HEAVY HAUL SEMINAR

JUNE 10-12, 2025

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L/V ratios – what do they mean?

Yi Wang, Stephen Wilk

MxV Rail

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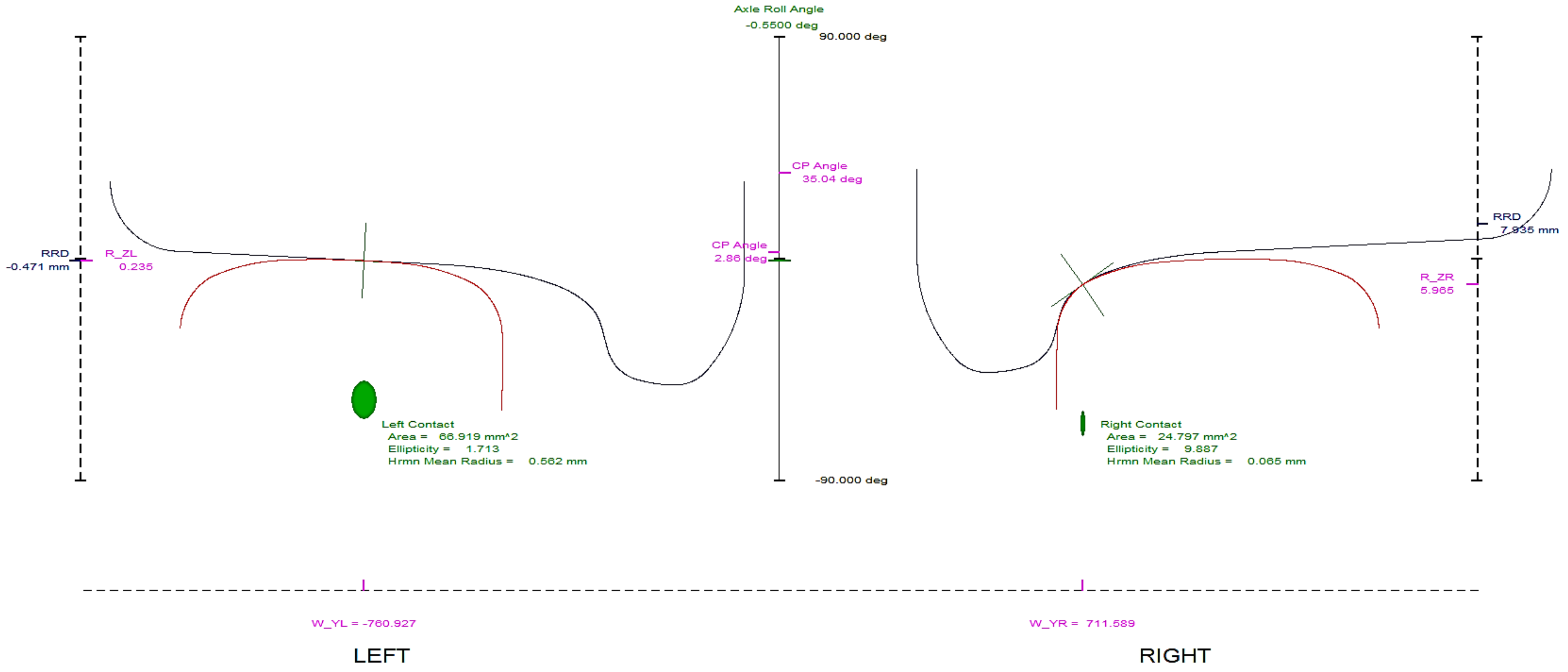
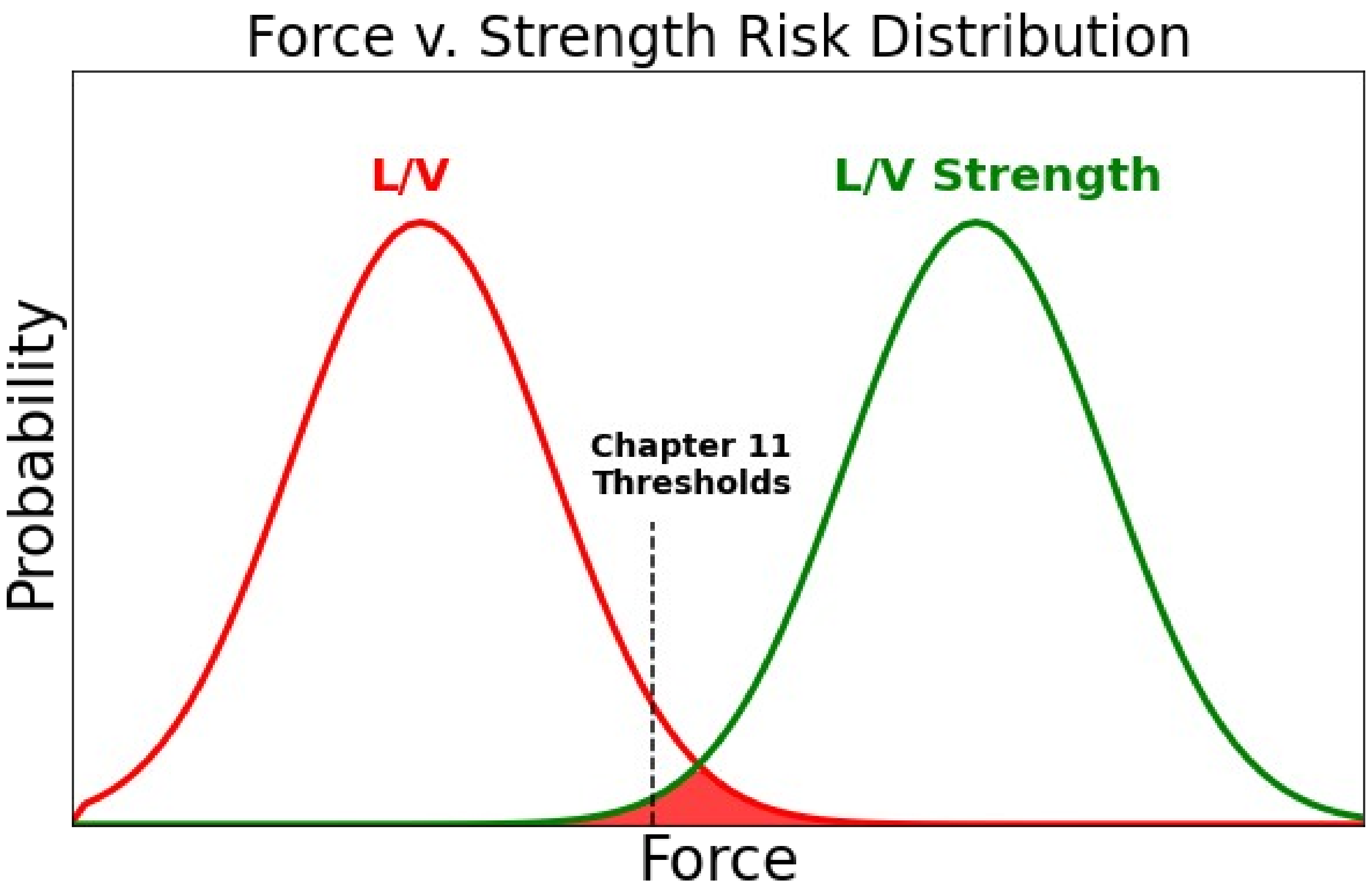
Motivation and goal





- L/V, aka Y/Q, derailment quotient, etc. – seemingly omnipresent
- Fundamental to wheel/rail interaction and railway safety
- Risk depends on both vehicle track interaction and track strength
- Often talked about in the vehicle track interaction community – are we speaking the same language and considering vehicle and track as a system?

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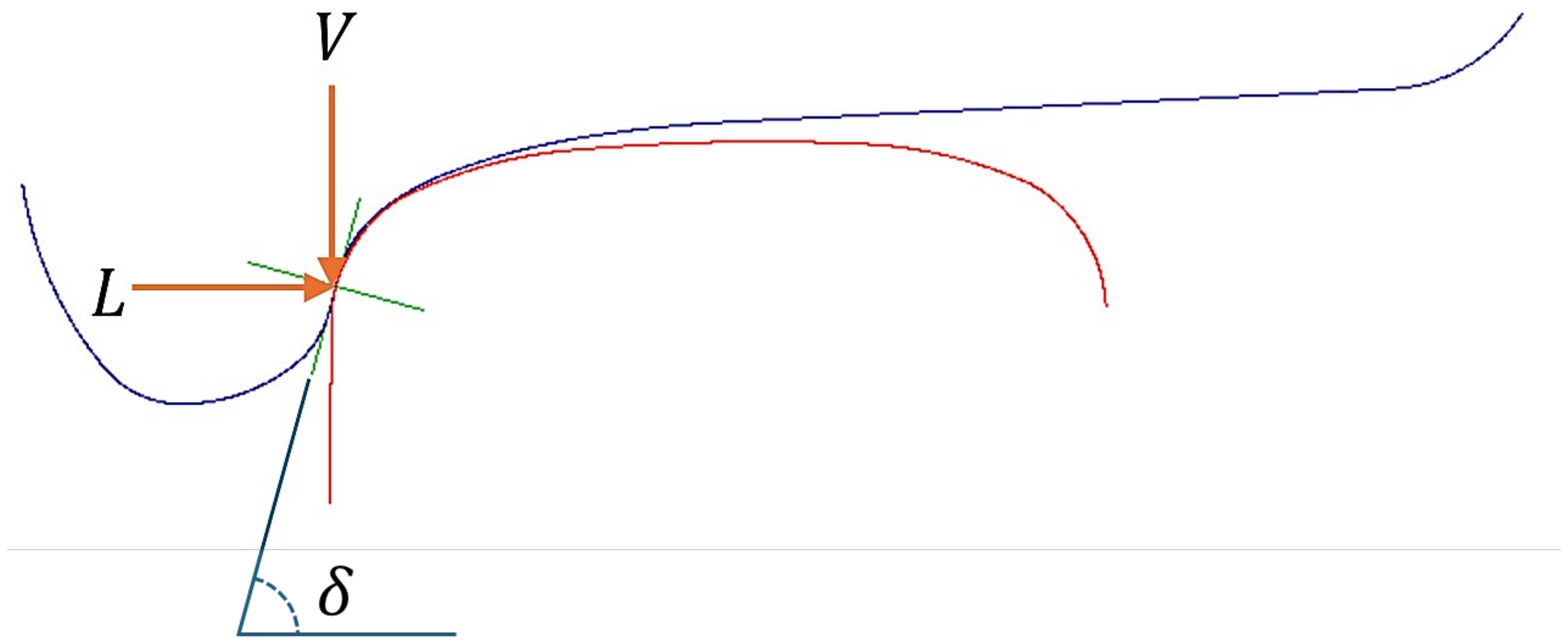
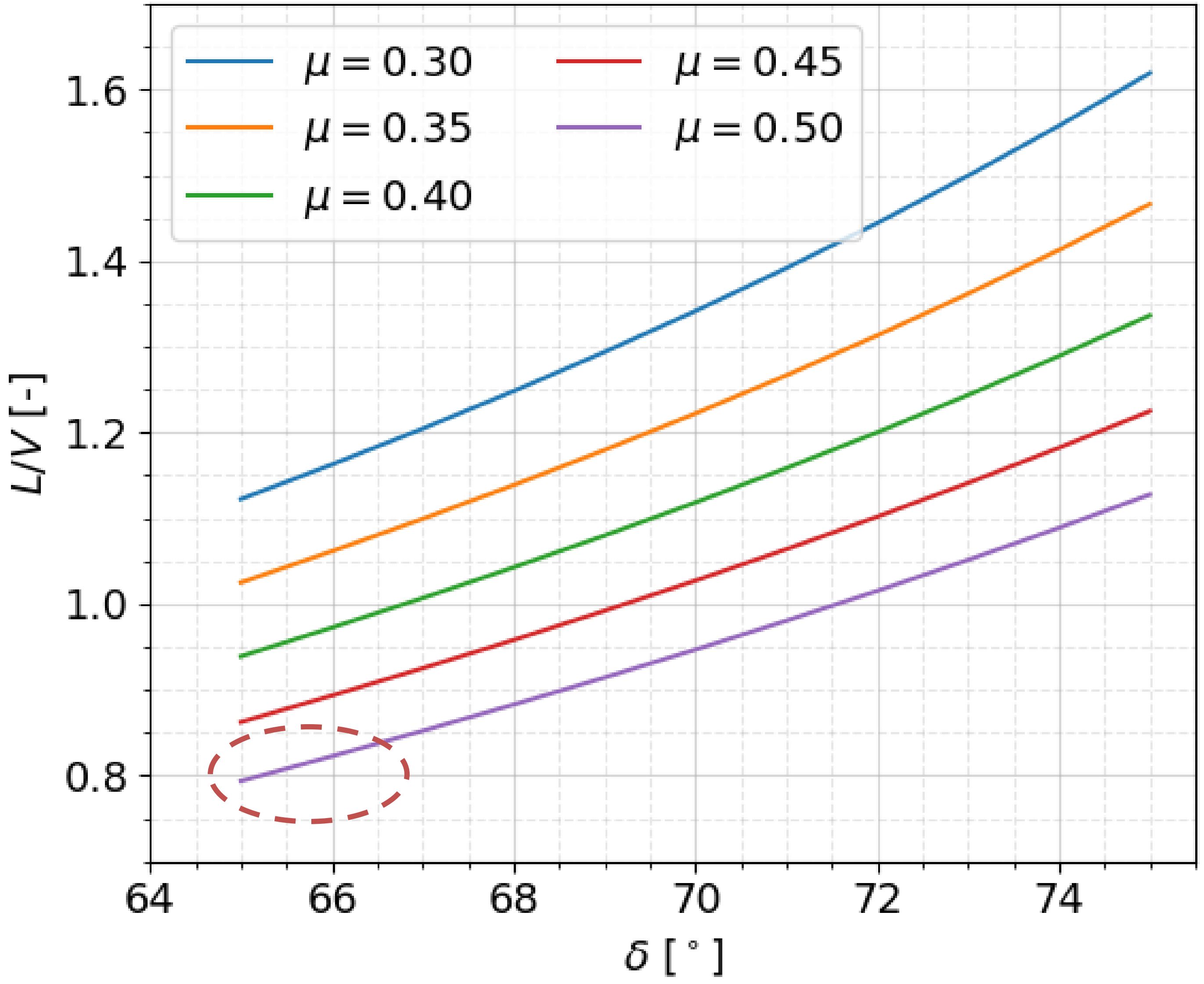
The classic case

Flange climb L/V criteria start with Nadal (Nadal, 1908)



$$\frac{L}{V} < \frac{\tan\delta - \mu}{1 + \mu\tan\delta}$$



- The number 0.82 is often referenced
- Why 0.82?

