Effects of Superelevation and Speed on Vehicle Curving in Heavy Axle Load Service

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Research & Tests

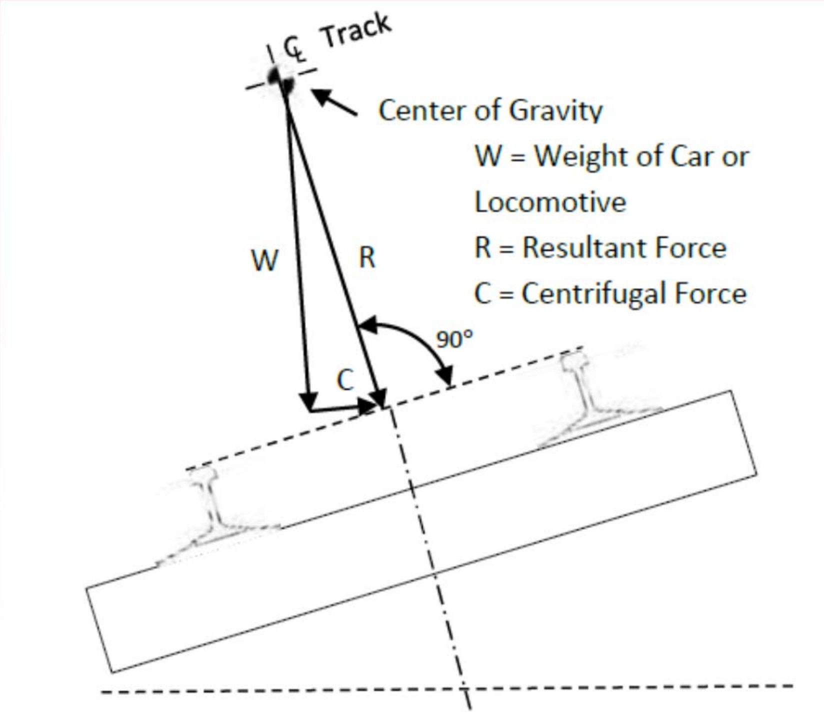
“I have a problem with rail wear and gage widening. I think I found the solution!”

- “I added 2” of elevation to all of my curves!”
- The supervisor is thinking of the highway vehicle dynamics model, where over-balancing centrifugal force causes a vehicle to move toward the low side.
- He believes that as he adds elevation, high rail lateral forces will decrease.

What is the 2nd myth of track maintenance?

- More elevation is better. I can fix my rail wear and gage-widening problems by adding more elevation!

- In theory and in practice, the reverse is true. Elevation above what is needed to achieve balance speed actually increases rail wear and gage-widening!



In theory…

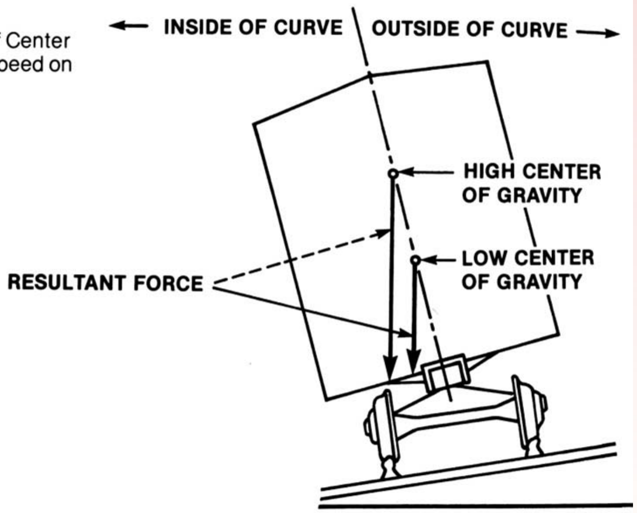


Figure 4-9
Effects of Height of Center of Gravity at Low Speed on Elevated Curves

AAR, FRA, RPI, TDC: <u>Track Train Dynamics to Improve Freight Train Performance</u>, Report R-185, 2nd Edition, 1986

1. Trains curving with <u>excess elevation</u> generally impose greater vertical loads on the low rail and greater steering tractions on the lead axle, resulting in low rail RCF and high gage-spread forces.

2. Trains curving at <u>underbalance elevation</u> impose greater vertical loads on the high rail, however trucks curve with a reduced angle of attack and generate lower lead axle steering tractions with resulting lower L/V ratios.

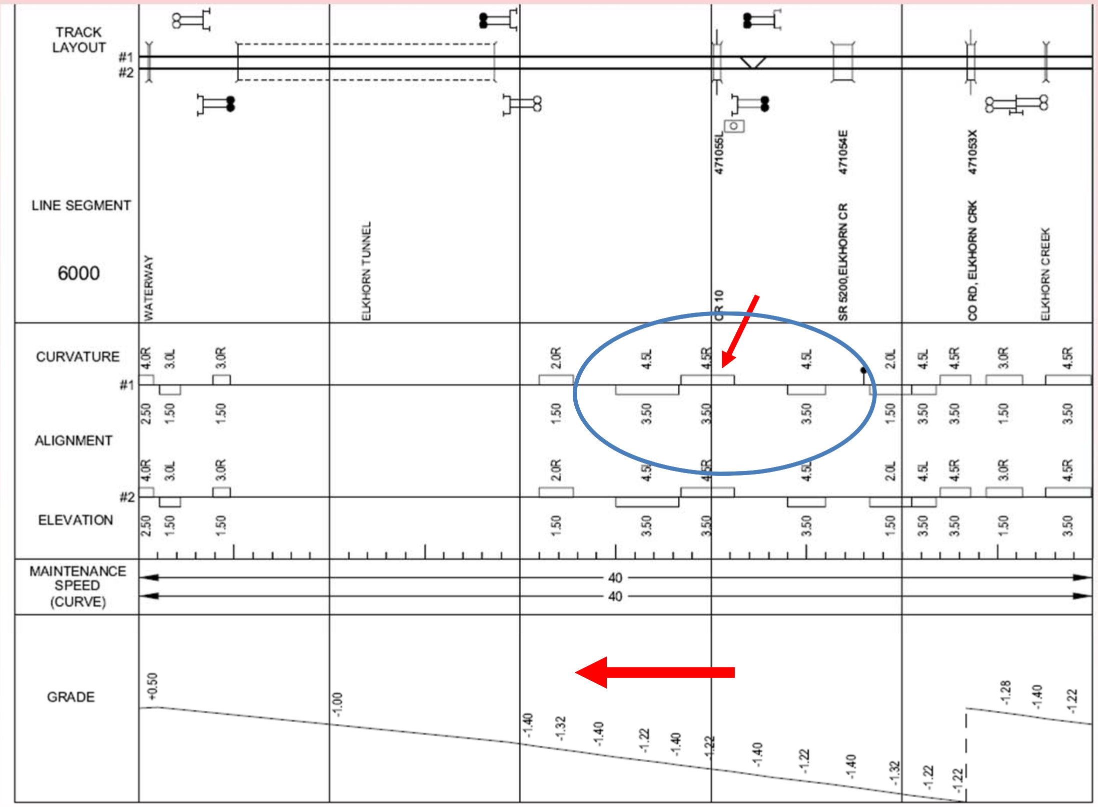
Can we validate these theories with a field test?

