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Load Effects of Truck Platooning on Existing Bridges in Oregon

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LOAD EFFECTS OF TRUCK PLATOONING ON EXISTING BRIDGES IN OREGON

BY

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ABSTRACT

Truck Platooning (TP) involves managing multiple trucks closely together to reduce aerodynamic drag. While TP offers benefits such as fuel savings, emission reductions, and enhanced safety, it raises concerns for existing infrastructure. This study reviews literature on TP and conducts bridge analyses comparing representative truck platoon configurations allowed under Oregon law with current truck loadings. It also explores the effects of truck head spacing and bridge span lengths, utilizing the research results to calculate rating factors using real-world case studies. The objective is to identify truck platoon configurations that may exceed acceptable load levels for Oregon bridges. The findings will contribute to policy recommendations, regulatory decisions, and updates to bridge load rating procedures in Oregon.

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1.0 INTRODUCTION

In recent years, the realm of autonomous vehicle technology has witnessed a notable advancement with the emergence of truck platooning – a pioneering concept where heavy trucks operate in close proximity to attain fuel efficiency and potentially pave the way for reduced labor through partial or full autonomous operations in the future. This innovative approach holds promise not only for substantial cost savings but also for its potential to revolutionize the logistics landscape. Truck platooning's projected accelerated adoption, surpassing that of conventional autonomous vehicles, underscores its significance and relevance in contemporary transportation strategies (Banker, 2019; Bishop, 2019).

At its core, truck platooning involves the synchronized operation of two or more trucks, employing cutting-edge technologies such as radar systems and vehicle-to-vehicle (V2V) communications. By coordinating the acceleration and braking of the lead and rear trucks, these systems enhance fuel economy, with human operators currently overseeing the process (Bishop, 2019). Yet, the true potential for enhanced return on investment becomes apparent when the follower truck is automated, a point highlighted by Bishop (2020a). Beyond the confines of the transportation sector, the ramifications of truck platooning extend to domains as diverse as forestry, mining, port drayage, and military logistics, as suggested by Bishop (2020a; Bishop, 2020b).

In the context of regulatory adjustments, recent legislative actions such as House Bill 4059 Section 40 have introduced allowances for vehicles employing "connected automated braking systems." This has implications for operational distances between vehicles and, subsequently, the loading dynamics on bridges. Notably, this regulatory shift acknowledges the potential strain platooned trucks could exert on bridge infrastructure. The cumulative loading effects could challenge the longevity of Oregon's bridges, necessitating a comprehensive exploration of the phenomenon's magnitude.

Evaluating the landscape of truck platooning in the United States, it becomes evident that its regulatory framework differs from that of Europe, fostering a diverse landscape of autonomous technology development by various companies. Unlike autonomous passenger vehicles, the swift assimilation of truck platooning is anticipated due to its immediate cost-saving advantages for trucking enterprises (Tsugawa et al., 2016).

The literature review brings to light a range of findings and gaps in knowledge with direct relevance to preserving Oregon's bridge infrastructure and alleviating the detriments imposed by truck platooning:

- The absence of top-down regulations on truck platooning in the U.S. prompts individual companies to develop their autonomous driving technologies, fostering a varied technological landscape.

- Studies indicate variable truck spacings, with potential fuel savings noted at close intervals but safety concerns necessitating greater distances in practice (Bevly et al., 2015).

- Structural analyses on the impact of truck platoons on bridges are scarce, primarily due to the complexity of platoon configurations and unknown parameters.

- Limited studies have extended beyond traditional 1D girder line analysis; exploration of distribution factors for 2D grillage models remains an unexplored avenue.

- Current analyses are based on hypothetical scenarios, underscoring the need for actual data for accurate assessments.

- Refined structural analyses hold the key to comprehensively understanding the potential effects of truck platoons on Oregon's bridges, laying the foundation for informed policy formulation.

2.0 MODELING THE DATASET

2.1 Representative Bridge Models to be Analyzed

Figure 2-1 shows the total number of bridges that existed in each dataset after different combinations of filters were applied. The goal was to reduce the dataset to a manageable amount of bridges while maintaining a representative set of bridges for analysis.

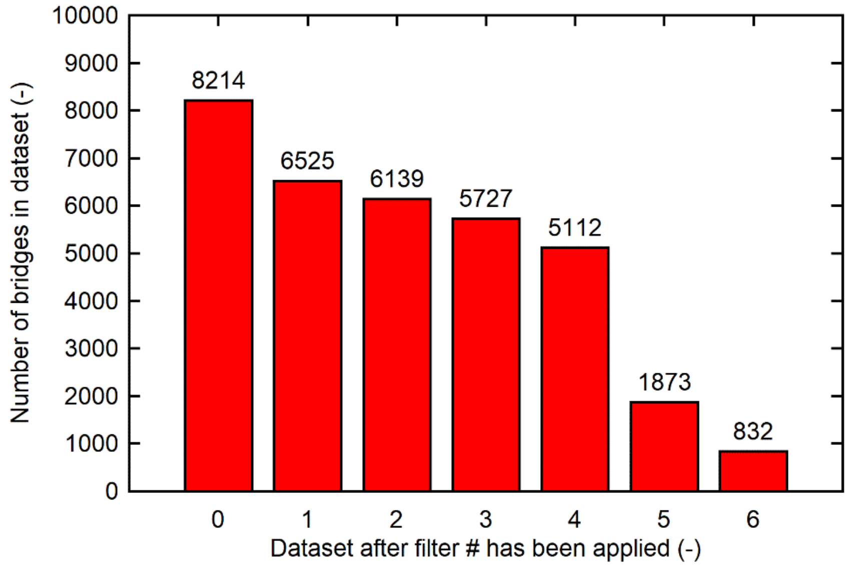

Figure 2-1: Size of datasets, Dataset 0 = unfiltered dataset, Dataset 6 = final dataset

Table 2-1 summarizes the selected NBI Items that were used as variables to characterize the final dataset and determine a set of representative bridge models. For each of these variables, histograms, frequency tables, and percentile tables (only for continuous variables) were created and are shown in Appendix A, Figures A1 to A40.

Table 2-1: NBI Items used as variables in this study. Terminology follows (FHWA 1995)

NBI Item	Name	Type	Unit	Filter?
27	Year built	Continuous	yr	No
31	Design load	Categorical	-	No
34	Skew	Continous	Degrees	Yes
41	Structure open, posted, or closed to traffic	Categorical	-	Yes
43A	Kind of material and/or design	Categorical	-	Yes
43B	Type of design and/or construction	Categorical	-	Yes
45	Number of spans in main unit	Discrete	-	No
48	Length of maximum span	Continous	m	No
58	Deck condition rating	Discrete	-	No
59	Superstructure condition rating	Discrete	-	No
63	Method used to determine operating rating	Categorical	-	Yes
64	Operating rating	Continous	ton	No
65	Method used to determine inventory rating	Categorical	-	Yes
66	Inventory rating	Continous	ton	No
104	Highway system of the inventory route	Categorical	-	Yes

The most typical bridge in the final dataset has the following characteristics (based on mode, i.e., highest frequency):

- was built in the early 1960s, i.e., is 55 to 60 years old
- was designed based on the HS 20 live load model (second most common: HS 25)
- has no skew, i.e., skew angle = 0 Degrees
- is made of prestressed concrete (followed by reinforced concrete)
- consists of a stringer/multi-beam or girder structural system (followed by slab)
- has either one or three spans (followed distantly by two, four, five, six, etc. spans)
- has a length of the maximum span, *L* = 12 to 16 m (for all bridges), and
  - bridges with one span (36% of all bridges): *L* = 12 to 16 m
  - bridges with two spans (8.3% of all bridges): *L* = 36 to 40 m
  - bridges with three spans (31% of all bridges): *L* = 12 to 16 m
  - bridges with four spans (7.2% of all bridges): *L* = 12 to 16 m
  - bridges with five spans (5.0% of all bridges): *L* = 20 to 24 m

- has a deck and superstructure condition rating of “7” (= good condition) followed closely by “6” (satisfactory condition)
- has an rating of 25 to 30 tons and 20 to 25 tons, respectively

The pertinent variables describing a bridge model are the number of spans encoded in NBI Item 45 and the lengths of the individual spans. For the latter, only the length of the longest span is available in NBI Item 48. Figure 2-2 illustrates the terminology used to describe representative bridge models with one to three spans.

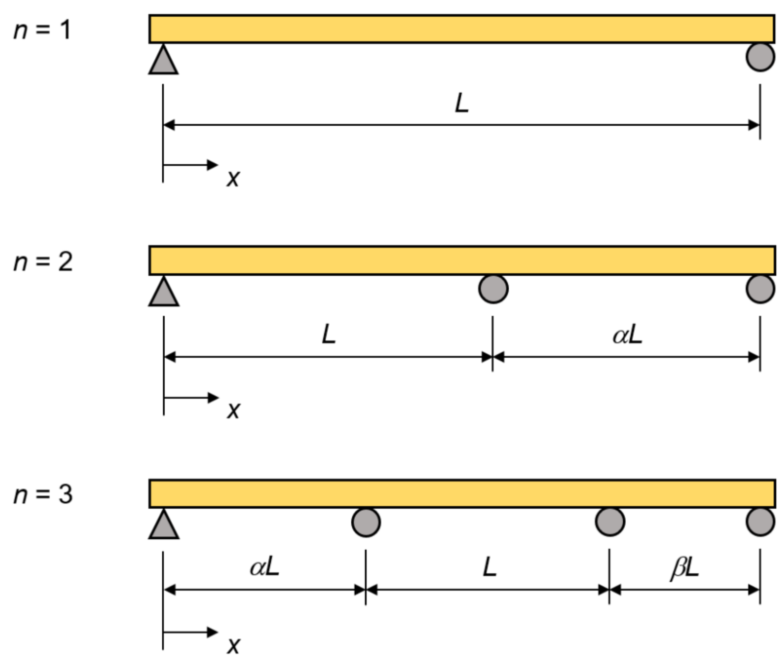

Figure 2-2: Illustration and terminology used for one to three spans

The following representative bridge model configurations are analyzed by means of moving load analysis for 749 cases:

- Single-span with L = 15 to 65 m (in steps of 5 m) – 11 cases
- Two-span with same L = 25 to 75 m (in steps of 5 m) and α = 1.0 to 0.75 (in steps of 0.05) – 66 cases
- Three-span with L = 15 to 80 m (in steps of 5 m), α = 1.0 to 0.75 (in steps of 0.05), and β = 1.0 to 0.65 (in steps of 0.05) – 672 cases

Lower and upper bounds of span lengths correspond approximately to the 30 and 99 percentiles. The following assumptions are made:

- There is no distinction between non-continuous and continuous construction the way it is coded in NBI Item 43A. If a multi-span bridge consists of non-continuous spans, then the results from the single-span bridge model shall be used.
- More than three spans are not considered; this is deemed sufficient to cover bridges with more spans.

2.2 Live-Load Models to be Analyzed

With a suite of representative bridge models, baseline and systematic moving load analyses were performed for the following 20 vehicle live loads, for which axle weight and spacing are known.

- Design live loads (1) - AASHTO LRFD HL-93
- Oregon legal trucks (3) - Type 3, 3S2, and 3-3
- Oregon specialized hauling vehicles (SHVs) (4) - SU4, 5, 6, and 7
- FAST Act emergency vehicles (EVs) (2) - EV2 and EV3
- Oregon continuous trip permit (CTP) trucks (3) - CTP-2A, 2B, and 3
- Oregon single trip permit (STP) trucks (7) - STP-3, 4A, 4B, 4C, 4D, 4E, and 5BW

"Baseline" analyses were conducted for each (non-platooned) vehicle listed above, e.g., the legal 3-3 truck shown in Figure 2-3, and created output (Section 2.3) for comparison with vehicle platoons.

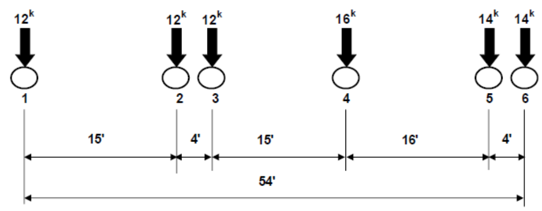

Figure 2-3: Axle weight and spacing for a legal 3-3 truck (1 kip = 4.448 kN, 1 ft = 0.3048 m)

"Systematic" analyses examined the effects of two and three-truck platoons for each vehicle listed above. To prevent exponential loading scenarios, only platoons of the same vehicles were considered, e.g., a platoon of two 3-3 legal trucks (see Figure 3-4) and not a platoon of a 3-3 with an STP-3A. Head spacing ranged from 10 ft to 60 ft in 10 ft increments (3 m to 18 m in 3 m increments) and will be uniform for three-truck platoons. For each vehicle listed above, 13 configurations (single baseline, 6 head spacings on two-truck platoon, and 6 head spacings on three-truck platoon) will be analyzed for each bridge model.

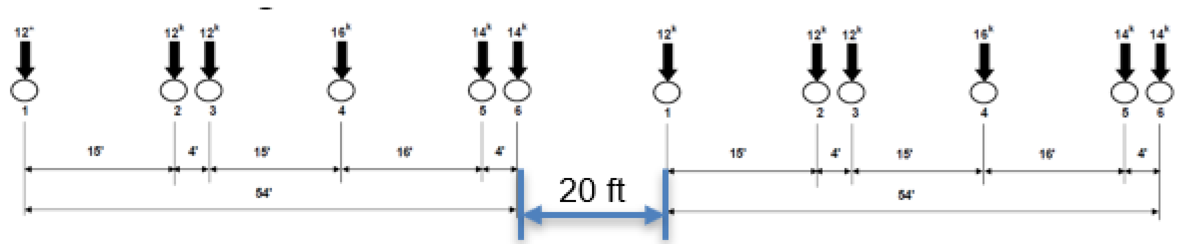

Figure 2-4: Axle weights and spacings for a platoon of two legal 3-3 trucks with 20 ft head space (1 kip = 4.448 kN, 1 ft = 0.3048 m)

Comparisons of live load effects, relative to dead load effect, were made between the systematic and baseline analysis output. In the event there were bridge models susceptible to specific truck platoons, additional "Targeted" analyses was conducted to find extreme scenarios that could be problematic.

For the 749 bridge models and 481 vehicle configurations, there are 360,269 analysis cases. For all analysis cases, the axle weights was swept across the bridge model in both directions. Load effects were determined by linear, static analysis at each pseudo-time step as the axle weights moved across the bridge model.

2.3 Description of Output to be Analyzed

For each analysis case, the bending moment and shear force were be recorded at uniform locations at 0.1L intervals along each bridge span of length L (Figure 2-5). These locations capture the worst effects of postitive bending near midspans and of negative moment and shear near continuous supports.

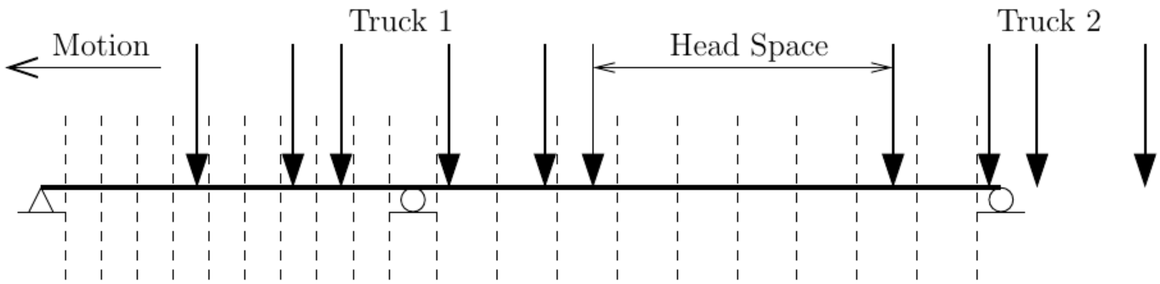

Figure 2-5: Monitoring locations (dashed lines) along each span of a two-span bridge model

For all analysis cases (combinations of vehicle/platoon and bridge model), the following quantities were reported at each monitoring location along each span:

- Maximum positive bending moment
- Shear coincident with maximum positive bending moment
- Maximum negative bending moment
- Shear coincident with maximum negative bending moment
- Maximum shear
- Bending moment coincident with maximum shear

The entire history of bending moment and shear force \\ were recorded during each analysis case, but only the maximum and coincident values listed above were reported.

3.0 RESULTS AND DISCUSSION

3.1 Building the Database

A database was established through MATLAB coding to import data files for the structural analysis results for the 749 different bridge types and 481 truck type combinations. The information included in the file was comprised of various parameters, such as bridge number, number of spans, length of each span, truck number, truck type, number of trucks, head spacing, maximum positive moment, maximum negative moment, and maximum shear for the entire bridge. For each maximum loading value, corresponding shear components and their respective locations on the bridge were recorded, except for shear, which had its maximum moment corresponding component and location.

To analyze a two or three span bridge, the MATLAB code treated each span individually. The maximum values of all span lengths, even though not representative of the maximum for the entire bridge, were recorded as well. Consequently, the exact same information that was gathered for the entire bridge was also collected separately for each span, including span one, span two, and span three.

In the process of compiling the data in this manner, a new opportunity arose regarding shear data. Since each span could have positive and negative shear values, the decision was made to record the maximum shear closest to each support. For example, in the case of a one-span bridge, there would be one maximum positive and negative moment and two maximum shears – one corresponding to the left support and the other corresponding to the right support.

Figure 3-1 is a plot of the data from a structural analysis run and identifies the data available in one row in the full dataset. It depicts a sample two-span bridge with the first span length of 131 feet and the second span length of 98.4 feet. The live load was modeled after the Type OR CTP-3 truck with a head spacing of 10-feet and platooned to three-trucks.

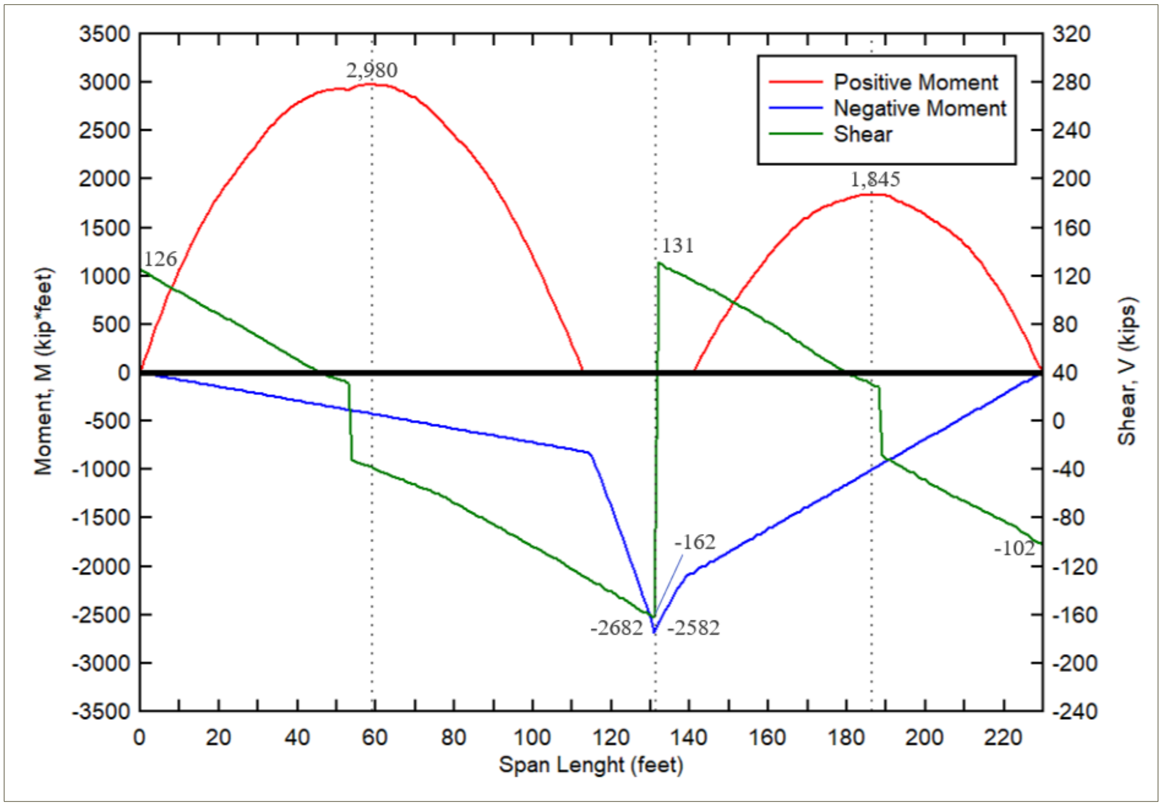

Figure 3-1: Example of the structural analysis results for a two-span bridge under a sample truck type combination pulled from MATLAB into one row of the database

3.2 Analysis of Dataset

This section presents an in-depth analysis of the dataset, focusing on an overall worst-case examination, as well as the effects of head spacing and span length on bridge behavior. Two distinct approaches were employed to evaluate the overall impacts: normalizing data using OR Type 3 Legal and OR Type 3S2 Legal truck types and calculating ratios that act as amplification factors of individual truck types. Lastly, a real case study uses the platooned live load ratios to calculate rating factors for bridge design considerations.

3.2.1 Overall Worst-Case Analysis

In the analysis, two distinct approaches were employed to evaluate the effect of different truck types on the internal force response of the analyzed bridges.

The first approach (Equation 1) involved calculating ratios based on one specific truck type, provided by the 2018 ODOT LRFR Manual, with zero head spacing for the OR Type 3 Legal truck type. The internal forces due to all trucks and truck types considering all head spacings were divided by the internal forces for single truck OR Type 3 Legal. This process was also repeated using the OR Type 3S2 Legal truck type. During this analysis, all EV (Emergency Vehicle), HL-93 Tandem, and HS-20 truck types, were excluded as they would not participate in platooning in real-world scenarios. The remaining truck types were examined for their worst-case load effects on bridges. Using histograms, Figure 4-2, the normalization of load effects (or internal forces) across all truck types allowed for a comprehensive evaluation of the maximum positive bending moment, maximum negative bending moment, and maximum shear of the entire bridge. To gain a deeper understanding, separate breakdowns were created for each maximum loading value, and histograms were generated to visualize the distribution of ratios greater than or equal to two and by truck type, as seen in Figure 4-3 and Figure 4-4. In all histograms, the frequency of data points exceeding 2.0 was significant. As a result, a decision was made to divide the data into smaller bins, as illustrated using Roman numerals. The same breakdown was repeated, considering only values at or above the 95th percentile, Figure 4-5 and Figure 4-6. Based on the histogram analysis, further categorizations were derived by examining truck frequency, which indicated the number of instances where a truck exceeded a certain threshold. Additionally, the breakdown was explored in terms of bridge types, leading to a noteworthy observation: bridges with longer spans demonstrated the highest ratios. For figures of the overall max positive bending, max negative bending, and max shear histograms normalized by the OR Type Legal, and OR Type 3S2 Legal, ratio of final bin, 95th percentile, and truck frequencies for maximum live load please refer to Appendix B, Figures B1 to B60.

$$Ratio = \frac{Internal\ Load}{Internal\ Load\ of\ a\ Single\ Truck\ (OR\ Type\ 3\ or\ 3S2\ Legal)} \quad \textbf{[EQ 1]}$$

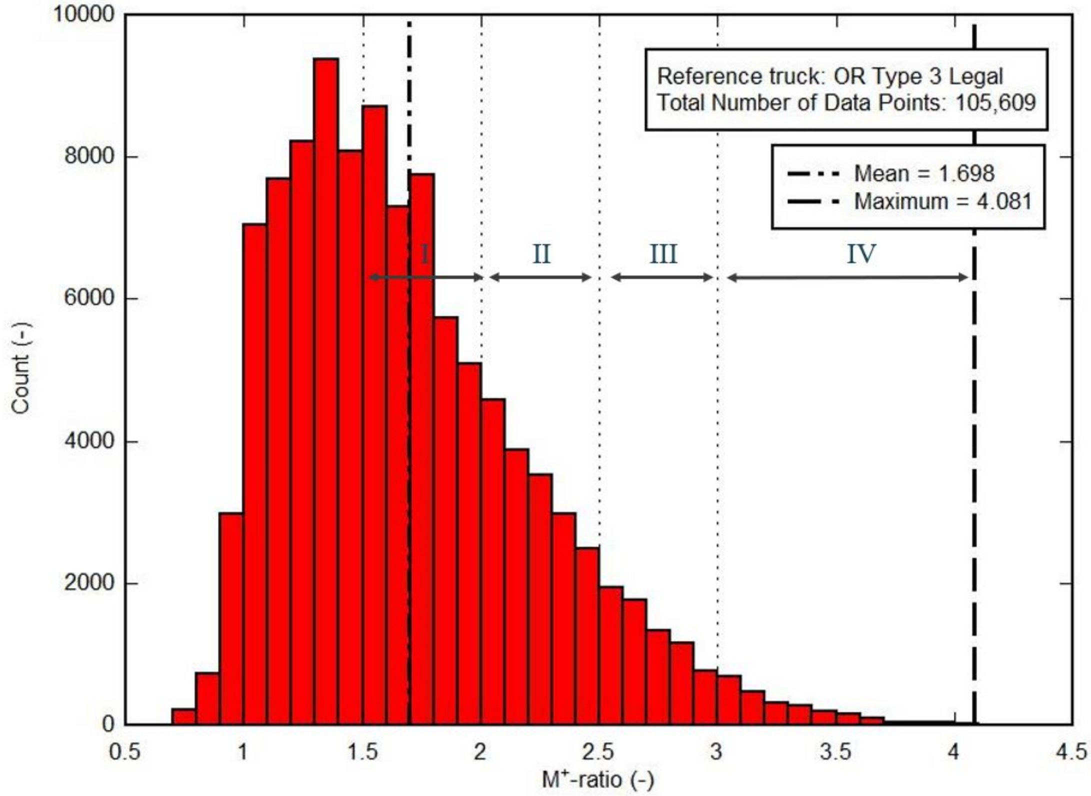

Figure 3-2:. Histogram of maximum positive bending moment ratio (full database) normalized by OR Type 3 Legal Truck

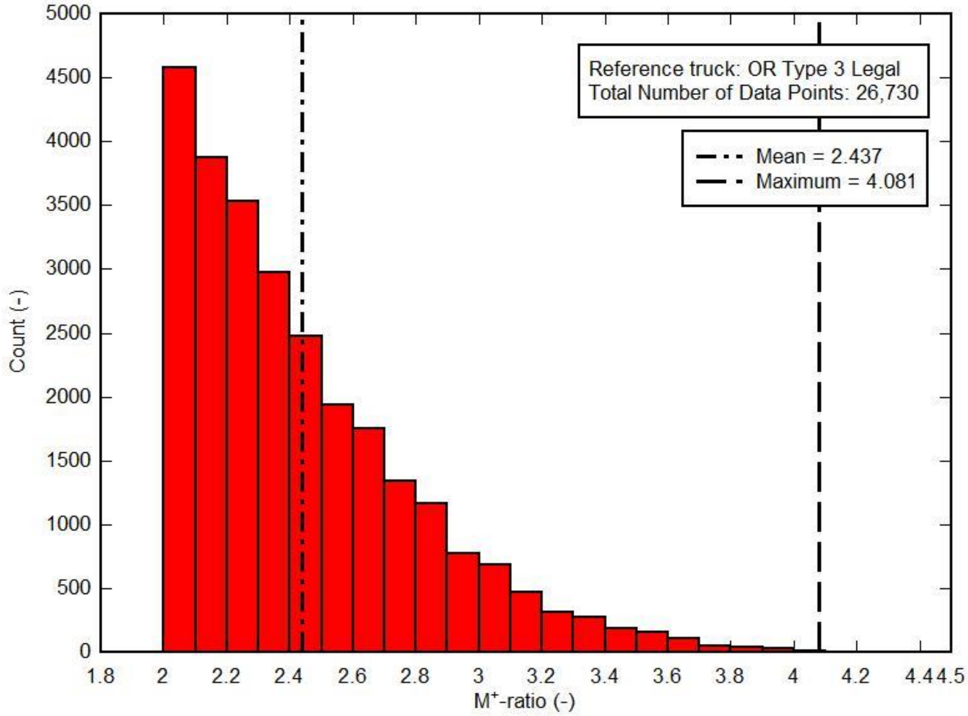

Figure 3-3: Histogram of maximum positive bending moment ratio (2.0+ ratio) normalized by OR Type 3 Legal Truck

In Figure 3-3, it is evident that the histogram representing the maximum positive bending moment highlights a total of 26,730 data points, each with a ratio of two or greater. These specific data points were singled out for a more detailed examination concerning the types of trucks involved, as illustrated in Figure 3-4. The primary aim was to discern how frequently a particular truck type appeared within this higher ratio range, thereby identifying the most commonly occurring worst truck type.

