Rail Transit Loading Conditions

FRA and FTA Crosstie and Fastening System Research Program
Industry Partners (IP) Meeting

Bonita Springs, FL

26 October 2016

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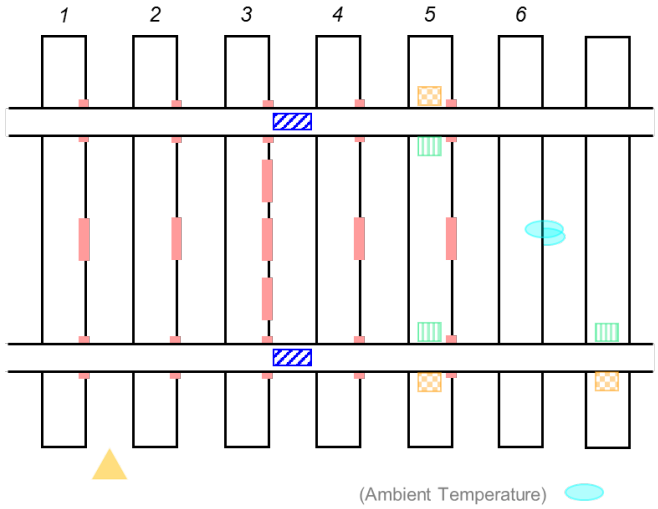
U.S. Department of Transportation
Federal Transit Administration

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- Field Quantification of Wheel-Rail Loads
  - Light Rail
  - Heavy Rail
  - Commuter Rail
- Discussion of Lateral to Vertical (L/V) Ratios
- Summary of Rail Transit Loading Conditions

Typical Field Instrumentation Map

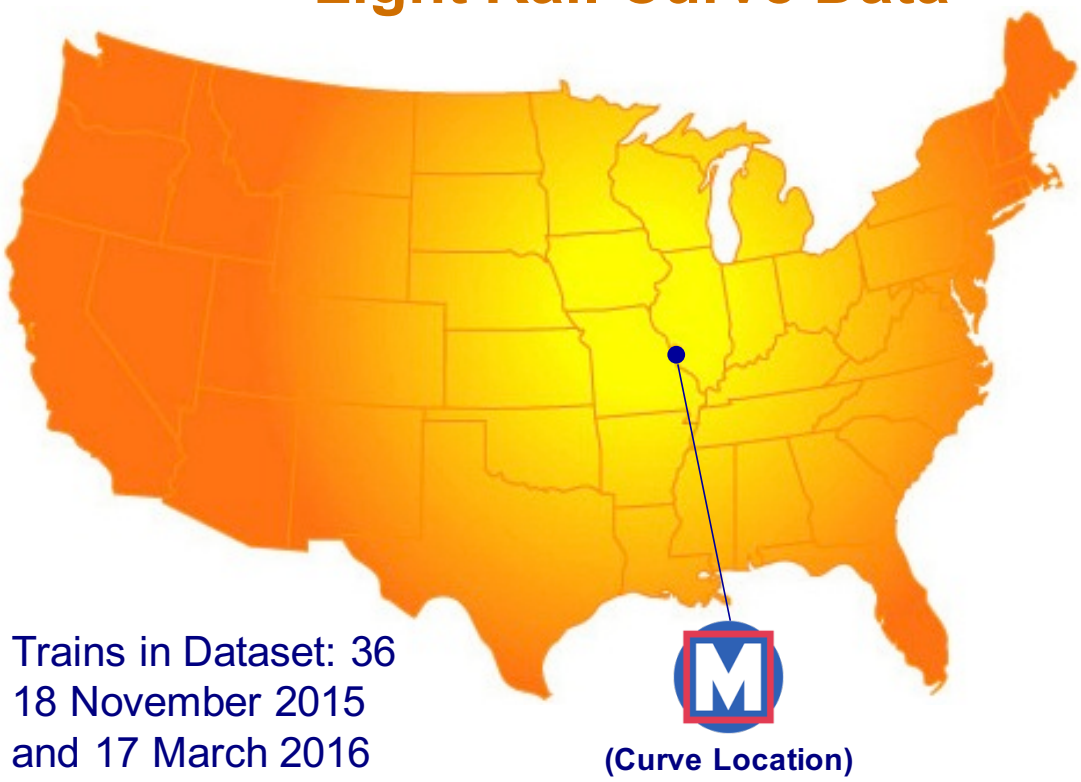


- Metrics to quantify:
  - Crosstie bending strain (crosstie moment design)
  - Rail displacements (fastening system design)
  - **Vertical and lateral input loads** (crosstie and fastening system design, and load environment characterization)
  - Crosstie temperature gradient

Crosstie Bending Strain
Vertical and Lateral Load (Wheel Loads)
Rail Displacement (Base Vertical, Base Lateral)
Rail Displacement (Base Vertical)
Thermocouple
Laser Trigger

Partner Agencies

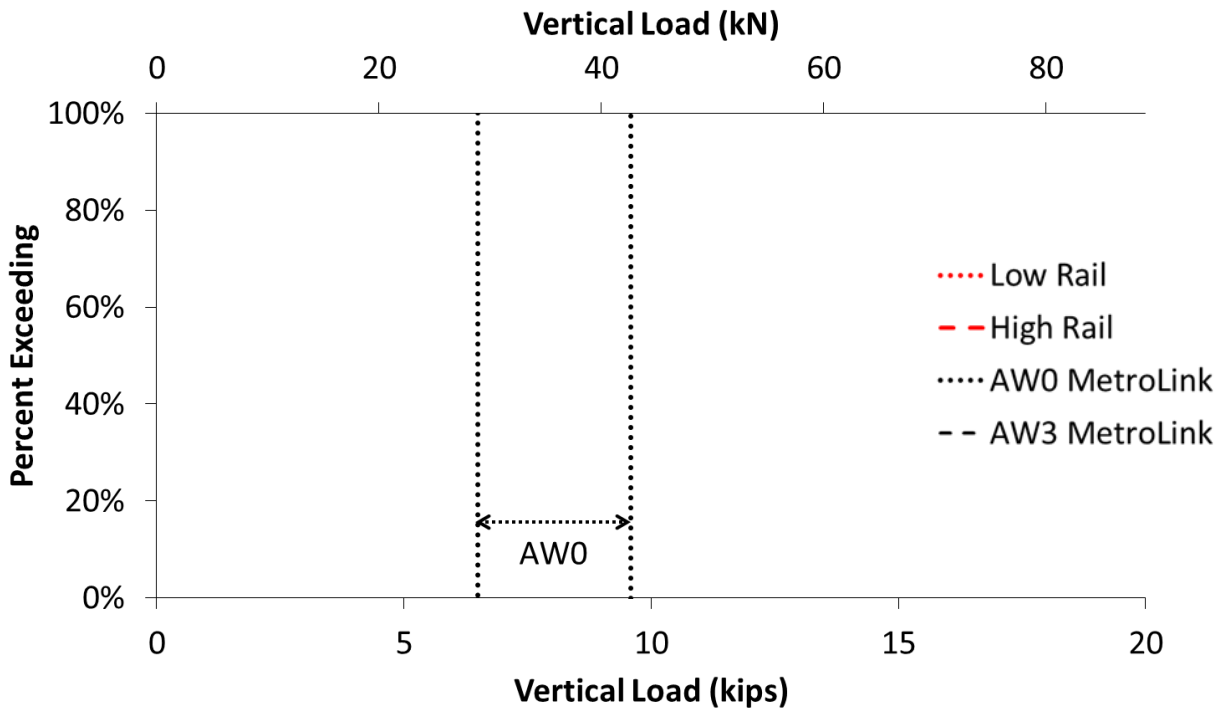
Light Rail Curve Data



Trains in Dataset: 36
18 November 2015
and 17 March 2016

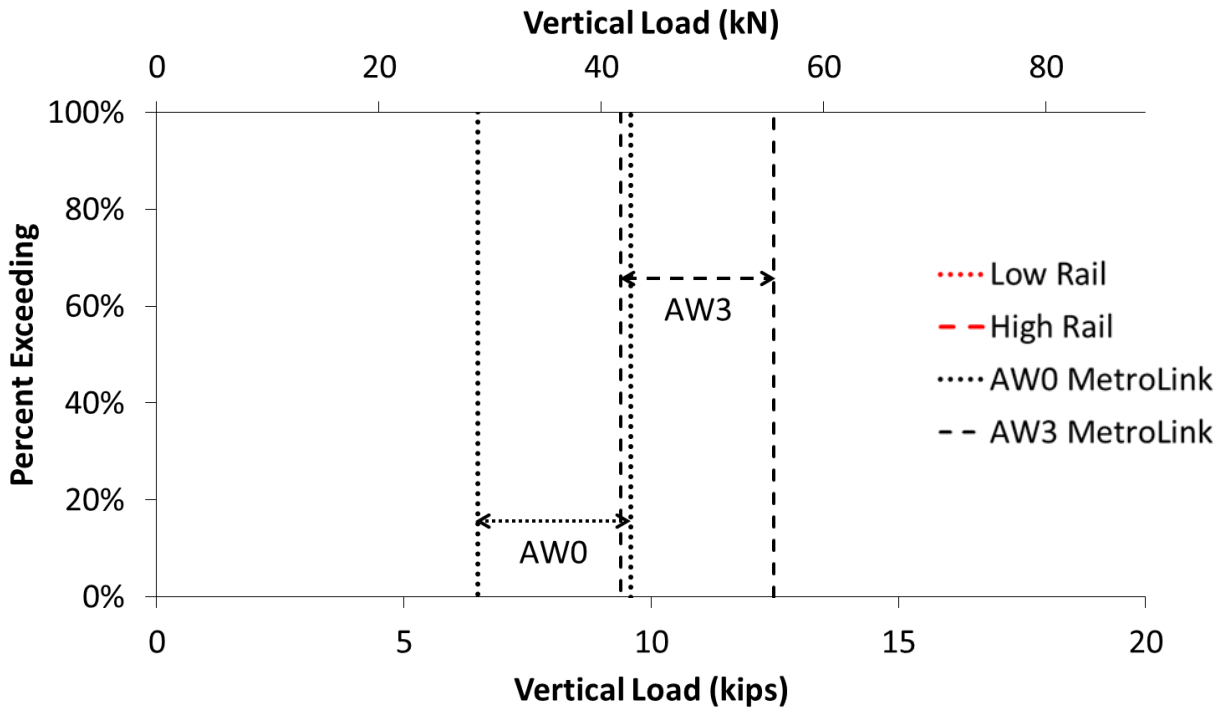
Vertical Rail Loads

St. Louis MetroLink (Curve)



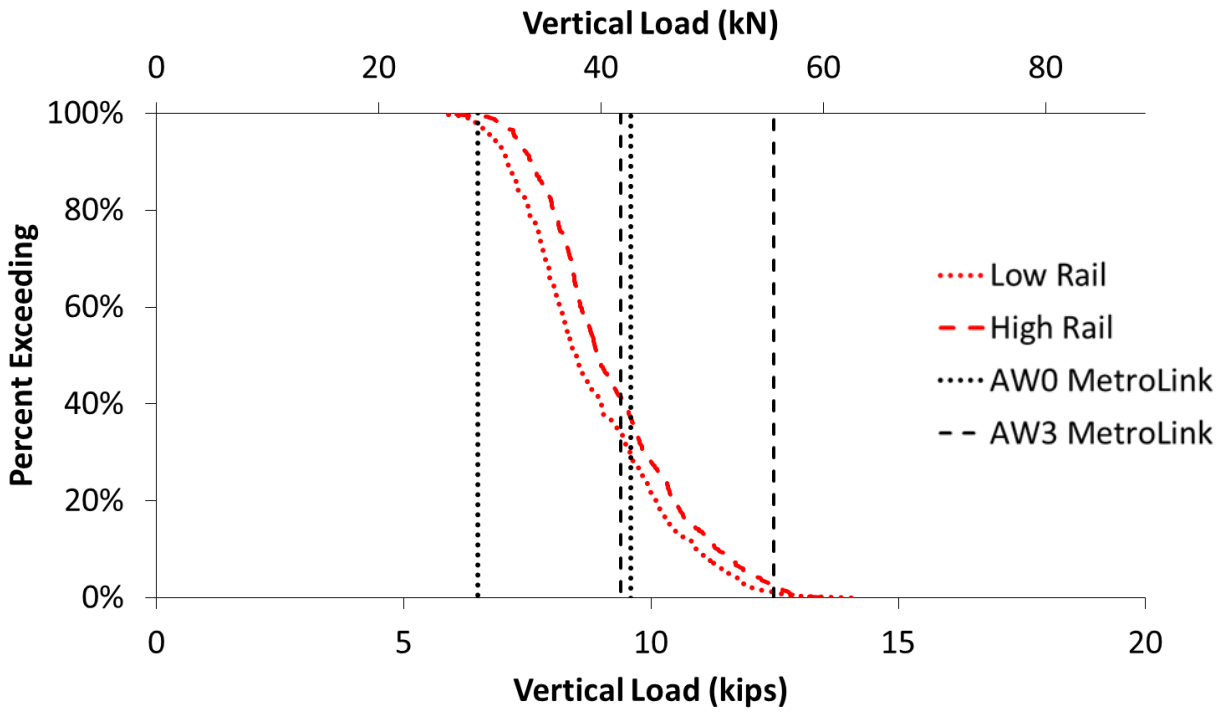
Vertical Rail Loads

St. Louis MetroLink (Curve)



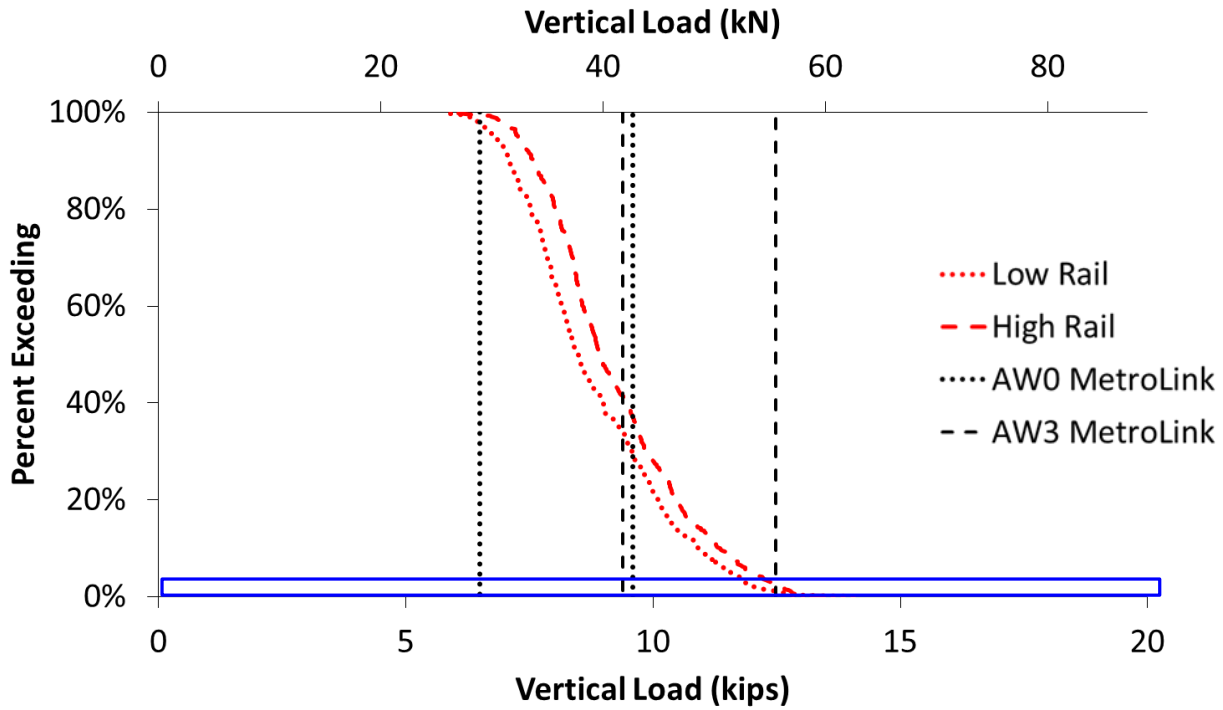
Vertical Rail Loads

St. Louis MetroLink (Curve)



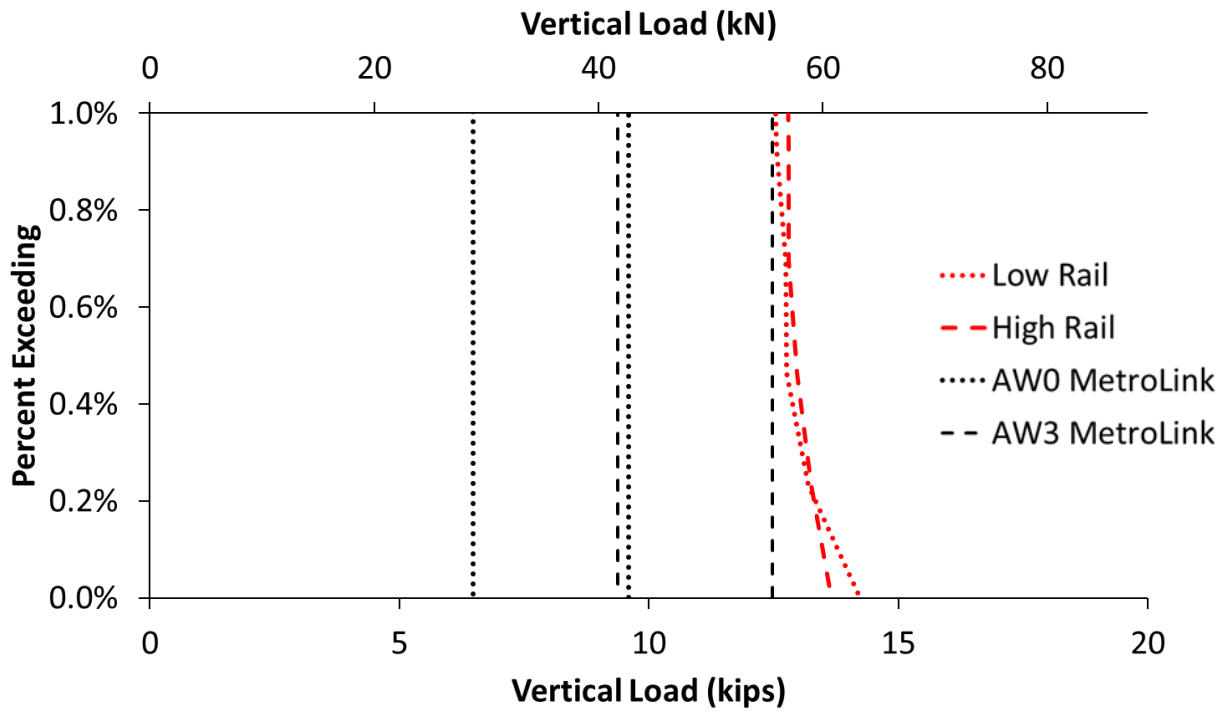
Vertical Rail Loads

St. Louis MetroLink (Curve)