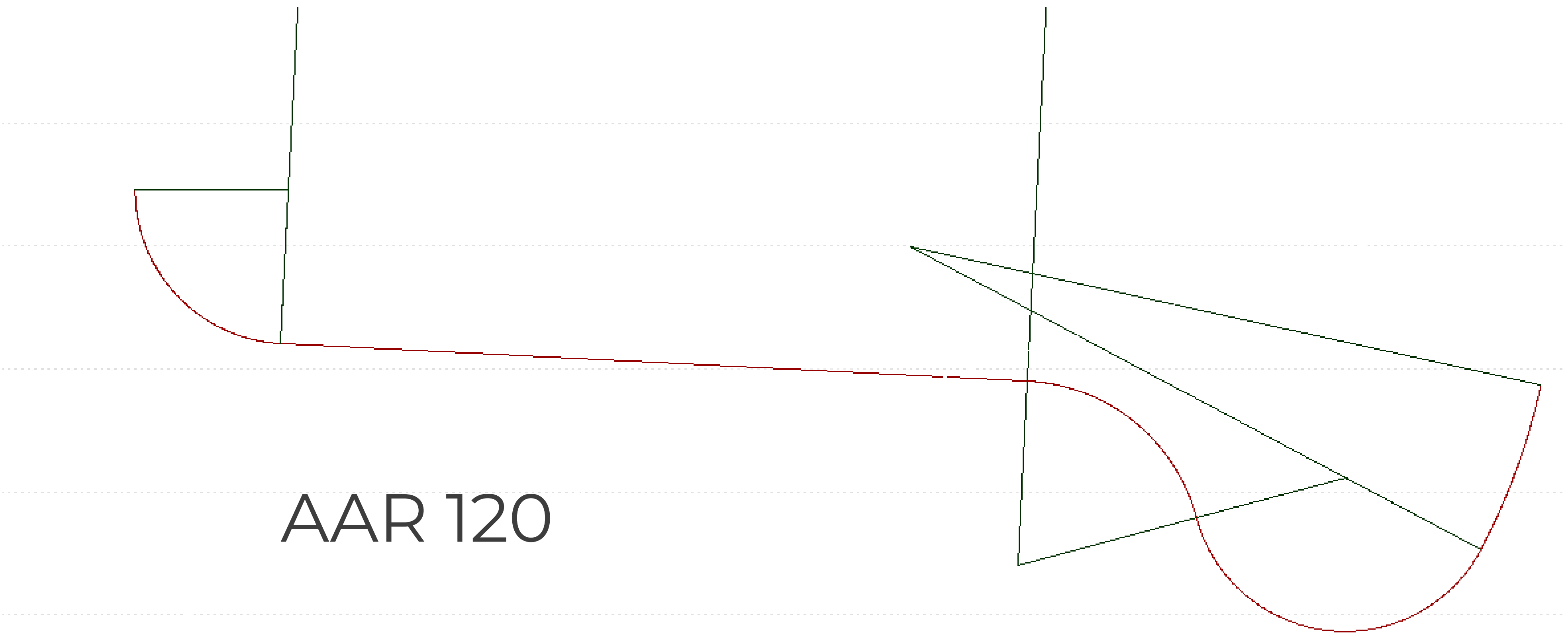
0.82

For the Nadal limit to be 0.82, we need:

- A wheel whose flange angle is less than 68°
- A coefficient of friction of 0.5 or greater

How seriously should we take 0.82 today?

Guess the wheel profile (no prizes)



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Nadal limit

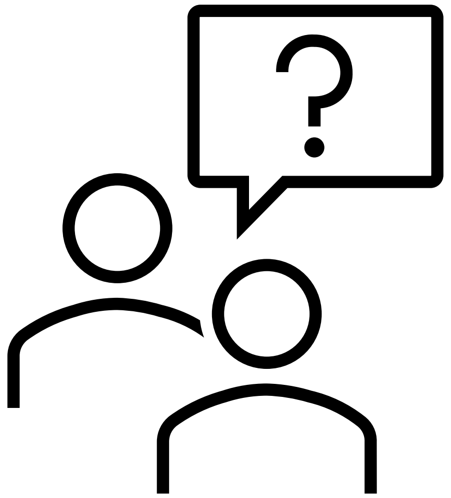
Considers two variables:

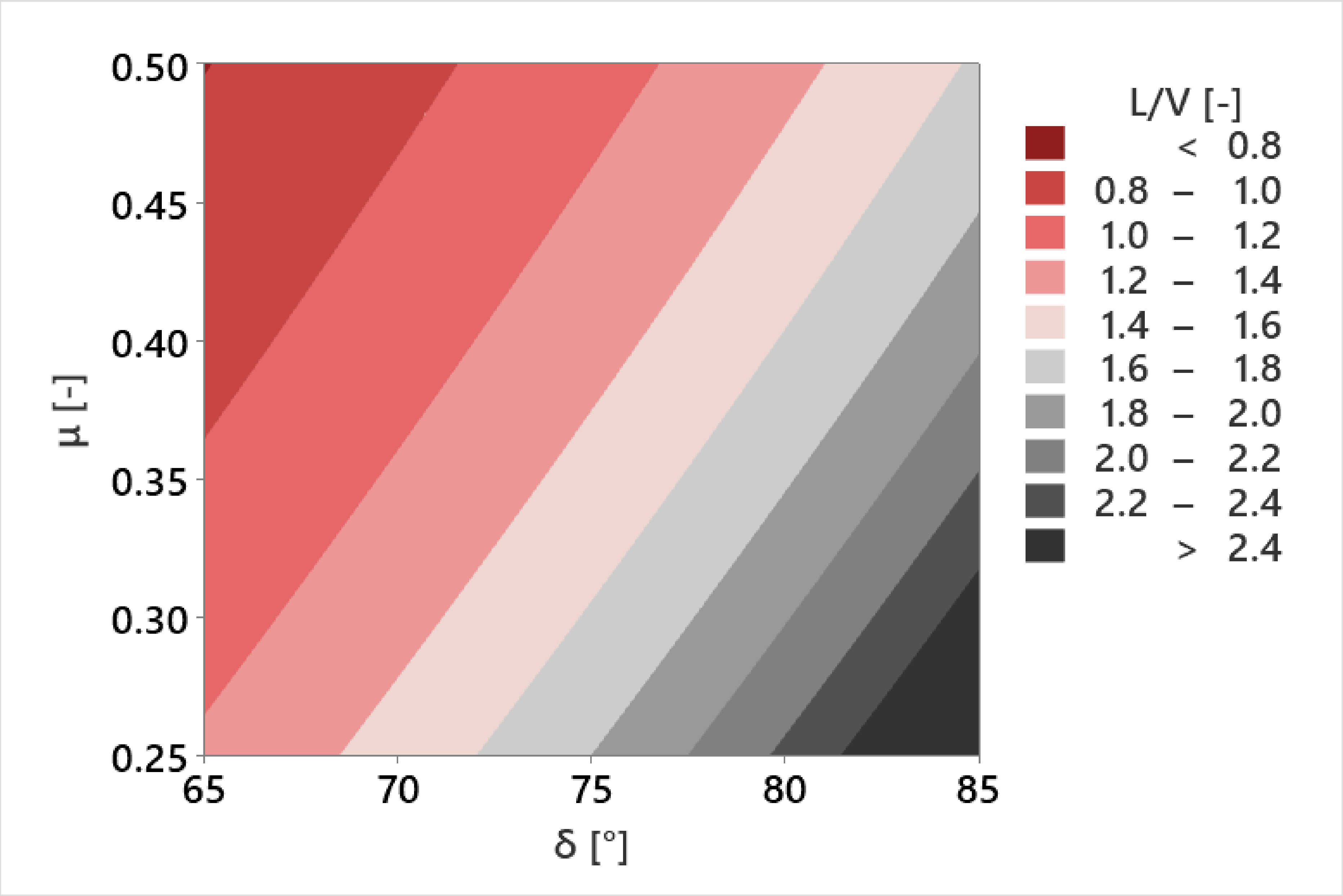
- Coefficient of friction (μ)
- Contact angle (δ)

$$\frac{L}{V} < \frac{\tan\delta - \mu}{1 + \mu\tan\delta}$$

Question: does μ or δ stay constant?

- For the same train?
- During the same run?
- At the same location?





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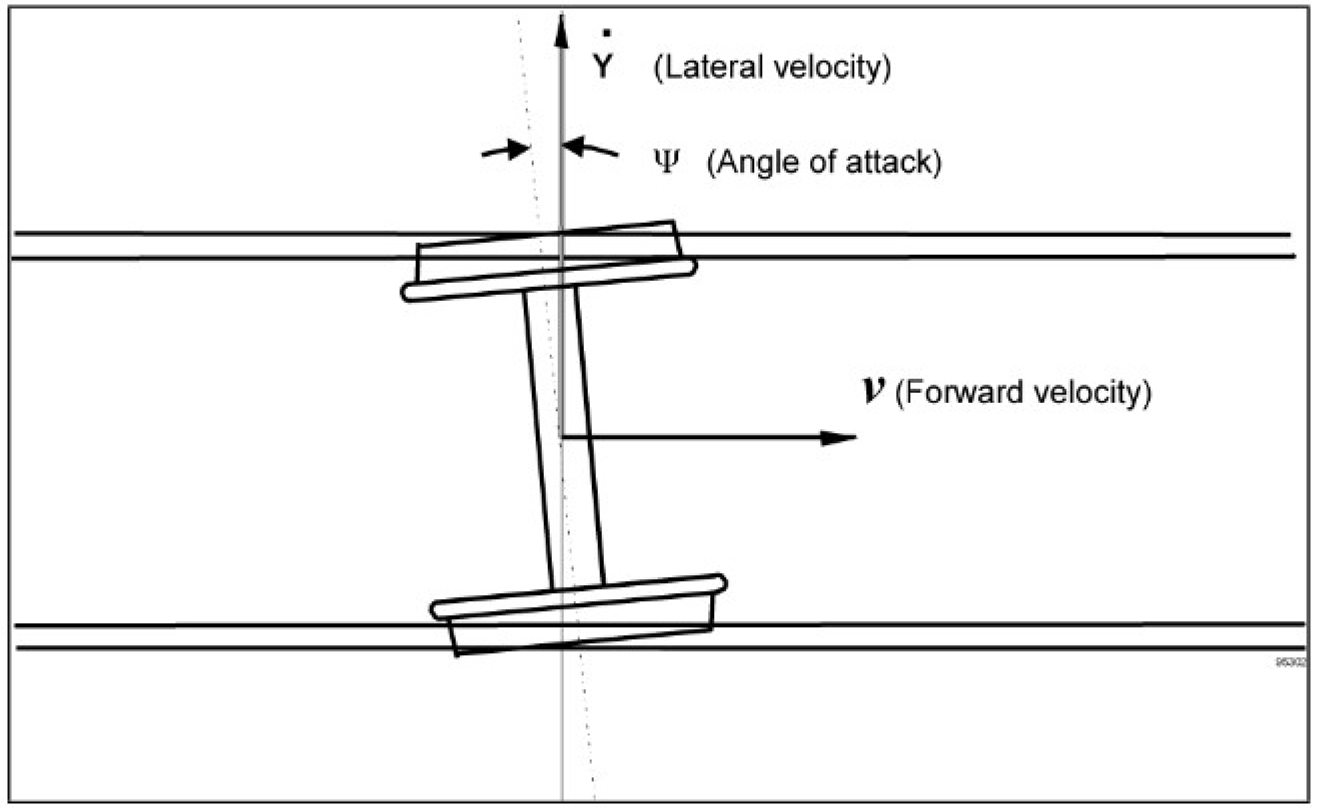
Weinstock

$$\left|\frac{L_F}{V_F}\right| + \left|\frac{L_{NF}}{V_{NF}}\right| < \frac{\tan\delta_F - \mu_F}{1 + \mu_F \tan\delta_F} + \mu_{NF}$$



- Nadal is correct for high angle of attack (AoA) and low longitudinal creep
- Nadal is "quite conservative" for lower angle of attack and larger longitudinal creep

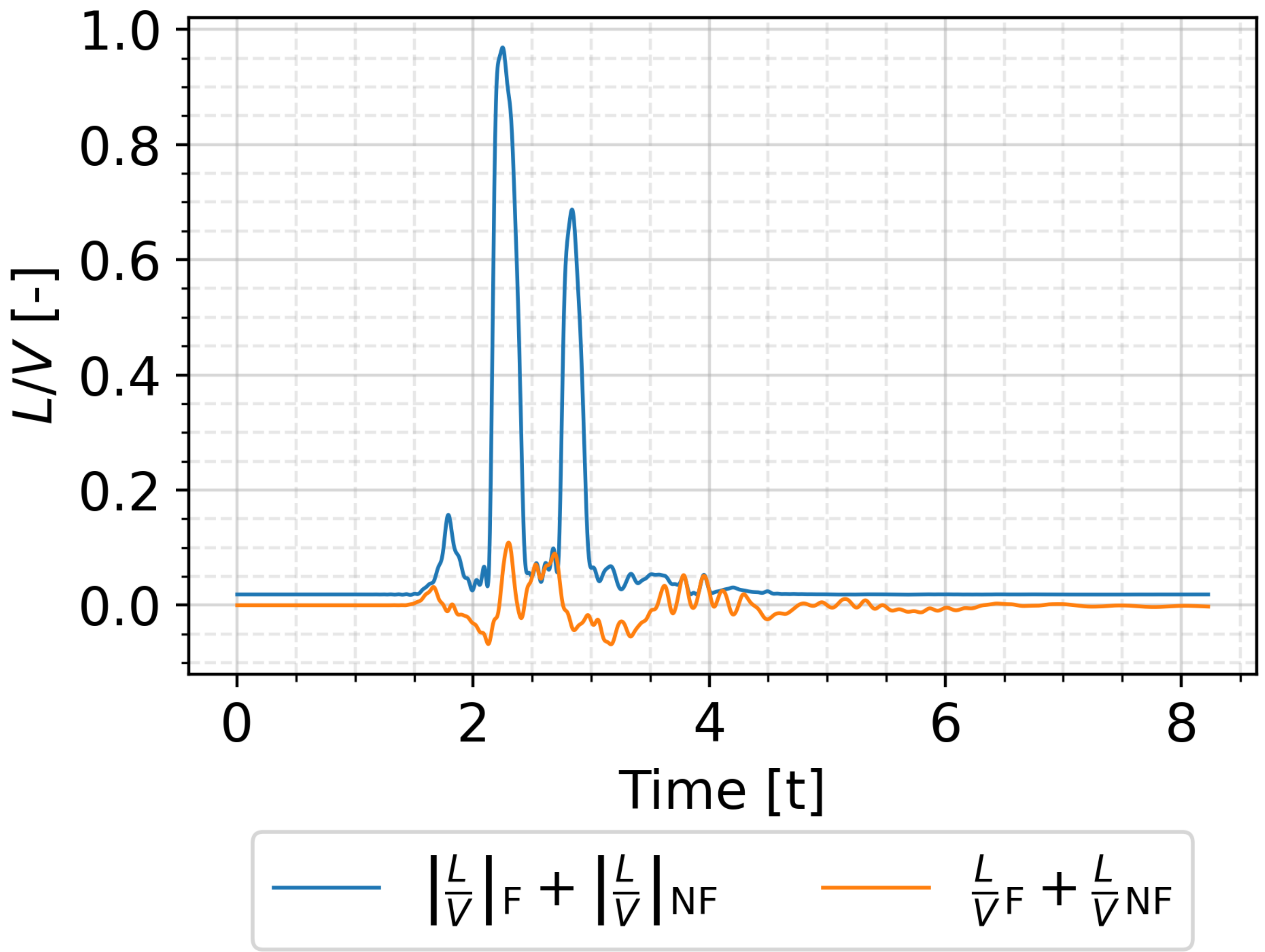
Derailment will not occur if any of the following is true (Weinstock, 1984):

