11th WCRR 2016
World Congress on Railway Research
29th May – 2nd June
Milan - Italy

Load Quantification for Light Rail, Heavy Rail, and Commuter Rail Transit Infrastructure

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Abstract
The type and magnitude of loads passing through the track superstructure have a great impact on both the design and the performance of concrete sleepers and fastening systems. To date, the majority of North American research focusing on quantifying rail infrastructure loading conditions has been conducted on heavy-haul freight railroads. However, the results and recommendations from these studies may not be applicable to the rail transit industry due to a variety of factors. Unlike freight railroads, which have standardized vehicle maximum gross rail loads and superstructure design practices, the rail transit industry is home to significant variety of vehicle and infrastructure designs. Some of the current transit infrastructure design practices, which were established decades ago, need to be updated with respect to today's loading environment, infrastructure types, and understanding of component and system-level behavior. This paper focuses on quantifying the current load environment for light rail, heavy rail, and commuter rail transit infrastructure in the United States. As an initial phase of this study, researchers at the University of Illinois at Urbana-Champaign (UIUC) conducted a literature review of different metrics used to evaluate the static, dynamic, impact, and rail seat loads for rail transit infrastructure. UIUC will compare these methods and their computed values to determine which provide the most accurate estimation of the expected loading condition given a set of operating and infrastructure characteristics. Proper load quantification for rail transit systems, gained through an improved understanding of load path and rail seat load, will help to establish the basis for developing recommendations for a mechanistic design process for rail transit infrastructure components. Ultimately, the results from this research will allow transit agencies to increase the effectiveness of their capital spending and they have the potential to improve safety, ride quality, capacity, and the life cycle of rail transit infrastructure.

1. Introduction

Understanding of the type and magnitude of loads entering the track system at the wheel-rail interface is critical to developing a holistic understanding of the structural performance of the track superstructure. Quantifying the loading condition is also the first step in further improving the design of the rail transit infrastructure and its components. A quantitative understanding of the loading environment can lead to optimized components and system designs for the unique loading conditions encountered in various rail transit systems. A great variety of transit vehicles are currently in operation in the United States due to the fact that transit agencies have the flexibility to modify their vehicle design to accommodate their infrastructure conditions and operational demands. Prior research at UIUC on load quantification has been focused on understanding the heavy-haul freight railroad loading environment. However, the results and recommendations from these studies may not be completely applicable to the transit industry, due to the fundamental differences between the infrastructure and operational characteristics of rail transit and heavy-haul freight railroads.

Presently, there is no widely accepted research on quantifying the loading environment for rail transit infrastructure and its components. There are, however, some focused reports and studies that can guide this research effort. The D-5 research report used data captured by a wheel impact load detector (WILD) on VIA Rail in Canada. The report shows that the typical static wheel loads of the VIA Rail vehicles are 16 to 18 kips (71 to 80 kN) with a maximum value of 38 kips (169 kN) (*1*). Vuchic documented the vehicle characteristics of several rail transit systems in the United States, Europe, and South America (*2*). The Track Design Handbook for Light Rail Transit summarized the vehicle characteristics from 26 light rail systems in the United States and Canada using 2010 data (*3*). Other examples of rail transit infrastructure track loading research are case studies that were commissioned by transit agencies (*4, 5*). However, there is no comprehensive study of rail transit vehicle characteristics in the United States across light rail, heavy rail, and commuter rail systems.

2. Rail Transit Static Load Quantification

In order to develop an understanding of the current state-of-practice regarding the loading environment of rail transit vehicles, researchers at UIUC collected information pertaining to rail transit vehicles using several sources. The 2013 Revenue Vehicle Inventory published by National Transit Database (NTD) is used as the primary reference of the rail transit vehicles in the United States (*6*). The 2013 Revenue Vehicle Inventory is a comprehensive database that contains up-to-date information of rail transit rolling stock from more than 40 of the nation's transit agencies (*6*). It provides rail transit vehicle fleet size and characteristics, including the owner, manufacturer, model number, and seating and standing capacity. However, it fails to document other critical vehicle characteristics, such as tare weight, number of axles, and wheel diameter (*6*).