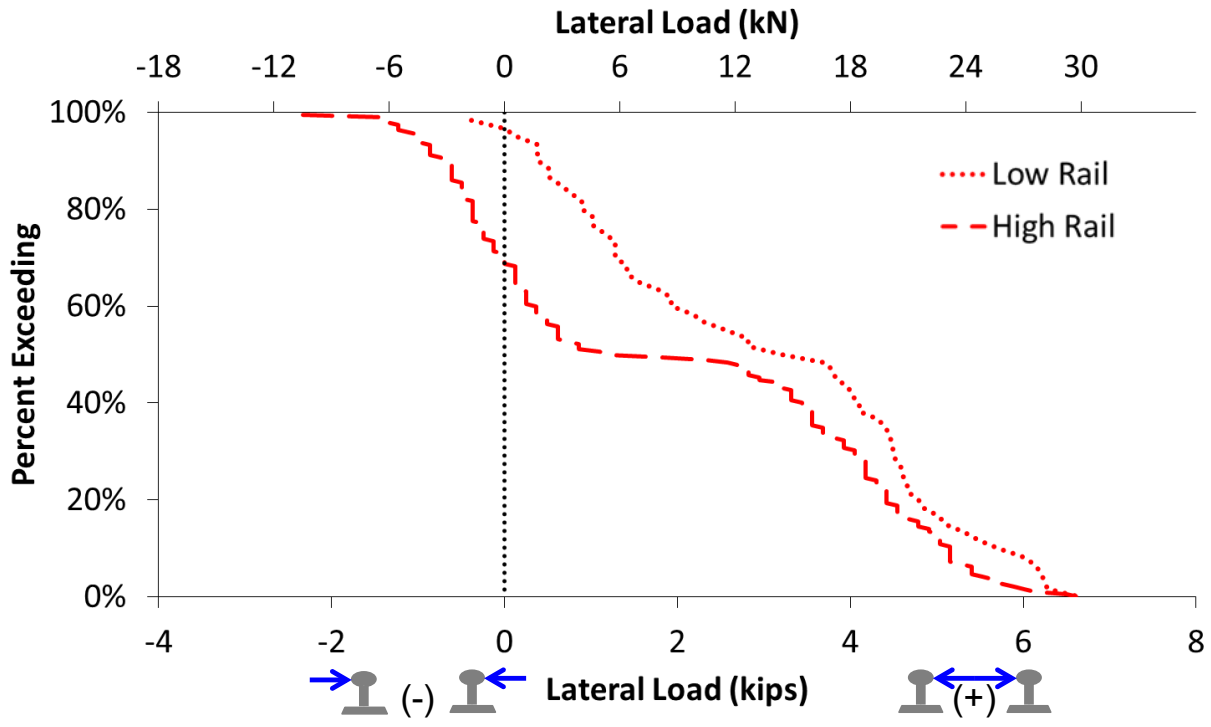
Vertical Rail Loads

St. Louis MetroLink (Curve)



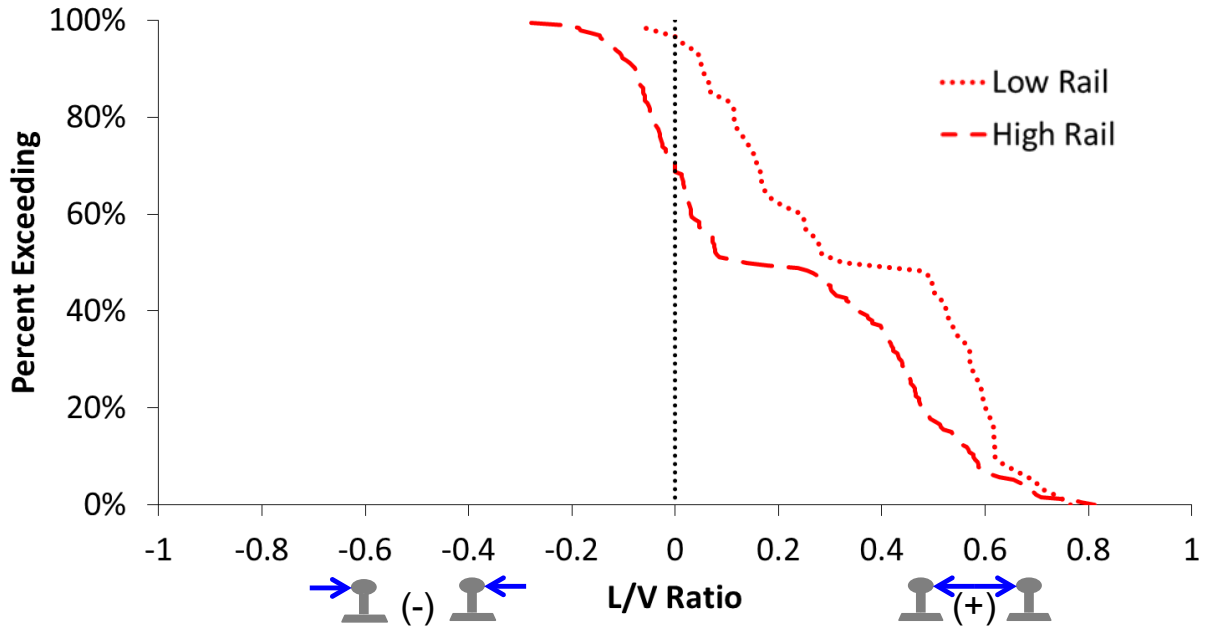
Lateral Rail Loads

St. Louis MetroLink (Curve)



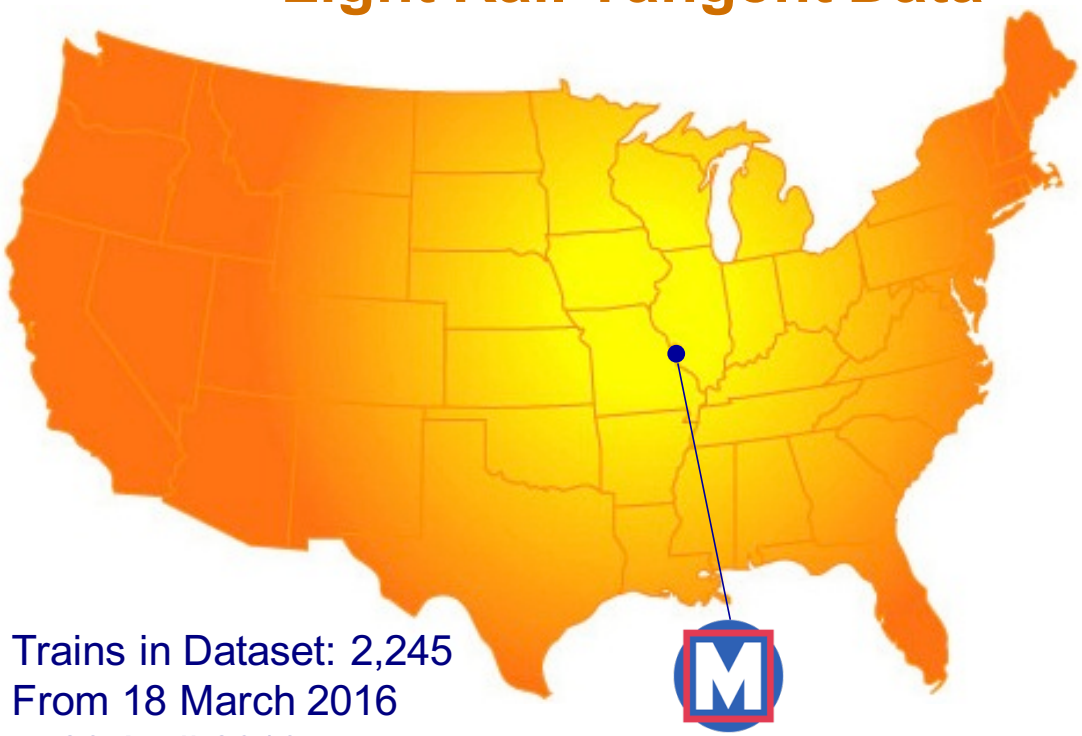
Lateral to Vertical (L/V) Ratios

St. Louis MetroLink (Curve)



Partner Agencies

Light Rail Tangent Data

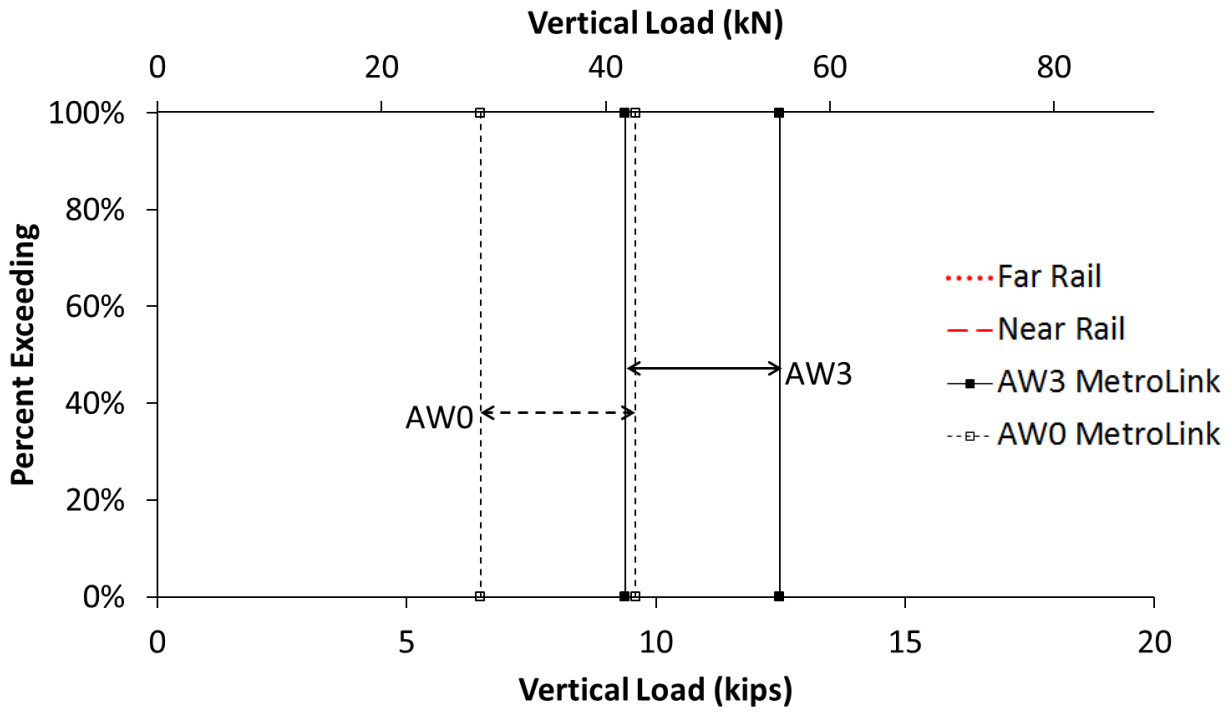


Trains in Dataset: 2,245
From 18 March 2016
to 26 April 2016

(Tangent Location)

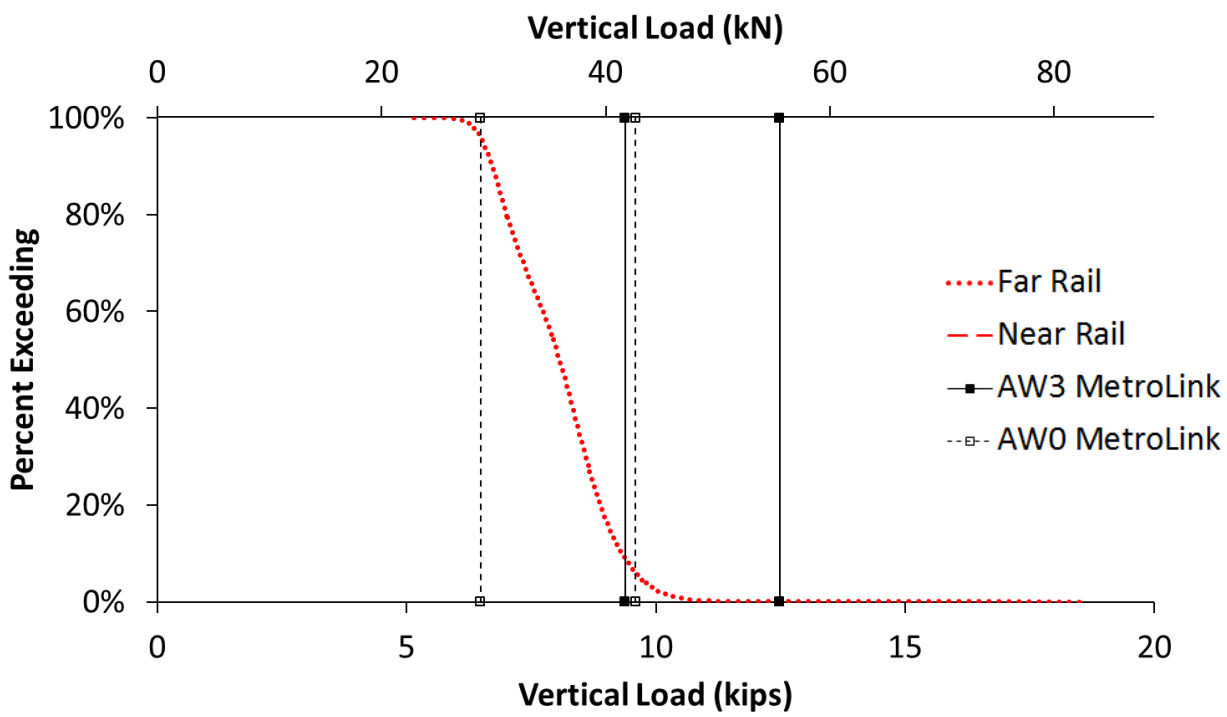
Vertical Rail Loads

St. Louis MetroLink (Tangent)



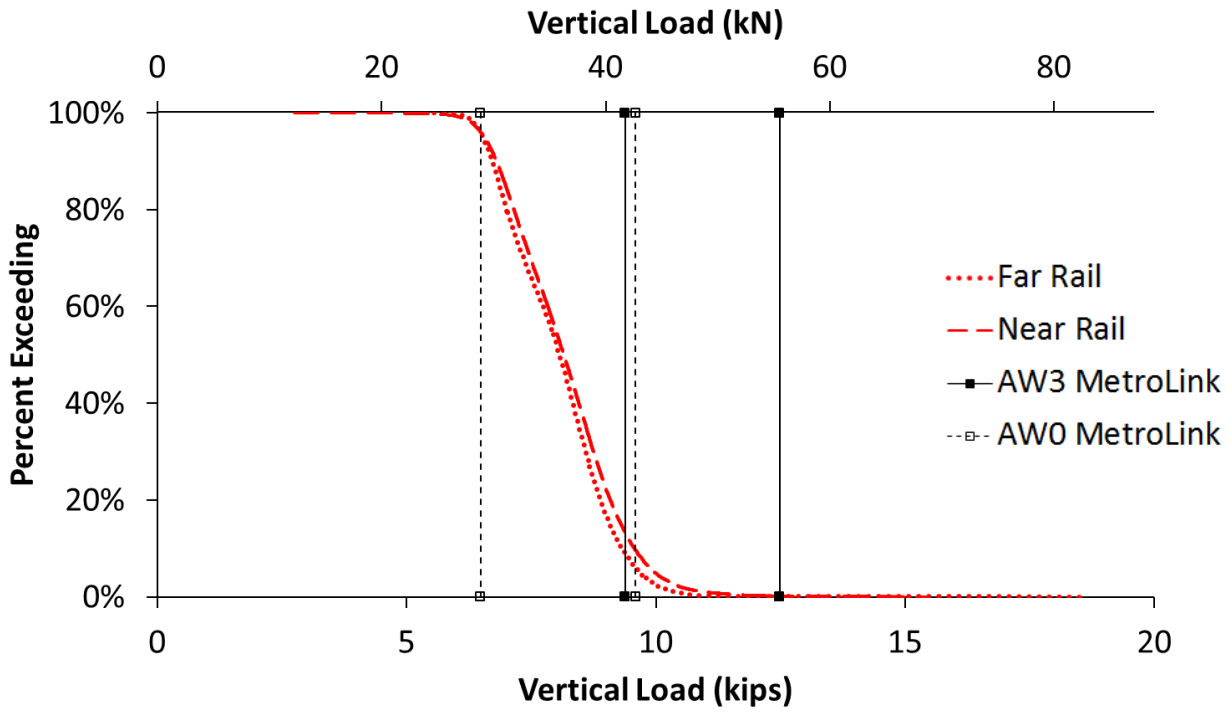
Vertical Rail Loads

St. Louis MetroLink (Tangent)



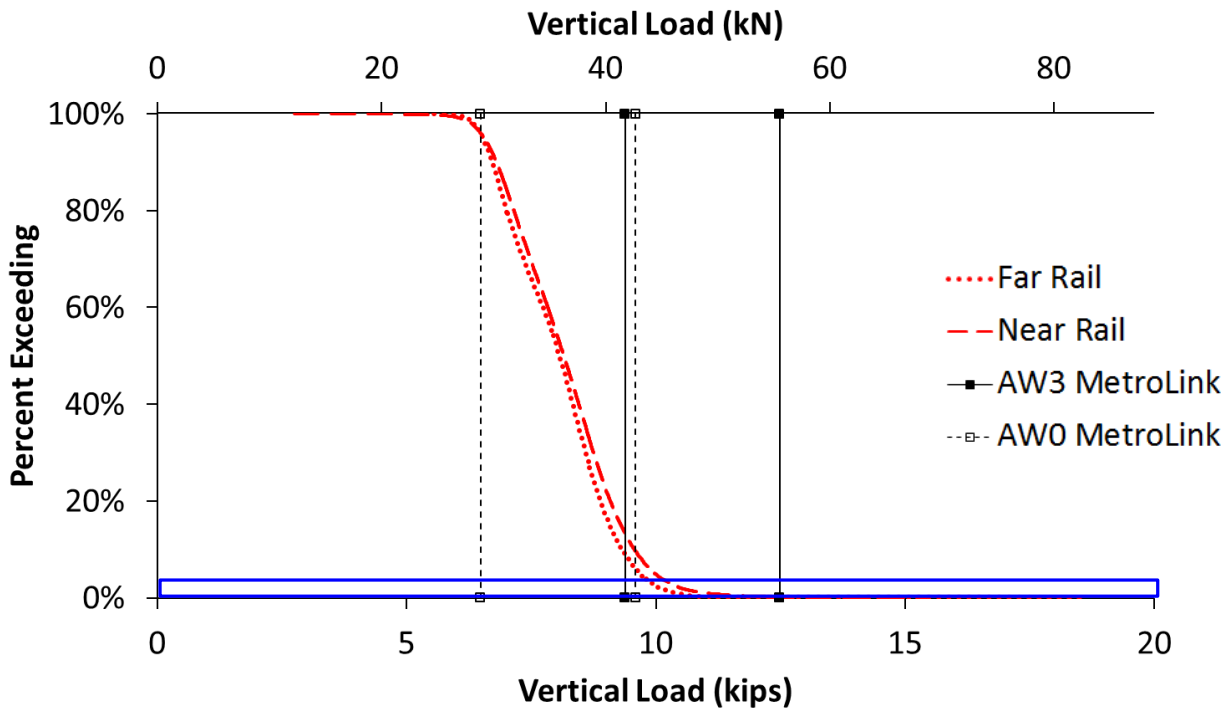
Vertical Rail Loads

St. Louis MetroLink (Tangent)