- All wheels below Nadal
- $V_F < V_{LF}$ and $\left|\frac{L_F}{V_F}\right| + \left|\frac{L_{NF}}{V_{NF}}\right| < \frac{\tan\delta_F - \mu_F}{1+\mu_F \tan\delta_F} + \mu_{NF}$
- $\left|\frac{L_F}{V_F}\right| + \left|\frac{L_{NF}}{V_{NF}}\right| < 1.0$
- $\operatorname{sgn} L_F = \operatorname{sgn} L_{NF}$ and $\left|\frac{L_F}{V_F}\right| + \left|\frac{L_{NF}}{V_{NF}}\right| < \frac{\tan\delta_F - \mu_F}{1+\mu_F \tan\delta_F} + \mu_{NF}$

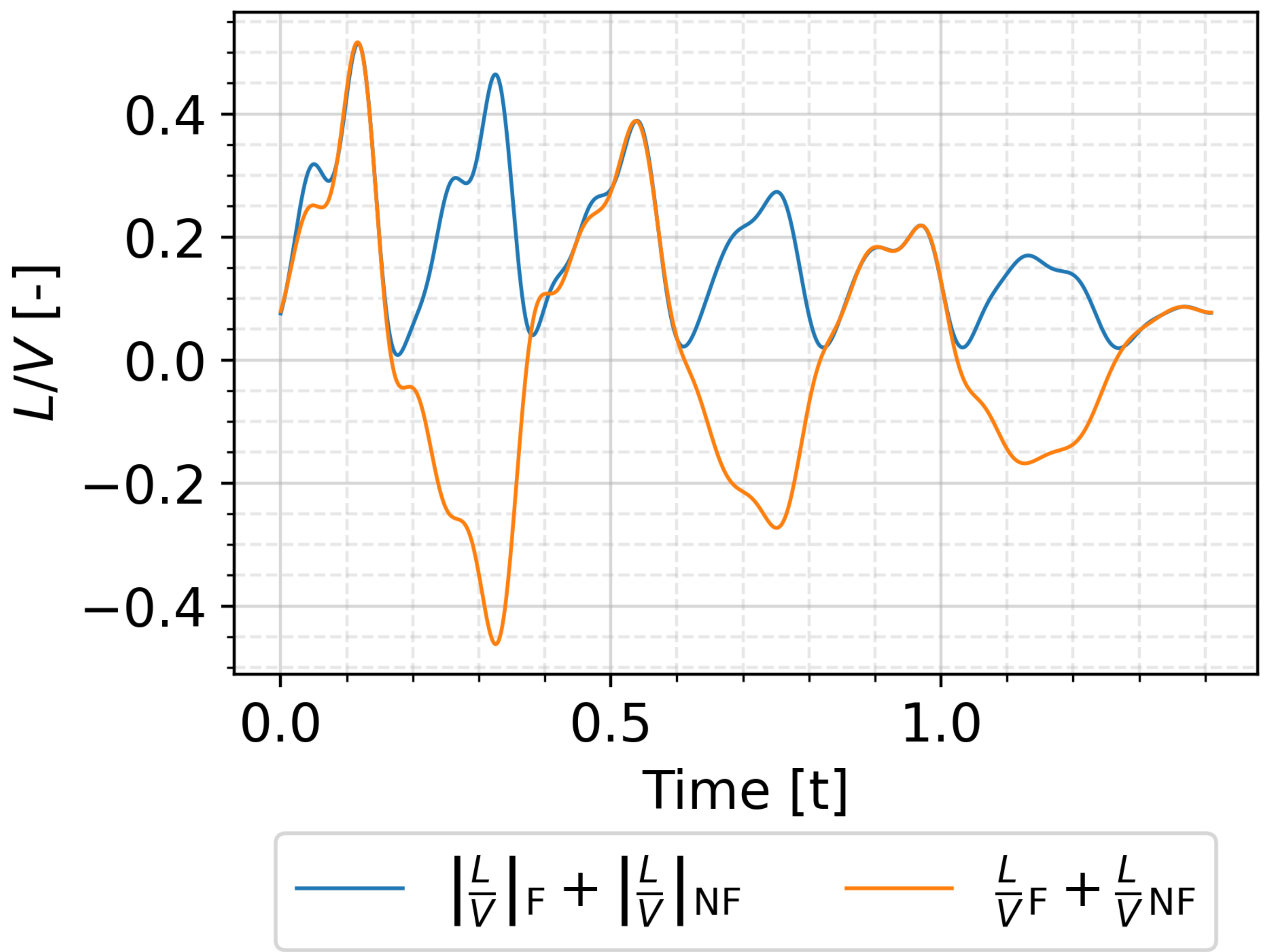
Weinstock example

Weinstock is useful and widely used in analysis, but one should always take a pause and think about what the axle sum L/V means.

Further analysis may not be needed:

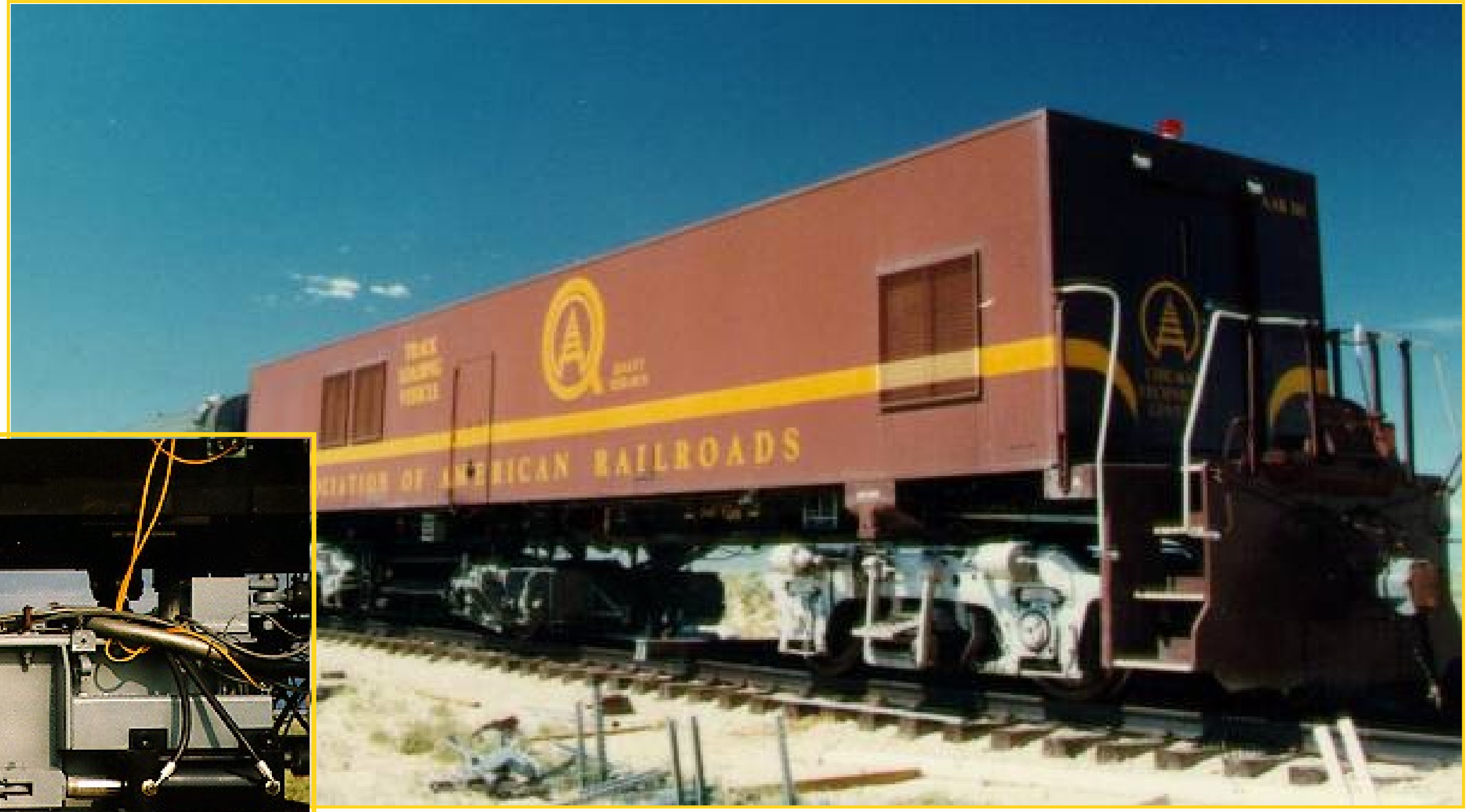


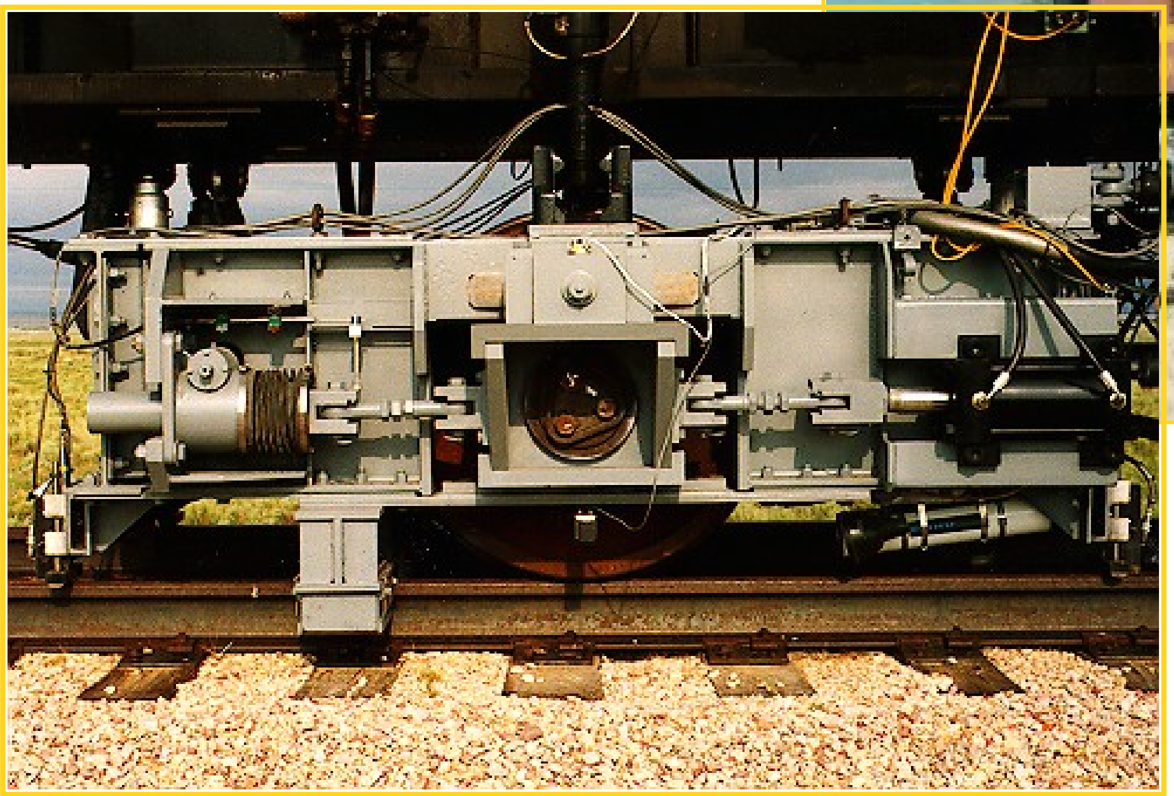
Further analysis most likely needed:



Other factors

- L/V by itself can be insufficient in describing derailment risk
- For a wheel to climb, a positive AoA and sufficient time are also required
  - Verified in testing (Shust & Elkins, 1997)





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Further development

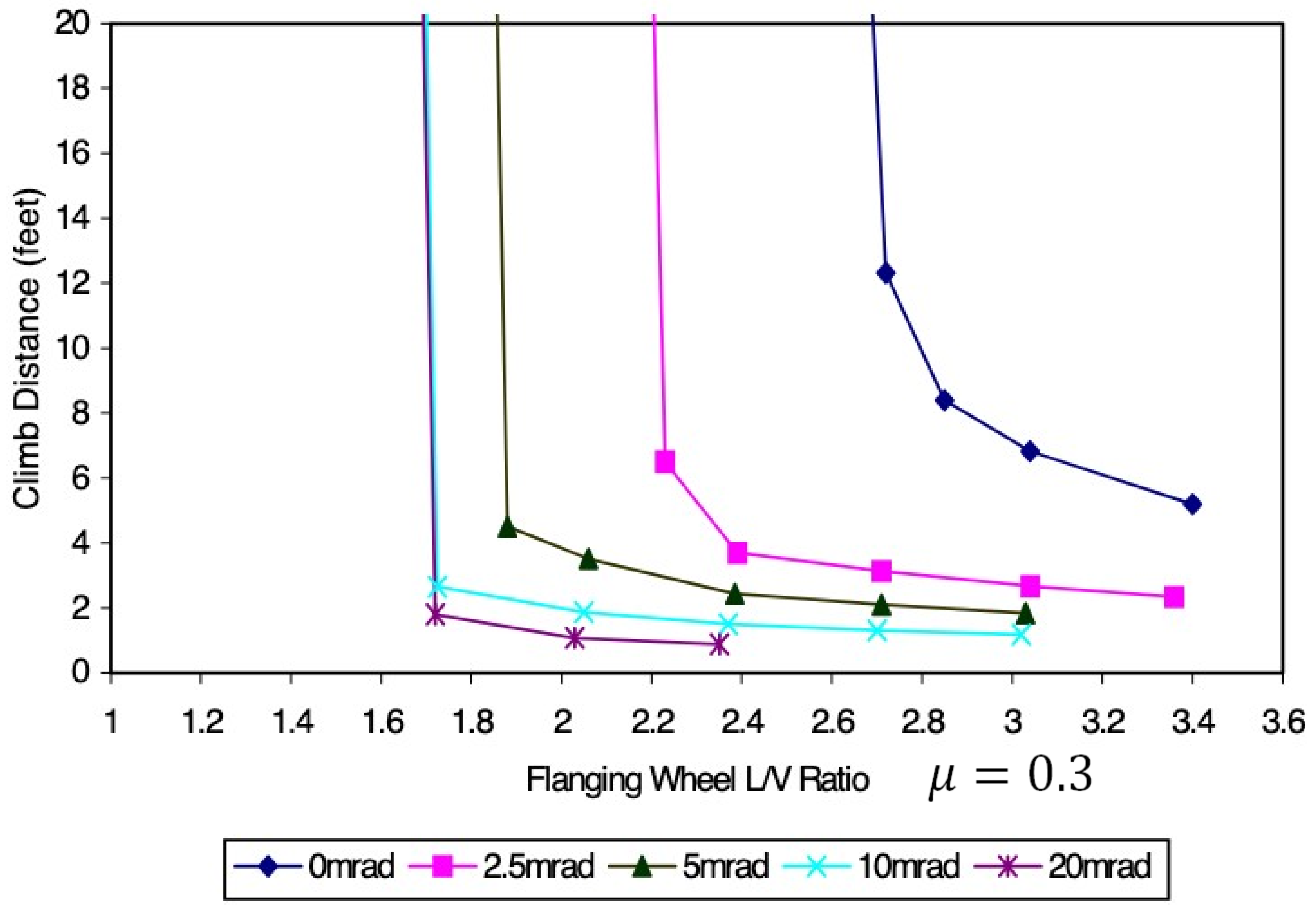
Other often cited criteria:

- Time duration based, i.e., JNR, EMD
- Distance based, i.e., 49 CFR 213.333
- Time or distance based, i.e., Chapter 11, AAR M-1001

Tests have shown that these can be exceeded without causing flange climb derailment (Wu & Elkins, 1999).

