Causes of Load Amplification: Using WILD Data to Quantify Wheel Loads

2013 Joint Rail Conference

Knoxville, TN

16-18 April 2013

Brandon J. Van Dyk, Marcus S. Dersch, J. Riley Edwards, Conrad Ruppert, Jr., and Christopher P.L. Barkan

U.S. Department of Transportation
Federal Railroad Administration

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- Objectives of quantifying load amplification
- Rail seat load calculation methodologies
- Wheel load distribution on shared infrastructure
  - Causes of load amplification
- Evaluation of load amplification factors
  - Dynamic wheel load factors
  - Impact factors
- Conclusions and Acknowledgements

FRA Tie and Fastening System BAA Objectives and Deliverables

U.S. Department of Transportation
Federal Railroad Administration

- **Program Objectives**
  - Conduct comprehensive international literature review and state-of-the-art assessment for design and performance
  - Conduct experimental laboratory and field testing, leading to improved recommended practices for design
  - Provide mechanistic design recommendations for concrete sleepers and fastening system design in the US
- **Program Deliverables**
  - Improved mechanistic design recommendations for concrete sleepers and fastening systems in the US
  - Improved safety due to increased strength of critical infrastructure components
  - Centralized knowledge and document depository for concrete sleepers and fastening systems

FRA Tie and Fastener BAA Industry Partners:

Union Pacific – Building America®
BNSF Railway
Amtrak®
Amsted RPS
Amsted Rail
GIC Ingeniería y Construcción S.A. de C.V.
Hanson
LB Foster CXT Concrete Ties

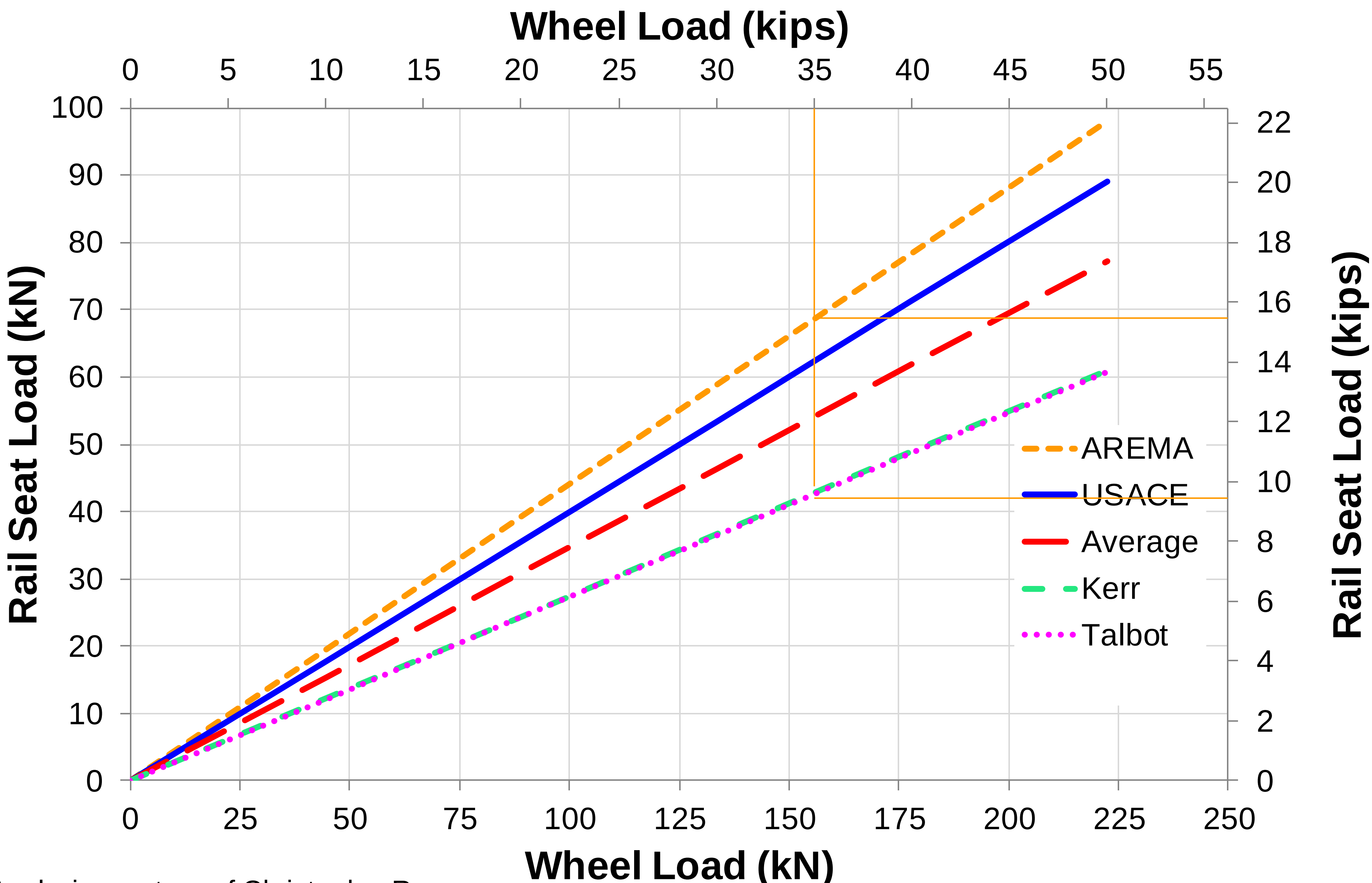
Principles of Mechanistic Design

1. Quantify track system input loads (wheel loads)
2. Qualitatively establish load path (free body diagrams, basic modeling, etc.)
3. Quantify demands on each component
   a. Laboratory experimentation
   b. Field experimentation
   c. Analytical modeling
4. Link quantitative data to component geometry and materials properties (materials decision)
5. Relate loading to failure modes
6. Investigate interdependencies through modeling
7. Establish mechanistic design practices and incorporate into AREMA Recommended Practices

Objectives

- Characterize and quantify increase above static wheel load due to several factors
  - Temperature
  - Speed
  - Irregularities
- Evaluate effectiveness of dynamic and impact wheel load factors
- Determine rail seat load entering tie and fastening system

Rail Seat Load Calculation Methodologies

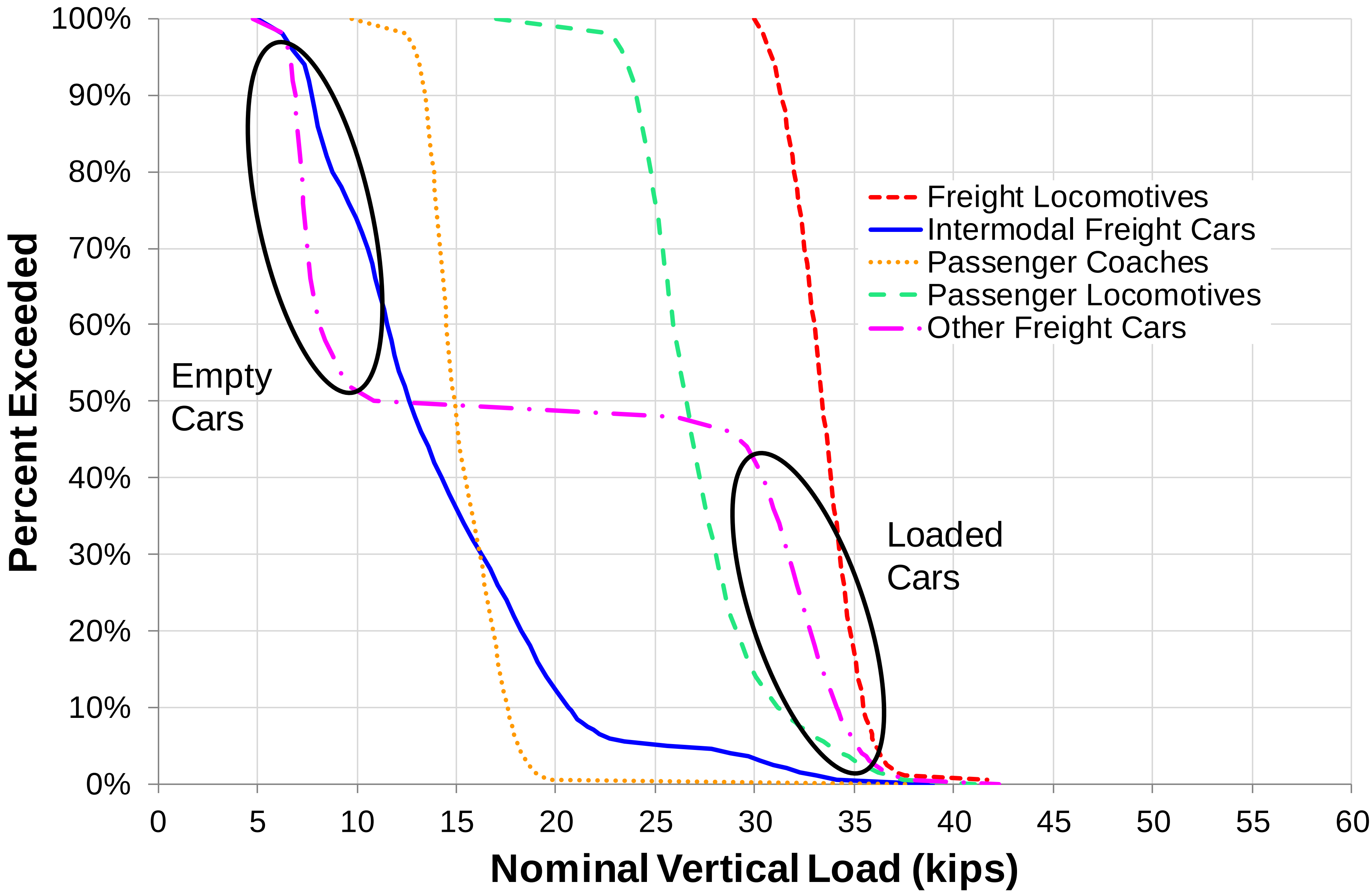


Analysis courtesy of Christopher Rapp

Wheel Impact Load Detectors (WILD)

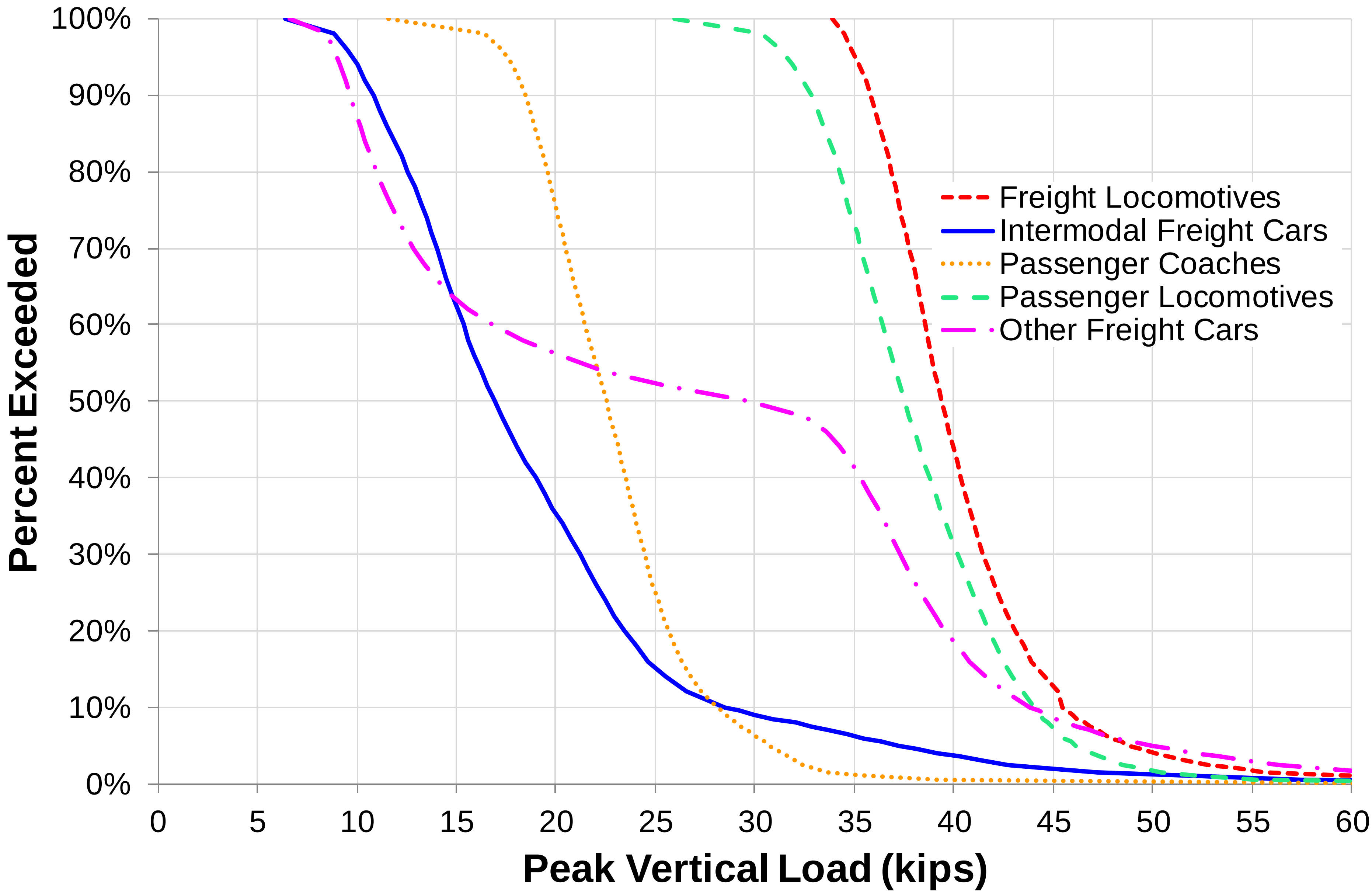
- Sixteen sets of strain gauges to detect full rotation of most wheels
- For each wheel,
  - Labels by vehicle type
  - Measures speed, nominal (static) wheel load, and peak wheel load

Traffic Distribution – Nominal Wheel Loads



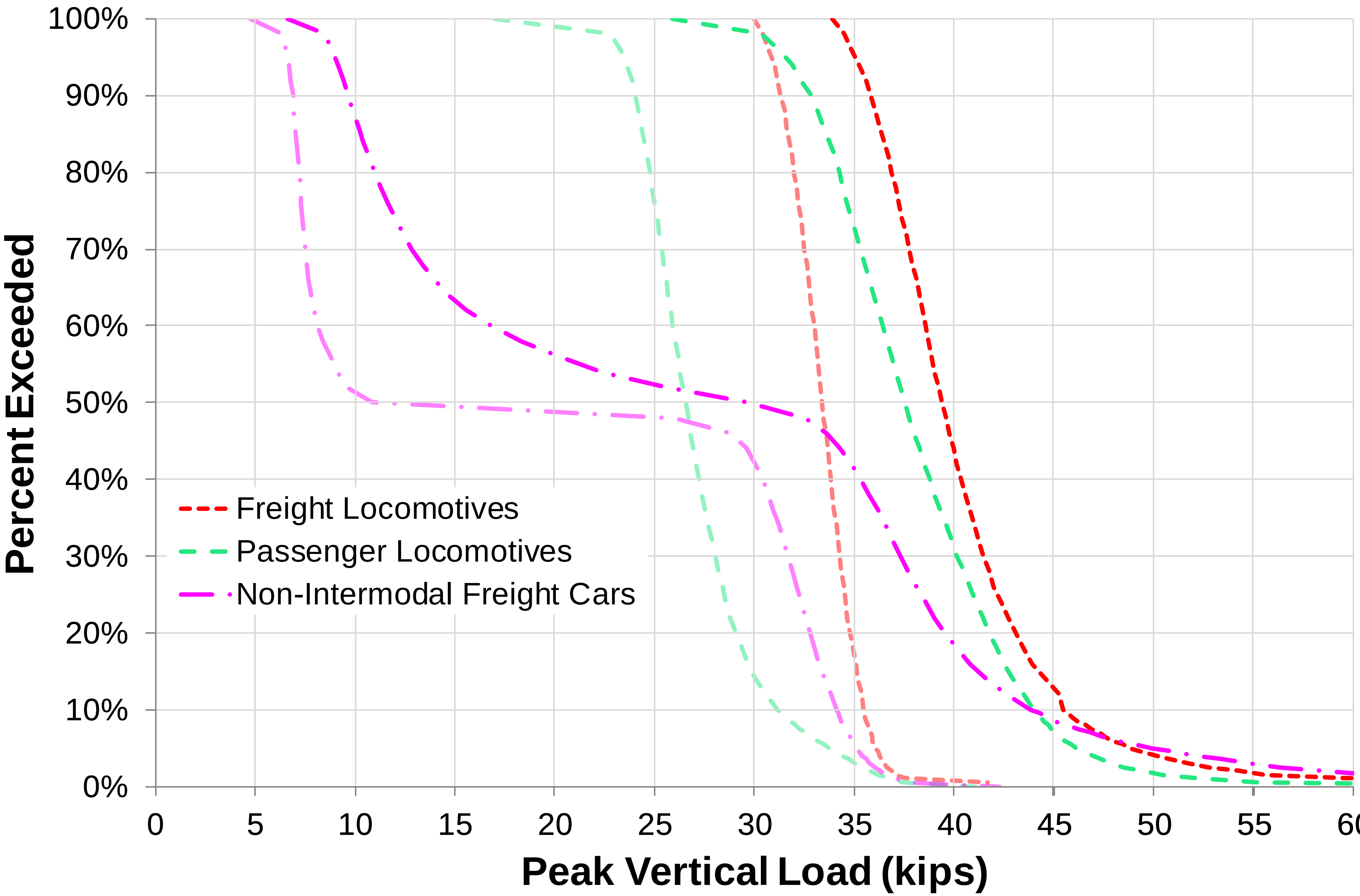
Source: Amtrak – Edgewood, MD (November 2010)

Traffic Distribution – Peak Wheel Loads



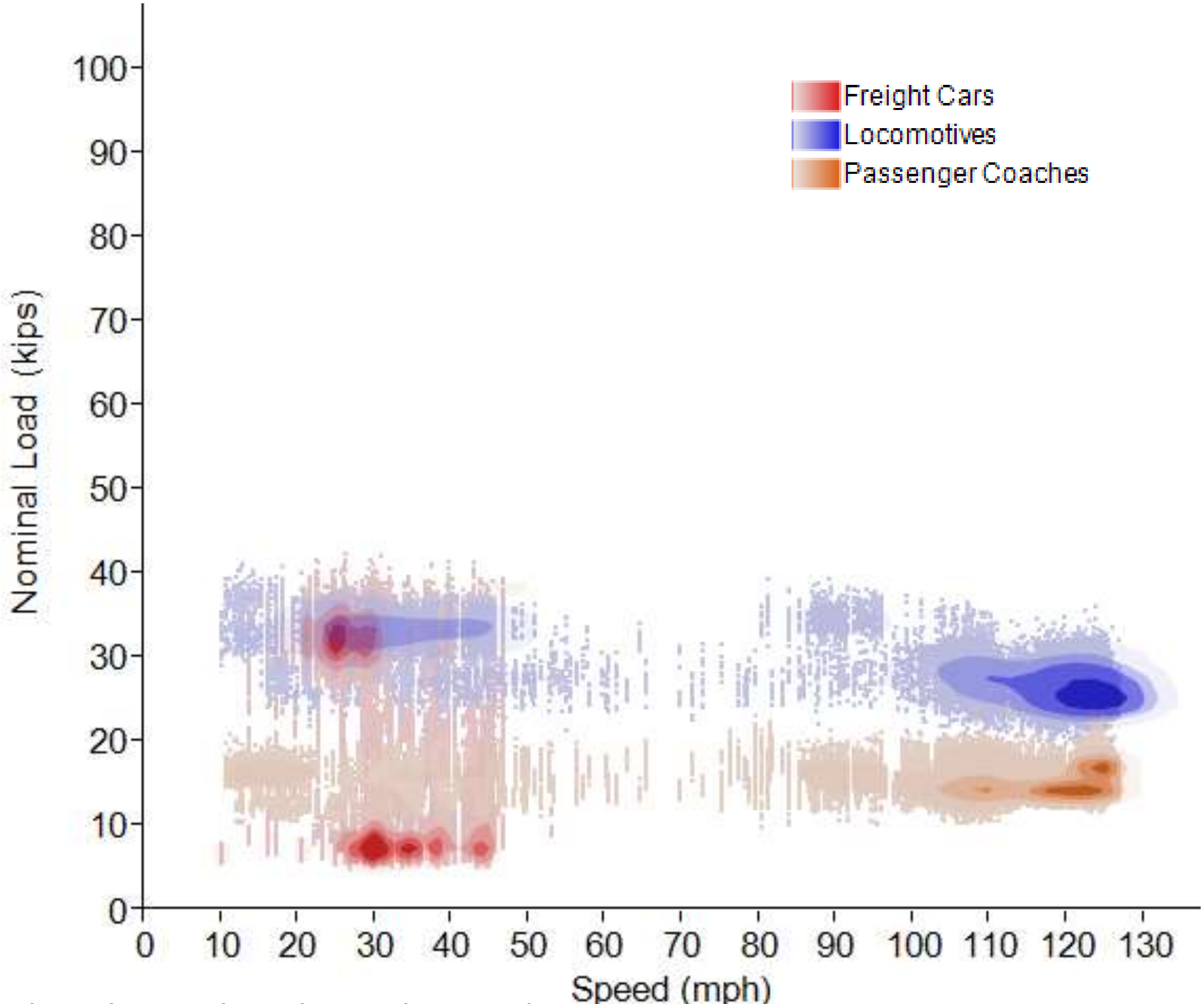
Source: Amtrak – Edgewood, MD (November 2010)

Nominal vs. Peak Vertical Load



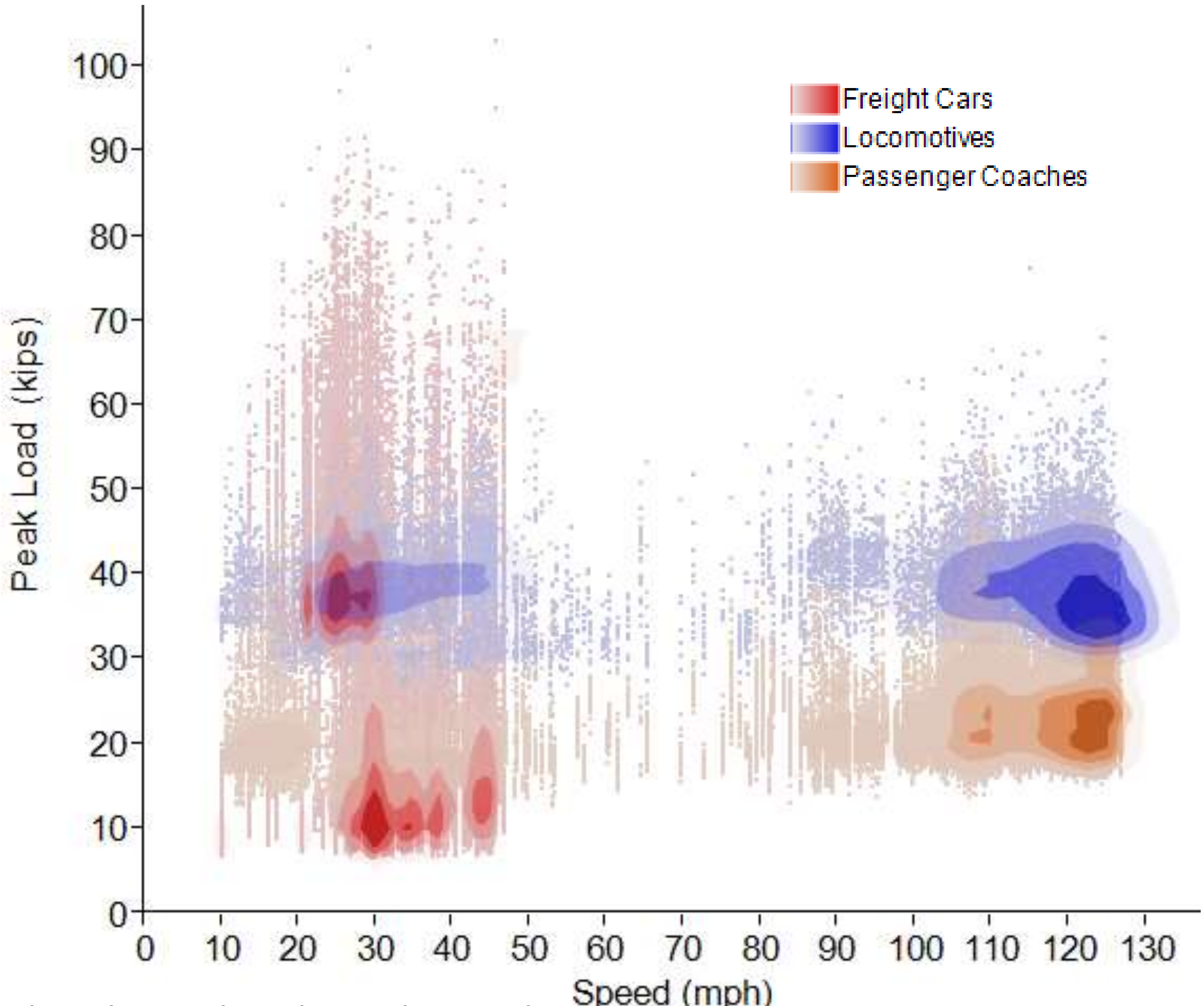
Source: Amtrak – Edgewood, MD (November 2010)