Upon isolating the data associated with these elevated ratios, it became evident that both Type OR CTP-3 and OR SU7 emerged as the predominant truck types with the highest frequency counts. This same analytical approach was applied to the 95th percentile dataset, comprising 5,282 data points, as depicted in Figure 3-5 and Figure 3-6. In almost all instances, the findings revealed that trucks of Type OR CTP-3 and OR SU7 exhibited the highest frequencies. The sole exception was observed in the final bin pertaining to negative bending moments, where Type OR TP-2B outpaced Type OR CTP-3.

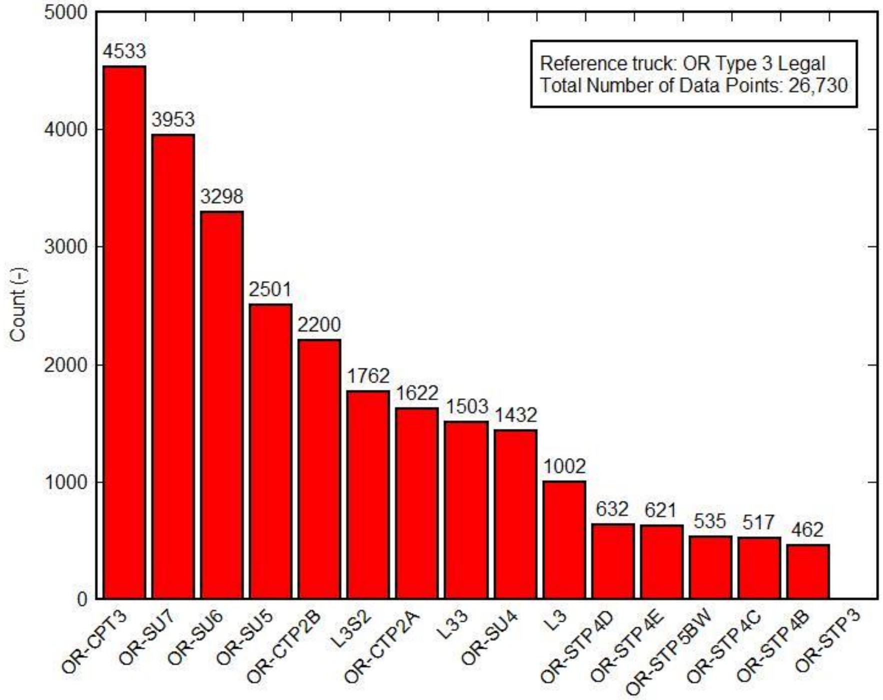

Figure 3-4: Histogram of maximum positive bending moment by truck type (2.0+ ratio) normalized by OR Type 3 Legal Truck

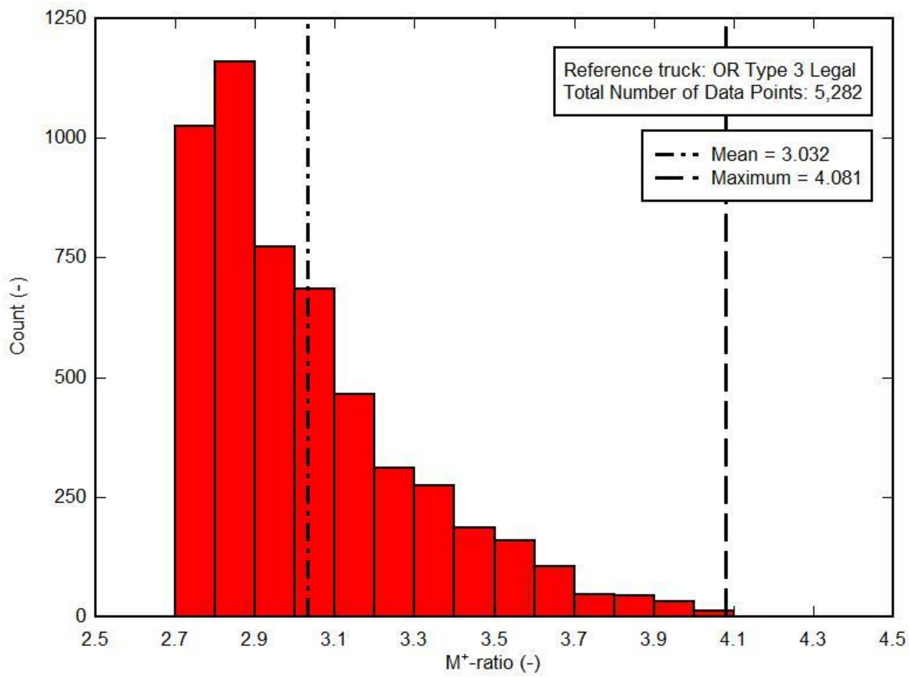

Figure 3-5: Histogram of maximum positive bending moment (the 95th percentile) normalized by OR Type 3 Legal Truck

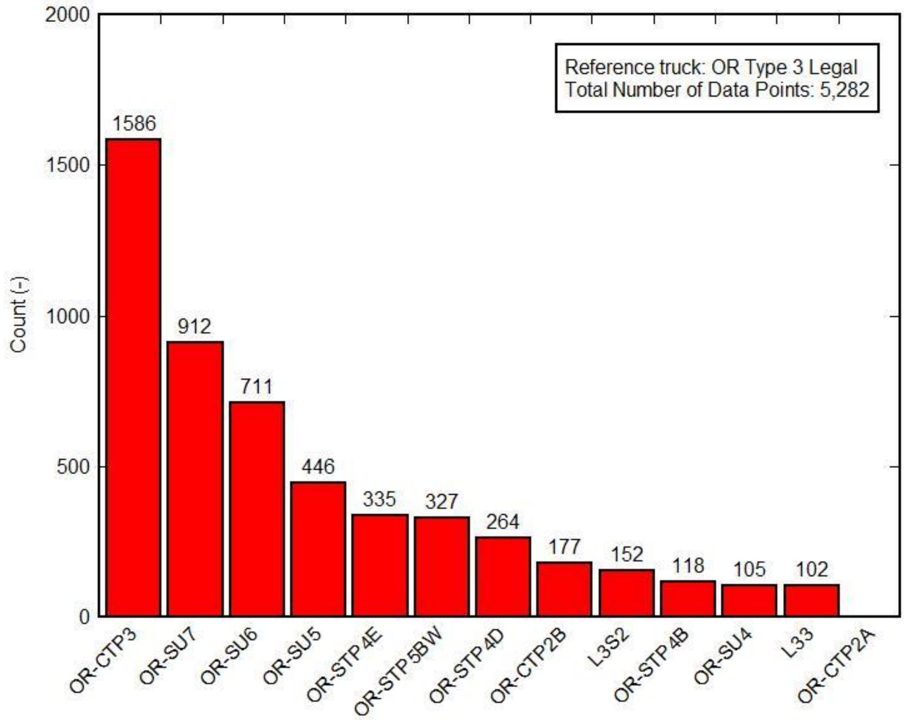

Figure 3-6: Histogram of maximum positive bending by truck type (the 95th percentile) normalized by OR Type 3 Legal Truck

The second approach (Equation 2) aimed to create ratios that show the amplification of each truck type by dividing the load effect of a platooned truck type (two or three-trucks and different head spacings) by the load effecting of a single truck of the same truck type. These ratios allowed us to assess the effect of live loading under specific truck conditions due to platooning. By applying these factors to individual bridge spans, we gained a more detailed understanding of the impact of platooning on bridge behavior for different truck types. These values were used in detail during the case study of a real-world bridge application.

$$Ratio = \frac{Internal\ Load\ of\ a\ Specific\ Truck\ Type}{Internal\ Load\ of\ a\ Single\ Truck\ for\ the\ Same\ Specific\ Truck\ Type} \qquad \textbf{[EQ 2]}$$

To identify the worst-case bridges, it was first determined which span the maximum loading, positive or negative moment or shear, was acting upon. This defined the span length for comparison. Then, the normalized ratio data for OR Type 3 Legal and OR Type 3S2 Legal were plotted for each bridge, truck and platoon combination based on the defined span length. The

Type OR CTP-3 truck at 10-foot head spacing was chosen as it was the worst overall truck type when looking at the histogram data above. Figures 4-7 through 4-9 show the resulting data for the ratios of the Type OR CTP-3 truck to the OR Type 3 Legal (L3) and the OR Type 3S2 Legal (L3S2) trucks comparing a single truck and a three-truck platoons at 10-foot head spacing.

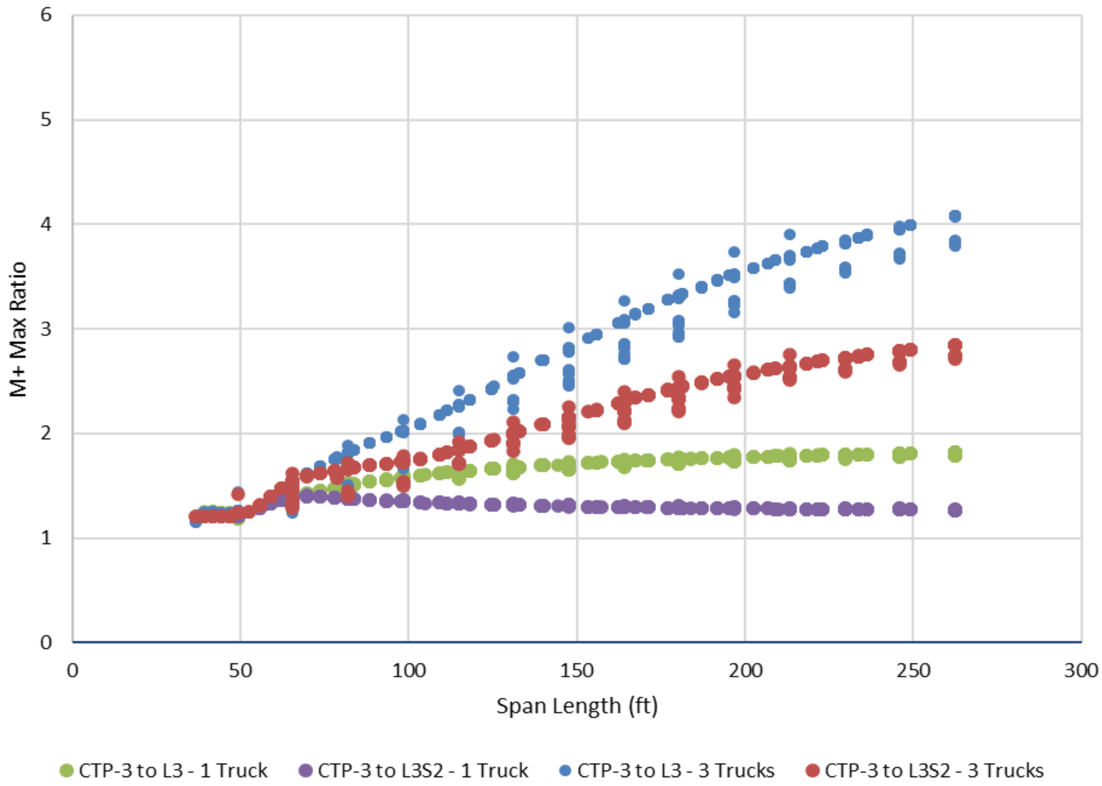

Figure 3-7: Maximum Positive Bending Moment to Span Length for the Type OR CTP-3 at 10-foot head spacing normalized by OR Type 3 Legal and OR Type 3S2 Legal

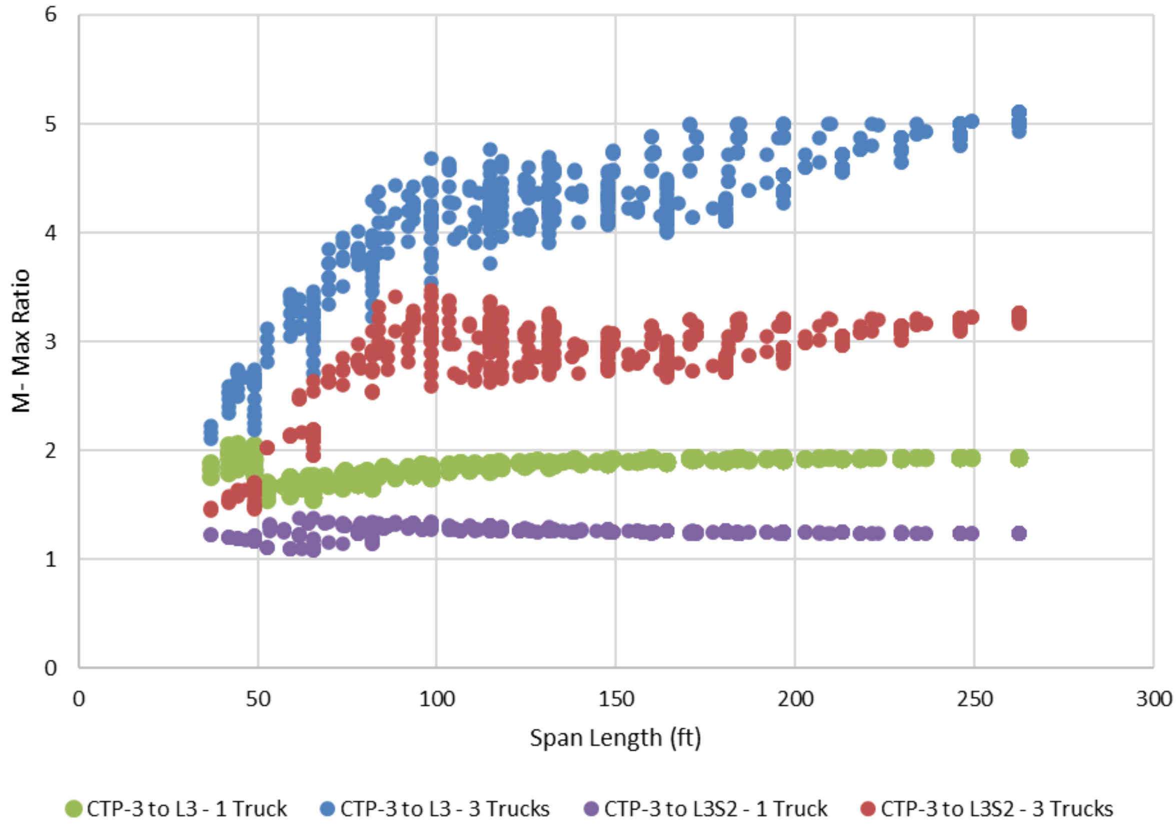

Figure 3-8: Maximum Negative Bending Moment to Span Length for the Type OR CTP-3 at 10-foot head spacing normalized by OR Type 3 Legal and OR Type 3S2 Legal

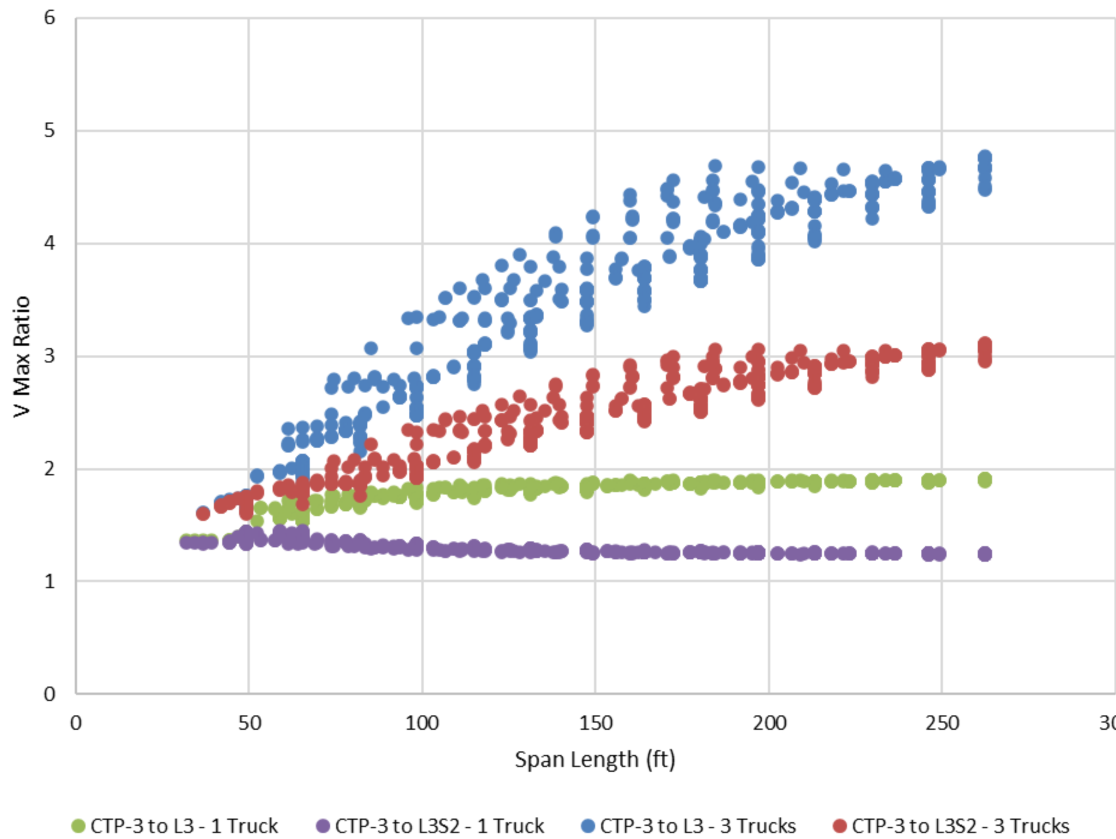

Figure 3-9: Maximum Shear to Span Length for the Type OR CTP-3 at 10-foot head spacing normalized by OR Type 3 Legal and OR Type 3S2 Legal

As evident from the graphs, longer span lengths tend to exhibit higher ratio values. This is present in the OR Type 3 Legal data for all three load outputs as well as the OR Type 3S2 Legal positive moment and shear ratios. However, as seen in the individual graph of the OR Type 3S2 Legal negative bending moment ratio Figure 4-8, some shorter span bridges resulted in a higher ratio. This is likely caused by the longer platoon lengths of the OR Type 3S2 Legal configurations as compared to some of the higher load, shorter length trucks. It would allow for more concentrated loads around the supports on short spans as compared to a longer truck on the same shorter span. Overall, the trend is for longer spans to have higher ratios. Therefore, the longest span bridges, the single span of 213 feet and the three-span bridges with two spans of length 262 feet, seem to be the worst bridges and the longest bridges analyzed.

Bridge number 11 of the single-span set (with a length of 213 feet) and bridge number 708 of the three-span set (with two spans having lengths of 262 feet) ended up being the worst-case bridges.

However, in the multi-span analysis, the worst-case bridges were all of the same subset with the first two spans having a length 262 feet (bridge numbers 702-709) and were all within 0.1% of bridge number 708’s total load effect.

In summary, both approaches provided valuable insights into the behavior of bridges under different loading scenarios, contributing to a comprehensive understanding of the bridge's structural response to varying truck types and platooning effects. The analysis highlighted that the Type OR CTP-3 and OR SU7 truck resulted in the highest load effect ratios. Additionally, when considering individual bridge spans, the longest bridge spans (262 feet), such as the 708-bridge exhibited highest load effect ratios.

3.2.2 The Effect of Specific Trucks by Span Length

To assess the influence of specific trucks on the load effects for different span lengths, HL-93 and all Type STP types were excluded from the dataset. However, single, one-truck types were left in to have available references for these truck types. The analysis was conducted considering the maxima of the entire bridge.

Based on insights from the overall worst-case analysis, the specific truck configurations that received further examination were Type OR CTP-3 (Figure 4-10), the OR Type 3 Legal (Figure 4-11), and OR SU7 (Figure 4-12). When comparing the Type OR CTP-3 to the OR Type 3 Legal truck configurations, intriguing patterns emerged. The graph for Type OR CTP-3 showed a relatively clustered behavior at around 100 and 120-foot span lengths. In contrast, OR Type 3 Legal at a 100-foot span length exhibited the three-truck platoon with 10-foot head spacing already reaching twice the baseline moment, accelerating more rapidly under load compared to Type OR CTP-3. Even at a 60-foot head spacing, Type OR CTP-3 remained close to the baseline up to 150 feet, while OR Type 3 Legal had already diverged from the baseline by the same point.

This observation emphasizes the significance of considering the specific truck type when designing for live load conditions. The span length does play a role, but it may vary in impact for different truck types. There isn't a one-size-fits-all cutoff point where platooning becomes a concern. The truck type's ratio is closely tied to the load rating factor analysis, indicating that the worst case for a bridge at a specific loading may not necessarily apply to all platooning scenarios. The platooning ratio from one-truck type may significantly differ from another, and the internal forces may be influenced accordingly.