TTCI and NS proposed a revenue service test where these theories could be validated. We looked for a site with these characteristics:

- A high-degree curve to maximize the lateral component of coupler force.
- Repeatable, heavy axle load train consists (similar car types, car weight and train length), such as loaded unit coal and grain trains.
- An ascending grade that causes trains to operate at maximum power and constant speed.

Test site established at Maybeury, WV

- NS's Bluefield - Portsmouth Line
- 4.5˚ curve
- 3.5" elevation
- 1.22% ascending grade
- Timetable speed 40 mph
- Balance speed 33 mph
- Consistent unit train make-up



Which trains did we evaluate?

To remove car weight, train length & train tonnage as variables, we looked at trains with:

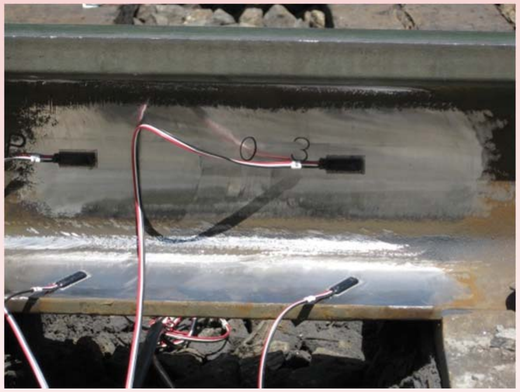
- 100 – 110 loaded cars (unit trains)
- 4 locomotives – 2 pulling & 2 pushing

Trains were generally all gondolas or all hoppers.

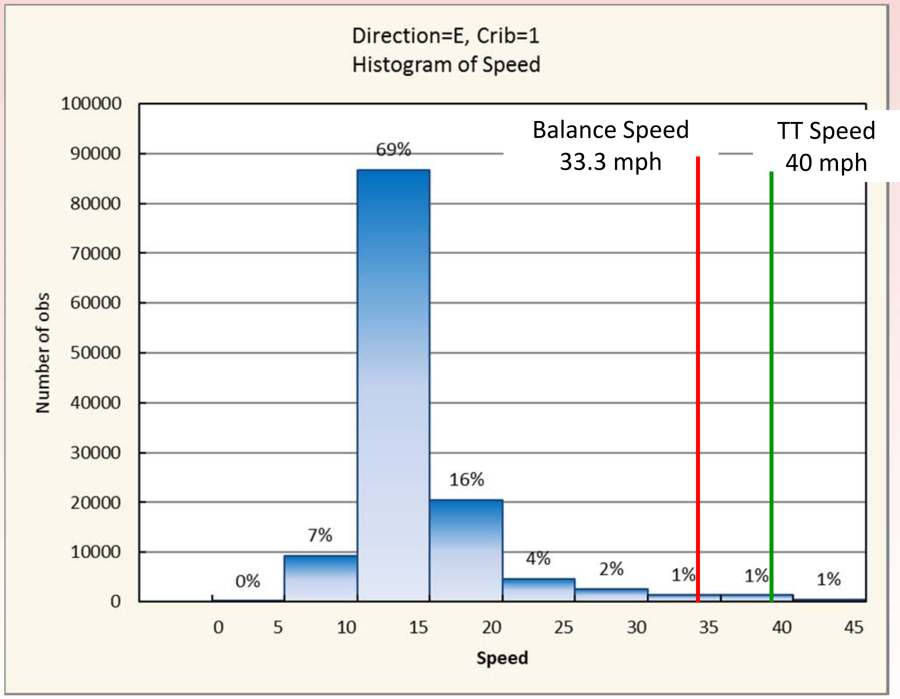
Because of the grade, all locomotives operated through the test site in notch 8.

What data did we collect?