Distribution of Nominal Wheel Loads



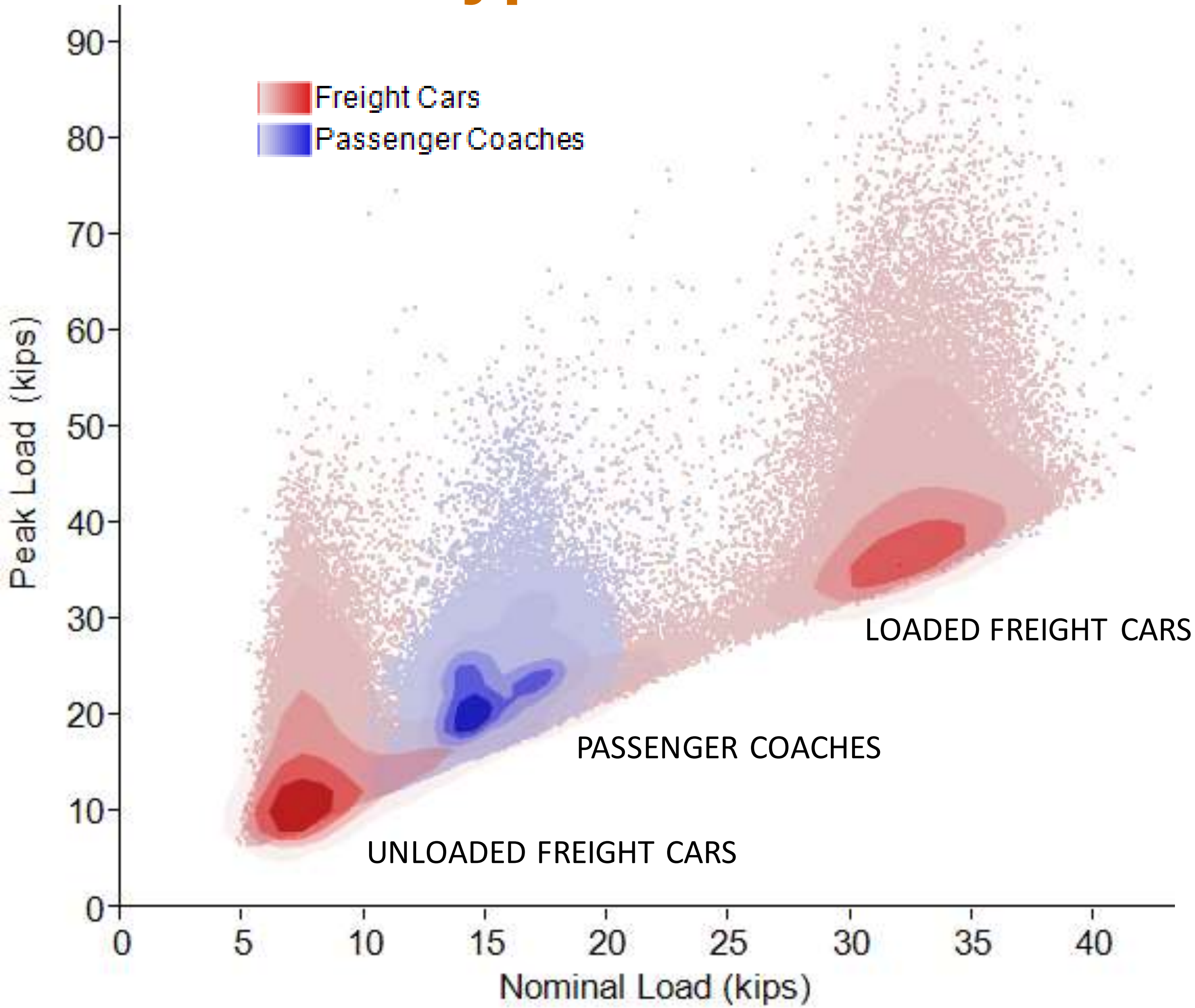
Source: Amtrak – Edgewood, MD (November 2010)

Distribution of Peak Wheel Loads



Source: Amtrak – Edgewood, MD (November 2010)

Effect of Traffic Type on Peak Wheel Load

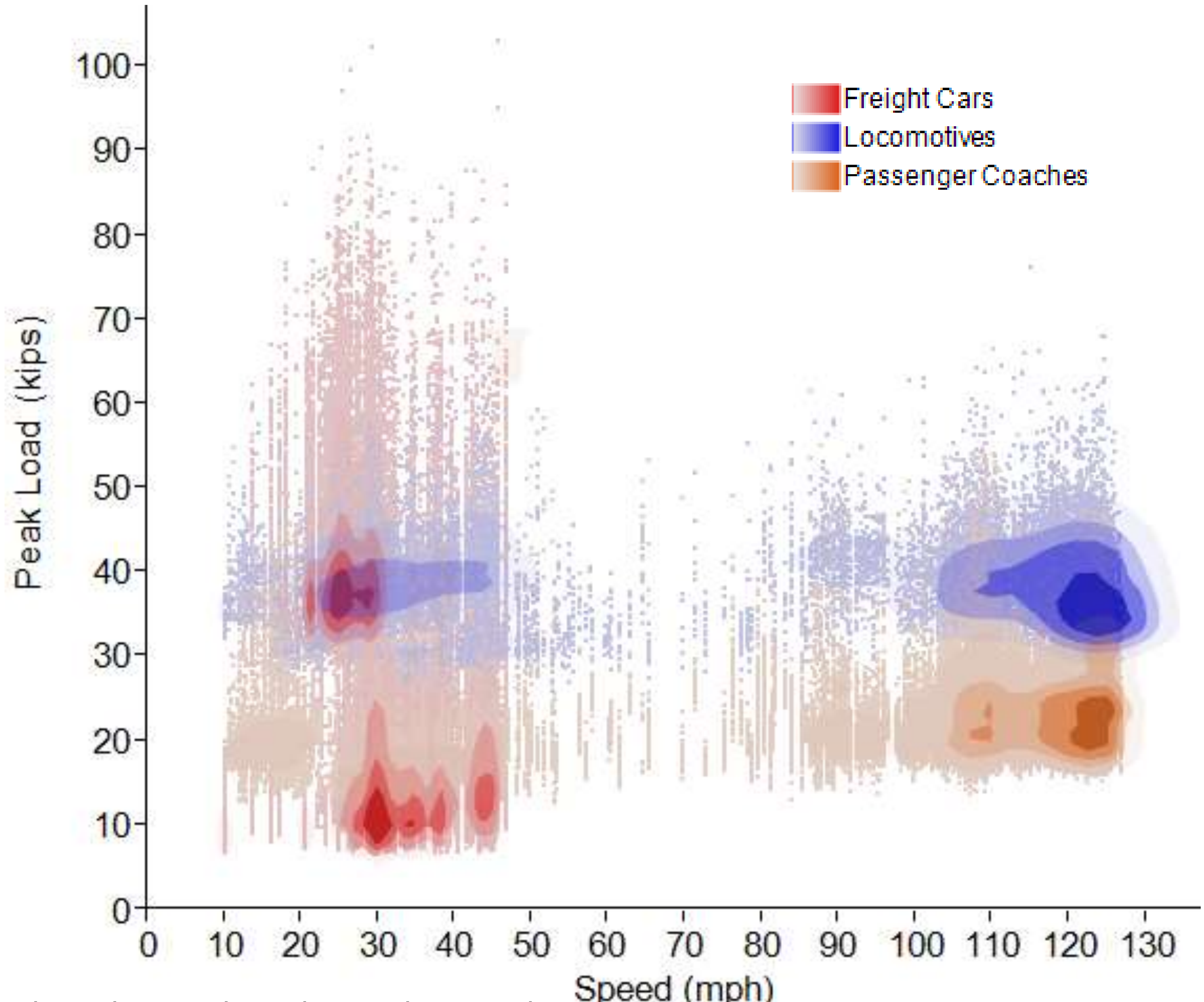


Source: Amtrak – Edgewood, MD (November 2010)

Dynamic vs. Impact Load

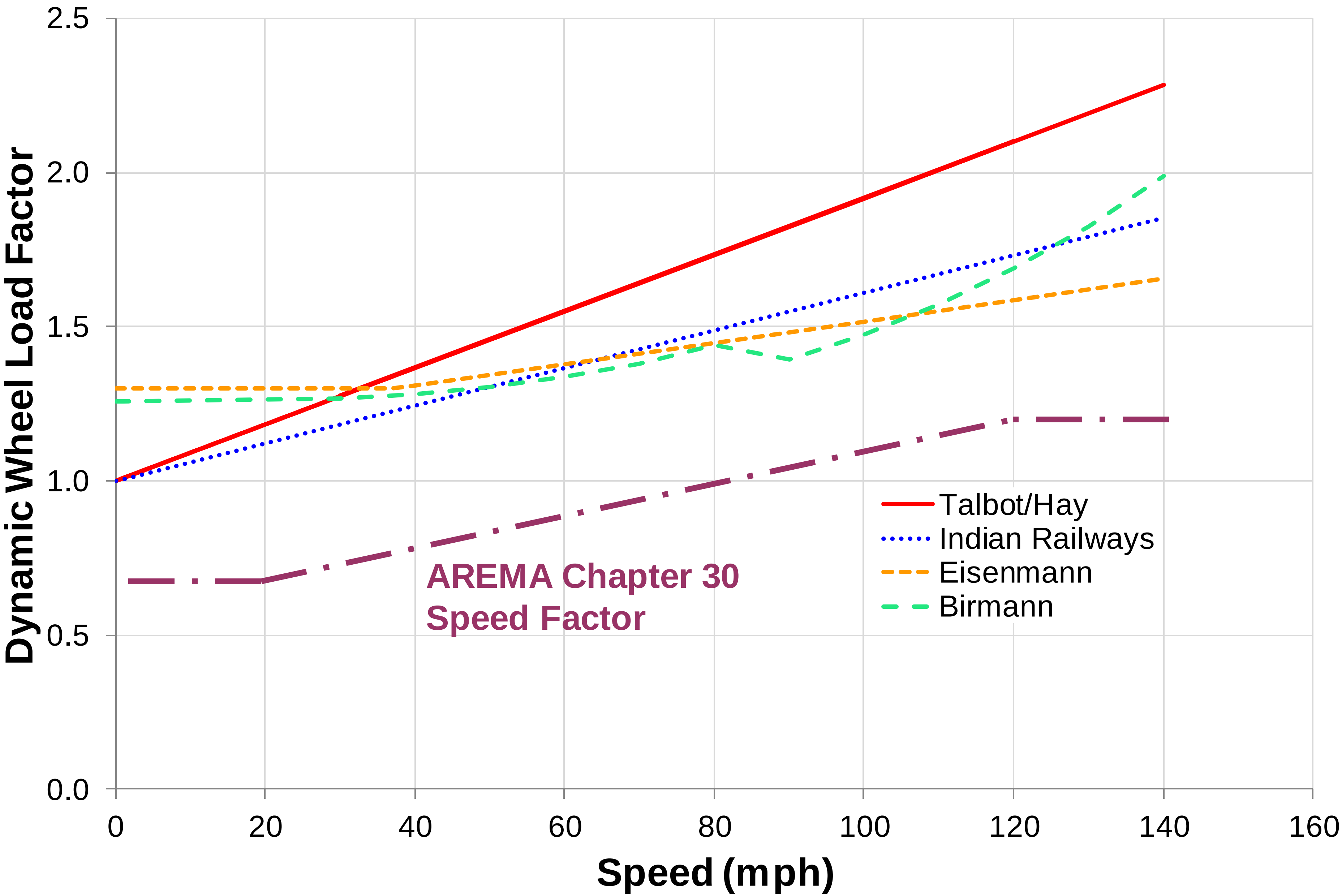
- Static load – load of vehicle at rest
- Quasi-static load – static load at speed, independent of time
- Dynamic load – high frequency effects of wheel/rail interaction, dependent on time
  - E.g., $\boldsymbol{Dynamic\ Factor = 1 + \frac{33(speed)}{100(diameter)}}$
- Impact load – high-frequency and short duration load caused by track and vehicle irregularities
  - E.g., increase of 200% (found in AREMA Chapter 30)

Effect of Speed on Wheel Load

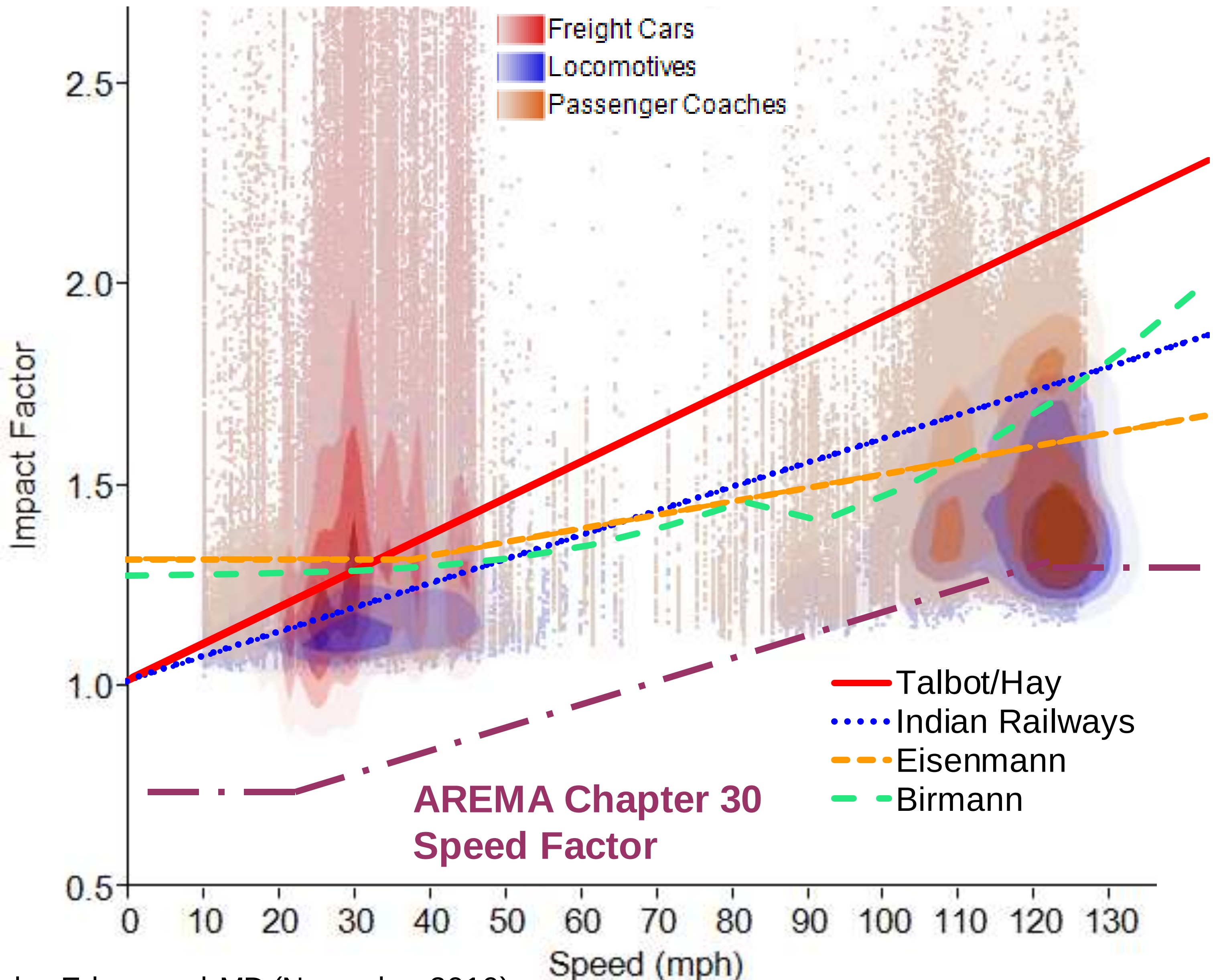


Source: Amtrak – Edgewood, MD (November 2010)

Comparison of Dynamic Wheel Load Factors

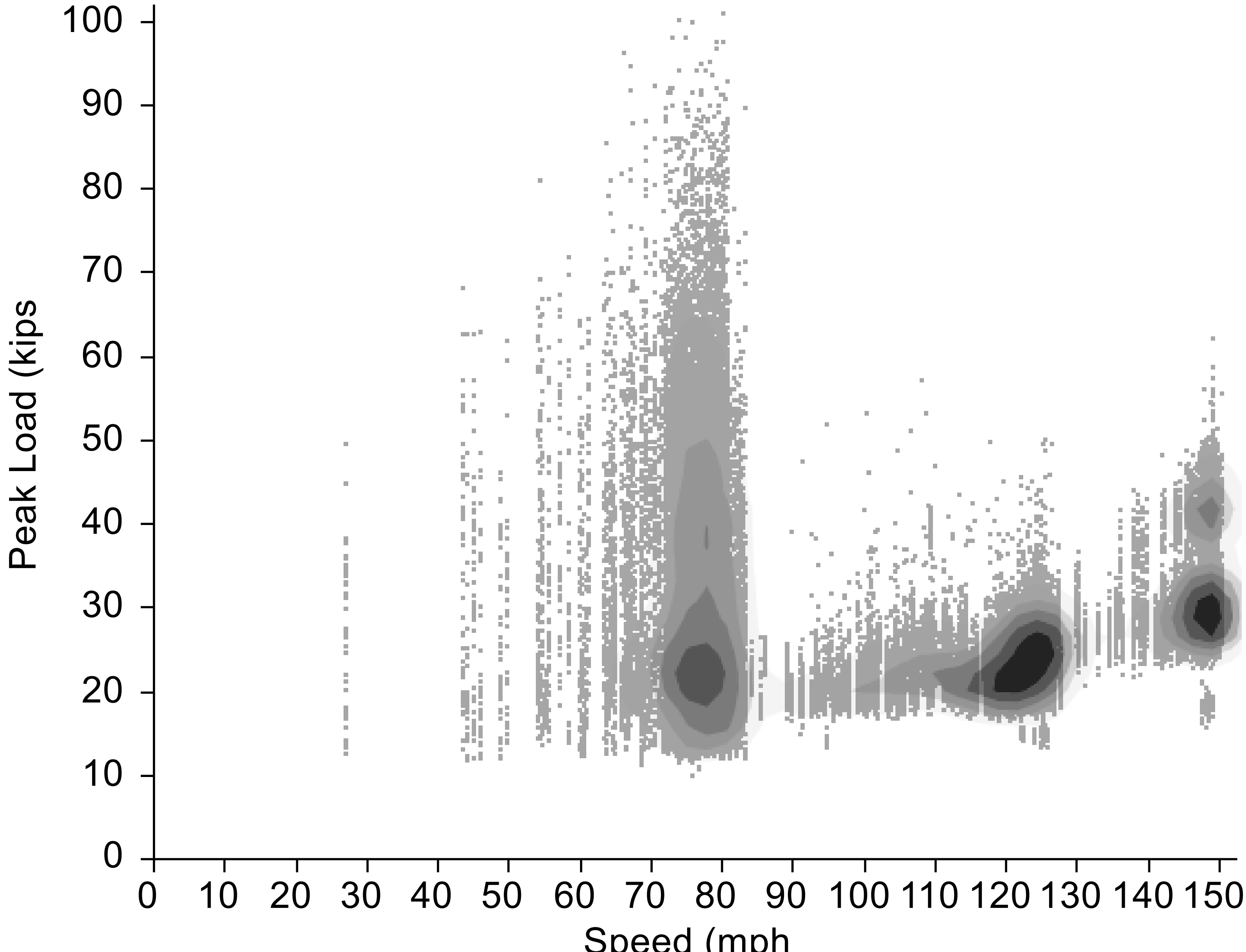


Dynamic Wheel Load Factors



Source: Amtrak – Edgewood, MD (November 2010)

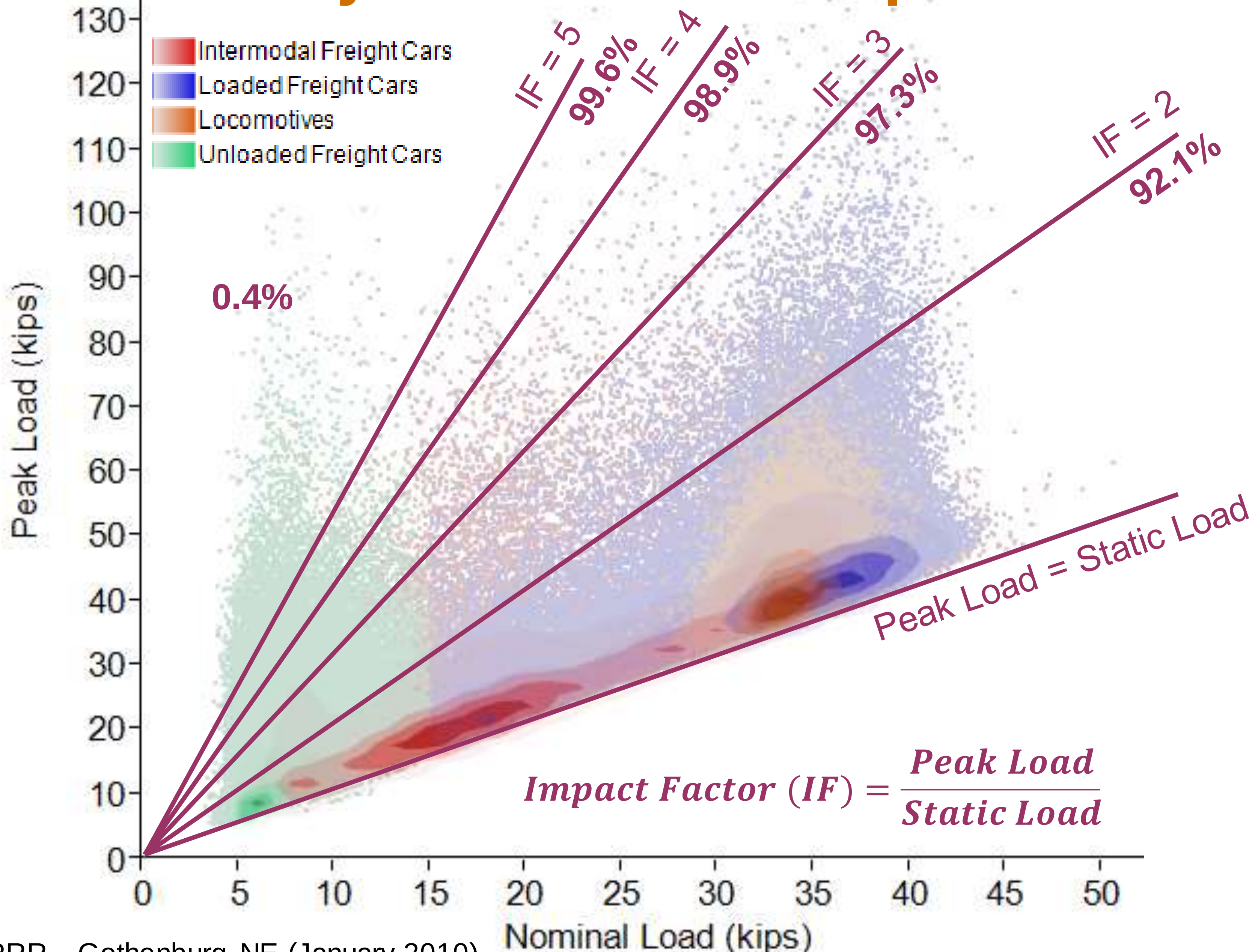
Effect of Wheel Condition on Peak Wheel Load



Source: Amtrak – Mansfied, MA (November 2010)

