Quantification of Impact Factors:
Results from Rail Transit Systems



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U.S. Department of Transportation
Federal Transit Administration

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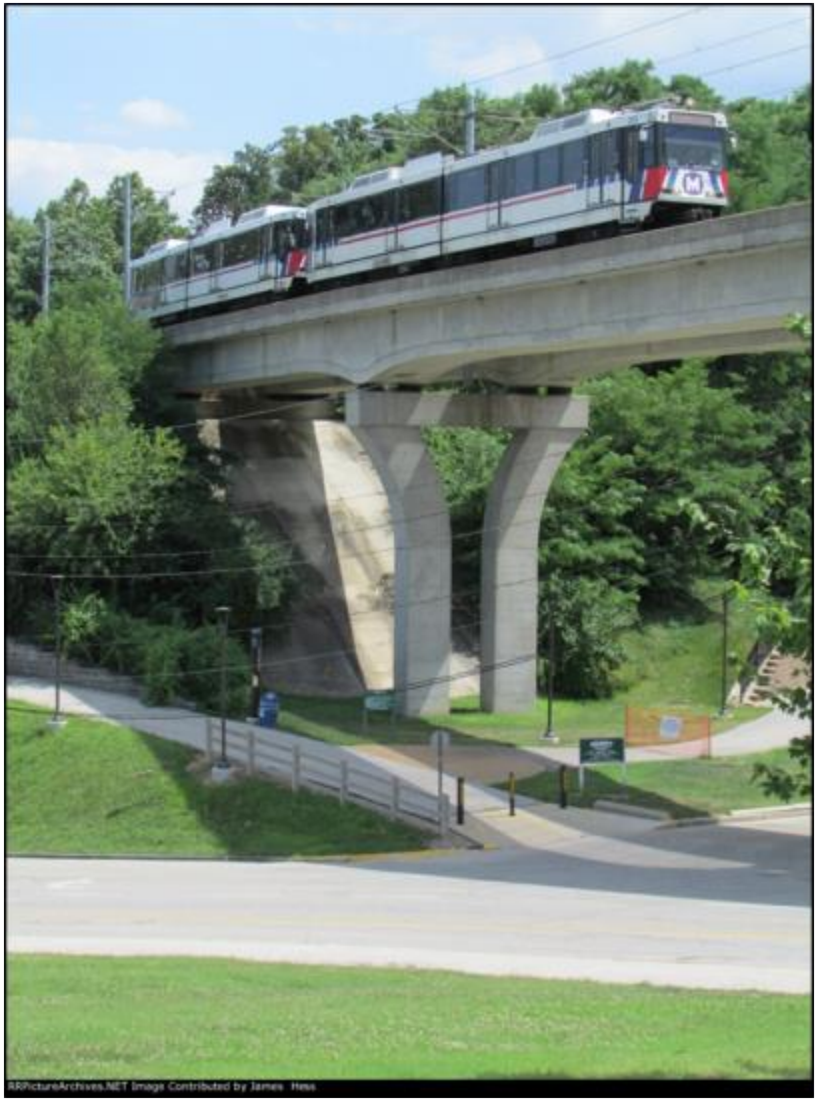
Outline

- Project Background
- Estimation of Static Loads
- Field Quantification of Wheel-Rail Loads
  - Light Rail
  - Heavy Rail
  - Commuter Rail
- Summary of Rail Transit Loading Conditions
- Future Research
- Questions and Comments



Background and Problem Statement

- Rail transit systems have unique loading conditions due to the variety of vehicles used from system to system
- Limited research has been conducted to understand the type and **magnitude of loads** in rail transit systems
- Aging rail transit infrastructure assets need to be well maintained or replaced to keep the system in a “state of good repair” – a USDOT Strategic Goal

FTA Project Mission

Characterize the desired performance and resiliency requirements for concrete crossties and fastening systems, quantify their behavior under load, and develop resilient infrastructure component design solutions for concrete crossties and fastening systems for rail transit operators.

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FTA Project Acknowledgements

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NURail Center

FTA Industry Partners:

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  - **National University Rail Center (NURail Center)**
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  - American Public Transportation Association (APTA)
  - New York City Transit (NYCTA)
  - Metra (Chicago, Ill.)
  - MetroLink (St. Louis, Mo.)
  - TriMet (Portland, Ore.)
  - Pandrol USA
  - Progress Rail Services
  - LBFoster, CXT Concrete Ties
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  - Hanson Professional Services, Inc.
  - Amtrak
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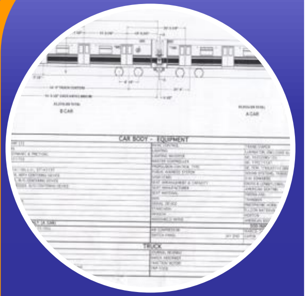
FTA Project Approach

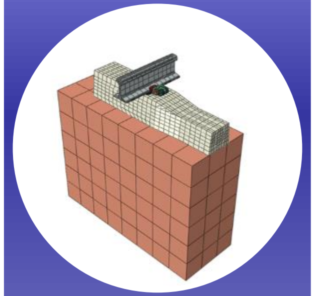


Paper Study

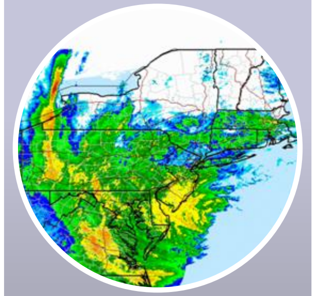
Industry Surveys

Field Data Collection

Laboratory Experimentation



Finite Element Modelling



Environmental Factors and Special Circumstances

Resilient Concrete Crosstie and Fastening System for Rail Transit

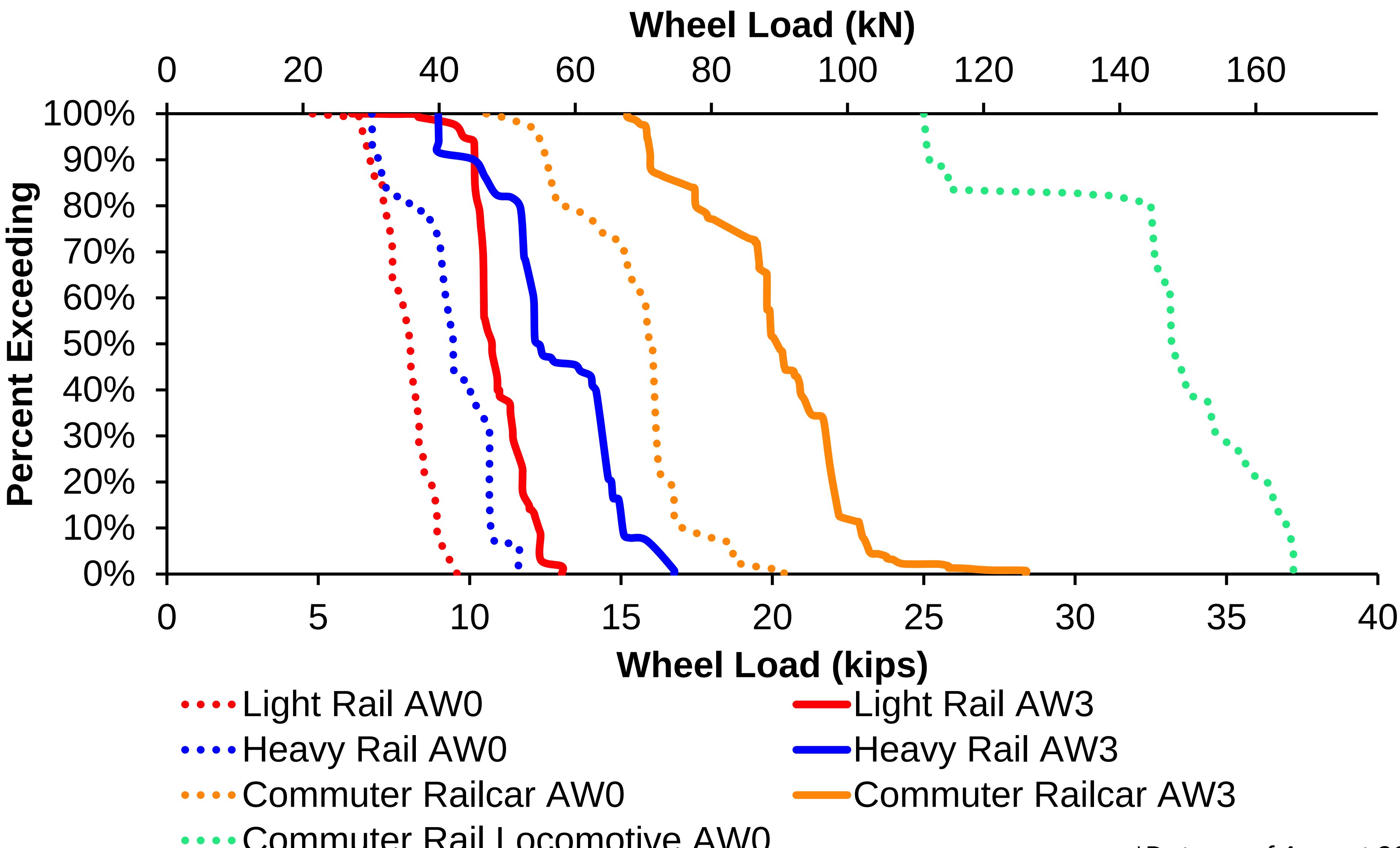
Rail Transit Vehicle Weight Definitions

- **AW0 (Empty Load)**
  - Empty vehicle weight, ready to operate
- AW1 (Seated Load)
  - Crew and fully seated passenger load + AW0
- AW2 (Design Load)
  - Standing passenger load at 4/m^2 + AW1
- **AW3 (Crush Load)**
  - **Maximum passenger capacity × average passenger weight + AW0**
- AW4 (Structural Design Load)
  - Standing passenger load at 8/m^2 + AW1