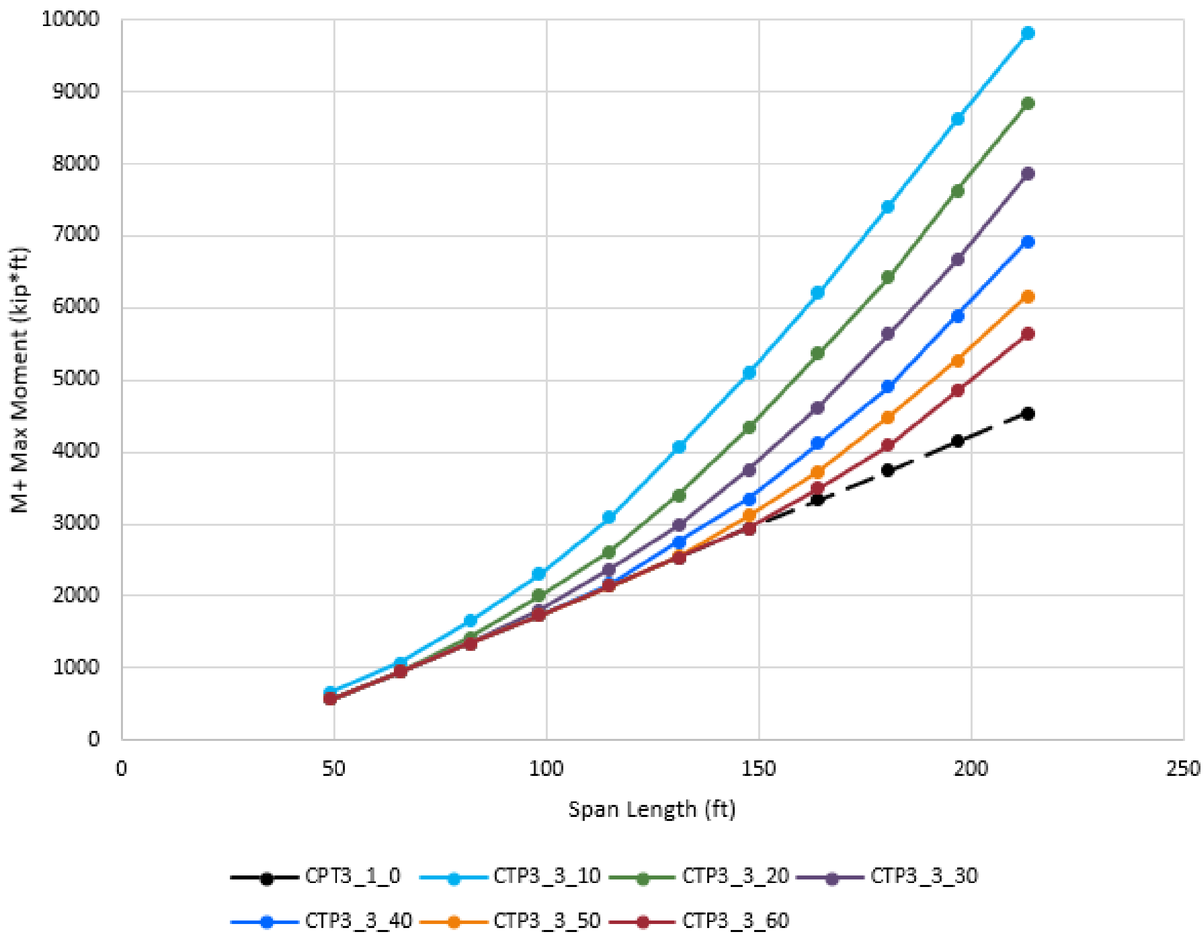

Figure 3-10: Type OR CTP-3 by Span Length

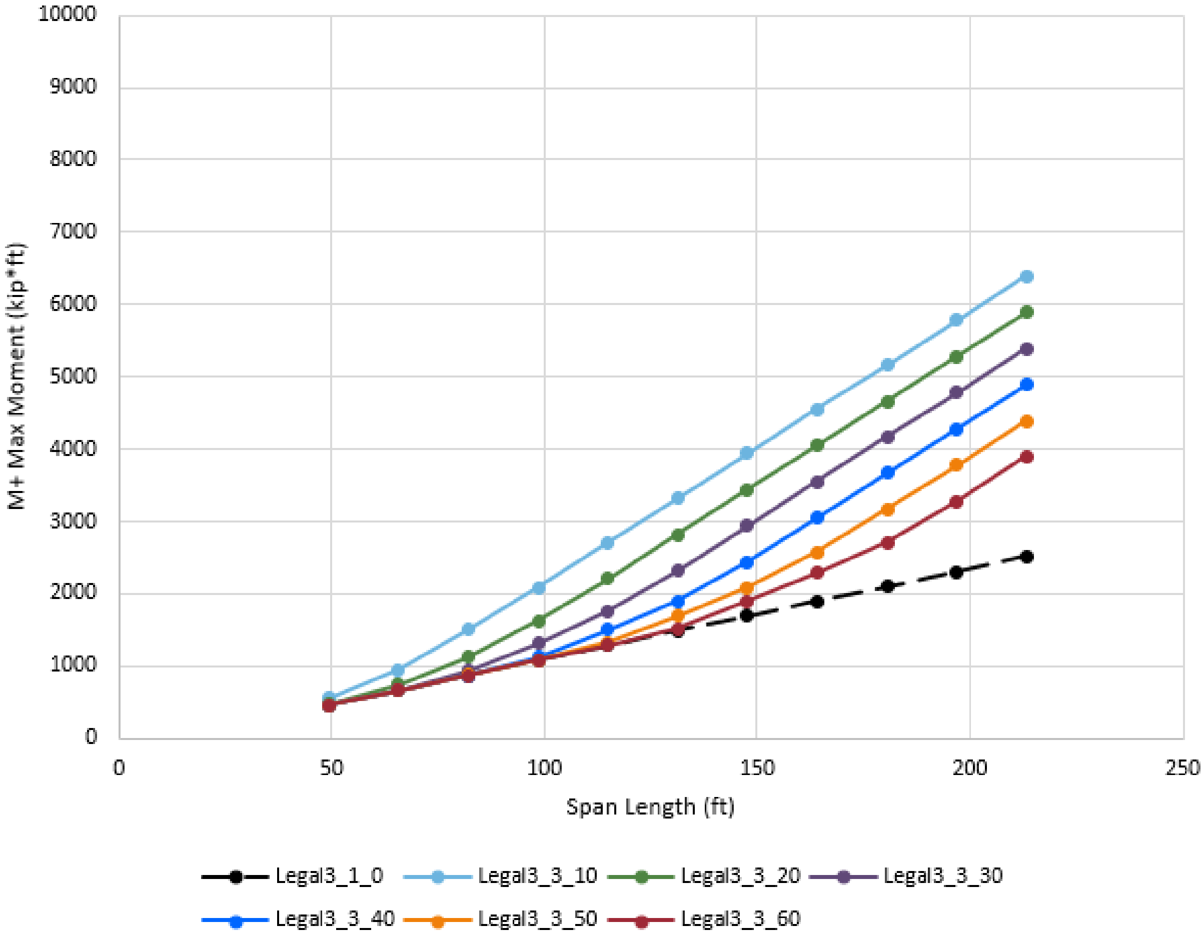

Figure 3-11: Type OR Type 3 Legal by Span Length

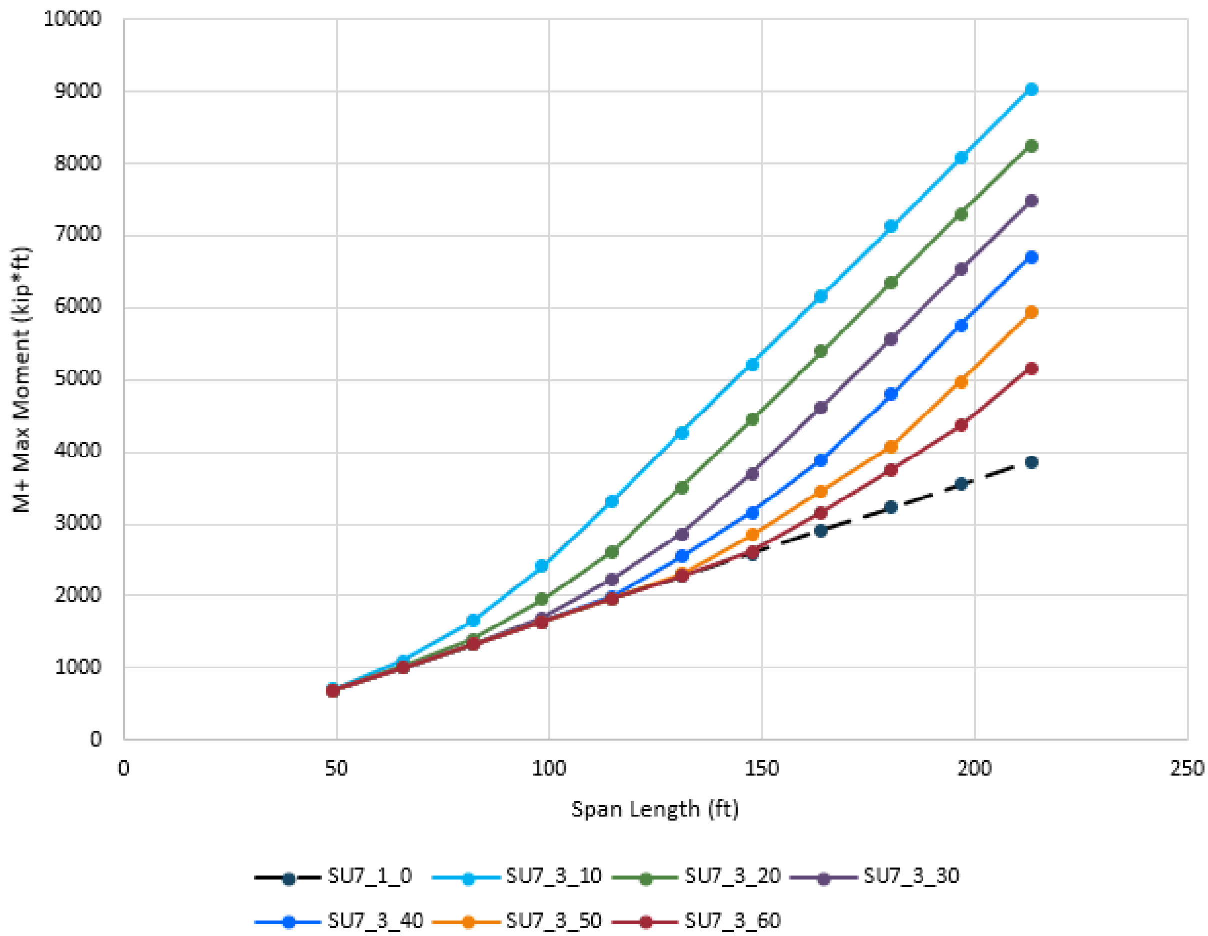

Figure 3-12: Type OR SU7 by Span Length

3.2.3 The Effect of Head Spacing

To maintain consistency, our analysis continued to focus on Type OR CTP-3, OR Type 3 Legal, OR Type 3S2 Legal, and OR SU7 trucks, exploring the impacts of two-truck and three-truck platooning scenarios based on head spacing. The average values of positive moment, negative moment, and shear across all bridges were calculated to compare with the maximum values and identify any potential outliers.

The ratio of one-truck to multiple truck platoons in the averages revealed interesting trends. OR Type 3 Legal exhibited the highest ratio, while Legal Type 3S2 had the lowest, except in the case of shear, where surprisingly Type OR CTP-3 at three-trucks showed the lowest ratio for truck platooning. This observation hinted at the normalization effect, highlighting the difference between the ratios that were normalized compared to the ratio of platooned truck types.

The analysis of average graphs revealed a significant difference between two-truck and three-truck platooning scenarios, Figure 3-13. Three-truck platoons demonstrated a more rapid decrease in average maximum moment compared to two-truck platoons, particularly evident in the positive moment graph, where the slopes of the two versions of the same truck type showed a distinct contrast.

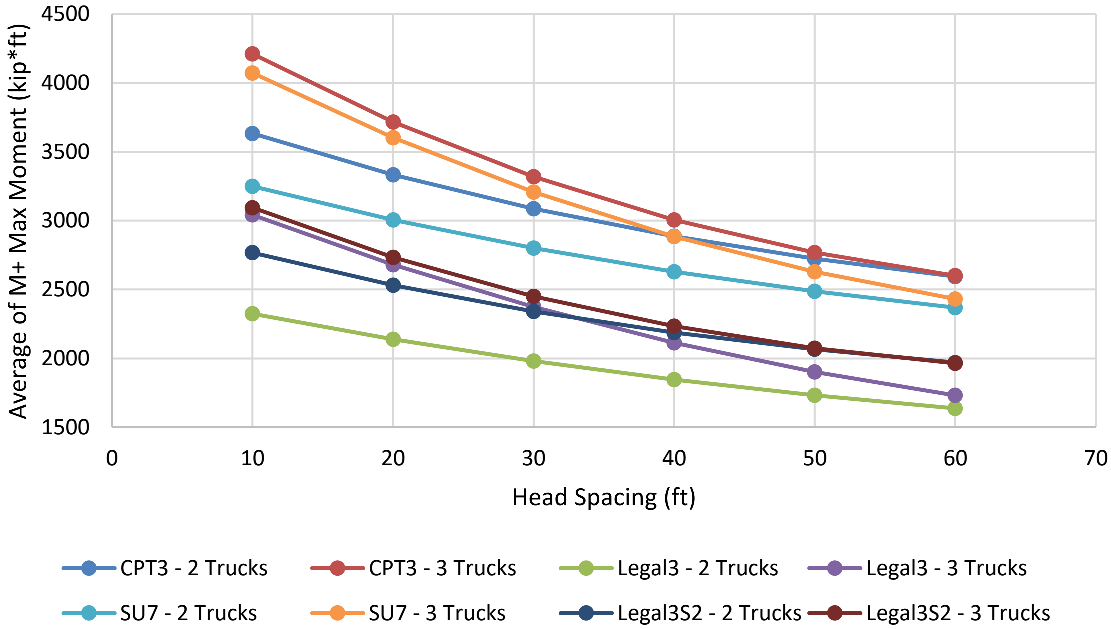

Figure 3-13: Effect of Head Spacing on Average Max Positive Moment of Two versus Three-Truck Platoons

The examination of maximum loading figures further supported the significance of head spacing in three-truck platooning scenarios, Figure 3-14. As the space between the three-trucks increased, the difference in distance of the load from the front truck to the rear truck grew more quickly, leading to a more rapid decrease in the maximum values. In contrast, for two-truck platoons, the effect of head spacing on the overall load spacing was less pronounced.

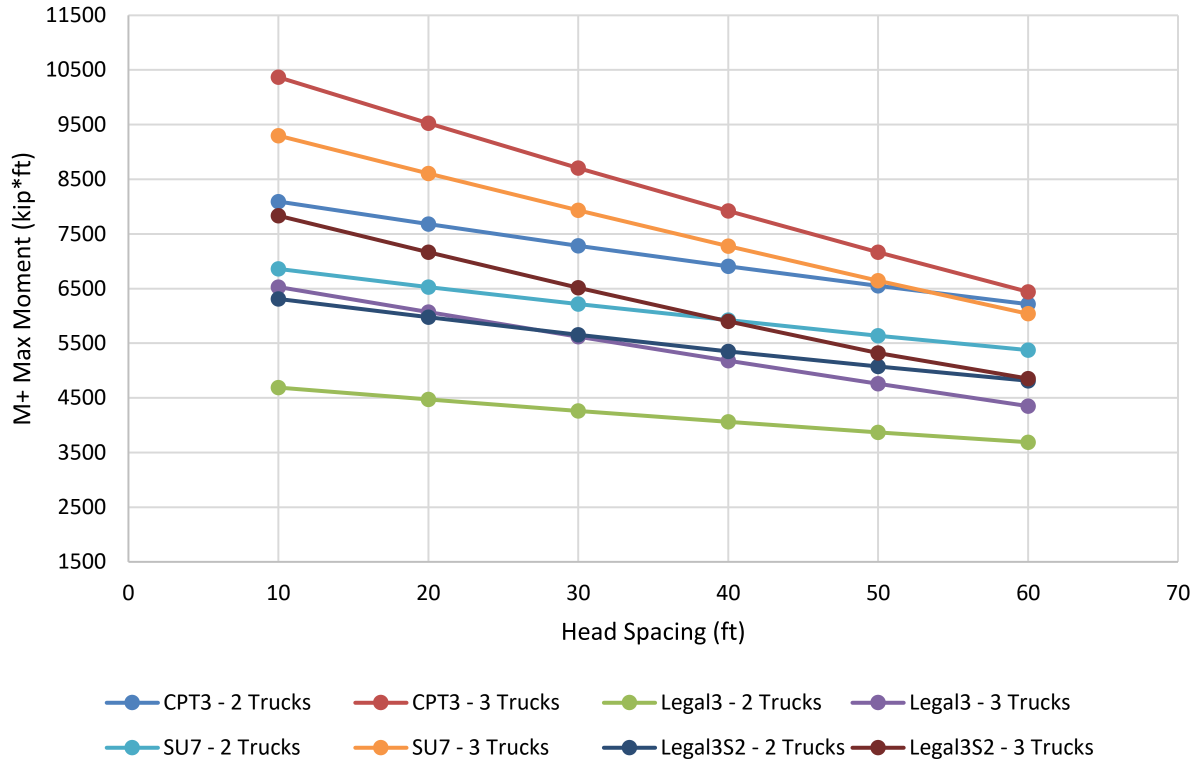

Figure 3-14: Effect of Head Spacing on Max Positive Moment of Two versus Three-Truck Platoons

Additional figures looking at the effect of head spacing for averages, maximums, and truck platooning ratios for positive and negative moments and shear can be found in Appendix B, Figures B61 – B70.

Focusing on bridge 708, one of the worst case three span bridges with span lengths 262 feet, 262 feet, and 184 feet, respectively, a targeted study was conducted looking at head spacing across truck types while excluding data from all other bridges. Analyzing this isolated case reaffirmed the trends observed in the average and maximum graphs, lending further support to the significance of head spacing in determining bridge behavior under platooning scenarios (Figures 3-15 to 3-17).

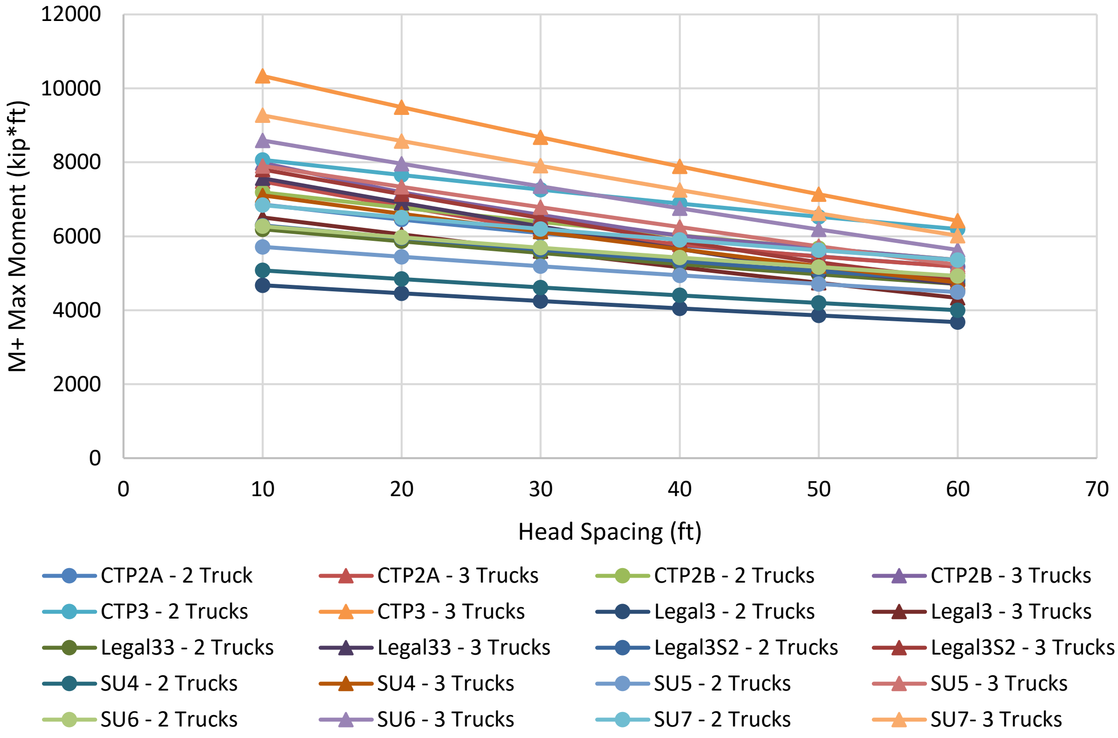

Figure 3-15: Effect of Head on Bridge 708 for the Max Positive Moment

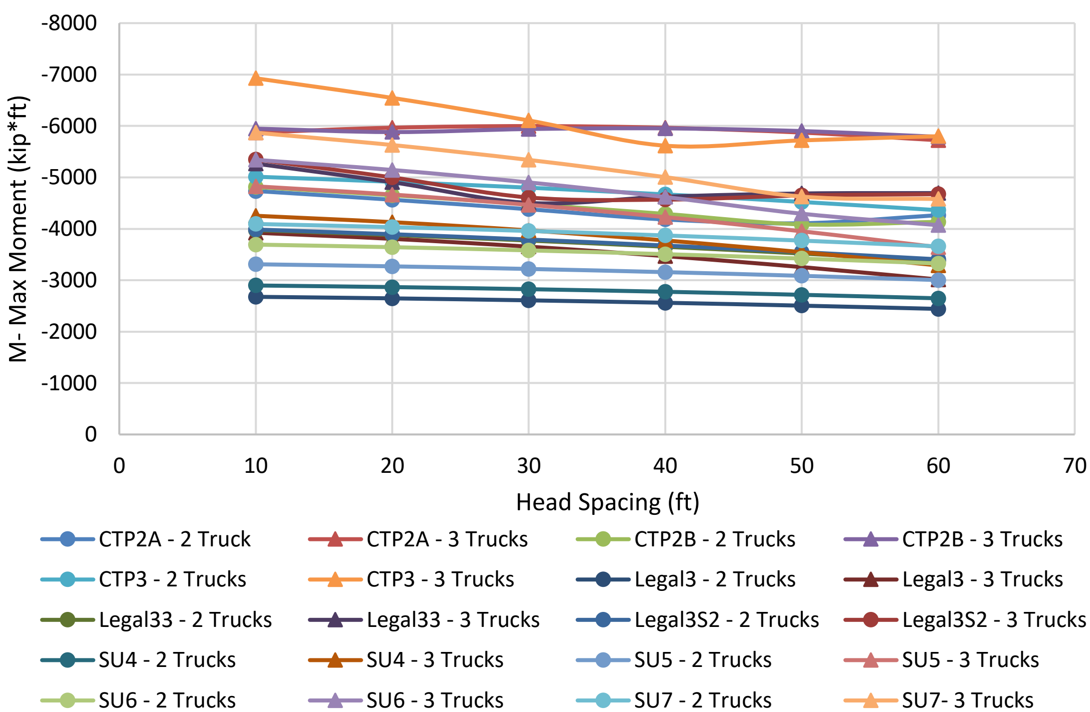

Figure 3-16: Effect of Head on Bridge 708 for the Max Negative Moment

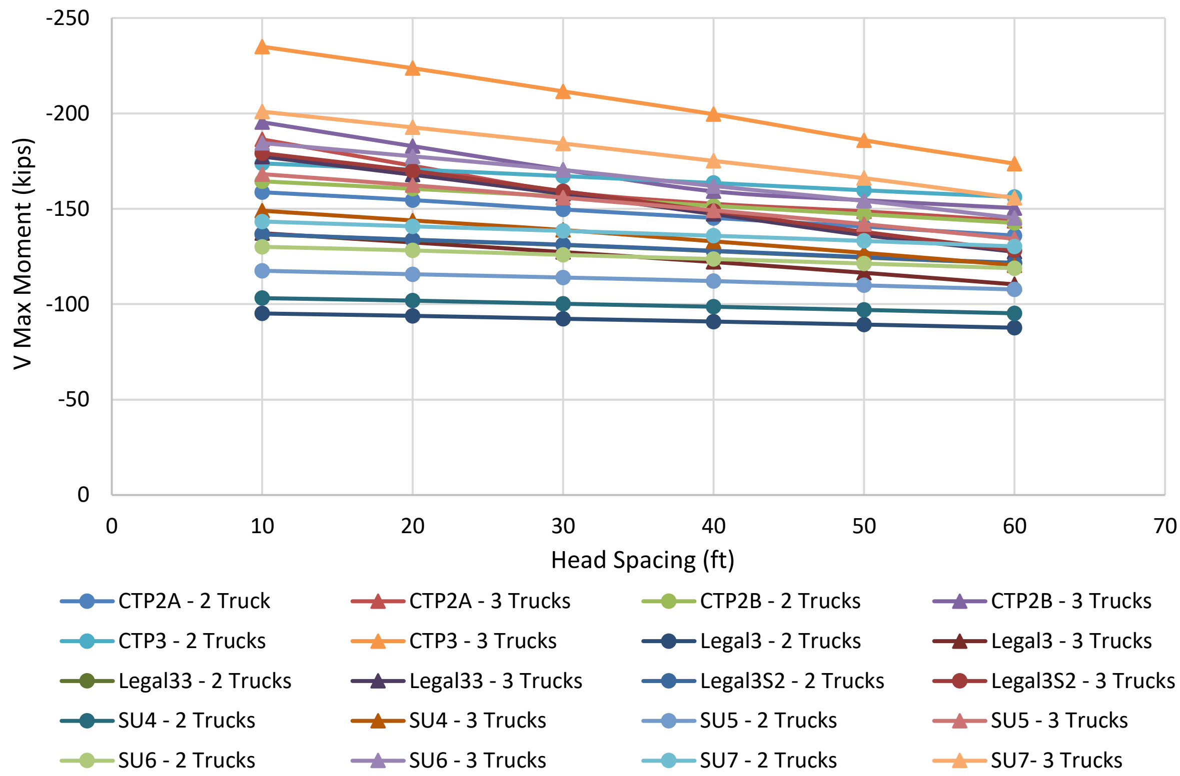

Figure 3-17: Effect of Head on Bridge 708 for the Max Shear

Removing data from all bridges to focus solely on this single bridge, we cleaned up the graphs to highlight Type OR CTP-3, OR Type 3 Legal, OR Type 3S2 Legal, and OR SU7. The patterns observed in the average and maximum graphs remained consistent, even in this isolated case (Figures 4-18 to 4-20).

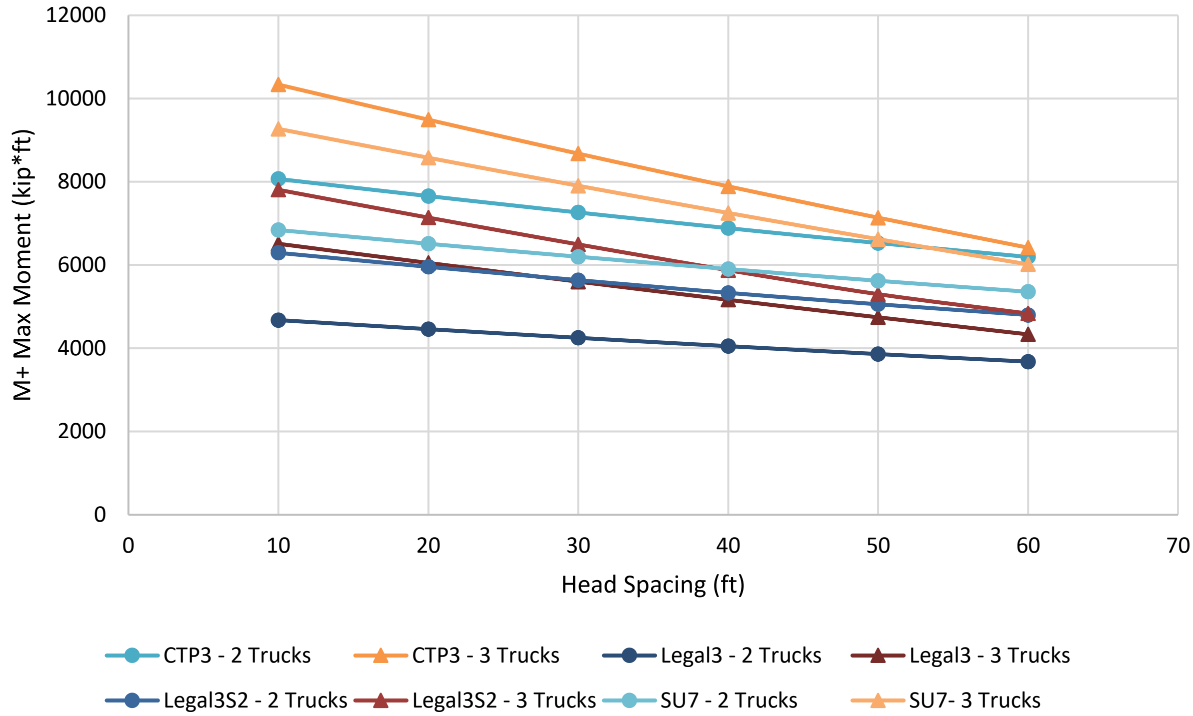

Figure 3-18: Effect of Head on Bridge 708 for the Max Positive Moment - Isolating Specific Truck Types

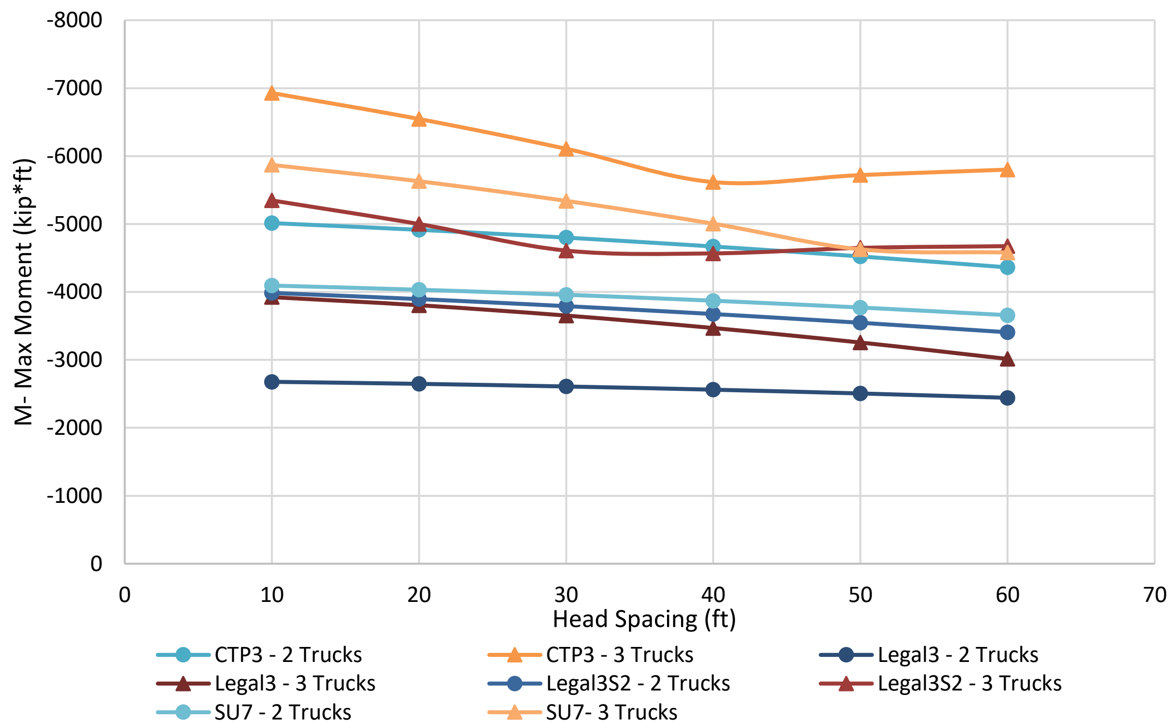

Figure 3-19: Effect of Head on Bridge 708 for the Max Negative Moment – Isolating Specific Truck Types

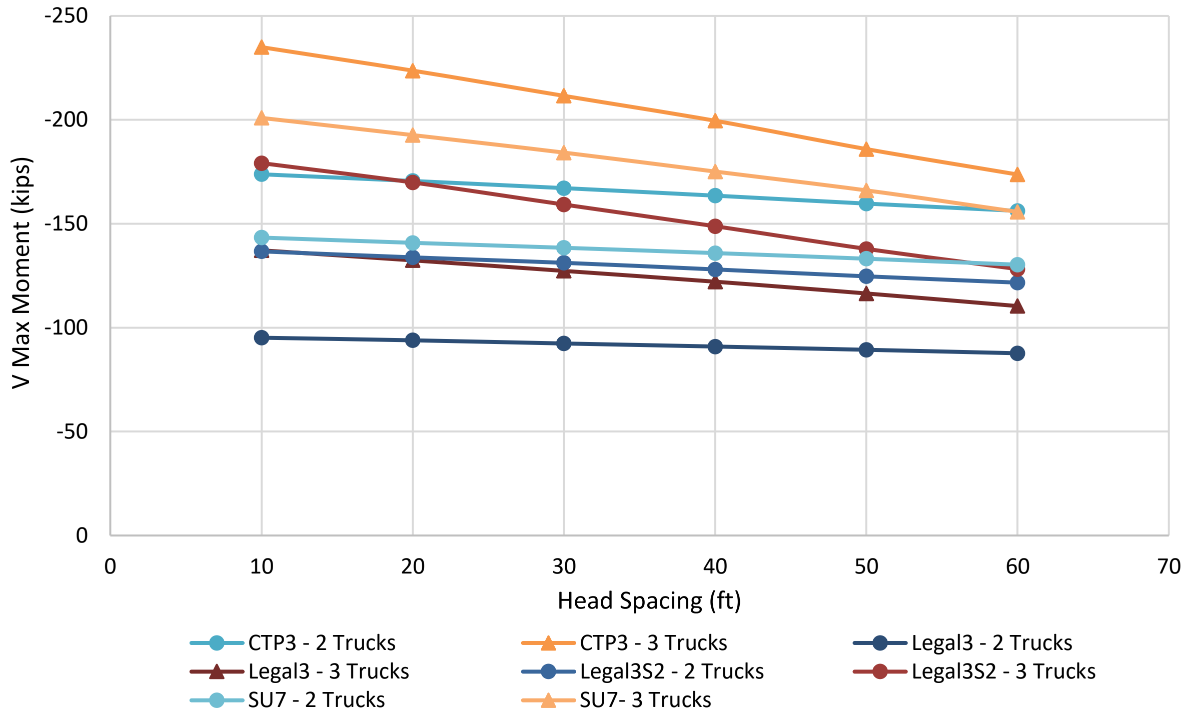

Figure 3-20: Effect of Head on Bridge 708 for the Max Shear Moment - Isolating Specific Truck Types

It is worth noting that the dip in the negative moment graphs, Figure 4-19, can likely be attributed to the size of the three-span bridge and the increasing head spacing. The distributed load of the three-trucks contributes to an increasing negative moment due to their specific locations on the bridge. This effect could be influenced by the length of the trucks, as evident in OR Type 3 Legal three-truck platoon, being one of the shortest trucks, which does not show the dip. Conversely, the OR Type 3S2 Legal trucks, being one of the longest, shows a dip starting at the 30-foot head spacing. These findings underscore the importance of head spacing and its interaction with truck types in understanding load effects under platooning scenarios.