Passenger Coaches

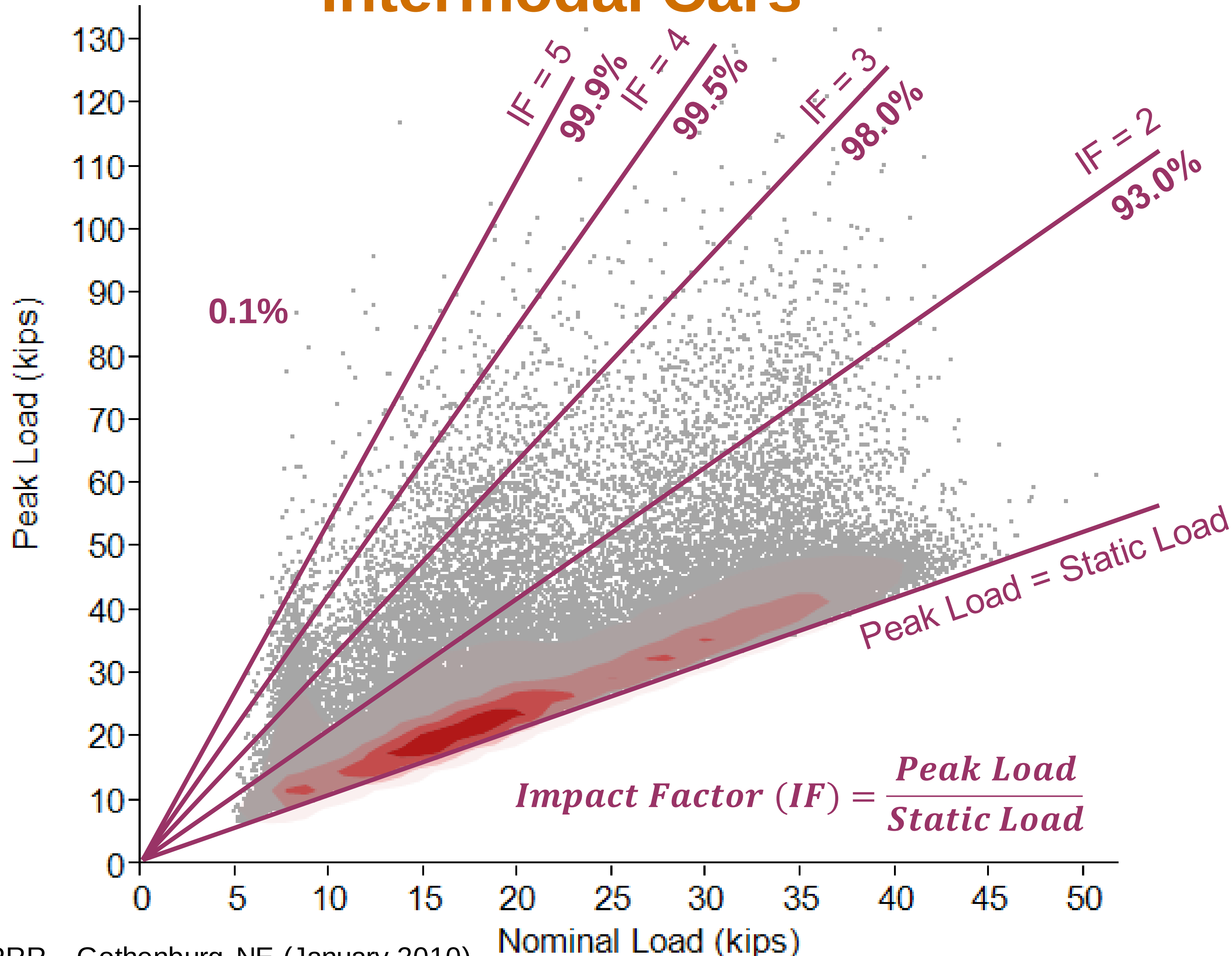
More than a Dynamic Factor: Impact Factor



$$Impact\ Factor\ (IF) = \frac{Peak\ Load}{Static\ Load}$$

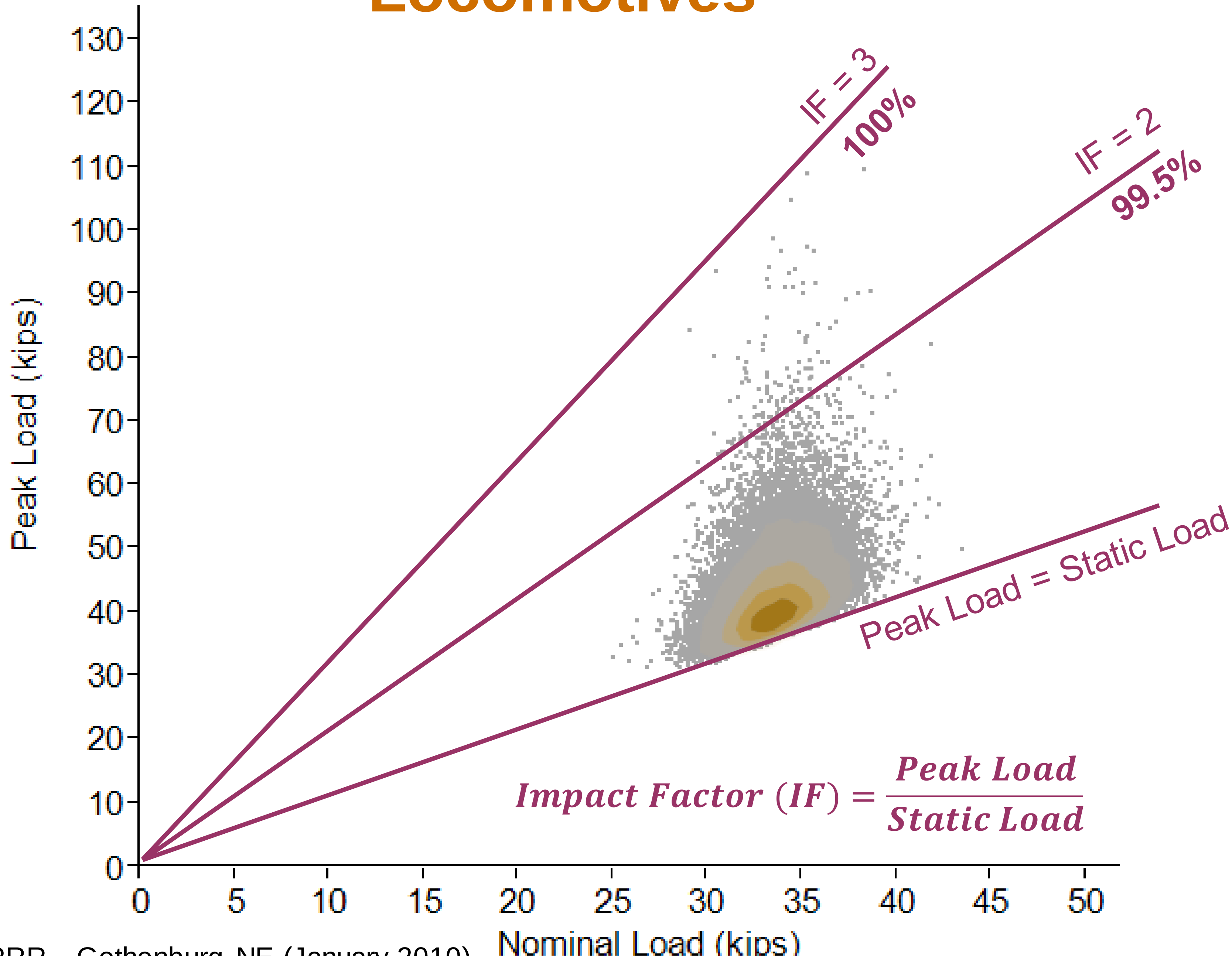
Source: UPRR – Gothenburg, NE (January 2010)

Intermodal Cars



Source: UPRR – Gothenburg, NE (January 2010)

Locomotives



$$Impact\ Factor\ (IF) = \frac{Peak\ Load}{Static\ Load}$$

Source: UPRR – Gothenburg, NE (January 2010)

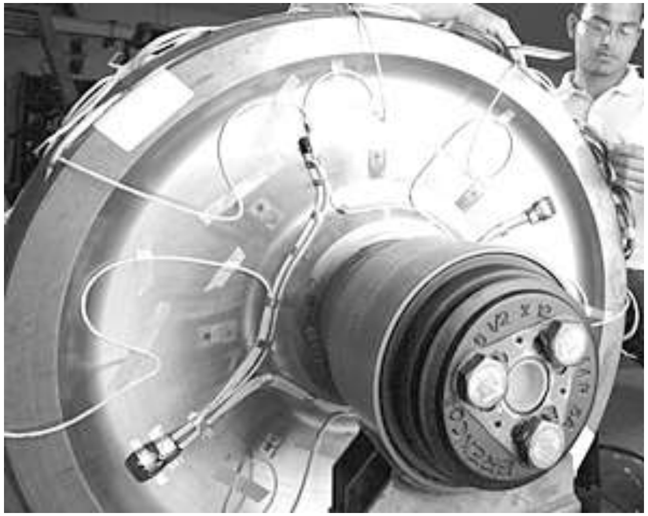
Thoughts on Impact Factor

- Chapter 30 Impact Factor (300%) exceeds majority of locomotive and loaded freight car loads
  - Greater impact factor may be necessary for lighter rolling stock (passenger coaches and unloaded freight cars)
  - Wheel condition significantly affects load
  - Speed causes highest impacts to be higher
- Evaluating effectiveness of impact factor dependent on static weight of car

Other Factors Affecting Wheel Loads

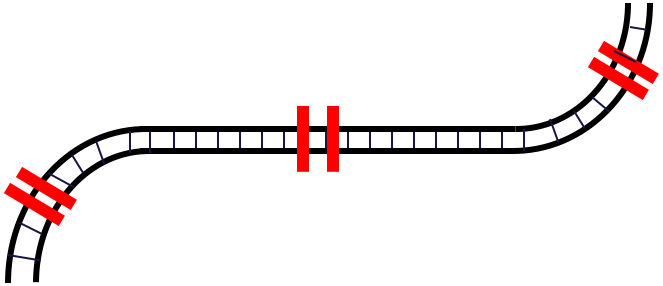
- Moisture and temperature
- Position within the train
- Curvature
- Grade
- Track quality

(Curvature, Grade, Track quality:) Need alternative data collection methods



Instrumented Wheel Set

UIUC Instrumentation Plan



Truck Performance Detector

Alternative Data Collection Methods

- Instrumented Wheel Set
  - Vehicle-mounted; collects data at 300 Hz
  - Measures vertical and lateral loads in tangent, curved, and graded sections
- Truck Performance Detector
  - Wayside detector in tangent and curved sections
  - Measures vertical and lateral loads of each wheel
- UIUC Instrumentation Plan
  - Instrumented track in tangent and curved sections
  - Continuously measures each wheel in multiple locations for vertical load, lateral load, and various deflections

Conclusions

- A clear distinction between dynamic and impact loads should exist
- Colder temperatures do not increase the majority of the wheel loads; stiffer subgrade does increase highest impact loads
- Various dynamic wheel load factors can be compared and evaluated
  - AREMA Chapter 30 Speed Factor may no longer reflect current loading trends
- Impact factor to account for wheel and track irregularities appropriate in many instances; requires further investigation

Acknowledgements

U.S. Department of Transportation

Federal Railroad Administration

- Funding for this research has been provided by the Federal Railroad Administration (FRA)
- Industry Partnership and support has been provided by
  - Union Pacific Railroad
  - BNSF Railway
  - National Railway Passenger Corporation (Amtrak)
  - Amsted RPS / Amsted Rail, Inc.
  - GIC Ingeniería y Construcción
  - Hanson Professional Services, Inc.
  - CXT Concrete Ties, Inc., LB Foster Company
  - TTX Company
- For assistance in data acquisition
  - Steve Crismer, Jonathan Wnek (Amtrak)
  - Steve Ashmore, Bill GeMeiner, Michael Pfeifer (Union Pacific)
  - Teever Handal, (PRT), Kevin Koch (TTCI), Jon Jeambey (TTX)
- For assistance in data processing and interpretation
  - Alex Schwarz, Andrew Stirk, Anusha Suryanarayanan (UIUC)

FRA Tie and Fastener BAA Industry Partners:

UNION PACIFIC BUILDING AMERICA®

BNSF RAILWAY

AMTRAK®

Amsted RPS

Amsted Rail

GIC
GIC INGENIERÍA Y CONSTRUCCIÓN S.A. DE C.V.

HANSON

LBFoster
CXT Concrete Ties

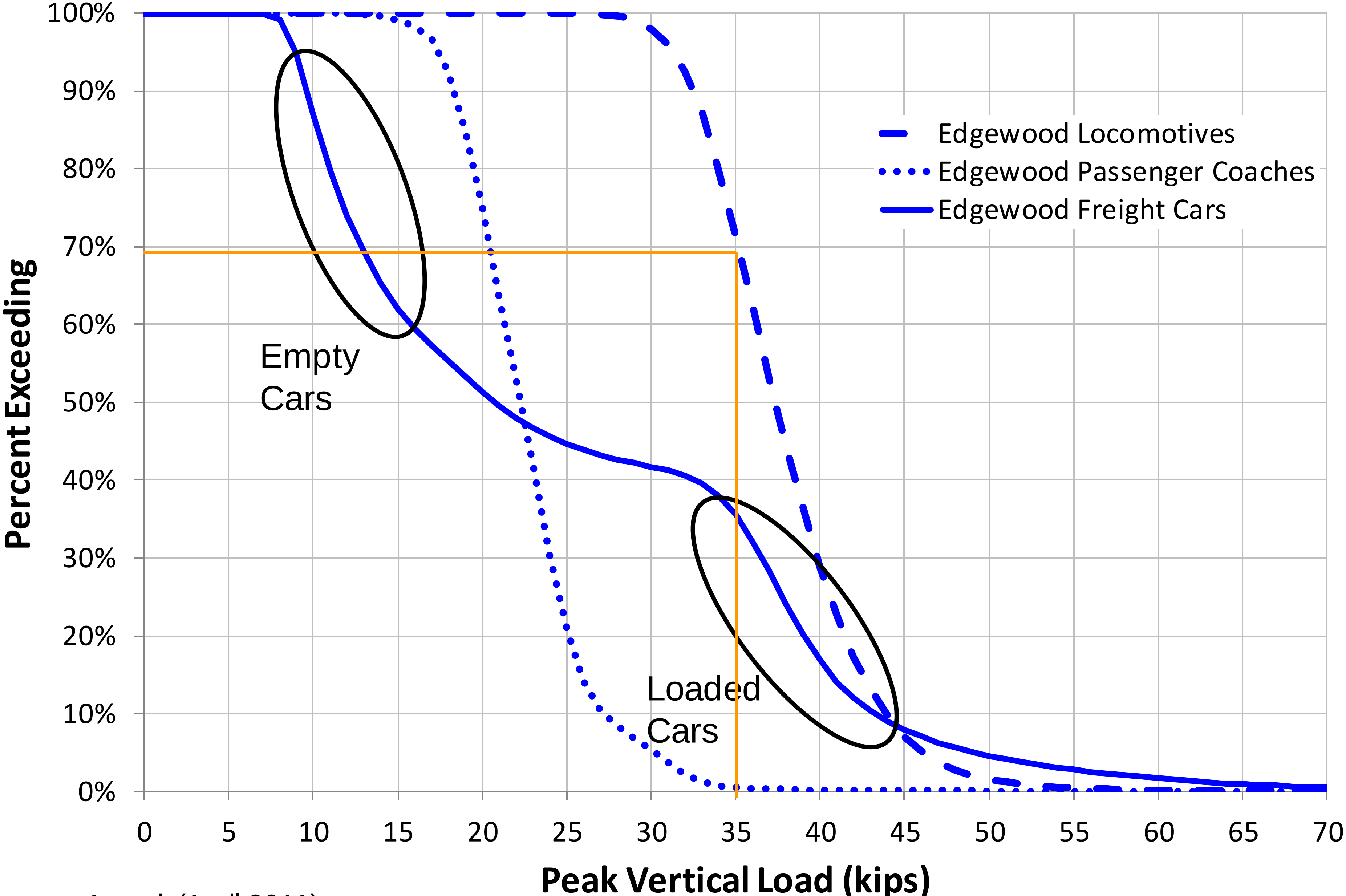
TTX

Questions

Brandon Van Dyk
Graduate Research Assistant
Rail Transportation and Engineering Center – RailTEC
University of Illinois at Urbana-Champaign
e-mail: vandyk2@illinois.edu

Appendix

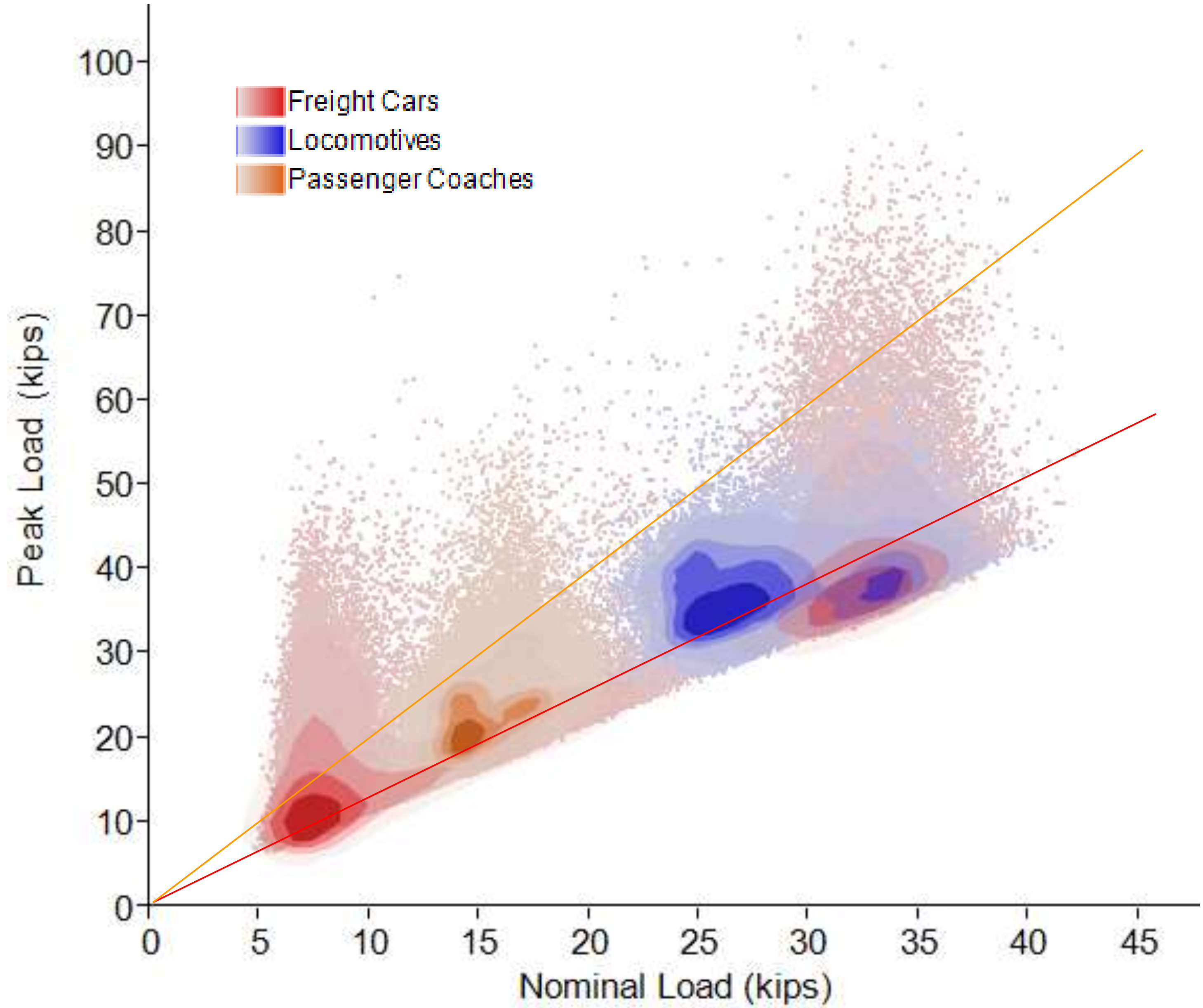
Variation of Loads on Amtrak's Northeast Corridor



Source: Amtrak (April 2011)

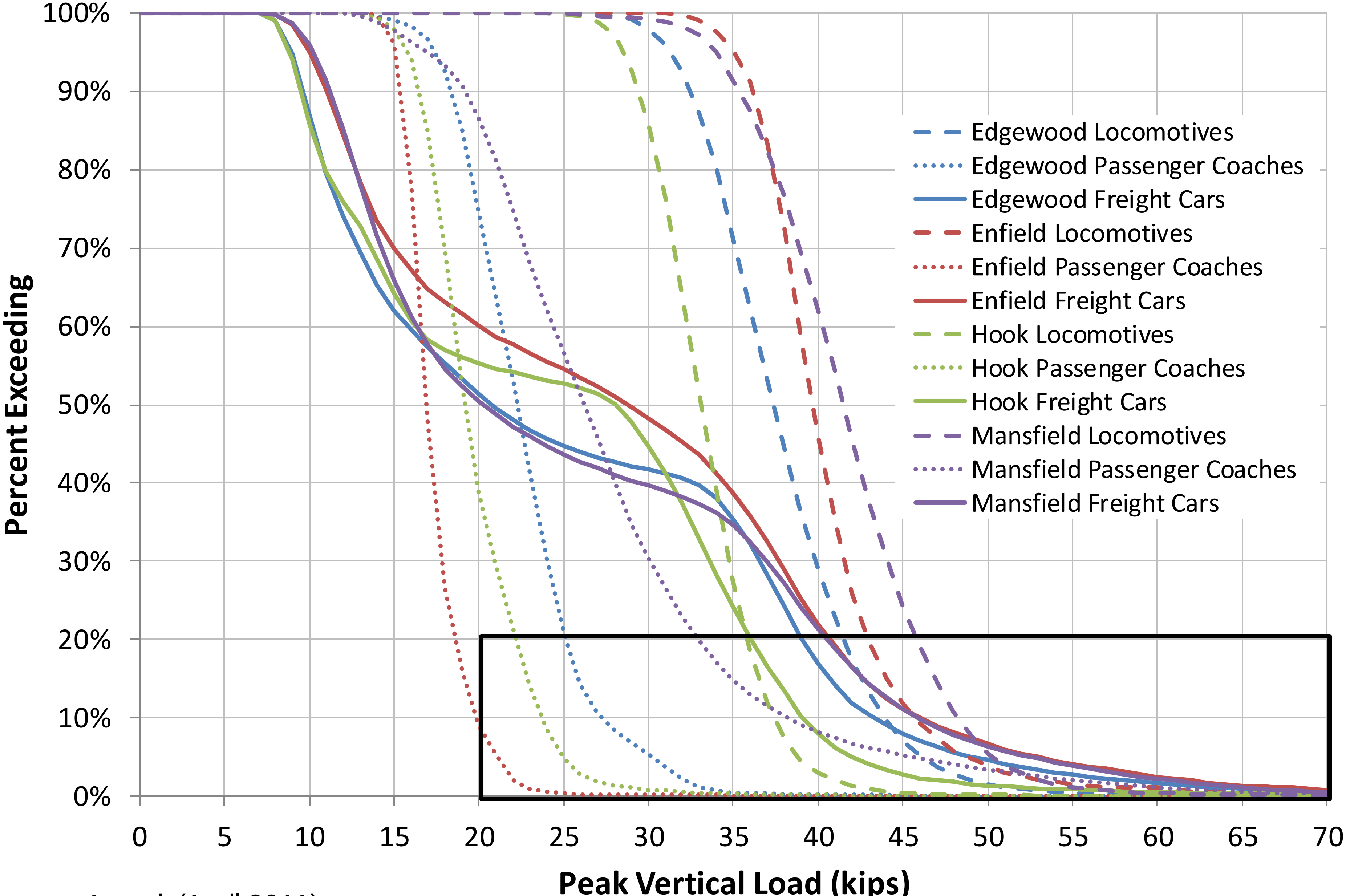
Future Work

- Further utilize IWS and UIUC data for lateral load information on curved and graded track
- Evaluate Chapter 30 tonnage factor using “dynamic” or “actual” tonnage
- Develop numerical model to predict loading environment