Extensive efforts were made to ensure the quality of the information used in this analysis and to obtain as much data as possible. It was not possible, however, to obtain information for every railcar. In addition, as rail transit systems are frequently purchasing new vehicles, selling vehicles to other systems, and retiring or rehabilitating old vehicles, it is difficult to keep the rolling stock information up to date in such a dynamic environment. The results stemming from this research are valid for understanding general differences in rail transit loading environment in the United States for the three rail transit modes. However, those seeking research on track structural design for transit systems should consult the transit agencies for the most up-to-date information.

2.1 Passenger Vehicle Weight Categories and Definitions

The rail transit industry is currently using the AW0 to AW4 standards to design cars that are used to transport passengers. AW0 is defined as the empty car weight without any passenger loading. AW1 is defined as the empty car weight plus the weight of seated passenger loads at maximum seating capacity. AW2 is defined as the sum of the AW1 load and the weight of standing passengers at the density of four passengers per square meter (3.3 passengers per yd^2). AW3, the crush load, is defined as the sum of the AW1 load and the weight of standing passengers at the density of six passengers per square meters (5.0 passengers per yd^2). AW4 is defined as the AW1 load and the weight of standing passengers at the density of eight passengers per square meters (6.7 passengers per yd^2). AW4 is not typically considered in track superstructure design since it is a theoretical loading only for bridge design and virtually certain to never be experienced in service. The rail transit industry is currently using the AW3 load as the maximum load that track components can withstand (*3*). Since commuter locomotives do not carry revenue passengers, only the AW0 load is used for calculating the weight of commuter locomotives.

Given that data on standing space are not generally available for most rail transit vehicles in the United States, an alternative expression of the AW3 load is used in this research effort, which equals to the empty car weight plus the product of average passenger weight and the maximum passenger capacity for the vehicle (*7*).

2.2 Empty Car Weight

Empty car weight, also known as tare weight or the AW0 load, was collected for all passenger vehicles considered in this research effort. UIUC collected the empty car weight for passenger vehicles and locomotives using various sources, including vehicle design specifications and datasheets published by vehicle manufacturers and transit agencies. Some transit authorities also directly provided their rolling stock data to UIUC. Although the empty car weight information is not available for all the transit rail vehicles, UIUC was able to locate information for 2,070 out of 2,070 (100%) light rail vehicles, 9,781 out of 11,474 (85%) heavy rail vehicles, 4,353 out of 6,047 (72%) commuter railcars, and 674 out of 738 (91%) commuter locomotives.

2.3 Average Passenger Weight

According to the Light Rail Design Handbook and the design specifications from rail transit agencies, the average passenger weight is specified to be 155 pounds (70 kg) (*3*). However, APTA research shows that 155 pounds (70 kg) is the median weight of the population in the 1970s, and the median weight of the population in the United States is currently 182 pounds (83 kg) (*8*). Most of transit agencies and track component suppliers are currently using 175 pounds (79 kg) as the average passenger weight. There are also examples of rail transit vehicle design using an average passenger weight of 165 pounds (75 kg) and 180 pounds (82 kg) for rail transit vehicles (*7, 9*). None of these values of average passenger weight fully address the increase in average weight since the 1970s. APTA's research suggests the use of 199 pounds (90 kg) for seated passenger weight, and 106 lbs/ft^2 (517 kg/m^2) for standing passenger weight, taking into account 10 pounds (4.5 kg) of personal items and 7 pounds (3.2 kg) for year round clothing (*8*). Since the data of standing area are generally unavailable for most of the railcars, it is impractical to calculate the total weight using the standing area. Additionally, this research fails to consider the weight of children, which might lower the average passenger weight. Therefore, we propose to use 195 pounds (88 kg) as the average passenger weight.