Rail Transit Vehicle Weight Quantification

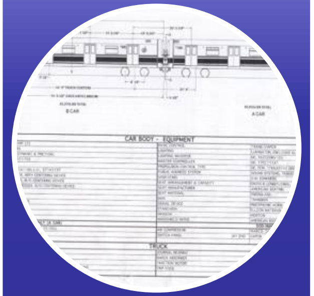
- AW0 and AW3 weights were calculated for rail transit vehicles operating within the United States as of August 2015
  - National Transit Database (NTD) Revenue Vehicle Inventory
  - Vehicle datasheets
- Data obtained and analyzed for:
  - 100% of light rail vehicles (2,072 of 2,072)
  - 85% of heavy rail vehicles (9,781 of 11,474)
  - 72% of commuter railcars (4,353 of 6,047)
  - 91% of commuter locomotives (674 of 738)
- 195 lbs. (88.5 kg) per person was used as average passenger weight for AW3 calculations based on multiple sources, including Federal Aviation Administration (FAA) standards
- **Data tabulated and balloted for inclusion in the AREMA Manual for Railway Engineering (2017 Version)**

Light Rail, Heavy Rail, and Commuter Rail Vehicle Wheel Load Distribution



**Data as of August 2015*

FTA Project Approach



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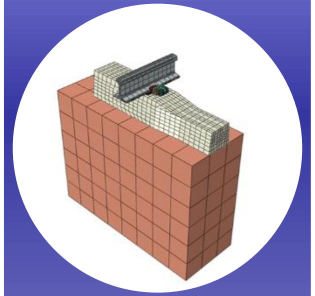

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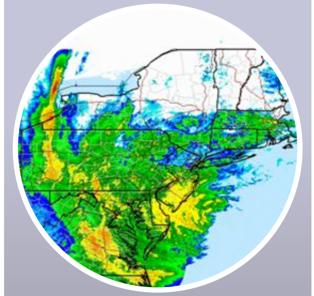
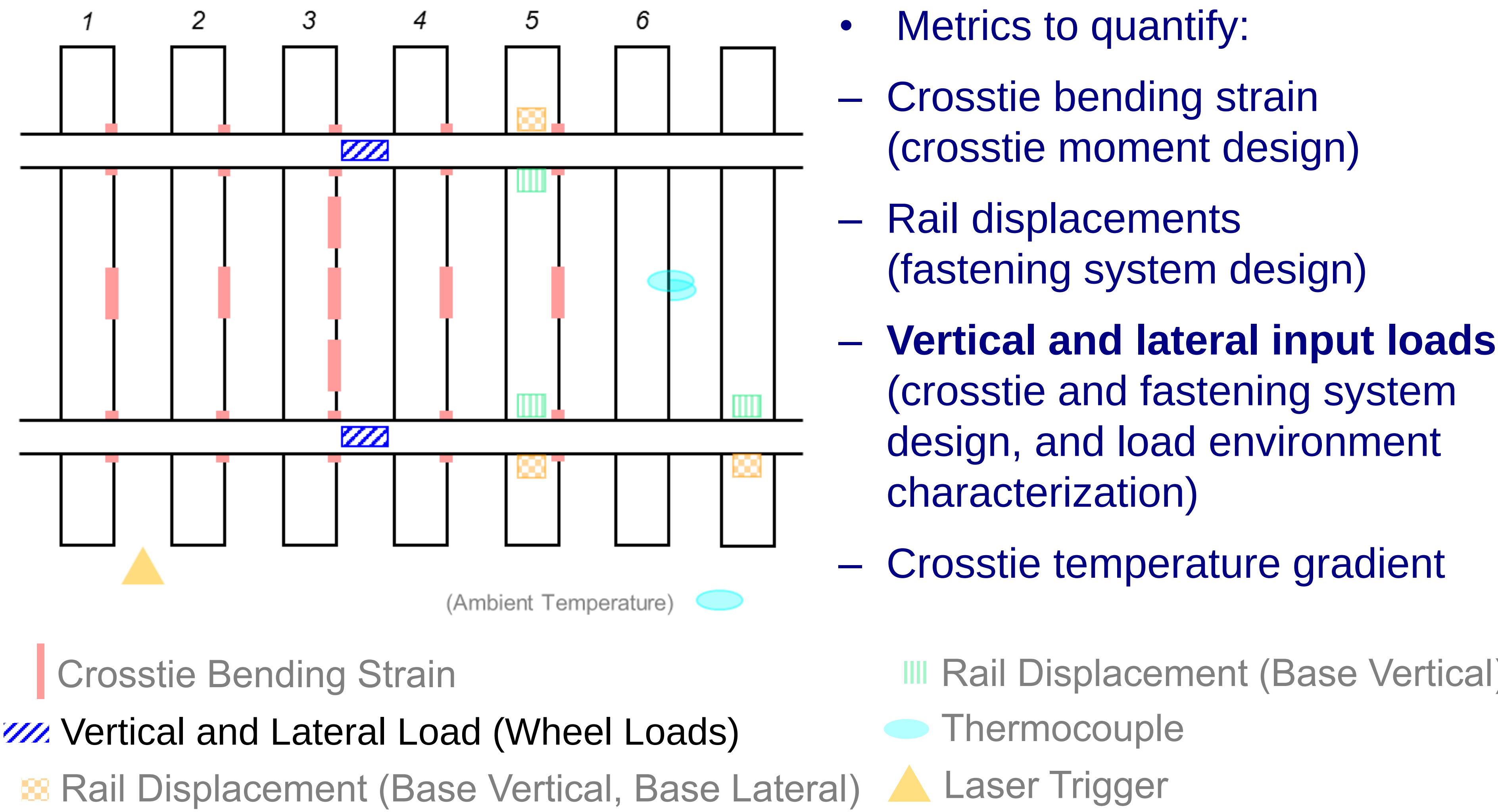


Environmental Factors and Special Circumstances

Resilient Concrete Crosstie and Fastening System for Rail Transit

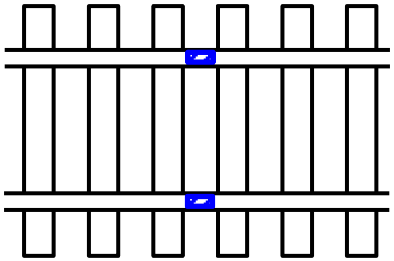
Typical Field Instrumentation Map



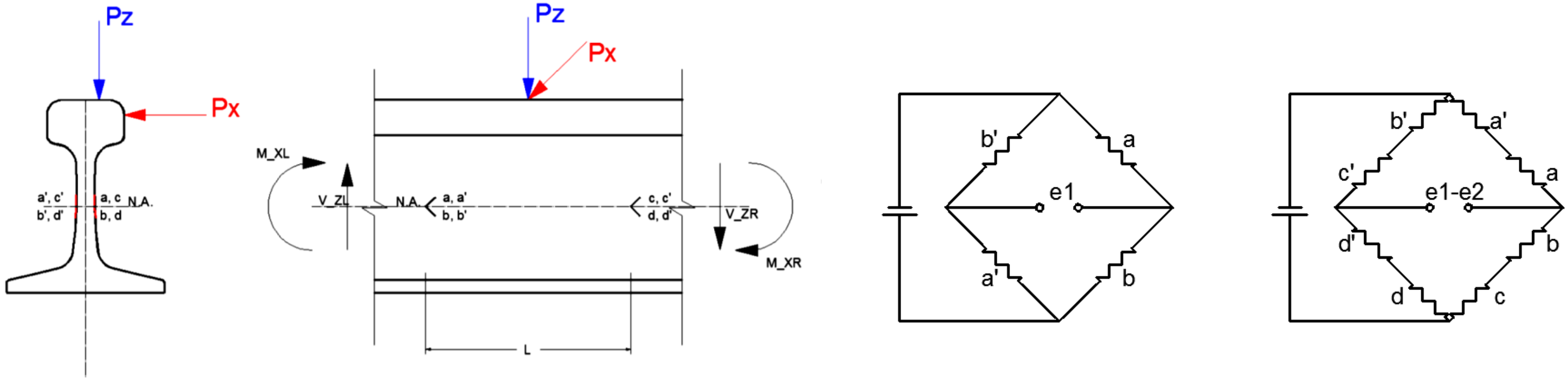
- Metrics to quantify:
  - Crosstie bending strain (crosstie moment design)
  - Rail displacements (fastening system design)
  - **Vertical and lateral input loads** (crosstie and fastening system design, and load environment characterization)
  - Crosstie temperature gradient