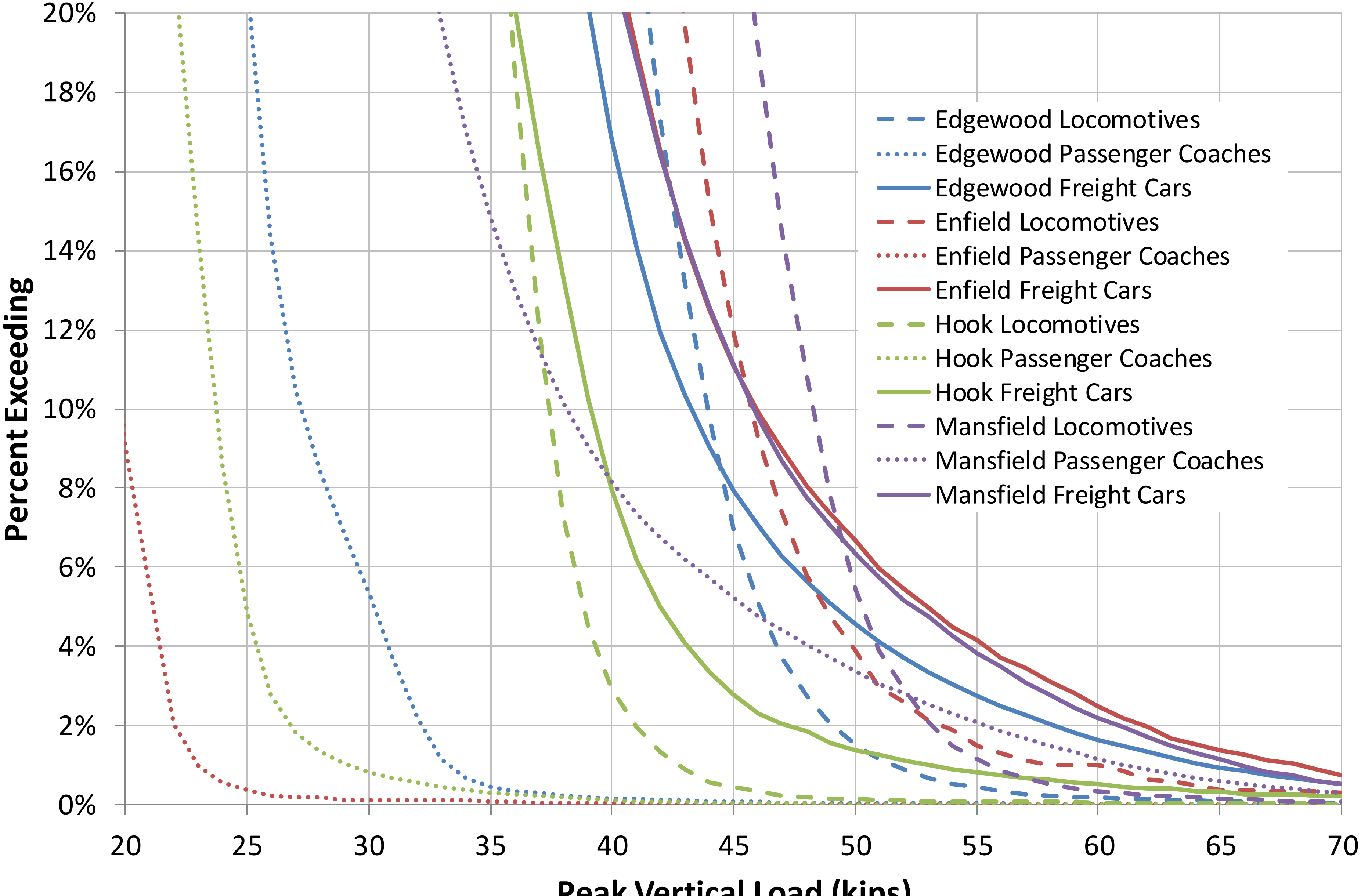
Source: Amtrak – Edgewood, MD (November 2010)

Variation of Loads on Amtrak's Northeast Corridor



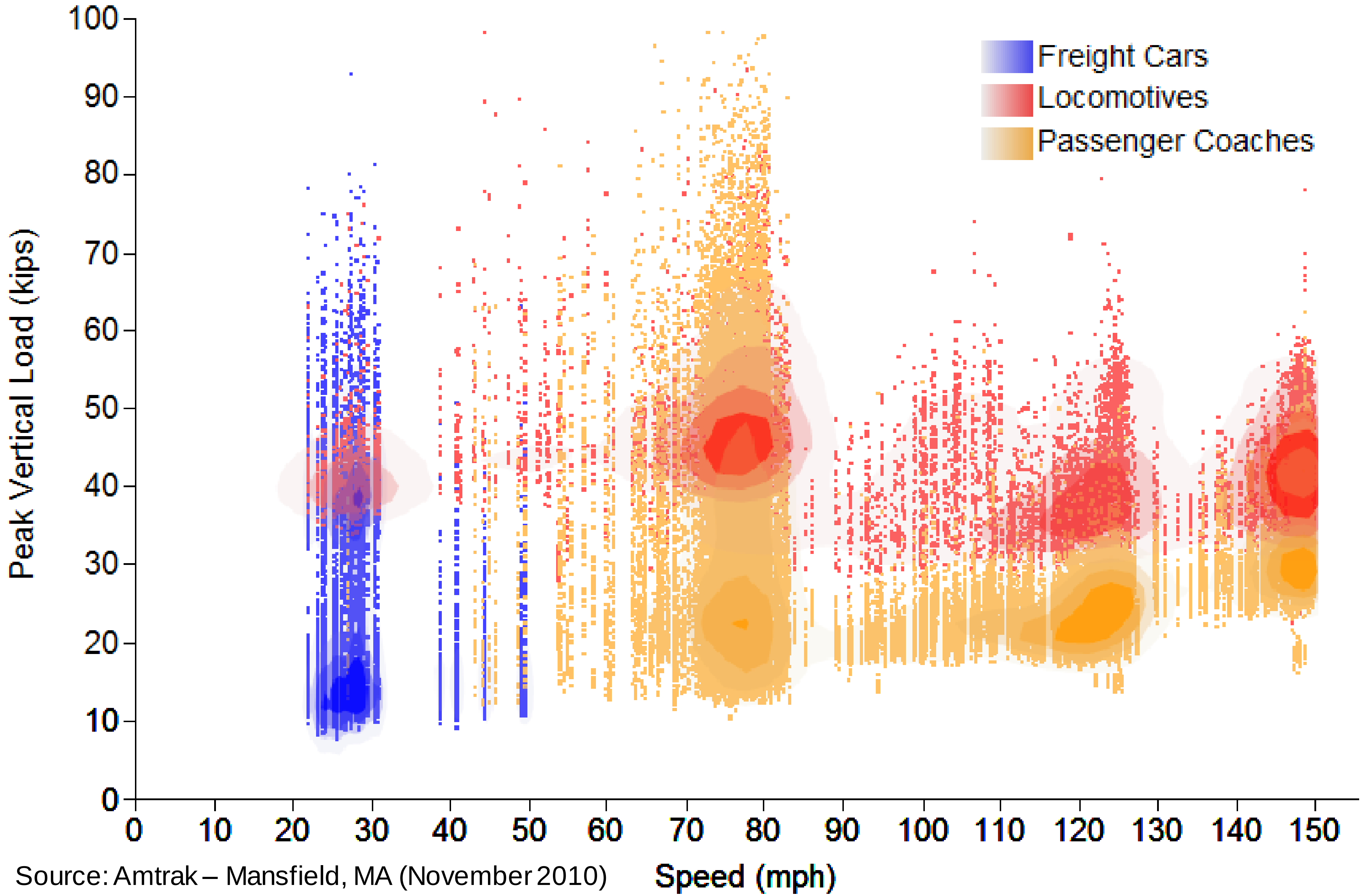
Source: Amtrak (April 2011)

Variation of Loads on Amtrak's Northeast Corridor



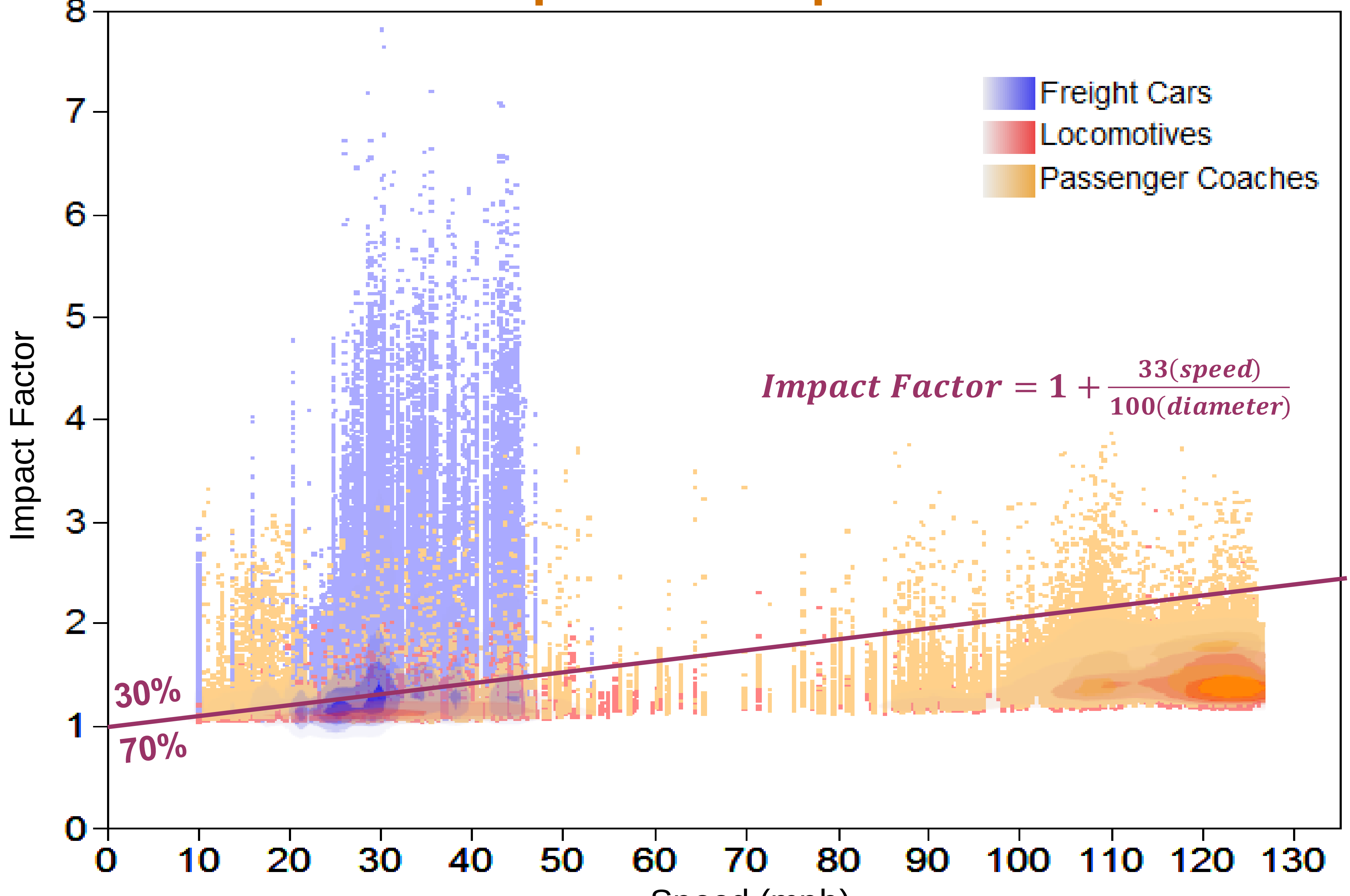
Source: Amtrak (April 2011)

Effect of Traffic Type on Wheel Load

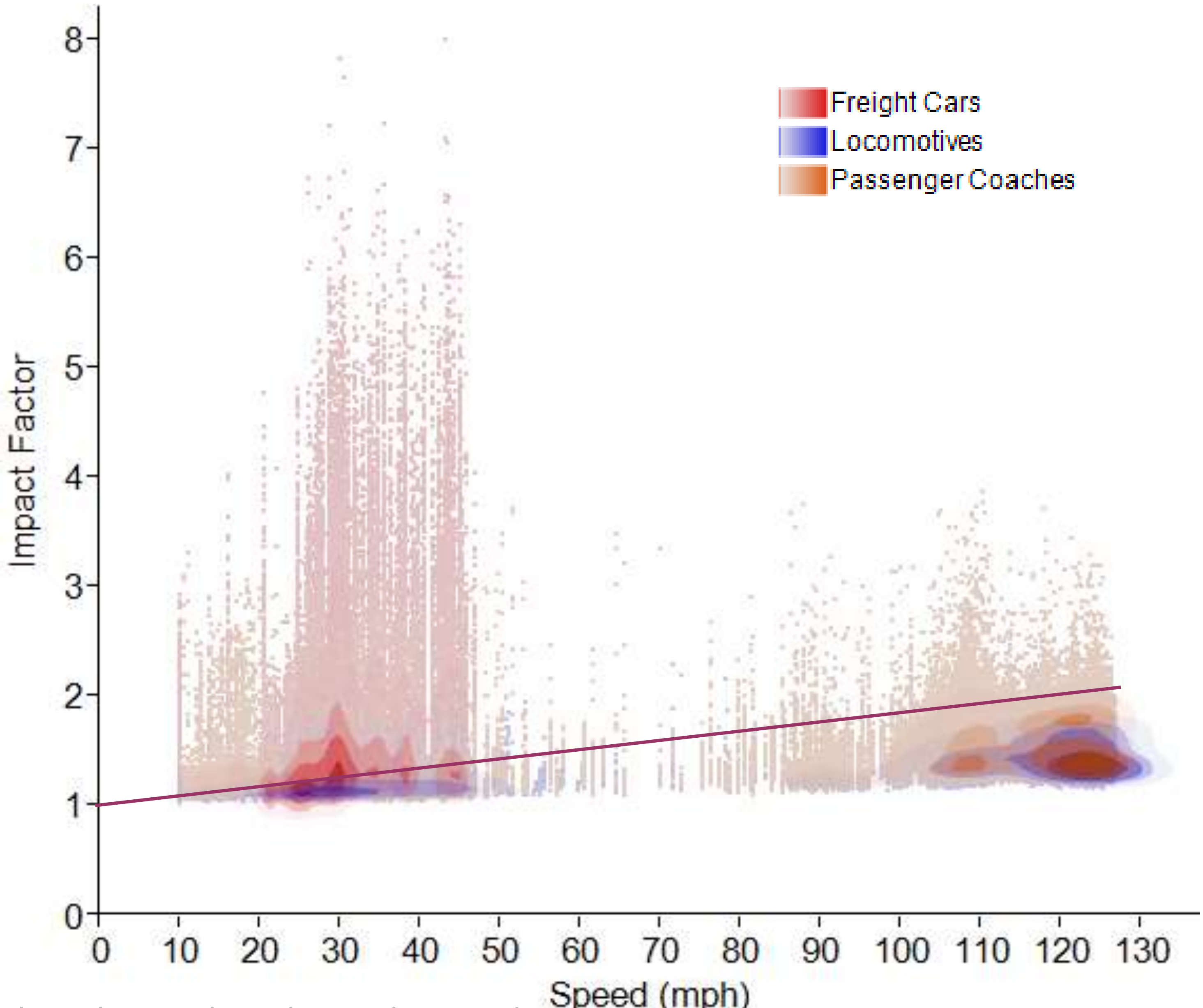


Source: Amtrak – Mansfield, MA (November 2010)

Effect of Speed on Impact Factor

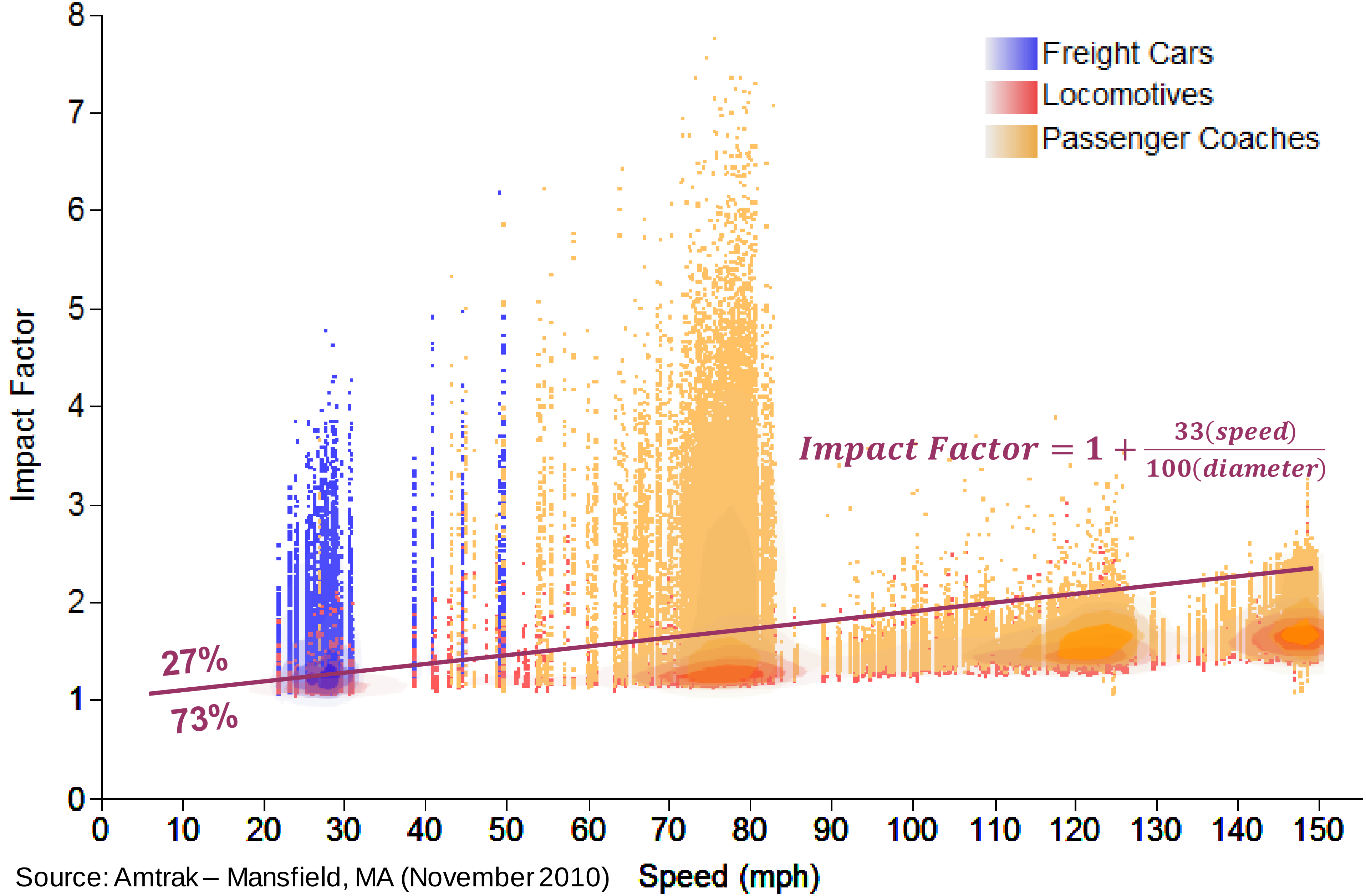


Source: Amtrak – Edgewood, MD (November 2010)



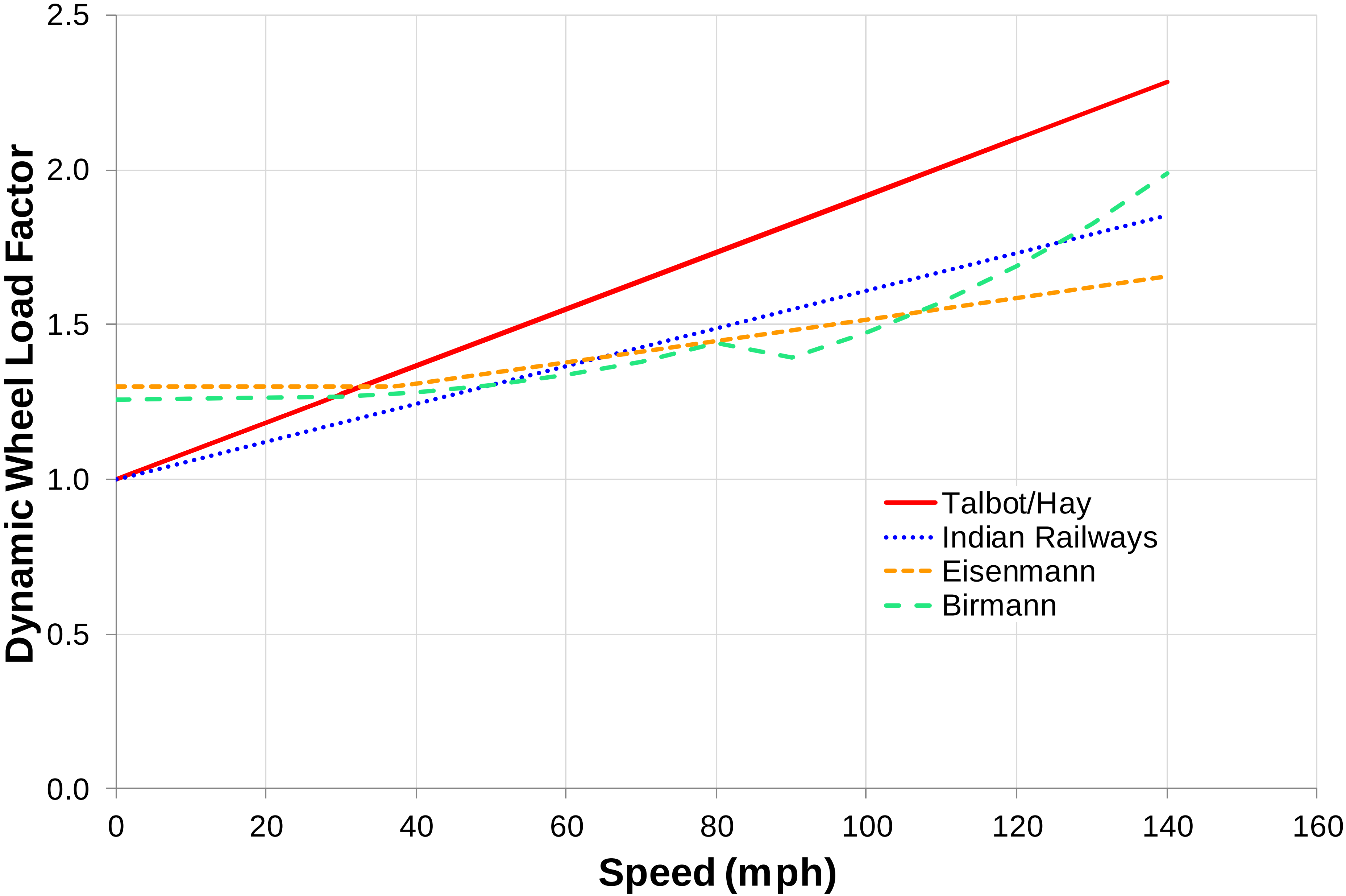
Source: Amtrak – Edgewood, MD (November 2010)