2.4 Railcar Passenger Capacity and Number of Active Revenue Vehicles

The 2013 Revenue Vehicle Inventory provides the passenger capacity, both seated and standing capacity, as well as the number of active revenue vehicles for each transit vehicle model in the United States (*6*). With the passenger capacity and the empty weight obtained for most of the transit rail vehicles in the United States, the AW0 and AW3 loads could be calculated, and the total transit vehicle weight distribution could be analyzed.

2.5 Results and Discussion Regarding Rail Vehicle Weights

The individual axle loads of the majority of light rail and heavy rail transit vehicles are not typically uniformly distributed for a given vehicle. Due to unbalanced weight distribution in the car body, the axle loads may vary. Overall, since the difference in axle loads on a given vehicle is relatively small, we assume the weight of the car is uniformly distributed on all axles. Therefore, the axle load is calculated by dividing the gross weight of car by the number of axles. The axle load distribution for three modes is shown in Figure 1. It shows the percentage of rail transit vehicles in the United States exceeding particular axle loads for light rail, heavy rail, and commuter rail systems.

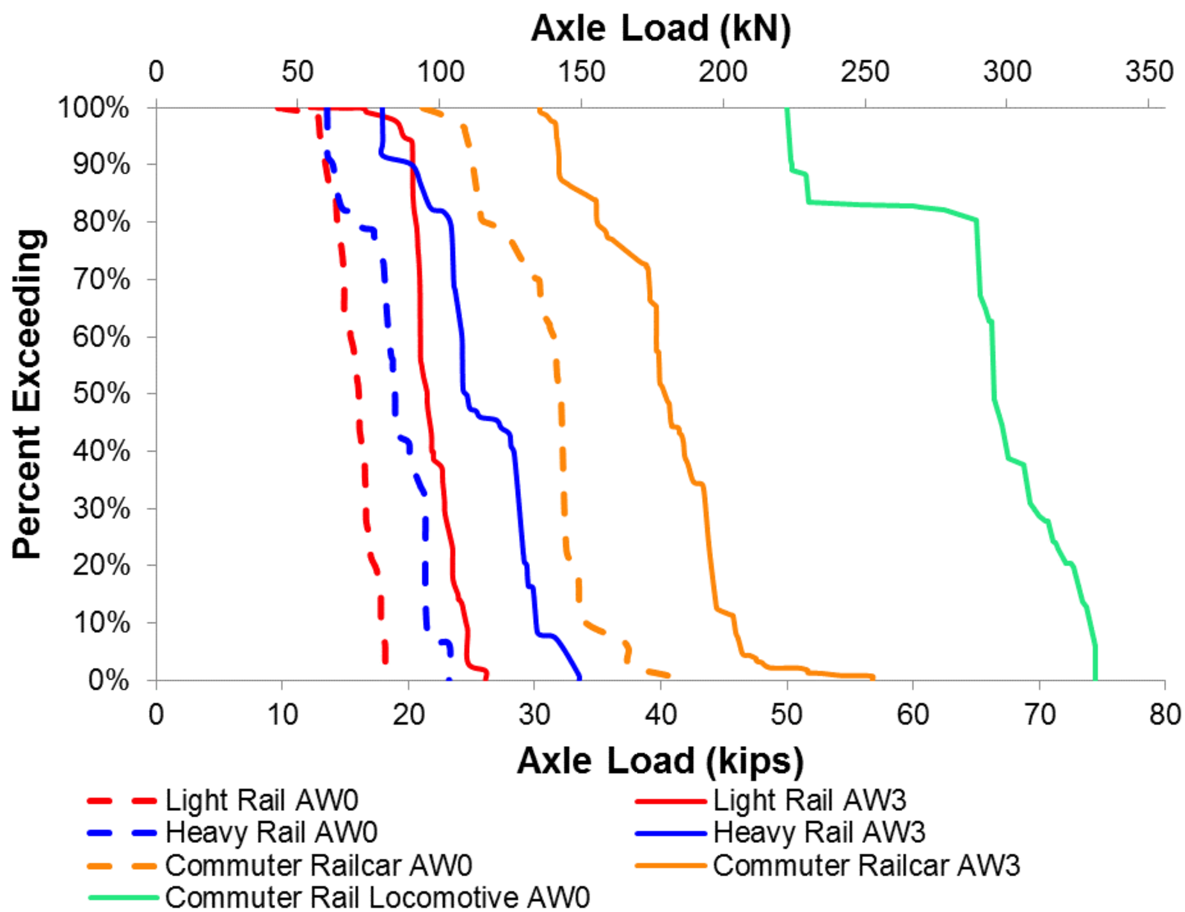

FIGURE 1 Light Rail, Heavy Rail, and Commuter Rail Axle Load Distribution.

It is important to note that rail transit vehicles do not always govern the design load of rail transit infrastructure. Many commuter rail systems and some light rail systems share their infrastructure with freight railroad rolling stock, which typically generate significantly higher axle loads. Additionally, work equipment, such as ballast cars, usually have higher axle loads than the