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**QUANTIFYING SHARED CORRIDOR WHEEL LOADING VARIATION USING
WHEEL IMPACT LOAD DETECTORS**

Brandon J. Van Dyk

Univ. of Illinois at
Urbana-Champaign
Dept. of Civil and
Environ. Engineering

205 N Mathews Ave, Urbana, IL 61801
vandyk2@illinois.edu

Marcus S. Dersch

Univ. of Illinois at
Urbana-Champaign
Dept. of Civil and
Environ. Engineering

205 N Mathews Ave, Urbana, IL 61801
mdersch2@illinois.edu

J. Riley Edwards

Univ. of Illinois at
Urbana-Champaign
Dept. of Civil and
Environ. Engineering

205 N Mathews Ave, Urbana, IL 61801
jedward2@illinois.edu

Conrad Ruppert, Jr.

Univ. of Illinois at
Urbana-Champaign
Dept. of Civil and
Environ. Engineering

205 N Mathews Ave, Urbana, IL 61801
ruppertc@illinois.edu

Christopher P.L. Barkan

Univ. of Illinois at
Urbana-Champaign
Dept. of Civil and
Environ. Engineering

205 N Mathews Ave, Urbana, IL 61801
cbarkan@illinois.edu

ABSTRACT

A sustained increase in heavy axle loads and cumulative freight tonnages, coupled with increased development of high speed passenger rail, is placing an increasing demand on railway infrastructure. Some of the most critical areas of the infrastructure in need of further research are track components used in high speed passenger, heavy haul, and shared infrastructure applications. In North America, many design guidelines for these systems use historical wheel loads that may not necessarily be representative of those seen on rail networks today. Without a clear understanding of the nature of these loads, it is impossible to adequately evaluate the superstructure to make design improvements. Therefore, researchers at the University of Illinois at Urbana-Champaign (UIUC) are conducting research to lay the groundwork for an improved and thorough understanding of the loading

environment entering the track structure. Wheel impact load detectors (WILDs) have been used in North America for decades to identify bad-acting wheels that could damage the rail infrastructure or result in a rolling stock failure. The WILD measures vertical and lateral rail loads imparted by the wheel at the wheel-rail interface, along with other pertinent information related to the specific wheel, car, and train passing the instrumented site. This information can be used to identify and classify trends in the loading features and other characteristics of the rolling stock. These trends not only provide a clearer picture of the existing loading environment created by widely varied traffic characteristics, but can be used in future design and maintenance planning of infrastructure according to the anticipated traffic. This paper will discuss the current trends in wheel loads across the North American rail network while investigating the effects of speed on dynamic and impact loads. Ultimately this work should

lead to useful distinctions of loads for improved design methodologies that are specific to the intended type of traffic traversing a given route or network.

INTRODUCTION

Historically, elements of the track superstructure in North America has been designed through a process that is generally based on practical experience, without a clear or analytical understanding of the loading environment causing particular failure mechanisms. Improvements in the design of track superstructure components may result in a more robust track structure if the loading environment can be adequately characterized.

The North American operating environment differs than the operating practices found throughout much of the rest of the world due to the prominence of rail freight transportation and shared infrastructure between heavy haul freight and intercity passenger traffic. One of the challenges created by this operating environment is the design of critical infrastructure components under such a widely varied loading spectrum.

To best determine how to describe the loads entering the track structure, one must explore possible causes of variation. This paper will use data from WILDs to identify sources of variation in the loading regime entering the track structure and develop a framework for understanding trends between some of the most critical parameters. Ultimately, these trends will provide a better understanding of the loading environment, laying the foundation for improved design and performance of critical infrastructure components.