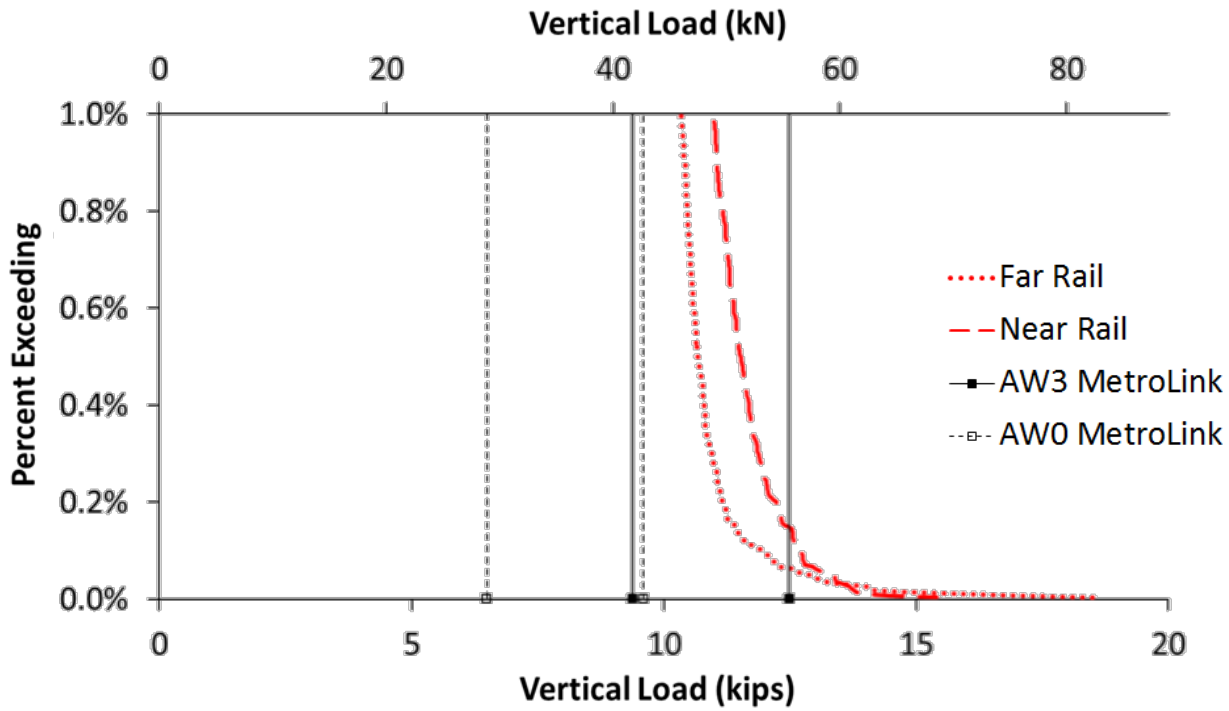
Vertical Rail Loads

St. Louis MetroLink (Tangent)



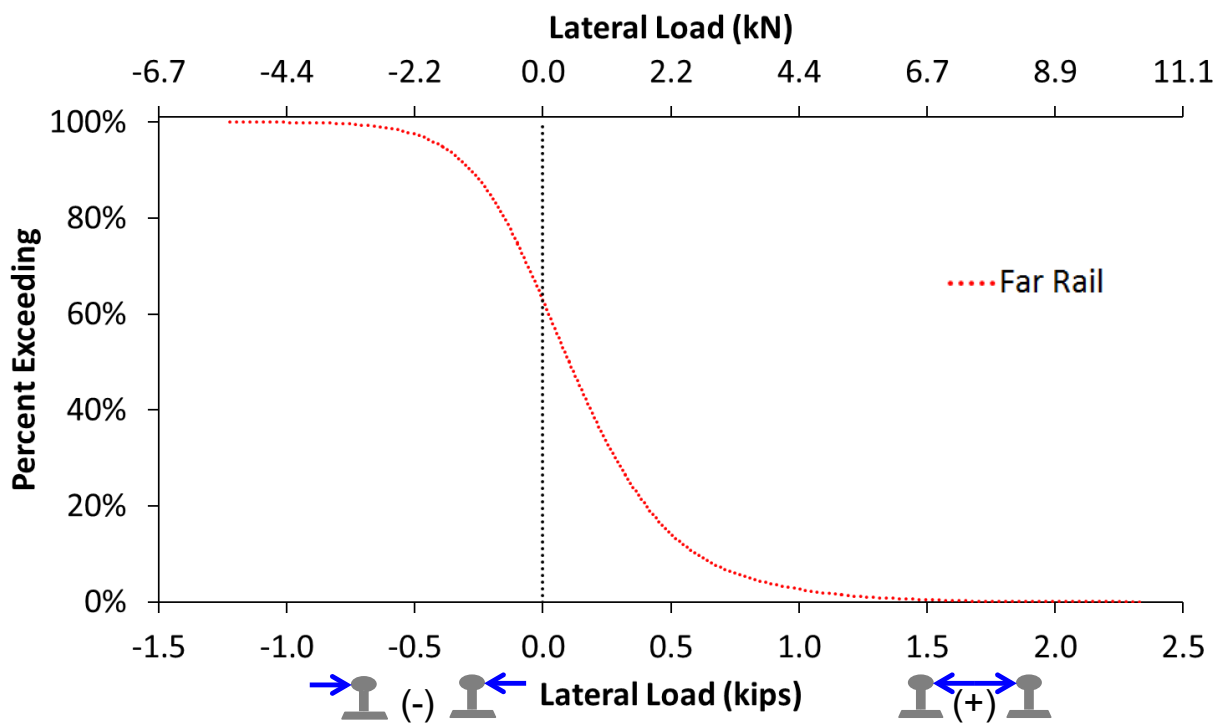
Vertical Rail Loads

St. Louis MetroLink (Tangent)



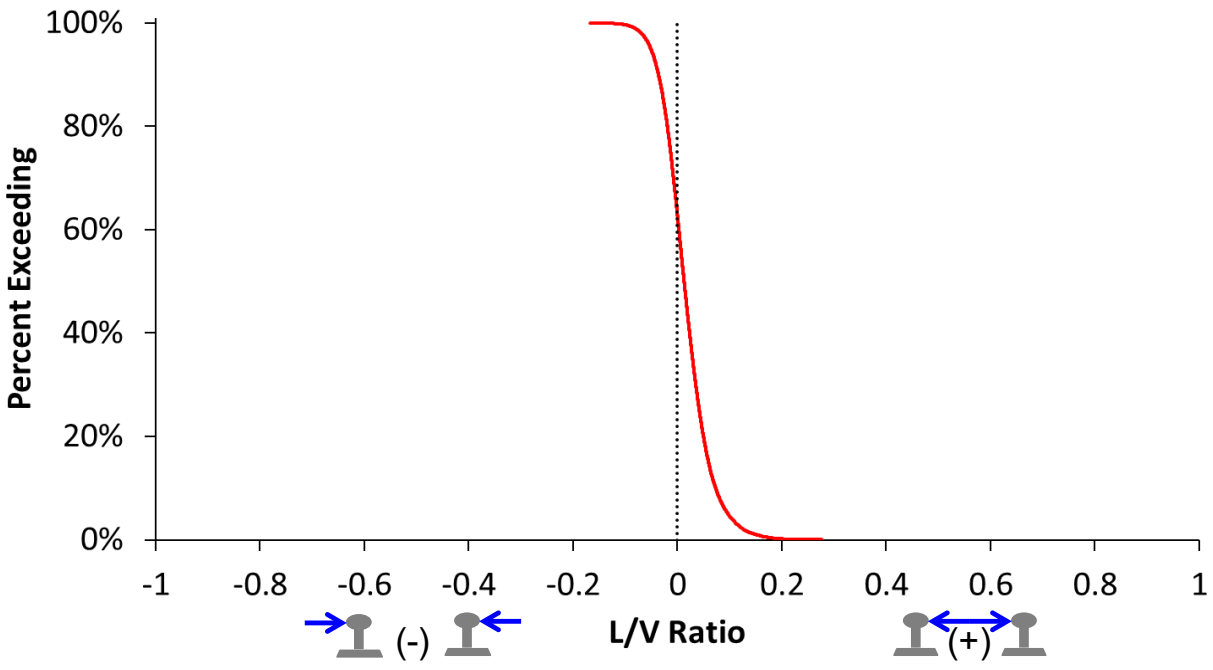
Lateral Rail Loads

St. Louis MetroLink (Tangent)



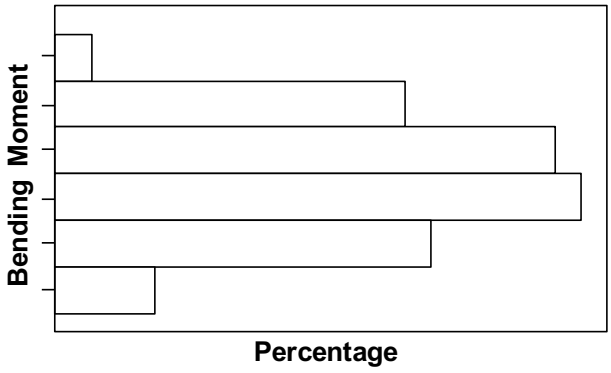
Lateral to Vertical (L/V) Ratios

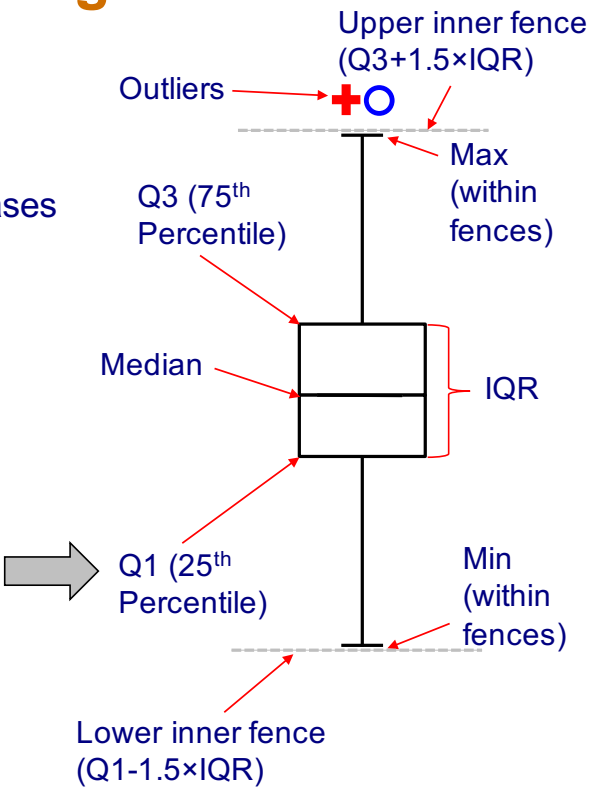
St. Louis MetroLink (Tangent)



Box Plot Background

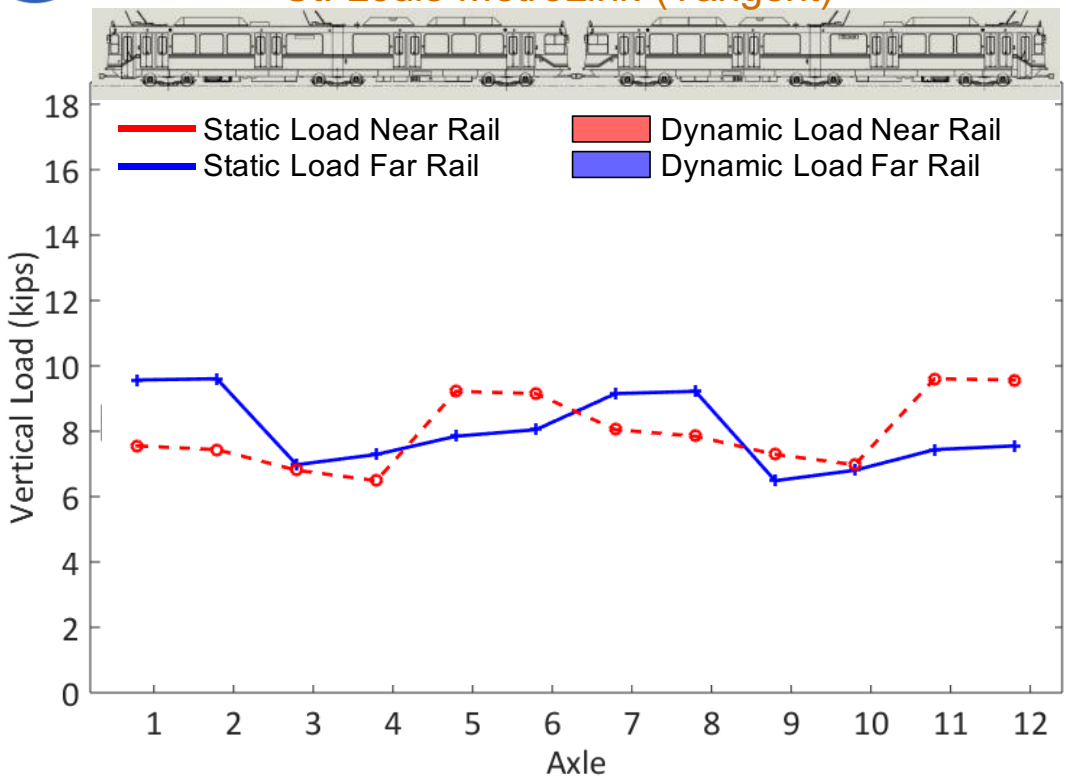
- Box plots are great to:
  - Visualize outliers
  - Compare variability of different cases
  - Check for symmetry
  - Check for normality
- 50% of Data are within the box





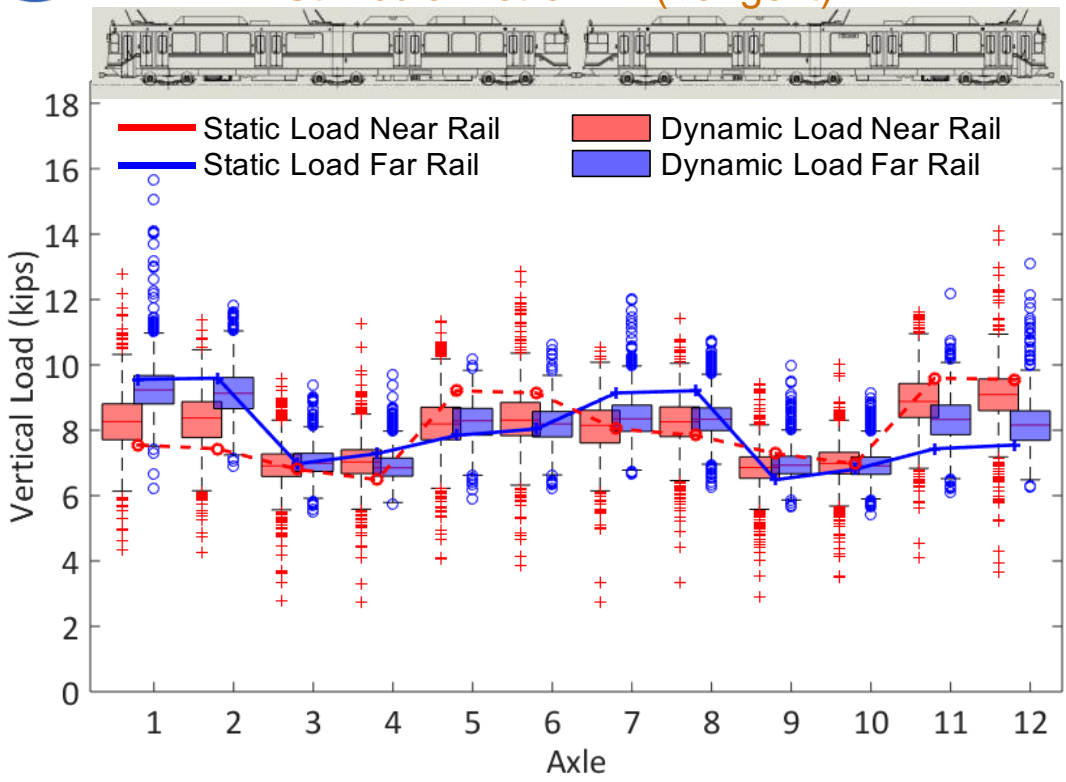
Vertical Wheel Loads

St. Louis MetroLink (Tangent)



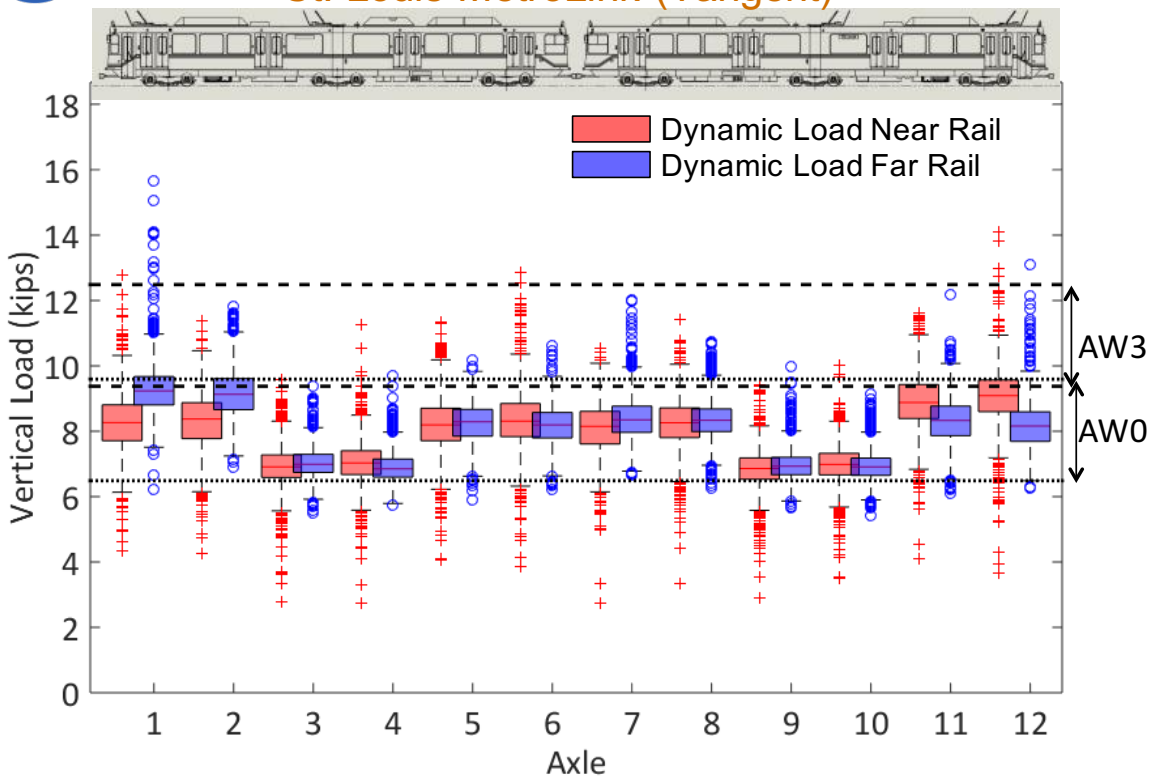
Vertical Wheel Loads

St. Louis MetroLink (Tangent)