- Also need to look at angle of attack

$$20 \text{ mrad} = 1.15°$$

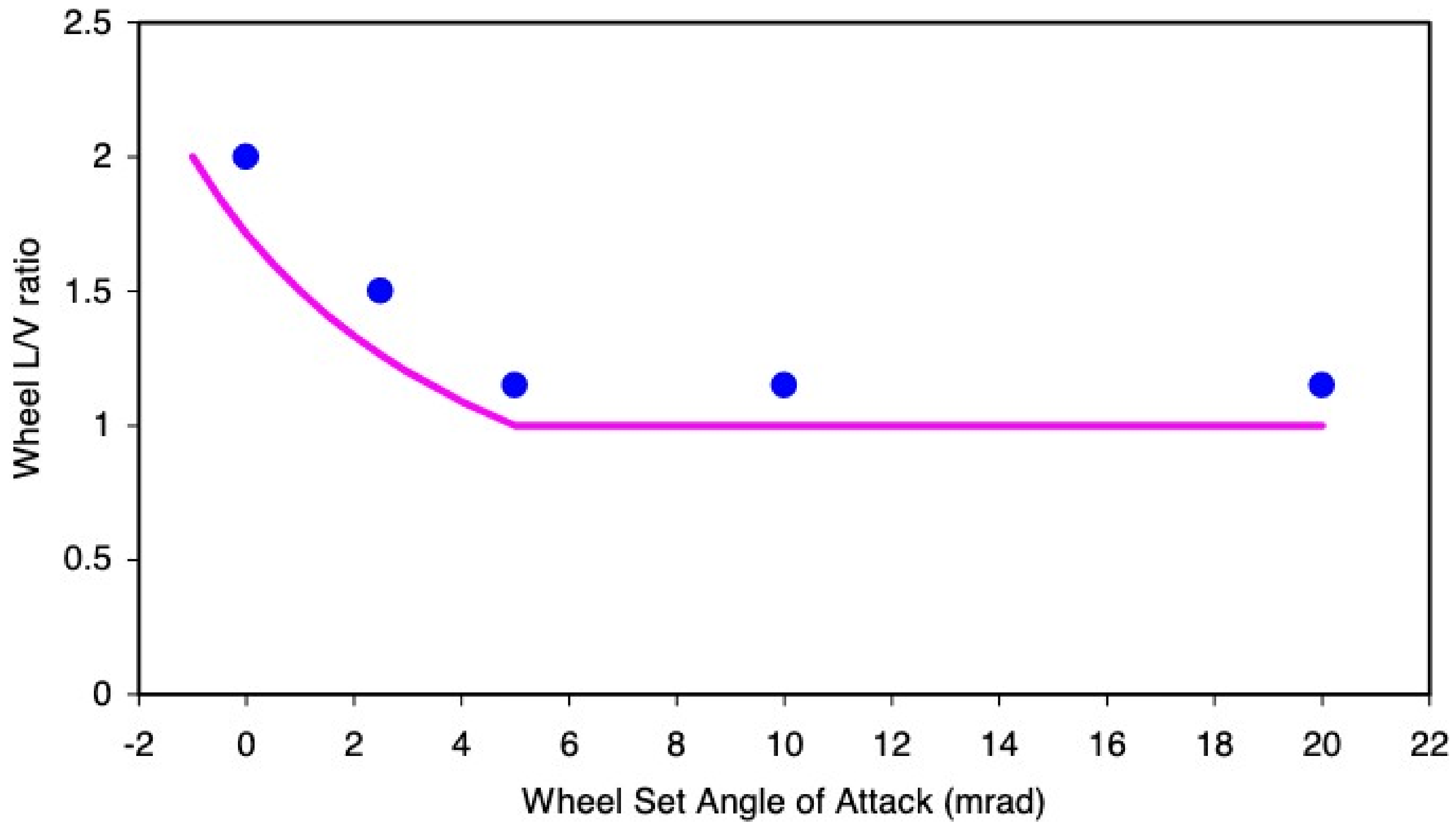


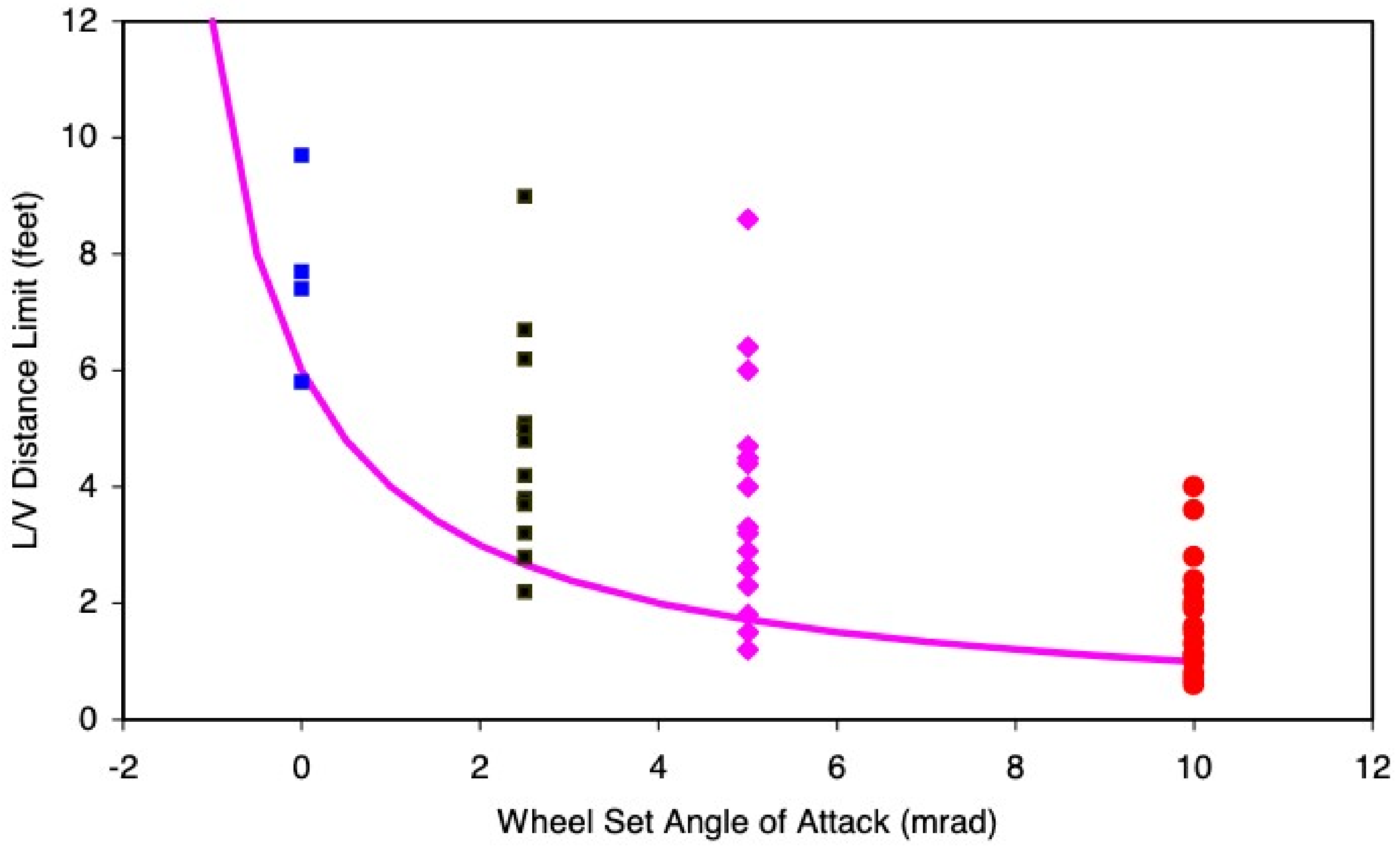
$\mu = 0.3$

Elkins/Wu criteria

Combined angle of attack (Ψ) and climb distance (d) derailment criteria (Wu & Elkins, 1999)

$$\frac{L}{V} < \begin{cases} 1.0, & \Psi < 0.5 \text{ mrad} \\ \dfrac{12}{\Psi + 7}, & \Psi \geq 0.5 \text{ mrad} \end{cases} \quad \text{and} \quad d < \begin{cases} \dfrac{12}{\Psi + 2}, & \Psi > -2 \text{ mrad} \\ \infty, & \Psi \leq -2 \text{ mrad} \end{cases}$$





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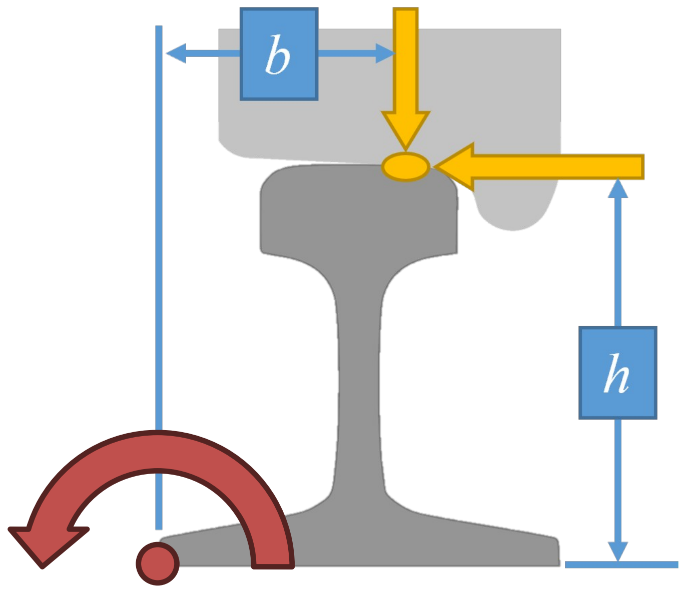
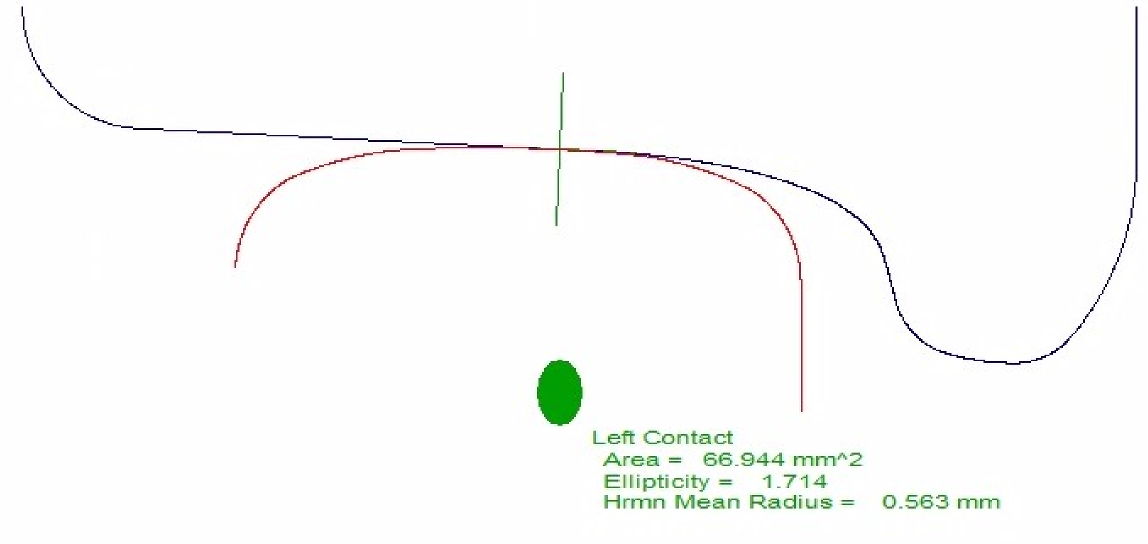
Rail rollover L/V

Often discussed L/V ratio that signifies the risk of rail rollover (Stetson, 1909)

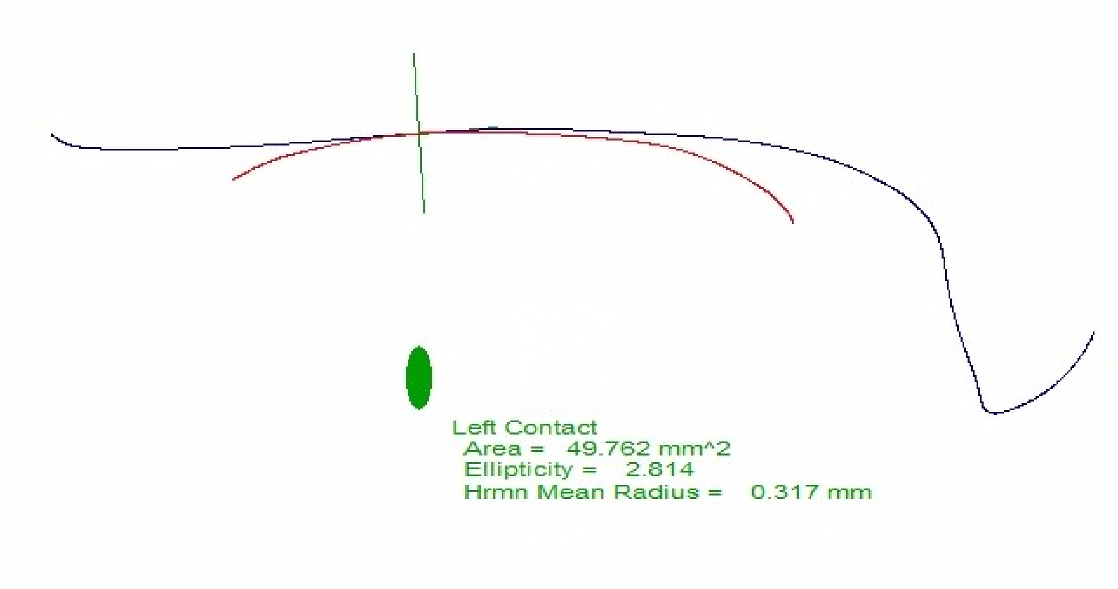


$$\left(\frac{L}{V}\right)_{\text{Truckside}} < \frac{b}{h}$$

Often emphasized example of rail rollover risk comparison



vs.