METHODOLOGIES AND MEASUREMENT TECHNOLOGIES

There are many different load quantification collection systems, instrumentation strategies, and technologies available to the rail industry, each serving a different purpose. For example, the acoustic bearing detector records and evaluates noise signatures to determine when stresses in wheel bearings exceed a safe threshold (1). Specifically, instrumented wheel sets (IWSs), truck performance detectors (TBDs), and wheel impact load detectors (WILDs) monitor forces at the wheel-rail interface. These methods have typically been used to monitor rolling stock performance and assess wheel and vehicle health. However, they can also be used to provide insight into the magnitude and distribution of loads entering the track structure. A clear understanding of this loading spectrum provides a foundation for any analysis or design of critical infrastructure components. Each wheel load measurement technology is useful for different reasons and can be utilized to answer specific questions related to loads entering the track structure.

The IWS is a wheel set deployed on any type of vehicle that measures the loads imparted by the car into the track structure. Strain gauges on the axle and wheel provide information related to vertical, lateral, and tangential forces created by the wheel set, as well as the contact patch position

on the head of the rail. The IWS then produces high frequency data with variable speed, track quality, curvature, grade, special trackwork, and track stiffness. In the future, UIUC will utilize IWS data from the Association of American Railroads (AAR) and TTX Company to provide insight into the effects of these parameters on forces experienced at the wheel-rail interface.

A WILD consists of a series of strain gauges mounted on the rail within the crib of the track structure to measure vertical rail deflection. The site is over 50 feet in length, with crossties at various spacings to capture a single wheel's rotation five times, recording peak (impact) forces, as well as average forces (2). Using an algorithm that analyzes variability along the site, these average, or nominal, forces are distilled to obtain an estimate of static wheel load. While the WILD has traditionally been used by infrastructure owners to detect and identify bad-acting wheels, it has also been proven to be a practical mechanism for producing reliable wheel data, according to a study performed by the AAR in which they reviewed the variation of measurements produced by the detector (3).



FIGURE 1. WILD SITE ON CANADIAN NATIONAL (2)

WILD sites are constructed on high-quality tangent track with concrete crossties, premium ballast, and well-compacted subgrade (possibly with hot mix asphalt underlayment) to reduce and potentially eliminate sources of load variation within the track structure (Fig. 1). Although loads experienced in other locations on the network may have higher magnitudes due to track geometry deviations, these data still provide representative information for networks throughout North America (4). The quality of infrastructure at a WILD site also reduces the variability due to track irregularities and support conditions.

Because WILDs are only utilized on tangent track where lateral to vertical load ratios (L/V) are lower, the information regarding lateral loads may not be as useful as if it were on curved track. Therefore, much of the analysis shown in this paper is derived from vertical loading data. It is the intent of the UIUC research team to further develop our understanding of lateral loads through the use of other technologies, such as IWS and TPDs.

SHARED USE LOADING ENVIRONMENT IN NORTH AMERICA

The railroad operating and loading environment in North America is different than much of the rest of the world. New shared railway corridors are developing throughout the United States as expanded and improved passenger rail service grows alongside and within the existing freight network. Changes in freight railroad infrastructure, rolling stock, and operating practices have introduced many challenges involving accommodation of passenger service while maintaining freight service (5). One of these challenges is the design and performance of critical infrastructure components. Because of the diverging nature of the wheel loads and speeds on shared-use infrastructure, designing components within the track structure requires some significant analysis. Most design decisions cannot be made without gaining a deeper, and quantitative, understanding of the entire load spectrum. To better understand these loads applied to the infrastructure, UIUC has acquired WILD data from sites throughout the United States from both Amtrak's Northeast Corridor (a shared corridor in operation for many decades) and the Union Pacific Railroad (UPRR). **Figure A1**, found in the appendix, illustrates how loads can vary on mixed-use lines, even within particular vehicle types. **Figure A2** shows the wide variation of loads on a heavy haul freight line as well.

SOURCES OF LOAD VARIATION

Wheel loads imparted into the track structure on North America's rail network vary due to many causes, including static load, speed, temperature, location, position within the train, curvature, and grade. Because WILDs are constructed on tangent track, and they are dispersed throughout the United States, they are able to capture all of these sources of variation except for curvature and grade.

