Mechanistic Design of Concrete Crossties for Rail Transit Systems

Project Overview and Field Bending Moment Results

2016 International Crosstie & Fastening System Symposium

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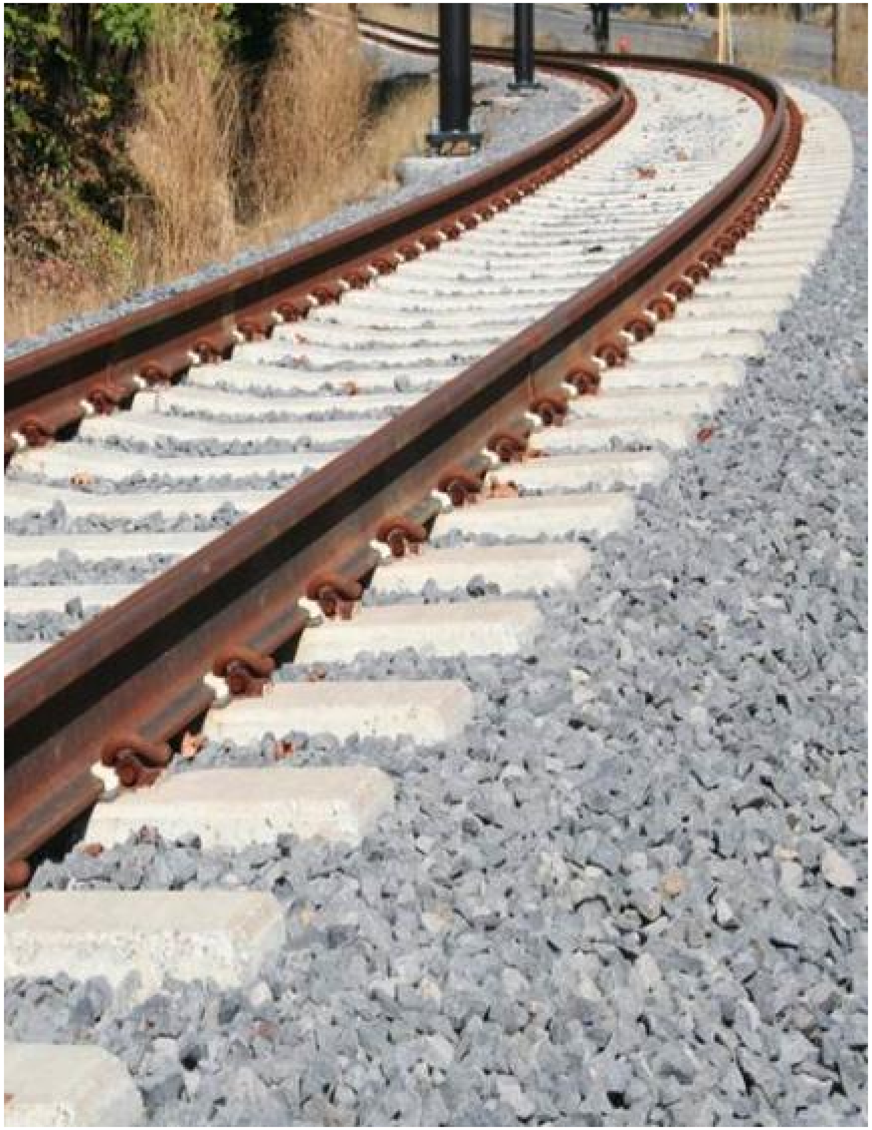
Outline

- Background and Problem Statement
- Mission and Approach
- Rail Transit Vehicle, Infrastructure, and System Characteristics
- Rail Transit Vehicle Weight & Wheel Loads
- Rail Transit Vehicle Impact Factors
- Field Data Collection
- Future Work



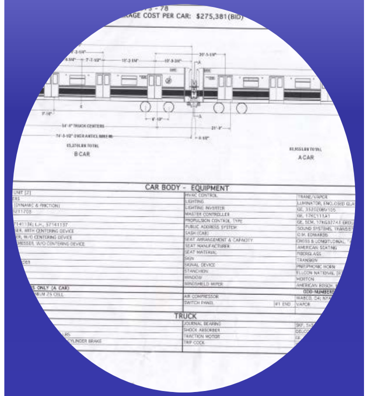
Background and Problem Statement

- 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

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.

Project Approach

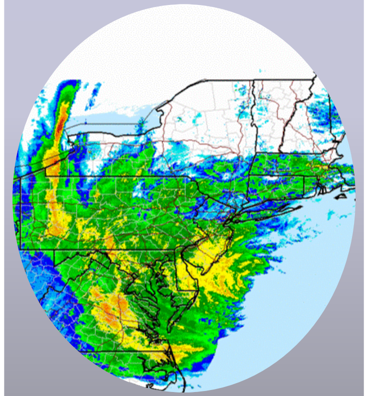


Paper Study

Industry Surveys

Field Data Collection

Laboratory Experimentation



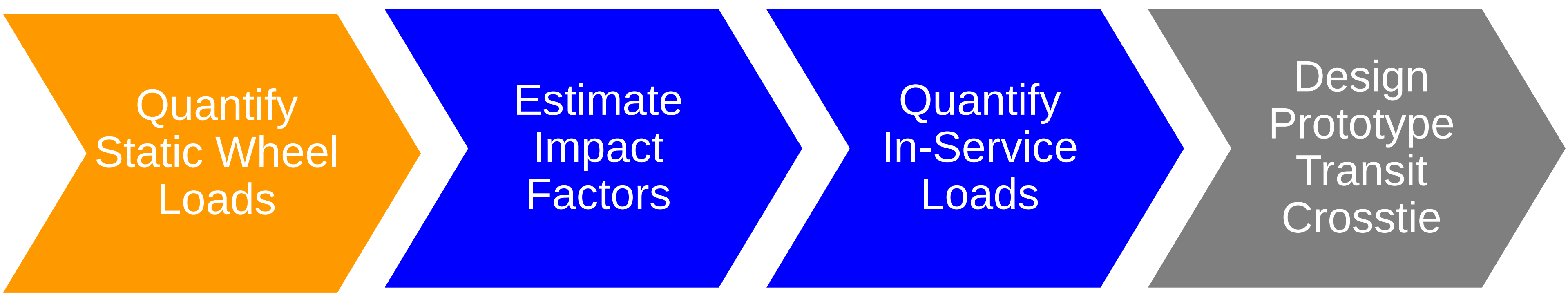
Environmental Factors and Special Circumstances

Resilient Concrete Crosstie and Fastening System for Rail Transit

Rail Transit Definitions and System Characteristics

	Light Rail (Tram)	Heavy Rail (Metro)	Commuter Rail
Capacity (prs/h)	6,000 – 20,000	10,000 – 60,000	8,000 – 45,000
Exclusive ROW	40% – 90%	100%	100%
Power Supply	Overhead/diesel	Third rail/overhead	Overhead/ third rail/diesel
Area Coverage	Central business district	Mostly central business district	Mostly suburban coverage
Station Spacing	0.25-1 mi (0.4-1.6 km)	0.5-2 mi (0.8-3.2 km)	2-5 mi (3.2-8 km)
Frequency	5-20 minutes	5-20 minutes	0.5-3 hours
Speed	20-55 mph (32-88 km/h)	50-80 mph (80-129 km/h)	30-125 mph (48-201 km/h)
Example			