We will revisit this later in this presentation

Net axle or truck L/V

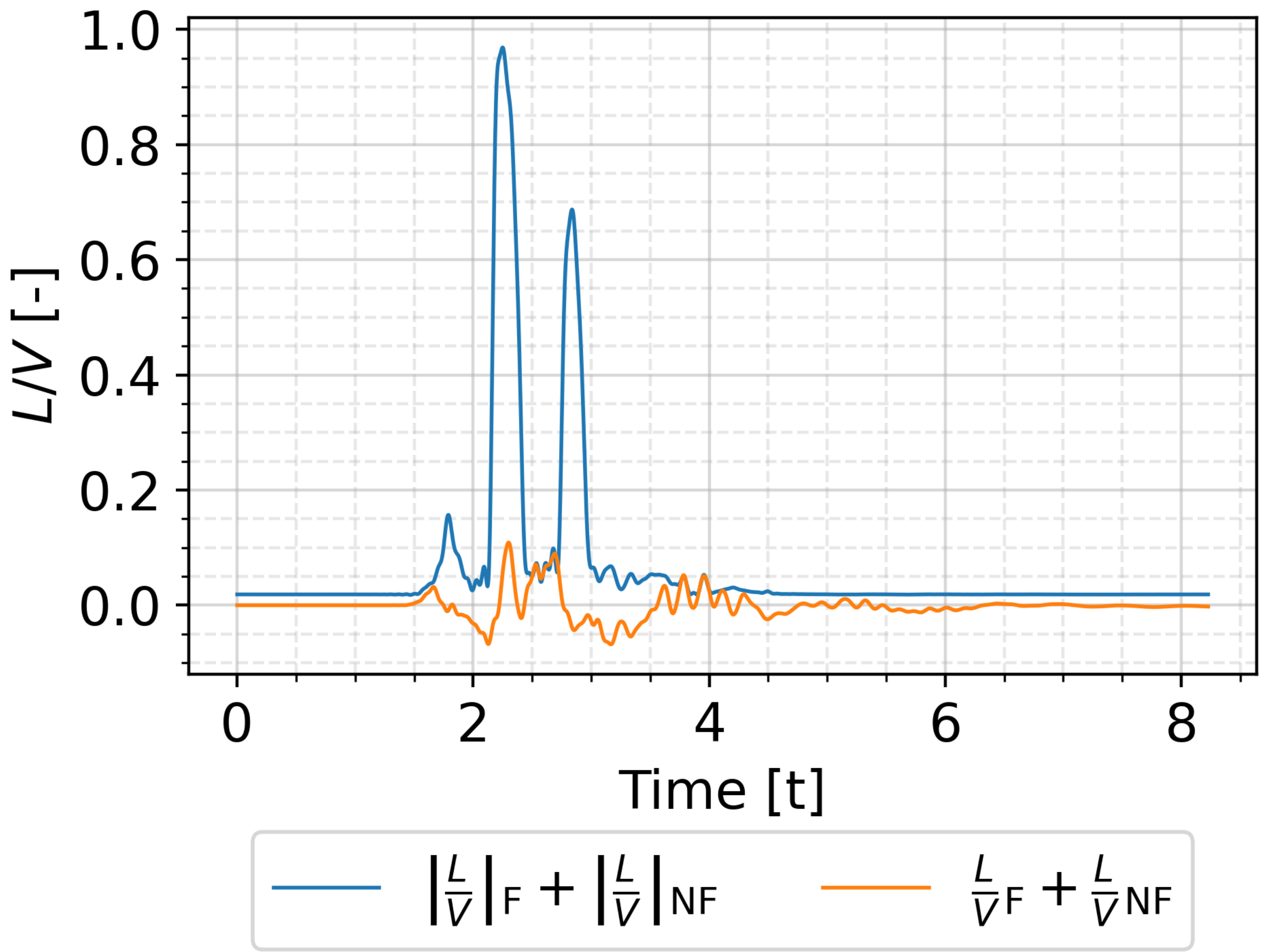
Sum of all wheel L/V on the axle or truck, i.e., gage spreading forces cancel each other out, however, there are times when it is the directional sum of the wheel lateral forces that matters more.

- The net lateral force could be high enough that in the right (wrong) conditions, the entire track panel shifts laterally
- Net axle or truck L/V is also a commonly used design value, e.g.,
  - Prud'homme
  - 49 CFR 213.333

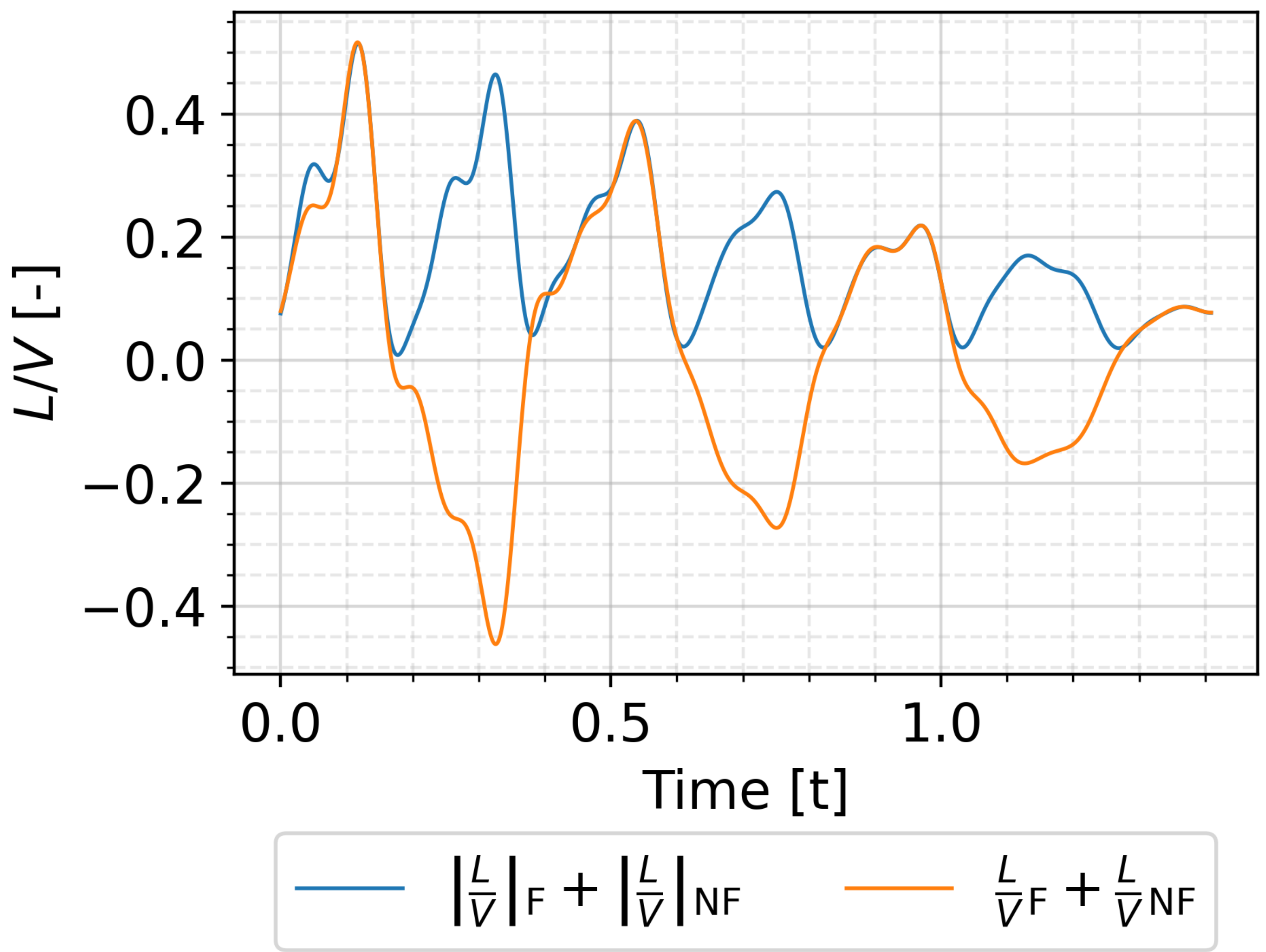
Example revisited

Although relatively low in axle sum L/V, the simulation on the right produces much higher net axle L/V than the simulation on the left.

Further analysis may not be needed:

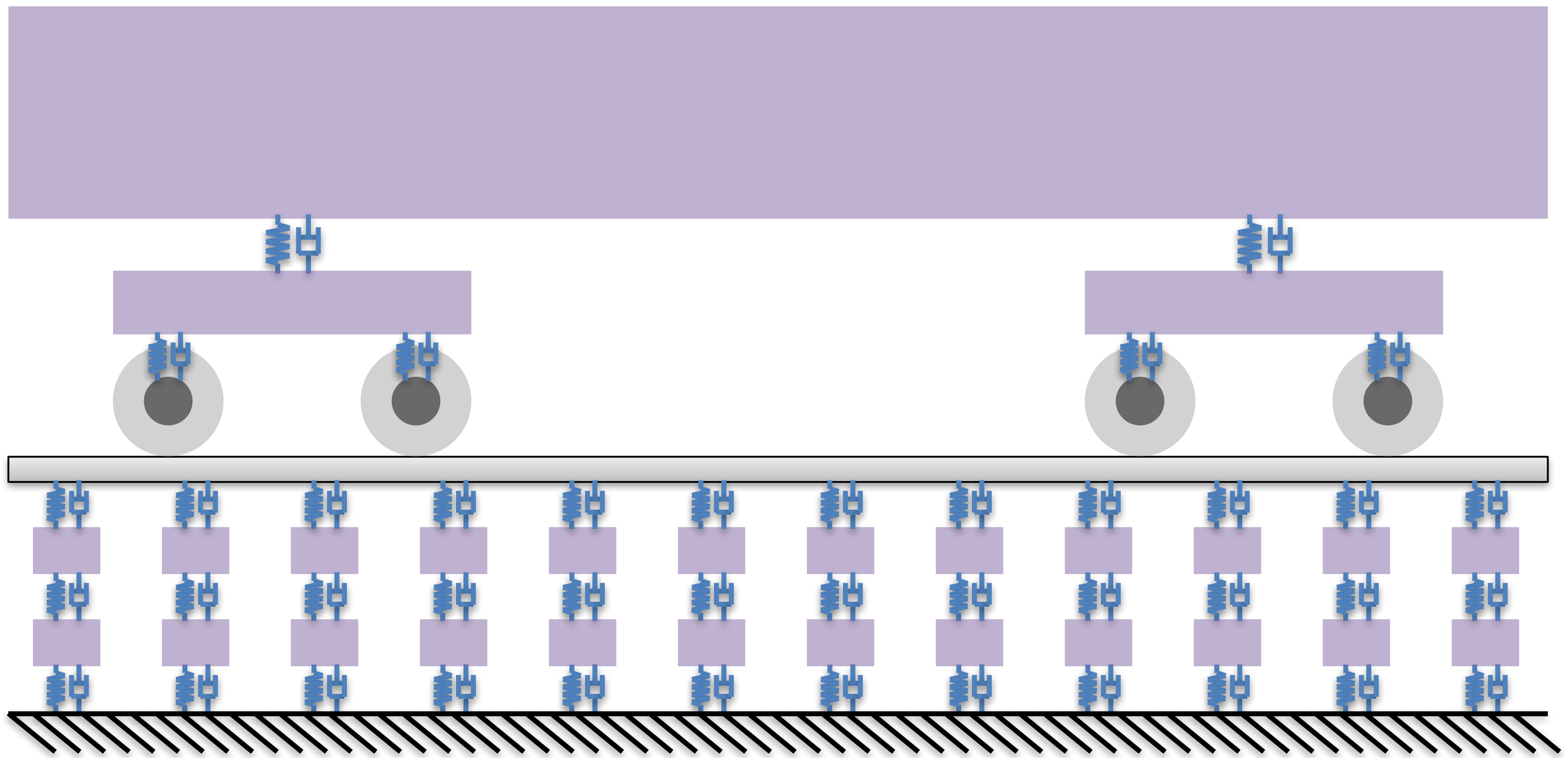


Further analysis most likely needed:



Vehicle-Track Interaction

- Criteria presented thus far focus on the static geometries of the wheel and rail profiles
- Track is not infinitely strong, displacements happen
  - Track displacement is not a binary



*Simplified diagram showing connections in one dimension – other dimensions also apply