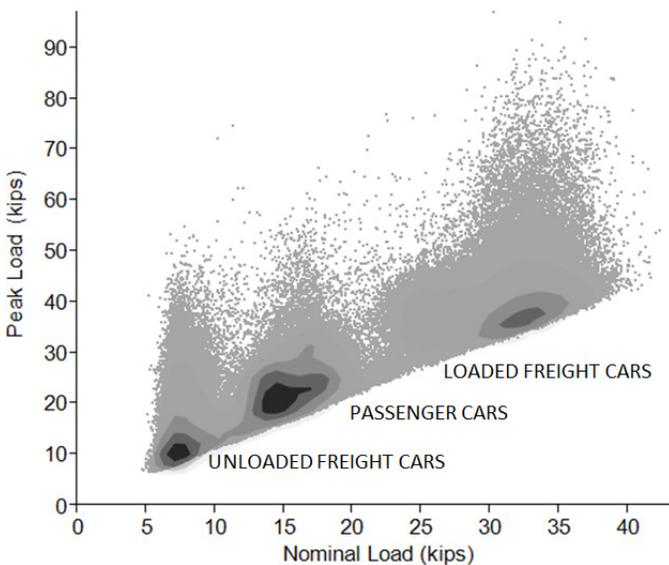


FIGURE 2. EFFECT OF CAR TYPE ON PEAK LOAD ON AMTRAK AT EDGEWOOD, MARYLAND (WILD DATA FROM NOVEMBER 2010)

The best indicator for the load expected to enter into the track structure is the static wheel load. This value, as expected, is highly dependent on the type of vehicle passing over the WILD. Heavier vehicles produce higher peak wheel loads, as shown in **Fig. 2**. Density contours are displayed to show areas of high data concentration. As can be seen in **Fig. 2**, there are clearly other factors affecting the peak load entering the track structure.

Field observations have suggested that loads at the wheel-rail interface produced by moving loads are greater than those produced by the same wheel loads at rest (6). Specifically, dynamic loads can be produced by roll, slip, lurch, shock, buff, torque, load transfer, vibration, and unequal distribution of lading within the rolling stock (7). Generally, dynamic and impact forces can be caused by imperfections in the moving vehicles (as listed above), geometric track imperfections, and variations in track stiffness (6). However, the relationship between speed and total vertical load is not easily quantified or characterized. As shown in **Fig 3**, the majority of the peak vertical wheel loads exhibit only mild increases with increased speed. This increase may simply be due to dynamic interaction between the naturally vibrating vehicle and track (8). However, the data do seem to confirm that, with increased speed, the largest impacts become more severe.

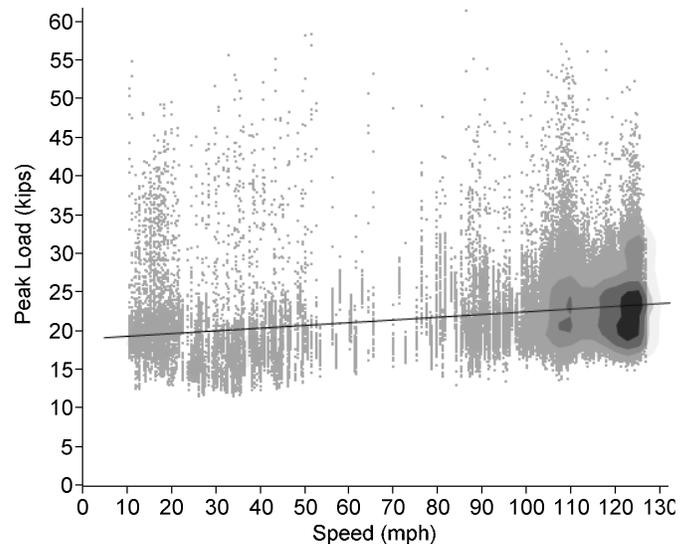


FIGURE 3. EFFECT OF SPEED ON PEAK LOAD ON AMTRAK AT EDGEWOOD, MARYLAND (PASSENGER WILD DATA FROM NOVEMBER 2010)

The location of the WILD site provides another very significant source of variation. Each site sees different distributions of car types and operating speeds. These varied traffic characteristics often produce widely varied loads at the wheel-rail interface. To illustrate this potential difference, **Fig. 4** compares freight traffic at Hook, PA with that at Gothenburg, NE. For example, 53% of all wheels passing the Hook WILD exceed 25 kips, whereas only 36% of all wheels passing the Gothenburg WILD exceed 25 kips. Conversely, 8% of wheels passing the Hook WILD exceed 40 kips and 23% of wheels passing the Gothenburg WILD exceed 40 kips.