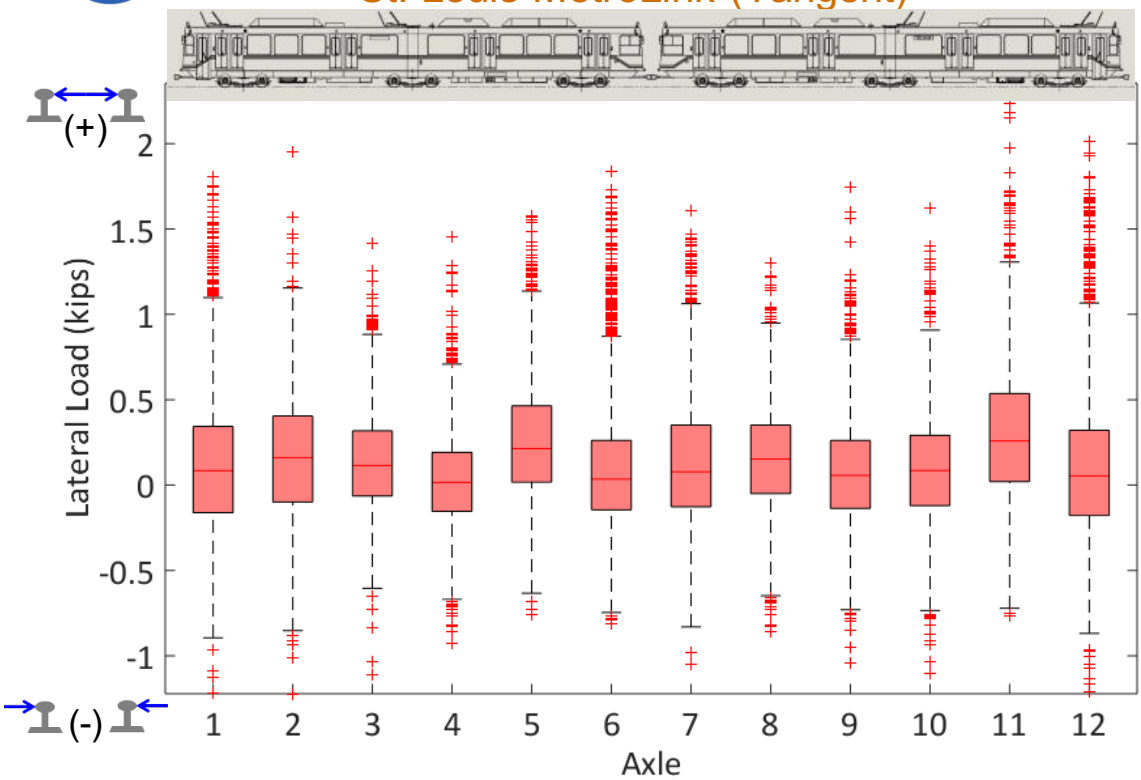
Vertical Wheel Loads

St. Louis MetroLink (Tangent)



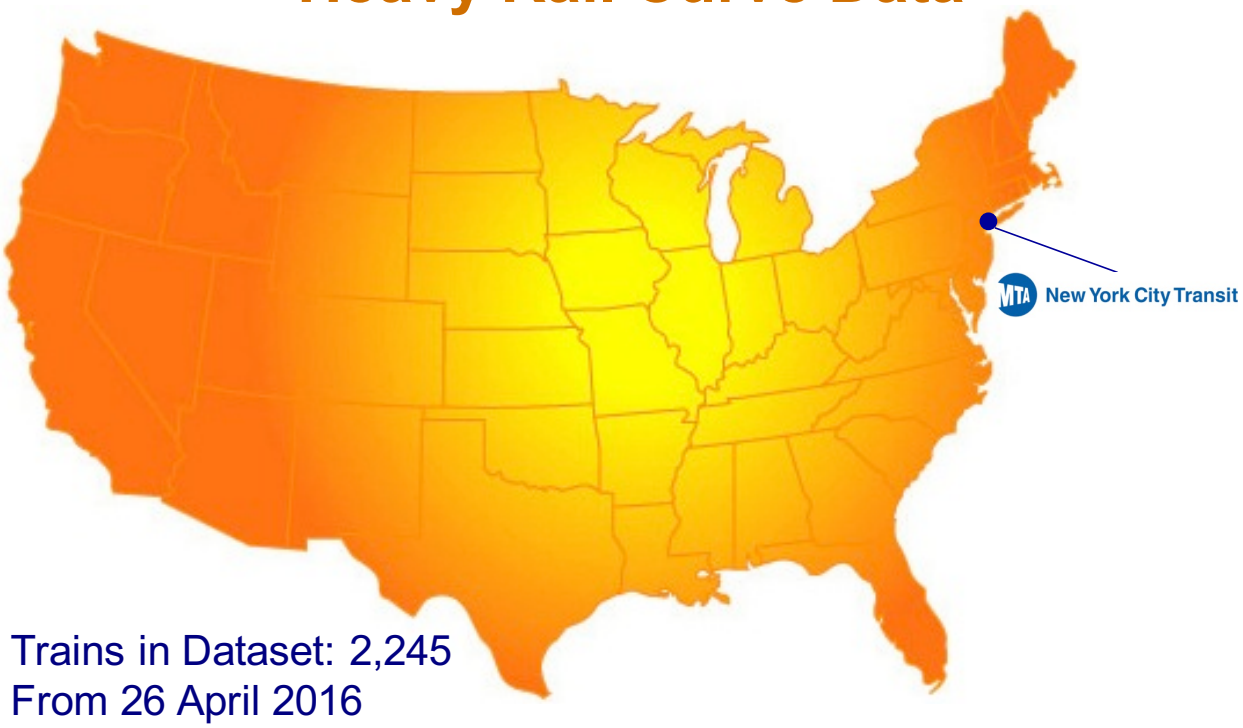
Lateral Wheel Loads

St. Louis MetroLink (Tangent)



Partner Agencies

Heavy Rail Curve Data

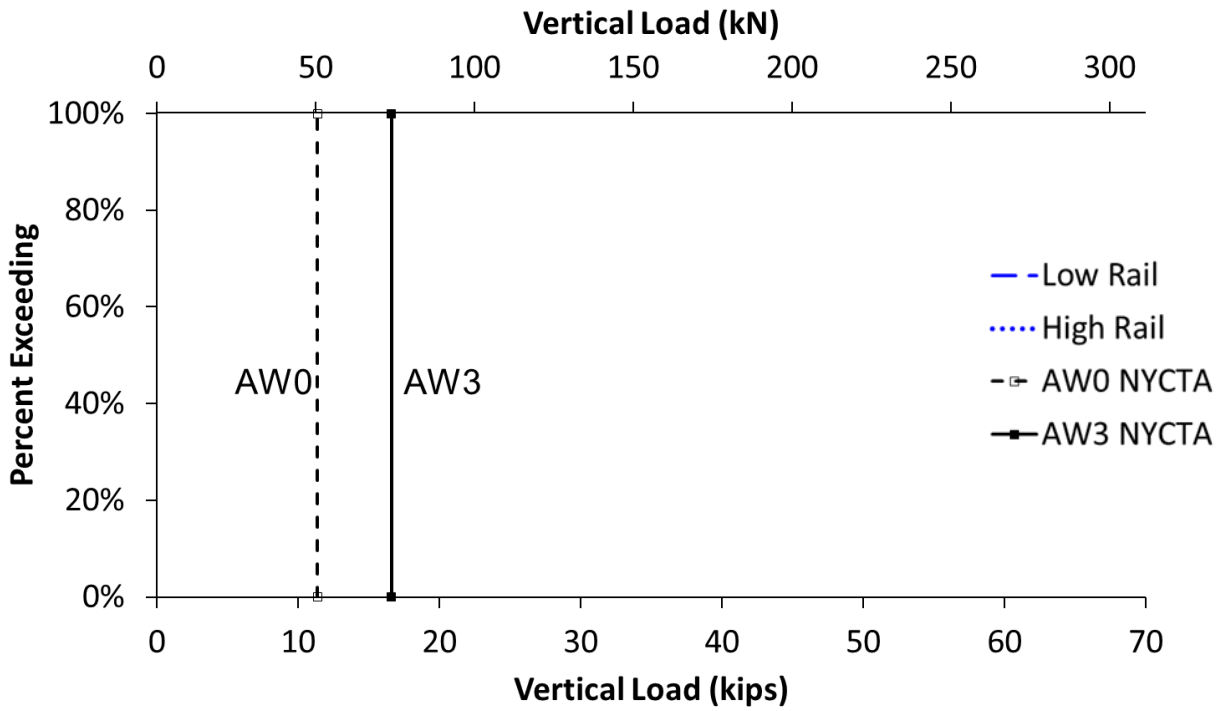


Trains in Dataset: 2,245
From 26 April 2016
to 30 June 2016

New York City Transit

Vertical Rail Loads

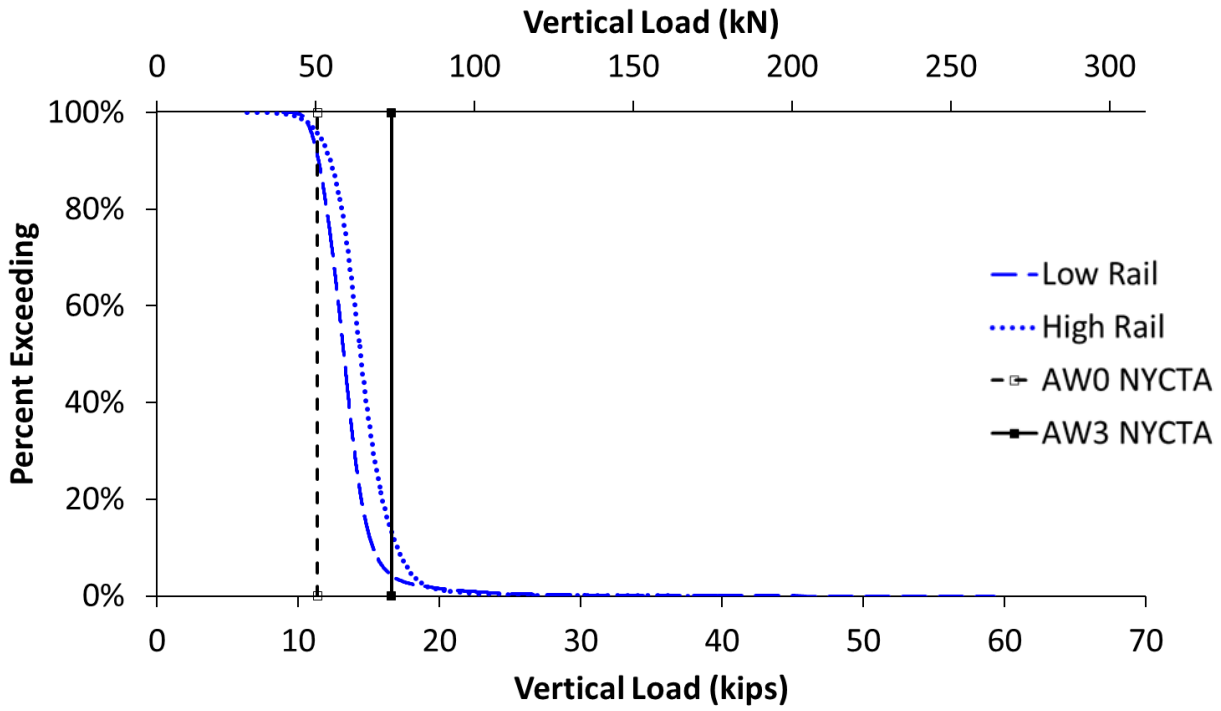
MTA New York City Transit (Curve)



New York City Transit

Vertical Rail Loads

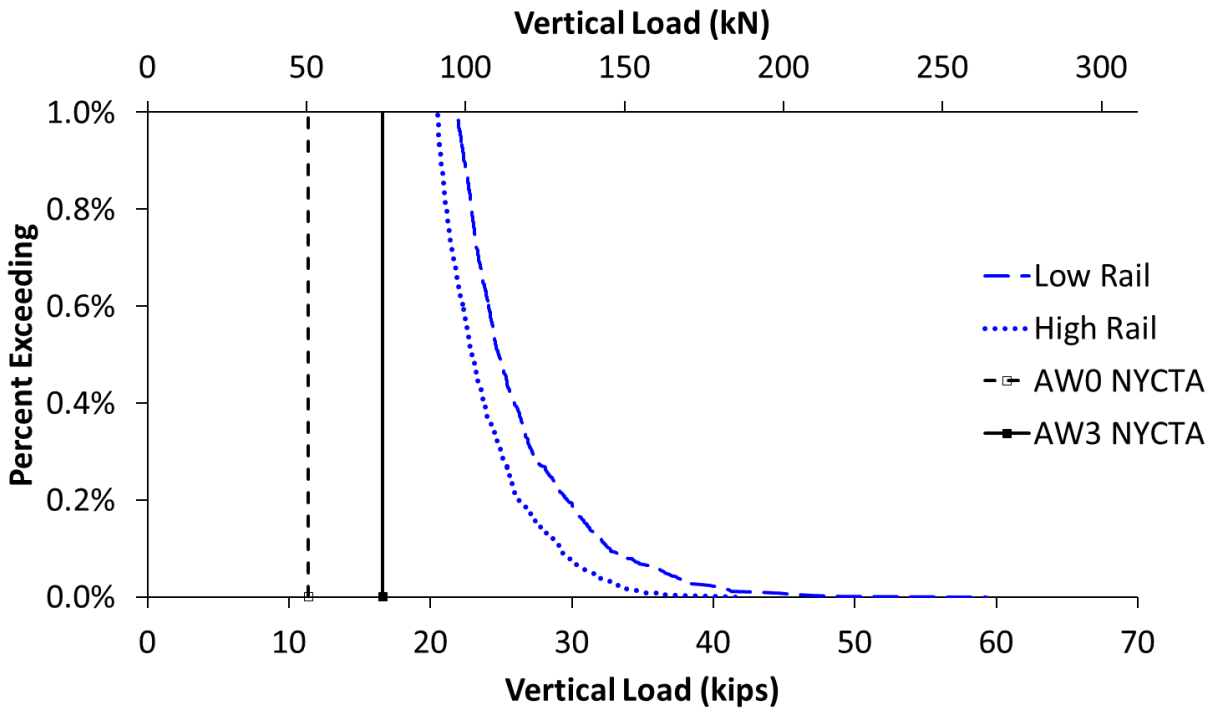
MTA New York City Transit (Curve)



New York City Transit

Vertical Rail Loads

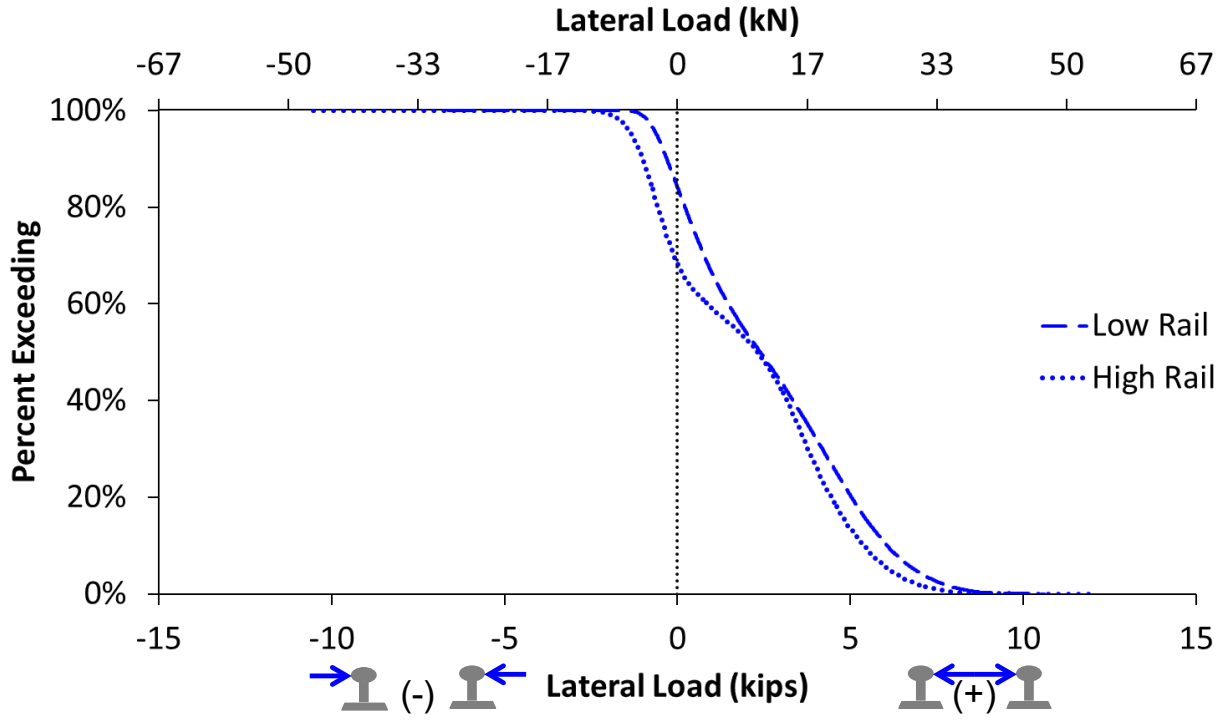
MTA New York City Transit (Curve)



New York City Transit

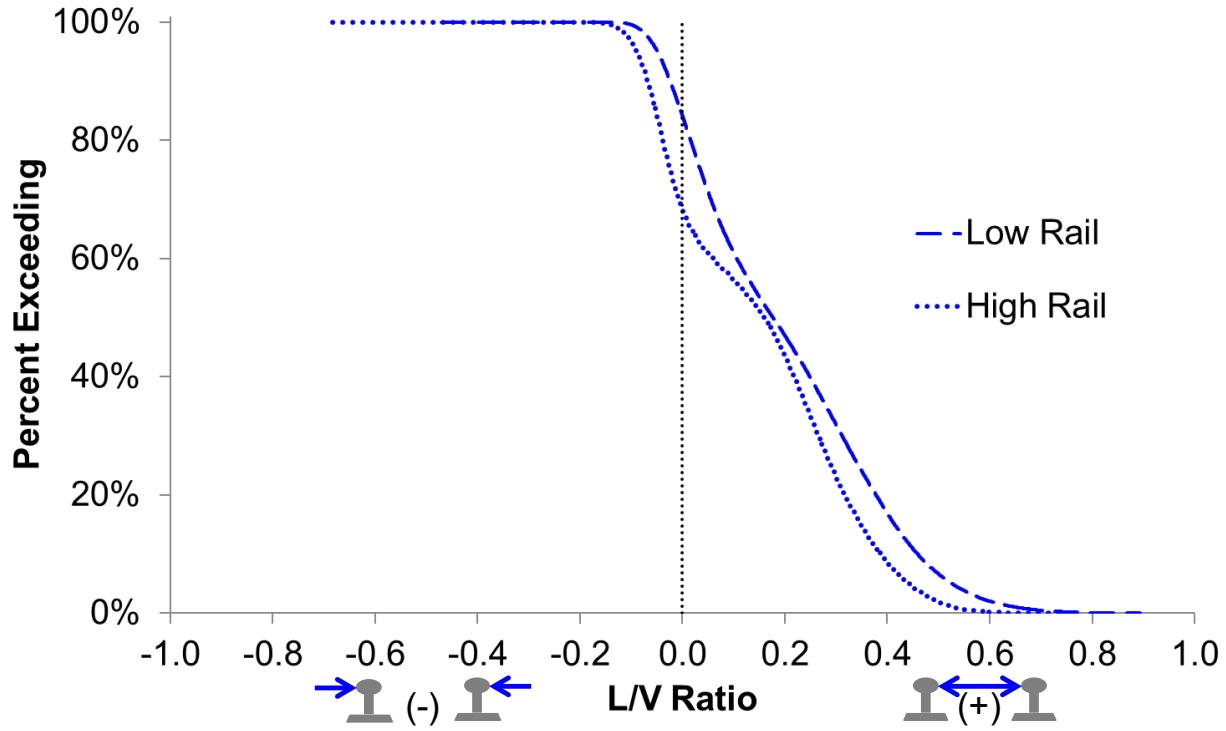
Lateral Rail Loads

MTA New York City Transit (Curve)