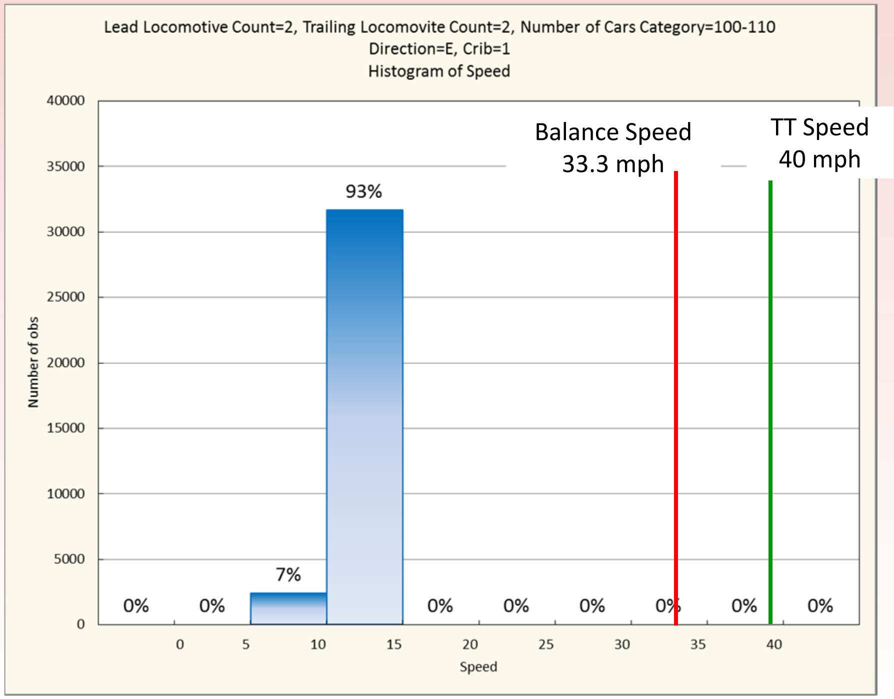
- For each axle: speed and vertical & lateral forces
- Date range June 13 – July 1, 2013
- 89 trains



Train speed distribution (Phase 1)



Axle speed distribution of all eastbound trains



Axle speed distribution of target trains
(eastbound, 100-110 cars, 2 + 2 locomotives)

What does a 100-car train, 2 + 2, at 12 mph look like?

What forces act on a car? How are these forces transmitted to the wheel/rail interface?

1. Gravity – the weight of the car
2. Centrifugal force – created by the combination of curvature and speed
   - the load differential between high & low rails is determined by centrifugal force and elevation
3. Coupler force; the lateral component of draft (tension) acts toward the low side; the lateral component of buff (compression) acts toward the high side

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4. Axle steering forces

Impact of coupler forces on vertical wheel load distribution between low and high rails

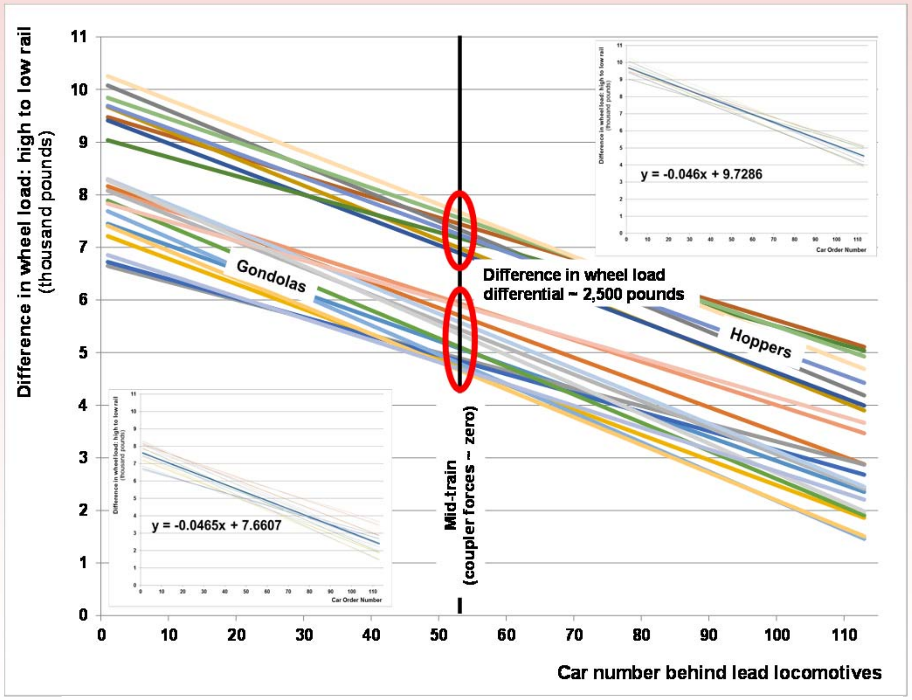
- First video segment: Coupler buff force rotates car body, and pushes truck, toward high rail.
- Second video segment: Coupler draft force rotates car body, and pulls truck, toward low rail.

How much of this model reflects full-scale conditions?

- ➢ Car body rotation and vertical load transfer – yes
- ➢ Truck translation – probably not

Vertical wheel load differentials, lead axles, vs. position in train (Phase 1)

100-110-car unit trains
with locomotives 2 + 2

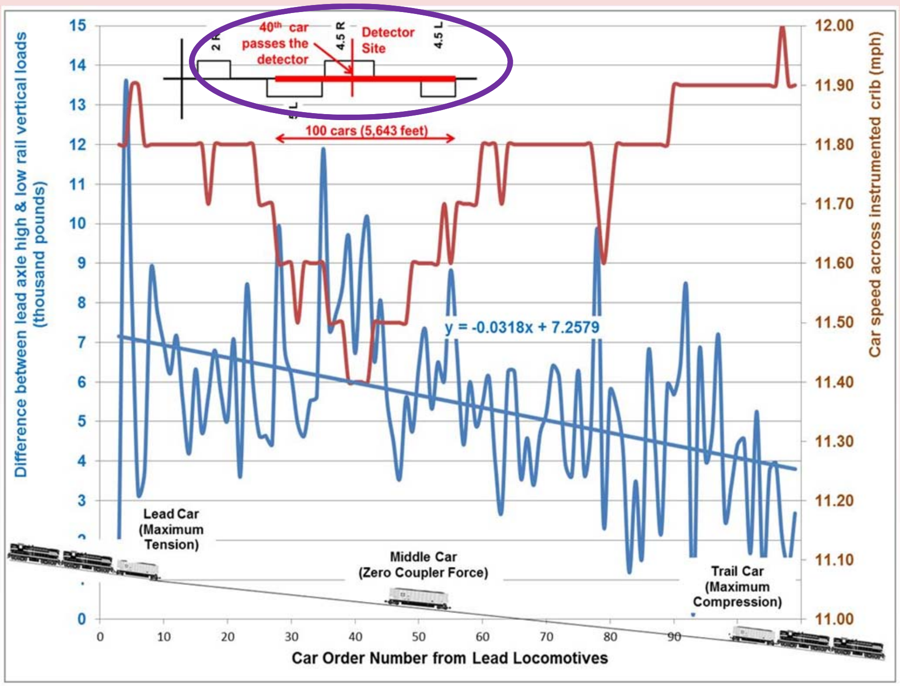


Tournay, Harry, et al: The Effect of Track Cant on Vehicle Curving : In-service Test Results Part III of III, TD14-015 , Transportation Technology Center, July 2014