Figure 4 also illustrates the different load magnitudes associated with loaded and unloaded freight cars, indicated by the steepest portions of each curve.

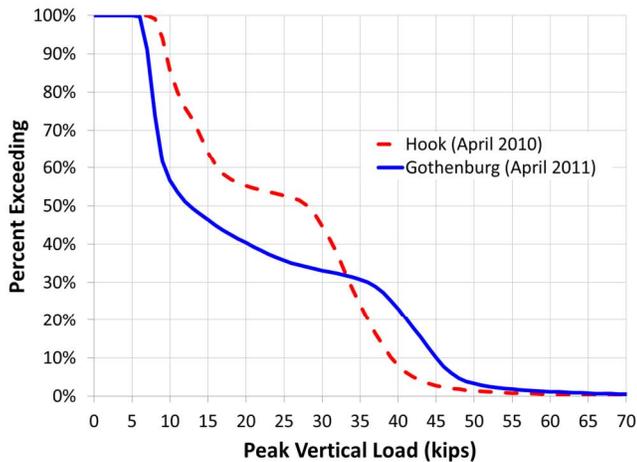


FIGURE 4. VARIATION OF PEAK VERTICAL LOADS BETWEEN HOOK, PENNSYLVANIA AND GOTHENBURG, NEBRASKA (FREIGHT CAR WILD DATA)

The variation depicted in **Fig. 4** is to be expected, as these two WILD sites are in different regions of the country, are owned by different companies with different maintenance practices, and have vastly different traffic compositions. However, WILD sites in the same region on infrastructure owned by one railroad can exhibit significant differences in loading also. **Figure 5** illustrates passenger coach wheel loads from four sites along Amtrak’s Northeast Corridor. Mansfield, Edgewood, and Hook experience *Acela Express* service, with speeds in excess of 100 mph. As shown in the figure, just 5% of the wheel loads captured at Hook exceed 25 kips, while almost 57% of the wheels passing over the Mansfield site produce peak loads in excess of 25 kips. The traffic compositions of these two sites are similar, yet there are evidently other sources of variability affecting the distribution of peak wheel loads.

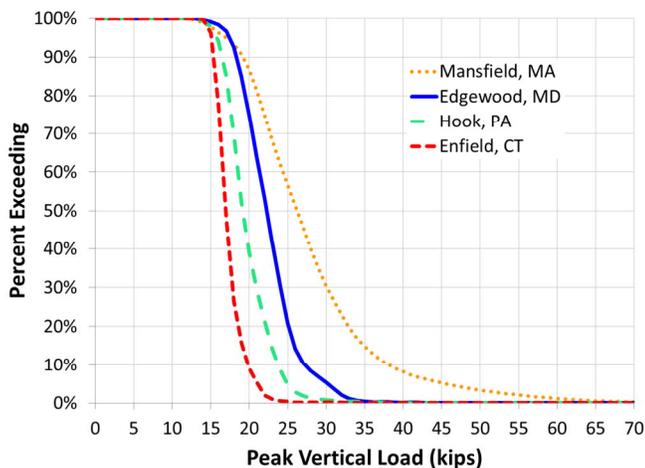


FIGURE 5. VARIATION OF PEAK VERTICAL LOADS ALONG AMTRAK’S NORTHEAST CORRIDOR (PASSENGER CAR WILD DATA FROM APRIL 2011)