3.3 Case Study: Real World Bridge Application – Rating Factor Analysis

To understand how platooning could affect the rating factor of a bridge that is in service, the live load ratios obtained from the platooning database were applied to the LRFR Strength Equation for the rating factor (Equation 1), where Capacity, Dead Load Effect, and Live Load Effect are internal forces, i.e., bending moment or shear force, evaluated at a specific location along the length of the bridge. Bridge 20026, a real-world bridge in Oregon, was specifically chosen. Bridge 20026 is a prestressed Bulb-T girder bridge comprising of two spans. The elevation view and the two spans are depicted in Figure 3-21, where the first span measures 91 feet 10 inches, while the second span is 142 feet 9 inches in length.

$$RF = \frac{\overbrace{\varphi_C \varphi_S \varphi \, (R_n)}^{\text{Capacity}} - \overbrace{(\gamma_{DC})(DC) - (\gamma_{DW})\,(DW)}^{\text{Dead Load Effect}}}{\underbrace{(\gamma_L)(LL+IM)}_{\text{Live Load Effect}}} \qquad \textbf{[EQ 1]}$$

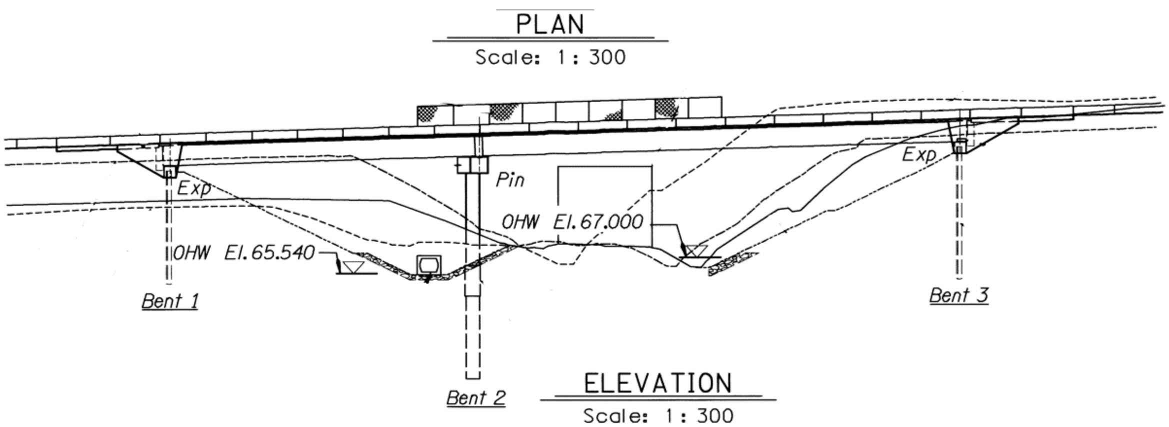

Figure 3-21: Elevation View of Bridge 2026

By utilizing the "Bridge Section Tier 2 Load Rating Summary Report" from ODOT (Appendix B, Figure B71) to calculate capacity and employing the "Wyoming Department of Transportation System Rating and Analysis of Structural Systems" (BRASS) files for Bridge 20026 to calculate the dead and live loads, the current rating factor was determined using the LRFR Strength Equation, equation 1. This calculation was verified against the "Bridge Section Tier 2 Load Rating Summary Report".

To calculate an updated rating factor, a similar bridge needed to be selected from the established database. Upon comparing the span lengths of Bridge 20026 with the platooning database, Bridge 35 was found to be the closest match. The first span of Bridge 35 measured 131 feet, while the second spanned a length of 98 feet.

Next, ratios were derived from one-truck versus two and three-trucks, considering different head spacings ranging from 10 to 60 feet. These ratios were calculated for various truck types, including OR Type 3 Legal, OR Type 3S2 Legal, Type 3-3 Legal, OR SU4, OR SU5, OR SU6, OR SU7, Type OR CTP-2A, Type OR CTP-2B, and Type OR CTP-3. However, in this case, the ratios were not obtained from the maximum positive moment for the entire bridge. Instead, they were based on the maximum positive moment per span length that corresponded to the span length of Bridge 20026. This adjustment was necessary because the live load rating created moments that were controlled by different spans for Type OR CTP-2A and Type OR CTP-2B. The new rating factors were then calculated by applying the above ratios to the live load in equation 1. The adjusted rating factors were then plotted per head spacing and can be seen in Figures 3-22 and 3-23.

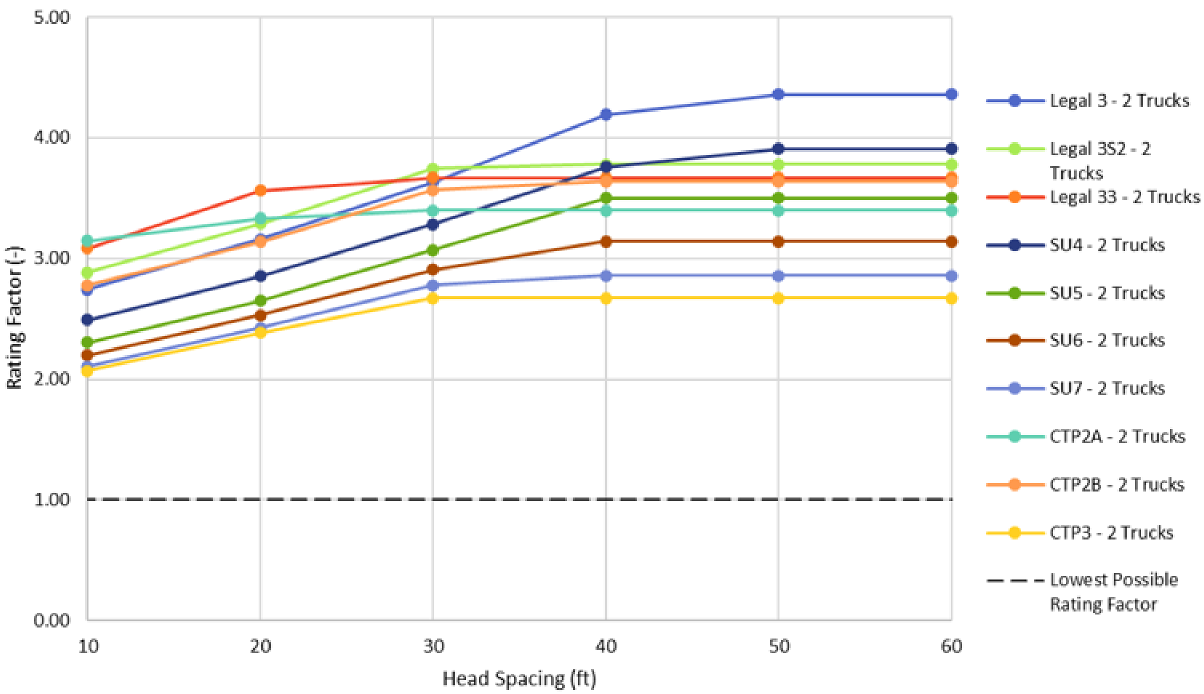

Figure 3-22: Rating Factor versus Head Spacing for Two-Truck Platoons

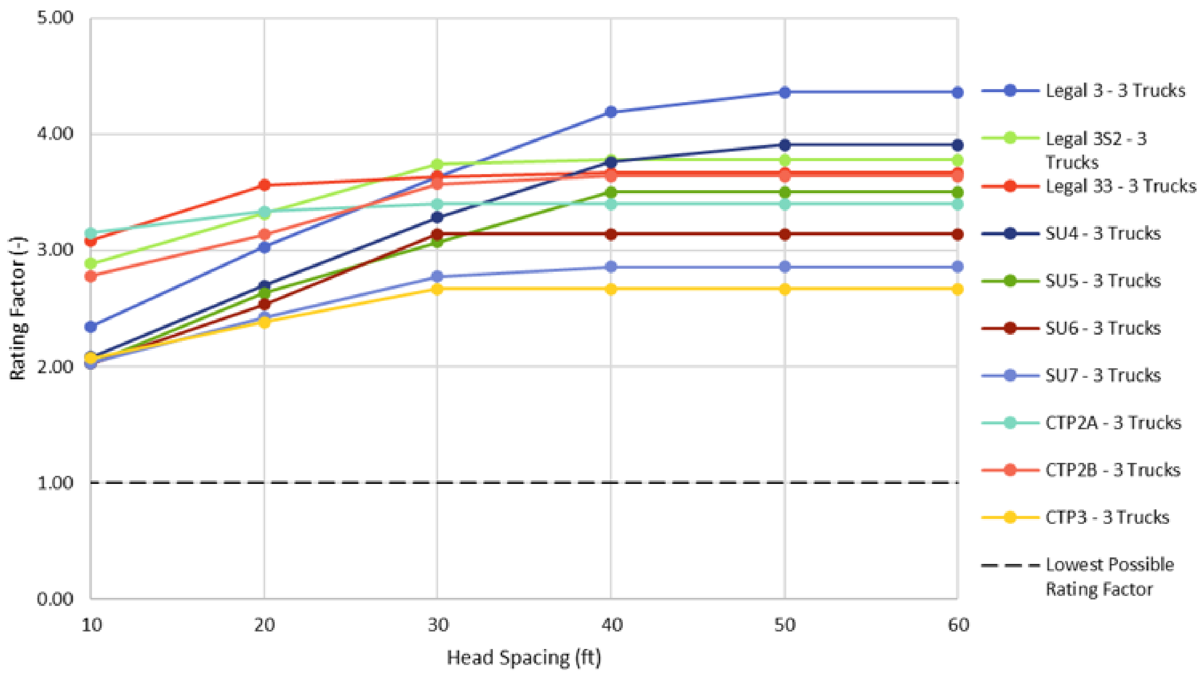

Figure 3-23: Rating Factor versus Head Spacing for Three-Truck Platoons

In the study conducted, it was observed that truck platooning consistently resulted in a decrease in the rating factor across all cases. Specifically for the bridge under consideration, the rating value never dropped below 2.0. By referring to Figures 3-22 and 3-23, it becomes evident that once the trucks are spaced at least 50 feet apart, the rating factor remains relatively flat and head spacing does not significantly influence the rating factor in most scenarios. This trend holds true for both two-truck and three-truck platoons. Individual truck types and their rating factors are available in Appendix B, Figures B72-B81.

4.0 SUMMARY AND CONCLUSIONS

In conclusion, the emerging technology of truck platooning holds immense potential for revolutionizing the transportation industry by enhancing fuel efficiency, traffic safety, and traffic flow in long-haul trucking. The implementation of automated driving technologies to facilitate truck platooning brings forth the prospect of optimized traffic management and improved driver comfort during extended journeys.

In the context of Oregon's transportation network, recent legislative changes, such as House Bill 4059, Section 40, have effectively permitted truck platooning by waiving headspace requirements for vehicles equipped with "connected automated braking systems." While this presents new opportunities for efficient freight transportation, the distinct behaviors of different truck types within platoons can significantly impact internal forces.

The research findings underscore that specific conditions can lead to notably higher internal load effects when they are normalized. This highlights potential concerns regarding the integrity and safety of bridges, particularly in cases involving the use of Type OR CTP-3 and OR SU7 truck platoons, which have emerged as the predominant truck types associated with the highest frequency of elevated ratios. Additionally, bridges featuring certain configurations, such as longer spans, may encounter significant challenges when subjected to truck platooning. This trend is evident in the analysis, where bridges with longer spans consistently exhibit the highest ratios. This pattern is particularly evident in the multi-span analysis, where a subset of bridges with the first two spans measuring 262 feet in length (bridge numbers 702-709) represents the worst-case scenario. Interestingly, the individual graph depicting the OR Type 3S2 Legal negative bending moment ratio in Figure 4-8 reveals that some shorter span bridges also exhibit elevated ratios. This phenomenon can likely be attributed to the longer platoon lengths of the OR Type 3S2 Legal configurations when compared to certain higher load and shorter length trucks. It is worth noting that the introduction of truck platooning poses a potential risk of structural inadequacy for bridges with lower rating factors. These factors are often influenced by economic considerations, including cost, materials, and maintenance.

As further exploration and analysis are essential for a comprehensive understanding of the intricate interactions between truck platooning and bridge performance, ongoing research should address scenarios involving truck platoons at tight spacing (less than 30 feet) of more than three trucks of Type OR CTP-3 and OR SU7 and analyze bridge spans exceeding lengths of 262 feet if applicable. This endeavor will facilitate informed policy recommendations and load rating updates that ensure the safe and sustainable integration of truck platooning within Oregon's existing transportation infrastructure. In navigating the evolving landscape of transportation technologies, it is imperative to strike a balance between innovation and structural safety to foster a resilient and efficient future for freight movement.

5.0 REFERENCES

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APPENDIX A

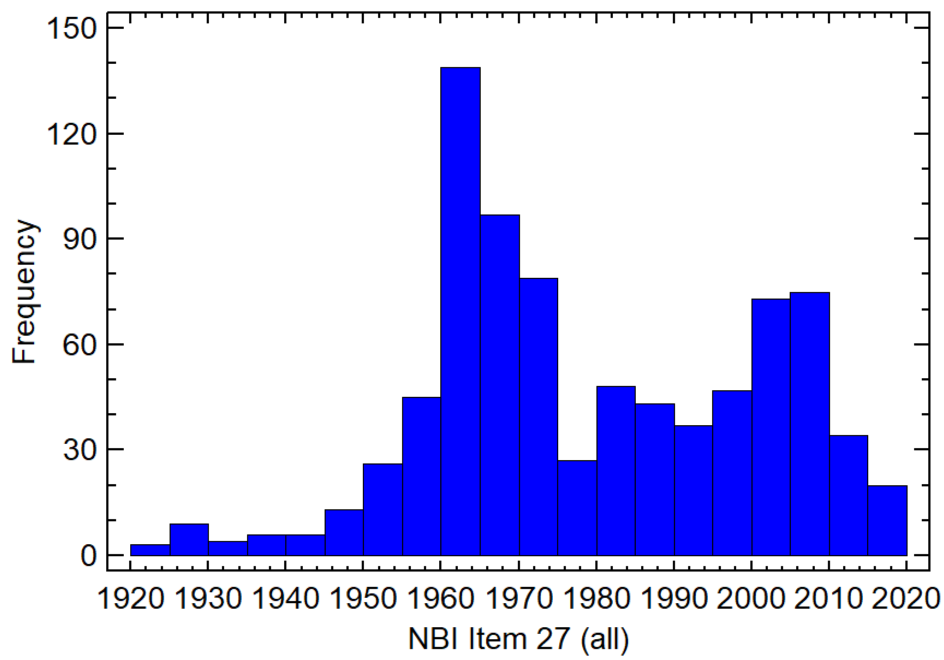


Figure A1. Histogram of NBI Item 27: Year built (yr).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	1920		1	0.0012	1	0.0012
1	1920	1925.0	1922.5	3	0.0036	4	0.0048
2	1925	1930.0	1927.5	9	0.0108	13	0.0156
3	1930	1935.0	1932.5	4	0.0048	17	0.0204
4	1935	1940.0	1937.5	6	0.0072	23	0.0276
5	1940	1945.0	1942.5	6	0.0072	29	0.0349
6	1945	1950.0	1947.5	13	0.0156	42	0.0505
7	1950	1955.0	1952.5	26	0.0313	68	0.0817
8	1955	1960.0	1957.5	45	0.0541	113	0.1358
9	1960	1965.0	1962.5	139	0.1671	252	0.3029
10	1965	1970.0	1967.5	97	0.1166	349	0.4195
11	1970	1975.0	1972.5	79	0.0950	428	0.5144
12	1975	1980.0	1977.5	27	0.0325	455	0.5469
13	1980	1985.0	1982.5	48	0.0577	503	0.6046
14	1985	1990.0	1987.5	43	0.0517	546	0.6563
15	1990	1995.0	1992.5	37	0.0445	583	0.7007
16	1995	2000.0	1997.5	47	0.0565	630	0.7572
17	2000	2005.0	2002.5	73	0.0877	703	0.8450
18	2005	2010.0	2007.5	75	0.0901	778	0.9351
19	2010	2015.0	2012.5	34	0.0409	812	0.9760
20	2015	2020.0	2017.5	20	0.0240	832	1.0000
	above	2020		0	0.0000	832	1.0000

Mean = 1979.86 Standard deviation = 20.9768

	Percentiles
10.0%	1958.0
20.0%	1963.0
30.0%	1965.0
40.0%	1970.0
50.0%	1974.0
60.0%	1985.0
70.0%	1995.0
80.0%	2003.0
90.0%	2008.0

Figure A2. Frequencies (left) and percentiles (right) of NBI Item 27: Year built (yr).

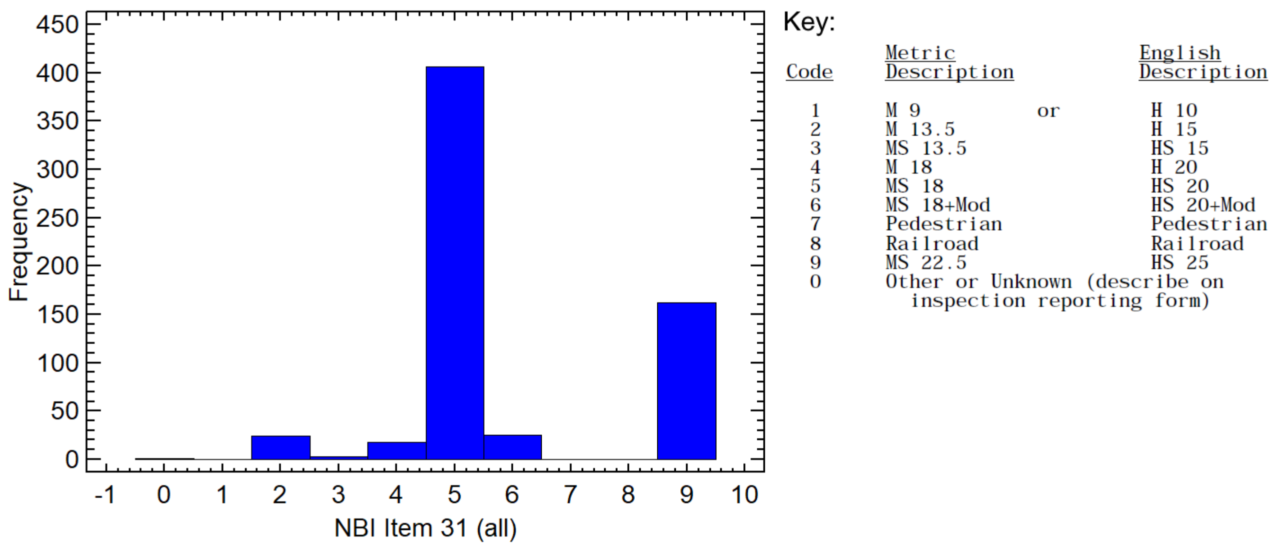


Figure A3. Histogram of NBI Item 31: Design load (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	1	0.0016	1	0.0016
2	0.5	1.5	1.0	0	0.0000	1	0.0016
3	1.5	2.5	2.0	24	0.0376	25	0.0391
4	2.5	3.5	3.0	3	0.0047	28	0.0438
5	3.5	4.5	4.0	18	0.0282	46	0.0720
6	4.5	5.5	5.0	406	0.6354	452	0.7074
7	5.5	6.5	6.0	25	0.0391	477	0.7465
8	6.5	7.5	7.0	0	0.0000	477	0.7465
9	7.5	8.5	8.0	0	0.0000	477	0.7465
10	8.5	9.5	9.0	162	0.2535	639	1.0000
	above	9.5		0	0.0000	639	1.0000

Figure A4. Frequencies of NBI Item 31: Design load (-).

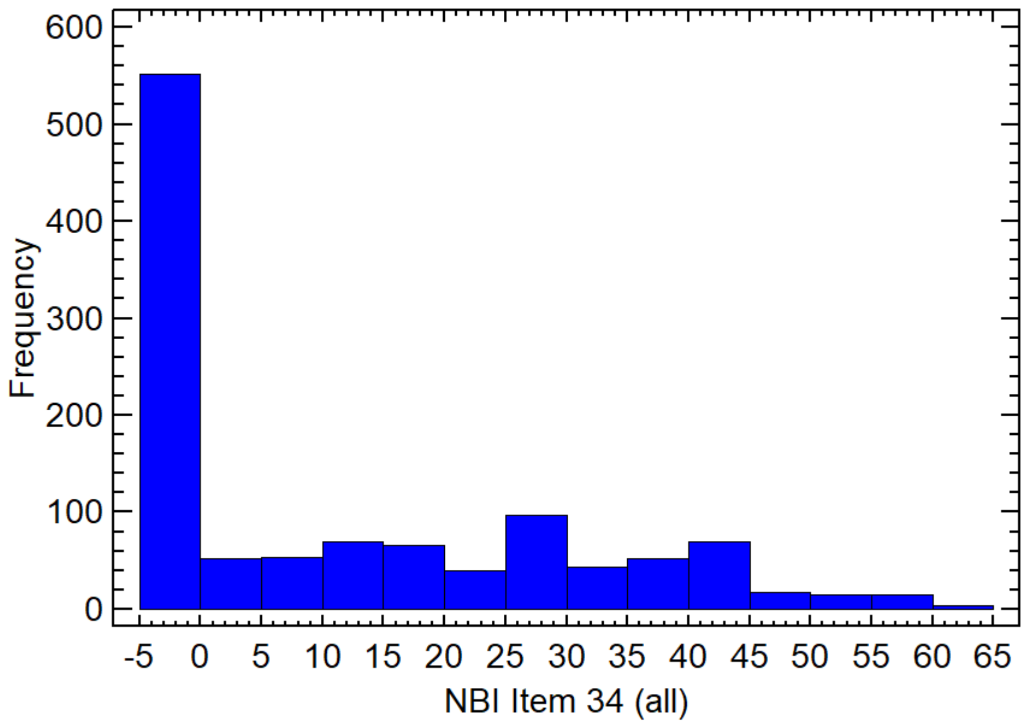


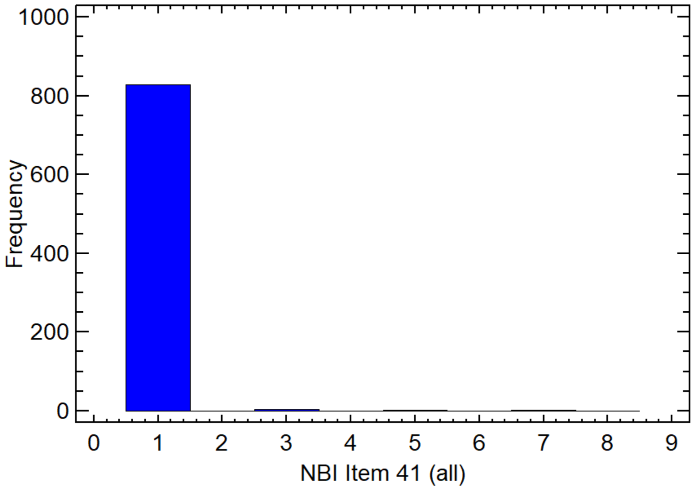
Figure A5. Histogram of NBI Item 34: Skew (Degrees).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-4		0	0.0000	0	0.0000
1	-4	0	-2.5	552	0.4698	552	0.4698
2	0	5.0	2.5	52	0.0443	604	0.5140
3	5	10.0	7.5	53	0.0451	657	0.5591
4	10	15.0	12.5	69	0.0587	726	0.6179
5	15	20.0	17.5	66	0.0562	792	0.6740
6	20	25.0	22.5	40	0.0340	832	0.7081
7	25	30.0	27.5	97	0.0826	929	0.7906
8	30	35.0	32.5	43	0.0366	972	0.8272
9	35	40.0	37.5	52	0.0443	1024	0.8715
10	40	45.0	42.5	69	0.0587	1093	0.9302
11	45	50.0	47.5	17	0.0145	1110	0.9447
12	50	55.0	52.5	15	0.0128	1125	0.9574
13	55	60.0	57.5	15	0.0128	1140	0.9702
14	60	65.0	62.5	4	0.0034	1144	0.9736
	above	65		31	0.0264	1175	1.0000

Mean = 15.9055 Standard deviation = 21.532

	Percentiles
10.0%	0
20.0%	0
30.0%	0
40.0%	0
50.0%	4.0
60.0%	14.0
70.0%	25.0
80.0%	33.0
90.0%	45.0

Figure A6. Frequencies (left) and percentiles (right) of NBI Item 34: Skew (Degrees).



Key:

Code	Description
A = 1	Open, no restriction
B = 2	Open, posting recommended but not legally implemented (all signs not in place or not correctly implemented)
D = 3	Open, would be posted or closed except for temporary shoring, etc. to allow for unrestricted traffic
E = 4	Open, temporary structure in place to carry legal loads while original structure is closed and awaiting replacement or rehabilitation
G = 5	New structure not yet open to traffic
K = 6	Bridge closed to all traffic
P = 7	Posted for load (may include other restrictions such as temporary bridges which are load posted)
R = 8	Posted for other load-capacity restriction (speed, number of vehicles on bridge, etc.)

Figure A7. Histogram of NBI Item 41: Structure open, posted, or closed to traffic (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	0	0.0000	0	0.0000
2	0.5	1.5	1.0	829	0.9940	829	0.9940
3	1.5	2.5	2.0	0	0.0000	829	0.9940
4	2.5	3.5	3.0	3	0.0036	832	0.9976
5	3.5	4.5	4.0	0	0.0000	832	0.9976
6	4.5	5.5	5.0	1	0.0012	833	0.9988
7	5.5	6.5	6.0	0	0.0000	833	0.9988
8	6.5	7.5	7.0	1	0.0012	834	1.0000
9	7.5	8.5	8.0	0	0.0000	834	1.0000
	above	8.5		0	0.0000	834	1.0000

Figure A8. Frequencies of NBI Item 41: Structure open, posted, or closed to traffic (-).