Rail Transit Vehicle Weight and Wheel Loads



Rail Transit Vehicle Weight Definitions

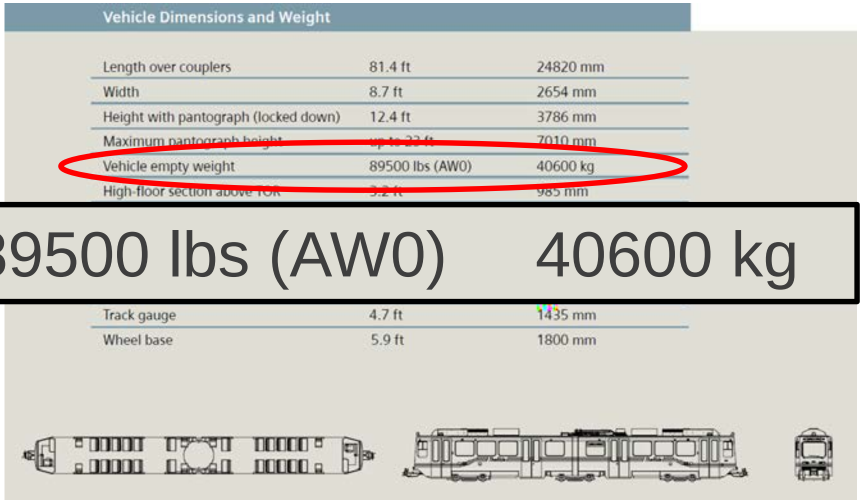
- AW0: Empty vehicle operating weight
- AW1 (Seated Load)
  - Fully seated passenger load + AW0
- AW2 (Design Load)
  - Standing passenger load at $4/m^2$ + AW1
- AW3 (Crush Load)
  - Standing passenger load at $6/m^2$ + AW1
- AW4 (Structural Design Load)
  - Standing passenger load at $8/m^2$ + AW1

Rail Transit Vehicle Weight Definitions

- AW0: Empty vehicle operating weight
- AW1 (Seated Load)
  - Fully seated passenger load + AW0
- AW2 (Design Load)
  - Standing passenger load at 4/m^2 + AW1
- **AW3 = Maximum Passenger Capacity × Average Passenger Weight + AW0**
- AW4 (Structural Design Load)
  - Standing passenger load at 8/m^2 + AW1

Rail Transit Vehicle Weight Definitions

- Rail transit vehicle information
  - National Transit Database (NTD) Revenue Vehicle Inventory
  - Vehicle datasheets



Vehicle empty weight 89500 lbs (AW0) 40600 kg

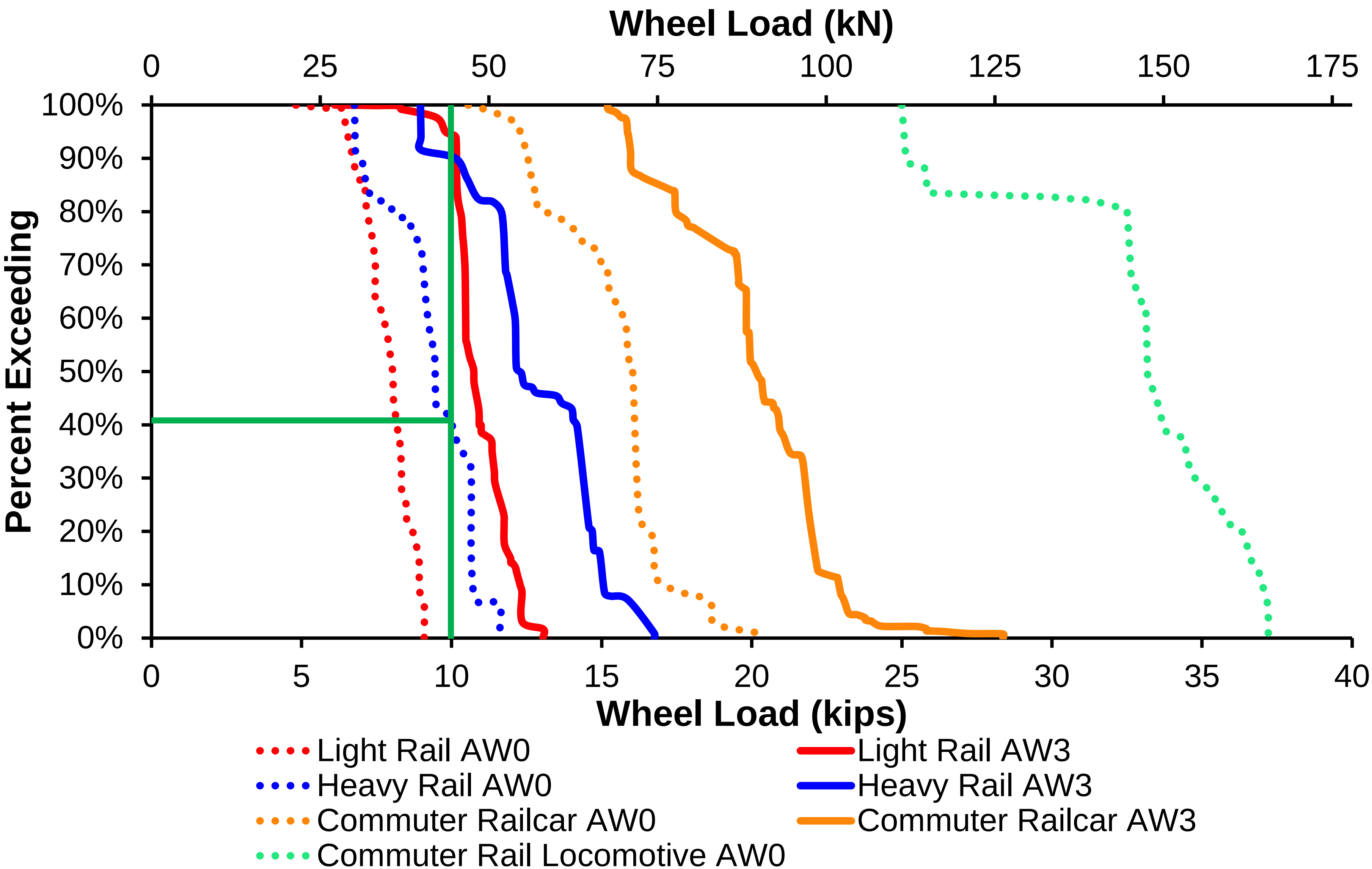
  - These sources provided data for:
    - 100% of light rail vehicles (2,072 of 2,072)
    - 85% of heavy rail vehicles (9,781 of 11,474)
    - 72% of commuter railcars (4,353 of 6,047)
    - 91% of commuter locomotives (674 of 738)

Rail Transit Vehicle Weight Definitions

- Average passenger weight
  - 155 lbs (70 kg) per passenger is currently used in the Light Rail Design Handbook*
  - Smith and Schroeder (2013) took a quantitative approach to account for the growth in rider size and weight over the last 30-40 years
  - Federal Aviation Administration (FAA) standards specify 195 lbs as the winter average adult passenger weight to account for carry-on luggage and seasonal clothing
- 195 lbs (88.5 kg) is used as average passenger weight

*Parsons Brinckerhoff, Inc. 2012. Track Design Handbook for Light Rail Transit, TCRP Report 155. Transit Research Board, Washington, DC, USA.