While it has already been shown that there is variability across sites due to varying traffic characteristics, there also exists seasonal variability in loading at a single site. According to Kerr, when the substructure of track is frozen, it becomes stiffer and causes higher loads at wheel-rail interface (6). In fact, certain conditions, including frozen ballast and subgrade, can result in up to a nine-fold increase in track stiffness from freshly-tamped track (6). Cold weather can also stiffen various damping components within the carbody, further increasing the wheel load (9). One would then expect significant variability in loads according to seasonal changes. In fact, UPRR has collected WILD data showing a clear increase in the number of severe impacts during the winter months on its network (10). Compared to other sites and other years, **Fig. 6** depicts relatively large month-to-month variability in peak loads experienced at UPRR’s Gothenburg, Nebraska WILD site. However, the loads do not follow the expected trend according to monthly temperature fluctuations at a location that sees fairly significant seasonal temperature variation. Therefore, there doesn’t appear to be enough evidence initially to conclude that seasonal variations affect the general shape of the wheel load distribution. Additional analysis will be required to determine true effect of seasonal fluctuation on severity of impact loads applied to the track structure.

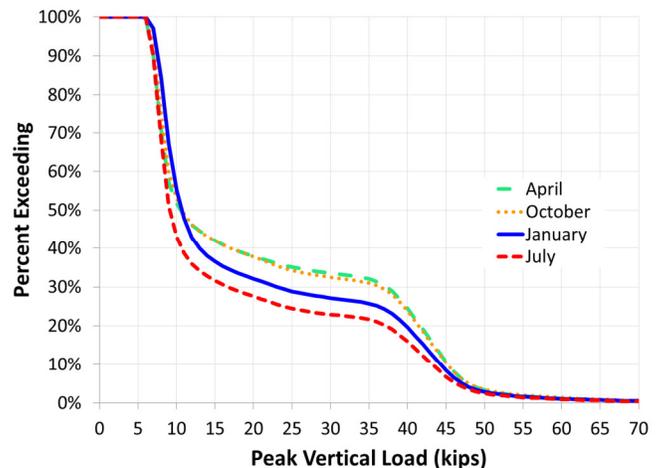


FIGURE 6. MONTHLY VARIATION OF PEAK VERTICAL LOADS ON UPRR AT GOTHENBURG, NEBRASKA (NON-INTERMODAL FREIGHT CAR WILD DATA FROM 2010)

Perhaps the greatest contributor to increases in loads entering the track structure as detected by the WILD is the condition of the wheel. Irregularities on the wheel can result in impacts that severely damage the rail and other components of the track structure. For instance, a 100-kip impact resulting from a flat wheel can increase the contact stress in the rail by up to 200% (10). Therefore, variability in the quality of wheels traveling over the infrastructure creates significant variation in the loads entering that structure. **Figure 7** shows peak wheel load as a function of speed for passenger coach data on Amtrak’s Northeast Corridor. The significant number of wheel loads exceeding 50 kips at roughly half the maximum speed suggests a high volume of bad-acting wheels

travelling over this WILD site. These wheels, therefore, are imparting loads up to six times their static load into the track structure, potentially causing great damage to the rail and other track components. The condition of these wheels may contribute to the site-specific diversity as shown in Fig. 5.

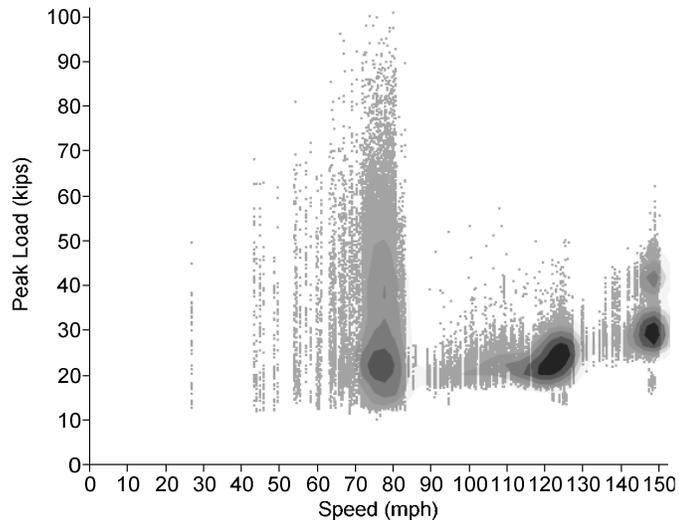


FIGURE 7. EFFECT OF WHEEL CONDITION ON PEAK LOAD ON AMTRAK AT MANSFIELD, MASSACHUSETTS (PASSENGER WILD DATA FROM NOVEMBER 2010)