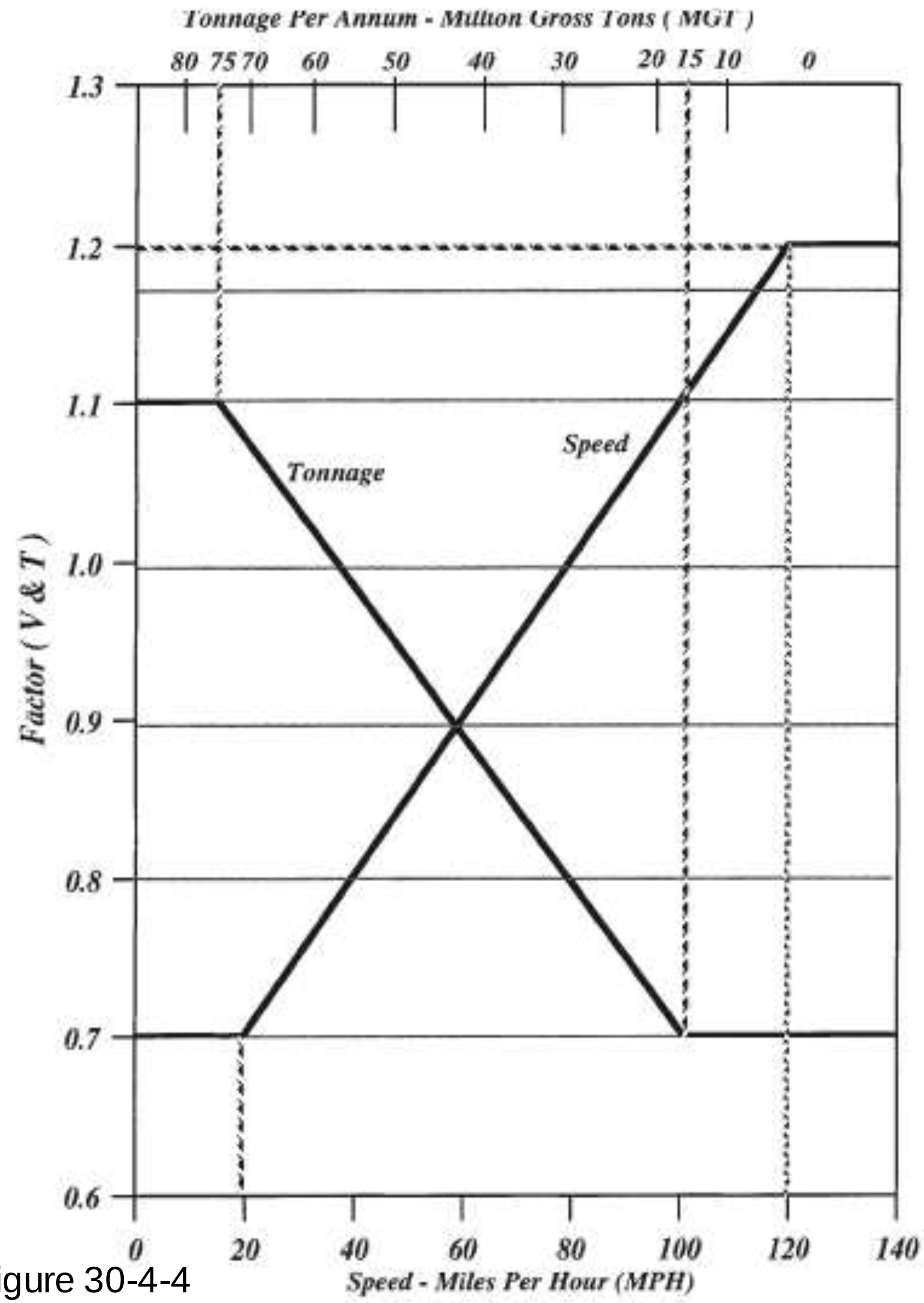
Effect of Speed on Impact Factor



Source: Amtrak – Mansfield, MA (November 2010)

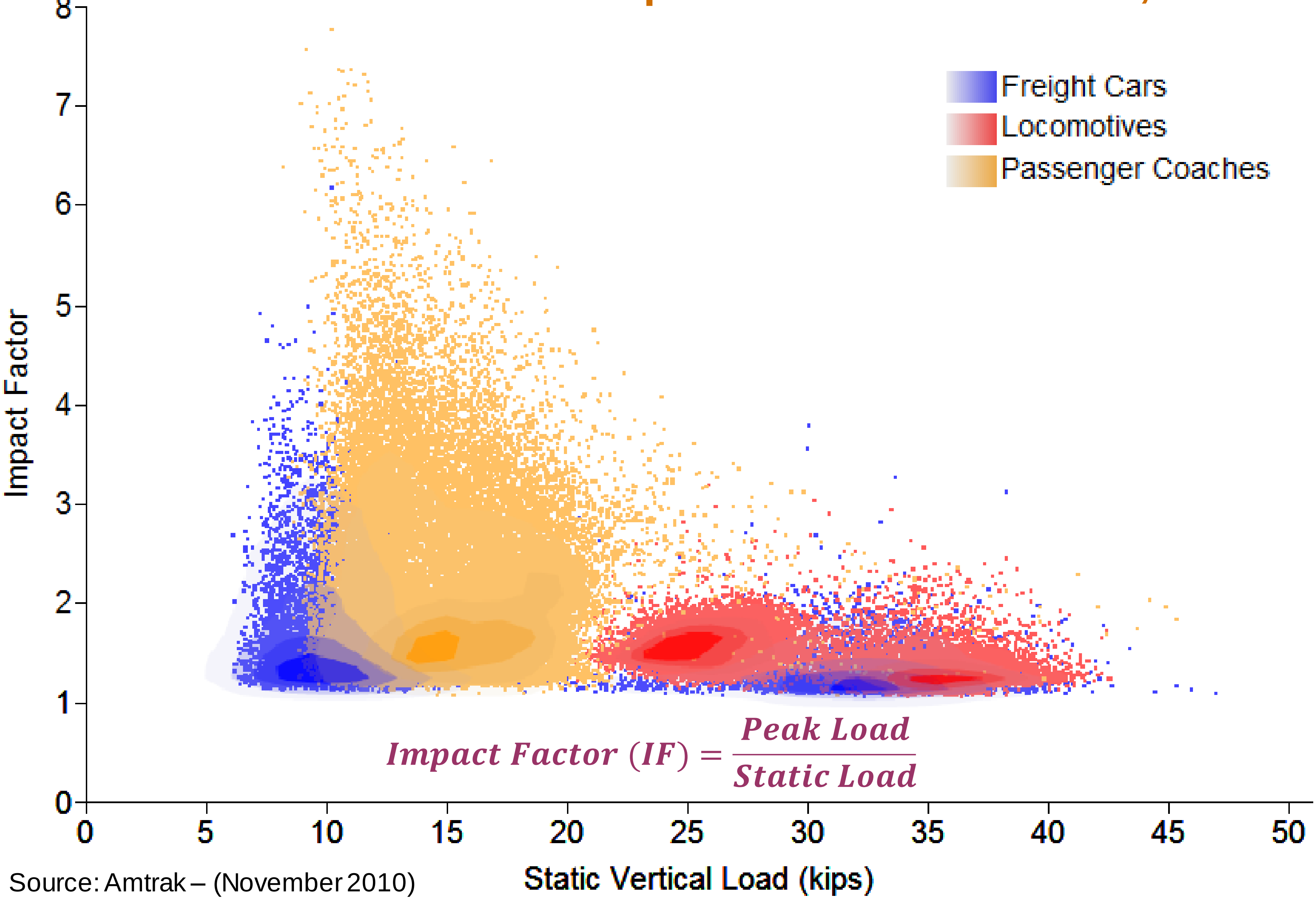
Comparison of Dynamic Wheel Load Factors





Source: AREMA Manual, Figure 30-4-4

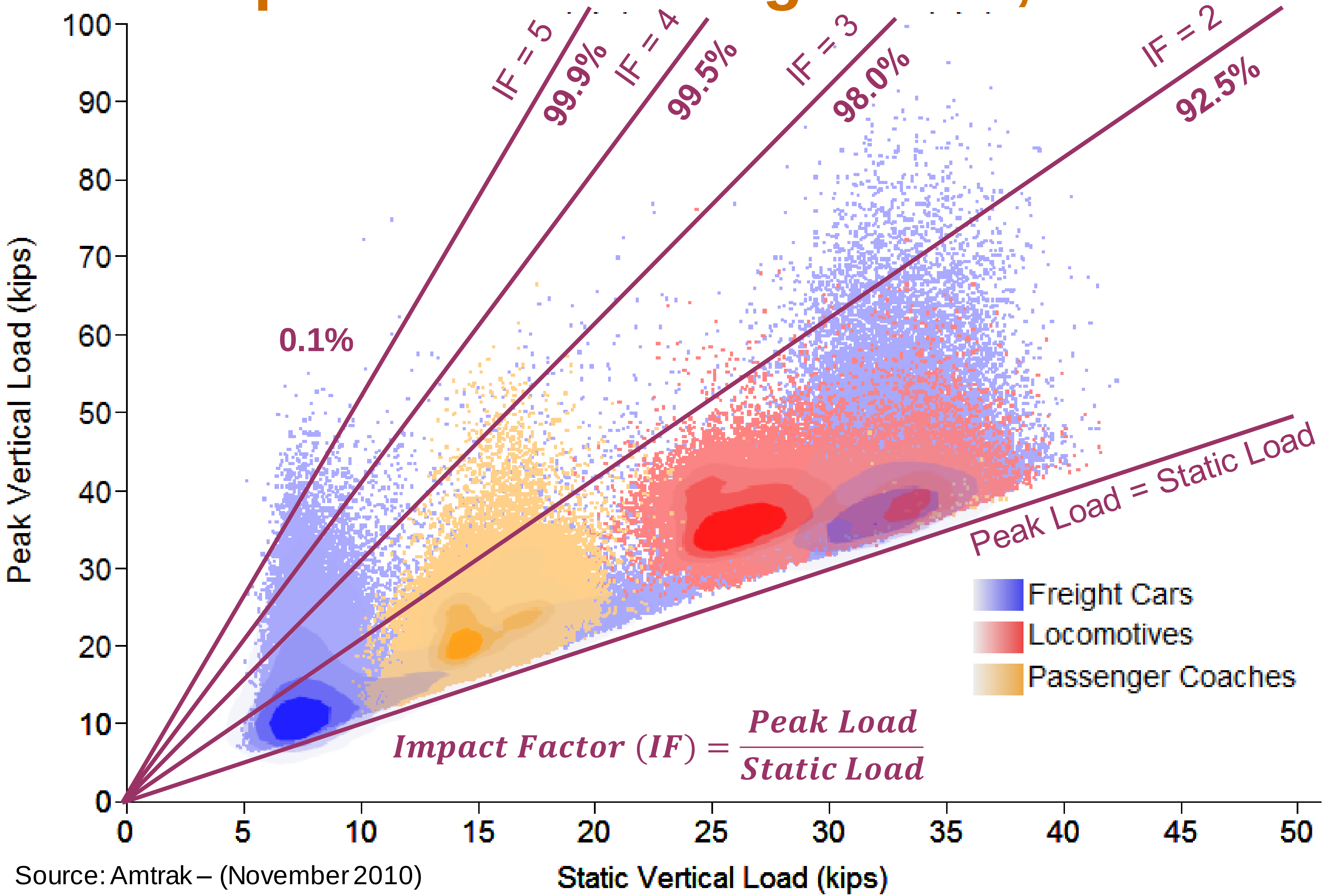
Effect of Static Load on Impact Factor – Mansfield, MA



$$\textit{Impact Factor (IF)} = \frac{\textit{Peak Load}}{\textit{Static Load}}$$

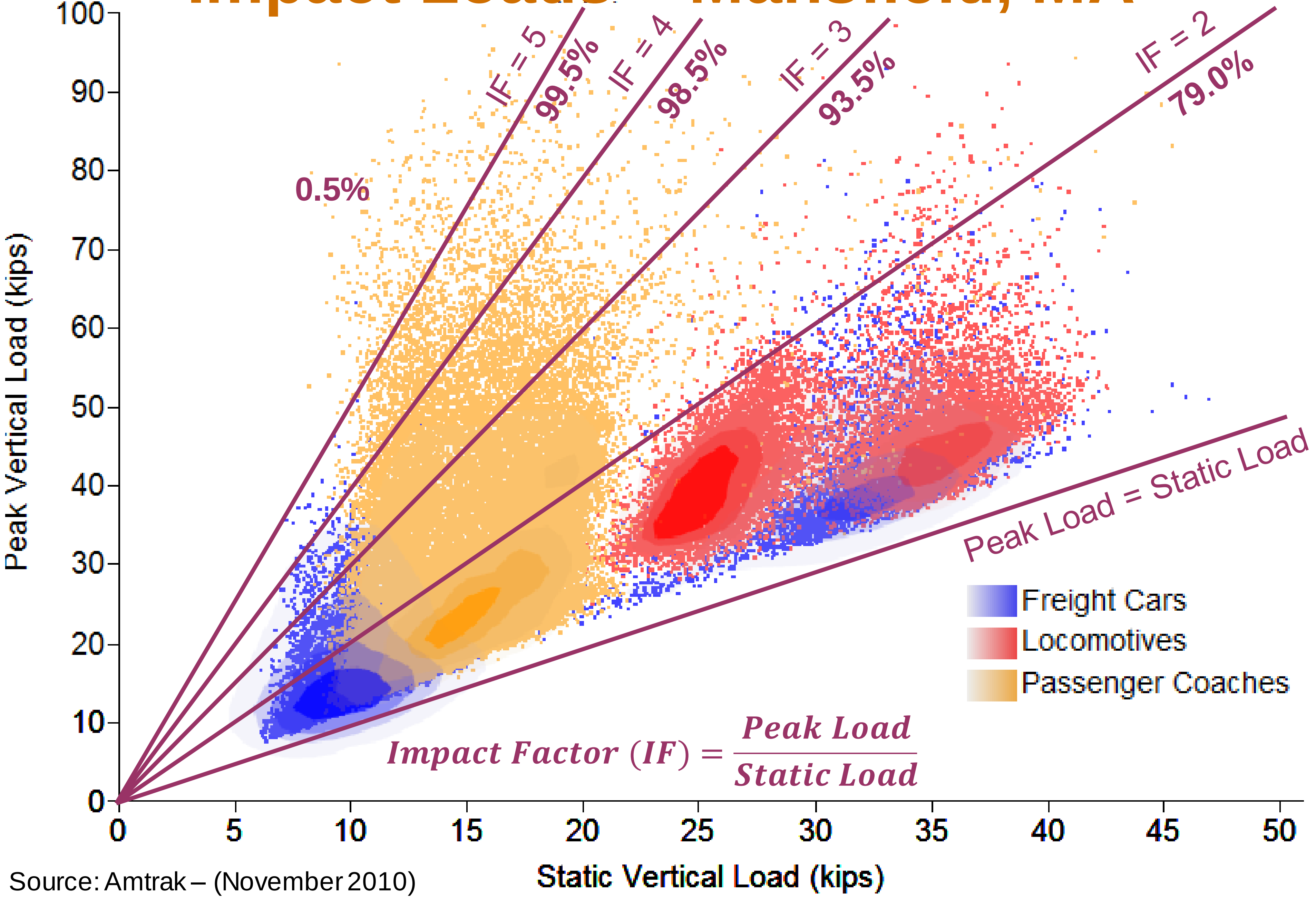
Source: Amtrak – (November 2010)

Impact Loads – Edgewood, MD



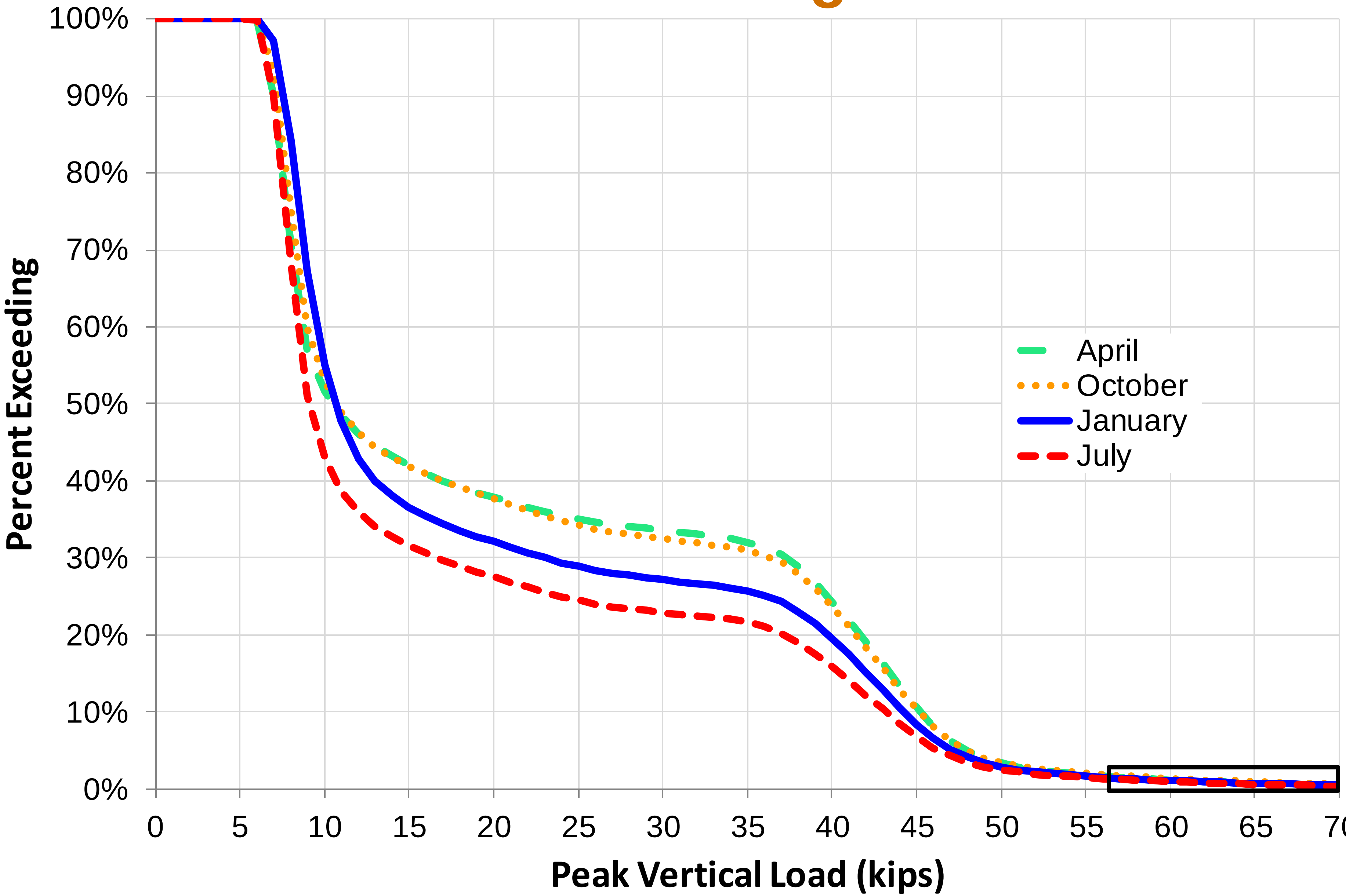
Source: Amtrak – (November 2010)

Impact Loads – Mansfield, MA



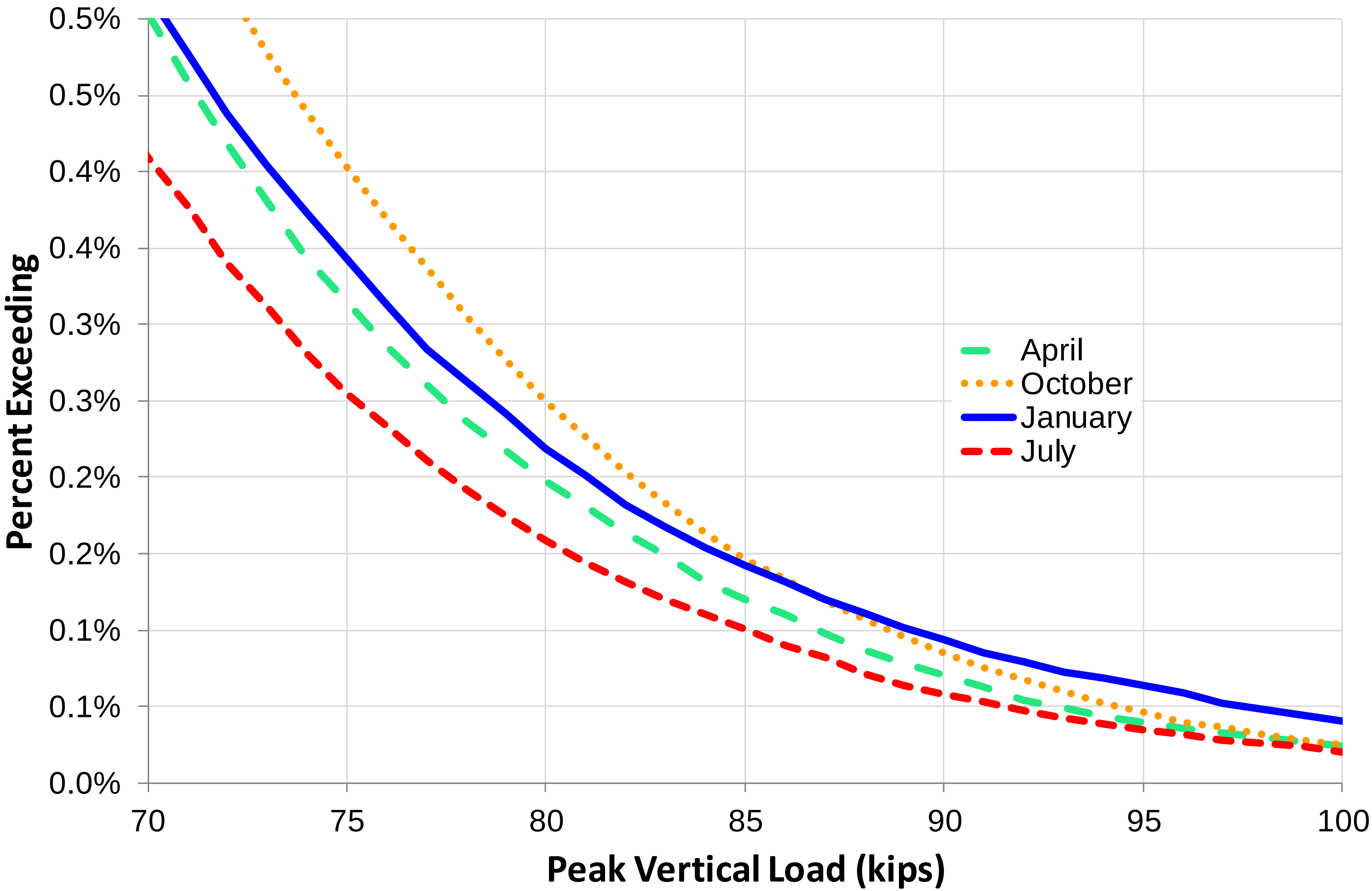
Source: Amtrak – (November 2010)

Seasonal Variation of Freight Wheel Loads



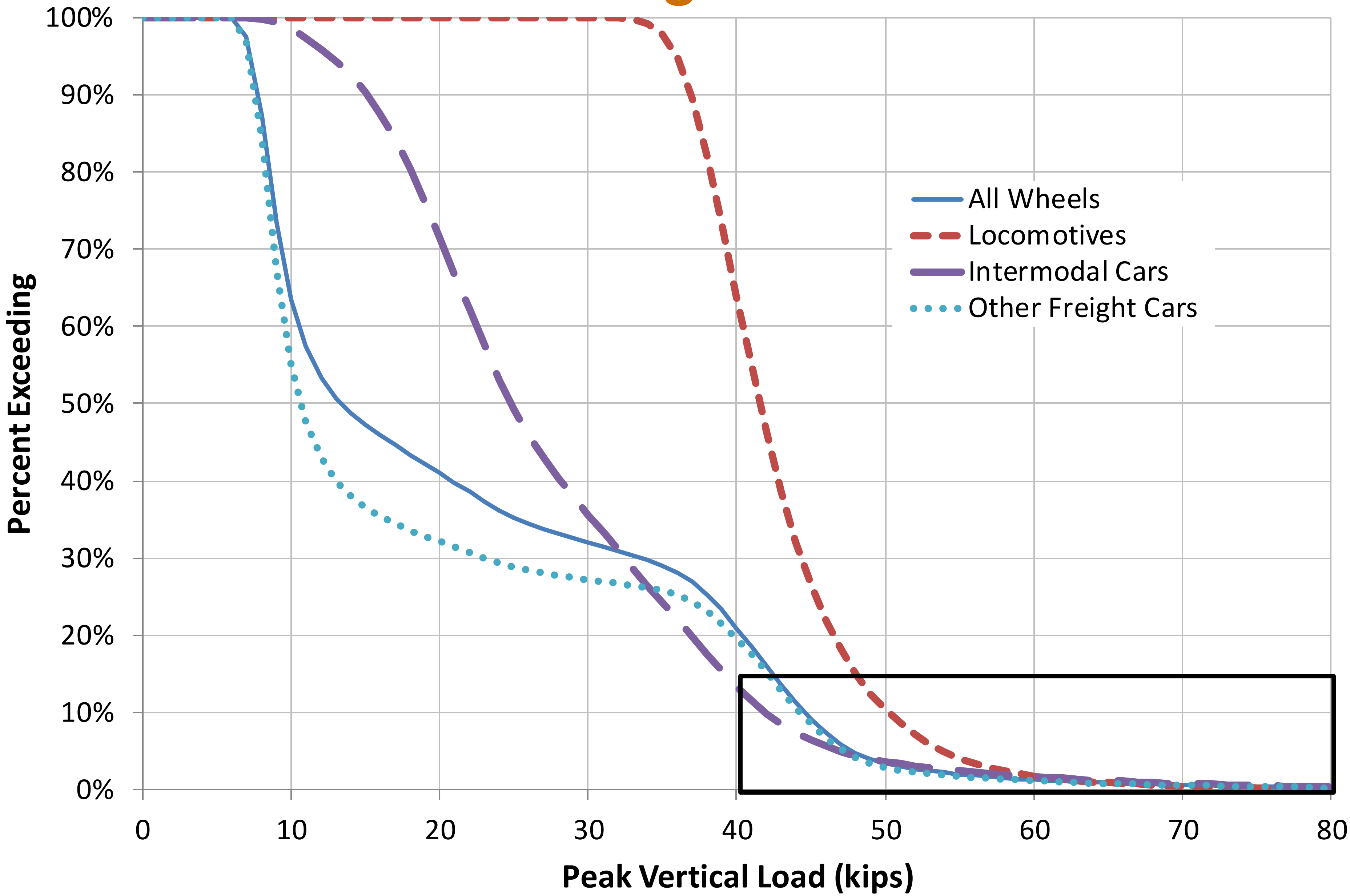
Source: Union Pacific – Gothenburg, NE (2010)