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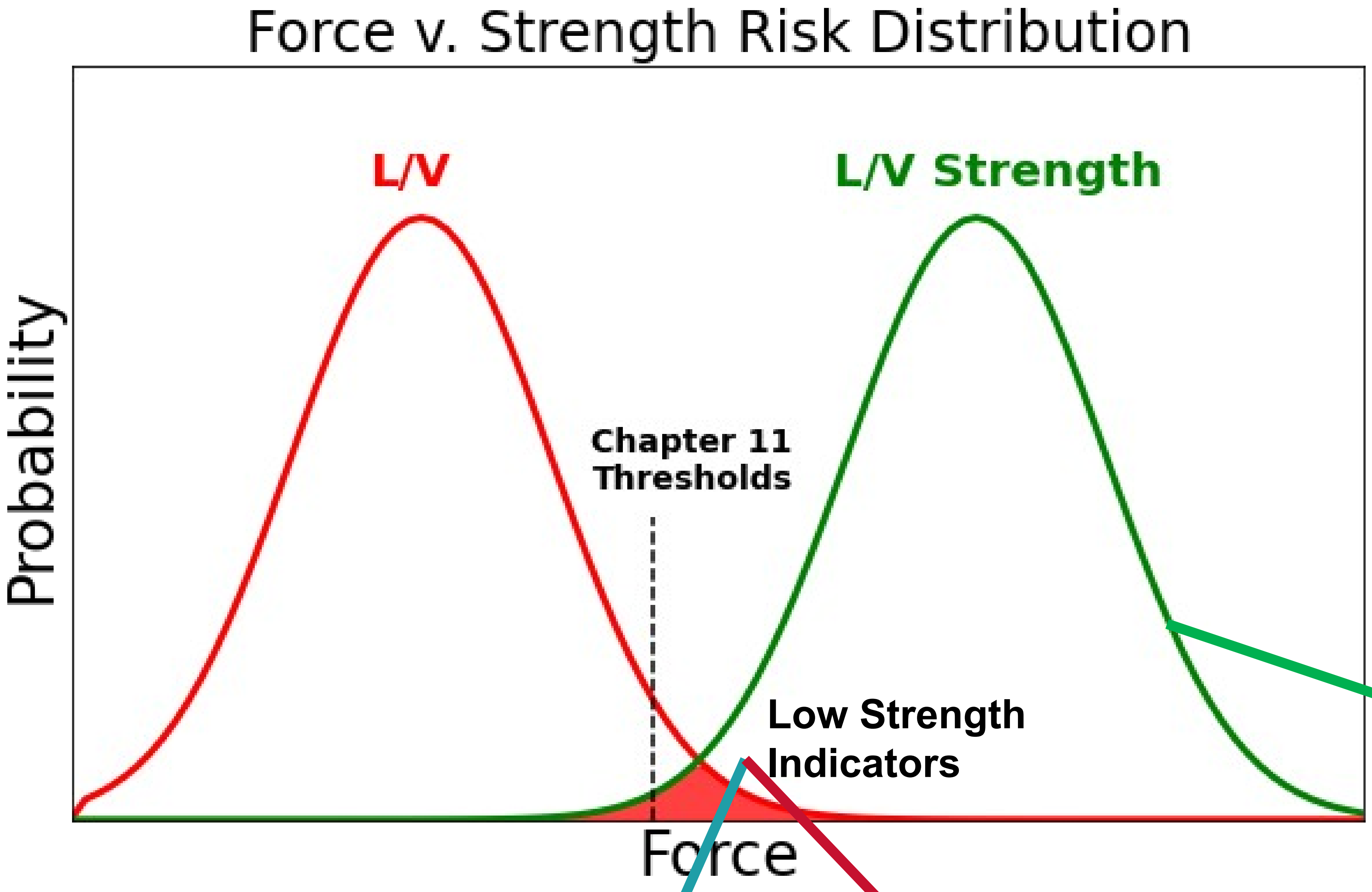
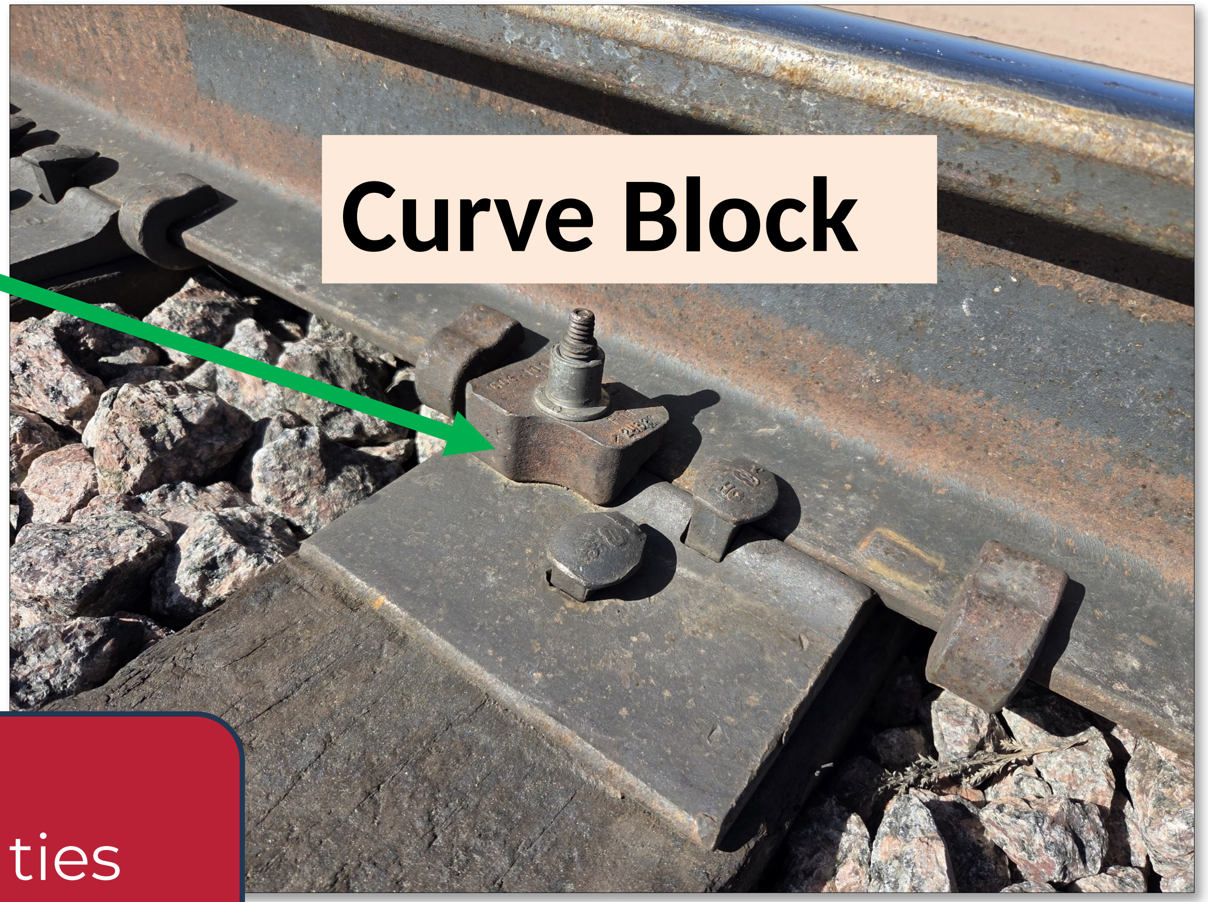
Rail Rollover / Gage Widening





Fastening System
- Plate Cutting / Rail Seat Abrasion
- Loose Spikes / Broken Fasteners

Ties
- Cracked concrete/composite ties
- Thermal bending of composite ties

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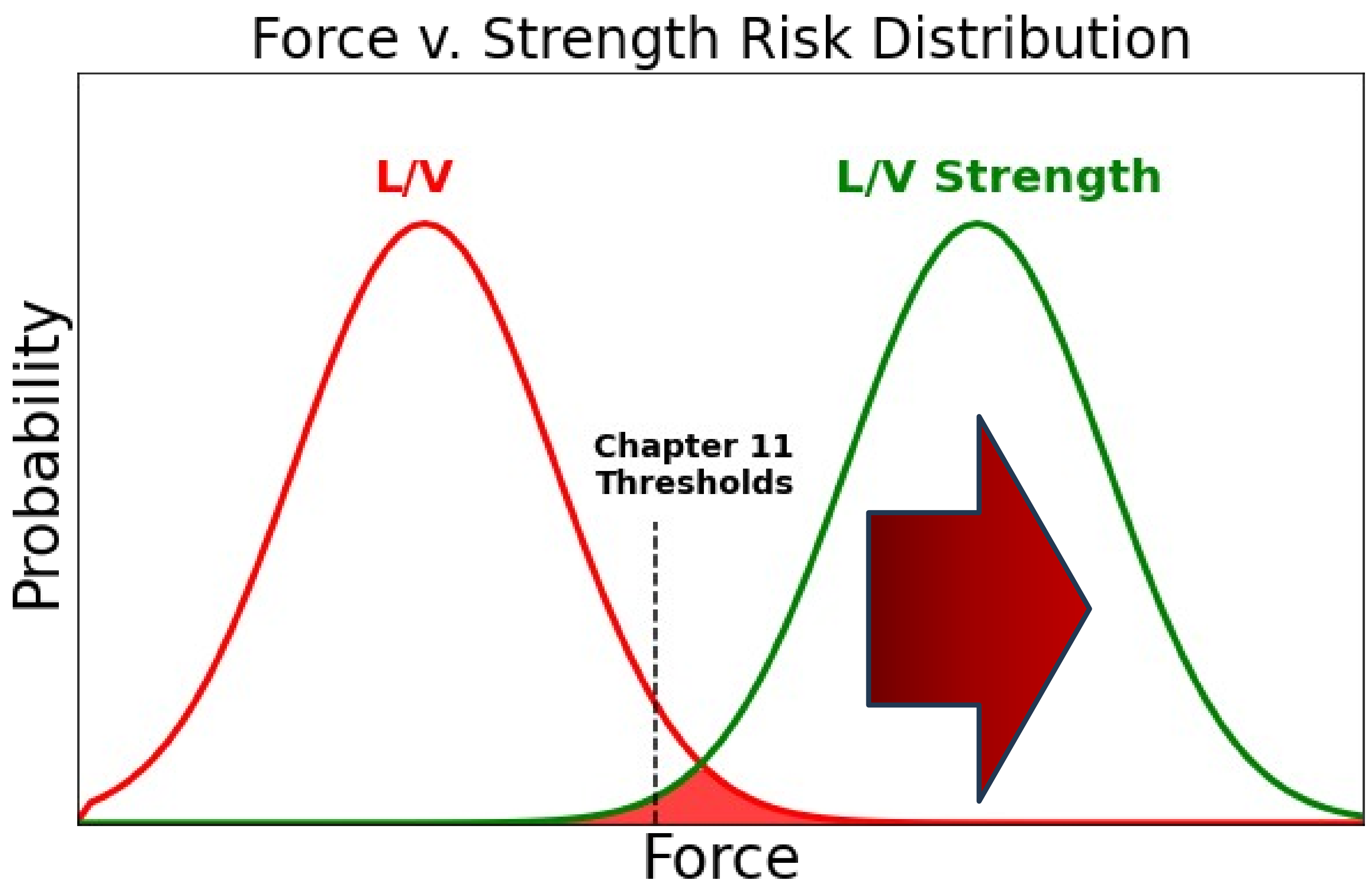
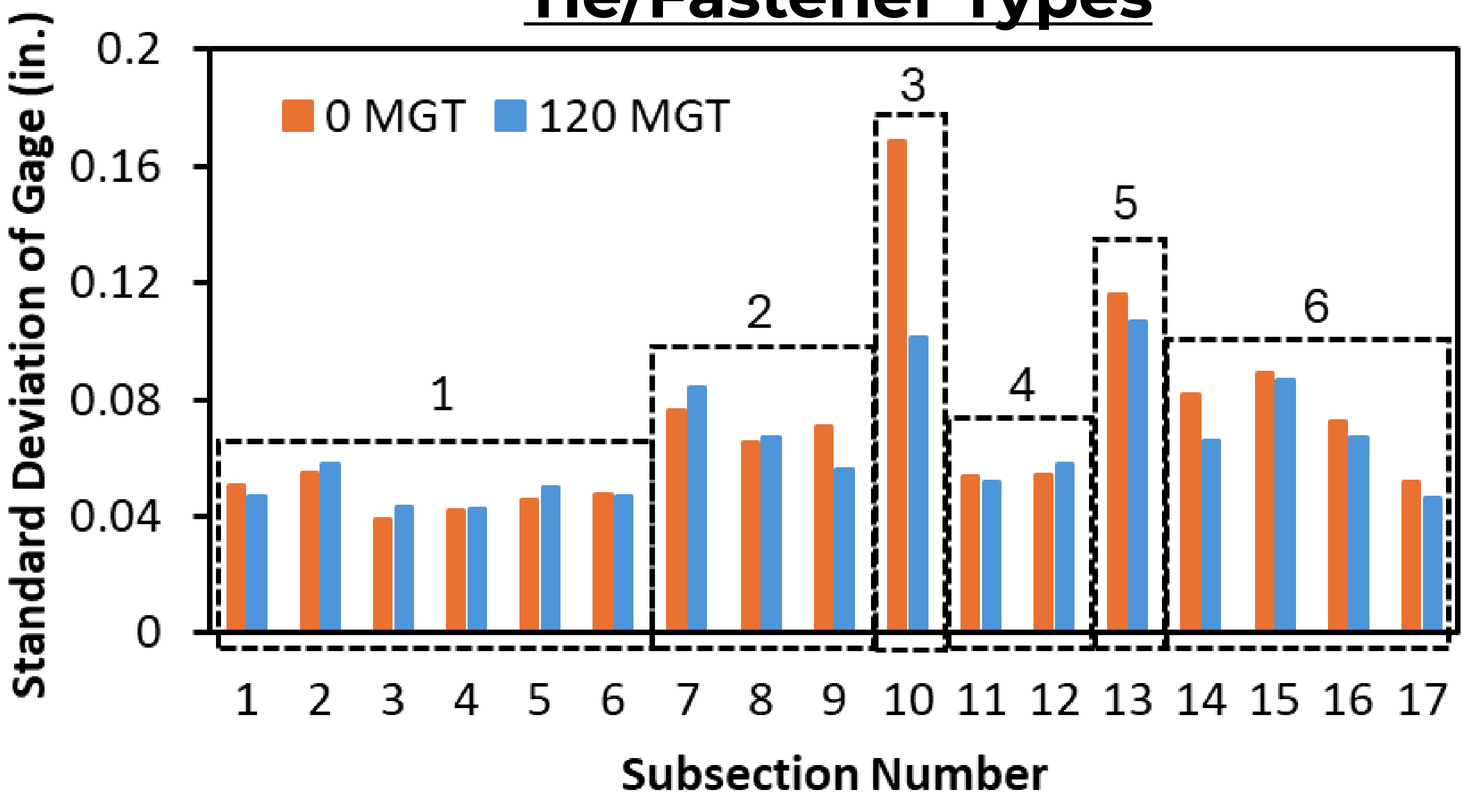
Measurements

- Ensuring new ties and fasteners resist gage widening is of the largest testing efforts for 'Ties and Fasteners'
- 'Truckside L/V strength' not directly measured



LTLF Testing at FAST® (unloaded gage strength)

Gage Measurements of Different Tie/Fastener Types



1. Concrete ties
2. wood ties with AREMA plates
3. Composite ties with AREMA plates
4. Wood ties with curve block plates
5. Interspersed concrete/wood ties
6. Wood ties with elastic fasteners

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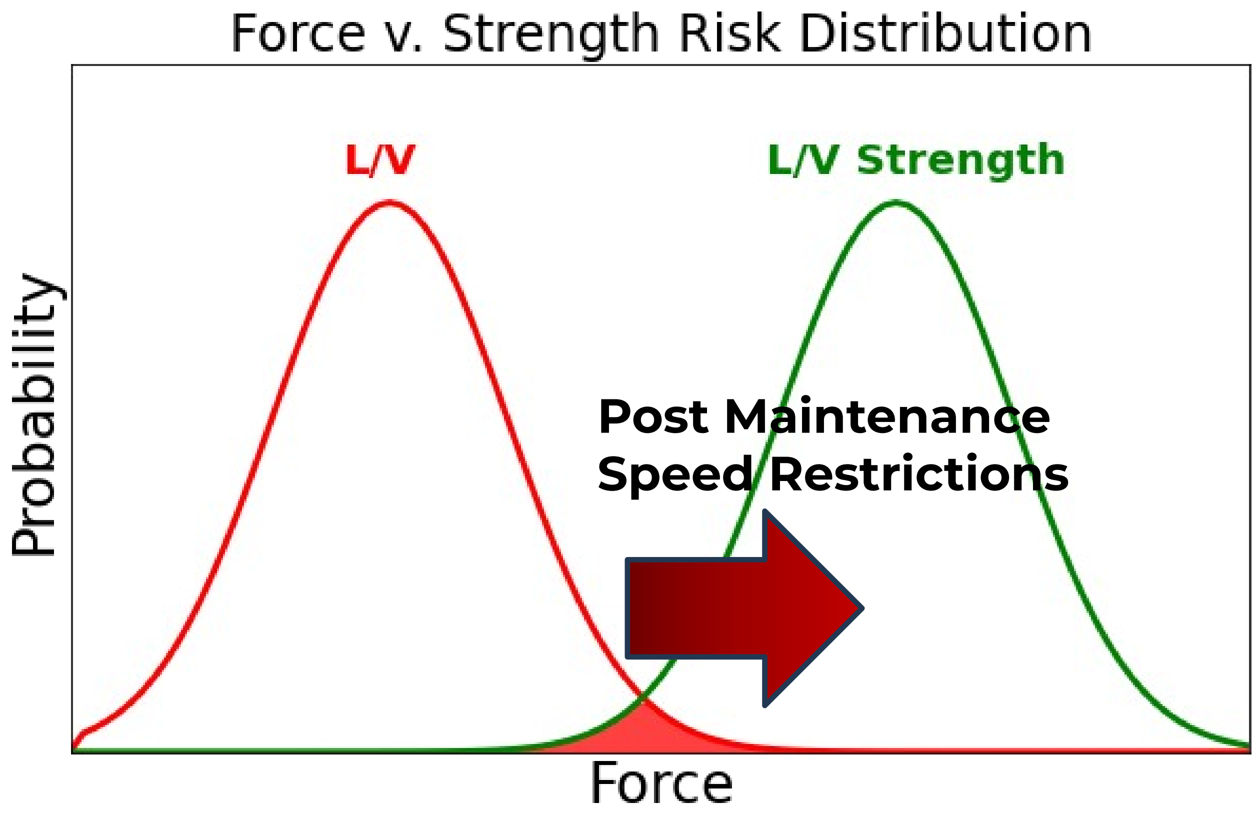
Net Truck L/V Strength