Because the WILD is installed on high-quality tangent track, the effect of wheel position within the truck, car, or train may not be fully realized. In the future, the UIUC research team will test this hypothesis using both WILD and IWS data to determine what effect, if any, the axle's position within the rolling stock has on the loading environment.

The effect of curvature and grade are also not clear from WILD data due to the detector's characteristics. While curvature significantly affects the lateral loads applied by the wheel, the vertical loads entering the track structure will also vary greatly. In the future, IWS data will also be used to investigate the effects of curvature and grade.

CONCLUSIONS AND FUTURE WORK

The following conclusions can be drawn from preliminary analysis of the data collected from Amtrak and UPRR WILD sites:

- The WILD is a useful tool for collecting and analyzing data entering the track structure
- Vehicle type and its associated static load provide a baseline for the expected total load at the wheel-rail interface
- Increasing speed mildly increases the most common wheel loads; however, severe impact loads become much more severe at higher speeds
- Traffic composition and other site-specific parameters play a significant role in the distribution of the loading environment

- Seasonal effects in load variation, while greatly contributing to the magnitude of severe impacts, minimally affect the majority of the wheel load distribution
- Wheel condition is a significant factor in determining expected loads entering the track structure

UIUC researchers will continue to analyze data provided by their industry partners to better understand the loading environment entering the track structure. Data collected by IWSs and instrumentation developed by UIUC will provide lateral and longitudinal loading insight in addition to the vertical loads discussed in this paper.

In the future, some relationships discussed above will be quantified using a statistically sophisticated mathematical model. This model will potentially be used to quantitatively describe the existing loading environment in North America. It may also be used as a prediction tool for wheel load given certain expected operating parameters (see Fig. 8).

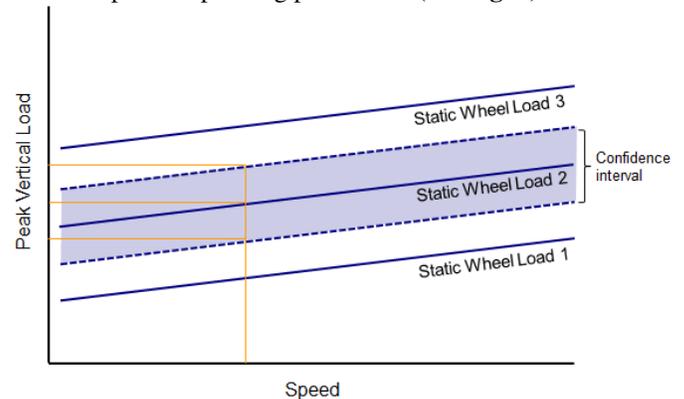


FIGURE 8. PROPOSED PREDICTION MODEL FOR EXPECTED PEAK VERTICAL WHEEL LOAD

The identification of loading variation sources, as well as quantitative relationships developed using multiple data collection methods will continue to paint a clearer picture of the loading environment entering the track structure. Once that picture is better understood, there exist opportunities for improvements to design and, eventually, performance of critical infrastructure components.