- Graph shows wheel load differentials (low rail minus high rail) of multiple trains: top bundle includes hopper trains (higher CG); bottom bundle includes gondola trains (lower CG).

- Wheel load differential at mid-train (red circles), the point of zero coupler force, is due entirely to elevation: 7+ kips for hoppers & 5+ kips for gons.
- Differentials above and below these values are due to coupler draft (head half) and buff (rear half) force.

For a one train, vertical wheel load differential and speed, lead axles, vs. position in train (Phase 1)



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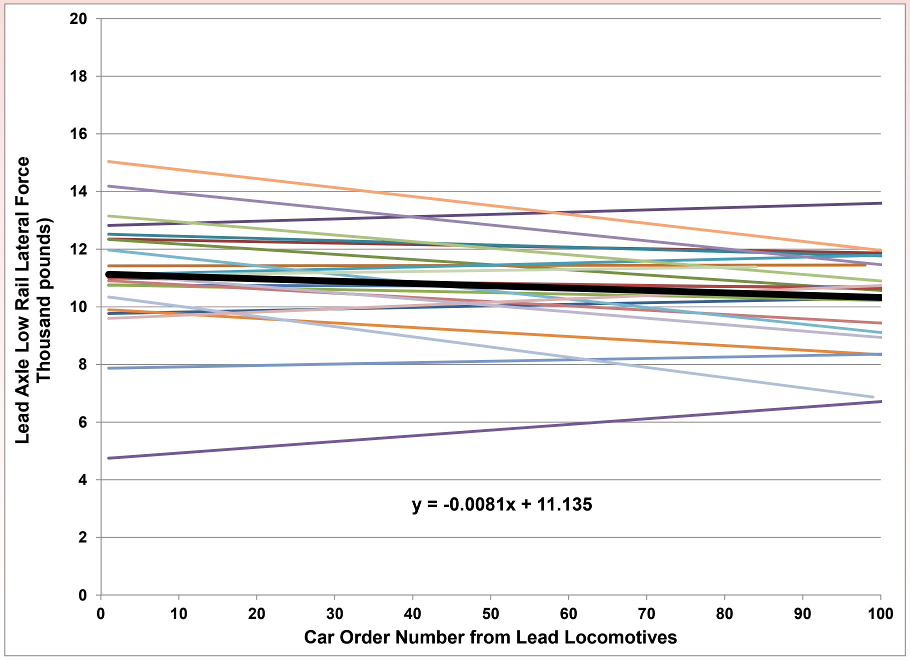
- Train is represented head-end (left) to rear-end (right)
- Blue lines represent vertical wheel load differentials; the differential is greatest at the head end
  - Vertical differential varied from roughly 7 kips (more weight on low rail) to 4 kips.
- Red line represents train speed
  - Train speed varied between 12.0 and 11.4 mph; minimum speed was recorded when the train occupied the three 4.5˚ curves simultaneously

Lateral force on low rail (lead axles of lead trucks) vs. position in train (Phase 1)



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- Lateral force lines for most trains show a very slight decrease from head end to rear end.
- We do not see the same coupler force effect on lateral wheel/rail forces that we do on vertical wheel/rail forces; lateral forces appear to be largely independent of position in train.

Conclusions (Phase 1)

- Balance elevation for trains operating on a 4.5˚ curve at 11.5 mph is 0.4”. With actual elevation 3.5”, the majority of tonnage trains operate at 3.1” excess (overbalance) elevation.
- There is significant wheel load transfer when curving at 3 inches underbalance. Load transfer was on the order of 10% (3.7 kips) for higher-CG hopper cars.
- Additional wheel load transfer of up to 3.2% (2.3 kips) was measured due to coupler forces applied by 2 locomotives (if all 4 locomotives were pulling, wheel load transfer would be up to 6.4% (4.6 kips)).
- Coupler buff & draft forces have a significant impact on vertical wheel load transfer, but a minimal impact on lateral forces as measured at the wheel/rail interface.