Instrumentation Overview

Vertical and Lateral Wheel Loads



- **Desired data**:
  – Vertical and lateral loads at the wheel-rail interface and rail seat
- **Instrumentation description and methodology:**
  – Industry standard strain gauge bridges applied to rail web and flange, similar to a wheel impact load detector (WILD) site
  – Based on previous UIUC field instrumentation, one instrumented crib per rail to approximate wheel loads throughout whole test section



Partner Agencies

Light Rail Tangent Data

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

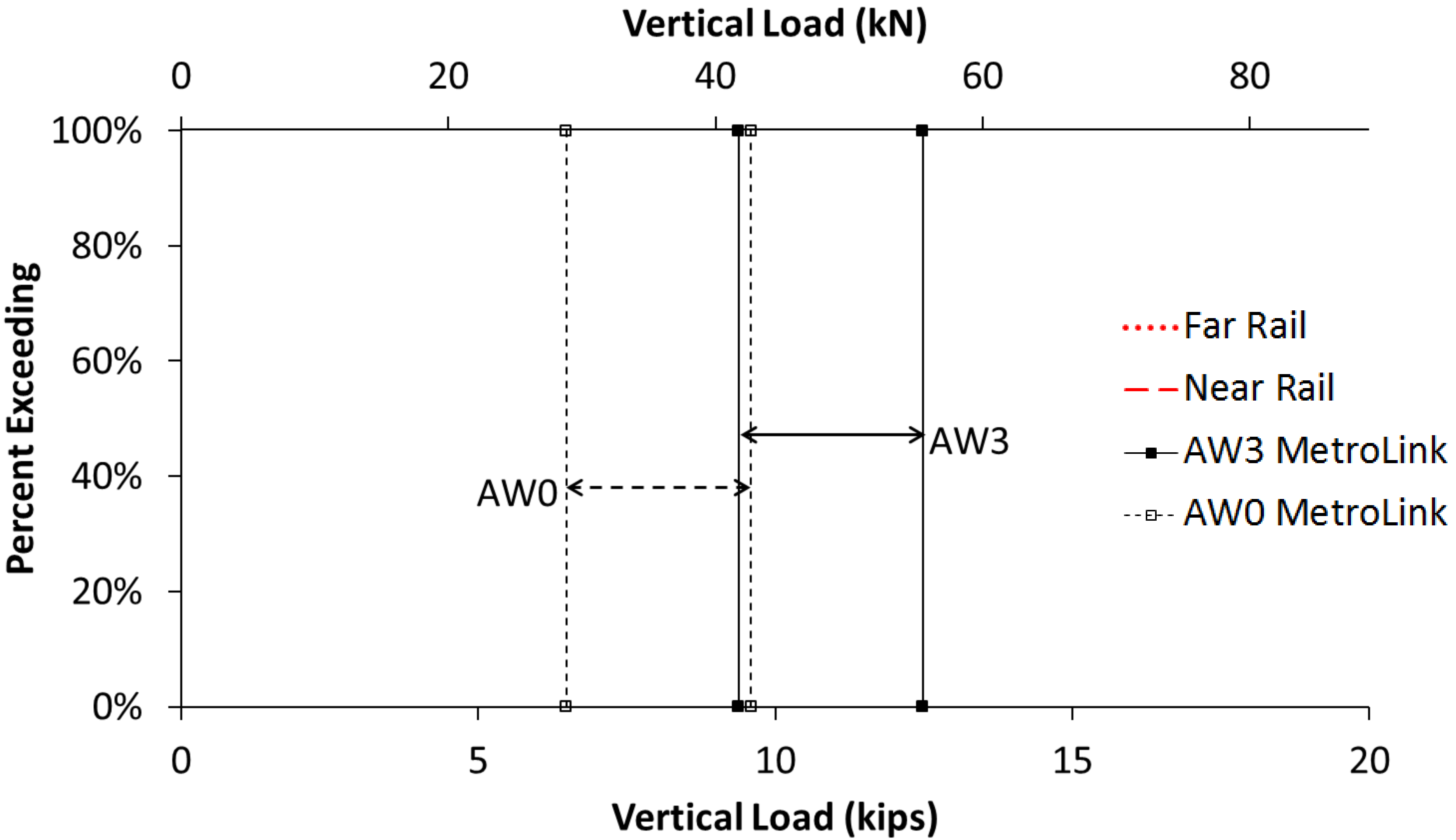
(Tangent Location)

MetroLink Tangent Location

- East St. Louis, IL
- Track speed: 55 MPH
- ~154 trains/day (Red & Blue lines)
- 0.9 miles west of Fairview Heights Station

Vertical Rail Loads

St. Louis MetroLink (Tangent)