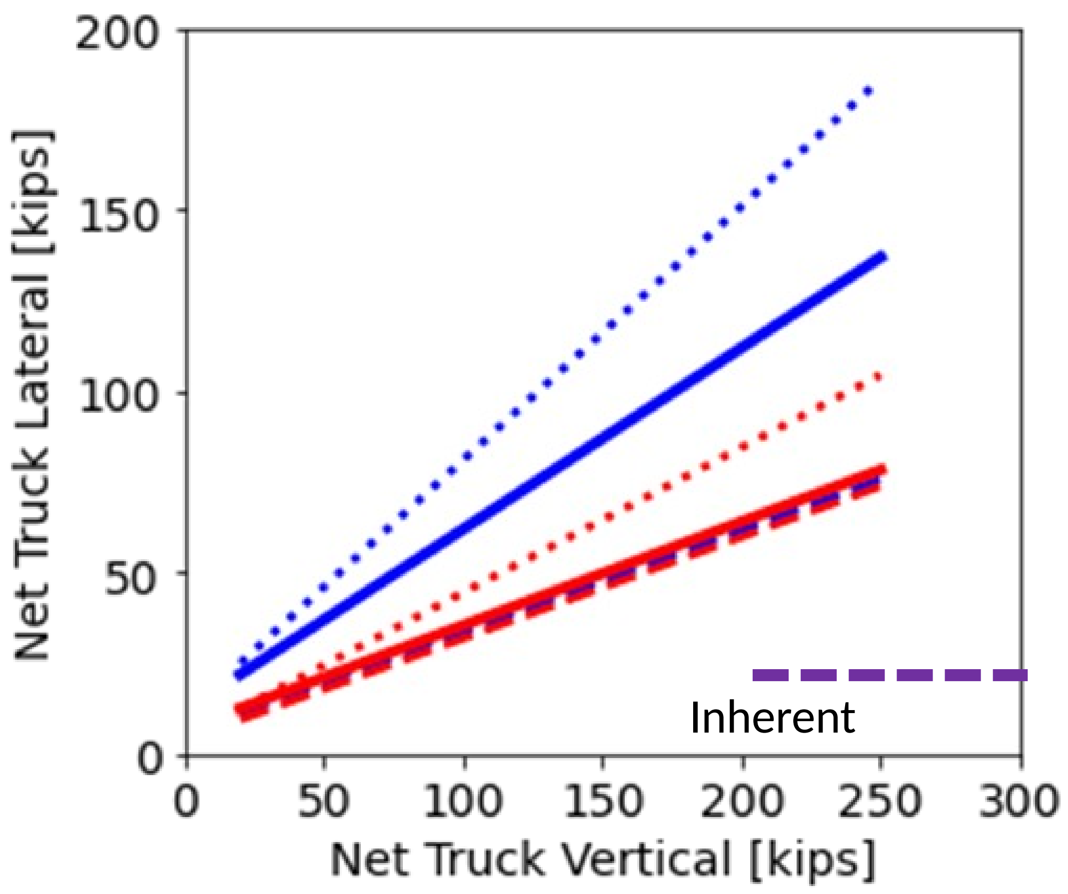
- NTLV and track buckle strength primarily resisted by the tie/ballast interface strength
- Track movement typically not from single factor but combination of factors

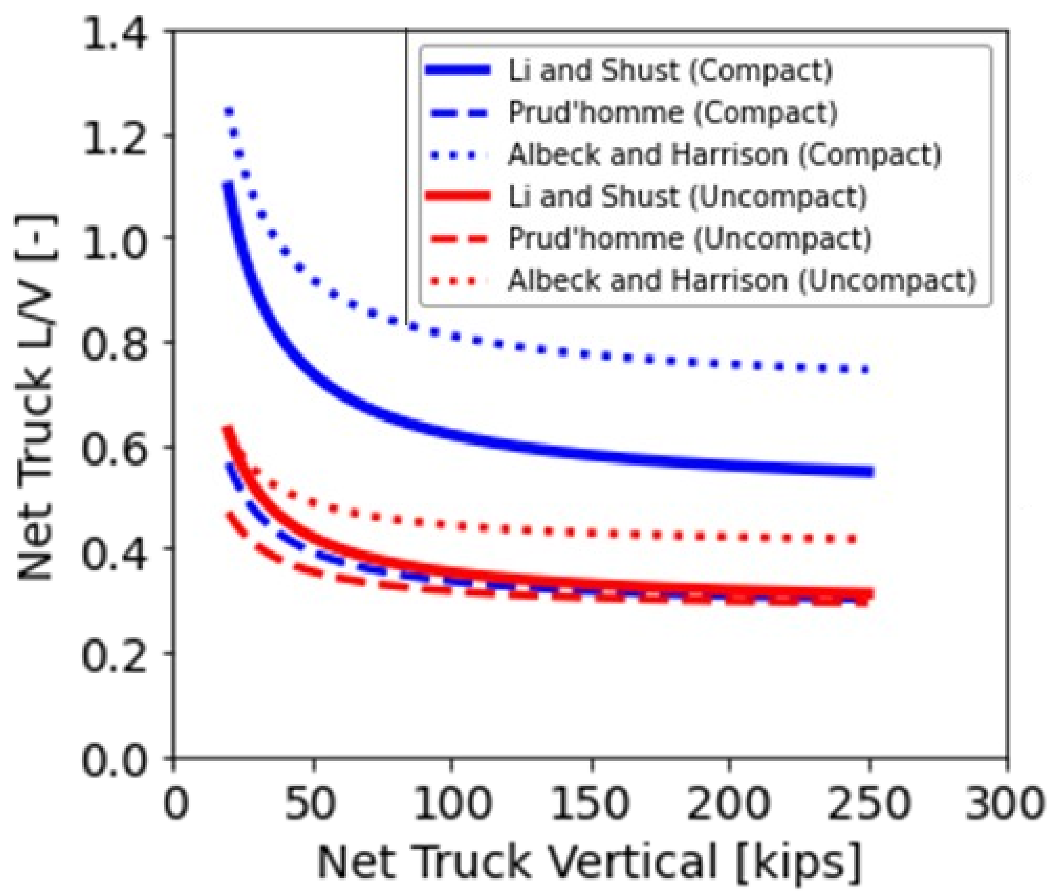


Ballast Contributors
- Recent Maintenance (disturbing tie/ballast interface)
- Tie and ballast types (friction and engagement)
- Amount of ballast

Other Contributors
- Longitudinal rail forces
- Fastener type and condition
- Anchors
- Track geometry
- Track curvature

Measurements and Criterion



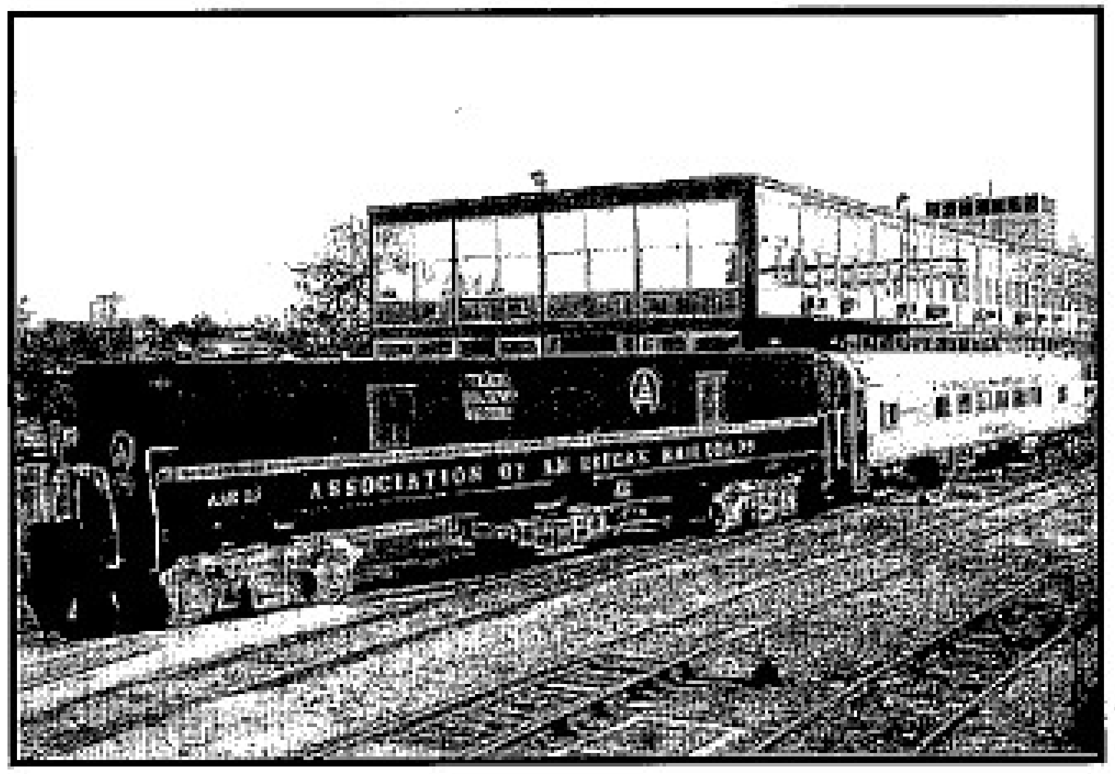


- NTLV and track buckle strength is highly frictional
- Inherent strength (truss-like track structure)