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ANNEX A

SHARED USE LOADING ENVIRONMENT FIGURES

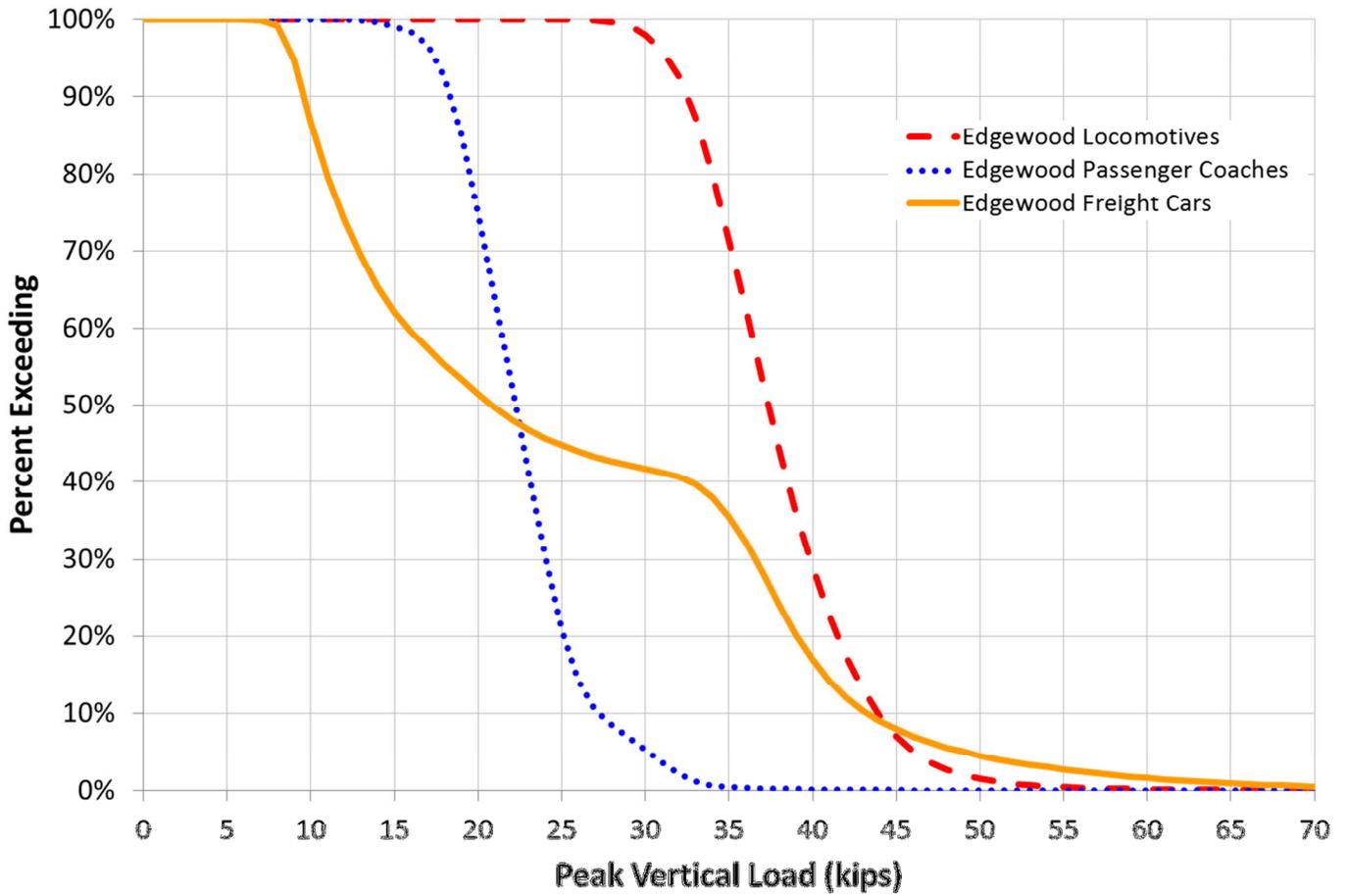


FIGURE A1. PERCENT EXCEEDING PARTICULAR PEAK VERTICAL LOADS ON AMTRAK AT EDGEWOOD, MARYLAND (WILD DATA FROM NOVEMBER 2010)