Vertical Rail Loads

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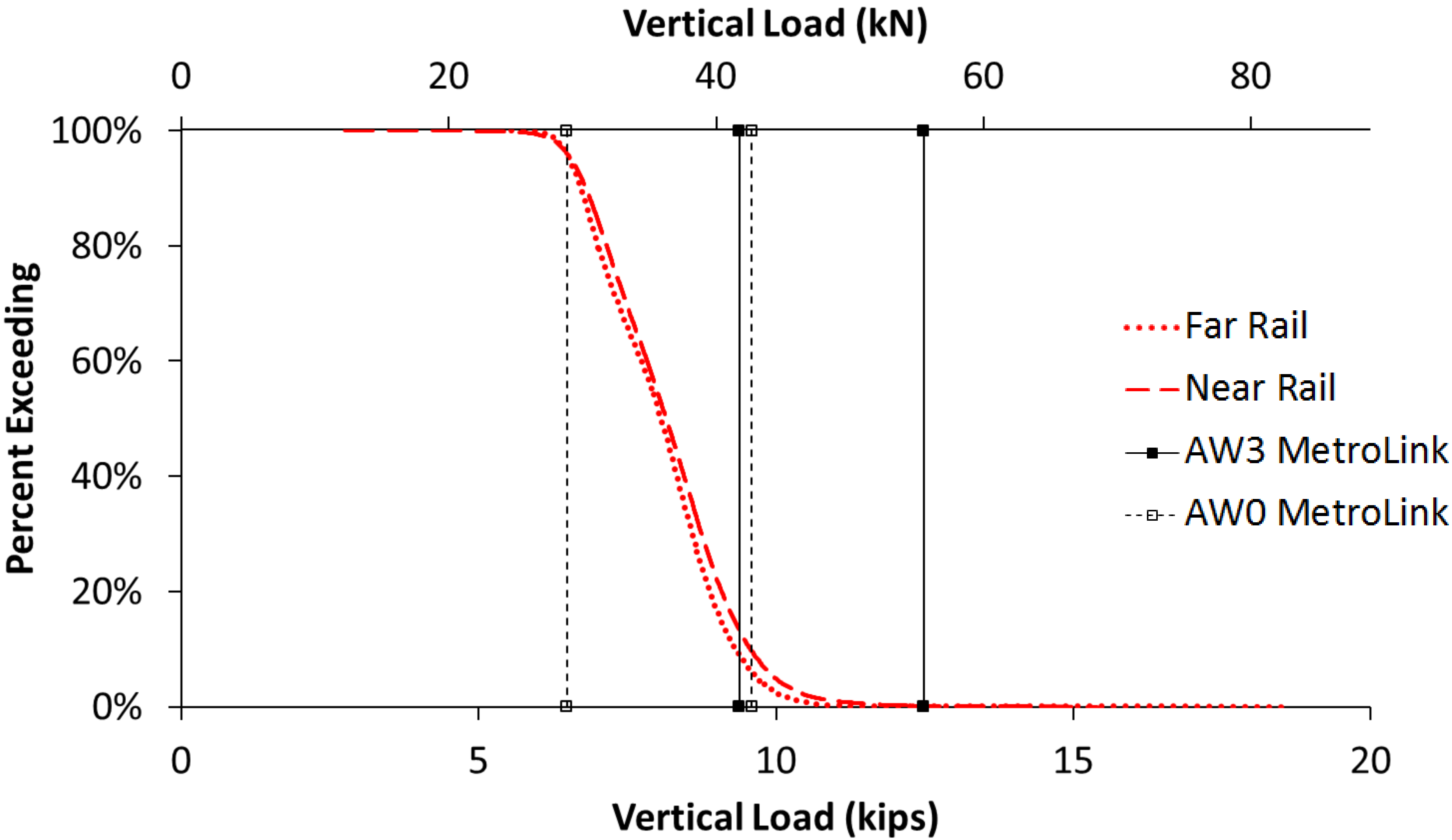
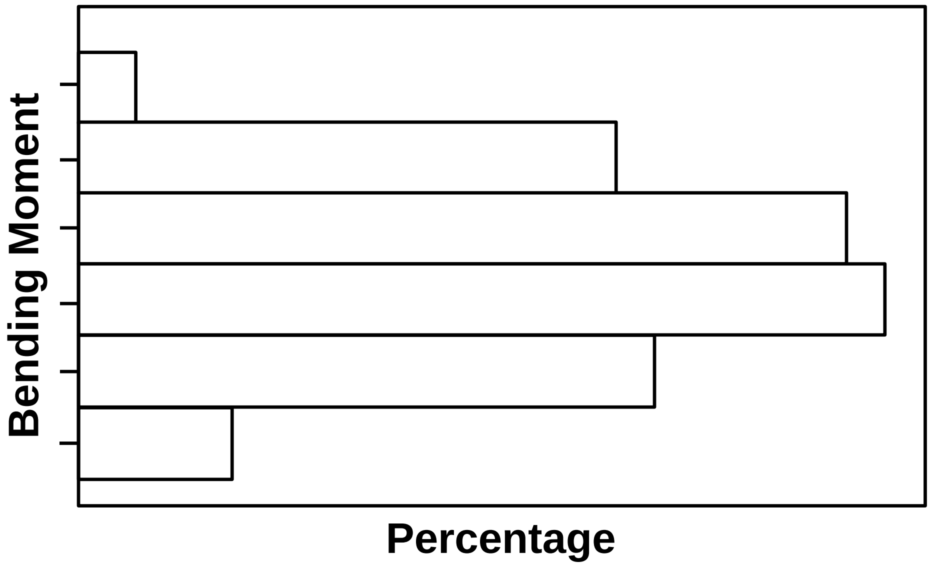
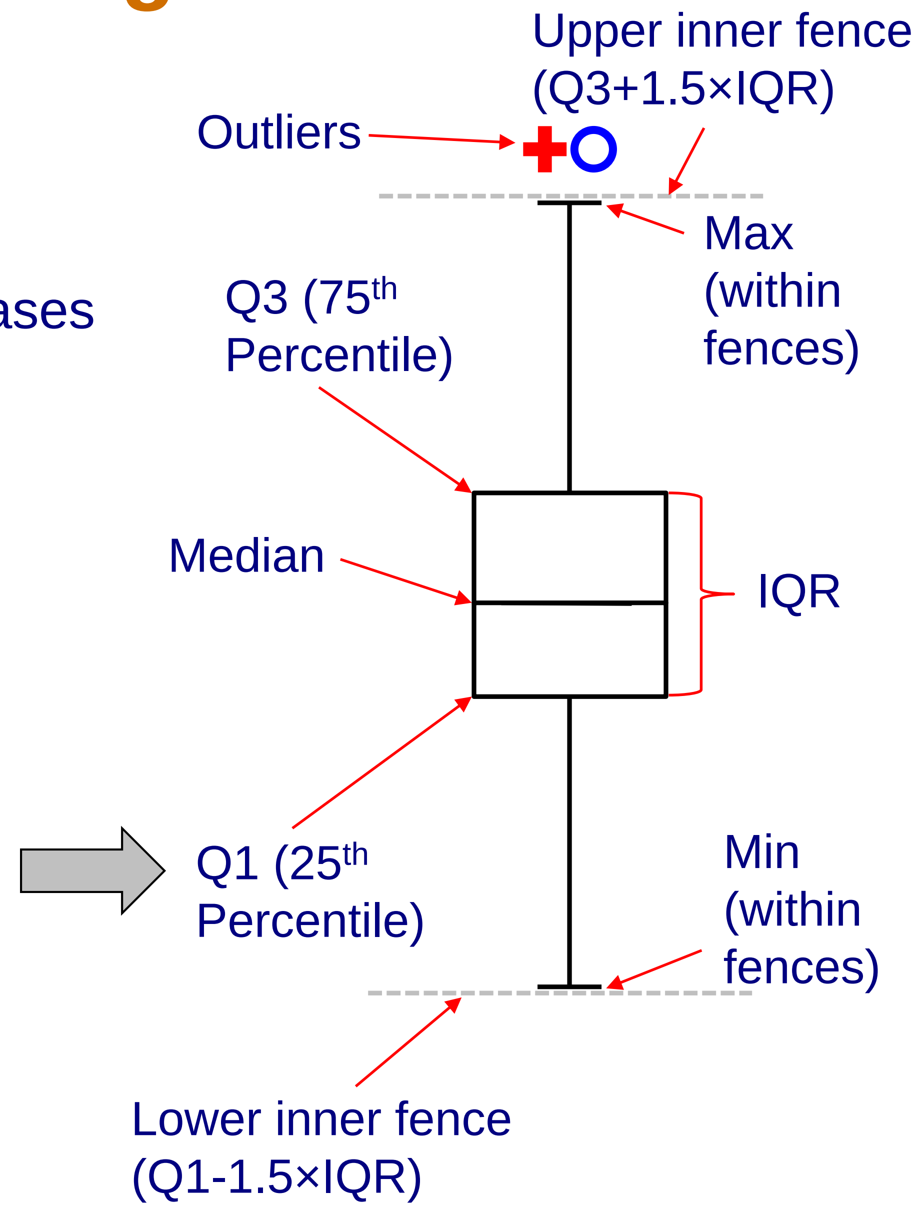


Box Plot Background

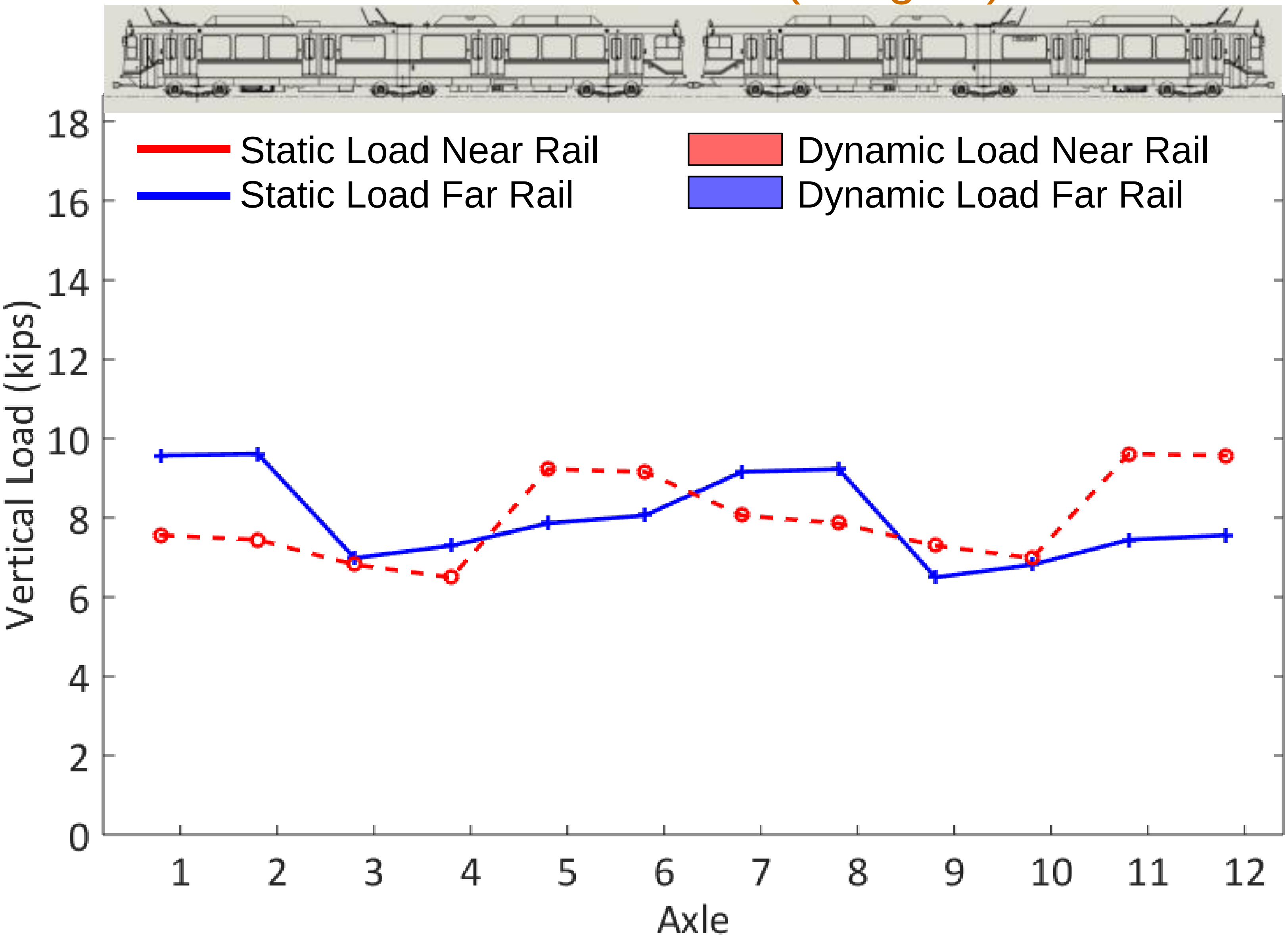
- Box plots are great to:
  - Visualize outliers
  - Compare variability of different cases
  - Check for symmetry
  - Check for normality
- 50% of Data are within the box