Seasonal Variation of Highest Freight Wheel Loads



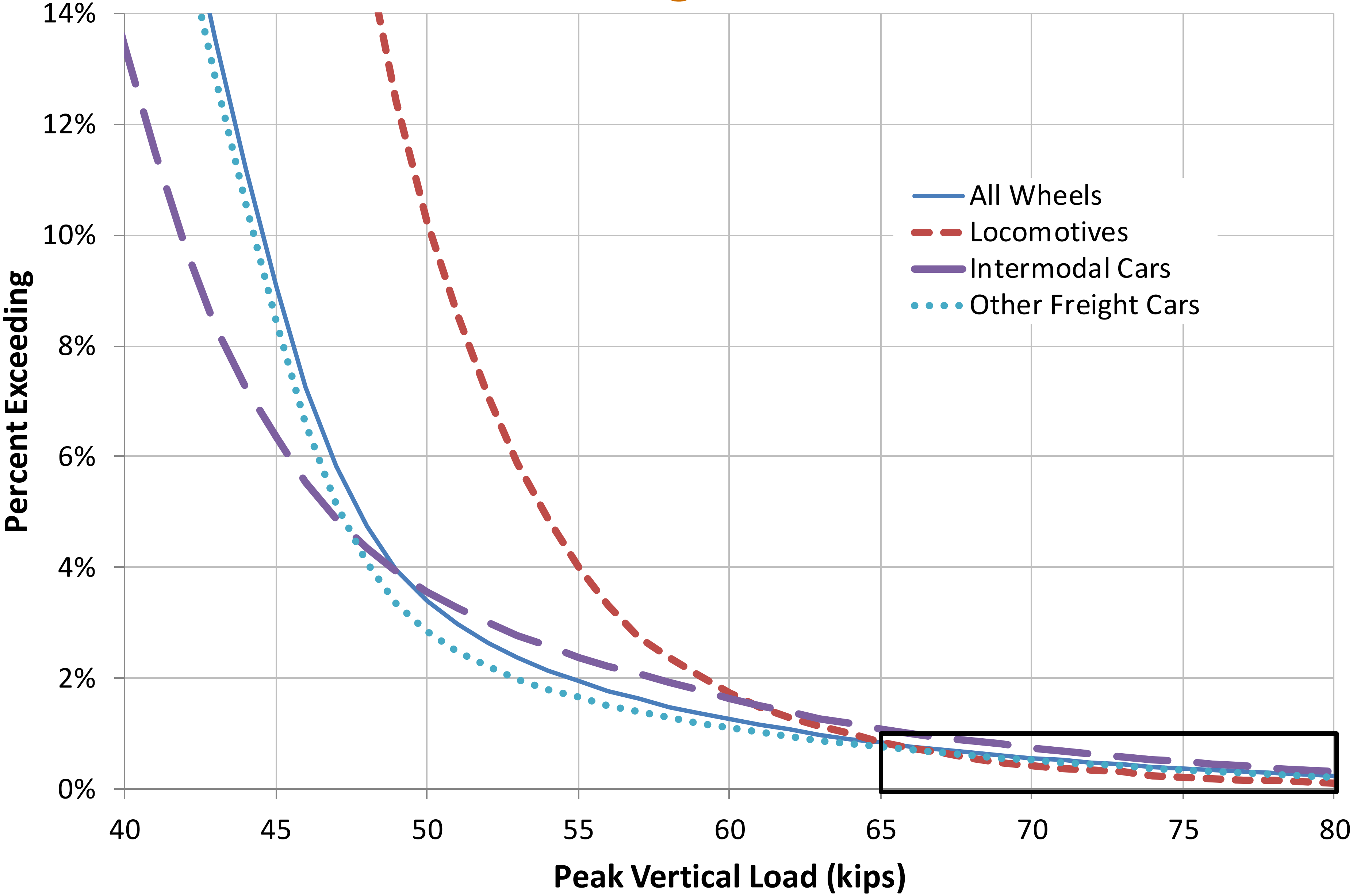
Source: Union Pacific – Gothenburg, NE (2010)

Variation of Freight Wheel Loads



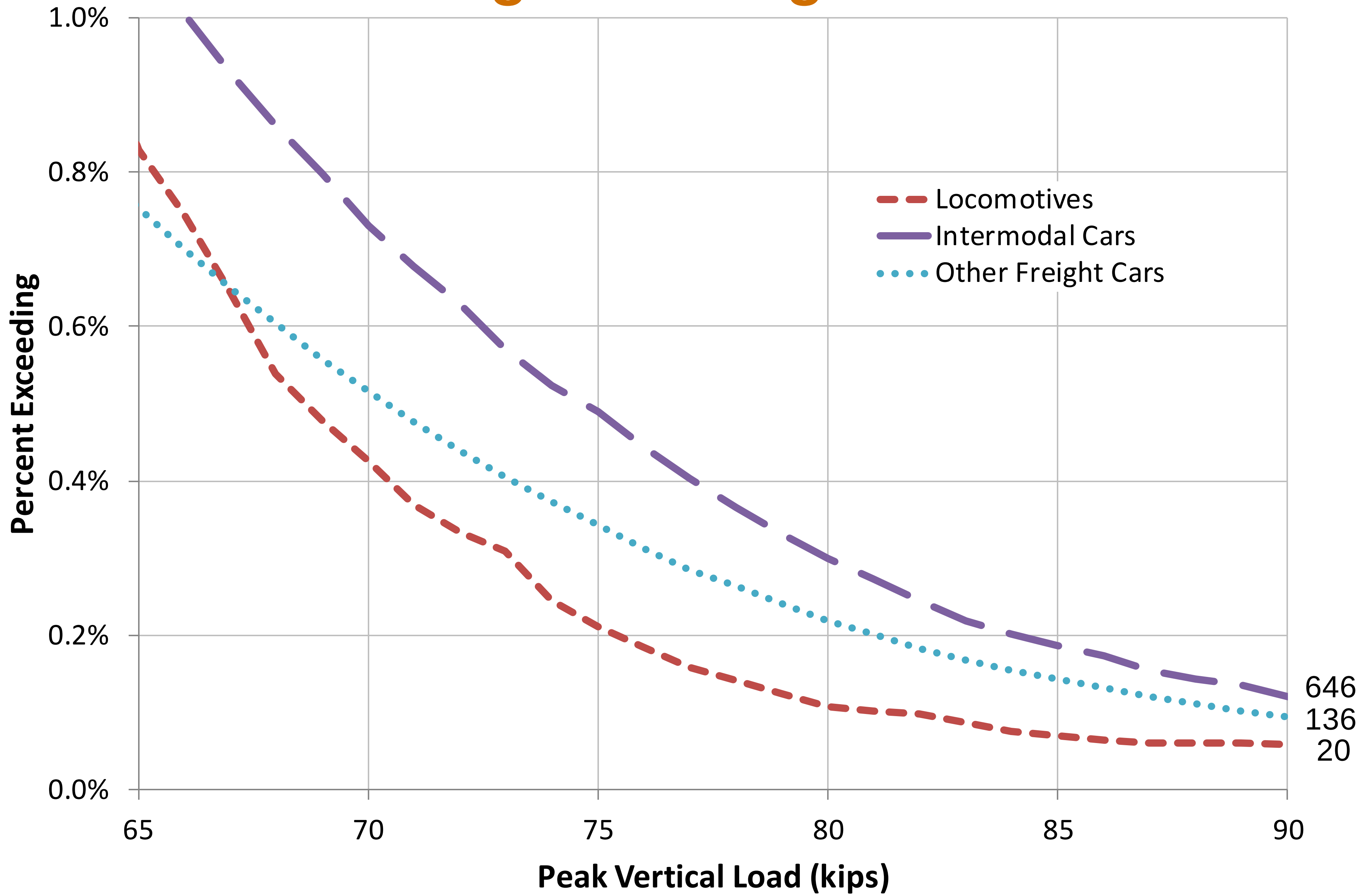
Source: Union Pacific – Gothenburg, NE (January 2010)

Variation of Freight Wheel Loads



Source: Union Pacific – Gothenburg, NE (January 2010)

Variation of Highest Freight Wheel Loads



Source: Union Pacific – Gothenburg, NE (January 2010)

Load Environment
AREMA Chapter 30 Section 1.2

- **Existing Content:**
  - Expected vertical, lateral, longitudinal loads at wheel/rail interface
  - Table 30-1-1 shows effects of traffic type, speed, and curvature
- **Proposed Improvements:**
  - Generally update based on current loading conditions
  - Complete areas where data are "estimated or interpolated"
  - Provide clearer definition and description of expected loads
- **Methodology:**
  - Use of existing wheel impact load detector (WILD) and instrumented wheel set (IWS) data
  - Define dynamic and impact loads based on data evidence
- **Timeline:**
  - Submit to full committee for ballot (Spring 2013)

SECTION 1.2 LOAD ENVIRONMENT

Table 30-1-1 defines the load environment expected to be encountered in North American Freight, High Speed Passenger and Transit Railroad segments of the industry. Specifically, Table 30-1-1 presents the available data in terms of vertical, horizontal and longitudinal loads that can be expected at the wheel/rail interface. The service categories are distinguished as follows. Mainline Freight represents lines other than Light Density Freight. Light Density Freight represents lines with less than five million gross tons and excludes A/C Traction. High Speed Passenger represents passenger loadings whether in mixed service or on dedicated routes. Speeds are given in miles per hour.

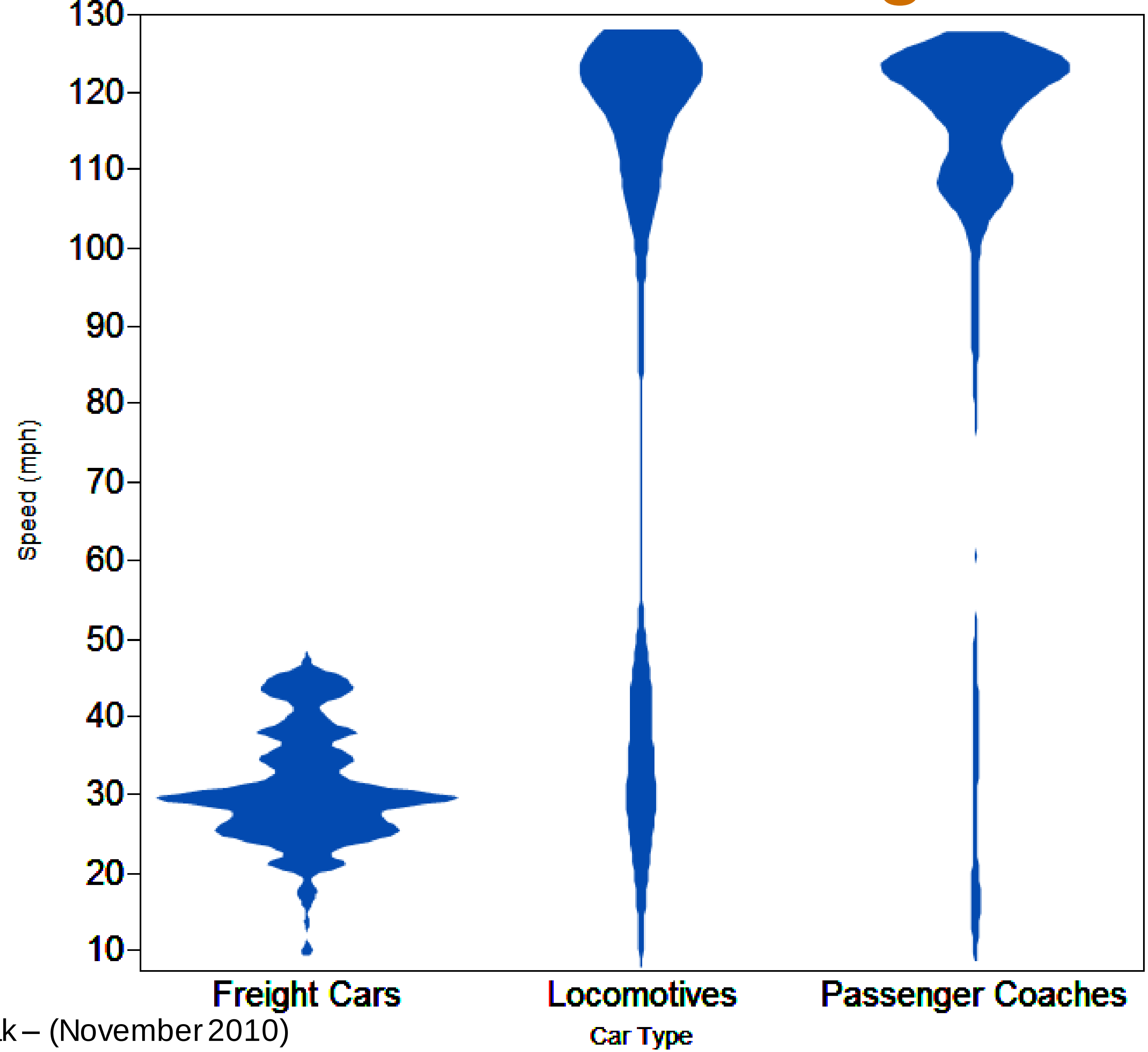
Table 30-1-1. Wheel to Rail Loads (kips)

CURVE	<2 DEG			2-5 DEG			>5 DEG		
SPEED	VERT	LAT	LONG	VERT	LAT	LONG	VERT	LAT	LONG
MAINLINE FREIGHT									
<40	80	20*	50	80	30*	50	80	30	50
40 to 60	120	30*	50	120	30*	50	120	30	50
>60	120	30	50	120	30	50	**	**	**
LIGHT DENSITY FREIGHT (no A/C Traction)									
<40	80	20	30	80	30*	30	80	30	30
40 to 60	120	30	30	120	30	30	120	30	30
>60	120	30	30	120	30	30	**	**	**
HIGH SPEED PASSENGER									
<90	100	10	25	100	18	25	100	20*	25
>90	100	18	25	100	18	25	**	**	**
TRANSIT									
No data available									

* This data estimated or interpolated

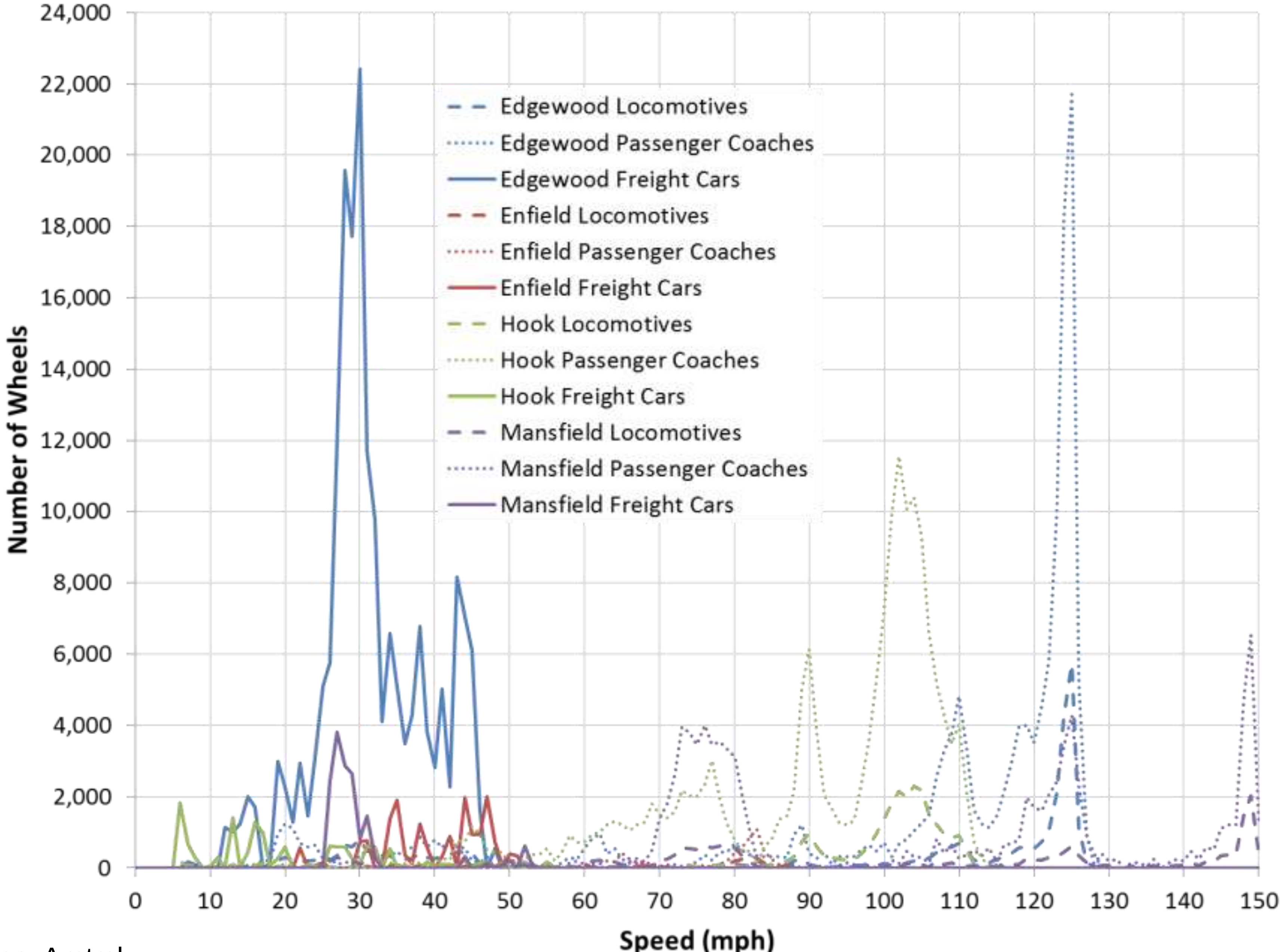
** Generally accepted superelevation practice excludes these values

Speed Characterization – Edgewood, MD



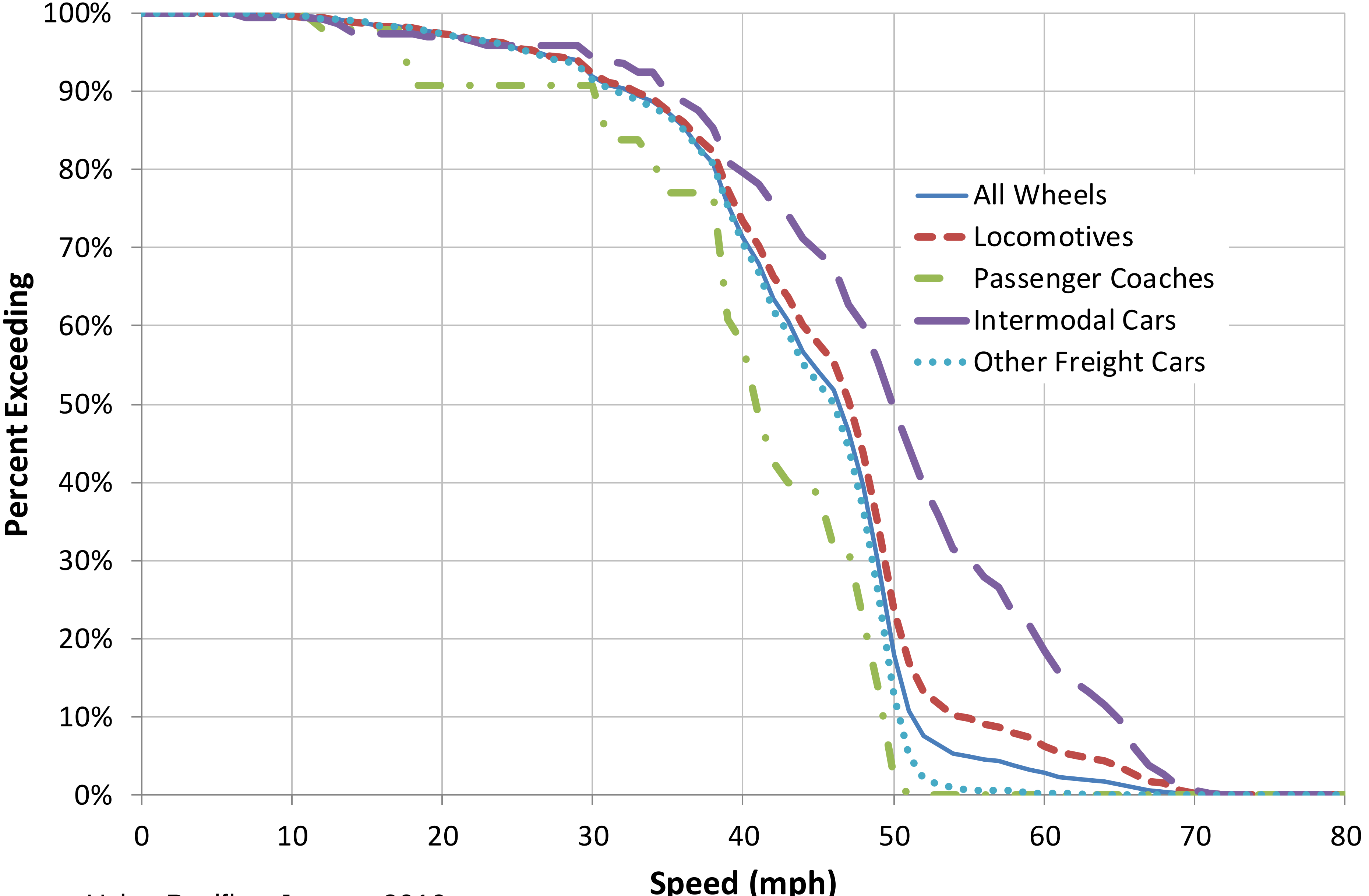
Source: Amtrak – (November 2010)

Characterization of Speeds on Amtrak's Northeast Corridor (April 2011)