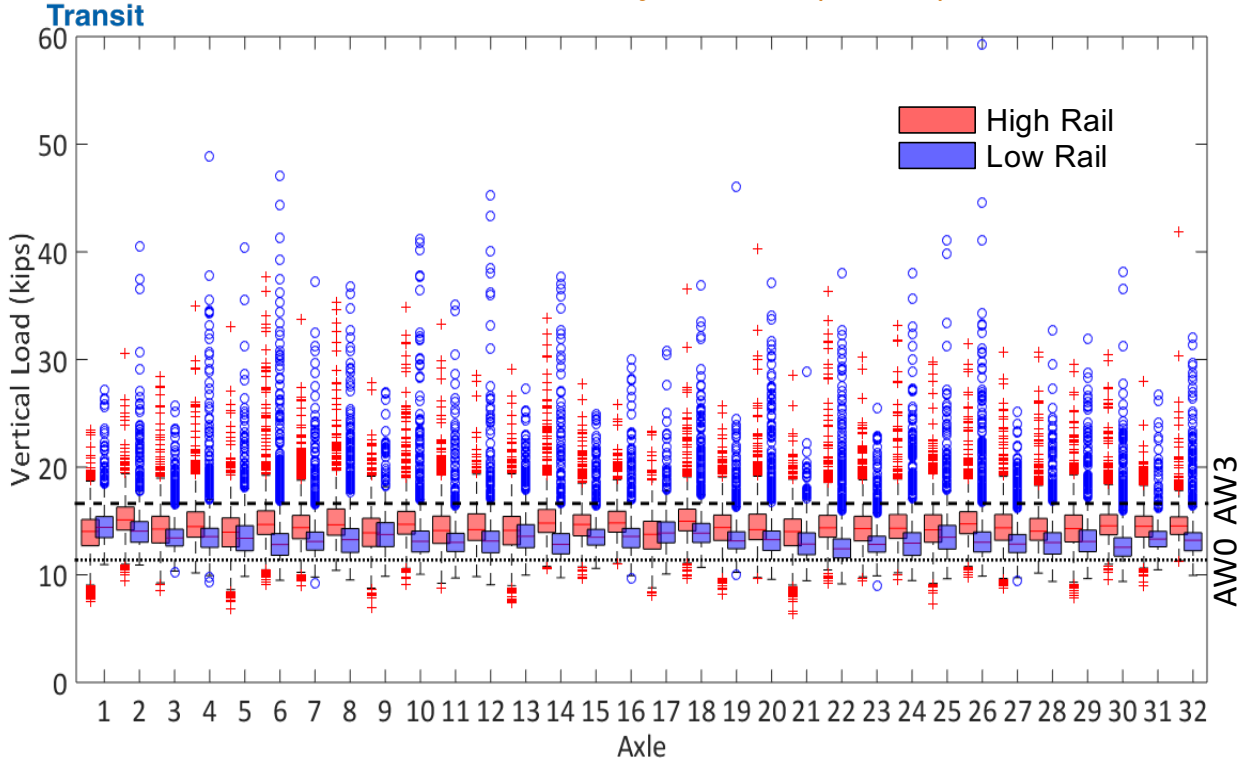
Lateral to Vertical (L/V) Ratios

MTA New York City Transit (Curve)



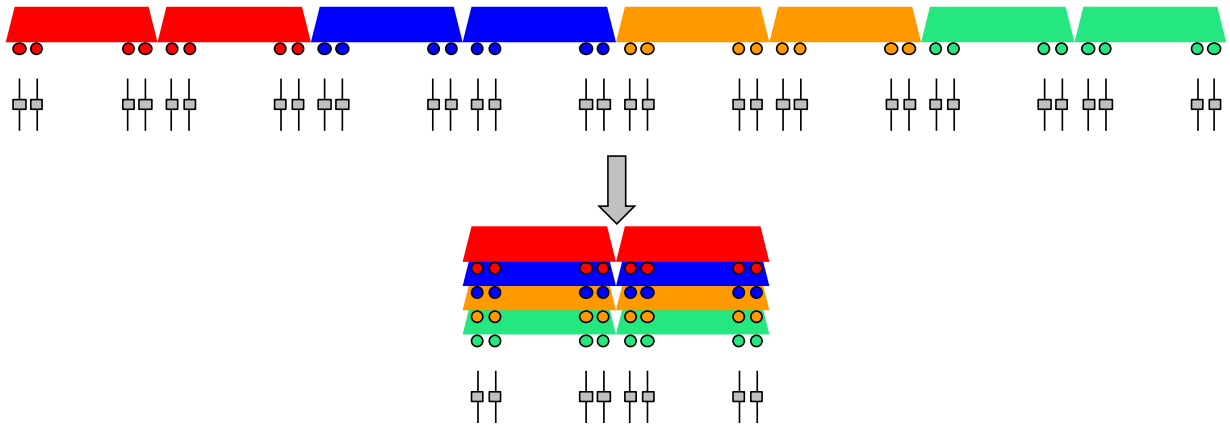
Vertical Wheel Loads

MTA New York City Transit (Curve)



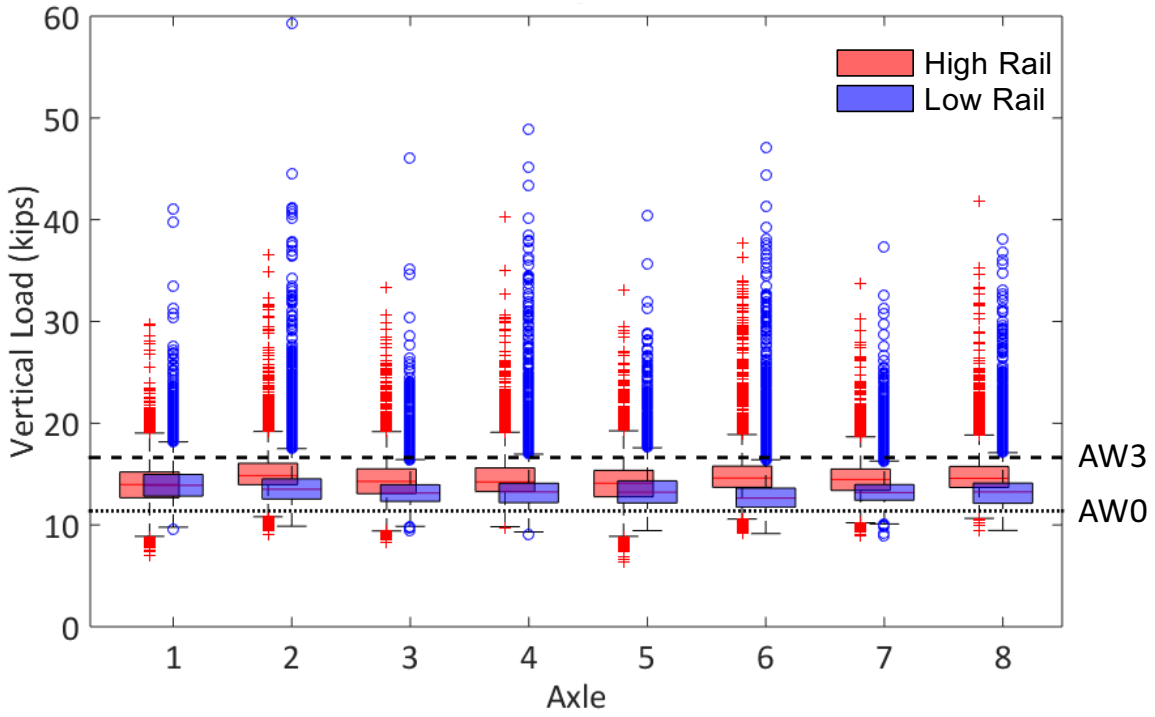
"Compressing" the Previous Chart

- Each NYCTA train consists of 4 two-car sets, so each 8 axles is a 'repeat' of the equipment (order aside)
- The last chart can be compressed by stacking 'repeat' axles



Vertical Wheel Loads

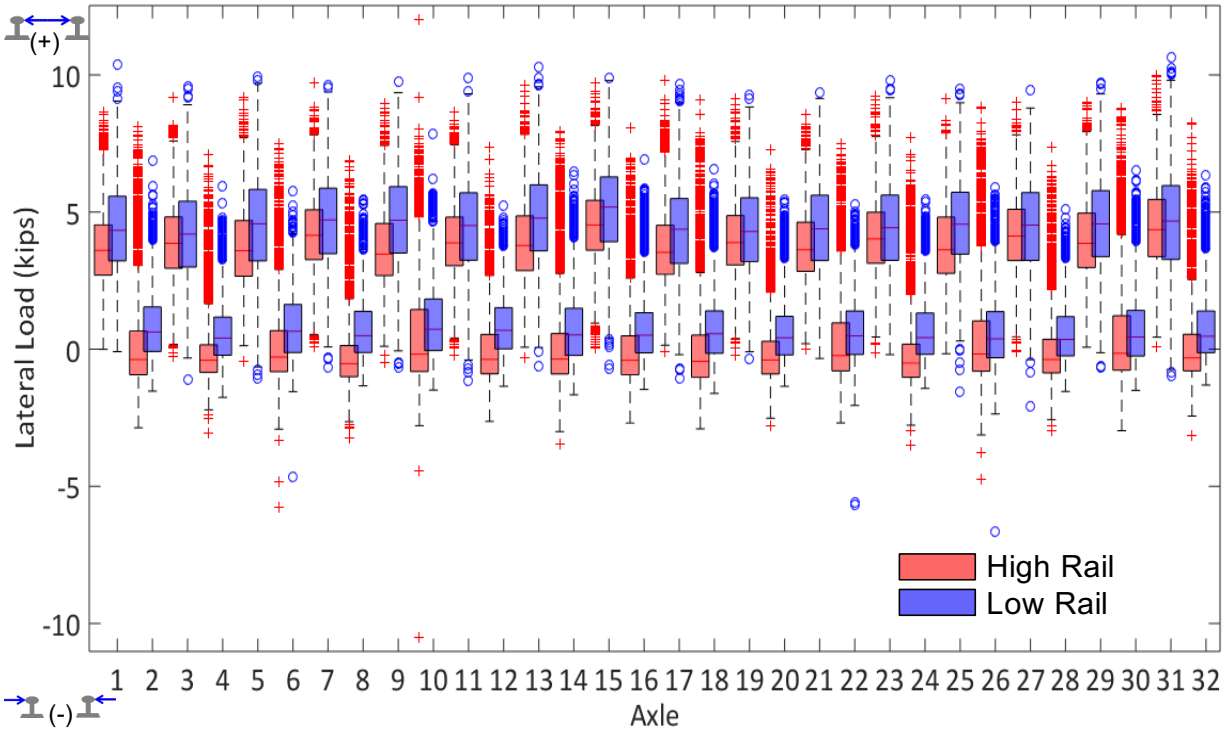
MTA New York City Transit (Curve)



New York City Transit

Lateral Wheel Loads

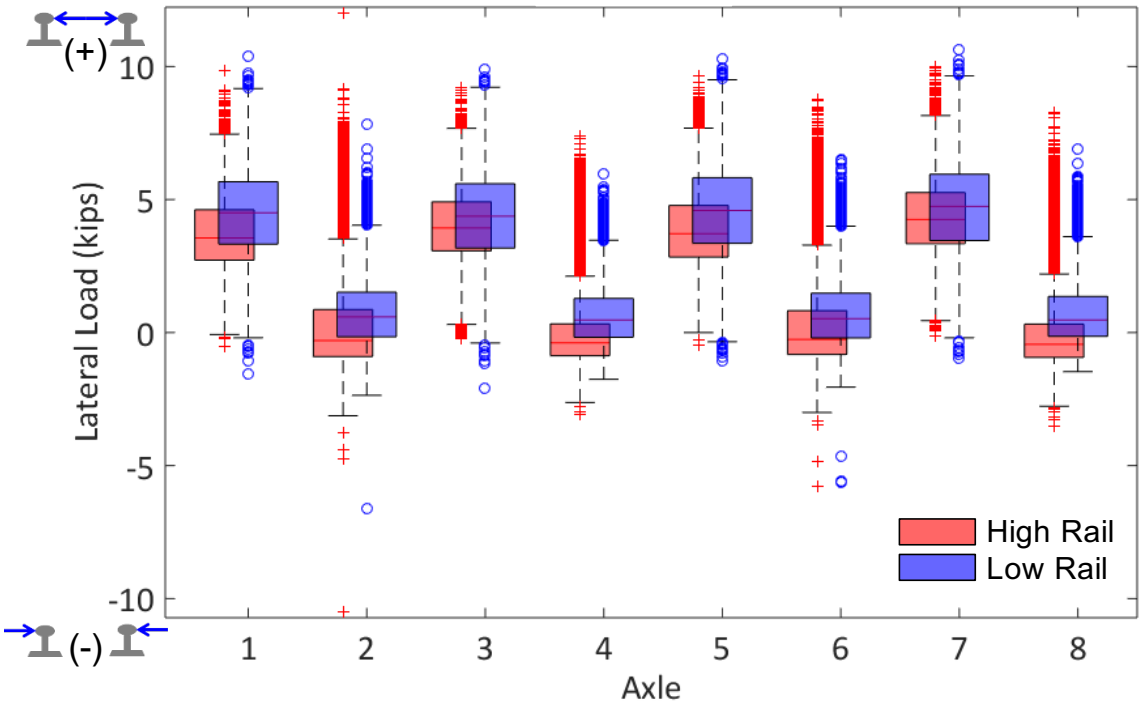
MTA New York City Transit (Curve)



New York City Transit

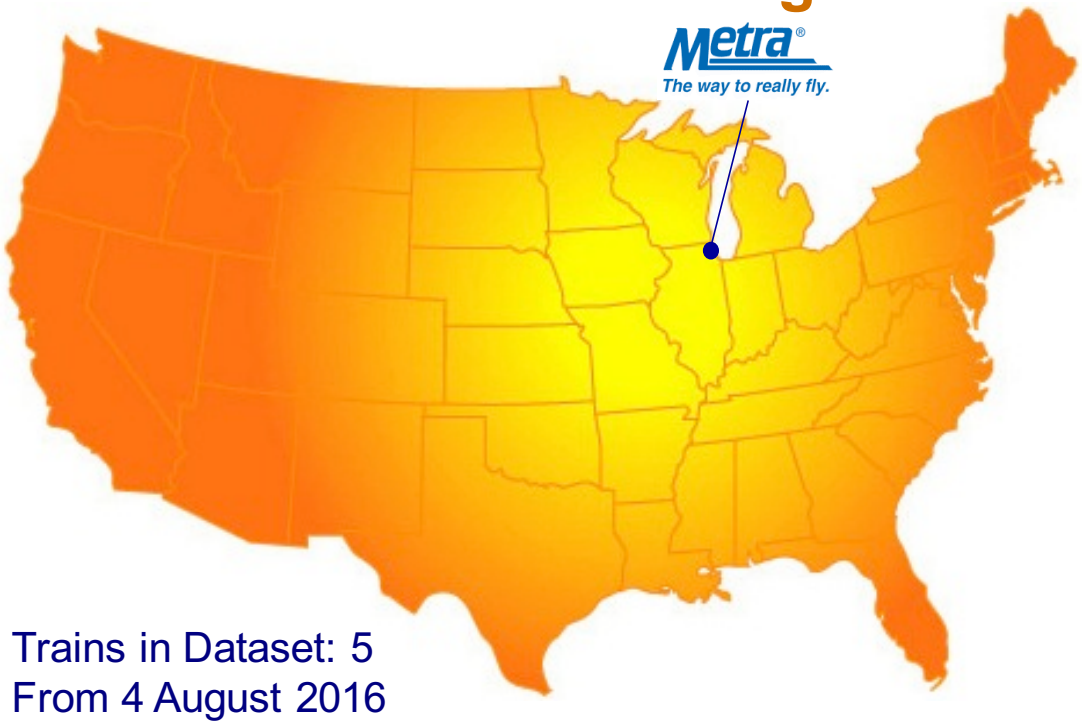
Lateral Wheel Loads

MTA New York City Transit (Curve)



Partner Agencies

Commuter Rail Tangent Data



Trains in Dataset: 5
From 4 August 2016
to 5 August 2016

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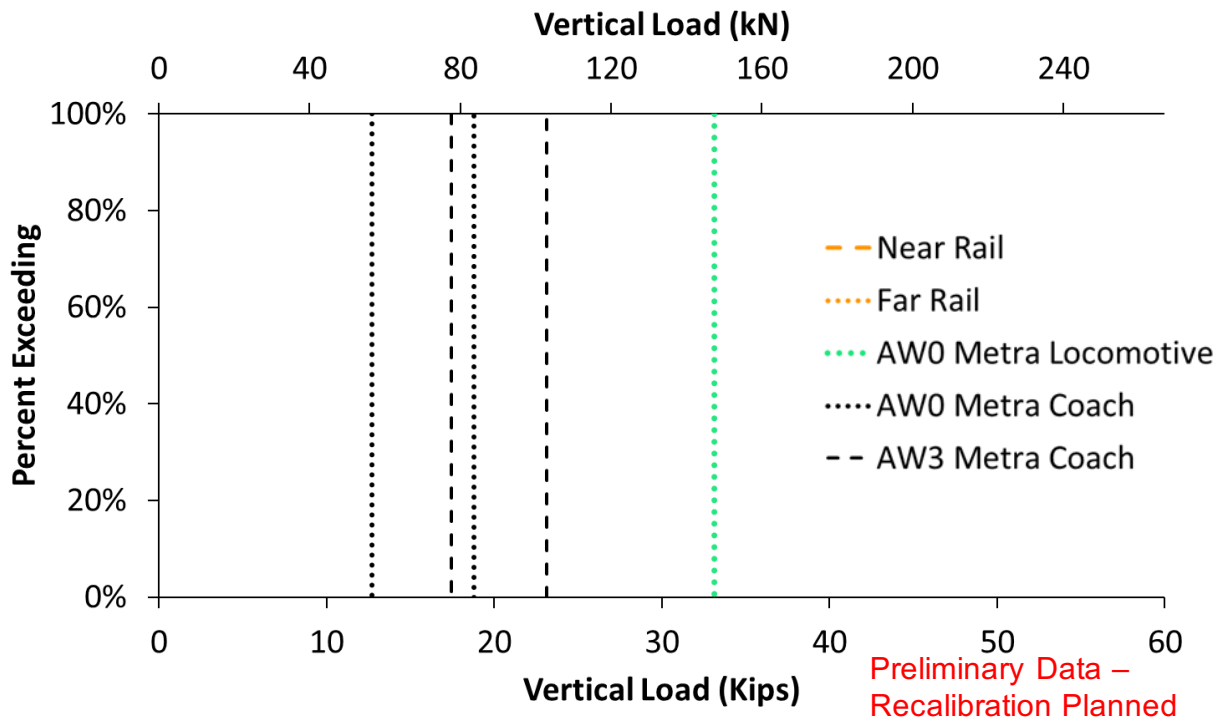
Vertical Rail Loads

Chicago Metra (Tangent)



Preliminary Data – Recalibration Planned

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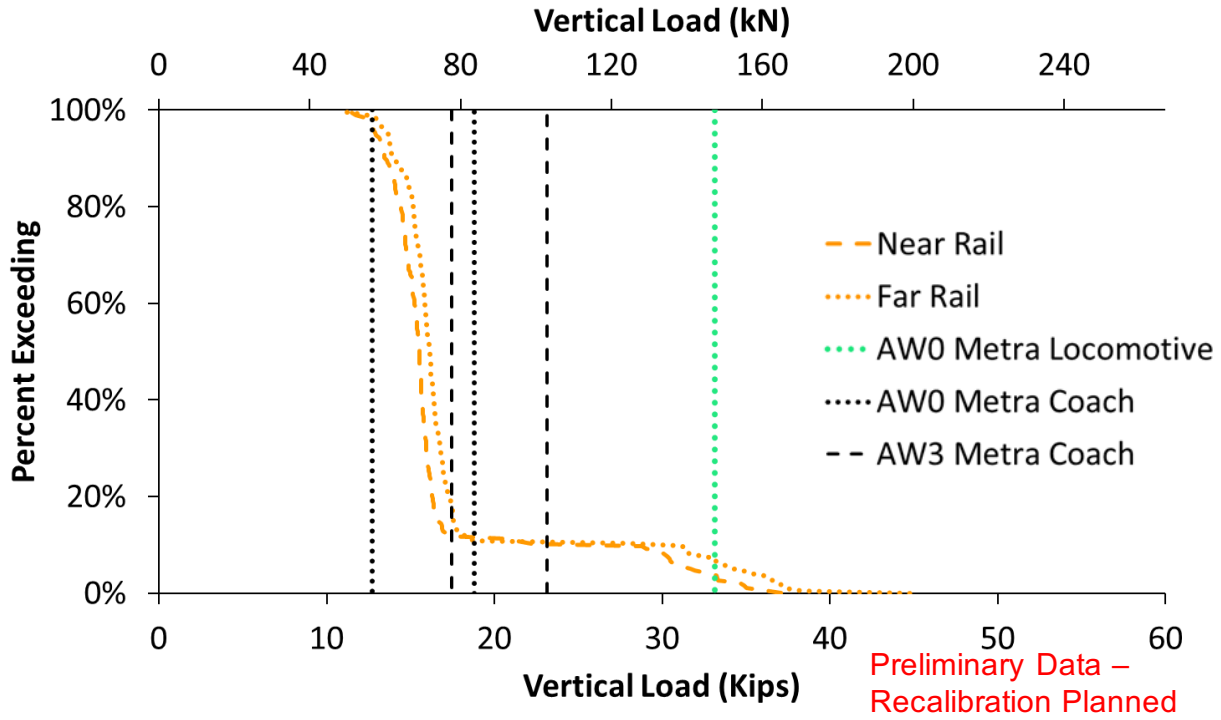
Vertical Rail Loads