Vertical Wheel Loads

St. Louis MetroLink (Tangent)



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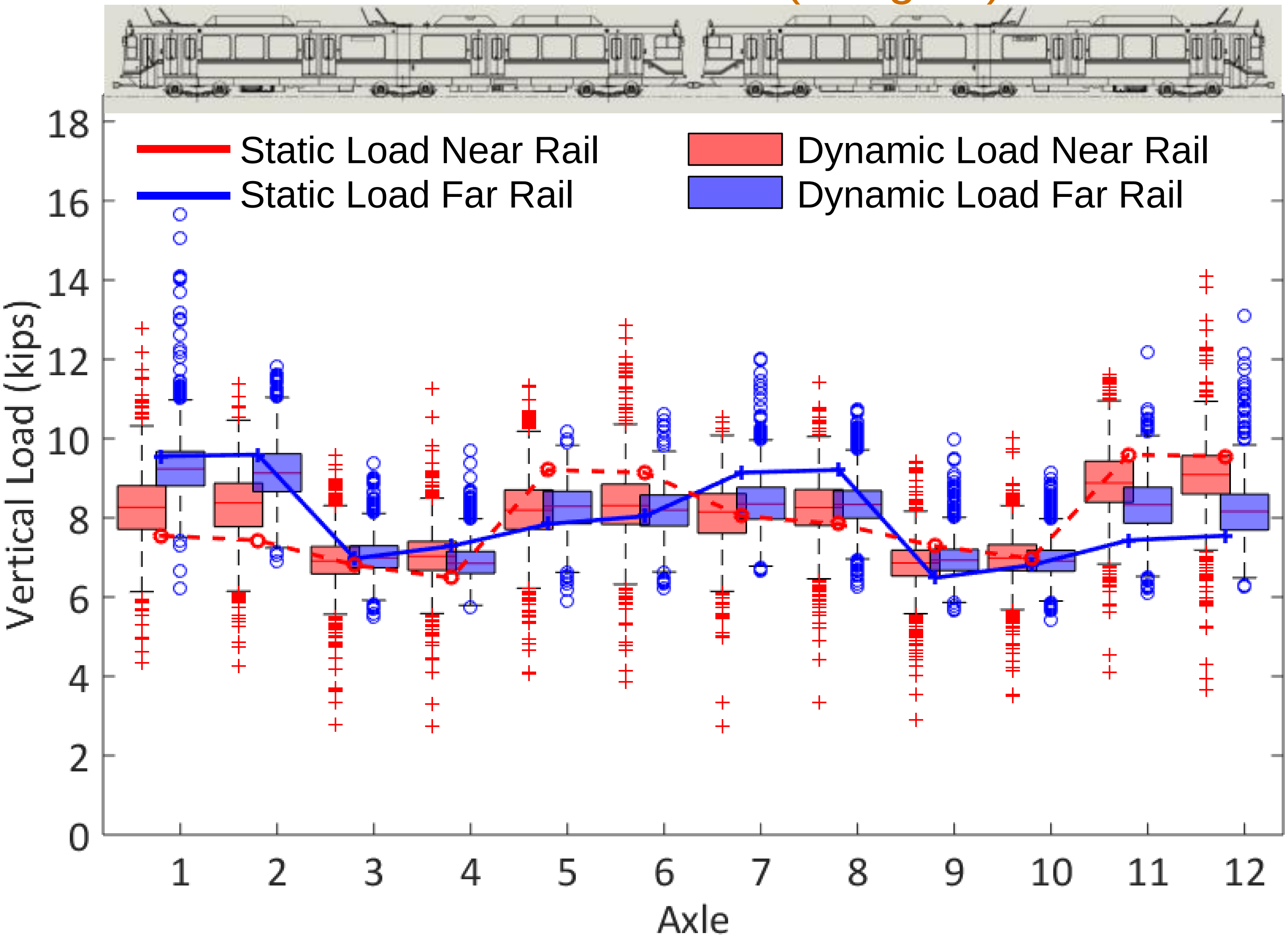