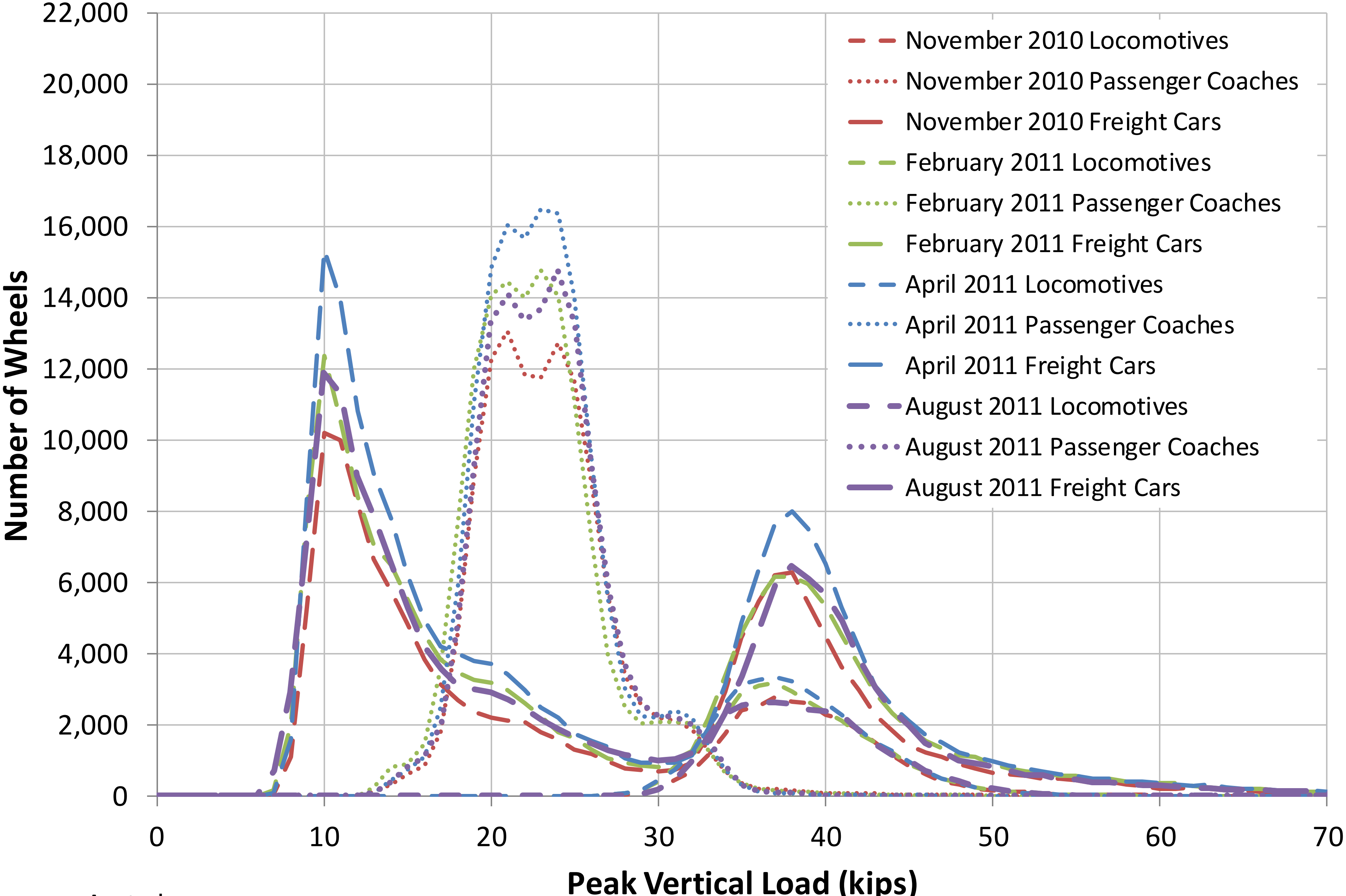
Source: Amtrak

Speed Characterization – Gothenburg, NE



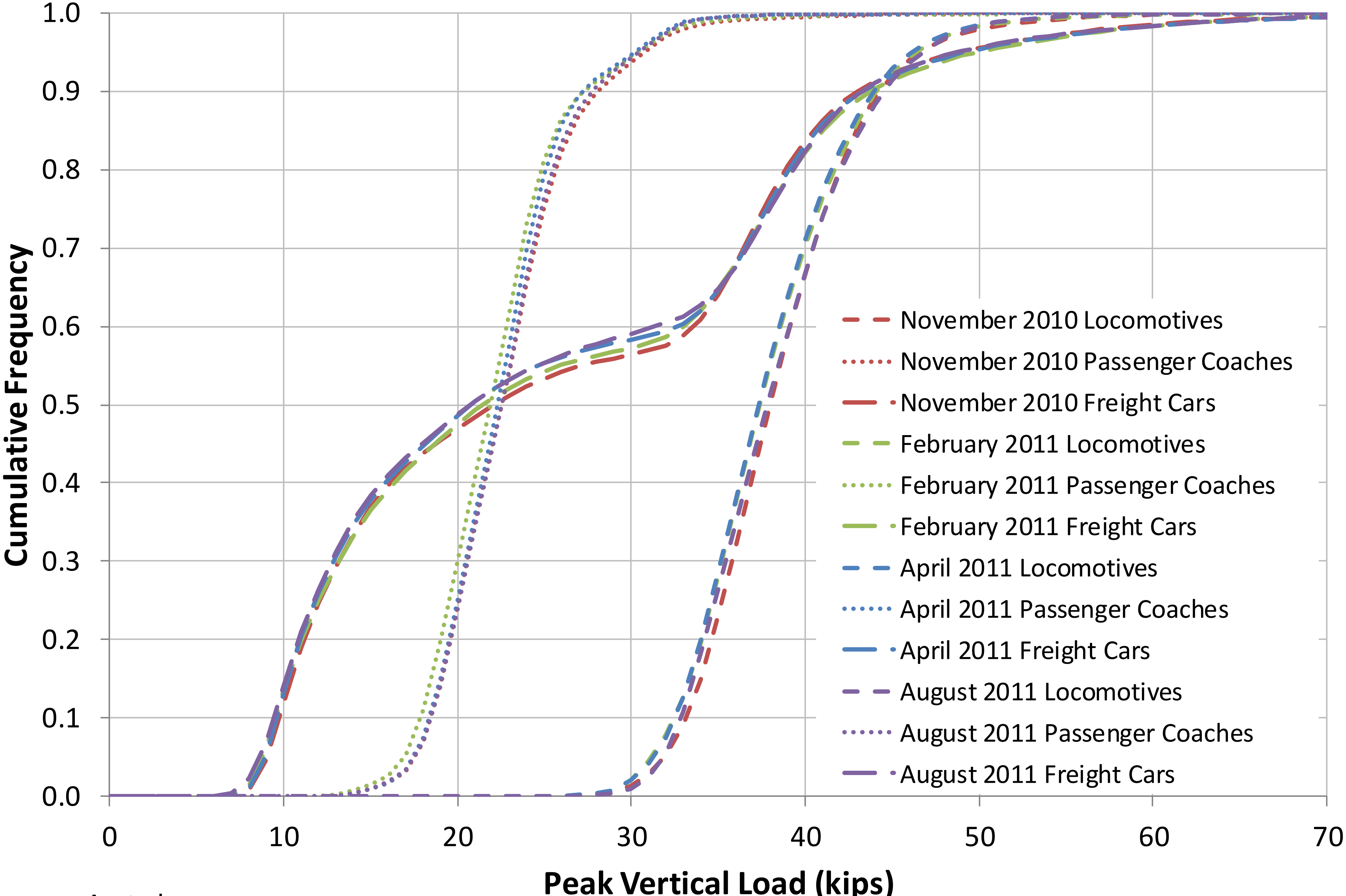
Source: Union Pacific – January 2010

Seasonal Effects on Peak Vertical Load – Edgewood, MD



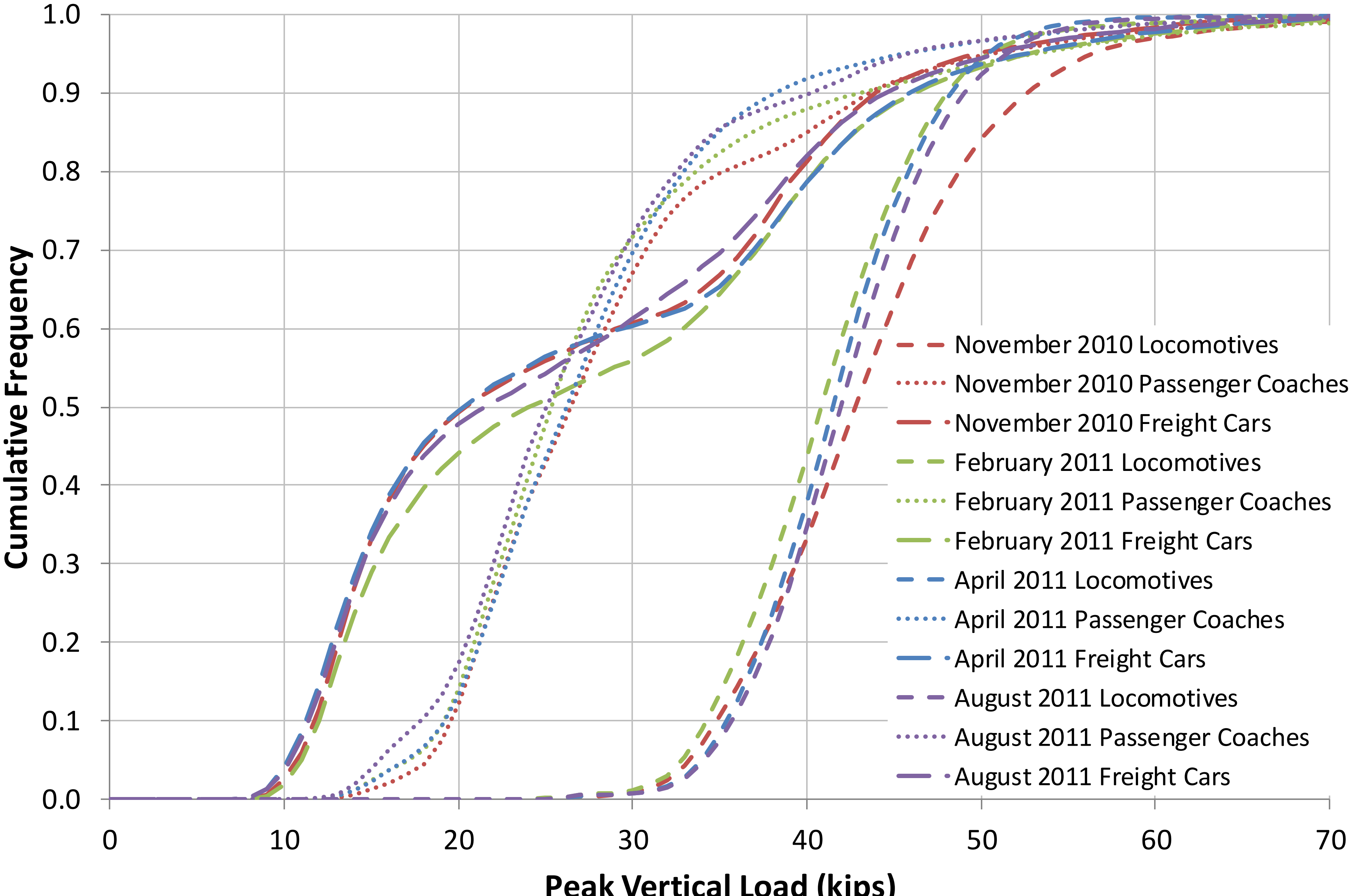
Source: Amtrak

Seasonal Effects on Peak Vertical Load – Edgewood, MD



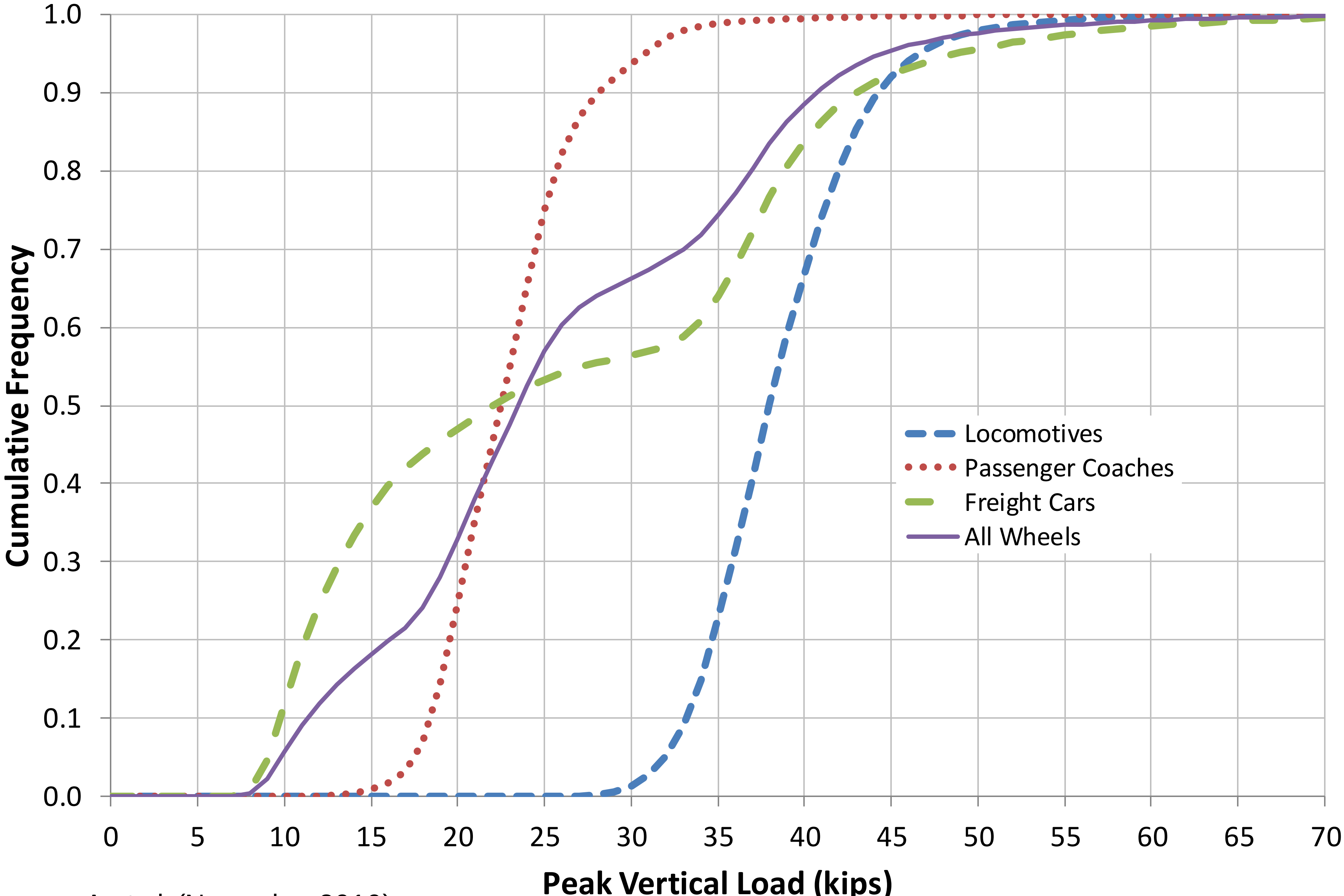
Source: Amtrak

Seasonal Effects on Peak Vertical Load – Mansfield, MA



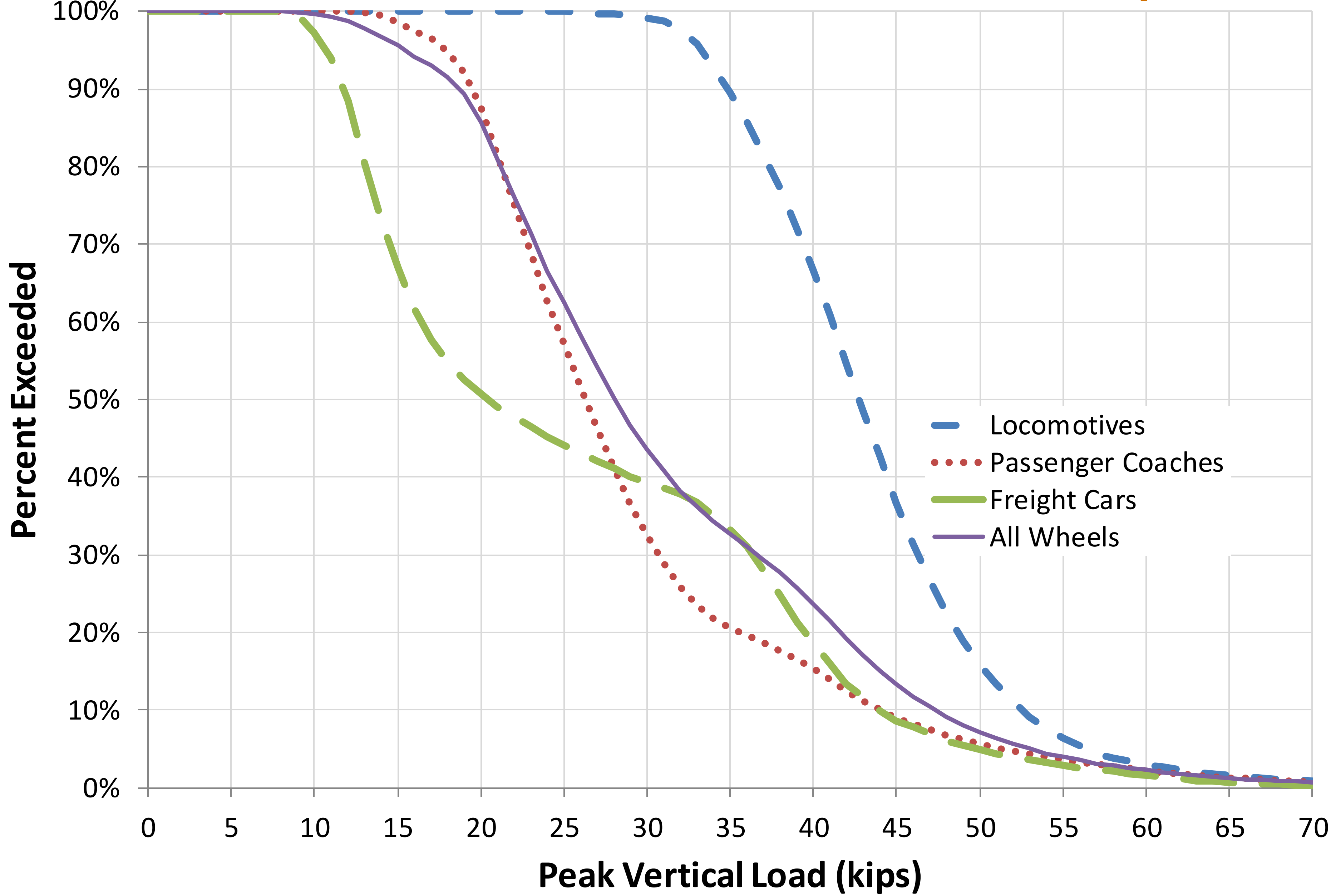
Source: Amtrak

Variations of Peak Vertical Load by Traffic – Edgewood, MD



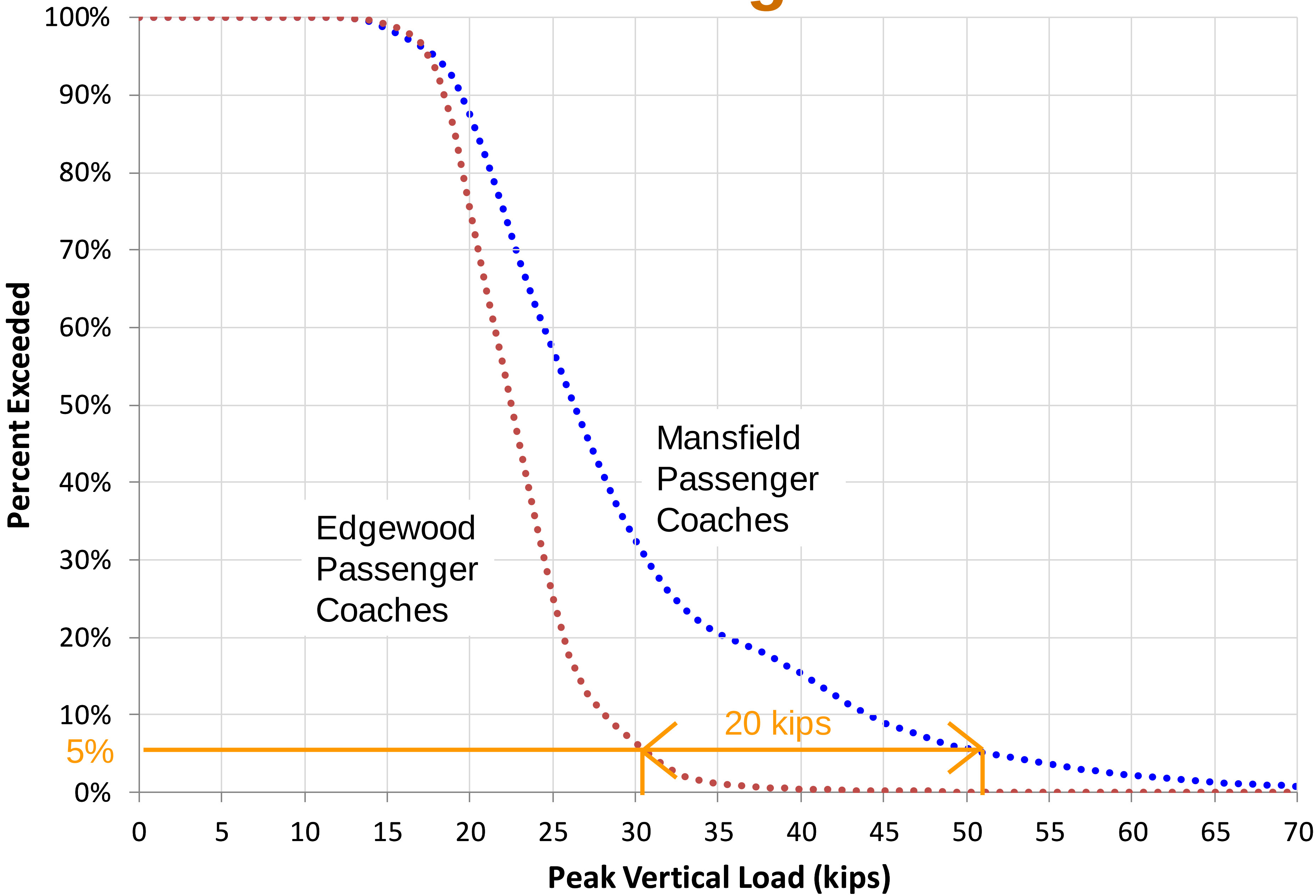
Source: Amtrak (November 2010)

Vertical Wheel Loads – Mansfield, MA



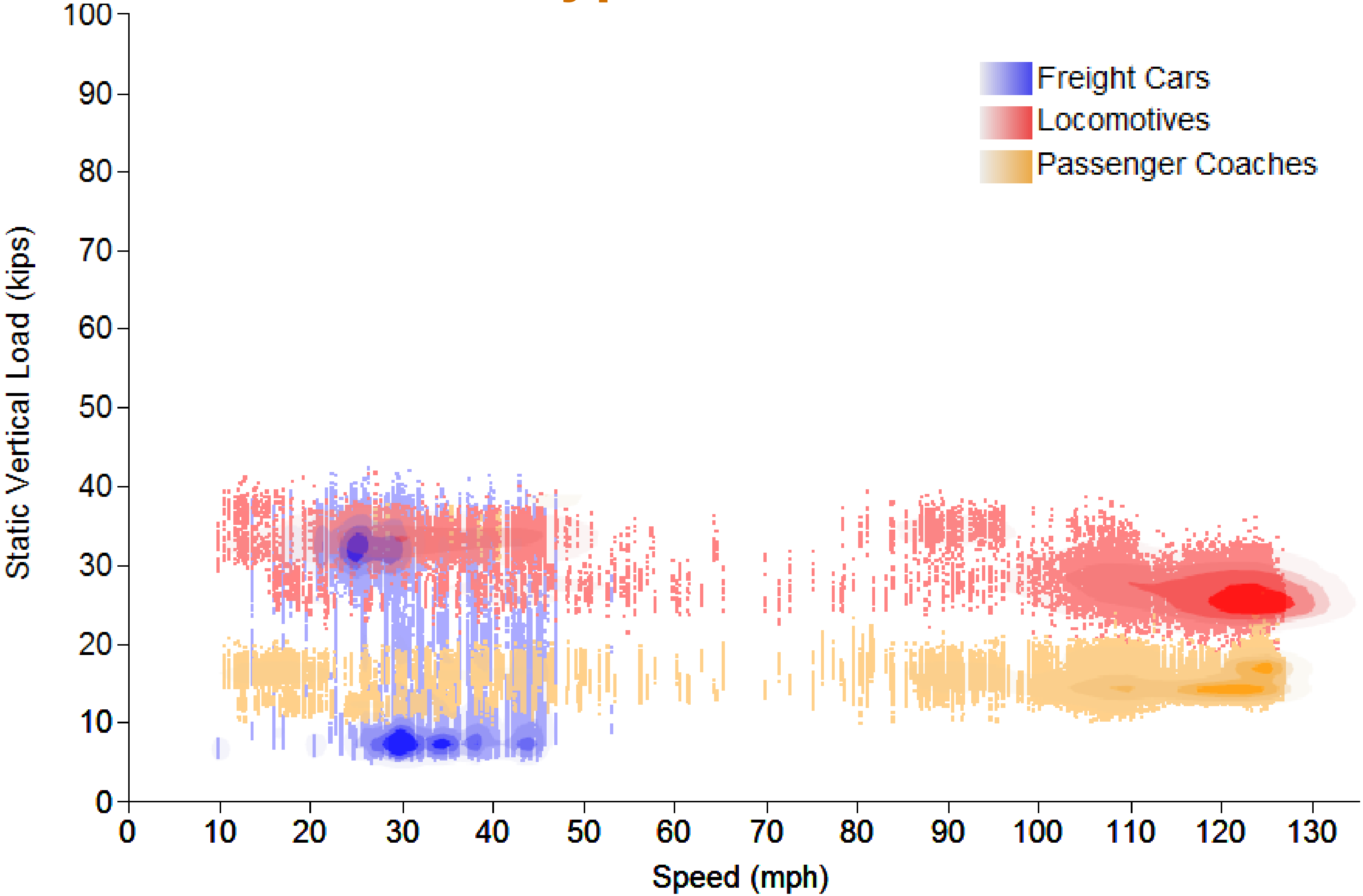
Source: Amtrak – Mansfield, MA (November 2010)

