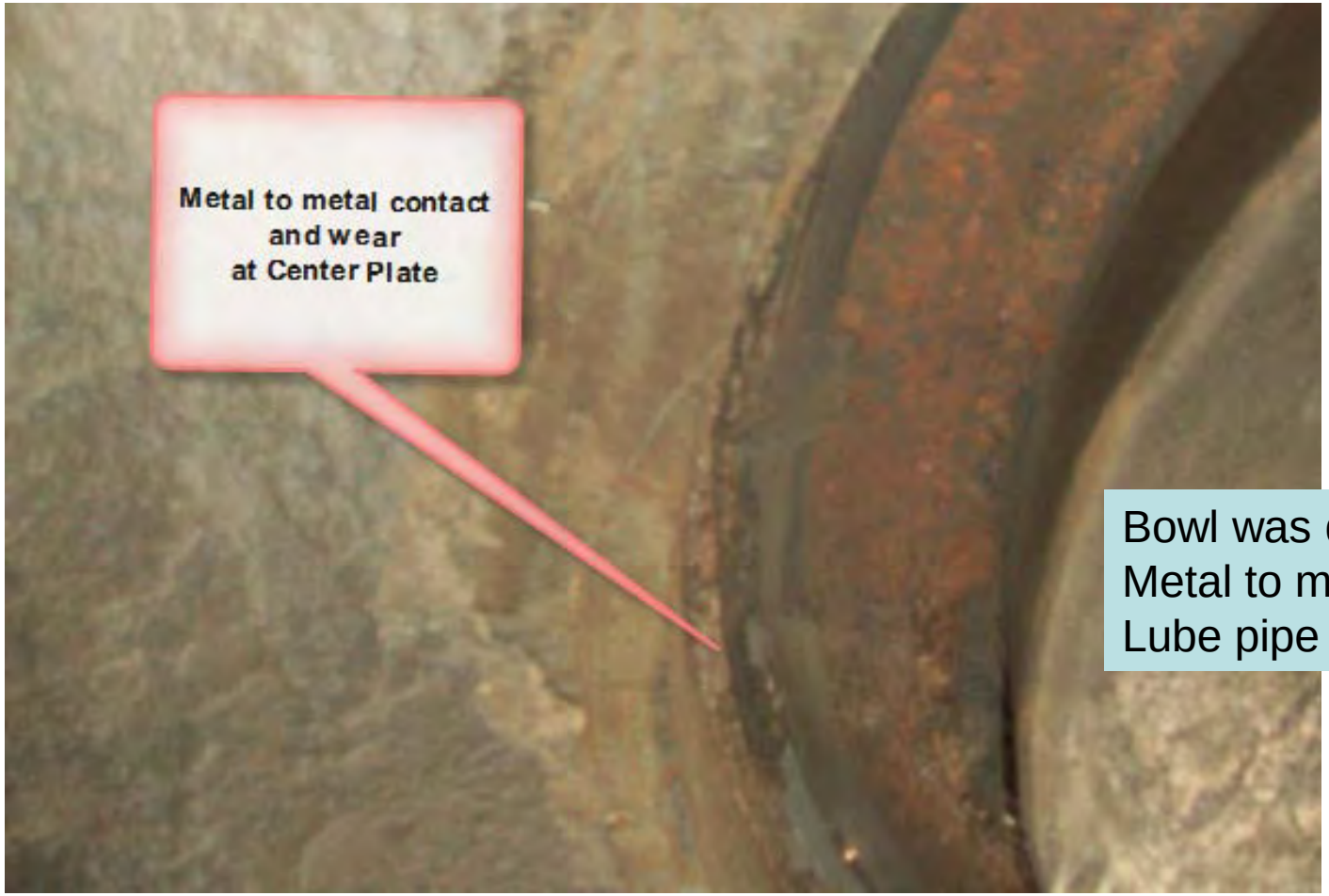
all units 1/16"	R6	L6	CSX limits
Rim Thickness	37	36.75	18
Flange Thickness	0	5	6
Flange Height	5.2	6.1	6
Reference Groove	26	25	
	R1	L1	CSX limits
Rim Thickness (1/16")	32	30	18
Flange Thickness	0	4	6
Flange Height	4	6	6
Reference Groove	19.78	26	

1/8 difference in radius between the R1 and L1, which may explain why L1 is moving to the left.

CSXT8062 #1 truck

- Wear Plates of different thicknesses

8062 #1 Center Plate



Bowl was dry
Metal to metal galling
Lube pipe broken

Bolster Wear Pads

CSXT 8062 Corrective actions

- #1 truck center bowl lube pipe repaired
- Replaced rubber bolster pads #1 truck
- Replaced worn pedestal liner #3 TM
- Replaced all four carbody wear pads with 5/8” pads
- Relocated #2 truck right rear carbody wear pad.
- True #1 and #6 TM, others as required to match
- Watch and see….