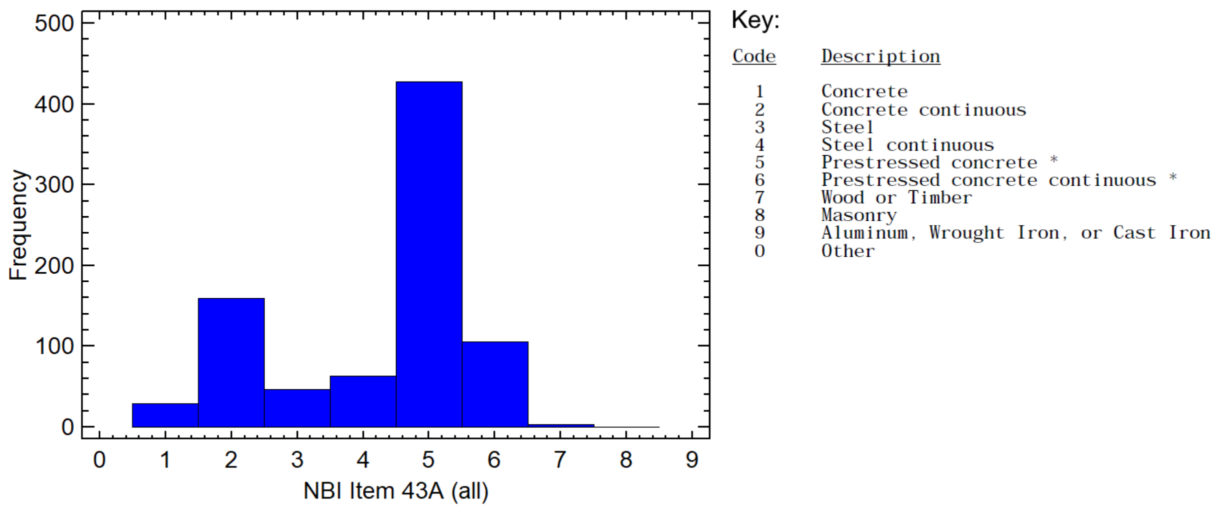
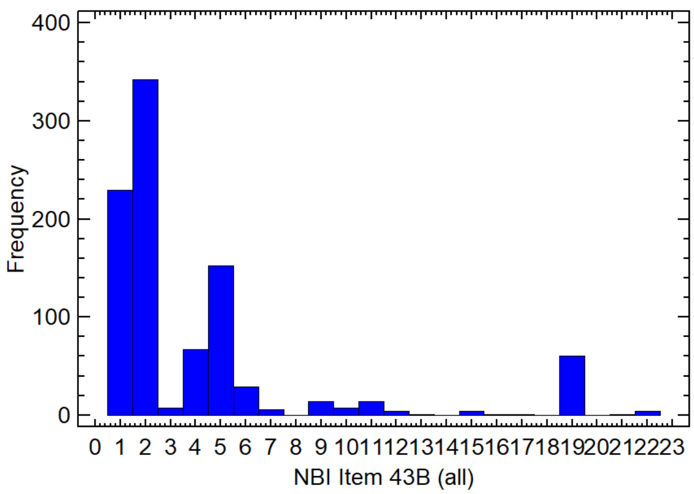


Figure A9. Histogram of NBI Item 43A: Kind of material and/or design (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	0	0.0000	0	0.0000
2	0.5	1.5	1.0	29	0.0347	29	0.0347
3	1.5	2.5	2.0	159	0.1904	188	0.2251
4	2.5	3.5	3.0	47	0.0563	235	0.2814
5	3.5	4.5	4.0	63	0.0754	298	0.3569
6	4.5	5.5	5.0	428	0.5126	726	0.8695
7	5.5	6.5	6.0	106	0.1269	832	0.9964
8	6.5	7.5	7.0	3	0.0036	835	1.0000
9	7.5	8.5	8.0	0	0.0000	835	1.0000
	above	8.5		0	0.0000	835	1.0000

Figure A10. Frequencies of NBI Item 43A: Kind of material and/or design* (-).



Key:

Code	Description
01	Slab
02	Stringer/Multi-beam or Girder
03	Girder and Floorbeam System
04	Tee Beam
05	Box Beam or Girders - Multiple
06	Box Beam or Girders - Single or Spread
07	Frame (except frame culverts)
08	Orthotropic
09	Truss - Deck
10	Truss - Thru
11	Arch - Deck
12	Arch - Thru
13	Suspension
14	Stayed Girder
15	Movable - Lift
16	Movable - Bascule
17	Movable - Swing
18	Tunnel
19	Culvert (includes frame culverts)
20 *	Mixed types
21	Segmental Box Girder
22	Channel Beam
00	Other

Figure A11. Histogram of NBI Item 43B: Type of design and/or construction (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	0	0.0000	0	0.0000
2	0.5	1.5	1.0	229	0.2428	229	0.2428
3	1.5	2.5	2.0	342	0.3627	571	0.6055
4	2.5	3.5	3.0	7	0.0074	578	0.6129
5	3.5	4.5	4.0	67	0.0710	645	0.6840
6	4.5	5.5	5.0	152	0.1612	797	0.8452
7	5.5	6.5	6.0	29	0.0308	826	0.8759
8	6.5	7.5	7.0	6	0.0064	832	0.8823
9	7.5	8.5	8.0	0	0.0000	832	0.8823
10	8.5	9.5	9.0	14	0.0148	846	0.8971
11	9.5	10.5	10.0	7	0.0074	853	0.9046
12	10.5	11.5	11.0	14	0.0148	867	0.9194
13	11.5	12.5	12.0	4	0.0042	871	0.9236
14	12.5	13.5	13.0	1	0.0011	872	0.9247
15	13.5	14.5	14.0	0	0.0000	872	0.9247
16	14.5	15.5	15.0	4	0.0042	876	0.9290
17	15.5	16.5	16.0	1	0.0011	877	0.9300
18	16.5	17.5	17.0	1	0.0011	878	0.9311
19	17.5	18.5	18.0	0	0.0000	878	0.9311
20	18.5	19.5	19.0	60	0.0636	938	0.9947
21	19.5	20.5	20.0	0	0.0000	938	0.9947
22	20.5	21.5	21.0	1	0.0011	939	0.9958
23	21.5	22.5	22.0	4	0.0042	943	1.0000
	above	22.5		0	0.0000	943	1.0000

Figure A12. Frequencies of NBI Item 43B: Type of design and/or construction (-).

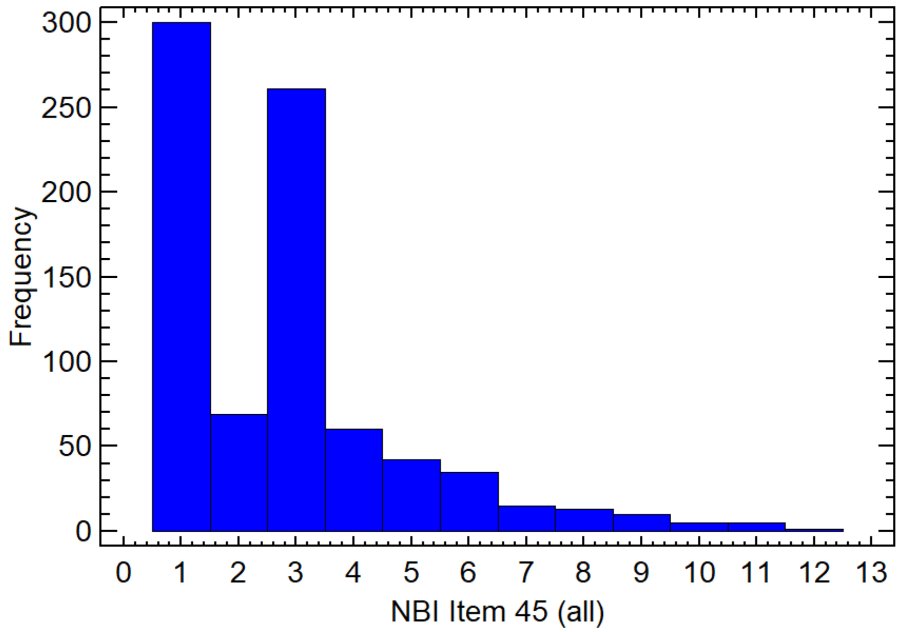


Figure A13. Histogram of NBI Item 45: Number of spans in main unit (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	0	0.0000	0	0.0000
2	0.5	1.5	1.0	300	0.3606	300	0.3606
3	1.5	2.5	2.0	69	0.0829	369	0.4435
4	2.5	3.5	3.0	261	0.3137	630	0.7572
5	3.5	4.5	4.0	60	0.0721	690	0.8293
6	4.5	5.5	5.0	42	0.0505	732	0.8798
7	5.5	6.5	6.0	35	0.0421	767	0.9219
8	6.5	7.5	7.0	15	0.0180	782	0.9399
9	7.5	8.5	8.0	13	0.0156	795	0.9555
10	8.5	9.5	9.0	10	0.0120	805	0.9675
11	9.5	10.5	10.0	5	0.0060	810	0.9736
12	10.5	11.5	11.0	5	0.0060	815	0.9796
13	11.5	12.5	12.0	1	0.0012	816	0.9808
	above	12.5		16	0.0192	832	1.0000

Figure A14. Frequencies of NBI Item 45: Number of spans in main unit (-).

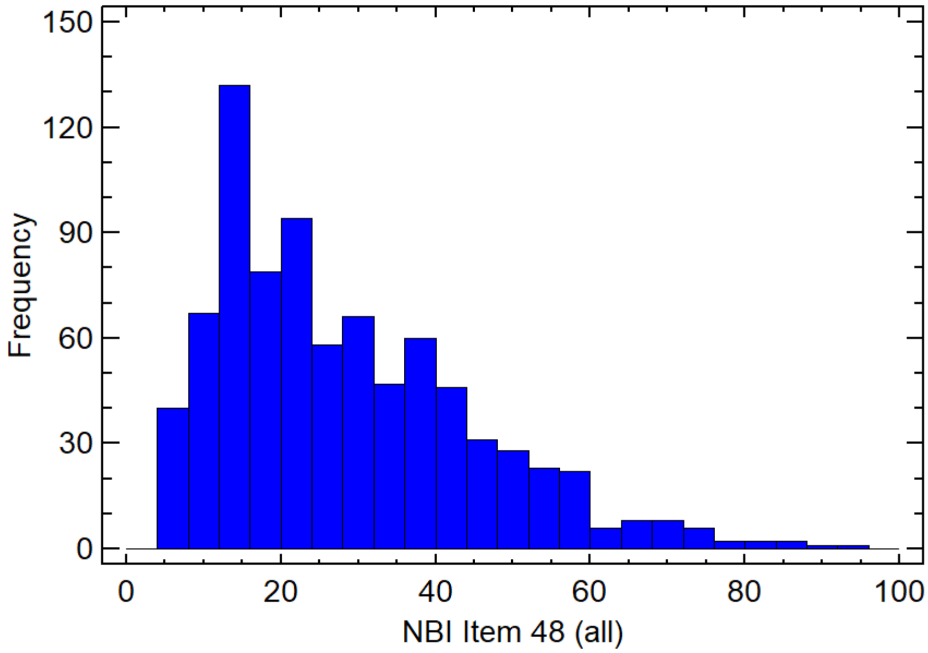


Figure A15. Histogram of NBI Item 48: Length of maximum span (all spans) (m).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	0		1	0.0012	1	0.0012
1	0	4.0	2.0	0	0.0000	1	0.0012
2	4	8.0	6.0	40	0.0481	41	0.0493
3	8	12.0	10.0	67	0.0805	108	0.1298
4	12	16.0	14.0	132	0.1587	240	0.2885
5	16	20.0	18.0	79	0.0950	319	0.3834
6	20	24.0	22.0	94	0.1130	413	0.4964
7	24	28.0	26.0	58	0.0697	471	0.5661
8	28	32.0	30.0	66	0.0793	537	0.6454
9	32	36.0	34.0	47	0.0565	584	0.7019
10	36	40.0	38.0	60	0.0721	644	0.7740
11	40	44.0	42.0	46	0.0553	690	0.8293
12	44	48.0	46.0	31	0.0373	721	0.8666
13	48	52.0	50.0	28	0.0337	749	0.9002
14	52	56.0	54.0	23	0.0276	772	0.9279
15	56	60.0	58.0	22	0.0264	794	0.9543
16	60	64.0	62.0	6	0.0072	800	0.9615
17	64	68.0	66.0	8	0.0096	808	0.9712
18	68	72.0	70.0	8	0.0096	816	0.9808
19	72	76.0	74.0	6	0.0072	822	0.9880
20	76	80.0	78.0	2	0.0024	824	0.9904
21	80	84.0	82.0	2	0.0024	826	0.9928
22	84	88.0	86.0	2	0.0024	828	0.9952
23	88	92.0	90.0	1	0.0012	829	0.9964
24	92	96.0	94.0	1	0.0012	830	0.9976
25	96	100.0	98.0	0	0.0000	830	0.9976
	above	100		2	0.0024	832	1.0000

Mean = 29.4139 Standard deviation = 30.4938

	Percentiles
30.0%	16.8
40.0%	20.4
50.0%	24.4
60.0%	30.2
70.0%	36.0
80.0%	42.1
90.0%	51.8
95.0%	59.1
99.0%	78.0

Figure A16. Frequencies (left) and percentiles (right) of NBI Item 48: Length of maximum span (all spans) (m).

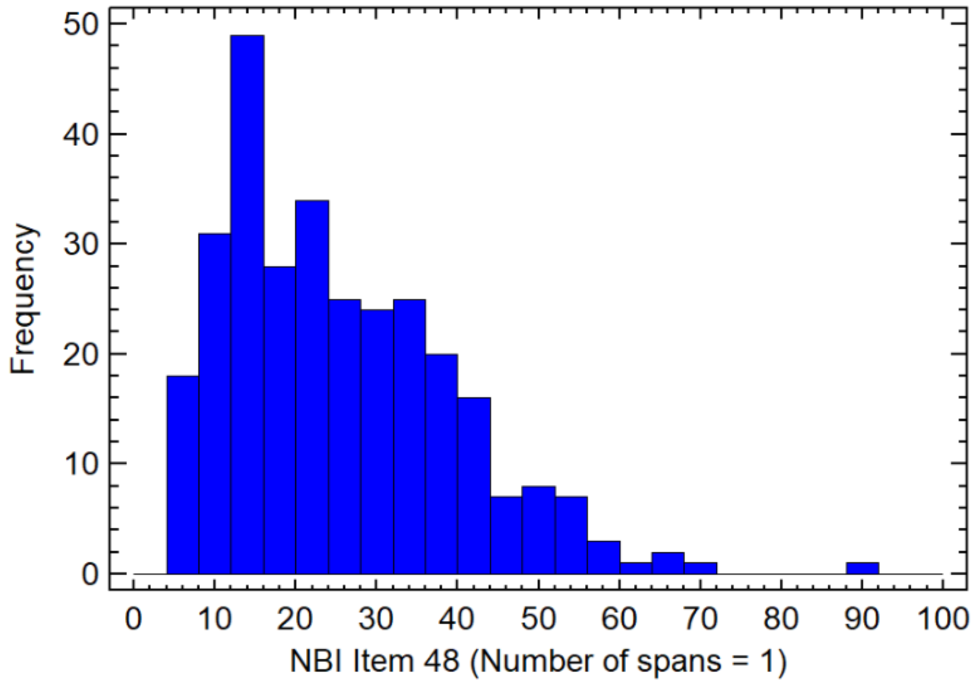


Figure A17. Histogram of NBI Item 48: Length of maximum span (# of spans = 1) (m).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	0		0	0.0000	0	0.0000
1	0	4.0	2.0	0	0.0000	0	0.0000
2	4	8.0	6.0	18	0.0600	18	0.0600
3	8	12.0	10.0	31	0.1033	49	0.1633
4	12	16.0	14.0	49	0.1633	98	0.3267
5	16	20.0	18.0	28	0.0933	126	0.4200
6	20	24.0	22.0	34	0.1133	160	0.5333
7	24	28.0	26.0	25	0.0833	185	0.6167
8	28	32.0	30.0	24	0.0800	209	0.6967
9	32	36.0	34.0	25	0.0833	234	0.7800
10	36	40.0	38.0	20	0.0667	254	0.8467
11	40	44.0	42.0	16	0.0533	270	0.9000
12	44	48.0	46.0	7	0.0233	277	0.9233
13	48	52.0	50.0	8	0.0267	285	0.9500
14	52	56.0	54.0	7	0.0233	292	0.9733
15	56	60.0	58.0	3	0.0100	295	0.9833
16	60	64.0	62.0	1	0.0033	296	0.9867
17	64	68.0	66.0	2	0.0067	298	0.9933
18	68	72.0	70.0	1	0.0033	299	0.9967
19	72	76.0	74.0	0	0.0000	299	0.9967
20	76	80.0	78.0	0	0.0000	299	0.9967
21	80	84.0	82.0	0	0.0000	299	0.9967
22	84	88.0	86.0	0	0.0000	299	0.9967
23	88	92.0	90.0	1	0.0033	300	1.0000
24	92	96.0	94.0	0	0.0000	300	1.0000
25	96	100.0	98.0	0	0.0000	300	1.0000
	above	100		0	0.0000	300	1.0000

Mean = 25.569 Standard deviation = 14.1211

	Percentiles
30.0%	15.2
40.0%	19.05
50.0%	22.25
60.0%	27.0
70.0%	32.55
80.0%	38.1
90.0%	44.05
95.0%	52.15
99.0%	65.65

Figure A18. Frequencies (left) and percentiles (right) of NBI Item 48: Length of maximum span (# of spans = 1) (m).

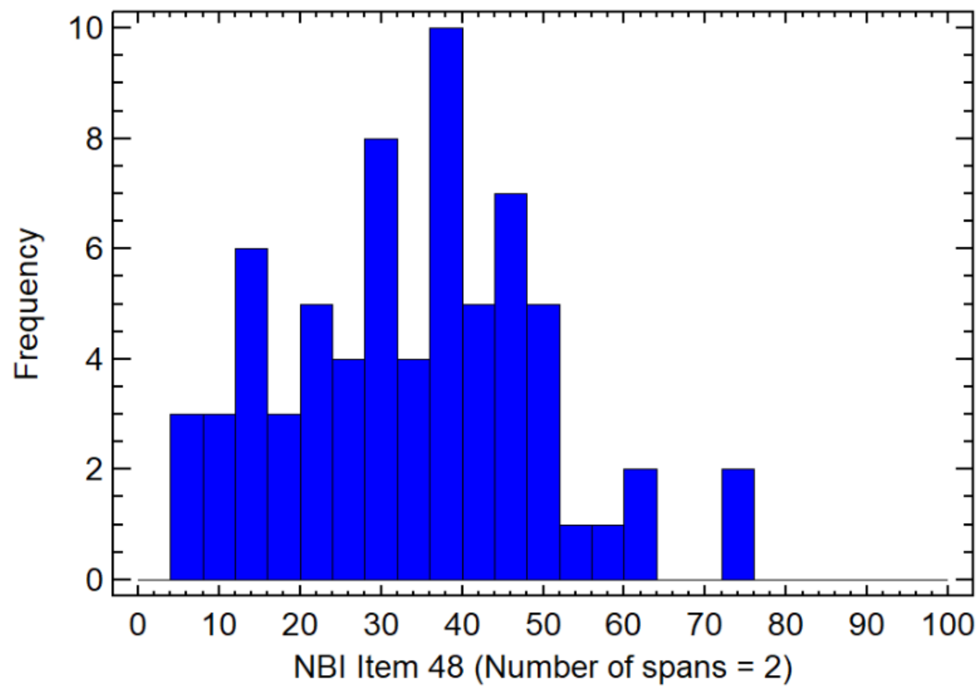


Figure A19. Histogram of NBI Item 48: Length of maximum span (# of spans = 2) (m).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	0		0	0.0000	0	0.0000
1	0	4.0	2.0	0	0.0000	0	0.0000
2	4	8.0	6.0	3	0.0435	3	0.0435
3	8	12.0	10.0	3	0.0435	6	0.0870
4	12	16.0	14.0	6	0.0870	12	0.1739
5	16	20.0	18.0	3	0.0435	15	0.2174
6	20	24.0	22.0	5	0.0725	20	0.2899
7	24	28.0	26.0	4	0.0580	24	0.3478
8	28	32.0	30.0	8	0.1159	32	0.4638
9	32	36.0	34.0	4	0.0580	36	0.5217
10	36	40.0	38.0	10	0.1449	46	0.6667
11	40	44.0	42.0	5	0.0725	51	0.7391
12	44	48.0	46.0	7	0.1014	58	0.8406
13	48	52.0	50.0	5	0.0725	63	0.9130
14	52	56.0	54.0	1	0.0145	64	0.9275
15	56	60.0	58.0	1	0.0145	65	0.9420
16	60	64.0	62.0	2	0.0290	67	0.9710
17	64	68.0	66.0	0	0.0000	67	0.9710
18	68	72.0	70.0	0	0.0000	67	0.9710
19	72	76.0	74.0	2	0.0290	69	1.0000
20	76	80.0	78.0	0	0.0000	69	1.0000
21	80	84.0	82.0	0	0.0000	69	1.0000
22	84	88.0	86.0	0	0.0000	69	1.0000
23	88	92.0	90.0	0	0.0000	69	1.0000
24	92	96.0	94.0	0	0.0000	69	1.0000
25	96	100.0	98.0	0	0.0000	69	1.0000
	above	100		0	0.0000	69	1.0000

Mean = 33.8159 Standard deviation = 15.6458

	Percentiles
30.0%	24.7
40.0%	29.9
50.0%	34.1
60.0%	38.4
70.0%	41.1
80.0%	46.0
90.0%	50.9
95.0%	61.0
99.0%	74.7

Figure A20. Frequencies (left) and percentiles (right) of NBI Item 48: Length of maximum span (# of spans = 2) (m).

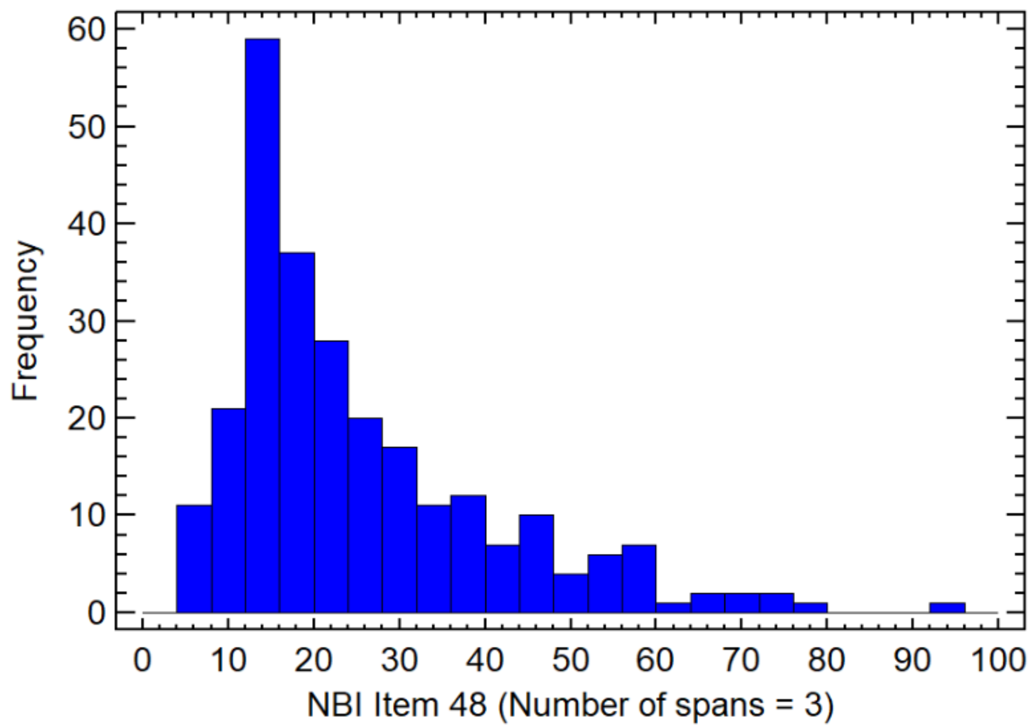


Figure A21. Histogram of NBI Item 48: Length of maximum span (# of spans = 3) (m).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	0		1	0.0038	1	0.0038
1	0	4.0	2.0	0	0.0000	1	0.0038
2	4	8.0	6.0	11	0.0421	12	0.0460
3	8	12.0	10.0	21	0.0805	33	0.1264
4	12	16.0	14.0	59	0.2261	92	0.3525
5	16	20.0	18.0	37	0.1418	129	0.4943
6	20	24.0	22.0	28	0.1073	157	0.6015
7	24	28.0	26.0	20	0.0766	177	0.6782
8	28	32.0	30.0	17	0.0651	194	0.7433
9	32	36.0	34.0	11	0.0421	205	0.7854
10	36	40.0	38.0	12	0.0460	217	0.8314
11	40	44.0	42.0	7	0.0268	224	0.8582
12	44	48.0	46.0	10	0.0383	234	0.8966
13	48	52.0	50.0	4	0.0153	238	0.9119
14	52	56.0	54.0	6	0.0230	244	0.9349
15	56	60.0	58.0	7	0.0268	251	0.9617
16	60	64.0	62.0	1	0.0038	252	0.9655
17	64	68.0	66.0	2	0.0077	254	0.9732
18	68	72.0	70.0	2	0.0077	256	0.9808
19	72	76.0	74.0	2	0.0077	258	0.9885
20	76	80.0	78.0	1	0.0038	259	0.9923
21	80	84.0	82.0	0	0.0000	259	0.9923
22	84	88.0	86.0	0	0.0000	259	0.9923
23	88	92.0	90.0	0	0.0000	259	0.9923
24	92	96.0	94.0	1	0.0038	260	0.9962
25	96	100.0	98.0	0	0.0000	260	0.9962
	above	100		1	0.0038	261	1.0000

Mean = 25.772 Standard deviation = 16.9927

	Percentiles
30.0%	15.2
40.0%	17.7
50.0%	20.1
60.0%	23.9
70.0%	29.9
80.0%	36.6
90.0%	48.8
95.0%	57.9
99.0%	78.0

Figure A22. Frequencies (left) and percentiles (right) of NBI Item 48: Length of maximum span (# of spans = 3) (m).