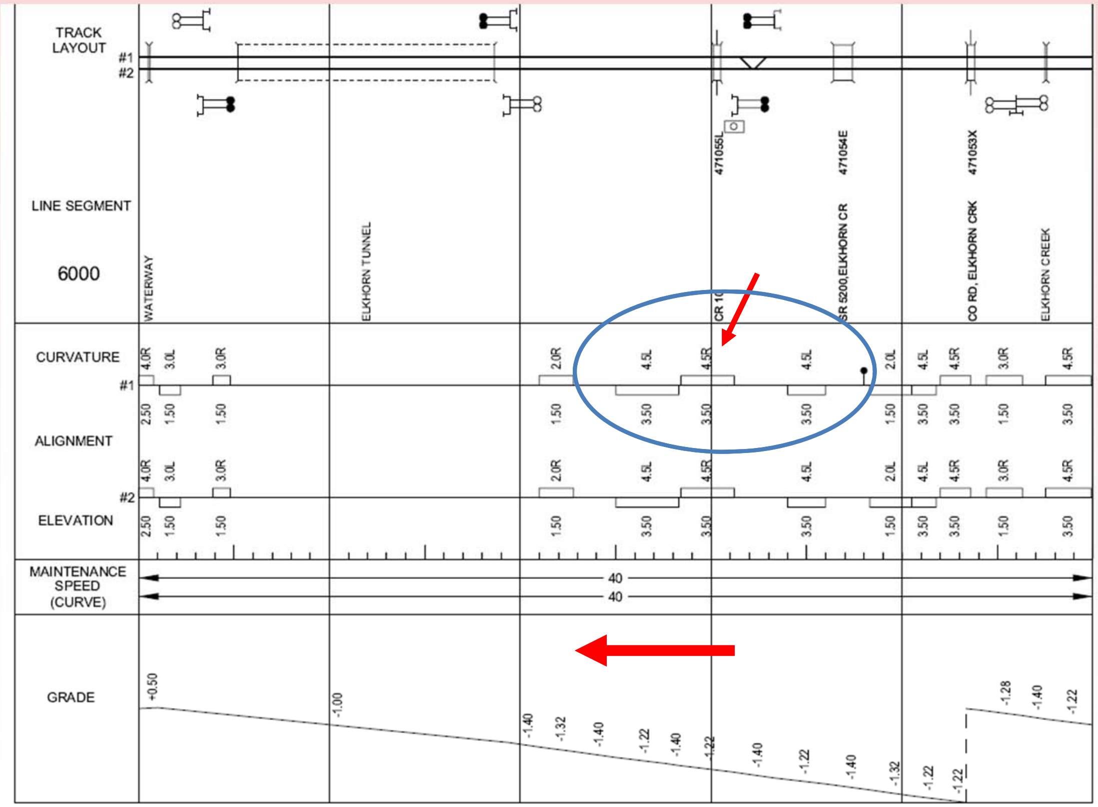
Recommendation

Add a phase 2 to the test:

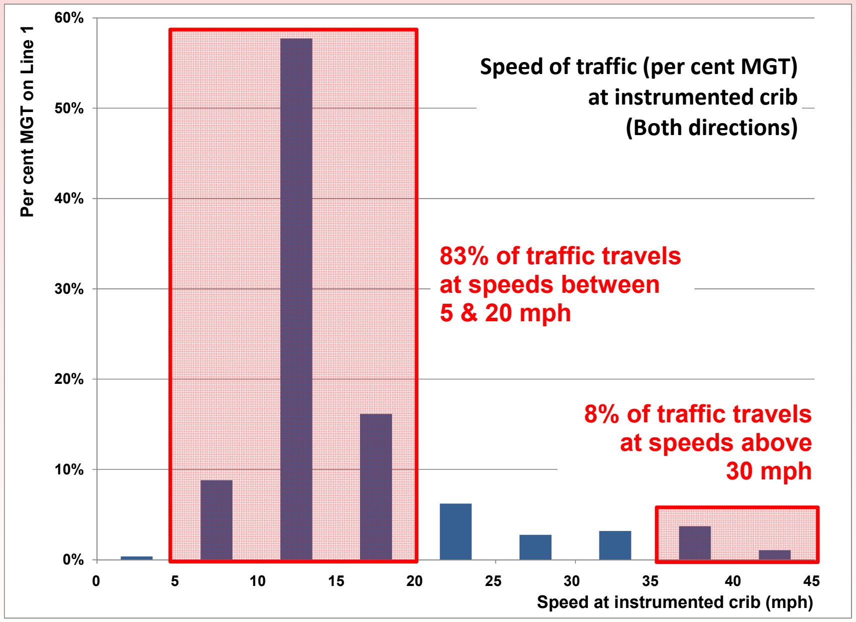
- Reduce the elevation of the the test curve and the two adjacent curves to 1” (minimum curve elevation on NS is 1”).
- Repeat the data collection to measure changes in speed and lateral & vertical forces.

Following Phase 1, we asked this question: Can we reduce elevation to see how vehicle dynamics change?

Objective: Convince Pocahontas Division Transportation to reduce speed on 1.1-miles of track from 40 mph to 30 mph, and ask Engineering to reduce elevation from 3-1/2” to 1”



How did we justify our request?



Speed of traffic as a function of MGT, all trains, both directions,

Tournay, Harry, et al: <u>The Effect of Track Cant on Vehicle Curving : In-service Test Results Part III of III</u>, TD14-015 , Transportation Technology Center, July 2014

1. Advancement of our knowledge of train dynamics; in other words, research!
2. Only a small number of trains would be adversely affected by a 10 mph speed reduction

Speed and track changes for Phase 2

- Transportation agreed to reduce speed from 40 mph to 30 mph through the three 4.5˚ curves.
- Engineering was able to reduce elevation with a minimum of trackwork – elevation could be reduced on an inside track without concern for clearance because of wide track centers; and sufficient ballast was available on the shoulders.

Track 1 – elevation 1”

Track 2 – elevation 3-1/2”

In Phase 2, what trains and data did we evaluate?

The same type trains:

- 100 – 110 loaded cars (unit trains)
- 4 locomotives – 2 pulling & 2 pushing
- Operation - still in notch 8