Chicago Metra (Tangent)



Preliminary Data – Recalibration Planned

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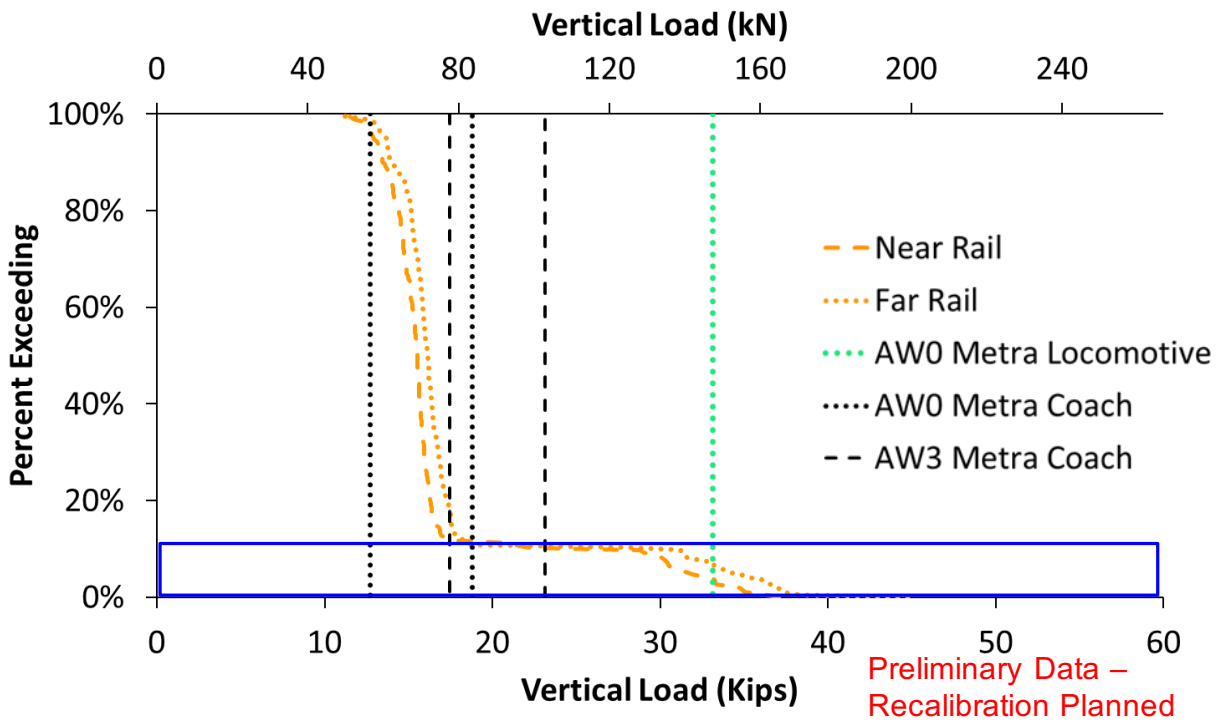
Vertical Rail Loads

Chicago Metra (Tangent)



Preliminary Data – Recalibration Planned

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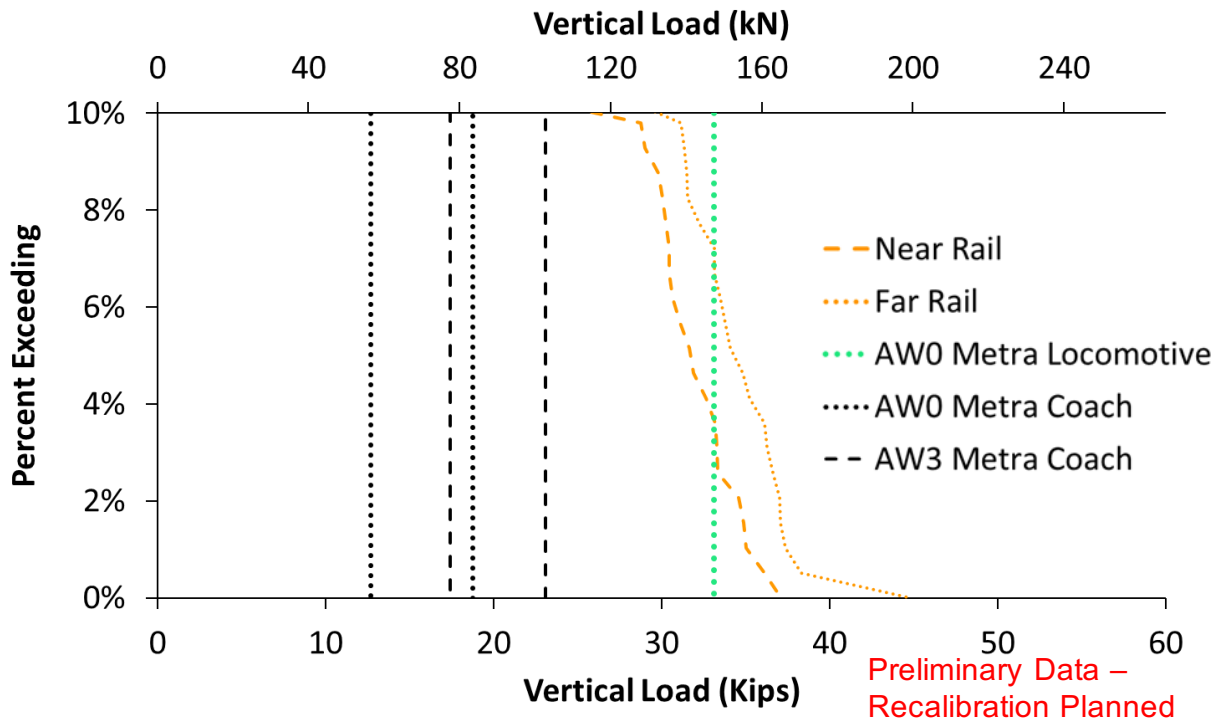
Vertical Rail Loads

Chicago Metra (Tangent)



Preliminary Data – Recalibration Planned

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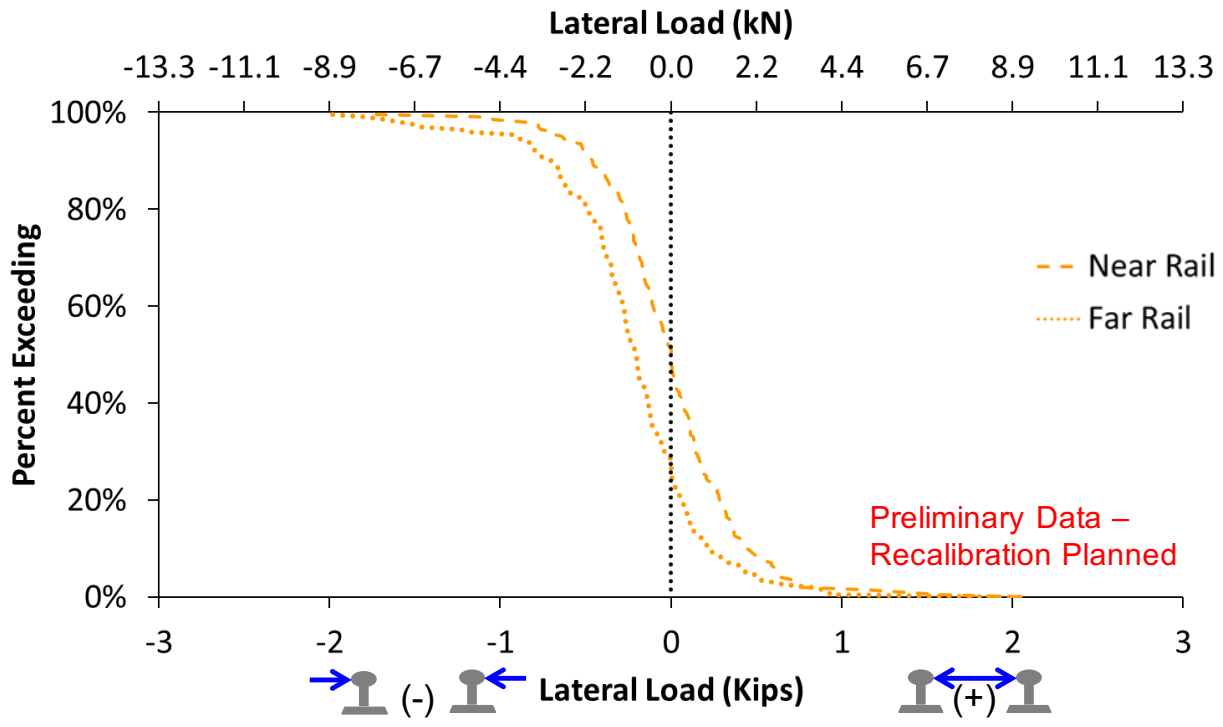
Lateral Rail Loads

Chicago Metra (Tangent)



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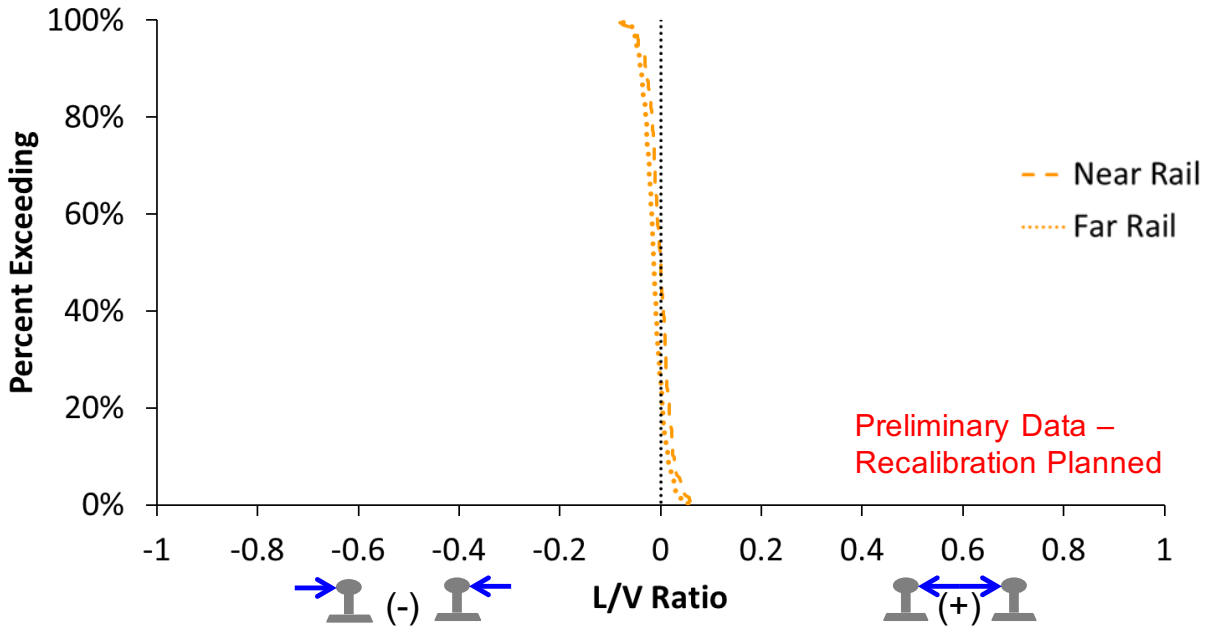
Lateral to Vertical (L/V) Ratios

Chicago Metra (Tangent)



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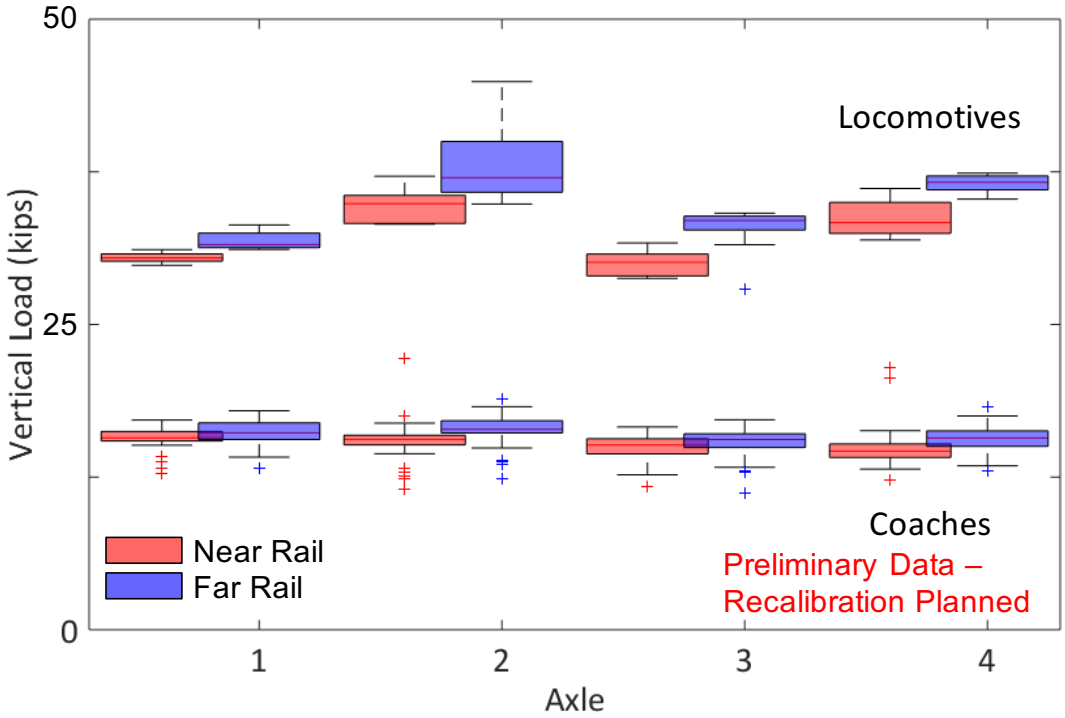
Vertical Wheel Loads

Chicago Metra (Tangent)



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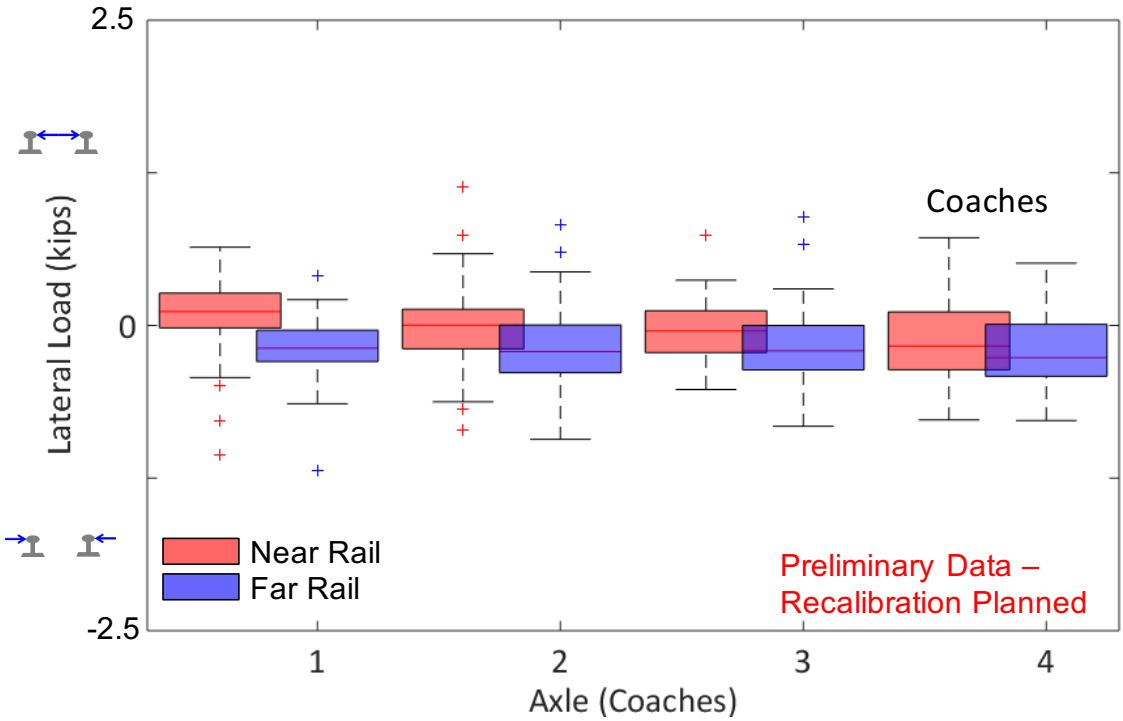
Lateral Wheel Loads

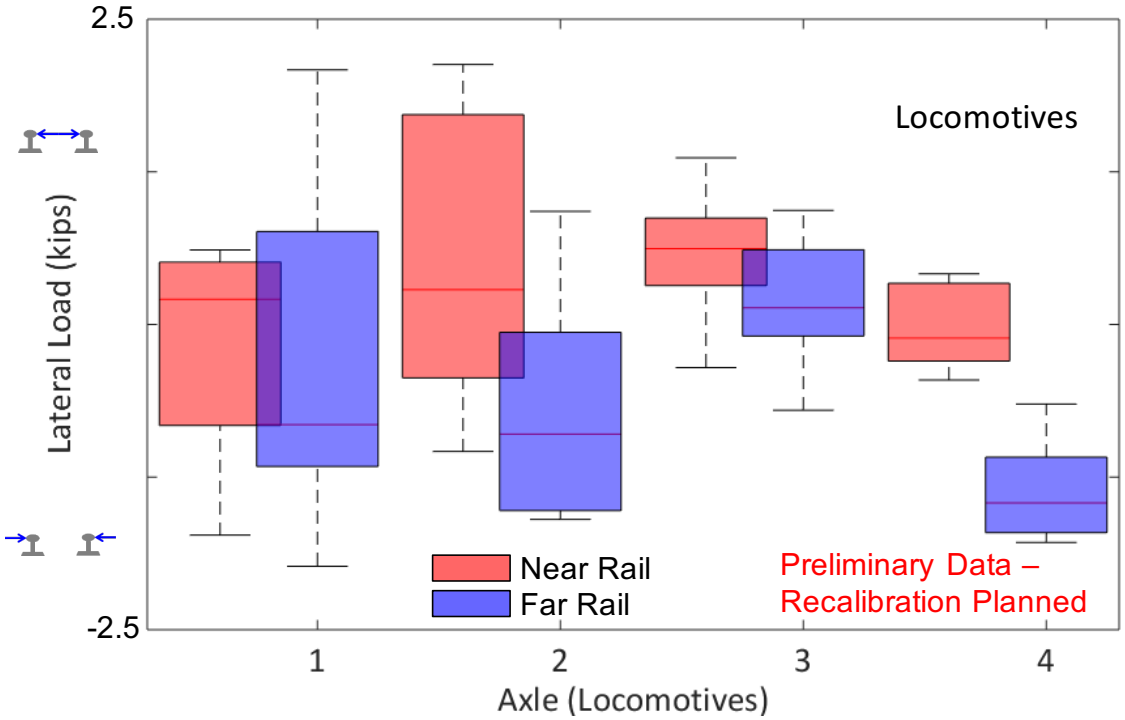
Chicago Metra (Tangent)