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



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

Imperial Units						
	AW0 Wheel Load (kips)			AW3 Wheel Load (kips)		
Vehicle Type	Minimum	Maximum	Average	Minimum	Maximum	Average
Light Rail	4.8	9.1	7.9	6.1	13.0	10.9
Heavy Rail	6.8	11.6	9.4	8.1	16.8	12.8
Commuter Railcar	10.6	20.4	10.6	15.2	28.4	20.0
Commuter Rail Locomotive	25.0	37.2	32.7	N/A	N/A	N/A

Metric Units						
	AW0 Wheel Load (kN)			AW3 Wheel Load (kN)		
Vehicle Type	Minimum	Maximum	Average	Minimum	Maximum	Average
Light Rail	21.4	40.5	35.2	27.1	57.9	48.5
Heavy Rail	30.3	51.6	41.8	36.0	74.8	57.0
Commuter Railcar	47.2	90.8	47.2	67.6	126.4	89.0
Commuter Rail Locomotive	111.3	165.5	145.5	N/A	N/A	N/A

- This data is balloted for inclusion in the American Railway Engineering and Maintenance-of-way Association (AREMA) Manual for Railway Engineering

Rail Transit Vehicle Impact Factors

Quantify Static Wheel Loads

Estimate Impact Factors

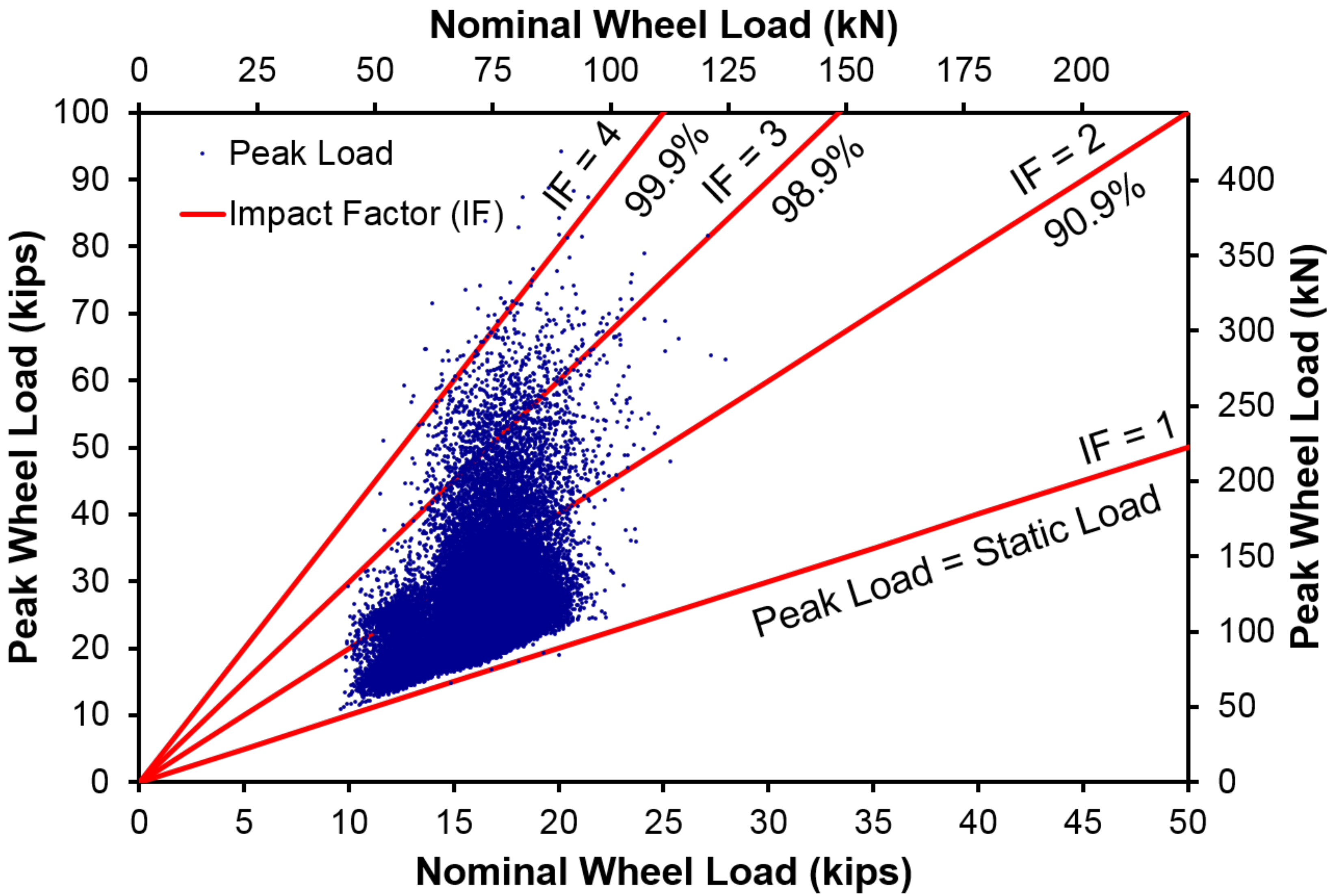
Quantify In-Service Loads

Design Resilient Transit Crosstie

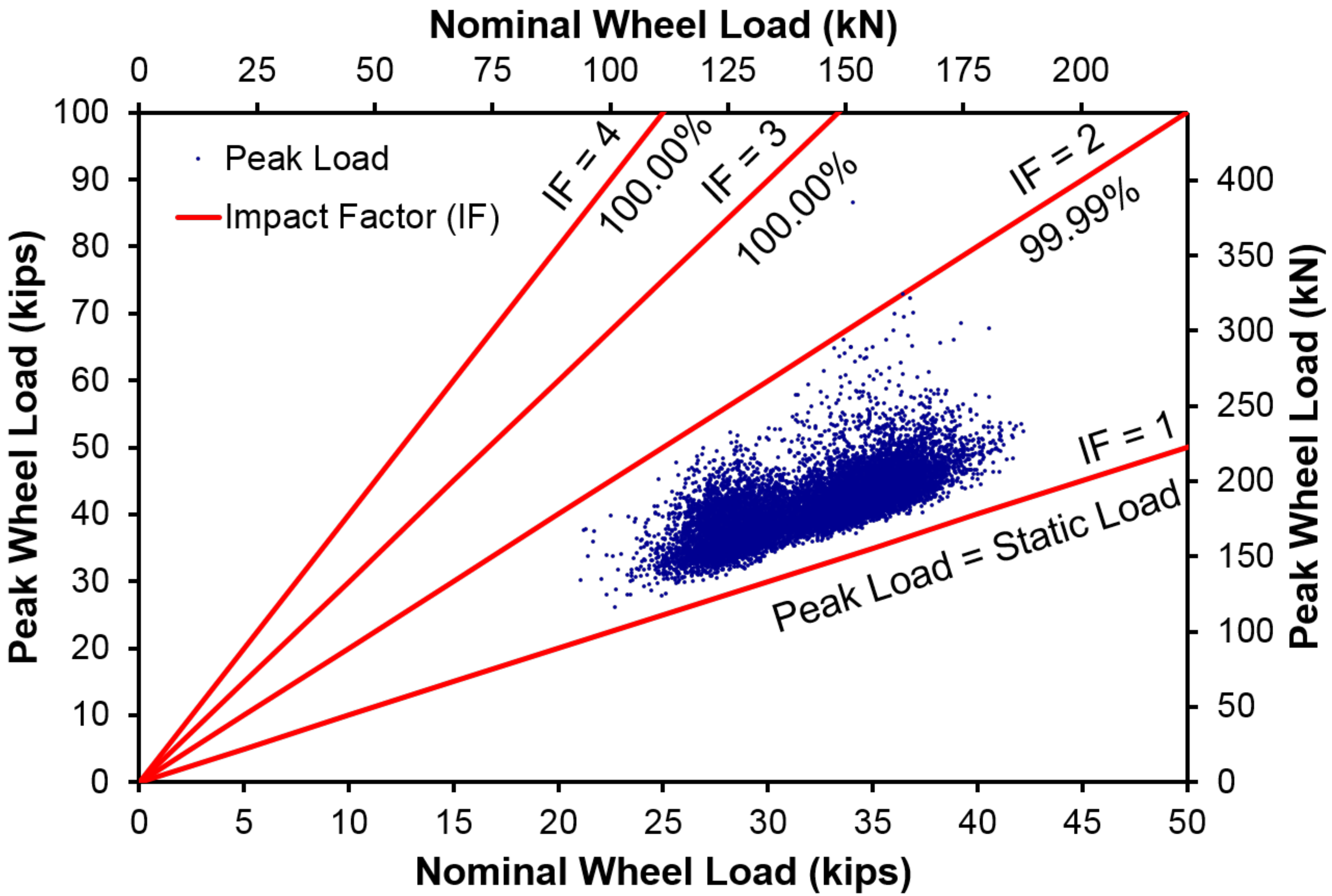
Rail Transit Vehicle Impact Factor