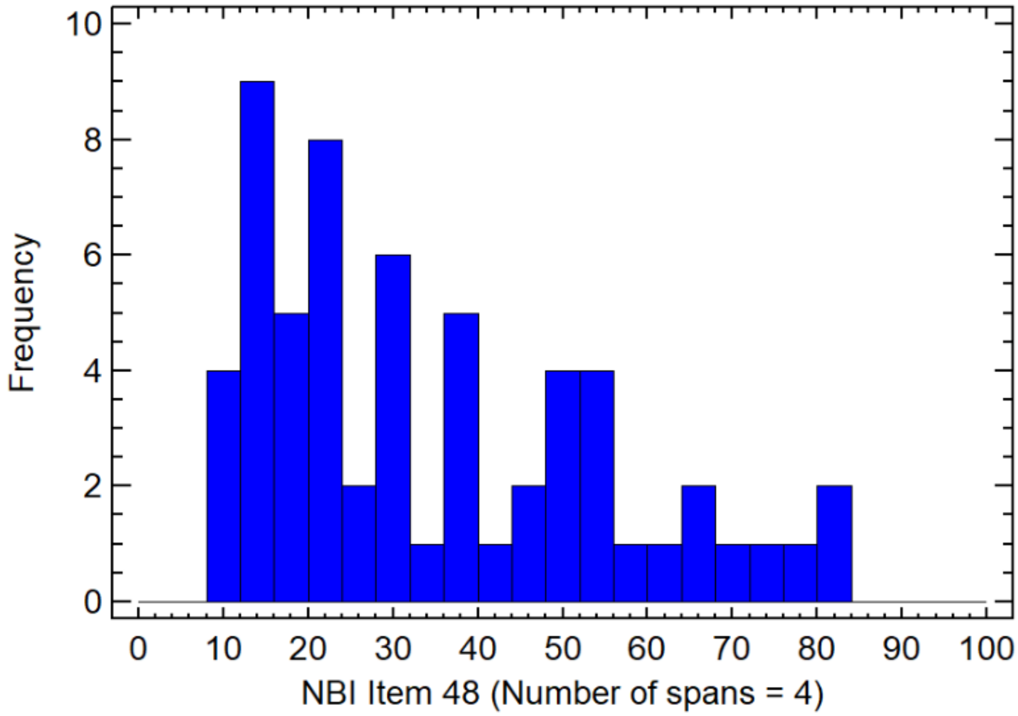


Figure A23. Histogram of NBI Item 48: Length of maximum span (# of spans = 4) (m).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	0		0	0.0000	0	0.0000
1	0	4.0	2.0	0	0.0000	0	0.0000
2	4	8.0	6.0	0	0.0000	0	0.0000
3	8	12.0	10.0	4	0.0667	4	0.0667
4	12	16.0	14.0	9	0.1500	13	0.2167
5	16	20.0	18.0	5	0.0833	18	0.3000
6	20	24.0	22.0	8	0.1333	26	0.4333
7	24	28.0	26.0	2	0.0333	28	0.4667
8	28	32.0	30.0	6	0.1000	34	0.5667
9	32	36.0	34.0	1	0.0167	35	0.5833
10	36	40.0	38.0	5	0.0833	40	0.6667
11	40	44.0	42.0	1	0.0167	41	0.6833
12	44	48.0	46.0	2	0.0333	43	0.7167
13	48	52.0	50.0	4	0.0667	47	0.7833
14	52	56.0	54.0	4	0.0667	51	0.8500
15	56	60.0	58.0	1	0.0167	52	0.8667
16	60	64.0	62.0	1	0.0167	53	0.8833
17	64	68.0	66.0	2	0.0333	55	0.9167
18	68	72.0	70.0	1	0.0167	56	0.9333
19	72	76.0	74.0	1	0.0167	57	0.9500
20	76	80.0	78.0	1	0.0167	58	0.9667
21	80	84.0	82.0	2	0.0333	60	1.0000
22	84	88.0	86.0	0	0.0000	60	1.0000
23	88	92.0	90.0	0	0.0000	60	1.0000
24	92	96.0	94.0	0	0.0000	60	1.0000
25	96	100.0	98.0	0	0.0000	60	1.0000
	above	100		0	0.0000	60	1.0000

Mean = 34.7667 Standard deviation = 20.2663

	Percentiles
30.0%	19.95
40.0%	21.45
50.0%	29.5
60.0%	38.4
70.0%	46.45
80.0%	52.4
90.0%	67.1
95.0%	74.7
99.0%	83.0

Figure A24. Frequencies (left) and percentiles (right) of NBI Item 48: Length of maximum span (# of spans = 4) (m).

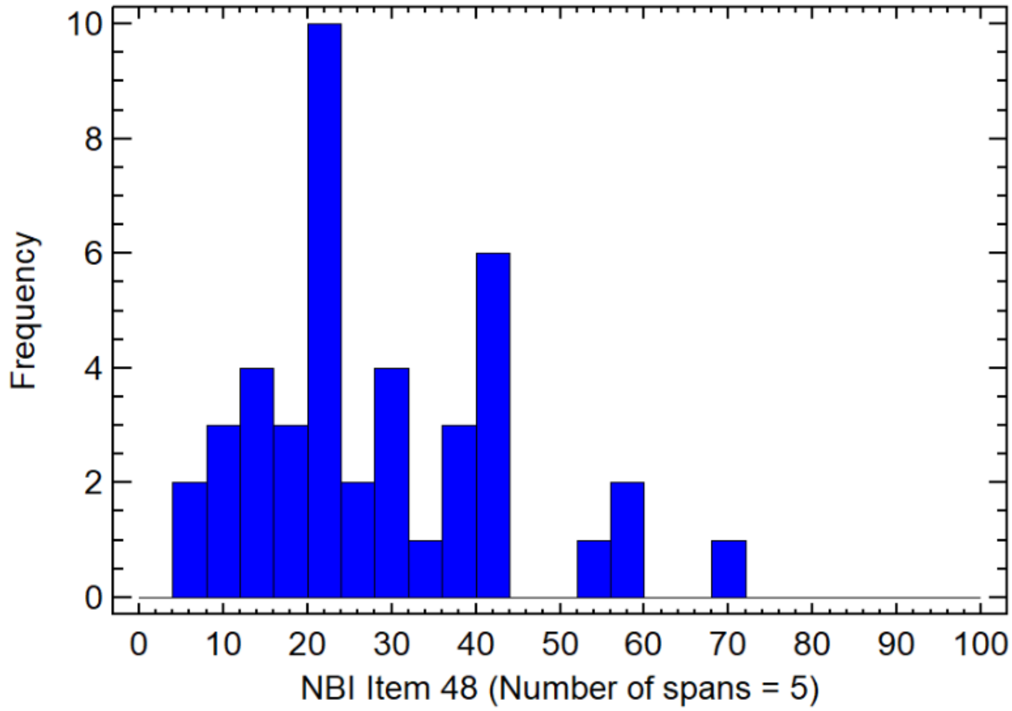


Figure A25. Histogram of NBI Item 48: Length of maximum span (# of spans = 5) (m).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	0		0	0.0000	0	0.0000
1	0	4.0	2.0	0	0.0000	0	0.0000
2	4	8.0	6.0	2	0.0476	2	0.0476
3	8	12.0	10.0	3	0.0714	5	0.1190
4	12	16.0	14.0	4	0.0952	9	0.2143
5	16	20.0	18.0	3	0.0714	12	0.2857
6	20	24.0	22.0	10	0.2381	22	0.5238
7	24	28.0	26.0	2	0.0476	24	0.5714
8	28	32.0	30.0	4	0.0952	28	0.6667
9	32	36.0	34.0	1	0.0238	29	0.6905
10	36	40.0	38.0	3	0.0714	32	0.7619
11	40	44.0	42.0	6	0.1429	38	0.9048
12	44	48.0	46.0	0	0.0000	38	0.9048
13	48	52.0	50.0	0	0.0000	38	0.9048
14	52	56.0	54.0	1	0.0238	39	0.9286
15	56	60.0	58.0	2	0.0476	41	0.9762
16	60	64.0	62.0	0	0.0000	41	0.9762
17	64	68.0	66.0	0	0.0000	41	0.9762
18	68	72.0	70.0	1	0.0238	42	1.0000
19	72	76.0	74.0	0	0.0000	42	1.0000
20	76	80.0	78.0	0	0.0000	42	1.0000
21	80	84.0	82.0	0	0.0000	42	1.0000
22	84	88.0	86.0	0	0.0000	42	1.0000
23	88	92.0	90.0	0	0.0000	42	1.0000
24	92	96.0	94.0	0	0.0000	42	1.0000
25	96	100.0	98.0	0	0.0000	42	1.0000
	above	100		0	0.0000	42	1.0000

Mean = 28.5738 Standard deviation = 15.1319

	Percentiles
30.0%	20.7
40.0%	22.6
50.0%	23.5
60.0%	29.6
70.0%	36.6
80.0%	42.0
90.0%	43.6
95.0%	57.3
99.0%	71.6

Figure A26. Frequencies (left) and percentiles (right) of NBI Item 48: Length of maximum span (# of spans = 5) (m).

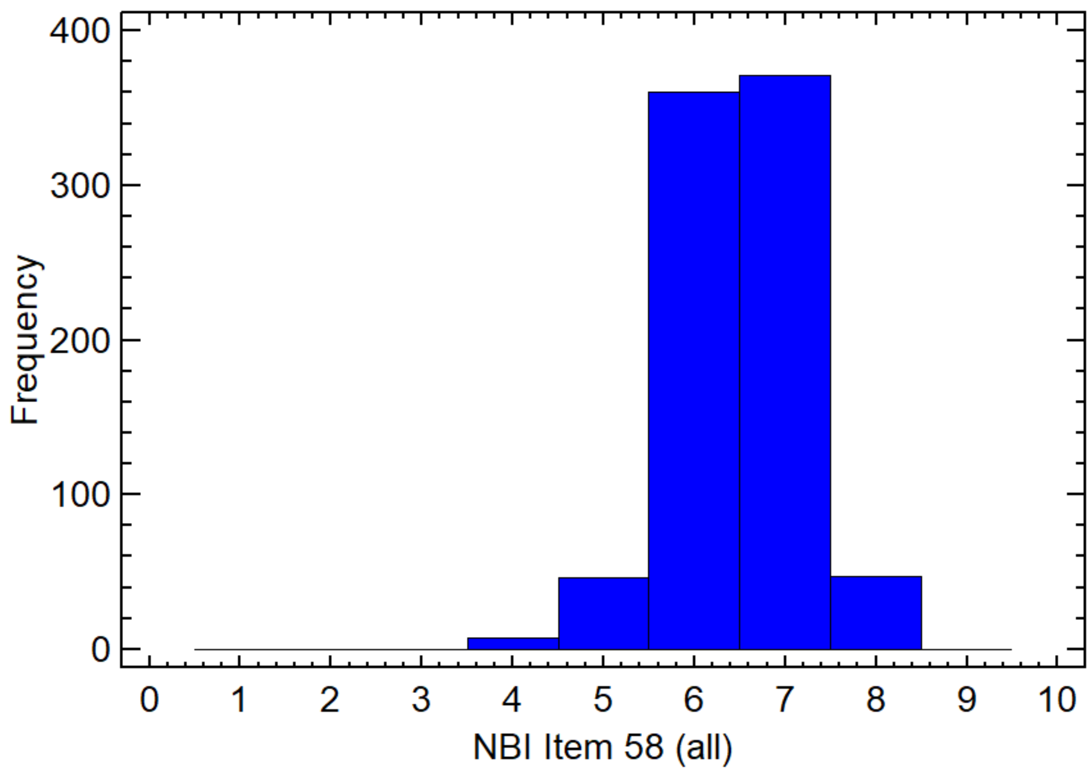


Figure A27. Histogram of NBI Item 58: Deck condition rating (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	0	0.0000	0	0.0000
2	0.5	1.5	1.0	0	0.0000	0	0.0000
3	1.5	2.5	2.0	0	0.0000	0	0.0000
4	2.5	3.5	3.0	0	0.0000	0	0.0000
5	3.5	4.5	4.0	7	0.0084	7	0.0084
6	4.5	5.5	5.0	46	0.0554	53	0.0638
7	5.5	6.5	6.0	360	0.4332	413	0.4970
8	6.5	7.5	7.0	371	0.4465	784	0.9434
9	7.5	8.5	8.0	47	0.0566	831	1.0000
10	8.5	9.5	9.0	0	0.0000	831	1.0000
	above	9.5		0	0.0000	831	1.0000

Figure A28. Frequencies (left) and percentiles (right) of NBI Item 58: Deck condition rating (-).

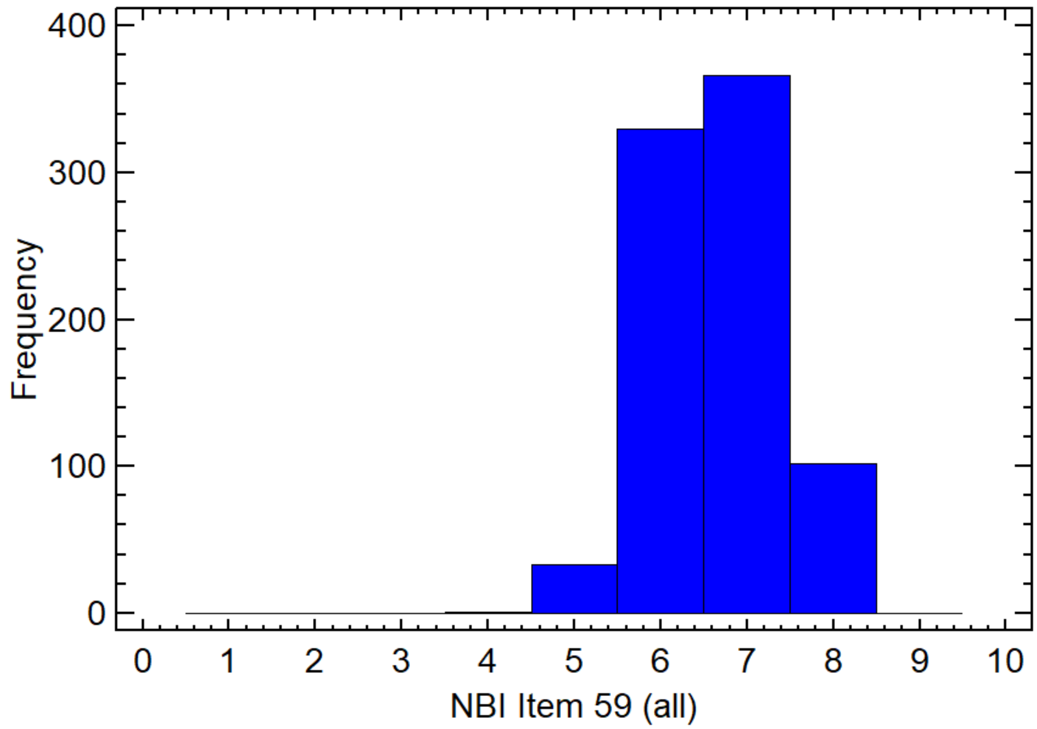


Figure A29. Histogram of NBI Item 59: Superstructure condition rating (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	0	0.0000	0	0.0000
2	0.5	1.5	1.0	0	0.0000	0	0.0000
3	1.5	2.5	2.0	0	0.0000	0	0.0000
4	2.5	3.5	3.0	0	0.0000	0	0.0000
5	3.5	4.5	4.0	1	0.0012	1	0.0012
6	4.5	5.5	5.0	33	0.0397	34	0.0409
7	5.5	6.5	6.0	330	0.3966	364	0.4375
8	6.5	7.5	7.0	366	0.4399	730	0.8774
9	7.5	8.5	8.0	102	0.1226	832	1.0000
10	8.5	9.5	9.0	0	0.0000	832	1.0000
	above	9.5		0	0.0000	832	1.0000

Figure A30. Frequencies (left) and percentiles (right) of NBI Item 59: Superstructure condition rating (-).

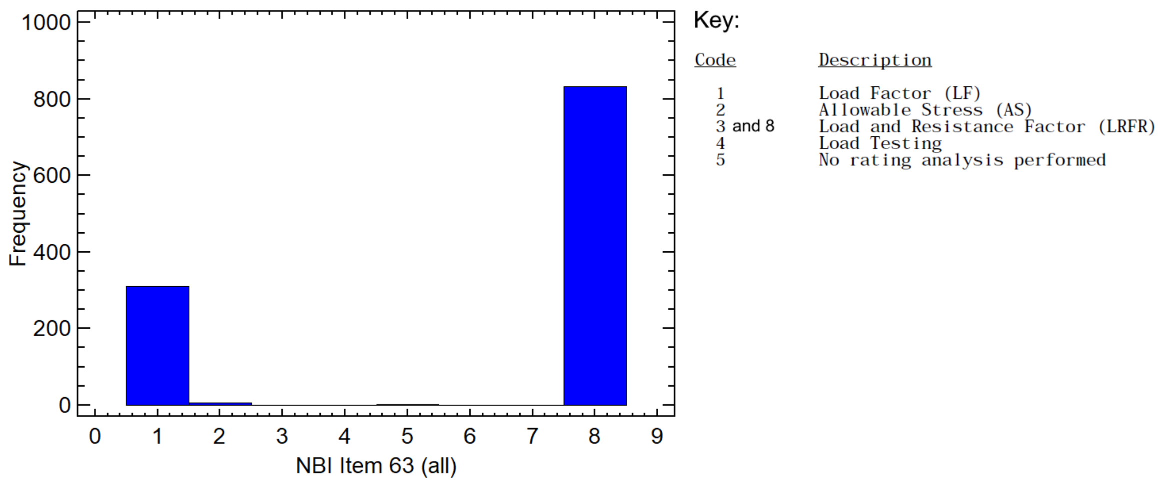


Figure A31. Histogram of NBI Item 63: Method used to determine operating rating (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	3	0.0026	3	0.0026
2	0.5	1.5	1.0	310	0.2691	313	0.2717
3	1.5	2.5	2.0	5	0.0043	318	0.2760
4	2.5	3.5	3.0	0	0.0000	318	0.2760
5	3.5	4.5	4.0	0	0.0000	318	0.2760
6	4.5	5.5	5.0	2	0.0017	320	0.2778
7	5.5	6.5	6.0	0	0.0000	320	0.2778
8	6.5	7.5	7.0	0	0.0000	320	0.2778
9	7.5	8.5	8.0	832	0.7222	1152	1.0000
	above	8.5		0	0.0000	1152	1.0000

Figure A32. Frequencies of NBI Item 63: Method used to determine operating rating (-).

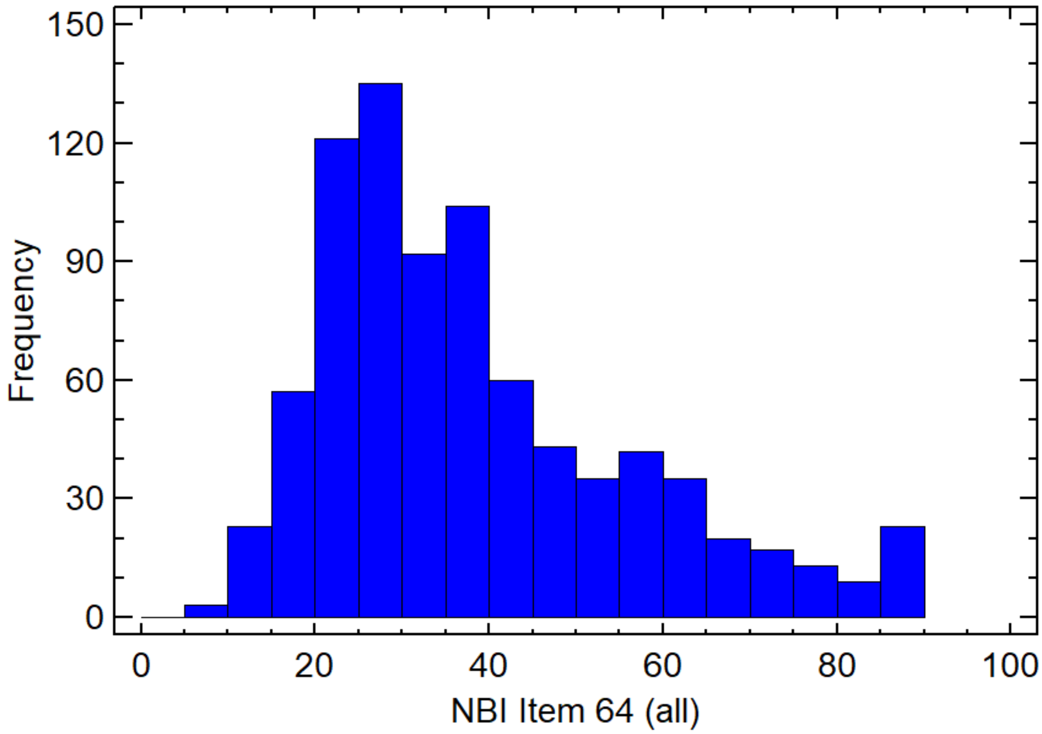


Figure A33. Histogram of NBI Item 64: Operating rating (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	0		0	0.0000	0	0.0000
1	0	5.0	2.5	0	0.0000	0	0.0000
2	5	10.0	7.5	3	0.0036	3	0.0036
3	10	15.0	12.5	23	0.0276	26	0.0313
4	15	20.0	17.5	57	0.0685	83	0.0998
5	20	25.0	22.5	121	0.1454	204	0.2452
6	25	30.0	27.5	135	0.1623	339	0.4075
7	30	35.0	32.5	92	0.1106	431	0.5180
8	35	40.0	37.5	104	0.1250	535	0.6430
9	40	45.0	42.5	60	0.0721	595	0.7151
10	45	50.0	47.5	43	0.0517	638	0.7668
11	50	55.0	52.5	35	0.0421	673	0.8089
12	55	60.0	57.5	42	0.0505	715	0.8594
13	60	65.0	62.5	35	0.0421	750	0.9014
14	65	70.0	67.5	20	0.0240	770	0.9255
15	70	75.0	72.5	17	0.0204	787	0.9459
16	75	80.0	77.5	13	0.0156	800	0.9615
17	80	85.0	82.5	9	0.0108	809	0.9724
18	85	90.0	87.5	23	0.0276	832	1.0000
	above	90		0	0.0000	832	1.0000

Mean = 38.6221 Standard deviation = 18.11

	Percentiles
10.0%	20.1
20.0%	24.0
30.0%	26.6
40.0%	29.8
50.0%	34.0
60.0%	38.6
70.0%	44.1
80.0%	54.1
90.0%	64.5

Figure A34. Frequencies (left) and percentiles (right) of NBI Item 64: Operating rating (-).

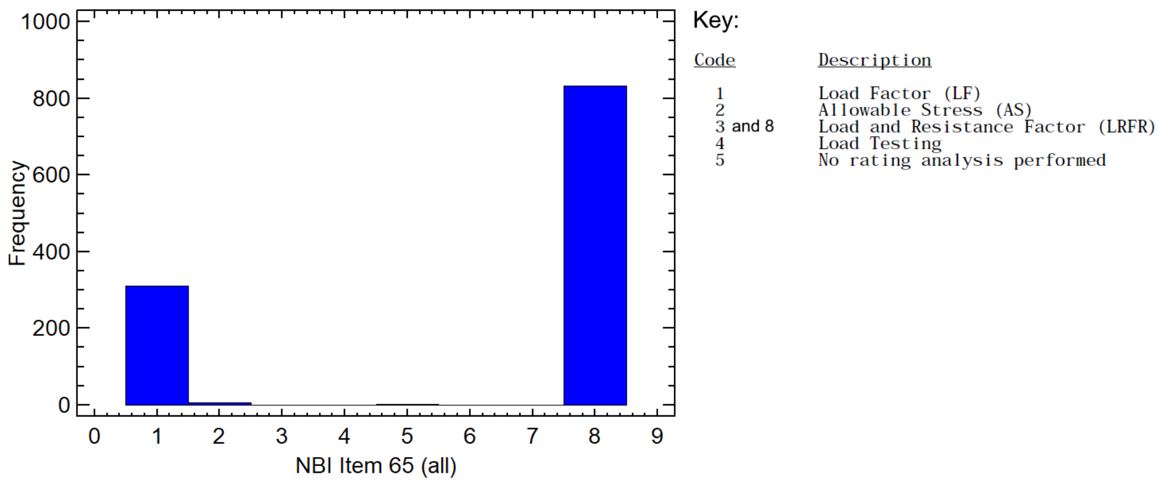


Figure A35. Histogram of NBI Item 65: Method used to determine inventory rating (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	3	0.0026	3	0.0026
2	0.5	1.5	1.0	310	0.2691	313	0.2717
3	1.5	2.5	2.0	5	0.0043	318	0.2760
4	2.5	3.5	3.0	0	0.0000	318	0.2760
5	3.5	4.5	4.0	0	0.0000	318	0.2760
6	4.5	5.5	5.0	2	0.0017	320	0.2778
7	5.5	6.5	6.0	0	0.0000	320	0.2778
8	6.5	7.5	7.0	0	0.0000	320	0.2778
9	7.5	8.5	8.0	832	0.7222	1152	1.0000
	above	8.5		0	0.0000	1152	1.0000

Figure A36. Frequencies of NBI Item 65: Method used to determine inventory rating (-).

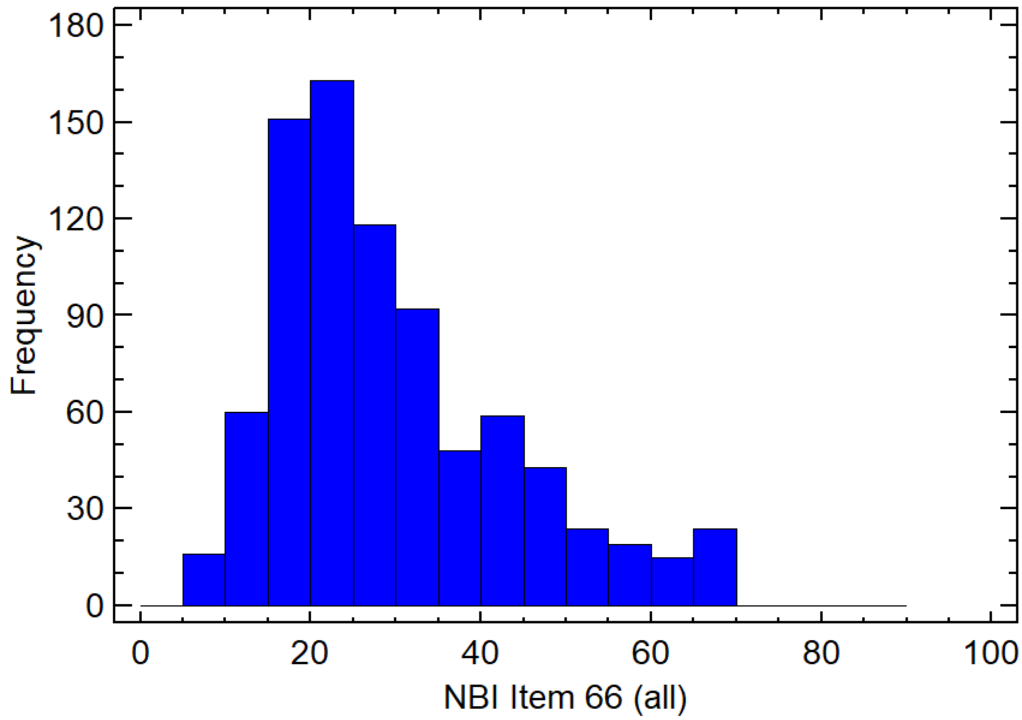


Figure A37. Histogram of NBI Item 66: Inventory rating (-).

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
	at or below	0		0	0.0000	0	0.0000
1	0	5.0	2.5	0	0.0000	0	0.0000
2	5	10.0	7.5	16	0.0192	16	0.0192
3	10	15.0	12.5	60	0.0721	76	0.0913
4	15	20.0	17.5	151	0.1815	227	0.2728
5	20	25.0	22.5	163	0.1959	390	0.4688
6	25	30.0	27.5	118	0.1418	508	0.6106
7	30	35.0	32.5	92	0.1106	600	0.7212
8	35	40.0	37.5	48	0.0577	648	0.7788
9	40	45.0	42.5	59	0.0709	707	0.8498
10	45	50.0	47.5	43	0.0517	750	0.9014
11	50	55.0	52.5	24	0.0288	774	0.9303
12	55	60.0	57.5	19	0.0228	793	0.9531
13	60	65.0	62.5	15	0.0180	808	0.9712
14	65	70.0	67.5	24	0.0288	832	1.0000
15	70	75.0	72.5	0	0.0000	832	1.0000
16	75	80.0	77.5	0	0.0000	832	1.0000
17	80	85.0	82.5	0	0.0000	832	1.0000
18	85	90.0	87.5	0	0.0000	832	1.0000
	above	90		0	0.0000	832	1.0000

Mean = 29.7944 Standard deviation = 13.9606

	Percentiles
10.0%	15.6
20.0%	18.5
30.0%	20.4
40.0%	23.0
50.0%	26.2
60.0%	29.8
70.0%	34.0
80.0%	41.8
90.0%	49.9

Figure A38. Frequencies (left) and percentiles (right) of NBI Item 66: Inventory rating (-).