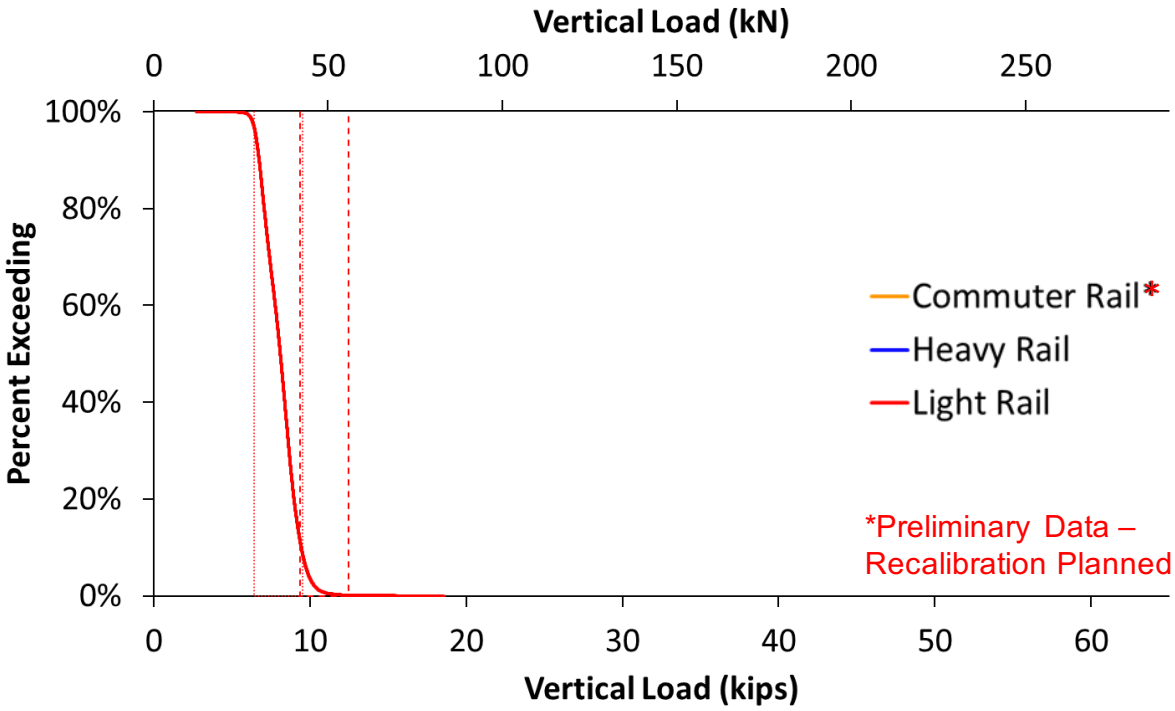
Metra®
The way to really fly.

Lateral Wheel Loads

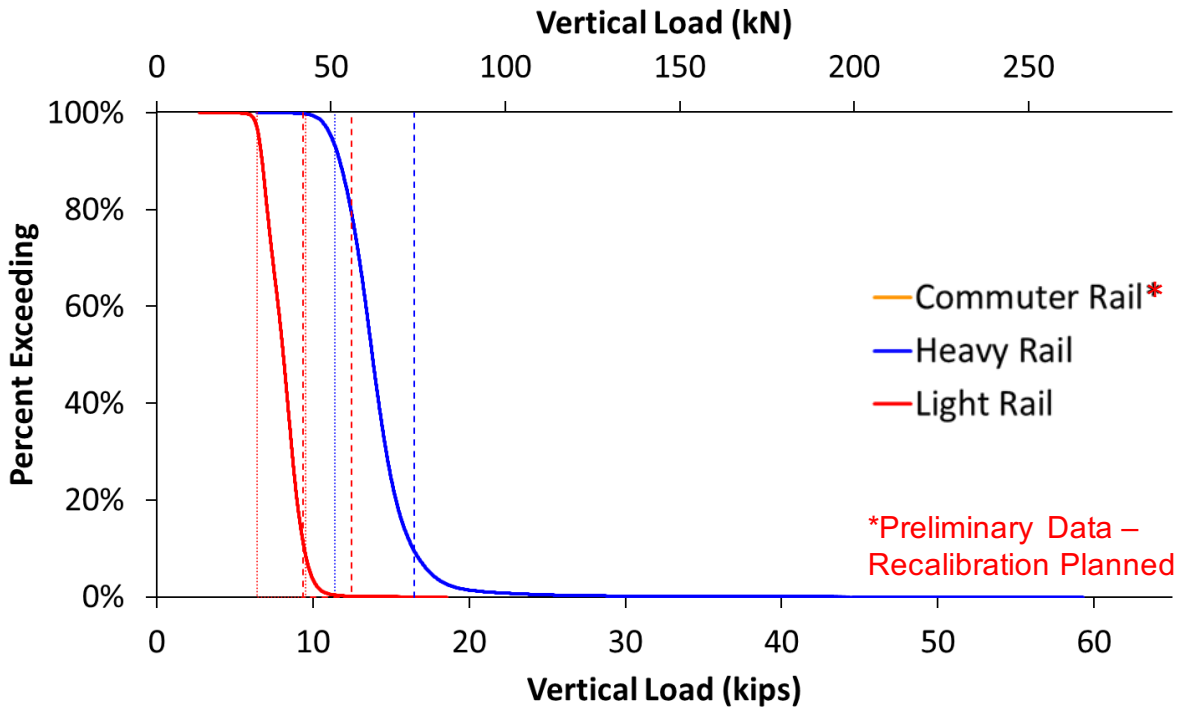
Chicago Metra (Tangent)