- Impact factor is defined as a percentage increase over static vertical loads intended to estimate the dynamic effect of wheel and rail irregularities
- AREMA recommends an impact factor of 200%, which indicates the design load is three times the static load, equivalent to an impact load factor of 3
- The same impact factor of three applies to both freight railroads and rail transit systems
- Data from a wheel impact load detector (WILD) site on Amtrak's Northeast Corridor between New York City and Washington DC were analyzed to determine optimum design impact factors

Peak Load vs. Nominal Wheel Load for Commuter Railcars



Peak Load vs. Nominal Wheel Load for Commuter Locomotives



Impact Factor Conclusions

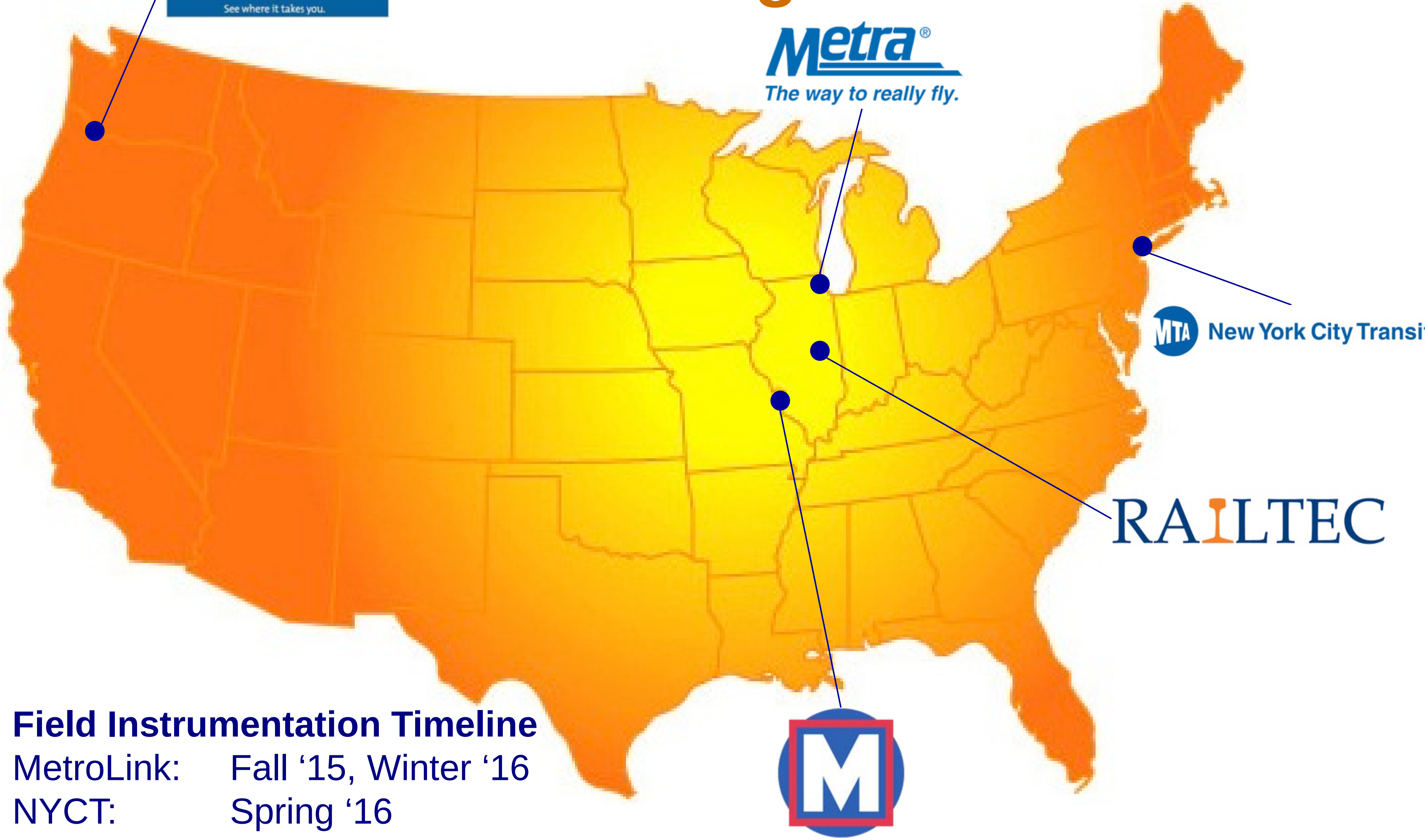
- Impact factor of 3 considers 98.9% of nominal commuter railcar wheel loads at the location analyzed
- Impact factor of 2 considers 99.9% of nominal commuter locomotive wheel loads at the location analyzed
- Different types of rail vehicles can impart higher or lower impact loads on the track
  - These data will be further compared to field data collected during this project
  - The 200% impact factor recommended by AREMA may not be applicable to design for all forms of rail transit