Distribution of Passenger Wheel Loads



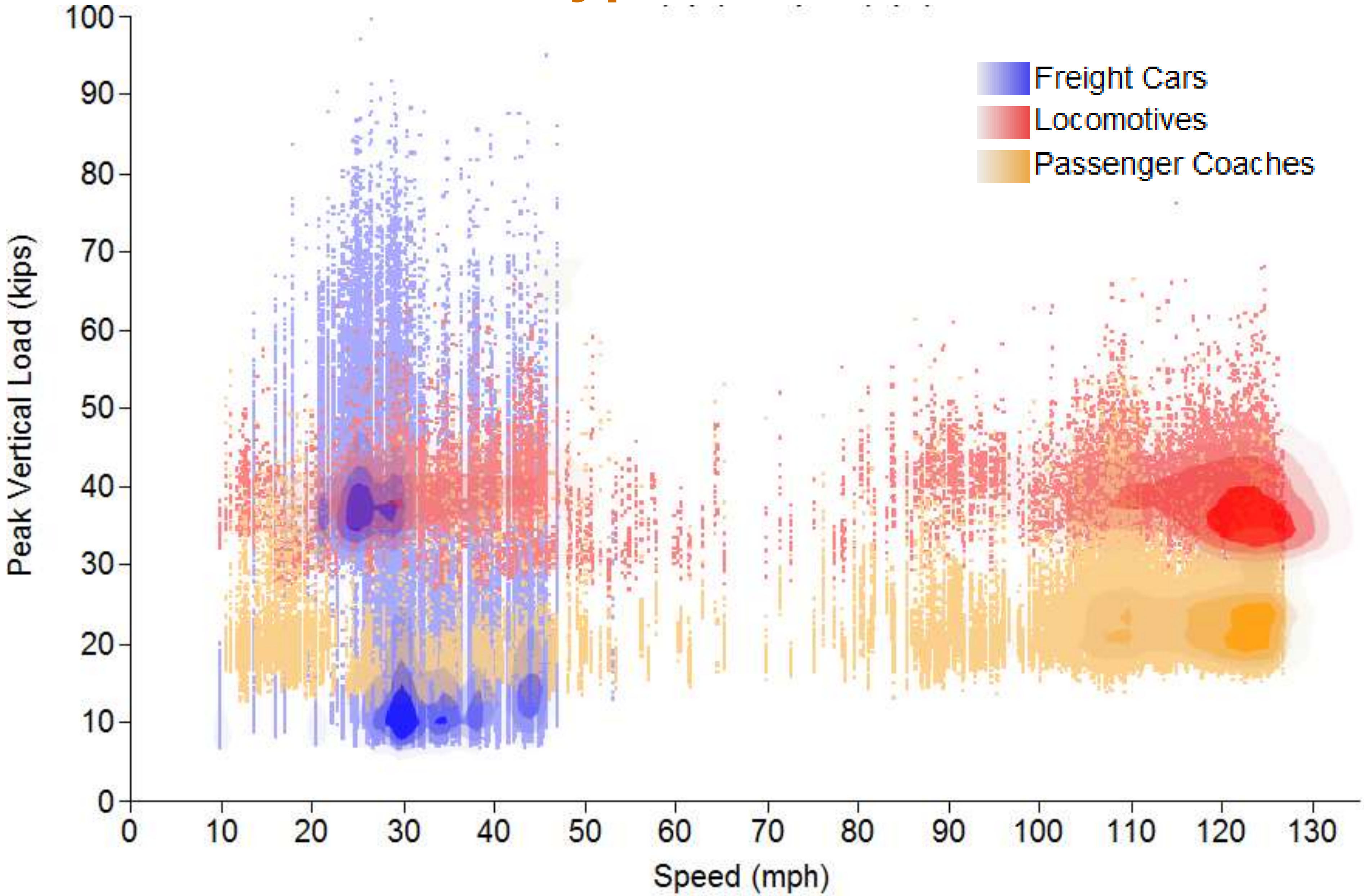
Source: Amtrak – November 2010

Effect of Traffic Type on Static Wheel Load



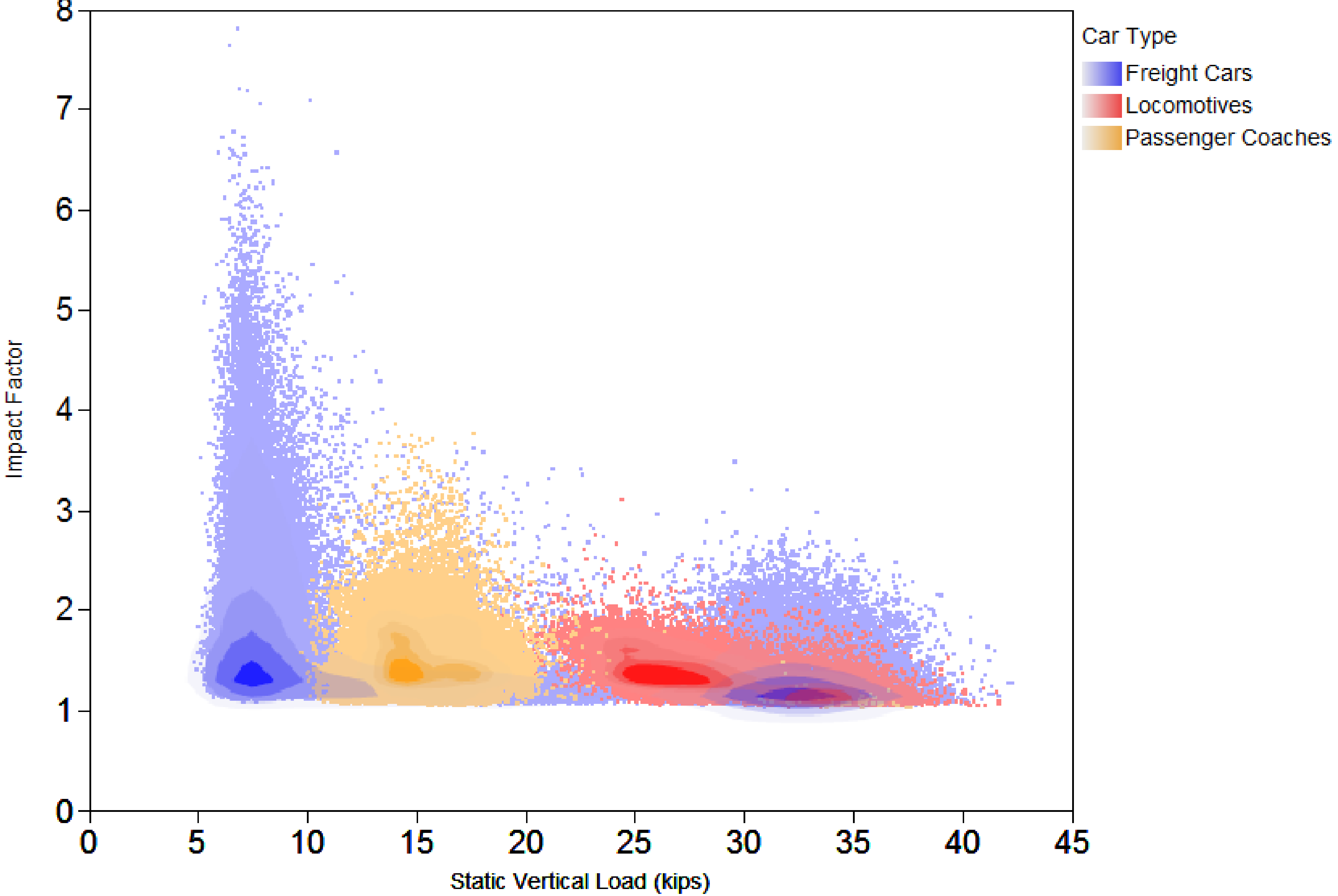
Source: Amtrak – Edgewood, MD (November 2010)

Effect of Traffic Type on Peak Wheel Load

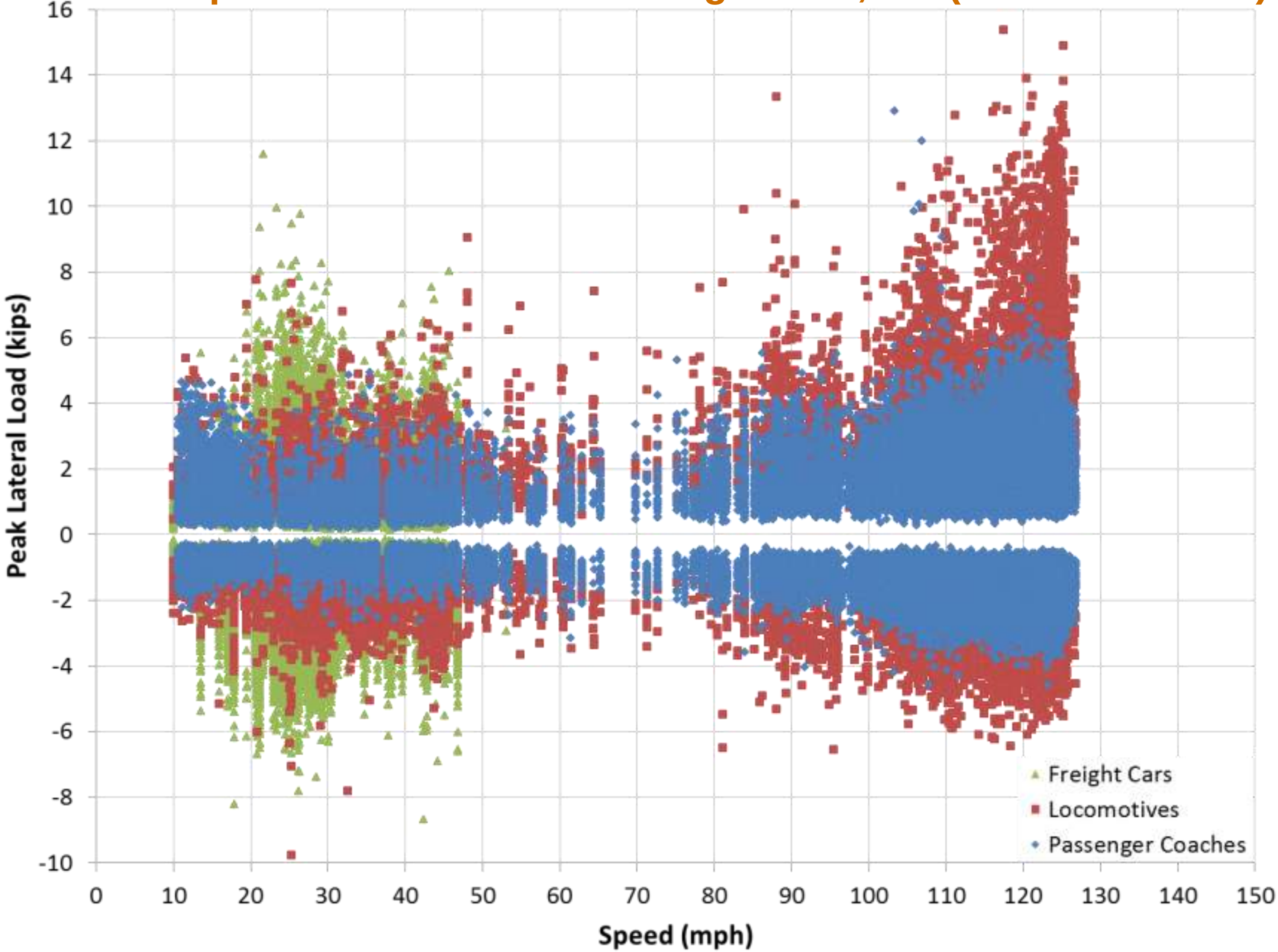


Source: Amtrak – Edgewood, MD (November 2010)

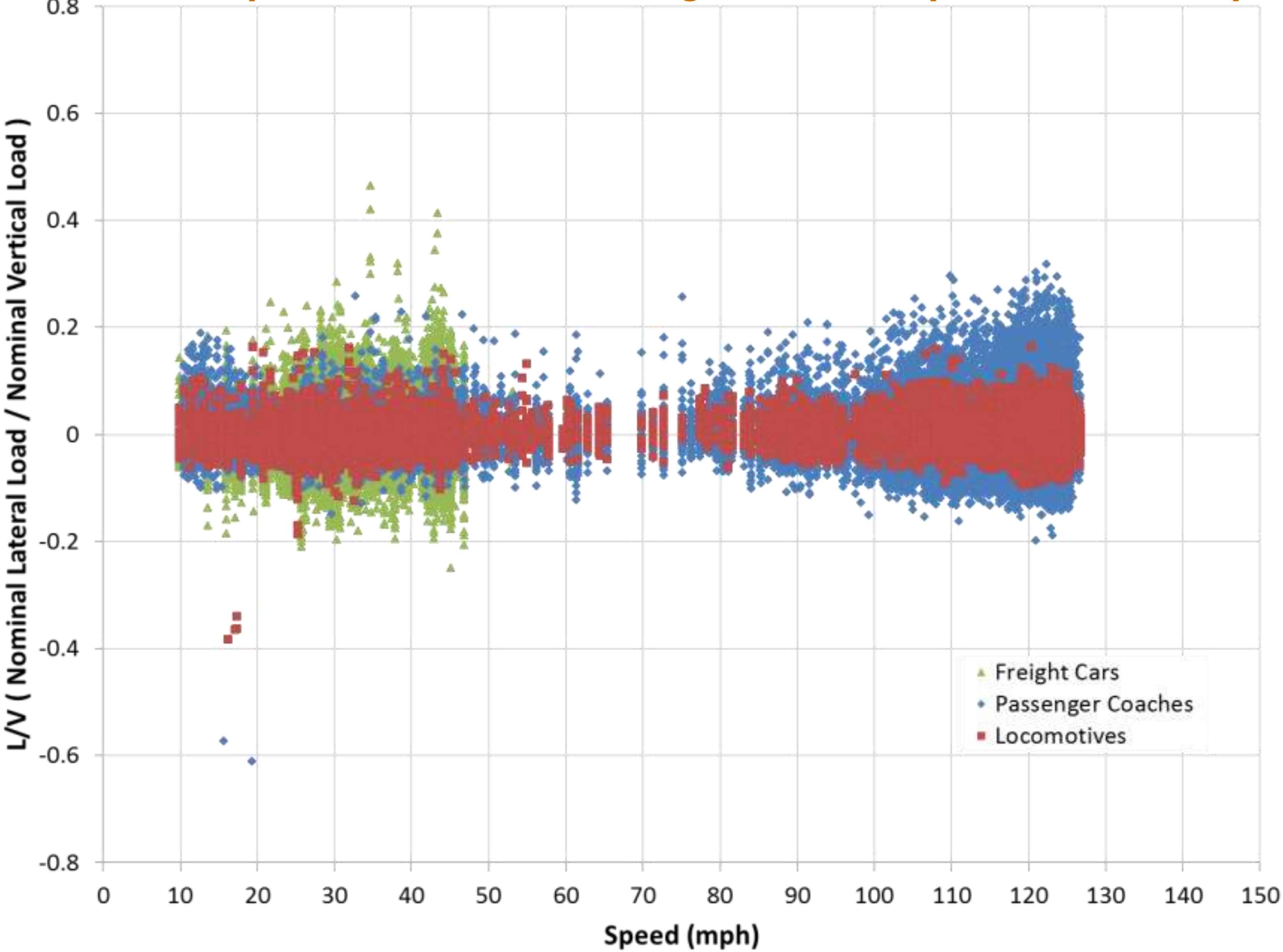
Load Effects on Impact Factor – Edgewood, MD (November 2010)



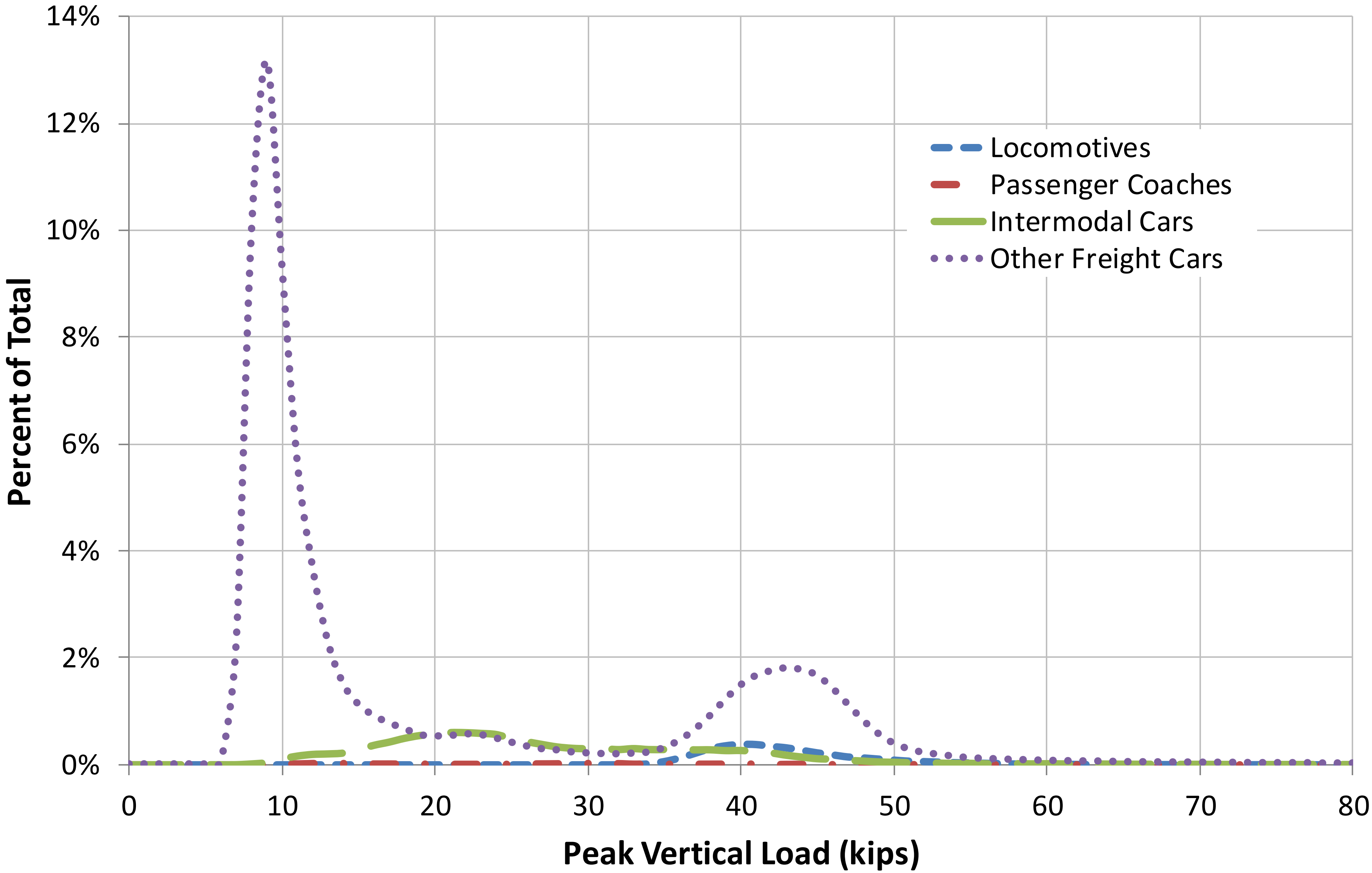
Effect of Speed on Lateral Load – Edgewood, MD (November 2010)



Effect of Speed on L/V Ratio – Edgewood, MD (November 2010)



Frequency of Peak Vertical Loads



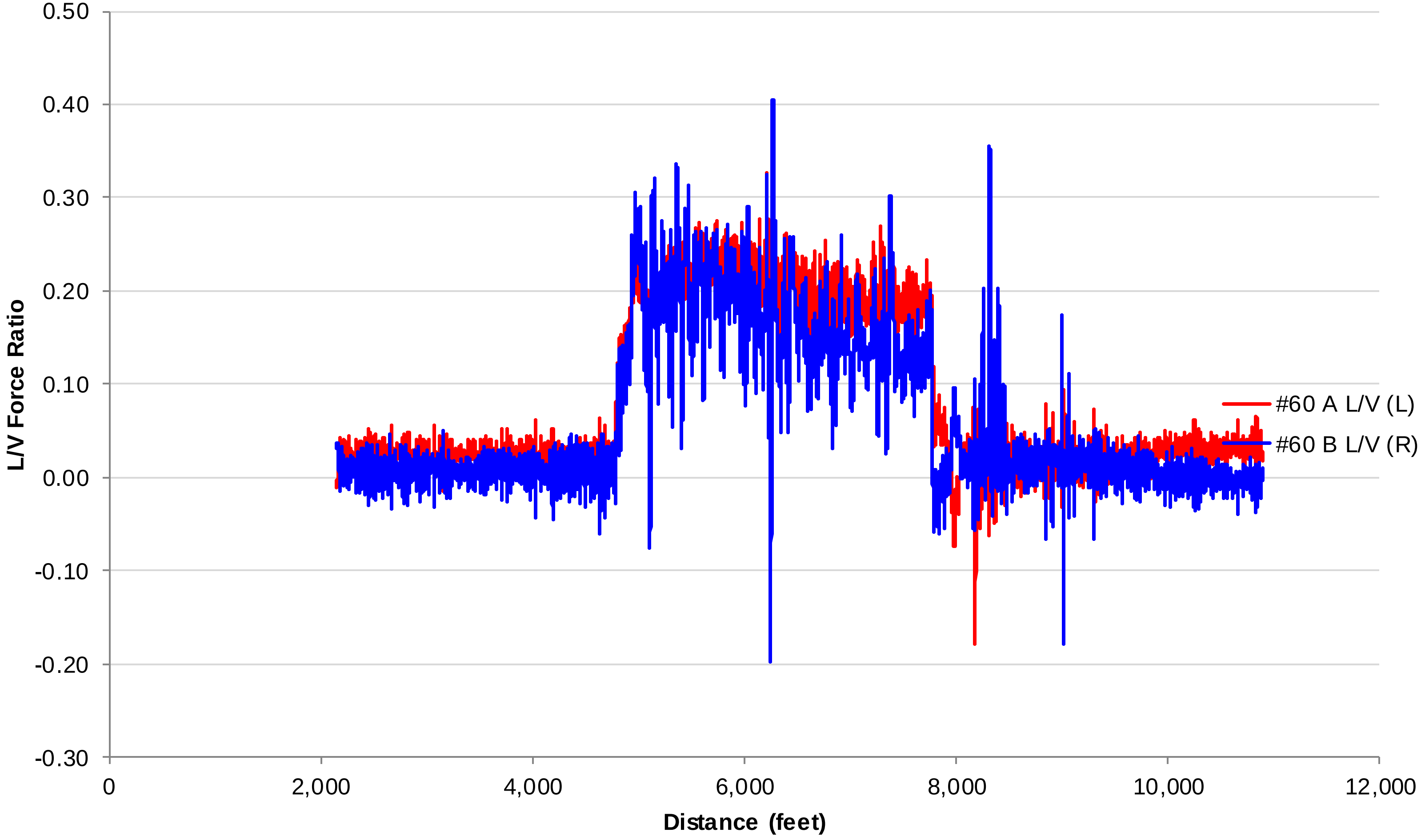
Source: Union Pacific – Gothenburg, NE (January 2010)

Where the WILD Things Are

- Mansfield, MA (1)
- Enfield, CT (2)
- Hook, PA (3)
- Edgewood, MD (4)

Source: University of Virginia


Union Pacific Railroad Current and Proposed WILD Site Locations
Fields
Sunset
Baskin
Westvaco
Peru
Red Desert
Martin Bay
Gothenburg
New Cambria
Chamberlin
Wister
Donaldson
Stuttgart
Millican
Elton
All Sites (With the Exception of Fields, OR) Provide Vertical and Lateral Measurements
In Service WILD Locations
Parsons Sub WILD .. Under Construction
Proposed WILD Installations - 2008 and Beyond
Truck Performance Detector (TPD) Location(s)
UNION PACIFIC
BUILDING AMERICA™


0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
L/V Force Ratio
0
2,000
4,000
6,000
8,000
10,000
12,000
Distance (feet)
#60 A L/V (L)
#60 B L/V (R)