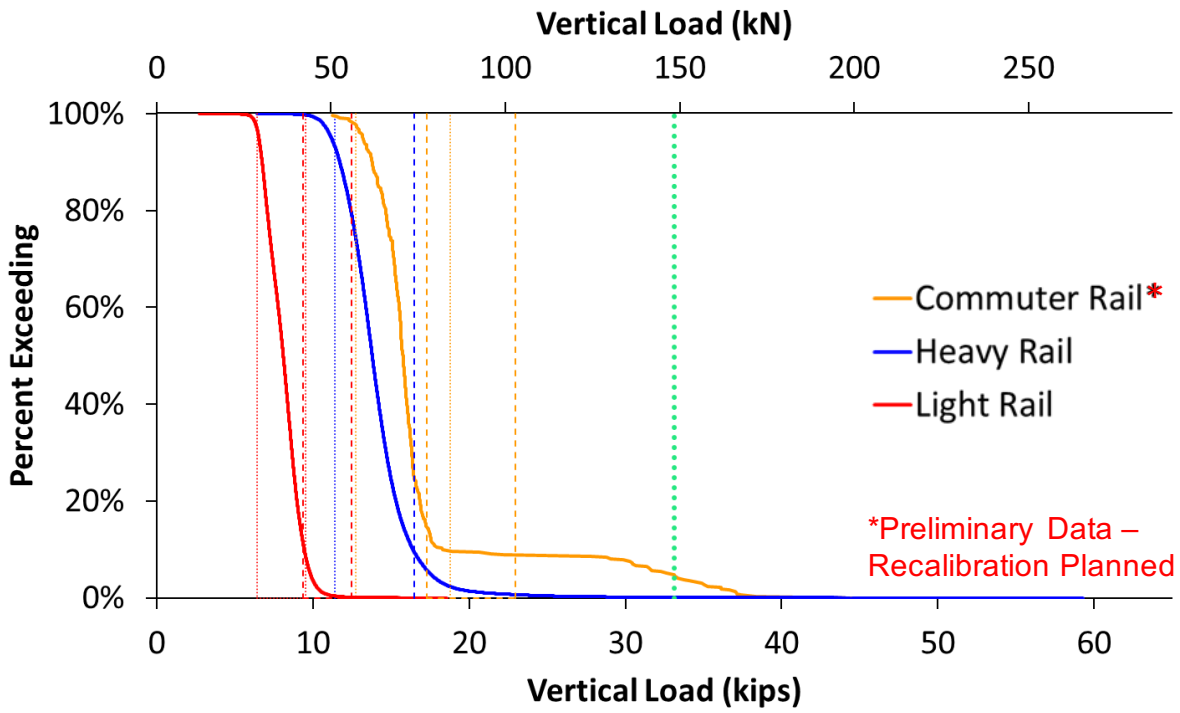
Modal Comparison: Vertical Wheel Loads



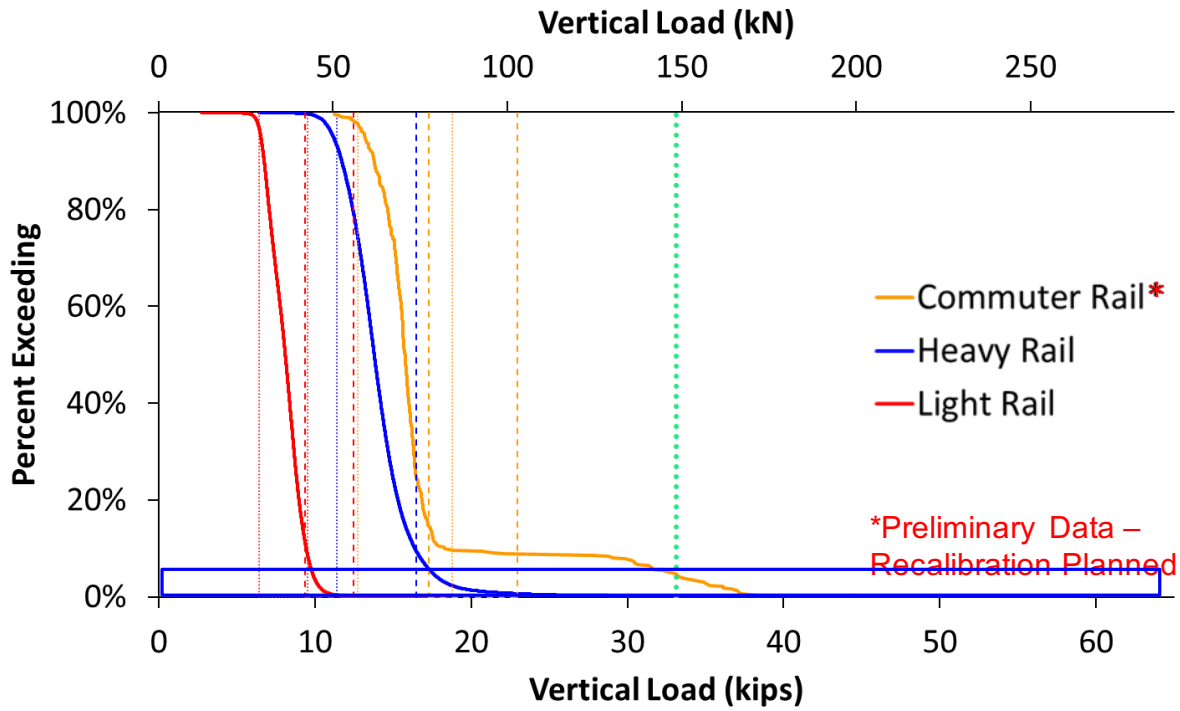
Modal Comparison: Vertical Wheel Loads



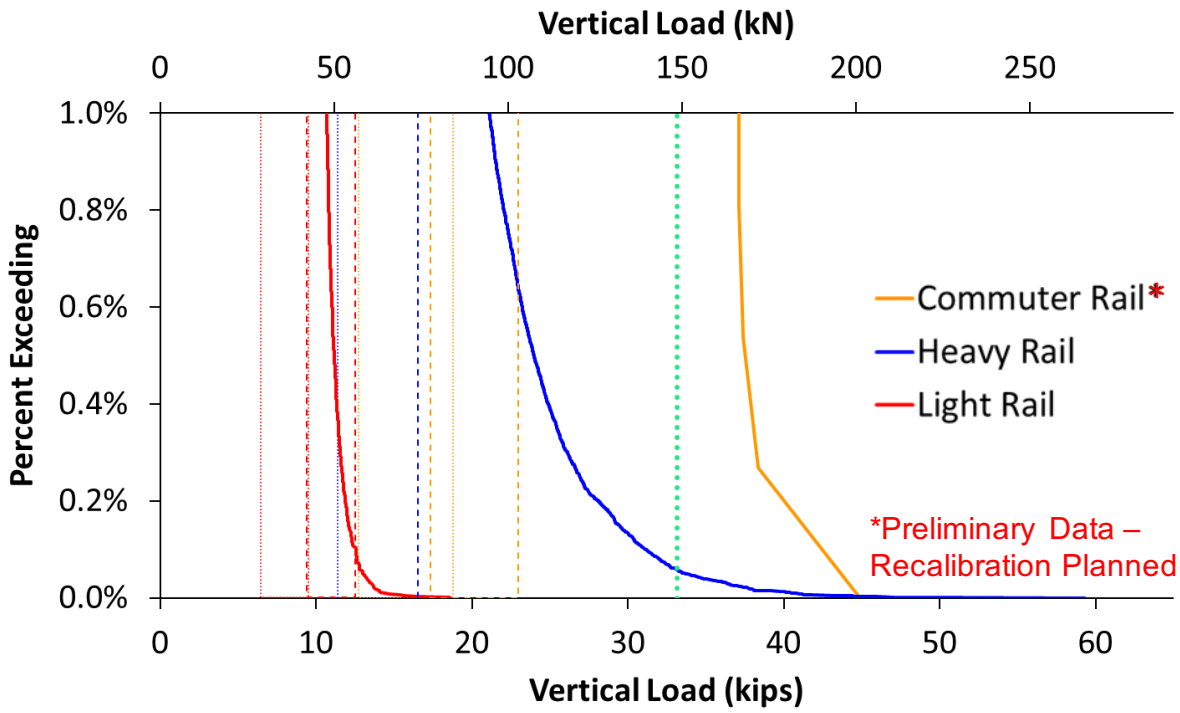
Modal Comparison: Vertical Wheel Loads



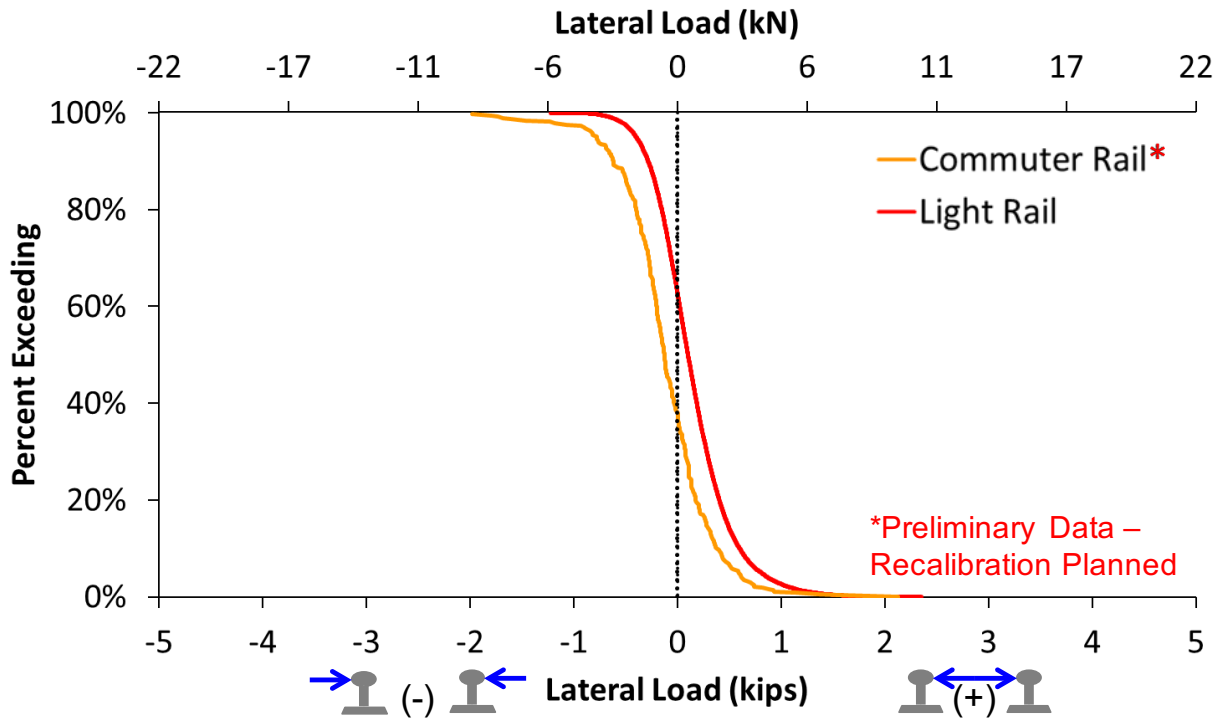
Modal Comparison: Vertical Wheel Loads



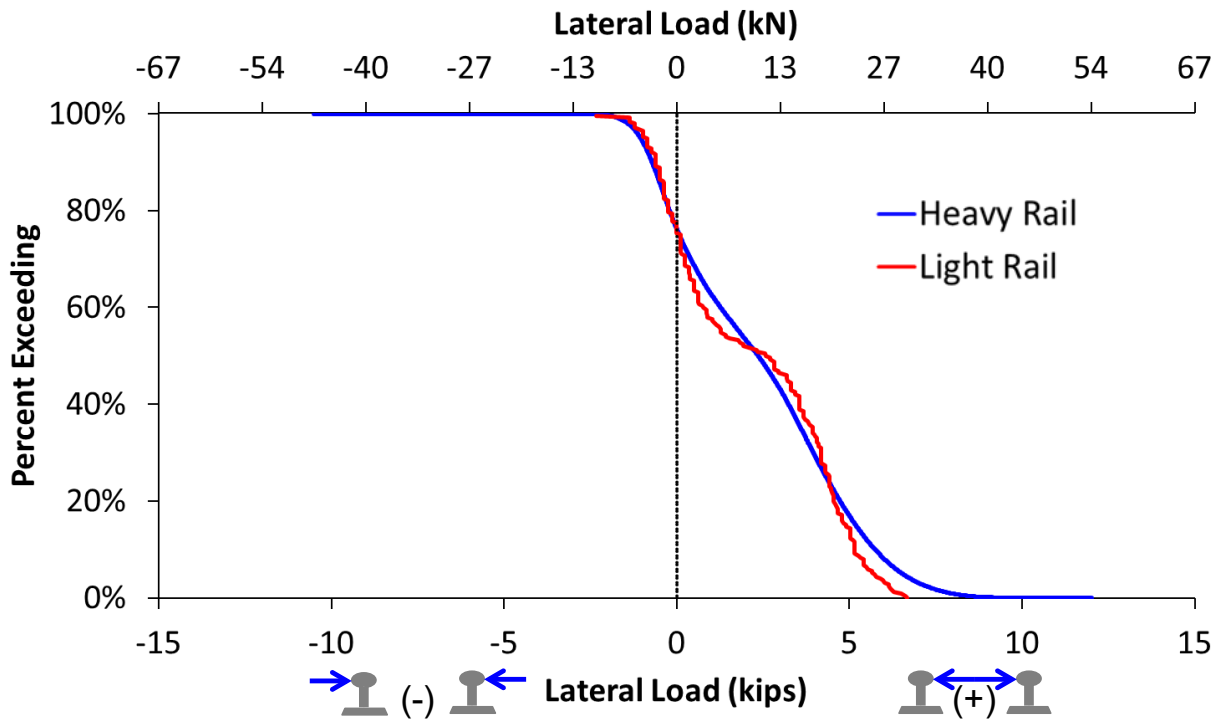
Modal Comparison: Vertical Wheel Loads



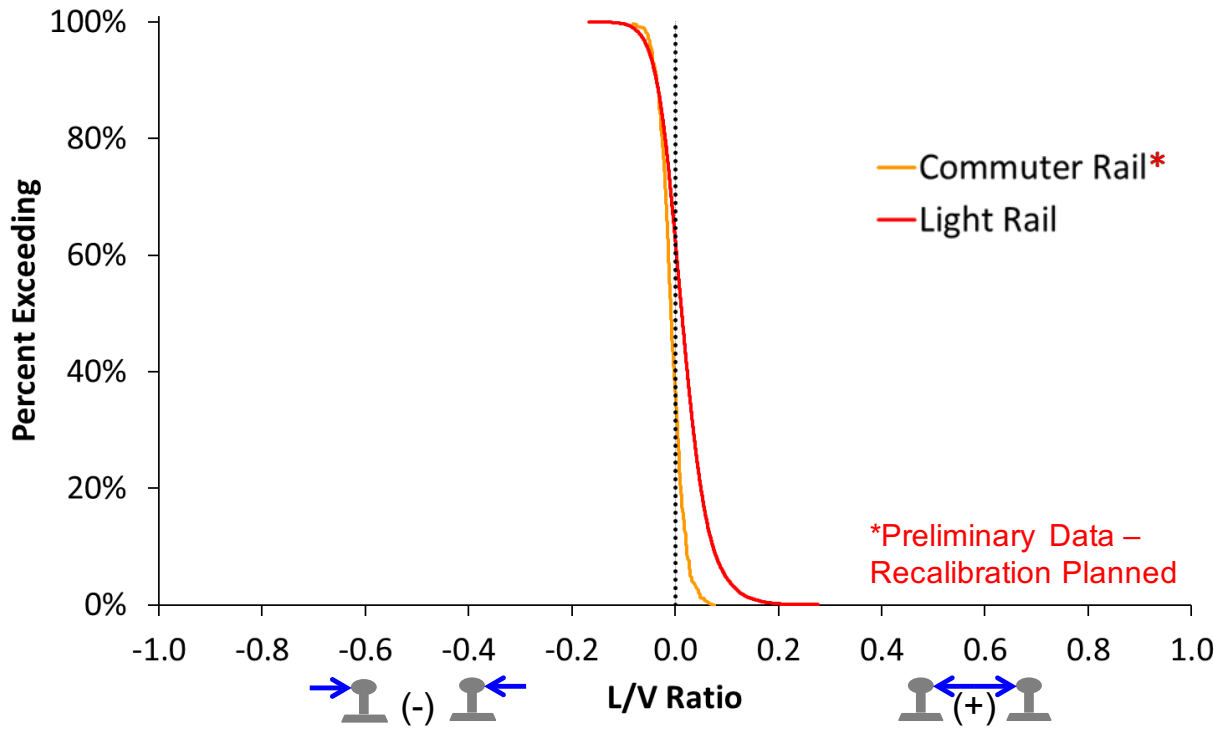
Modal Comparison: Lateral Loads Tangent Locations



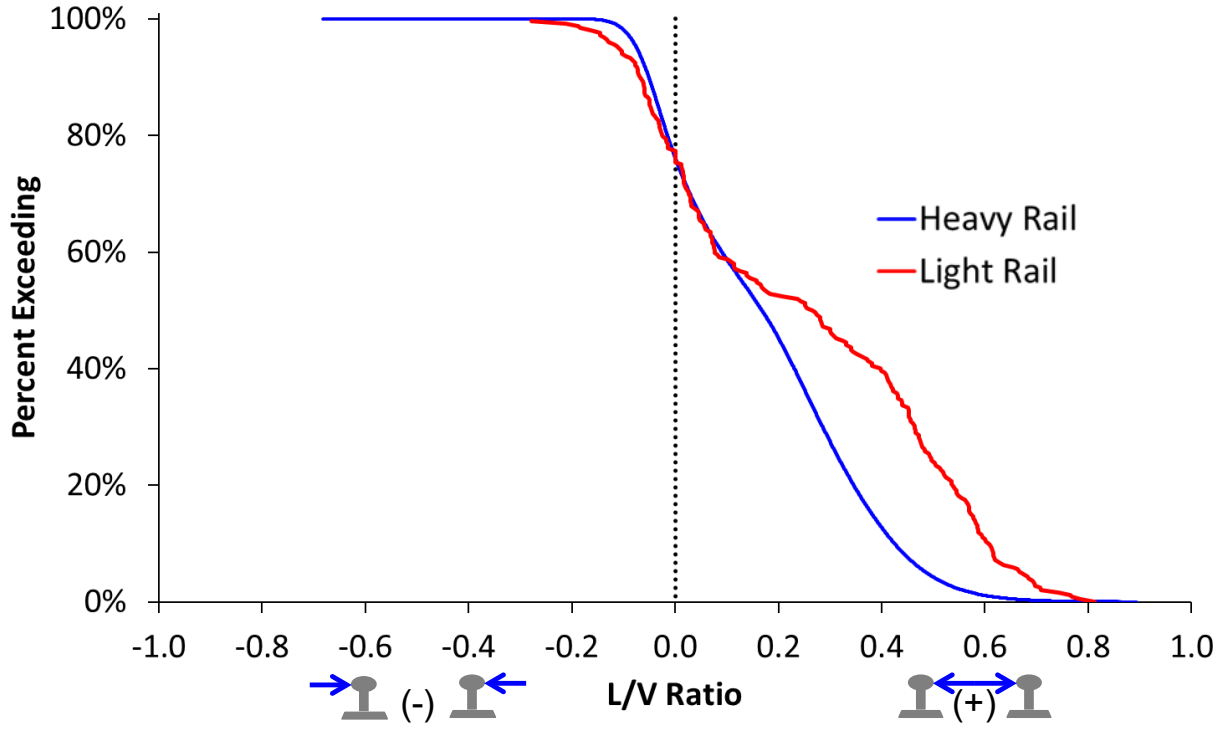
Modal Comparison: Lateral Loads Curve Locations



Modal Comparison: L/V Ratios Tangent Locations



Modal Comparison: L/V Ratios Curve Locations



Vertical Load Percentiles for Each Mode

Percentile Vertical Load	Light Rail (Tangent) kips (kN)	Heavy Rail (Curve) kips (kN)	Commuter Rail* (Tangent) kips (kN)
Minimum	2.7 (12.2)	6.4 (28.5)	11.2 (49.9)
50%	8.1 (36.0)	13.8 (61.4)	15.8 (70.1)
90%	9.4 (42.0)	16.4 (72.9)	18.3 (81.3)
95%	9.8 (43.8)	17.5 (77.8)	32.6 (145.2)
99%	10.7 (47.5)	21.1 (93.8)	37.1 (165.0)
Maximum	18.6 (82.6)	59.3 (263.9)	44.9 (199.7)
Sample Size (Wheel Passes)	53,880	143,680	372
Max. AW0	9.59 (42.6)	11.4 (50.6)	18.7 (83.5)
Max. AW3	12.5 (55.5)	16.6 (74.0)	23.1 (103.0)

*Preliminary Data – Recalibration Planned

Impact Factor Percentiles for Each Mode

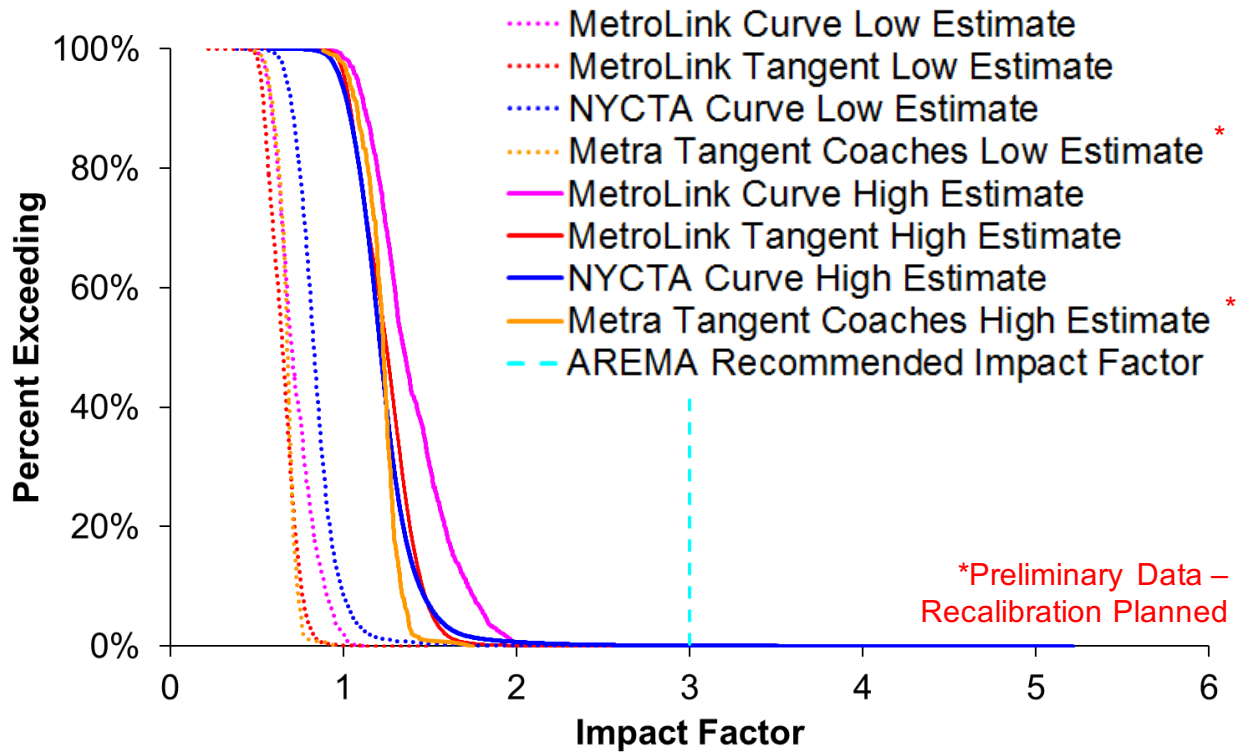
Percentile Impact Factor	Light Rail (Curve)	Light Rail (Tangent)	Heavy Rail (Curve)	Commuter Rail* (Tangent, Coaches)
Minimum	0.47 – 0.91	0.22 - 0.42	0.39 - 0.56	0.49 - 0.88
50%	0.70 – 1.35	0.65 - 1.25	0.83 - 1.21	0.68 - 1.23
90%	0.90 – 1.72	0.76 - 1.46	0.99 - 1.44	0.73 - 1.33
95%	0.94 – 1.82	0.79 - 1.52	1.05 - 1.54	0.76 - 1.37
99%	1.02 – 1.97	0.86 - 1.65	1.27 - 1.85	0.79 - 1.44
Maximum	1.14 – 2.19	1.49 - 2.86	3.57 - 5.21	0.96 - 1.74

$$Impact\ Factor = \frac{Dynamic\ Load}{Static\ Load}$$

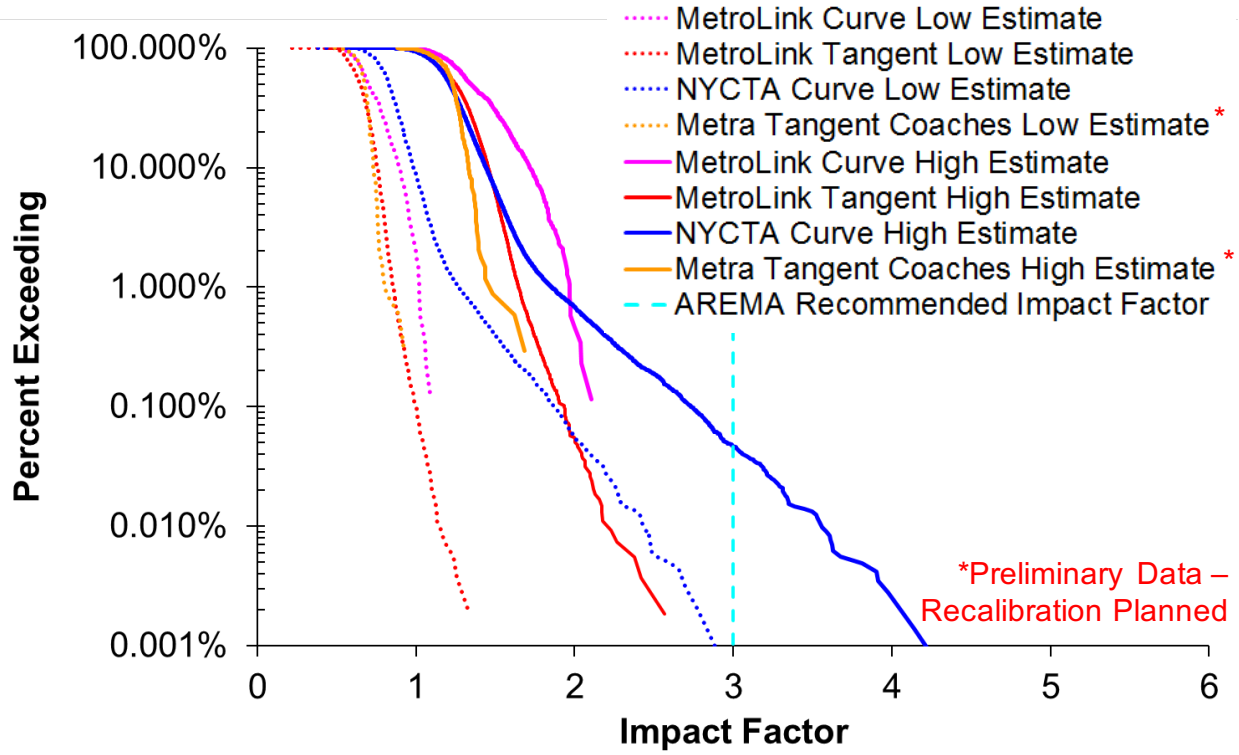
Static load is compared to Min. AW0 and Max. AW3

*Preliminary Data – Recalibration Planned

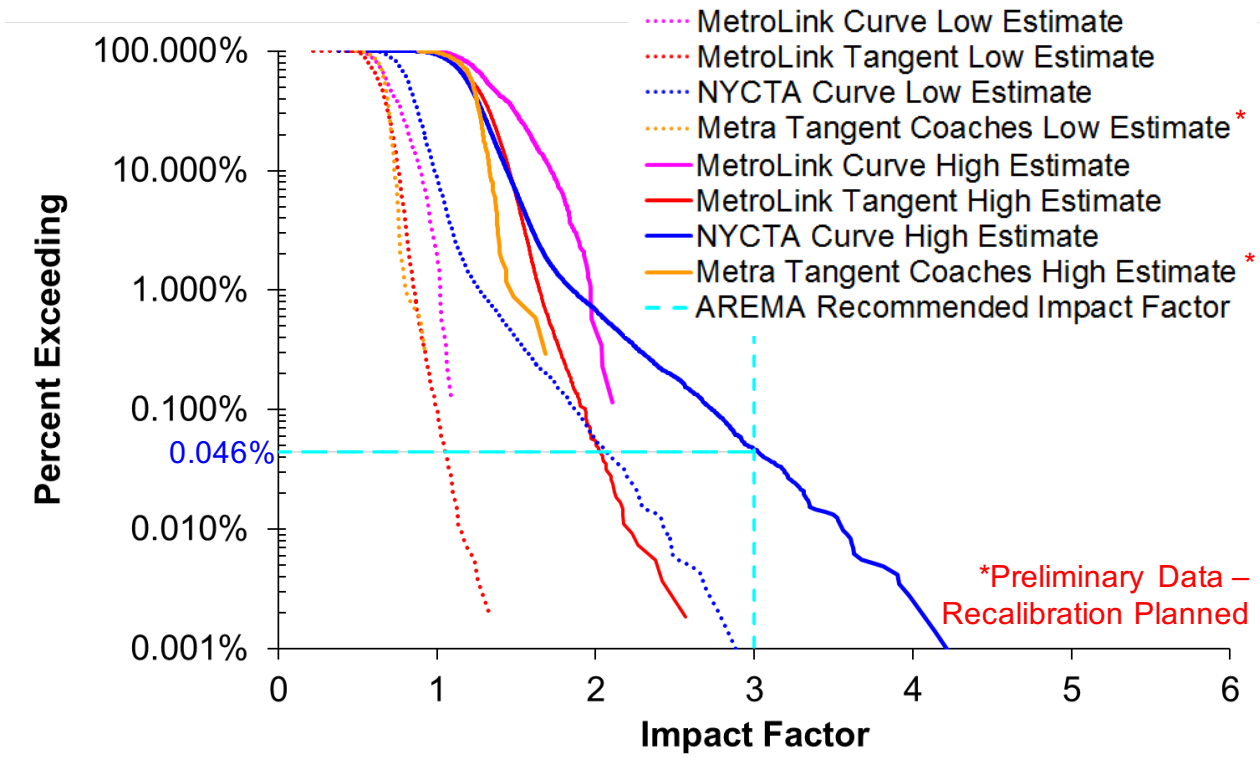
Impact Factor Comparison Chart



Impact Factor Comparison Chart



Impact Factor Comparison Chart



Lateral Load Percentiles for Each Mode

Percentile Lateral Load	Light Rail (Curve) kips (kN)	Light Rail (Tangent) kips (kN)	Heavy Rail (Curve) kips (kN)	Commuter Rail* (Tangent) kips (kN)
Minimum	-2.3 (-10.4)	-1.2 (-5.4)	-10.5 (-46.8)	-1.9 (-8.8)
50%	2.6 (11.5)	0.1 (0.5)	2.4 (10.5)	-0.1 (-0.6)
90%	5.2 (22.9)	0.6 (2.7)	5.7 (25.6)	0.4 (1.7)
95%	5.7 (25.4)	0.8 (3.6)	6.5 (29.1)	0.6 (2.6)
99%	6.4 (28.4)	1.3 (5.7)	7.9 (35.0)	0.9 (4.2)
Maximum	6.7 (29.7)	2.4 (10.4)	12.0 (53.5)	2.1 (9.5)
Sample Size (Wheel Passes)	120	26,690	143,680	372

*Preliminary Data – Recalibration Planned

Rail Load Data Conclusions

- Instrumentation has successfully captured wheel-rail loading data from 3 rail transit modes at 4 field sites
- At both curve locations, the high rail experiences the largest load in 99% of cases while the low rail experiences the absolute maximum load
- In comparing tangent locations, the L/V ratio varies more for lighter equipment (light rail vs. commuter rail), but this difference is not as distinct for curve sites
- Impact Factors for differ between modes; for example, between heavy and light rail the impact factor is:
  - 2.7 times greater at maximum load
  - 1.7 times greater at 99th percentile load

Path Forward

- Analyze extreme cases to understand better the environment leading to high wheel loads
- Study the influence of speed on vertical & lateral loads
- Use field data to evaluate the effectiveness of dynamic factor models and rail seat load models for light, heavy, and commuter rail systems
- Further study of L/V ratios and track/train dynamics
- Perform analysis of seasonal variation
- Recalibration and further collection of Metra data
- Further investigation of maintenance-of-way equipment loading conditions and their influence on design

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Progress Rail A Caterpillar Company
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LBFoster CXT Concrete Ties

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