Field Data Collection

Purpose of Field Data Collection

- Field experimentation is used to quantify the in-service demands placed on the track system across loading conditions and environments
- 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)

Partner Agencies

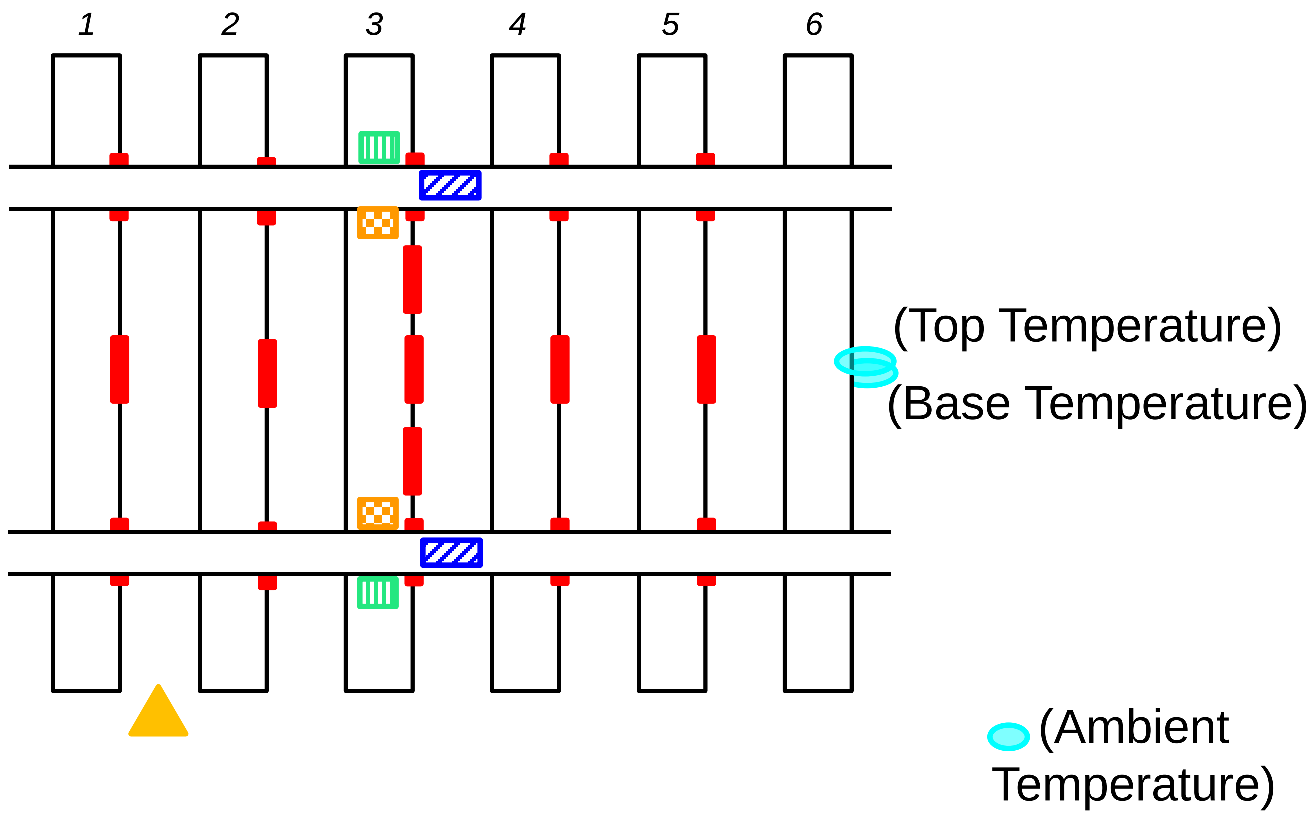


Field Instrumentation Timeline

MetroLink: Fall ‘15, Winter ‘16
NYCT: Spring ‘16
Metra: Summer ‘16
TriMet: TBD

Field Instrumentation Map

(STL MetroLink Tangent and NYCTA Curve)



Crosstie Bending Strain

Vertical and Lateral Wheel Loads

Laser Trigger

Rail Displacement (Base Vertical & Lateral)

Rail Displacement (Base Vertical)

Thermocouple

Automated Data Acquisition System

- Automated data collection systems have been deployed at St. Louis MetroLink and New York City Transit sites
  - Uses National Instruments (NI) Compact DAQ (cDAQ) equipment
- Laser sensor triggers data collection every time a train passes the site

- Thermocouple data is recorded every 5 minutes, 24 hours per day
- A third system will be installed at the Metra site in summer 2016

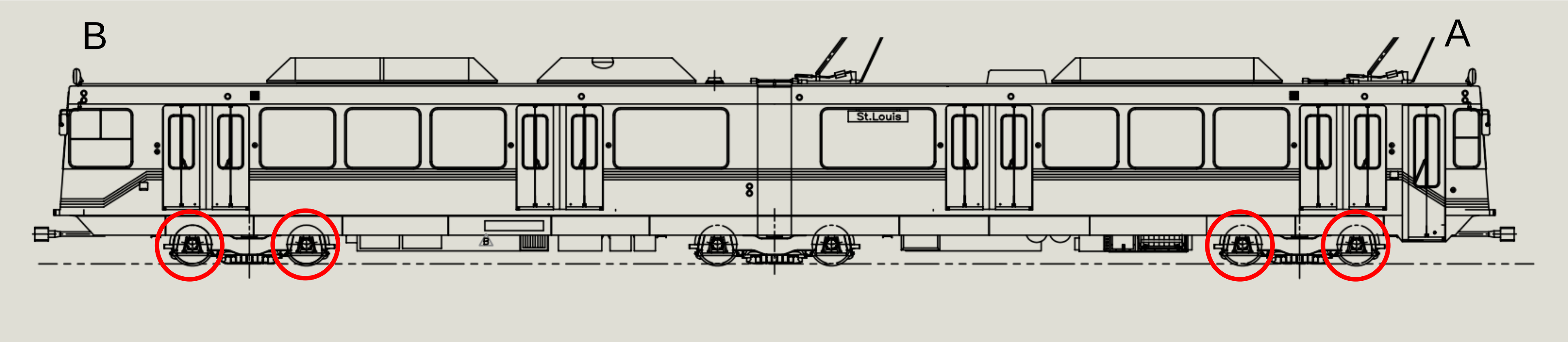
Preliminary Data Collection with Automated DAQ

- **MetroLink Site**
  - 154 train data files per day
  - Tangent location
  - Maximum operating speed: 55 mph (88 km/h)
  - Deployed on March 18, 2016
- **New York City Transit Site**
  - 88 train data files per day
  - Curve location: 3.6° (485 m radius)
  - Maximum operating speed: 30 mph (48 km/h)
  - Deployed on April 25, 2016