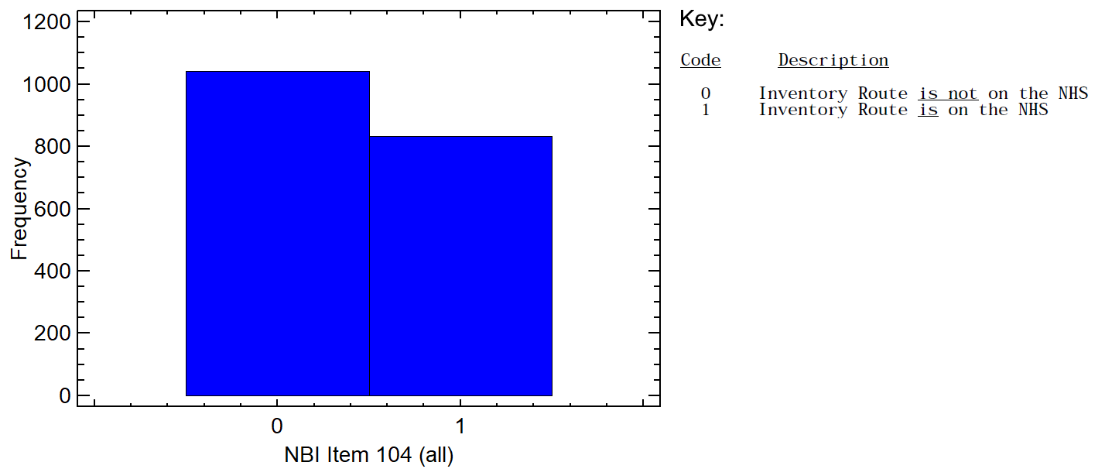


Figure A39. Histogram of NBI Item 104: Highway system of the inventory route (-).

Class	*Lower Limit*	*Upper Limit*	*Midpoint*	*Frequency*	*Relative Frequency*	*Cumulative Frequency*	*Cum. Rel. Frequency*
	at or below	-0.5		0	0.0000	0	0.0000
1	-0.5	0.5	0	1041	0.5558	1041	0.5558
2	0.5	1.5	1.0	832	0.4442	1873	1.0000
	above	1.5		0	0.0000	1873	1.0000

Figure A40. Frequencies of NBI Item 104: Highway system of the inventory route (-).

APPENDIX B

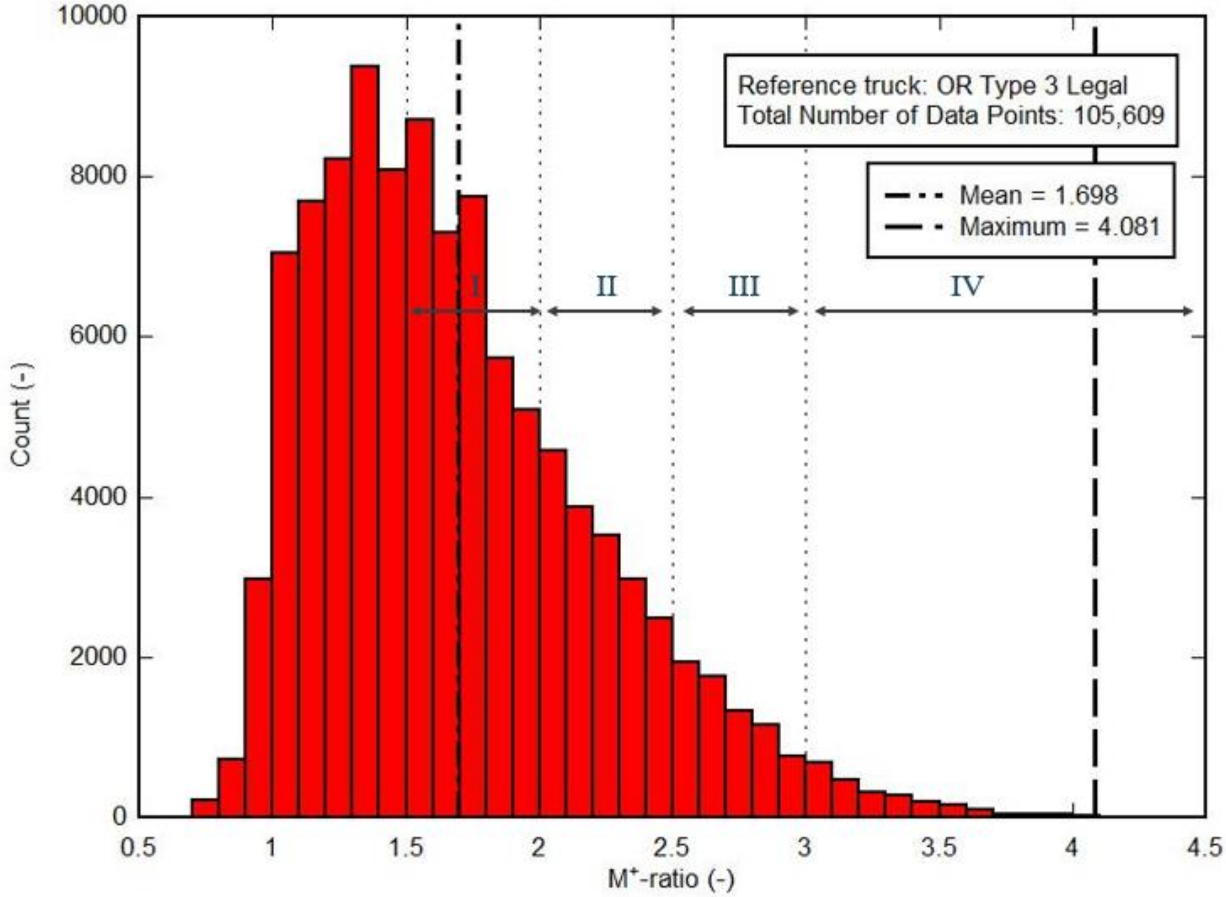


Figure B1. Histogram of maximum positive bending moment ratio (full database) normalized by OR Type 3 Legal Truck

Class	*Count*
0.70	208
0.80	719
0.90	2966
1.00	7053
1.10	7690
1.20	8221
1.30	9374
1.40	8083
1.50	8711
1.60	7300
1.70	7744
1.80	5727
1.90	5085
2.00	4581
2.10	3876
2.20	3529
2.30	2976
2.40	2476
2.50	1942
2.60	1754
2.70	1338
2.80	1160
2.90	772
3.00	685
3.10	465
3.20	311
3.30	275
3.40	186
3.50	160
3.60	106
3.70	47
3.80	44
3.90	33
4.00	13

Figure B2. Count of maximum positive bending moment ratio (full database) normalized by OR Type 3 Legal Truck

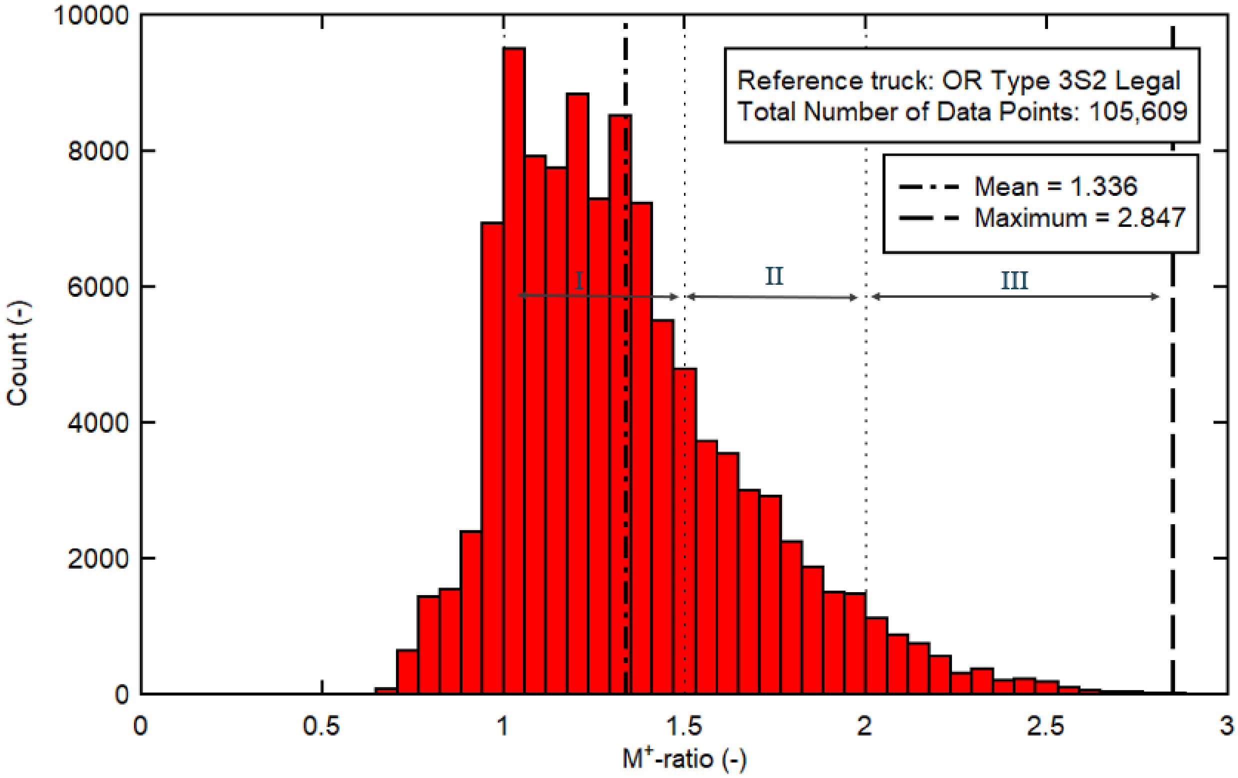


Figure B3. Histogram of maximum positive bending moment ratio (full database) normalized by OR Type 3S2 Legal Truck

Class	*Count*
0.65	88
0.71	654
0.76	1441
0.82	1549
0.88	2388
0.94	6933
1.00	9507
1.06	7912
1.12	7758
1.18	8841
1.24	7287
1.29	8524
1.35	7224
1.41	5501
1.47	4787
1.53	3730
1.59	3551
1.65	2990
1.71	2911
1.76	2256
1.82	1868
1.88	1490
1.94	1484
2.00	1131
2.06	883
2.12	752
2.18	557
2.24	318
2.29	378
2.35	206
2.41	233
2.47	182
2.53	112
2.59	55
2.65	37
2.71	48
2.76	30
2.82	13

Figure B4. Count of maximum positive bending moment ratio (full database) normalized by OR Type 3S2 Legal Truck

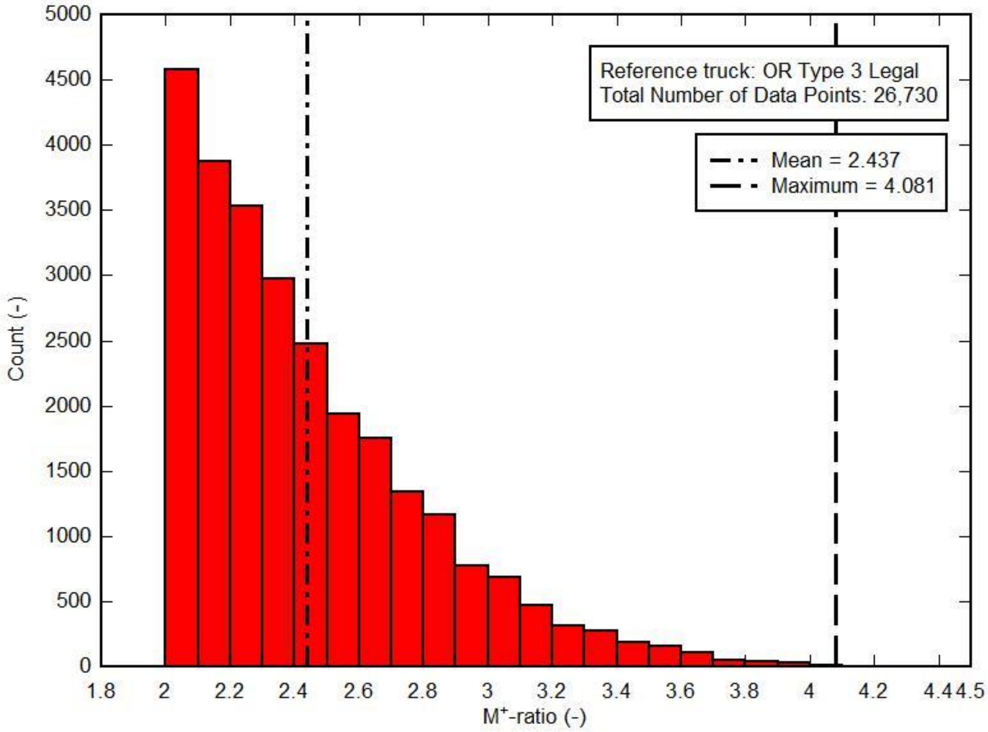


Figure B5. Histogram of maximum positive bending moment ratio (2.0+ ratio) normalized by OR Type 3 Legal Truck

Class	***Count***
2.00	4582
2.10	3876
2.20	3529
2.30	2976
2.40	2476
2.50	1942
2.60	1754
2.70	1338
2.80	1160
2.90	772
3.00	685
3.10	465
3.20	311
3.30	275
3.40	186
3.50	160
3.60	106
3.70	47
3.80	44
3.90	33
4.00	13

Figure B6. Count of maximum positive bending moment ratio (2.0+ ratio) normalized by OR Type 3 Legal Truck

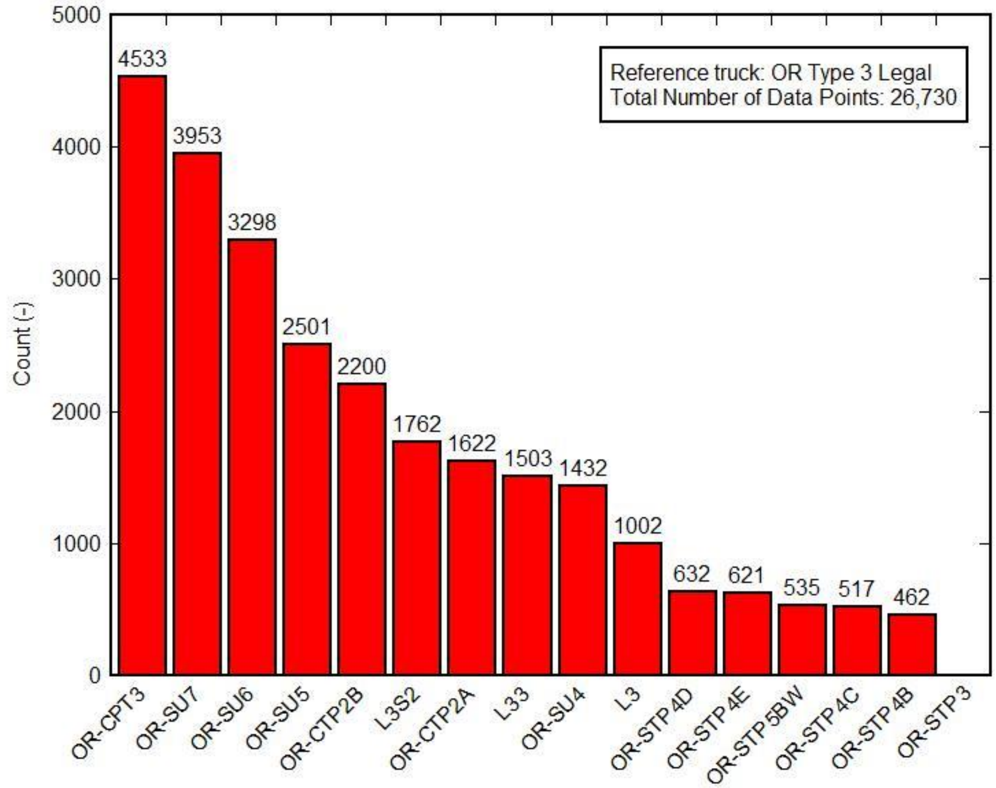


Figure B7. Histogram of maximum positive bending moment by truck type (2.0+ ratio) normalized by OR Type 3 Legal Truck

Truck Type	*Count*
CTP3	4533
SU7	3953
SU6	3298
SU5	2501
CTP2B	2200
Legal3S2	1762
CTP2A	1622
Legal33	1503
SU4	1432
Legal3	1002
STP4D	632
STP4E	621
STP5BW	535
STP4C	517
STP4B	462
STP3	157

Figure B8. Count of maximum positive bending moment by truck type (2.0+ ratio) normalized by OR Type 3 Legal Truck

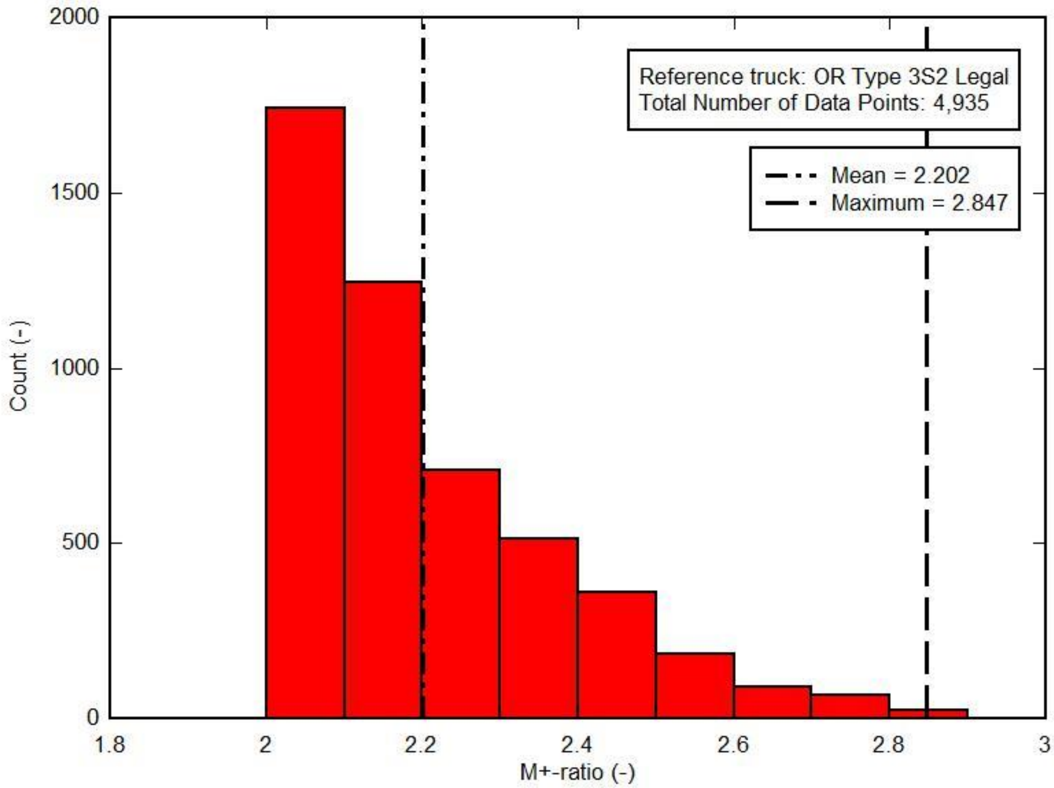


Figure B9. Histogram of maximum positive bending moment ratio (2.0+ ratio) normalized by OR Type 3S2 Legal Truck

.

Class	Count
2.00	1742
2.10	1245
2.20	708
2.30	514
2.40	359
2.50	185
2.60	91
2.70	67
2.80	24

Figure B10. Count of maximum positive bending moment ratio (2.0+ ratio) normalized by OR Type 3S2 Legal Truck

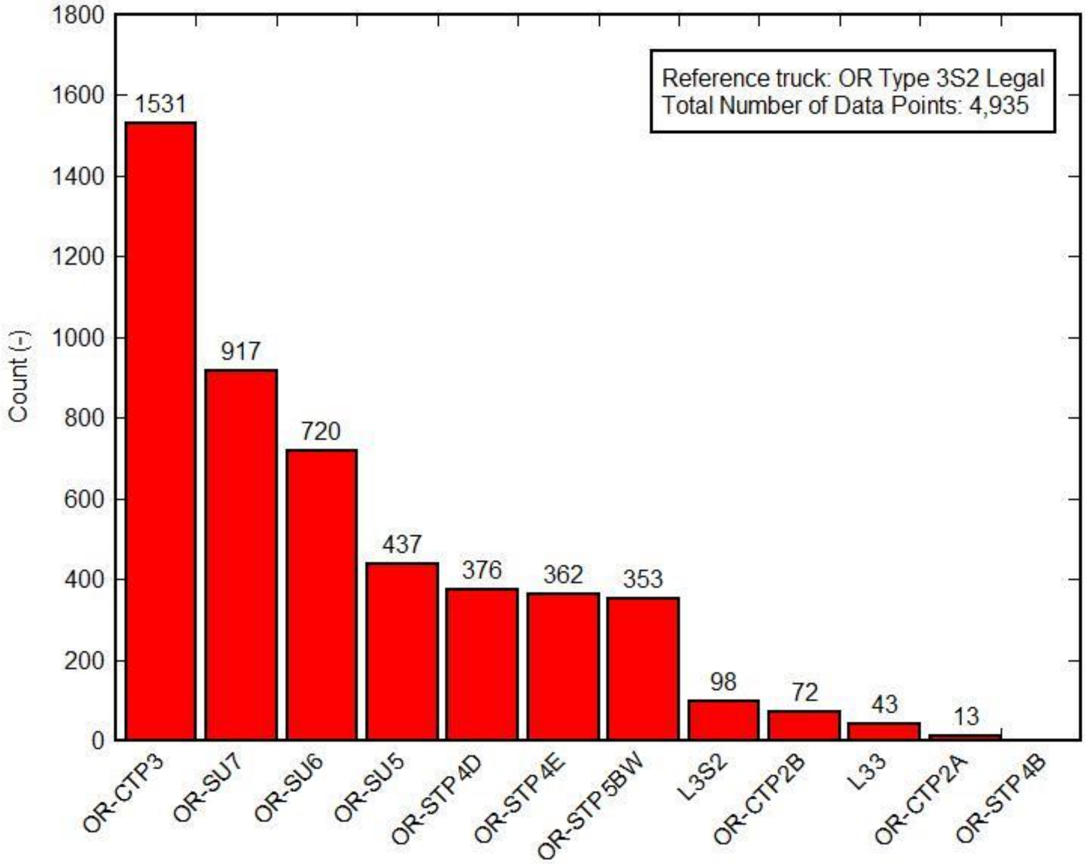


Figure B11. Histogram of maximum positive bending moment by truck type (2.0+ ratio) normalized by OR Type 3S2 Legal Truck

Truck Type	***Count***
CTP3	1531
SU7	917
SU6	720
SU5	437
STP4D	376
STP4E	362
STP5BW	353
Legal3S2	98
CTP2B	72
Legal33	43
CTP2A	13
STP4B	13

Figure B12. Count of maximum positive bending moment by truck type (2.0+ ratio) normalized by OR Type 3S2 Legal Truck

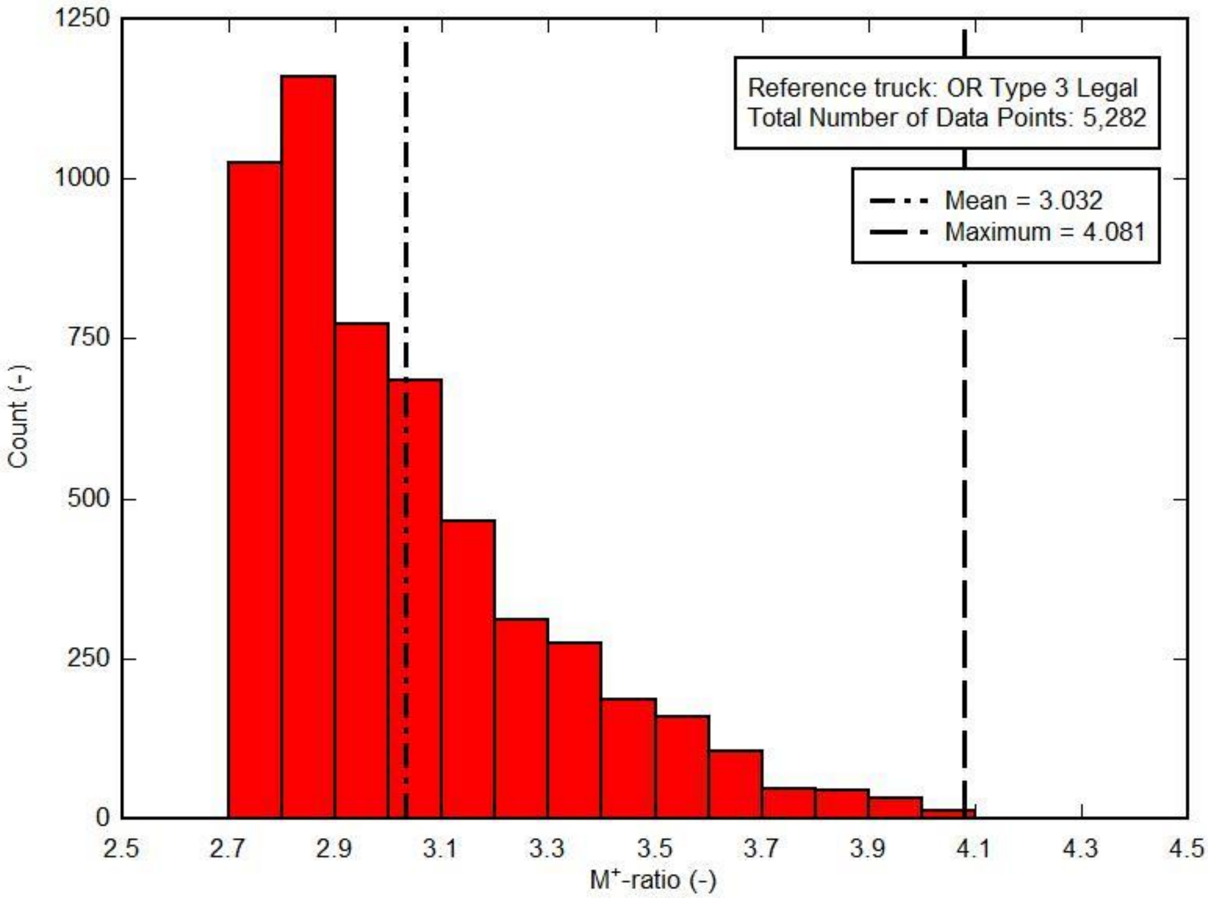


Figure B13. Histogram of maximum positive bending moment (the 95th percentile) normalized by OR Type 3 Legal Truck

Class	***Count***
2.70	1025
2.80	1160
2.90	772
3.00	685
3.10	465
3.20	311
3.30	275
3.40	186
3.50	160
3.60	106
3.70	47
3.80	44
3.90	33
4.00	13

Figure B14. Count of maximum positive bending moment (the 95th percentile) normalized by OR Type 3 Legal Truck