passenger vehicles. For instance, the largest AW3 axle load of passenger railcars on the Massachusetts Bay Transportation Authority (MBTA) heavy rail system is 33.5 kips (149 kN); while the static axle load of work equipment on MBTA heavy rail system could be as high as 38 kips (169 kN) (*10*).

3. Evaluation of Impact Factor

The concept of impact factor has been adopted by the rail industry to calculate the increase in wheel load due to track and wheel irregularities and speed. The American Railway Engineering and Maintenance-of-way Association (AREMA) Manual on Railway Engineering (hereafter referred to as the "AREMA Manual") defines the impact factor as a percentage increase over static vertical loads intended to estimate the dynamic effect of wheel and rail irregularities (*11*). The AREMA Manual currently specifies an impact factor of 200%, which indicates the design load is three times the static load, equivalent to an impact load factor of three (*12*). Since the use of impact factors in the AREMA Manual is the same for both freight railroads and rail transit systems, the WILD data show that the current impact factor may not be suitable for rail transit loading environment. The applicability of the impact factor requires further studies with respect to today's rail transit loading environment. Due to the difference between commuter railcars and locomotives in terms of loading characteristics, these two types of commuter rail equipment are analyzed separately. Using the Wheel Impact Load Detector (WILD) data at Edgewood, MD, Marcus Hook, PA, and Mansfield, MA, the peak load is plotted against the nominal load in Figures 2 and 3 for commuter railcars and locomotives respectively with lines representing the impact factor of one, two, three, and four.