Multiple Criterion
- Prud'homme
- Li and Shust
- Others

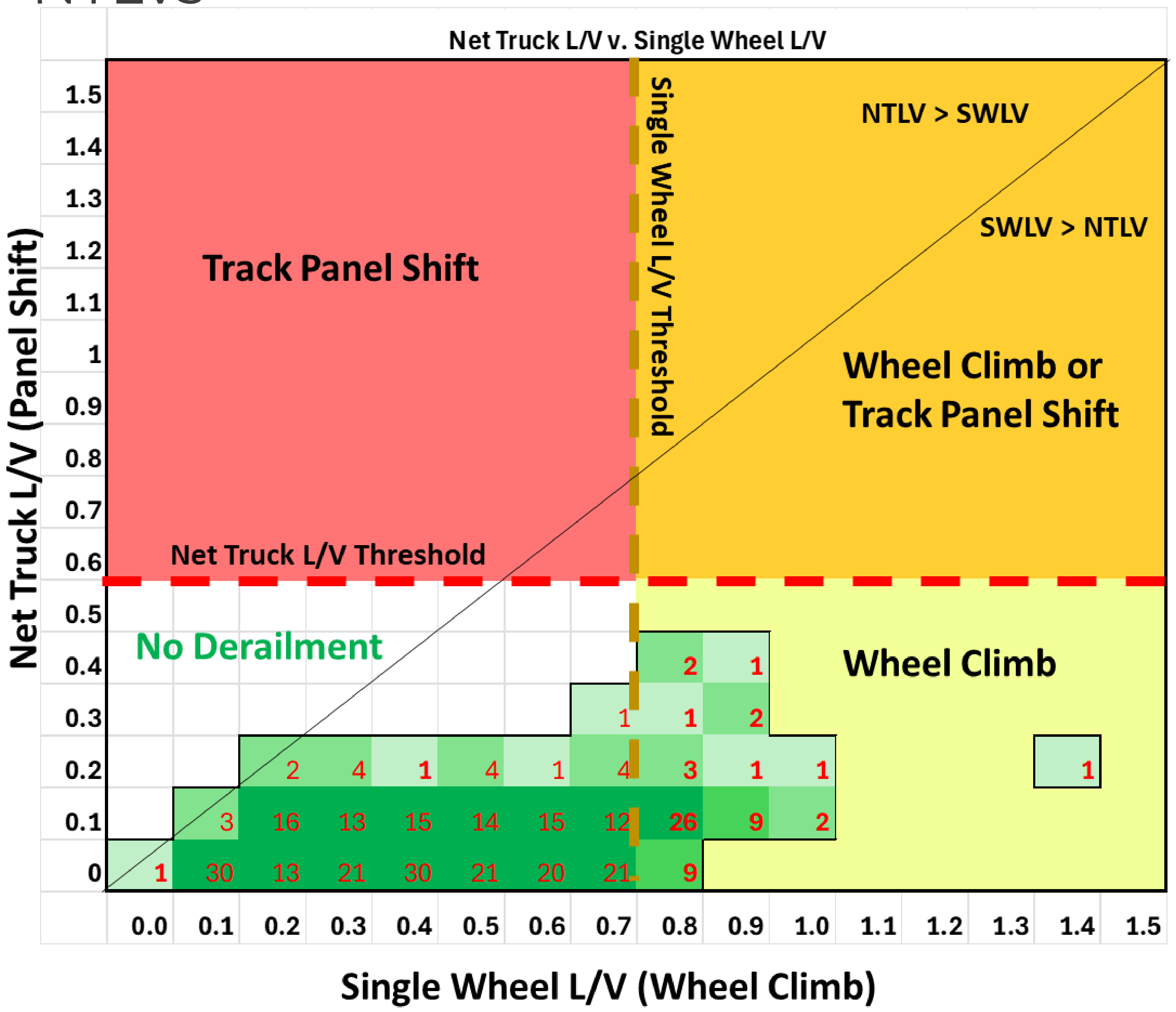
Single Tie Push Test (STPT) - Unloaded

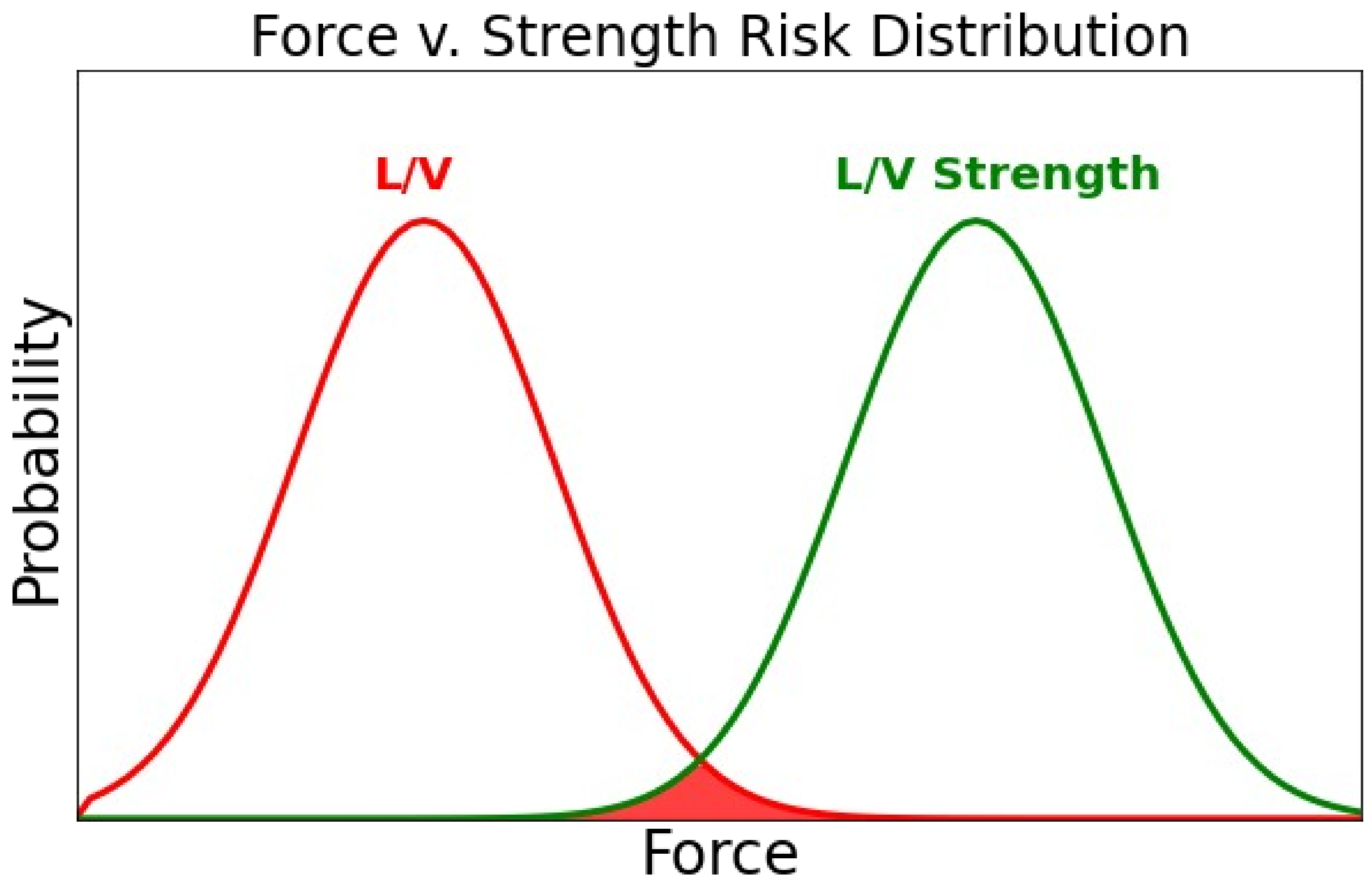
Track Loading Vehicle (TLV) - Loaded



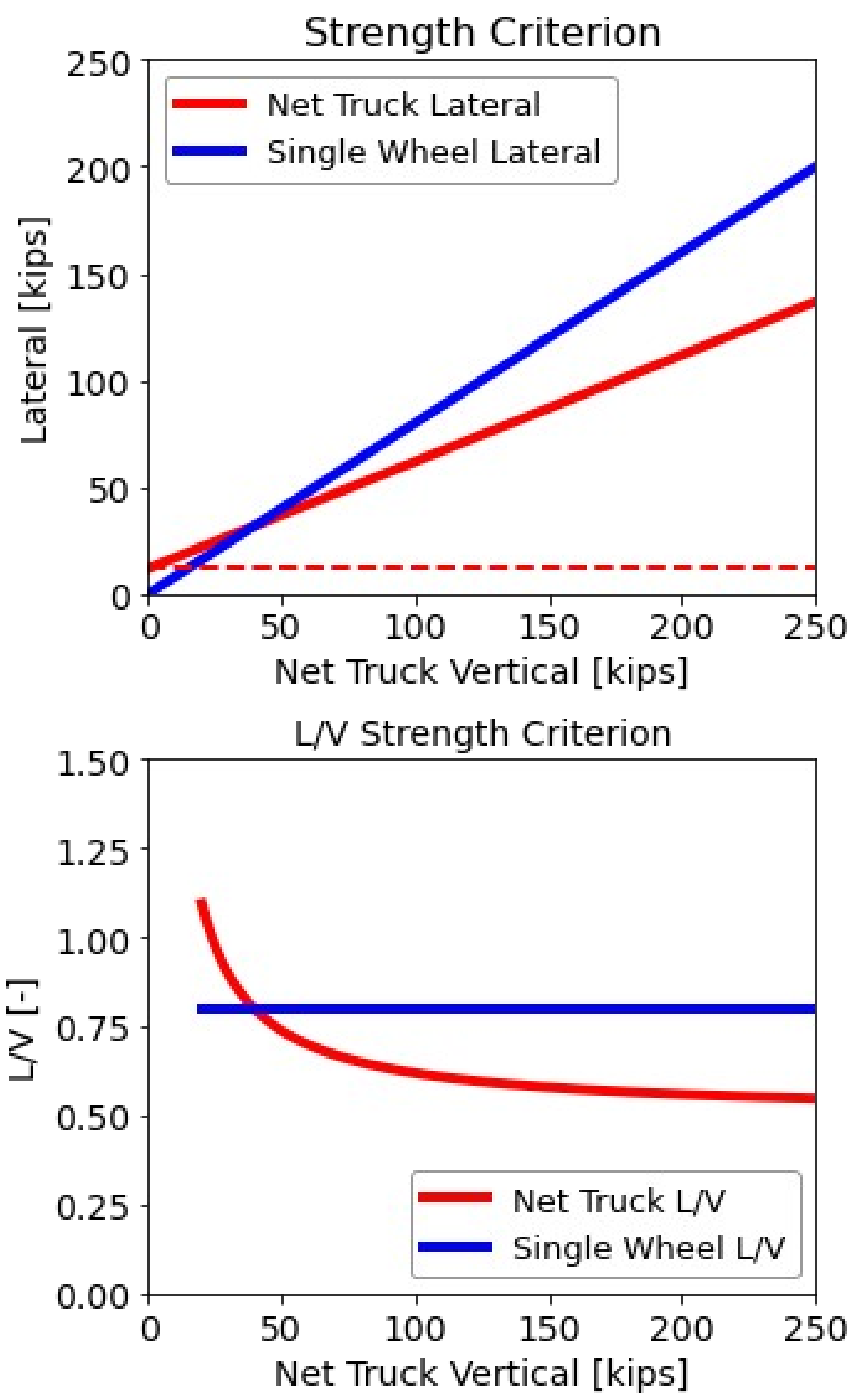
Different L/V Strengths

- Single Wheel L/V ≥ Truckside L/V ≥ NTLV
  - Assuming Chapter 11 thresholds,   Wheel climb > Rail Rollover > NTLV
- Need unique combination of L/Vs and strengths to get track misalignments from NTLVs

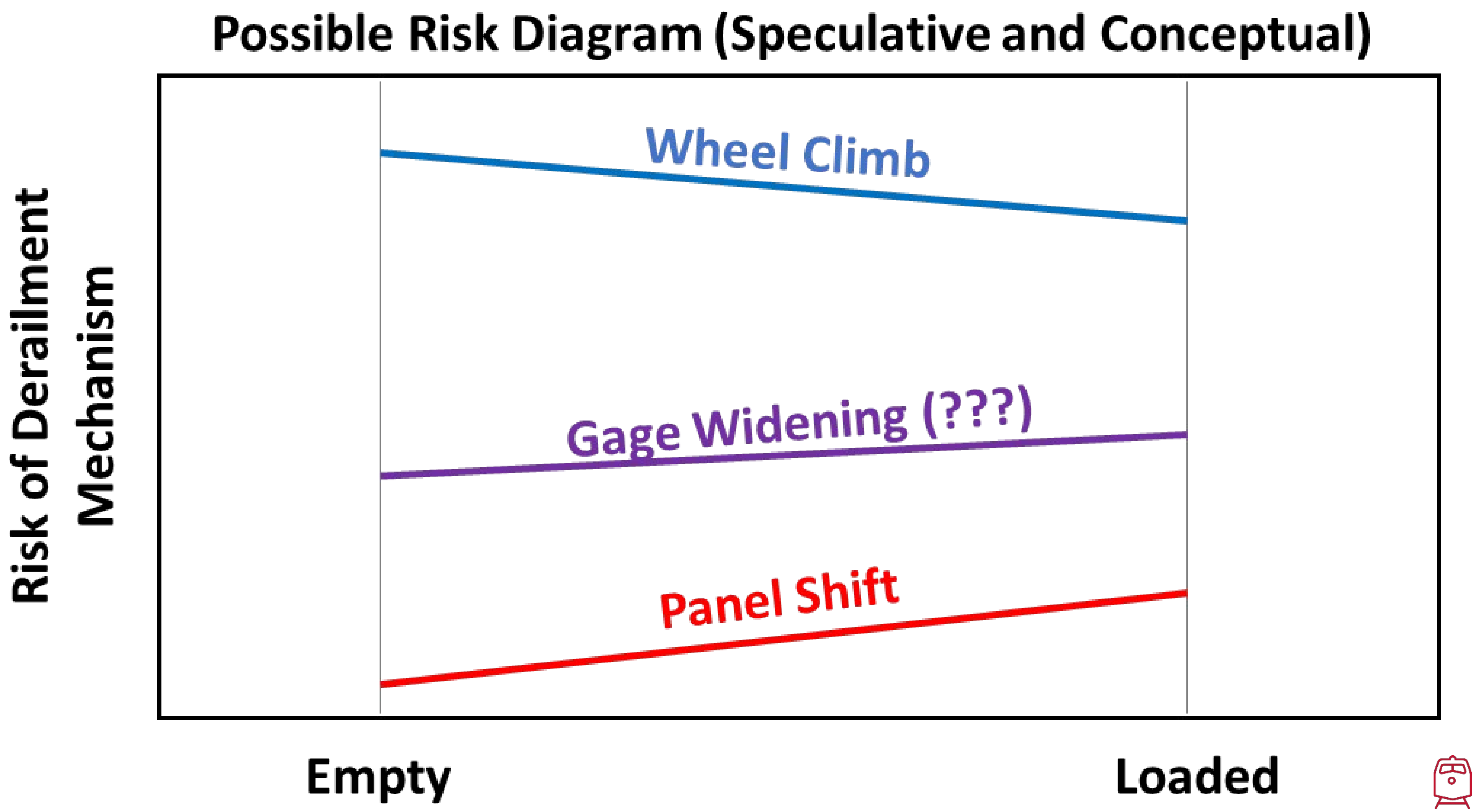




Effect of Load



- Inherent track strength for panel shift and gage widening/rail rollover may make wheel climb even more likely for lighter axle loads



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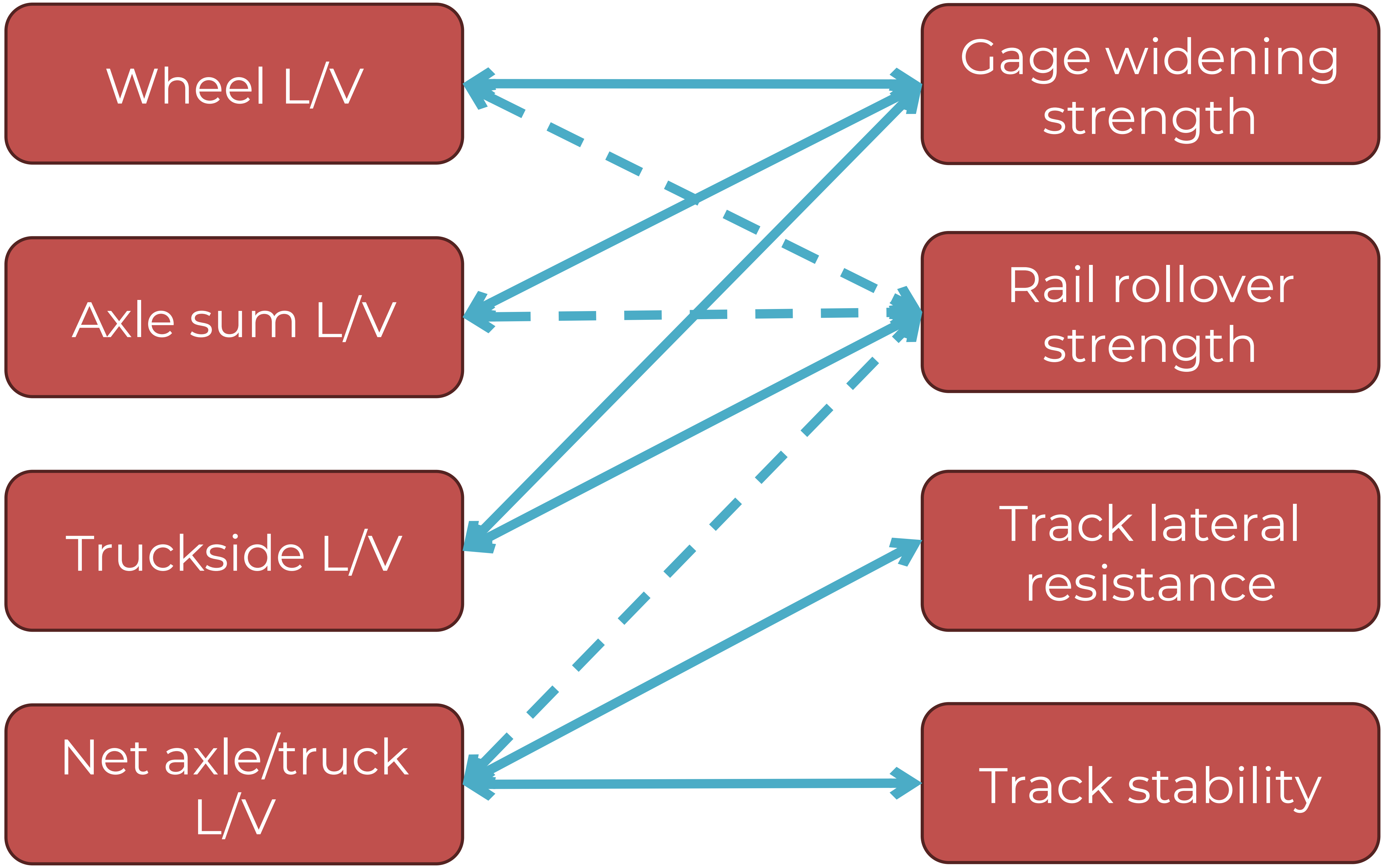
Vehicle track system

- L/V thresholds are not static in practice – affected by many factors related to both vehicle and track

- For an action generated by the vehicle, there exists a reaction from the track structure

Vehicle track system

Links between the factors presented. More can be considered.



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Summary

Topics discussed in this presentation:

- Backgrounds of various L/V ratios and their applications
- Angle of attack and duration considerations for wheel climb
- L/V thresholds are not static – they correspond to contact conditions and track strength
- Track strength factors that affect L/V thresholds

Vehicle dynamics and track strength are integral to each other and often should be considered as a system in practice.

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Thank you!