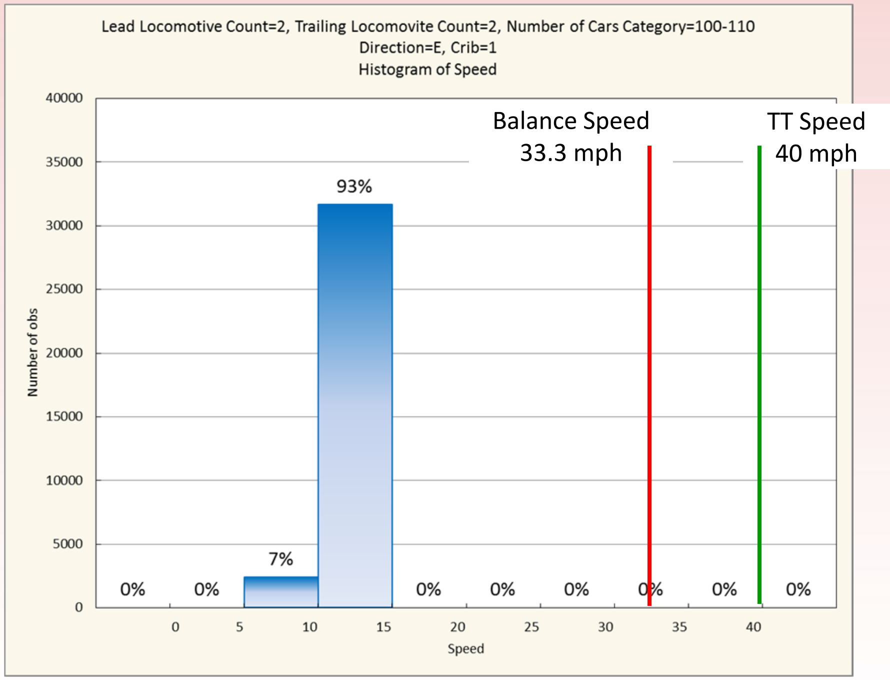
The same data:

- For each axle: speed and vertical & lateral forces
- Date range Aug 27 – Oct 10, 2015
- 85 trains

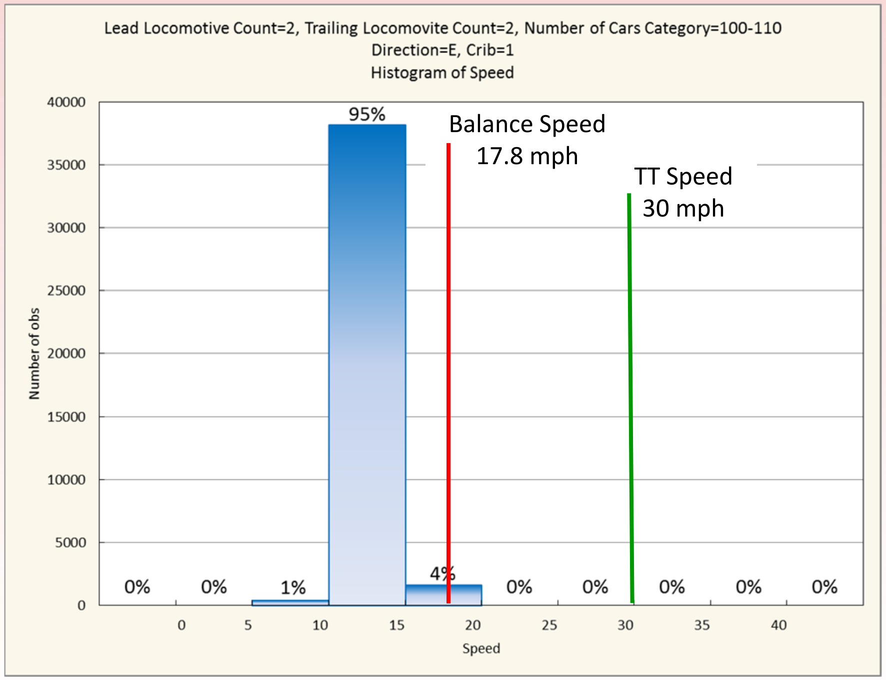
Data analysis

- Train speed
- Vertical wheel load differential
- L/V ratios, high and low rails
- Gage-spread force

Train speed distribution, Phases 1 & 2

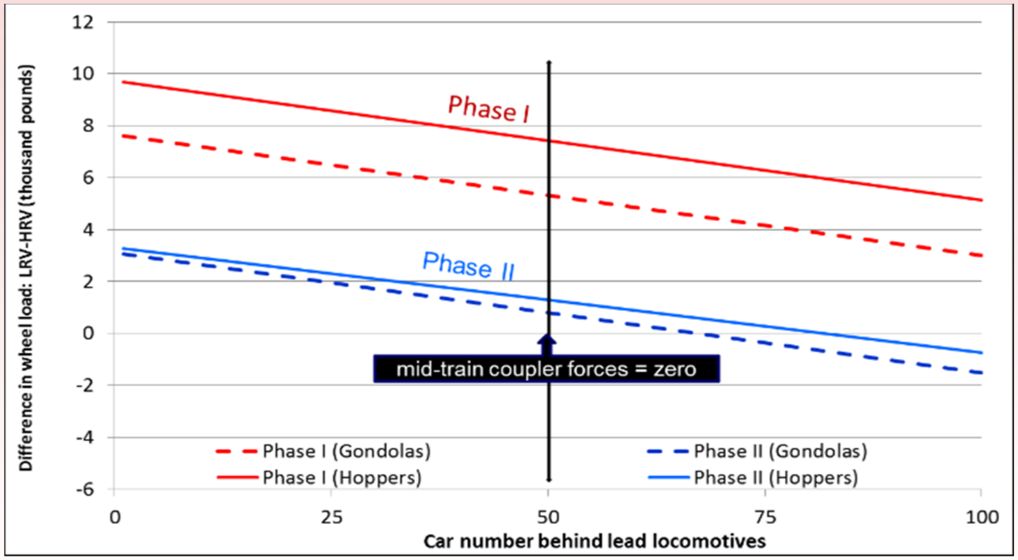


Phase 1 - Axle speed distribution of target trains (eastbound, 100-110 car and 2 + 2 locomotives)



Phase 2 - Axle speed distribution of target trains (eastbound, 100-110 car and 2 + 2 locomotives)

Vertical wheel load differentials (lead axles of lead trucks) vs. position in train, Phases 1 & 2