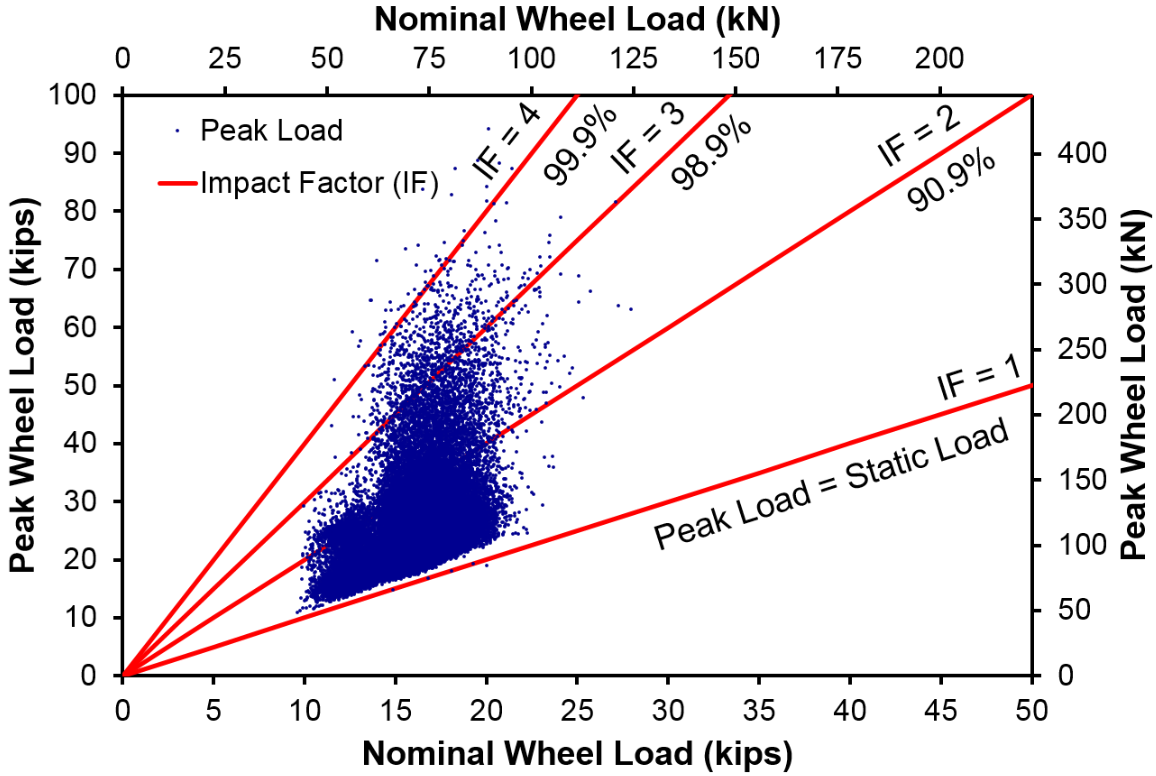

FIGURE 2 Relationship between peak and nominal wheel loads of commuter railcars on Amtrak Infrastructure at Edgewood, MD, Marcus Hook, PA, and Mansfield, MA (WILD data from 2010 and 2011) and design impact factors.