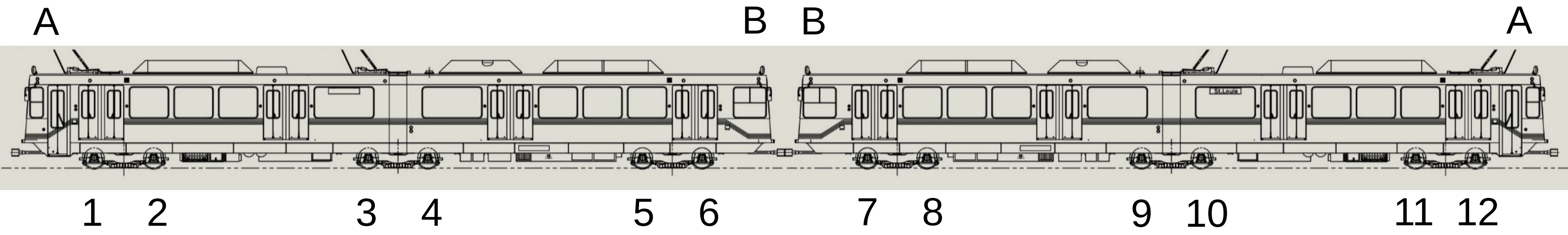
MetroLink Light Rail Vehicles

Siemens SD-400 & SD-460

- 2-vehicle (12 axle) trainsets
- Traction motor and gearbox locations:

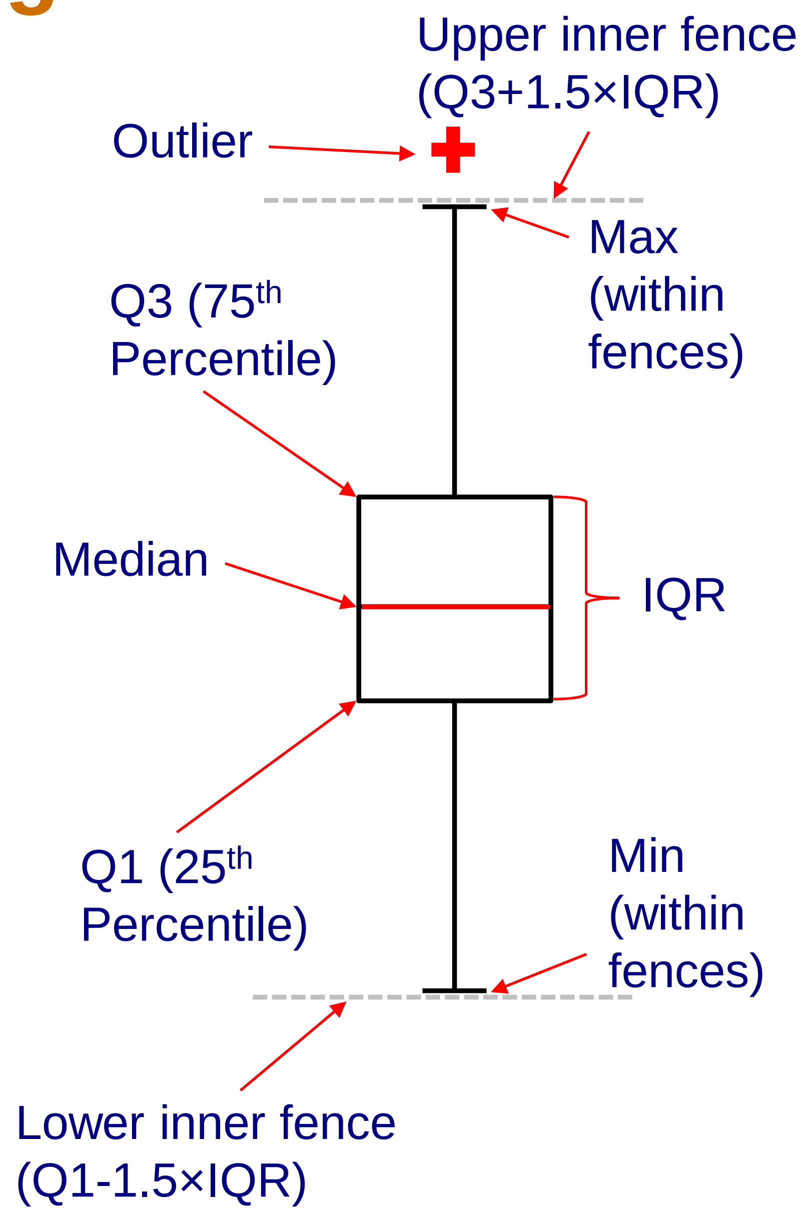


- Normal trainset configuration:



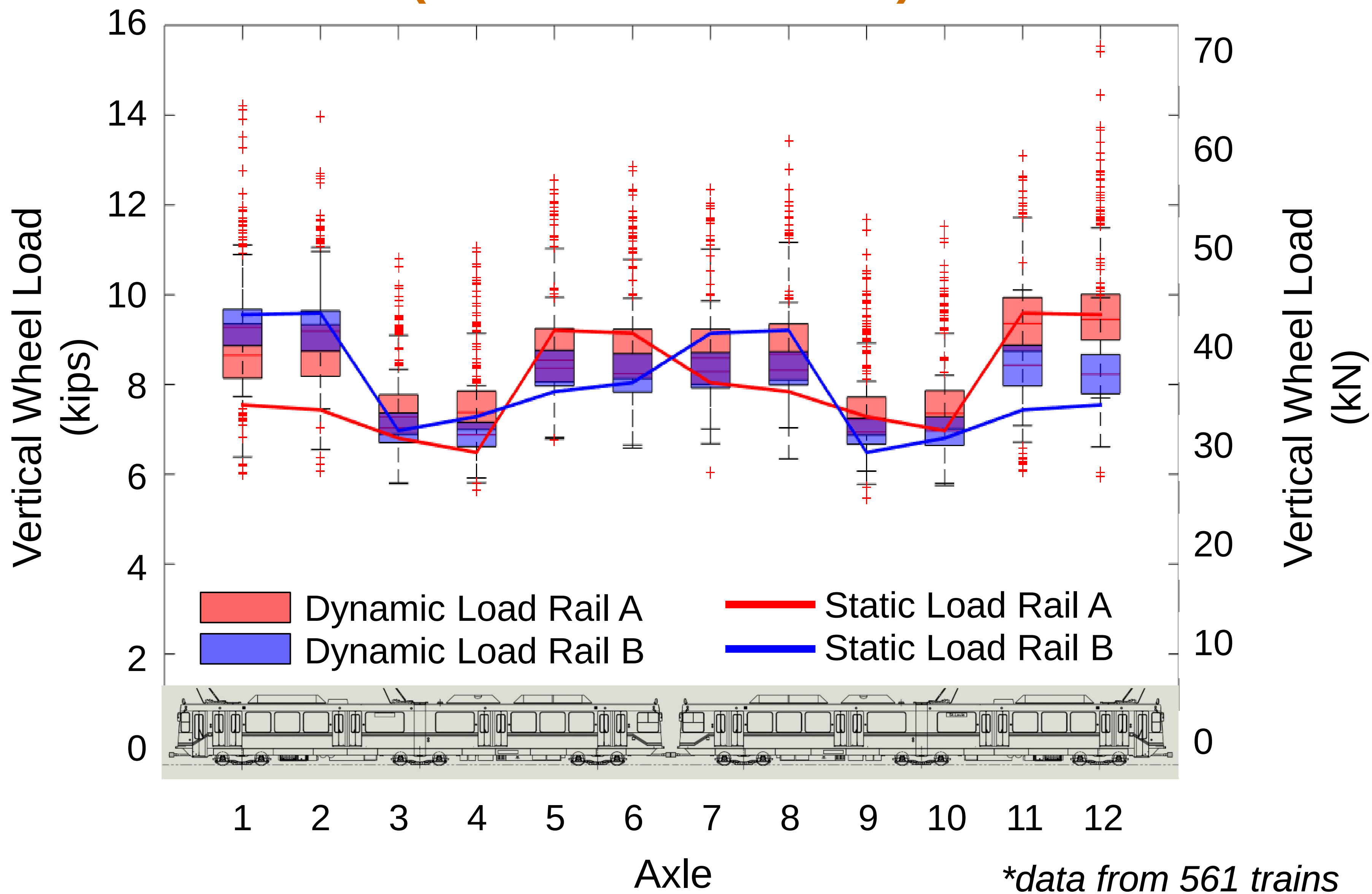
Box Plot Background

- Box plots are great to:
  - Visualize outliers
  - Compare variability of different cases
  - Check for symmetry
  - Check for normality



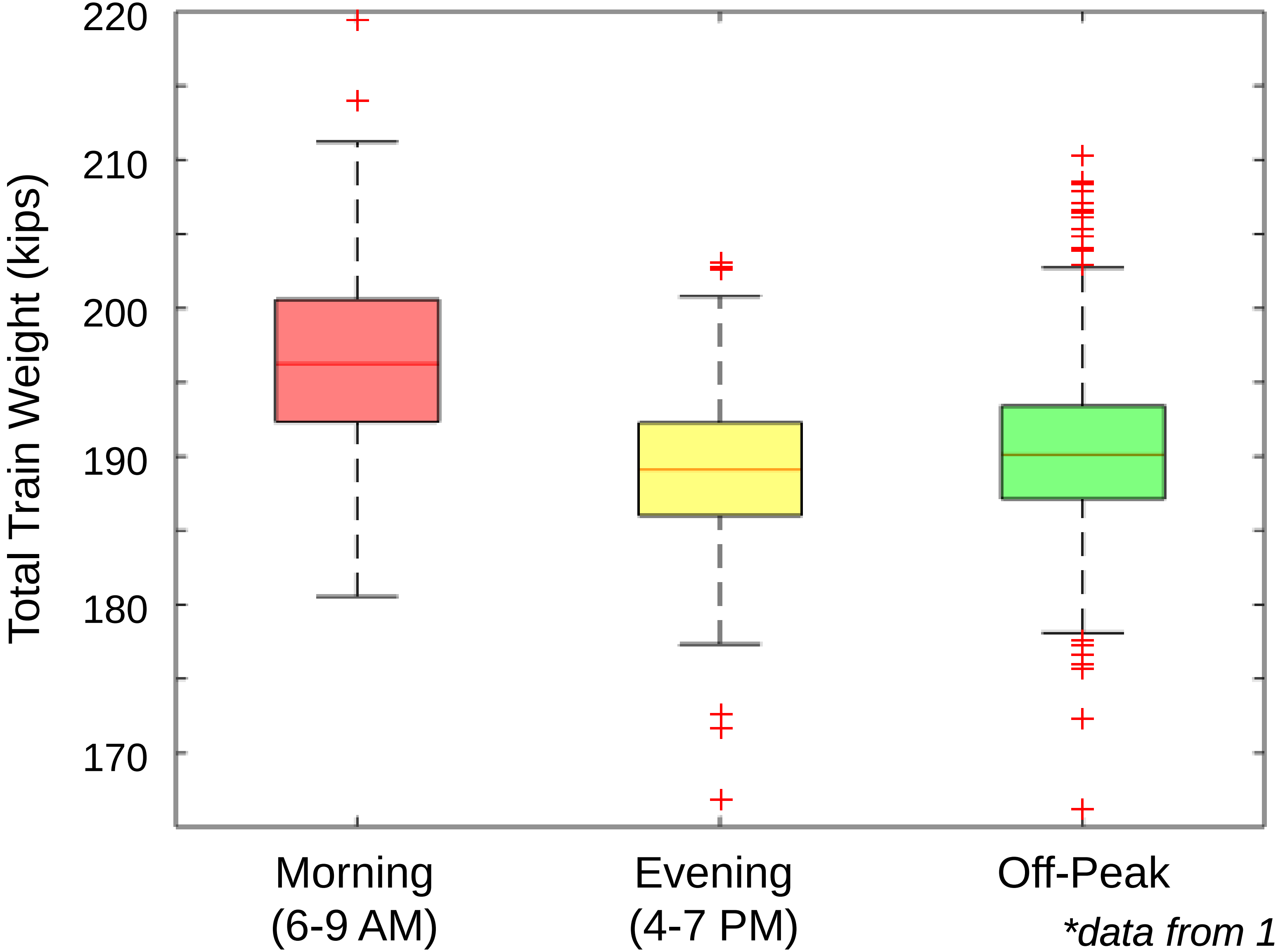
Light Rail Vertical Loads

(St. Louis MetroLink)