Vertical Wheel Loads

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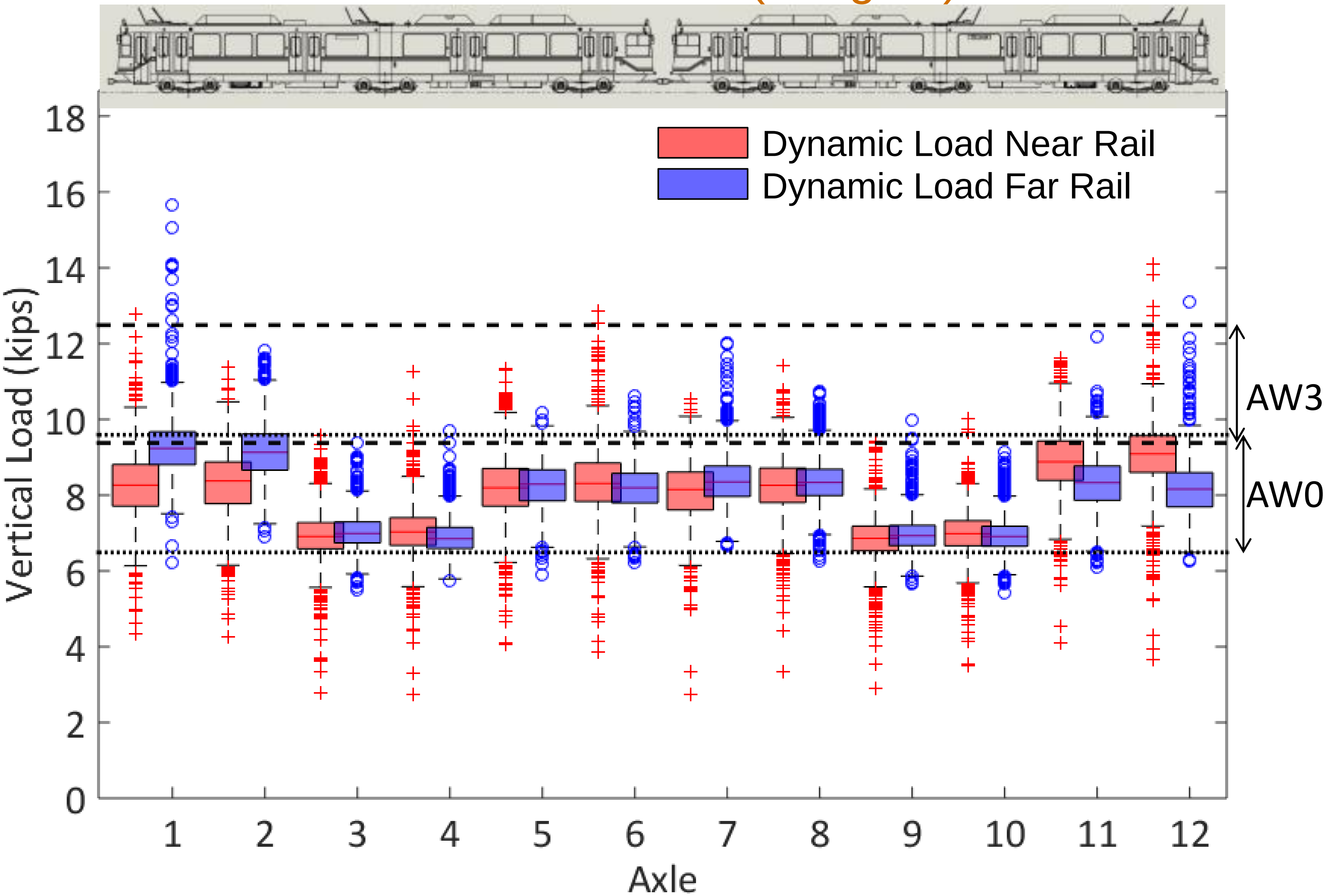
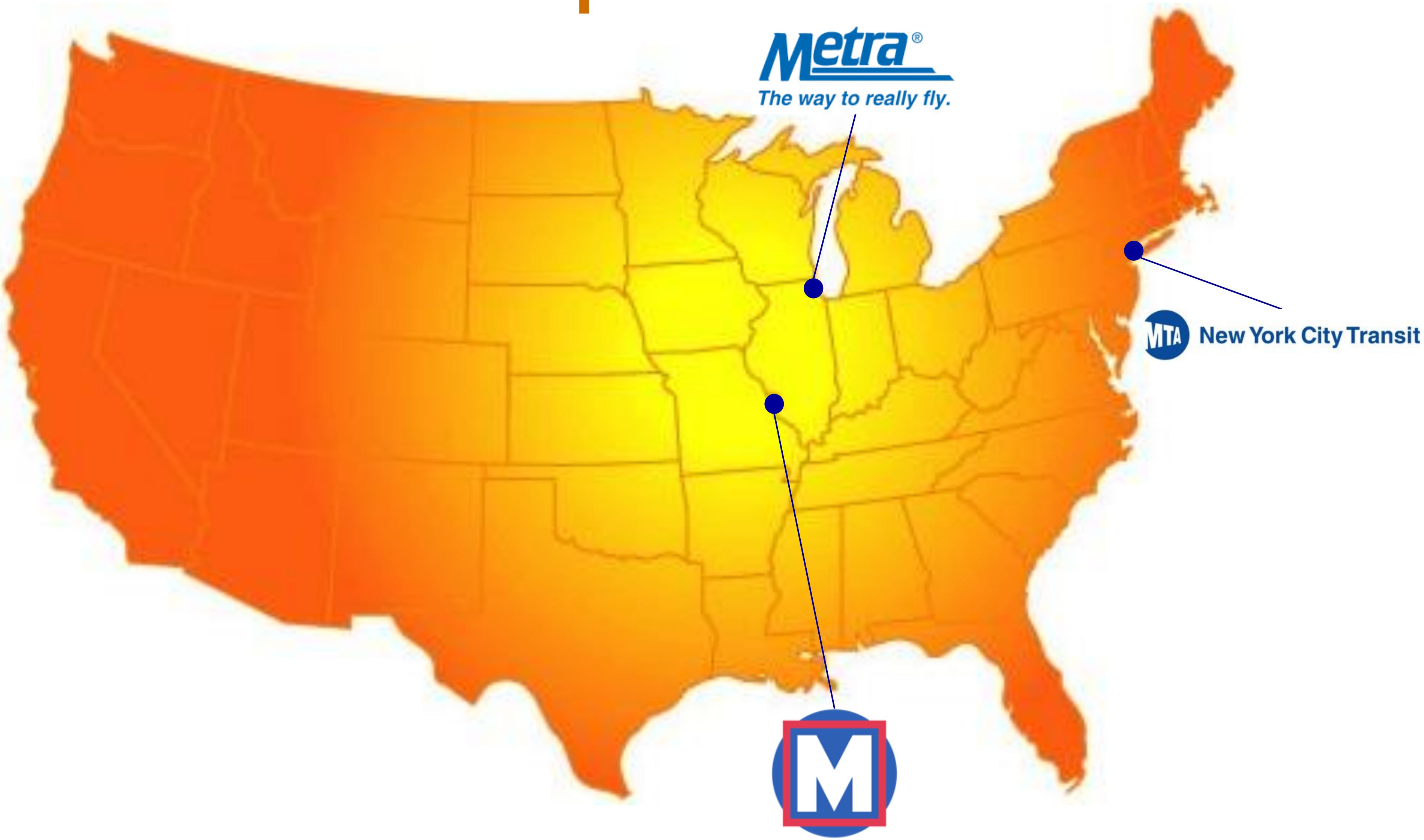
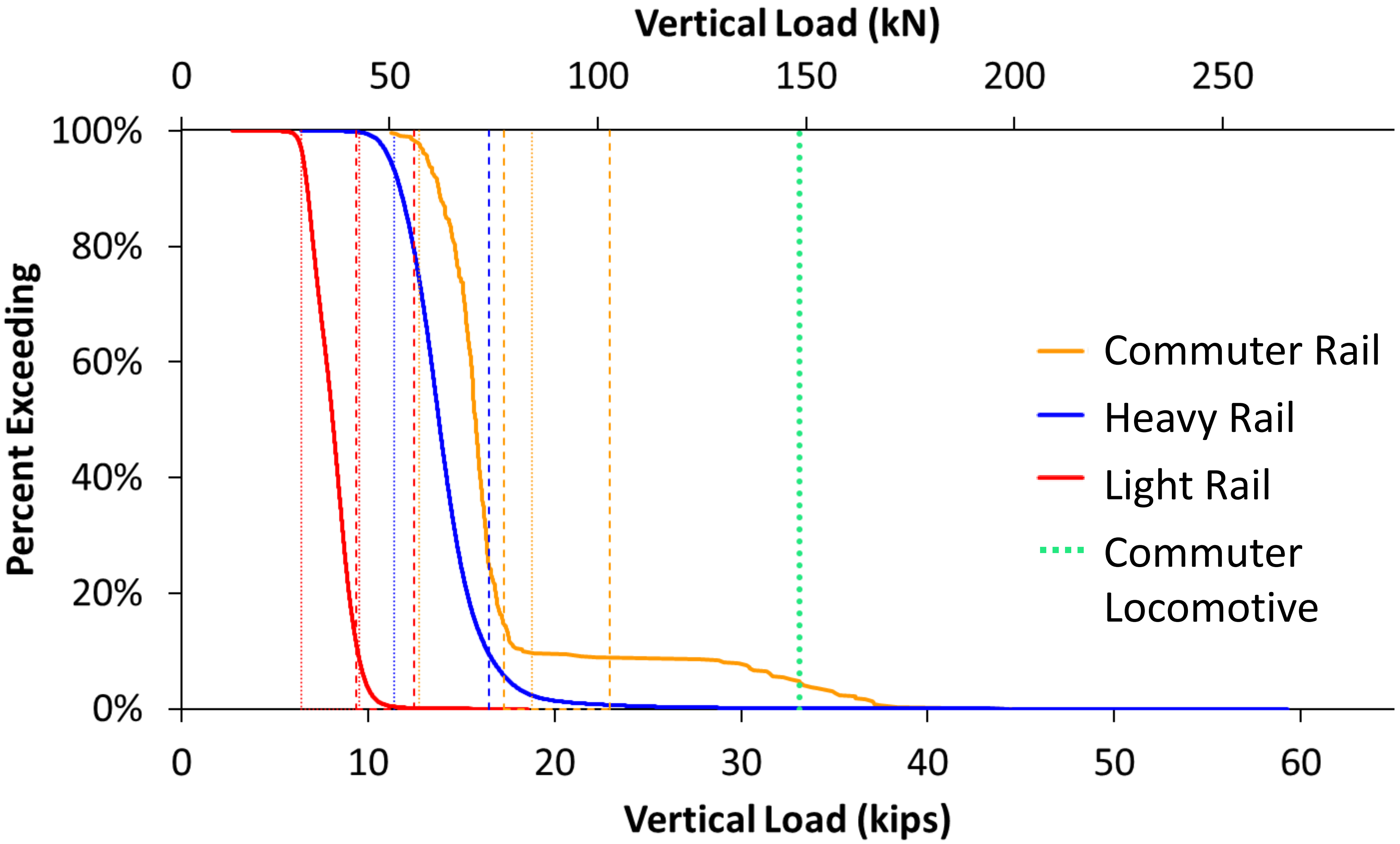


Comparative Data



Modal Comparison: Vertical Wheel Loads



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)