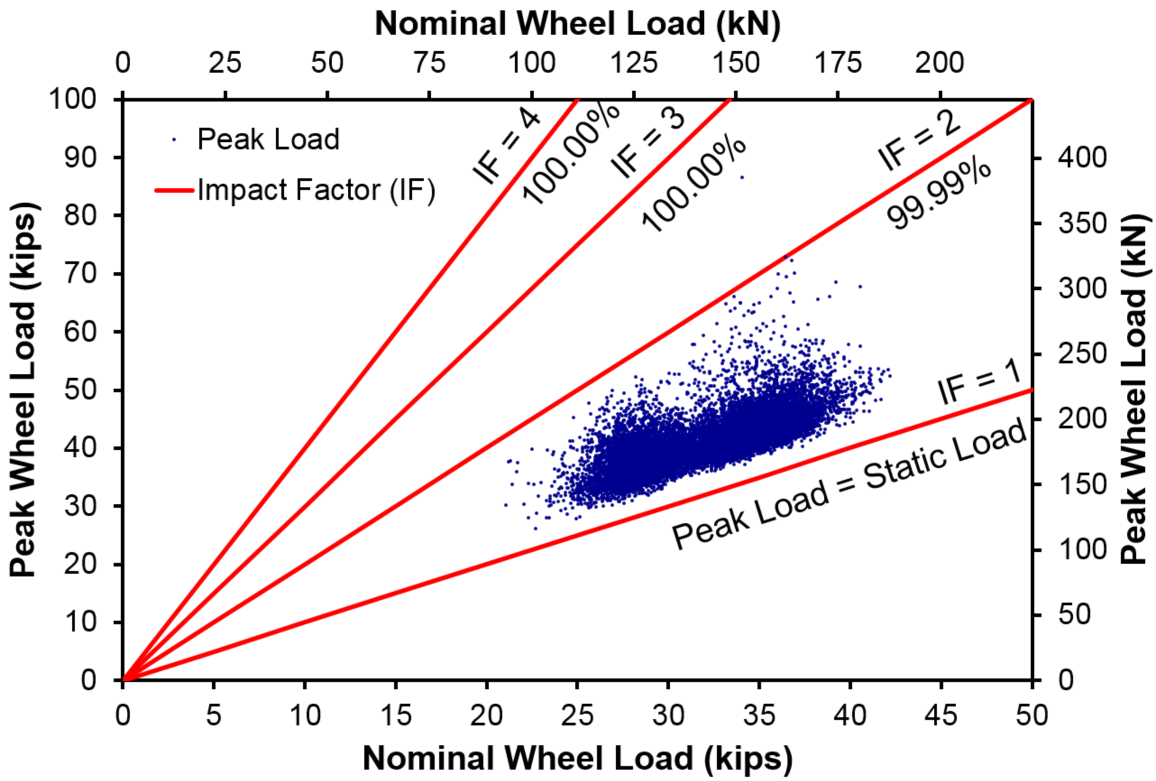

FIGURE 3 Relationship between peak and nominal wheel loads of commuter locomotives on Amtrak Infrastructure at Edgewood, MD, Marcus Hook, PA, and Mansfield, MA (WILD data from 2010 and 2011) and design impact factors.

Figures 2 and 3 show that the impact factor of three exceeds 98.9% and 100% of the commuter railcar and locomotives wheel loads, respectively. This indicates that the impact factor of three specified by the AREMA Manual is adequate for calculating the design load for commuter rail vehicles. Figure 5 shows that the impact factor of two exceeds 99.99% of the commuter locomotives wheel loads, which indicates an impact factor of two is sufficient for calculating the peak wheel load for commuter locomotives. As the nominal wheels of commuter locomotives are significantly higher than those of commuter railcars, an impact factor of two for commuter locomotives could reduce the design load for passenger-only track. WILD sites are typically constructed on tangent track using premium track components so that track irregularities are minimized in order to better understand the health of the rolling stock. More demanding track conditions and other track irregularities could result in the need for a higher impact factor.

4. Conclusions and Future Work

A comprehensive static load quantification has been conducted for light, heavy, and commuter rail transit systems in the United States. A better understanding of rail transit loading environment was developed using industry databases and design recommendations. The applicability of several dynamic factors to rail transit loading environment was evaluated by comparing the predicted results with WILD data measured on commuter rail rolling stock. Most dynamic factors are able to predict peak wheel loads for commuter rail systems with high-level accuracy and precision. The effectiveness of the impact factor of 3 was also studied with respective to today's rail transit loading environment in the United States. It is shown that the impact factor of three is adequate for quantifying the effect of track and wheel irregularities on commuter rail transit systems, and provides a conservative estimate of wheel loads. Future work could incorporate WILD (or similar) data from light rail and heavy rail transit systems to evaluate the effectiveness of the dynamic factors and impact factors on light rail and heavy rail transit systems. Ultimately, load quantification for rail transit infrastructure enables transit agencies to optimize the design of their track components, increase infrastructure service life, and minimize over conservative designs. Furthermore, by improving the design and performance of track components, the results of this paper could increase the effectiveness of capital spending and lengthen the life cycle of rail transit infrastructure and its components.

5. Acknowledgements
The authors would like to thank the National University Rail (NURail) Center and the United States Department of Transportation (US DOT) Federal Transit Administration (FTA) for providing funding for this project. The published material in this report represents the position of the authors and not necessarily that of US DOT. Industry partnership has been provided by American Public Transportation Association (APTA), New York City Transit (New York, NY), Metra (Chicago, IL), MetroLink (St. Louis, MO), TriMet (Portland, OR), Pandrol USA, RPS, Inc., GIC, LB Foster - CXT Concrete Ties, Hanson Professional Services, Inc., and National Railroad Passenger Corporation (Amtrak). J. Riley Edwards has been supported in part by grants to the UIUC Rail Transportation and Engineering Center (RailTEC) from CN, Hanson Professional Services, and the George Krambles Transportation Scholarship Fund. For providing direction, advice, and resources, the authors would like to thank Bill Moorhead from Trammco, LLC and Alexandria Brtis from Metra.

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