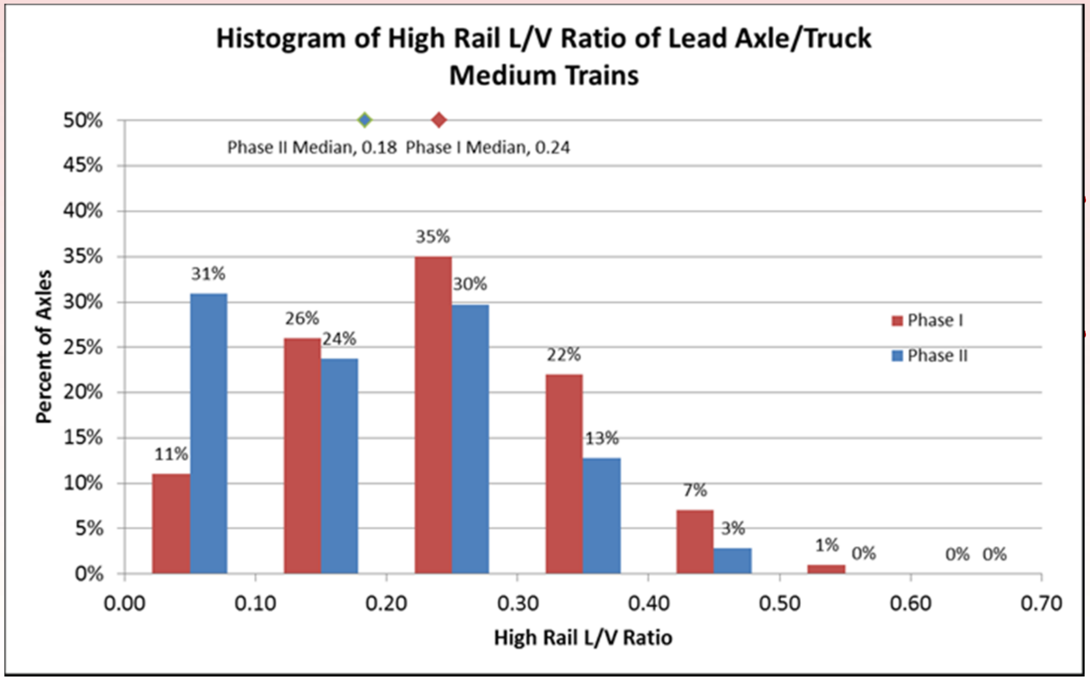


Regression Lines of Wheel Load Differentials Across Lead Axles vs. Position in Train for Multiple Gondola and Hopper Trains.

		Load Transfer Across Lead Wheelset (x1000 pounds)		
		Lead Car	Mid Train Car	Trail Car
Gondolas	Phase I	7.61	5.33	3.01
	Phase II	3.07	0.80	-1.51
Hoppers	Phase I	9.68	7.43	5.13
	Phase II	3.27	1.29	-0.73

Table: Load transfer (in kips) across lead axles for gondolas and hoppers at three locations in train (lead, middle & trail car). The difference between gondola and hopper values is due to a different CG.

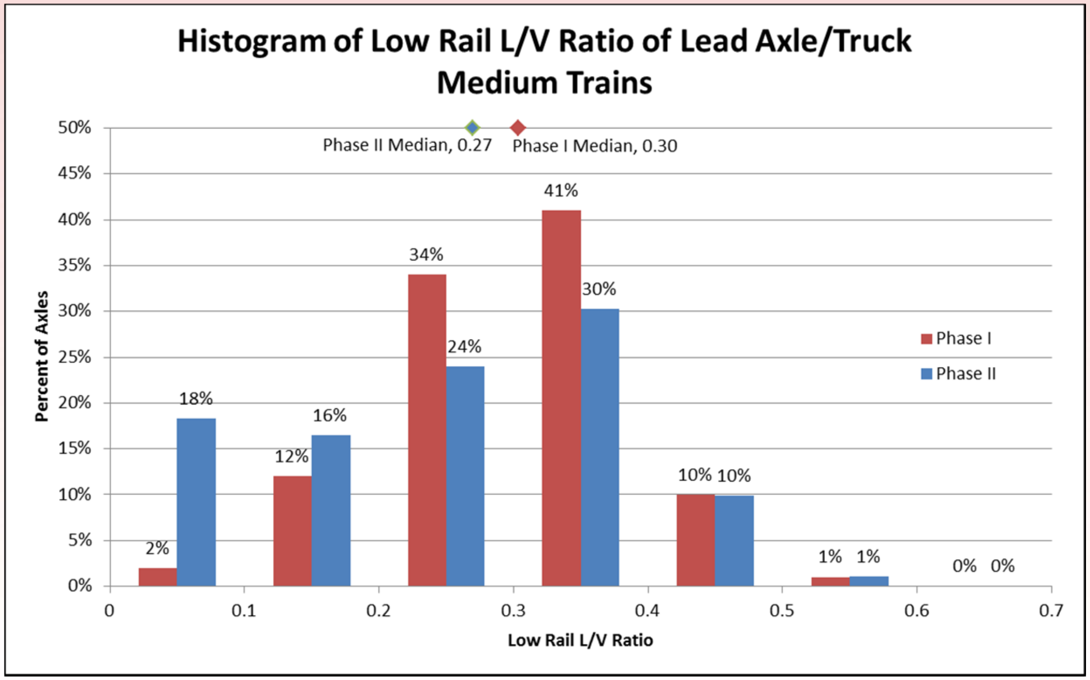
High rail L/V ratio (lead axles of lead trucks), Phases 1 & 2



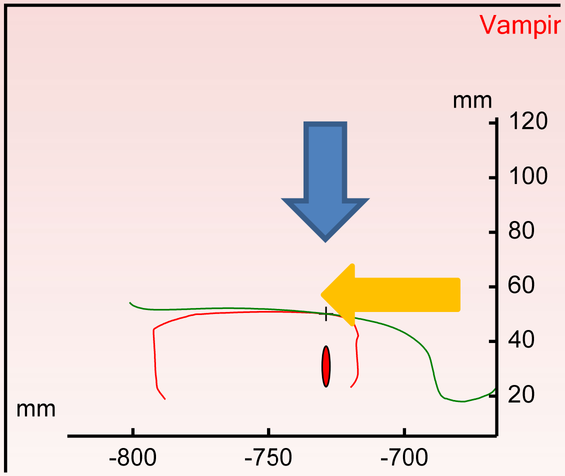
- High rail L/V ratios decreased from Phase 1 to Phase 2.
- Primary reason: The “V” in L/V increased, due to less wheel load transfer from the high rail.