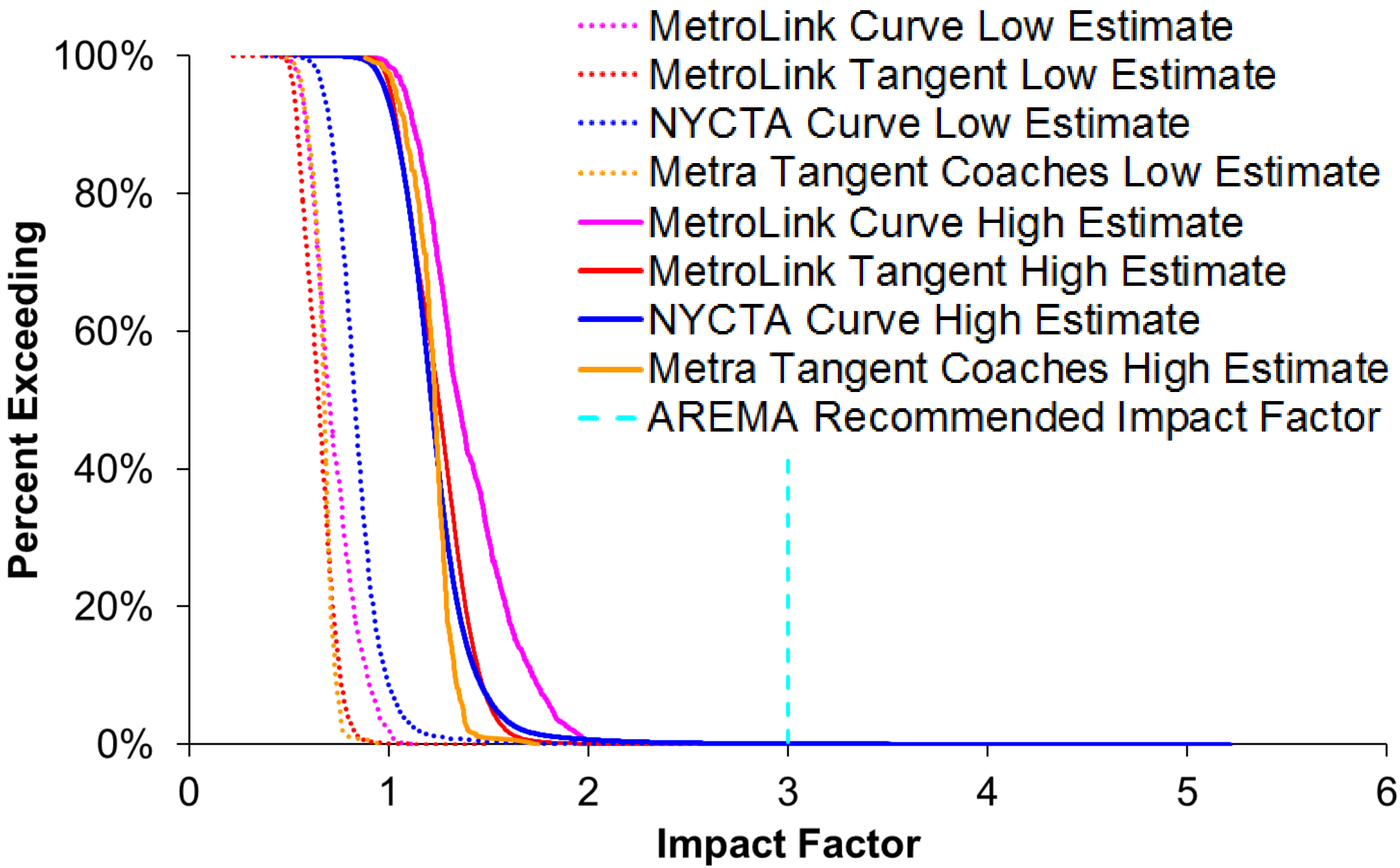
Impact Factor Percentiles for Each Mode

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

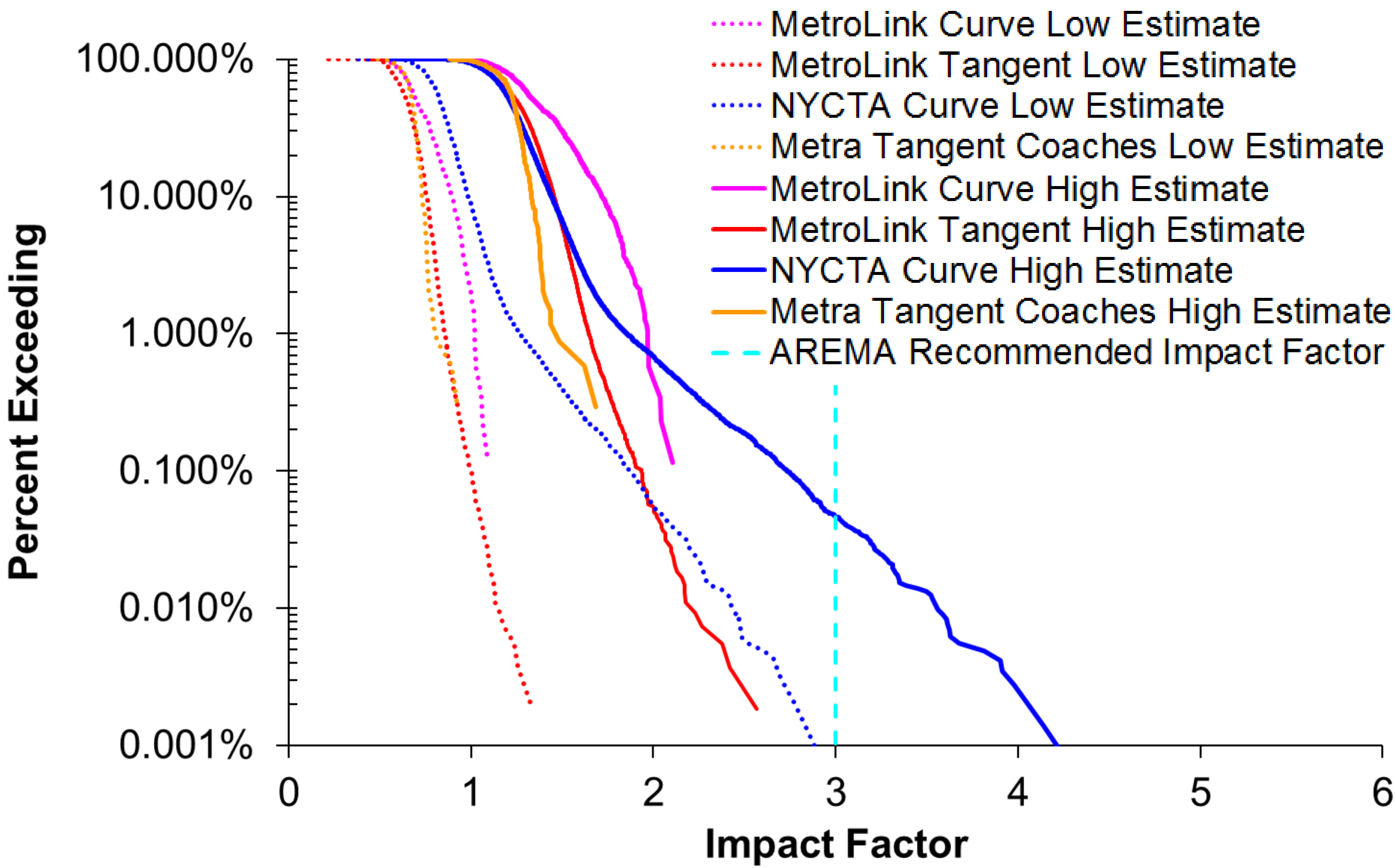
$$Impact\ Factor = \frac{Dynamic\ Load}{Static\ Load}$$