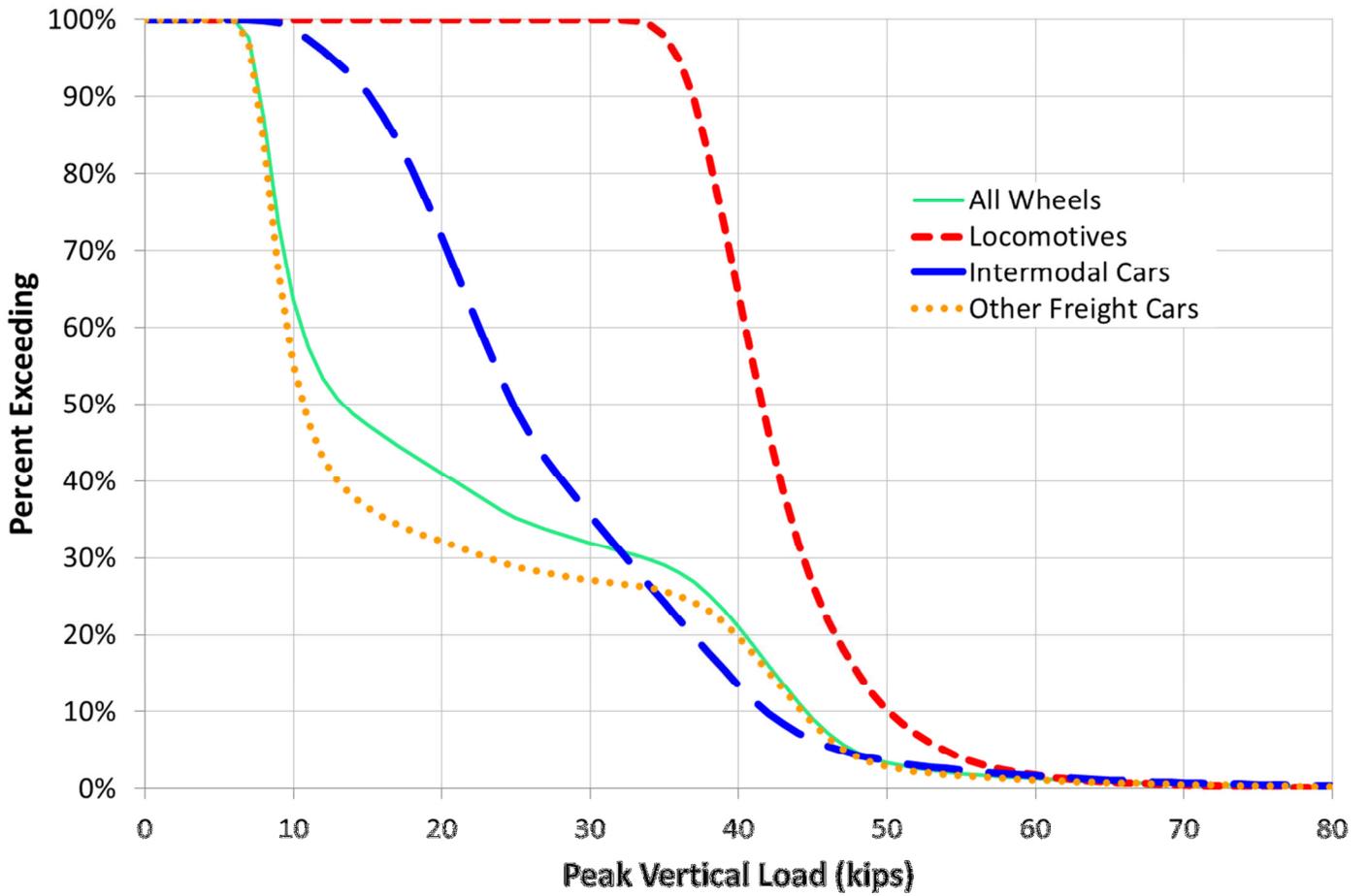


FIGURE A2. PERCENT EXCEEDING PARTICULAR PEAK VERTICAL LOADS ON UPRR AT GOTHENBURG, NEBRASKA (WILD DATA FROM JANUARY 2010)