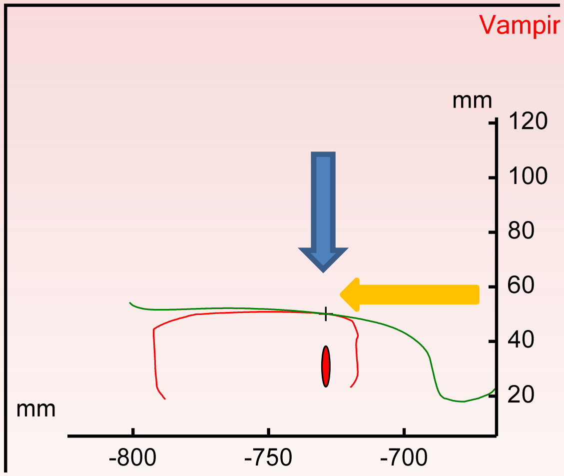
Low rail L/V ratio (lead axles of lead trucks), Phases 1 & 2

- If high rail L/V decreased because of an increase in “V,” can we expect that low rail L/V would increase because of a corresponding decrease in “V”?
- In fact, low rail L/V ratios actually decreased from Phase 1 to Phase 2!



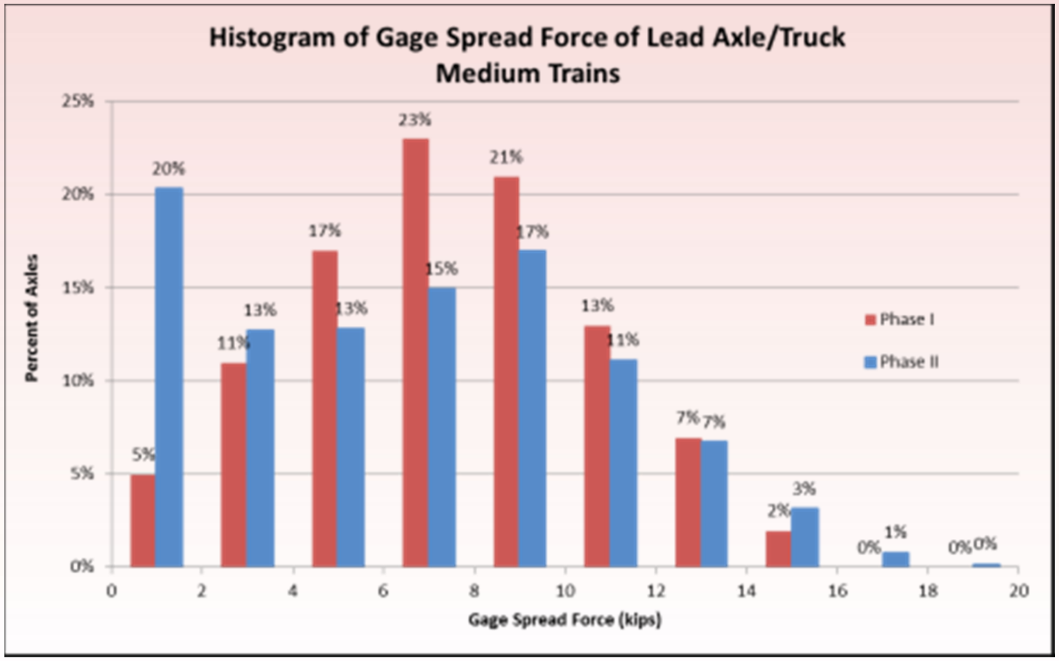
Why did low rail L/V ratios decrease?



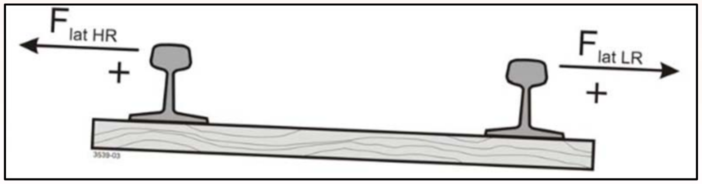


Lateral force on the low rail is generated by friction between wheel tread and rail. Maximum lateral force occurs when the friction is saturated - when F = N x µ. By reducing N (due to load transfer), maximum lateral (friction) force is also reduced.

Gage-spread force (lead axles of lead trucks), Phases 1 & 2



- Gage-spread force is the smaller of high and low rail lateral forces
- Reducing the elevation reduced gage-spread forces – note a reduction in the 4 – 12 kip bins and a 15 percentage-point increase in the 0 – 2 kip bin.



Conclusions

When operating closer to balance speed, lead axles demonstrated:

- Smaller vertical wheel load differentials between high and low rails
- Reduced high rail L/V ratios
- Slightly reduced low rail L/V ratios
- Reduced gage-spreading forces
- No measurable change in speed

For the lowest stress and the least maintenance,

- Consider the full spectrum of train speeds
- Identify the dominate tonnage trains
- Try to balance the speed or elevation for those heavy trains

Acknowledgements – who gets the credit for this project?

- Strain gauge & data collection equipment – Instrumentation Services & Kevin Conn (NS)
- Project originator and data analysis – Harry Tournay (TTCI)
- Additional data analysis & graphs – Chris Pinney, Russ Walker, Ryan Alishio, Sabri Cakdi & Kenny Morrison (TTCI)
- Changes to train speed and track elevation – NS's Pocahontas Division

Questions & Discussion