$Static\ load\ is\ bounded\ by$
$Min.AW0\ and\ Max.AW3$

Impact Factor Comparison Chart



Impact Factor Comparison Chart



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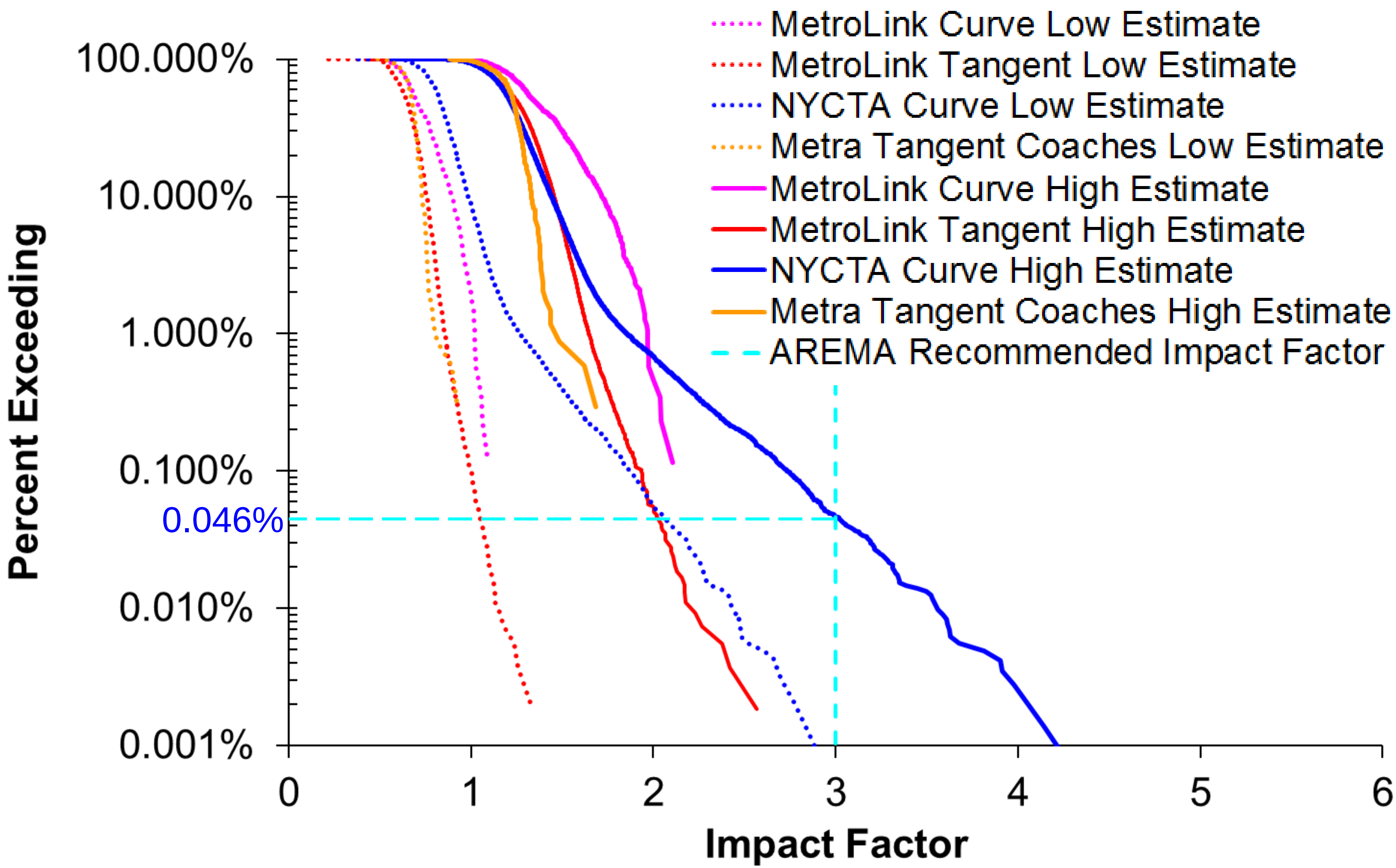
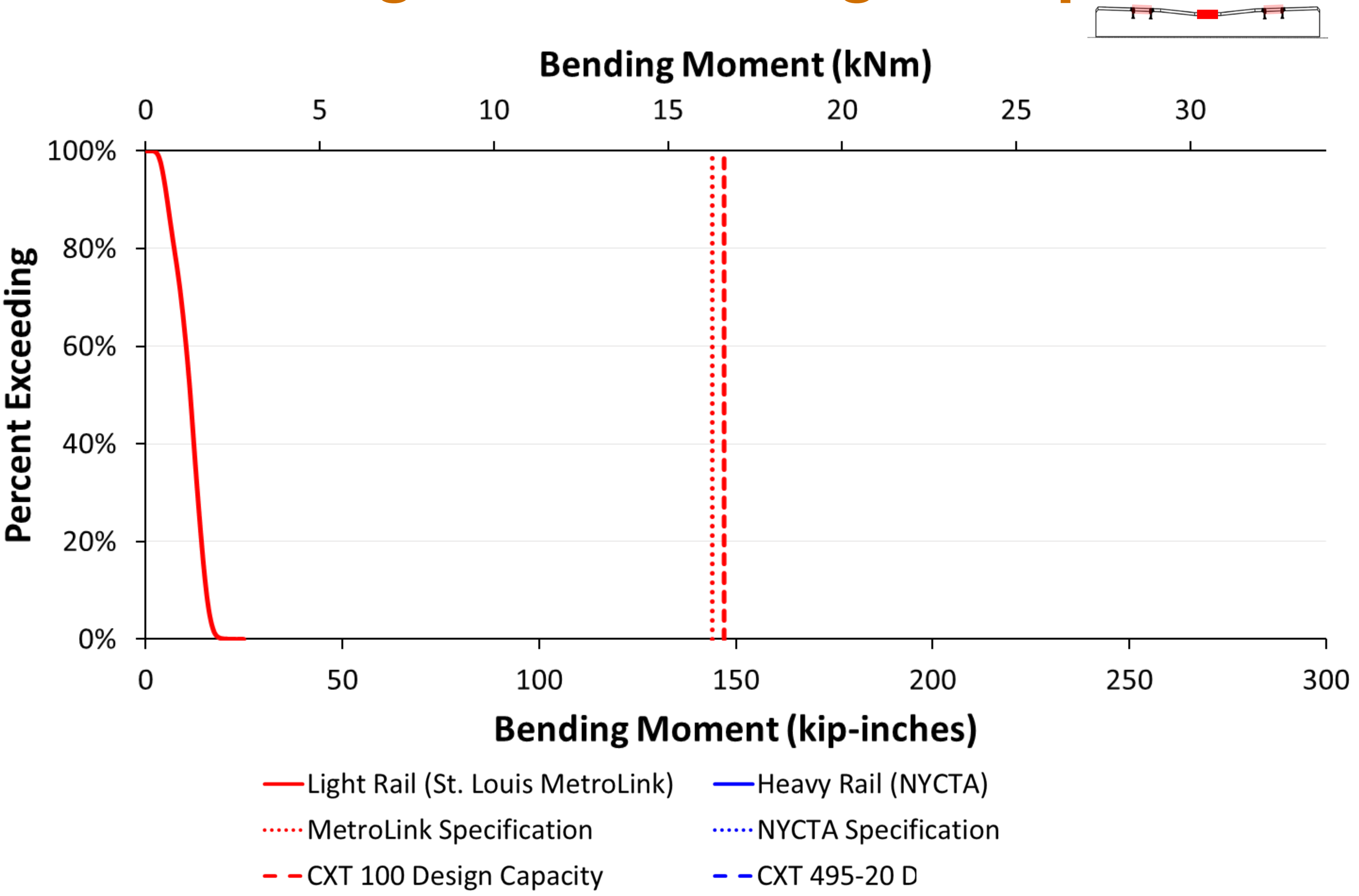


Center Negative Bending Comparison



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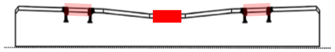

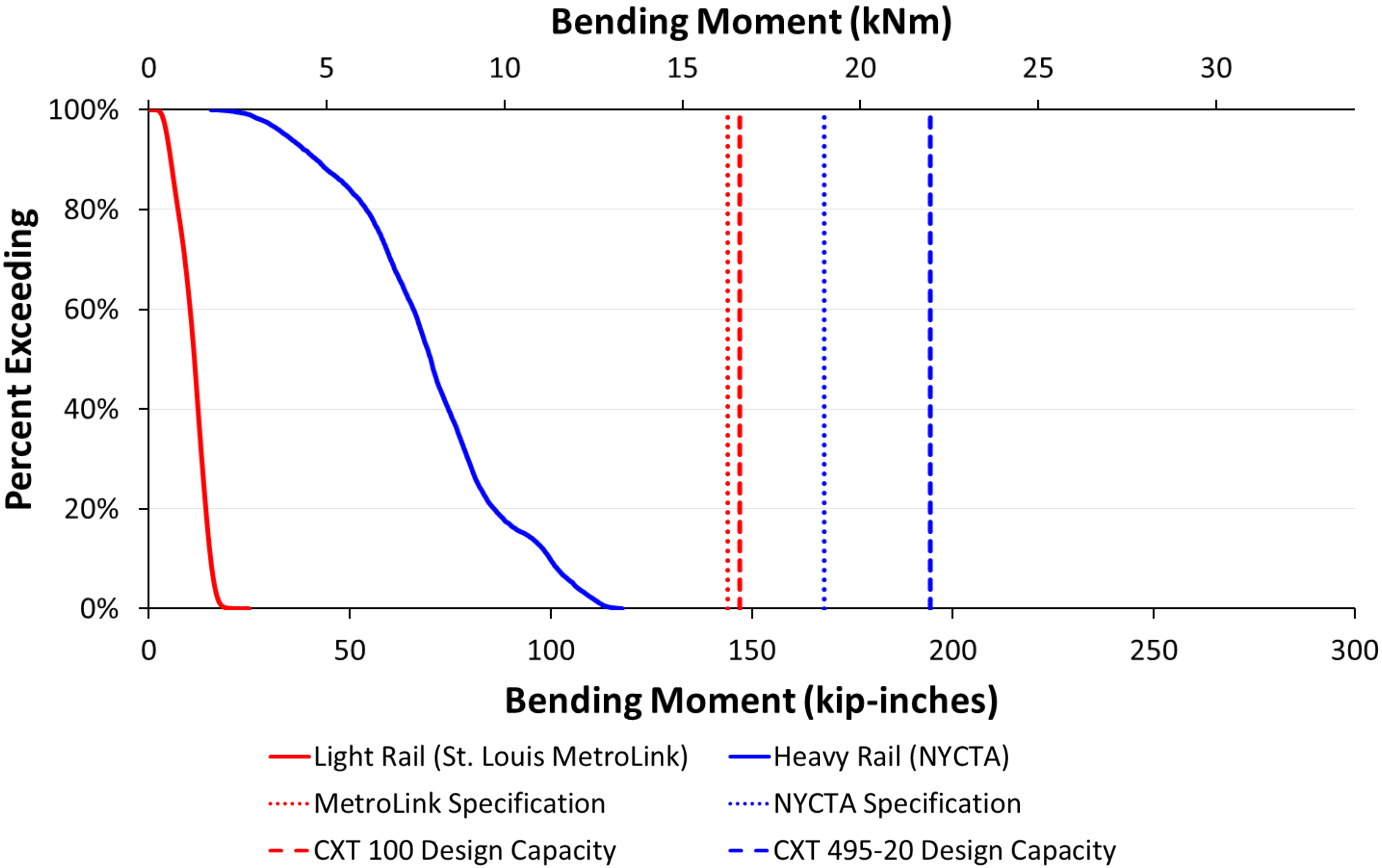

Vertical Rail Load Data Conclusions

- Instrumentation was deployed and has successfully captured wheel-rail loading data from 3 rail transit modes at 4 field sites
- Impact Factors differ between modes; for example, between heavy and light rail the impact factor is:
  - 2.7 times greater at maximum load for heavy rail
  - 1.7 times greater at 99th percentile load for heavy rail
- The currently-accepted impact factor of 3 (e.g. 200% per AREMA) should be re-considered on a modal basis, and possibly on a system-by-system basis

Future Research & Path Forward

- Analyze extreme cases to understand better the environment leading to high wheel loads
  - Compare to other metrics (e.g. tie bending moments)
- 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
- Perform analysis of seasonal variation
- *Further investigation of maintenance-of-way equipment loading conditions and their influence on design*

Acknowledgements

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