Locomotive Opportunities?

- There's an opportunity to use TGI data to flag wheels for inspection and true.
- Suggest something like 3 measurements > 14mm Tp as a place to start, create NOS incident to WTQ/TMC and general inspection at **next shopping**.
  - We use WILDS to create these kinds of incidents for impacts, TGI would just be another piece of information for shop use.

Current CSX Car Rules, Tracking Position and Shift:

- SHIFT:
  - 3 or more Tracking Position in for axle in truck > 20mm
    - ***Satisfies "Condemnable" criteria IAW AAR****
  - At least 1 Shift measurement > 17mm
    - Identifies condition (what car has been doing)
    - Inspect adjacent wheel set, look for broken springs or side frame bearing condition that may have car loading on one side of truck or other.
- Tracking Error:
  - 3 or more Tracking Position in for axle in truck > 20mm
    - ***Satisfies "Condemnable" criteria IAW AAR****
  - At least 1 Tracking Error measurement > 34 mm
    - Identifies condition (what car has been doing)
    - Inspect adjacent wheel set, look for broken springs or side frame bearing condition that may have car loading on one side of truck or other.

At 20mm Tp, can wheel be turned for another life?

TGI: An IMPLICIT detector

Criteria	WILD and Acoustic (Explicit)	TGI (Implicit)
Condition	BILLABLE	INSPECT
Billing	DATA ONLY required to support billing	Must inspect and manually write up
Component	REPLACE THIS	May be one of several in a system
Specificity	WHEEL or BEARING	Truck (SYSTEM)
AAR Rules	MUST HAVE to use data to condemn and bill	Not necessary, as long as we find only actionable cars.
DATA	Required to maintain data to support billing	Not required, must have write-up to support billing.
Action	REPLACE	INSPECT
Measurement	Component Condition	System Performance
What it provides	Condition	Symptom
Our response	We know there's a problem, here it is	We know there's a problem, look for it

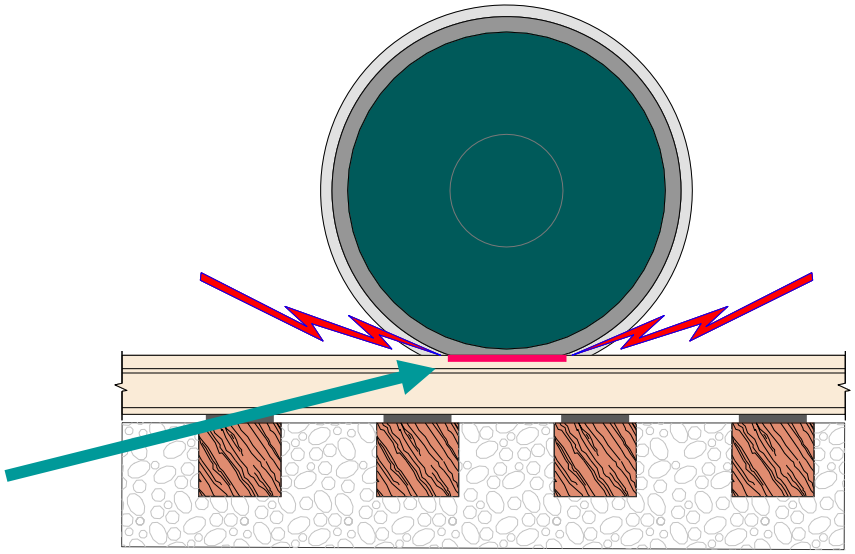
Geometry Based Truck Inspection: A reliable inspection device

- TGI can identify wheel and truck conditions that are not easily discerned by manual visual inspection and can provide insight into the cause of train accidents.
- Cars flagged by TGI using current thresholds have billable repair items, but more importantly, that are not running properly.
  - TGI won't flag some well-running cars that have AAR billable conditions.
- "Billable" repairs may not address root cause.
  - "Not Billable" does not equal "Good"
- AAR repair rules may need to be revised to allow for earlier intervention and wheel/rail life extension.
- New criteria for:
  - Rate of Change vs Explicit Limit
  - Connicity, Positive and Negative
  - Asymmetrical wear
  - Delta Diameter
  - **Flange Root Wear vs Wheel Hollow**

Track and Equipment Health: Systemic Approach

- Railroads are all about steel wheels and steel rails.
- In the past, we've fixed one, or the other, without considering the overall effect.
  - Current Culture DISCOURAGES.
- The "Rail Renaissance" is information and technology driven and requires a systemic approach, and looking at the INTERFACE between wheel and rail, and making decisions based on improving things at the interface.

Equipment Health:
JWDS: MECHANICAL



Track Health:
ITIS: ENGINEERING