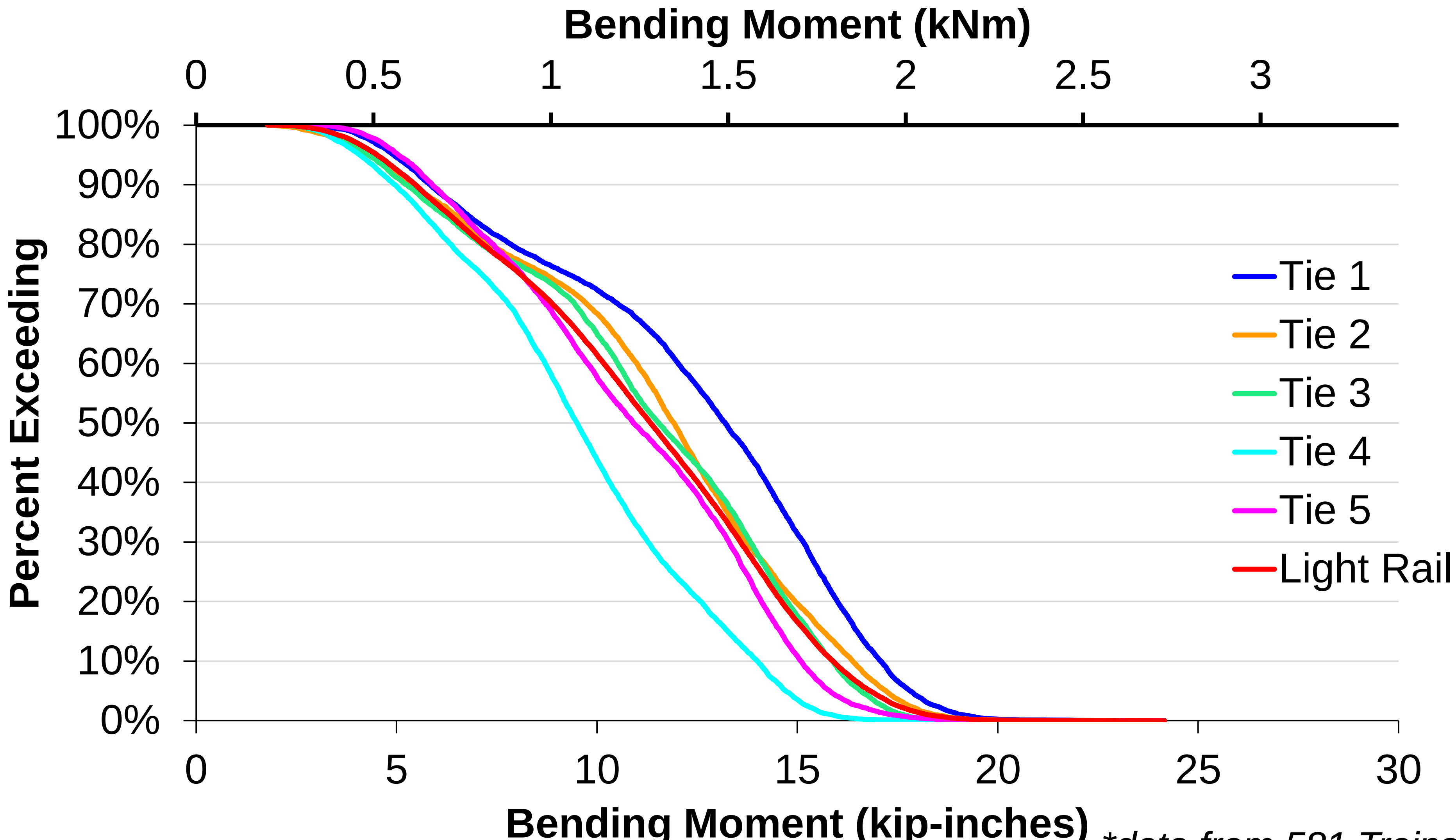
**data from 561 trains*

Peak vs. Off-Peak Weekday Loading
(St. Louis MetroLink)



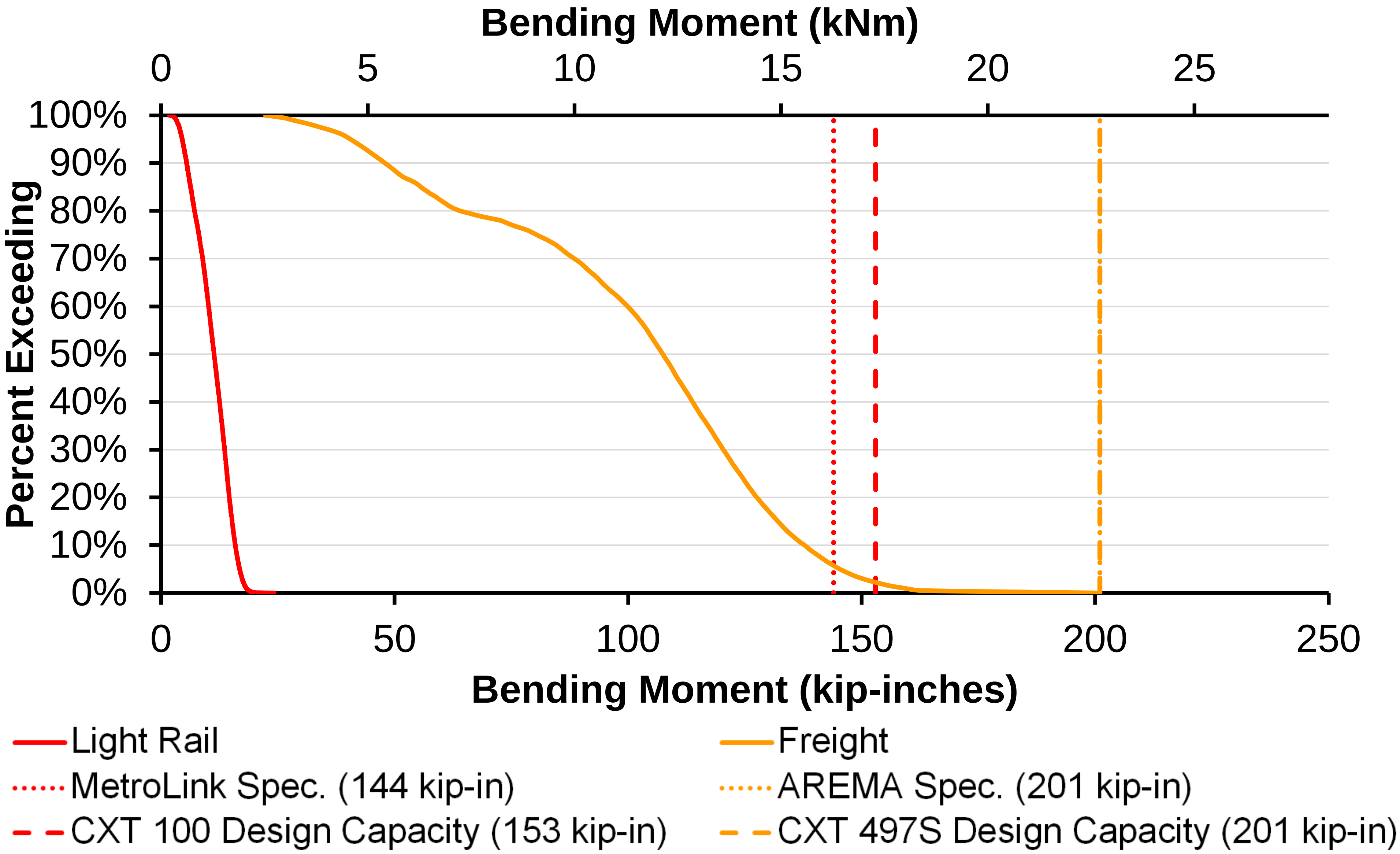
**data from 1,501 Trains*

Center Negative Bending
(St. Louis MetroLink)



**data from 581 Trains*

Center Negative Bending Comparison
(St. Louis MetroLink)



Field Data Collection Conclusions

- Automated data collection systems can be deployed at remote locations and will run reliably for long durations
- In-service wheel loads may be up to 1.5 times more than the static wheel load for a light rail transit vehicle
- Large amounts of data collected at automated sites requires automated or semi-automated data processing
- From MetroLink data
  - Wheel loads 15.8 kips (70 kN) and lower
  - Center negative moments 24.2 kip-inches (2.73 kN-m) and lower
- Reserve capacity – highest measured moment would have to be increased by a factor of 5 to reach the center bending capacity for light rail ties used on MetroLink

Immediate Path Forward

- Further expand the understanding of vehicle and infrastructure characteristics for rail transit systems
- Incorporate field data to evaluate the effectiveness of dynamic factor models and rail seat load models for light rail and heavy rail systems
- Install automated data collection system on commuter rail transit system (Metra, Chicago, IL, USA)

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  - MetroLink (St. Louis, Mo.)
  - TriMet (Portland, Ore.)
  - Pandrol USA
  - Progress Rail Services
  - LBFoster, CXT Concrete Ties
  - GIC Inc.
  - Hanson Professional Services, Inc.
  - Amtrak

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