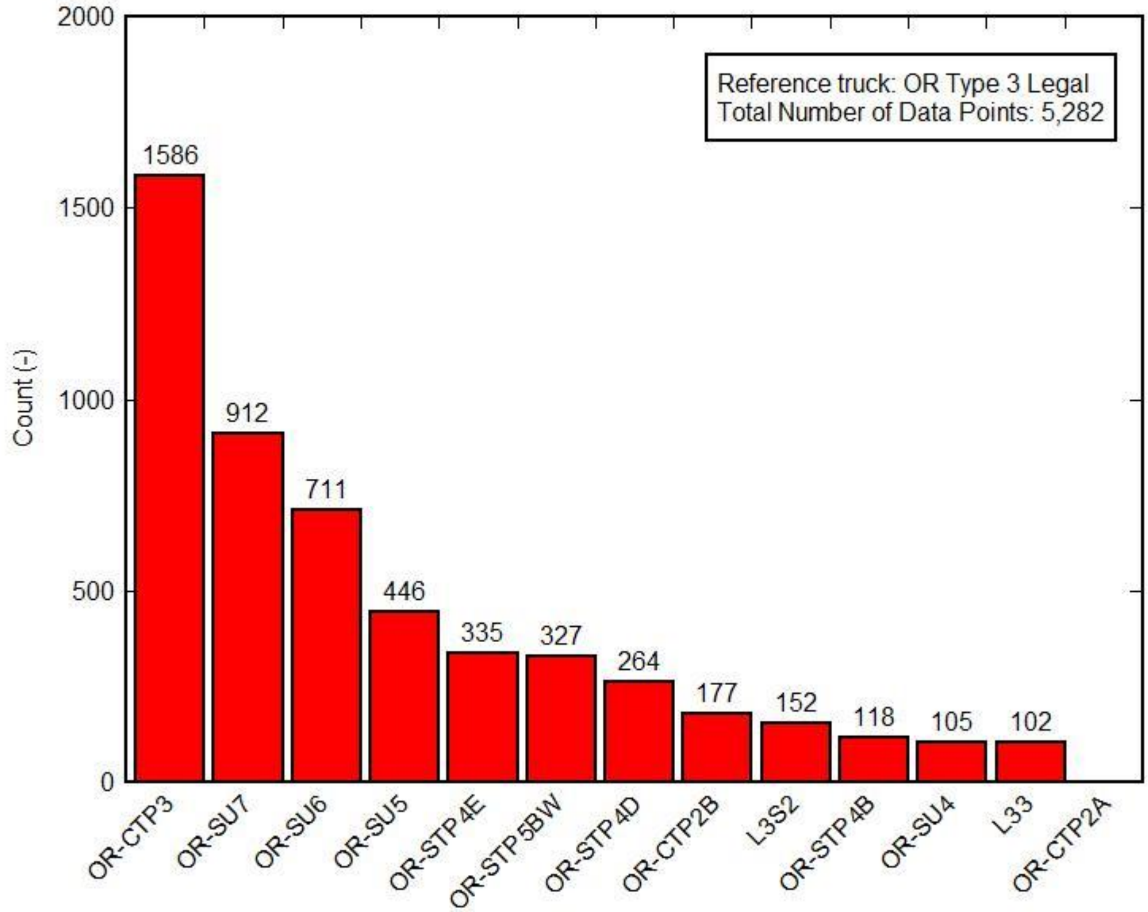


Figure B15. Histogram of maximum positive bending by truck type (the 95th percentile) normalized by OR Type 3 Legal Truck

Truck Type	***Count***
CTP3	1586
SU7	912
SU6	711
SU5	446
STP4E	335
STP5BW	327
STP4D	264
CTP2B	177
Legal3S2	152
STP4B	118
SU4	105
Legal33	102
CTP2A	47

Figure B16. Count of maximum positive bending by truck type (the 95th percentile) normalized by OR Type 3 Legal Truck

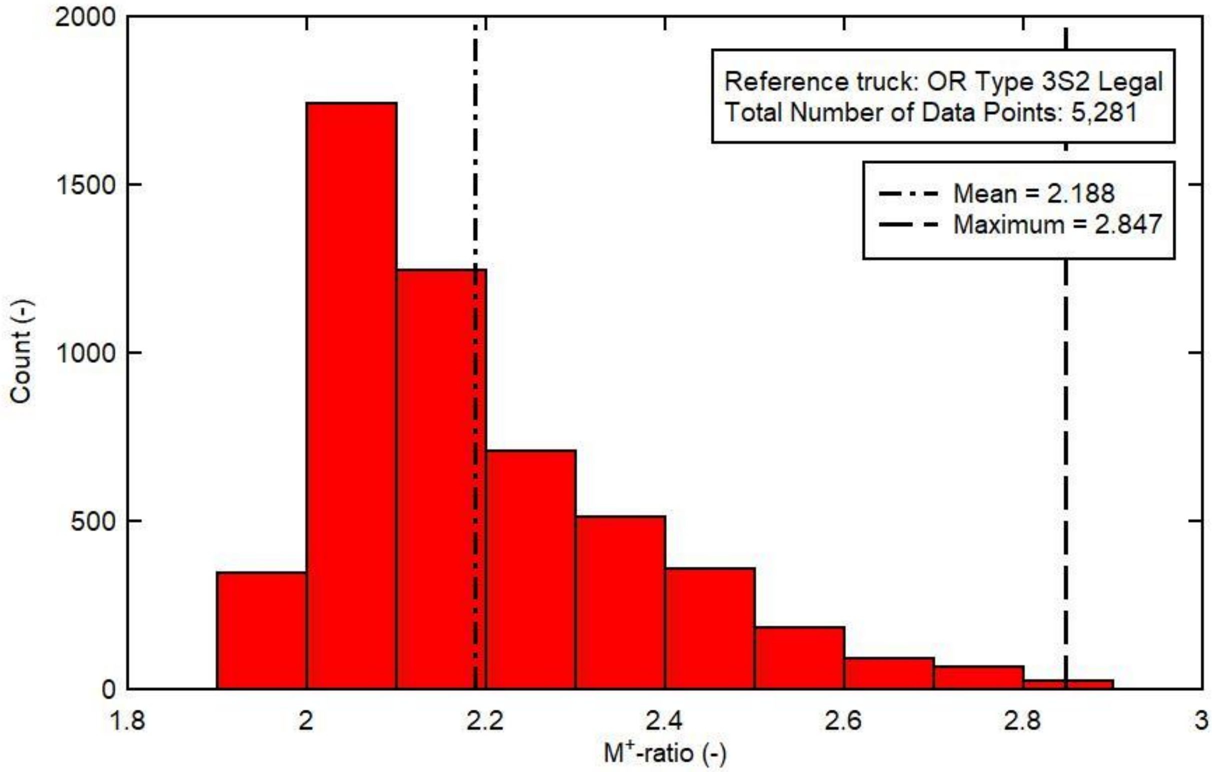


Figure B17. Histogram of maximum positive bending moment (the 95th percentile) normalized by OR Type 3S2 Legal Truck

Class	*Count*
1.90	346
2.00	1742
2.10	1245
2.20	708
2.30	514
2.40	359
2.50	185
2.60	91
2.70	67
2.80	24

Figure B18. Count of maximum positive bending moment (the 95th percentile) normalized by OR Type 3S2 Legal Truck

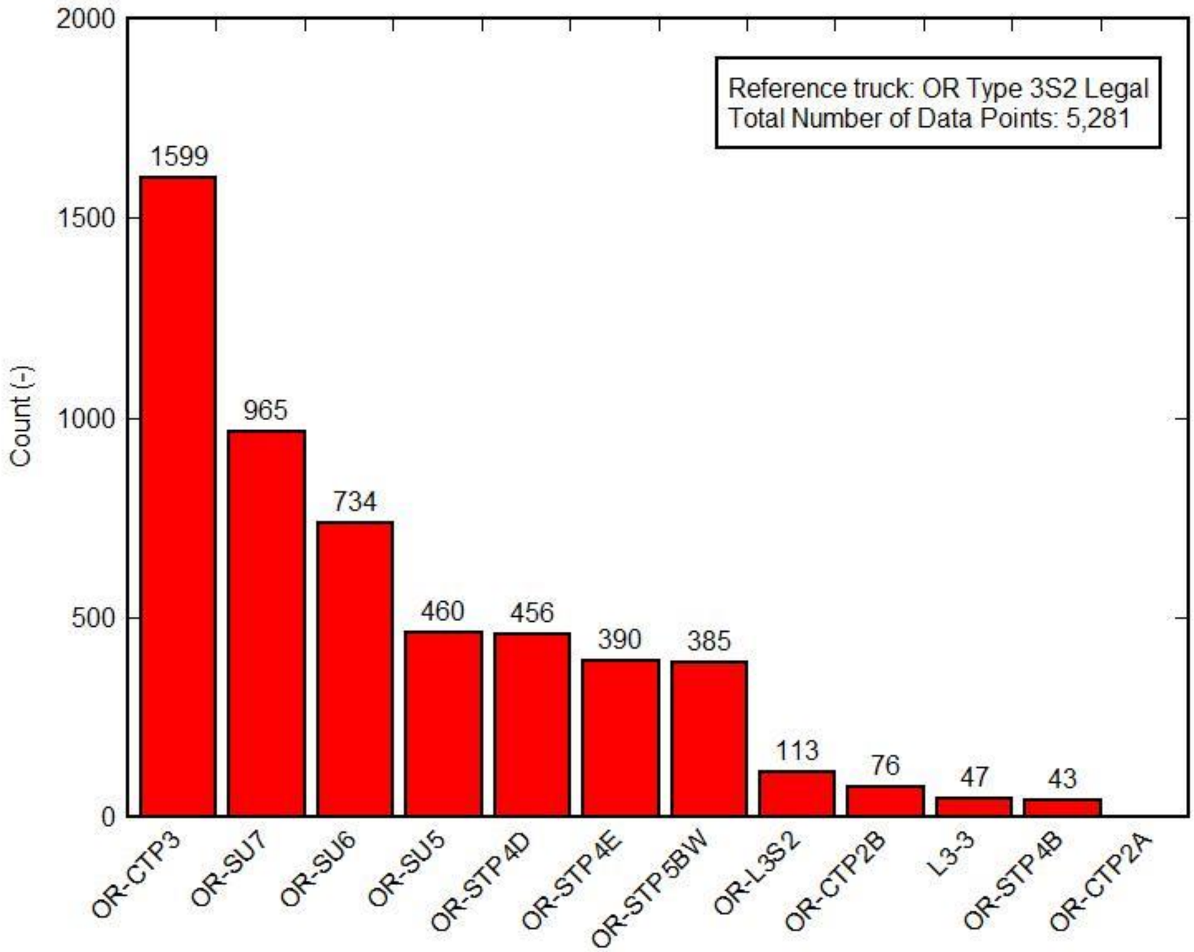


Figure B19. Histogram of maximum positive bending by truck type (the 95th percentile) normalized by OR Type 3S2 Legal Truck

Truck Type	*Count*
CTP3	1599
SU7	965
SU6	734
SU5	460
STP4D	456
STP4E	390
STP5BW	385
Legal3S2	113
CTP2B	76
Legal33	47
STP4B	43
CTP2A	13

Figure B20. Count of maximum positive bending by truck type (the 95th percentile) normalized by OR Type 3S2 Legal Truck

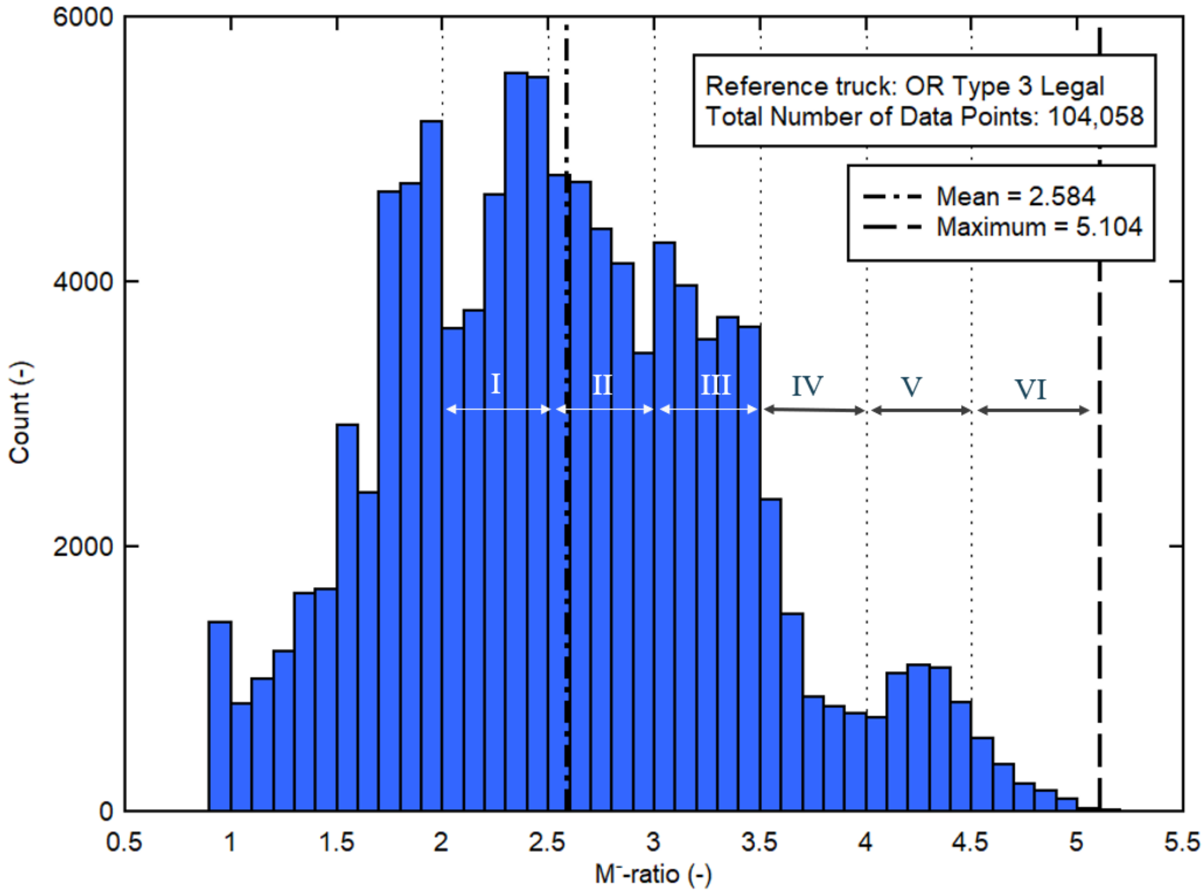


Figure B21. Histogram of maximum negative bending moment ratio (full database) normalized by OR Type 3 Legal Truck

Class	*Count*
0.90	1427
1.00	810
1.10	995
1.20	1209
1.30	1649
1.40	1681
1.50	2921
1.60	2406
1.70	4679
1.80	4742
1.90	5205
2.00	3649
2.10	3787
2.20	4663
2.30	5571
2.40	5533
2.50	4802
2.60	4746
2.70	4392
2.80	4142
2.90	3458
3.00	4291
3.10	3965
3.20	3568
3.30	3735
3.40	3653
3.50	2352
3.60	1493
3.70	860
3.80	794
3.90	740
4.00	708
4.10	1039
4.20	1108
4.30	1080
4.40	823
4.50	550
4.60	351
4.70	204
4.80	153
4.90	93
5.00	18
5.10	13

Figure B22. Count of maximum negative bending moment ratio (full database) normalized by OR Type 3 Legal Truck

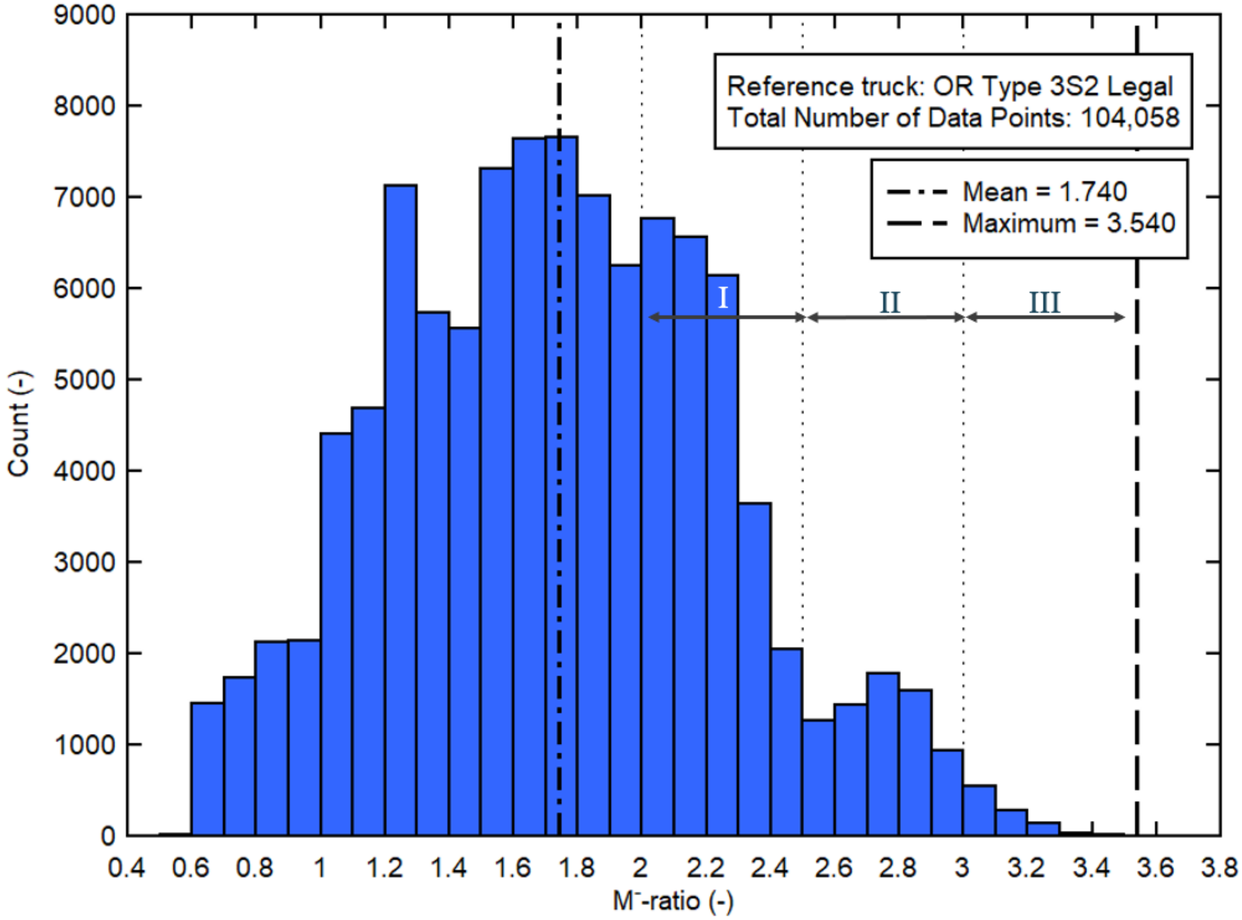


Figure B23. Histogram of maximum negative bending moment ratio (full database) normalized by OR Type 3S2 Legal Truck

Class	*Count*
0.50	18
0.60	1449
0.70	1732
0.80	2125
0.90	2148
1.00	4404
1.10	4682
1.20	7121
1.30	5733
1.40	5567
1.50	7309
1.60	7644
1.70	7655
1.80	7020
1.90	6254
2.00	6773
2.10	6564
2.20	6146
2.30	3636
2.40	2053
2.50	1258
2.60	1437
2.70	1788
2.80	1591
2.90	938
3.00	552
3.10	286
3.20	135
3.30	28
3.40	8
3.50	4

Figure B24. Count of maximum negative bending moment ratio (full database) normalized by OR Type 3S2 Legal Truck

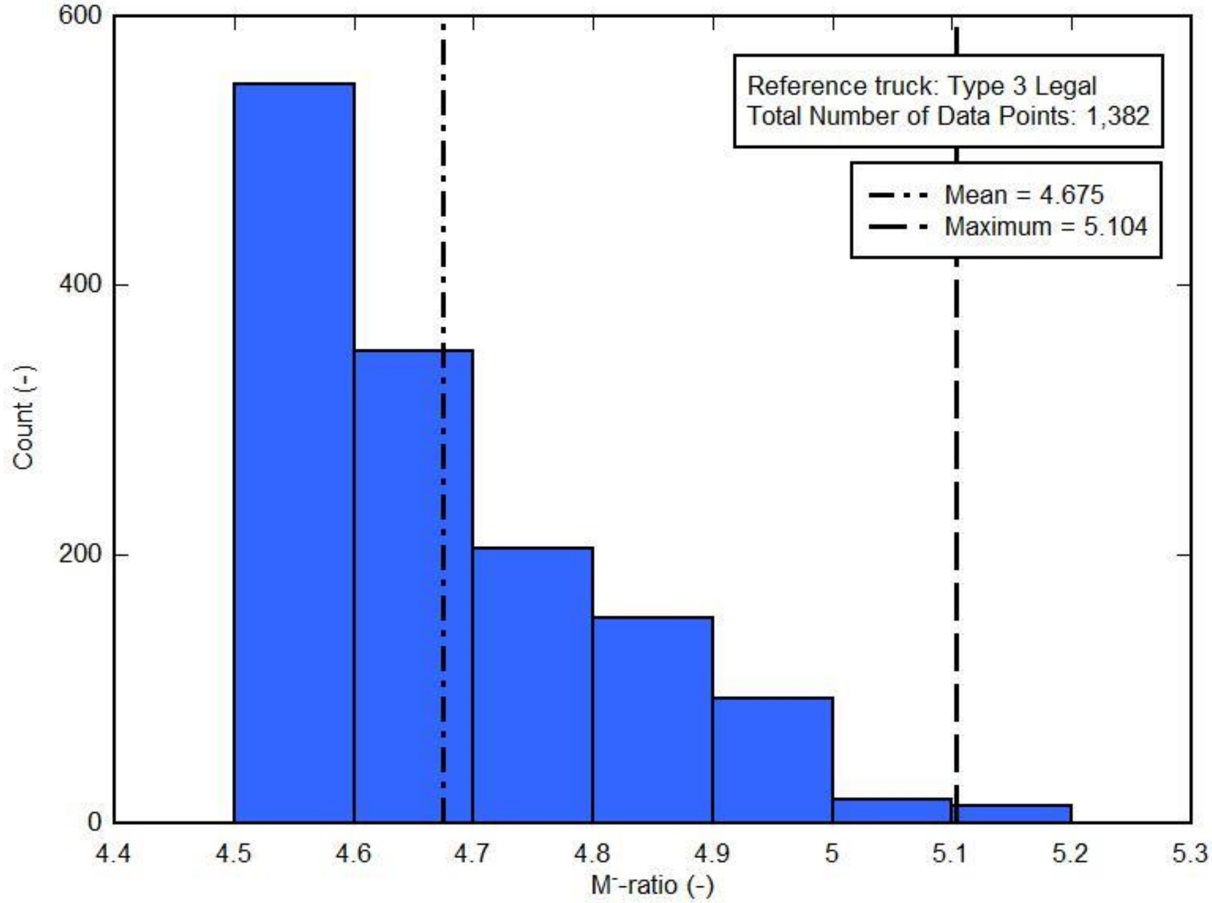


Figure B25. Histogram of maximum negative bending moment ratio (4.5+ ratio) normalized by OR Type 3 Legal Truck

Class	*Count*
4.50	550
4.60	351
4.70	204
4.80	153
4.90	93
5.00	18
5.10	13

Figure B26. Count of maximum negative bending moment ratio (4.5+ ratio) normalized by OR Type 3 Legal Truck

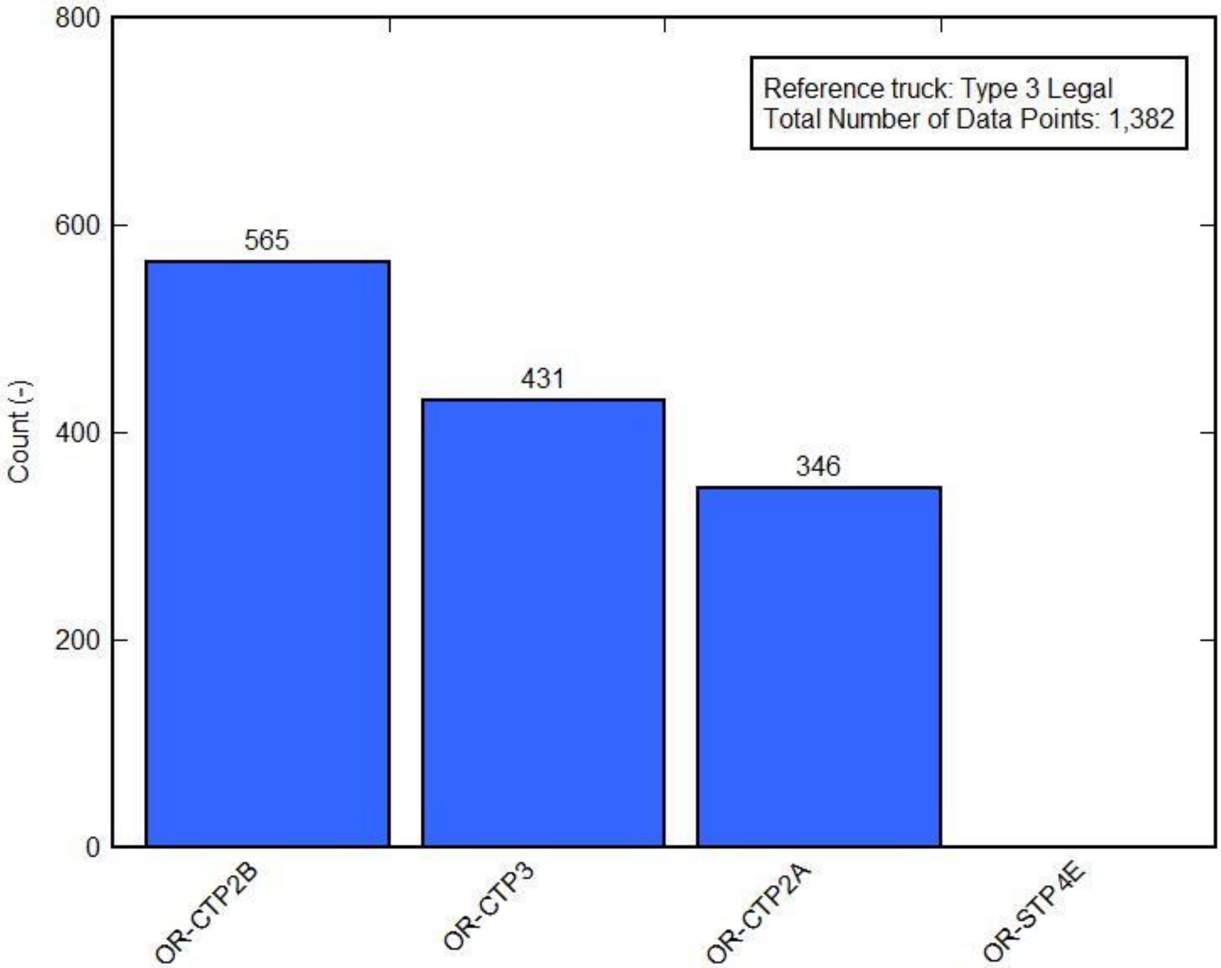


Figure B27. Histogram of maximum negative bending moment by truck type (4.5+ ratio) normalized by OR Type 3 Legal Truck

Truck Type	***Count***
CTP2B	565
CTP3	431
CTP2A	346
STP4E	40

Figure B28. Count of maximum negative bending moment by truck type (2.0+ ratio) normalized by OR Type 3 Legal Truck

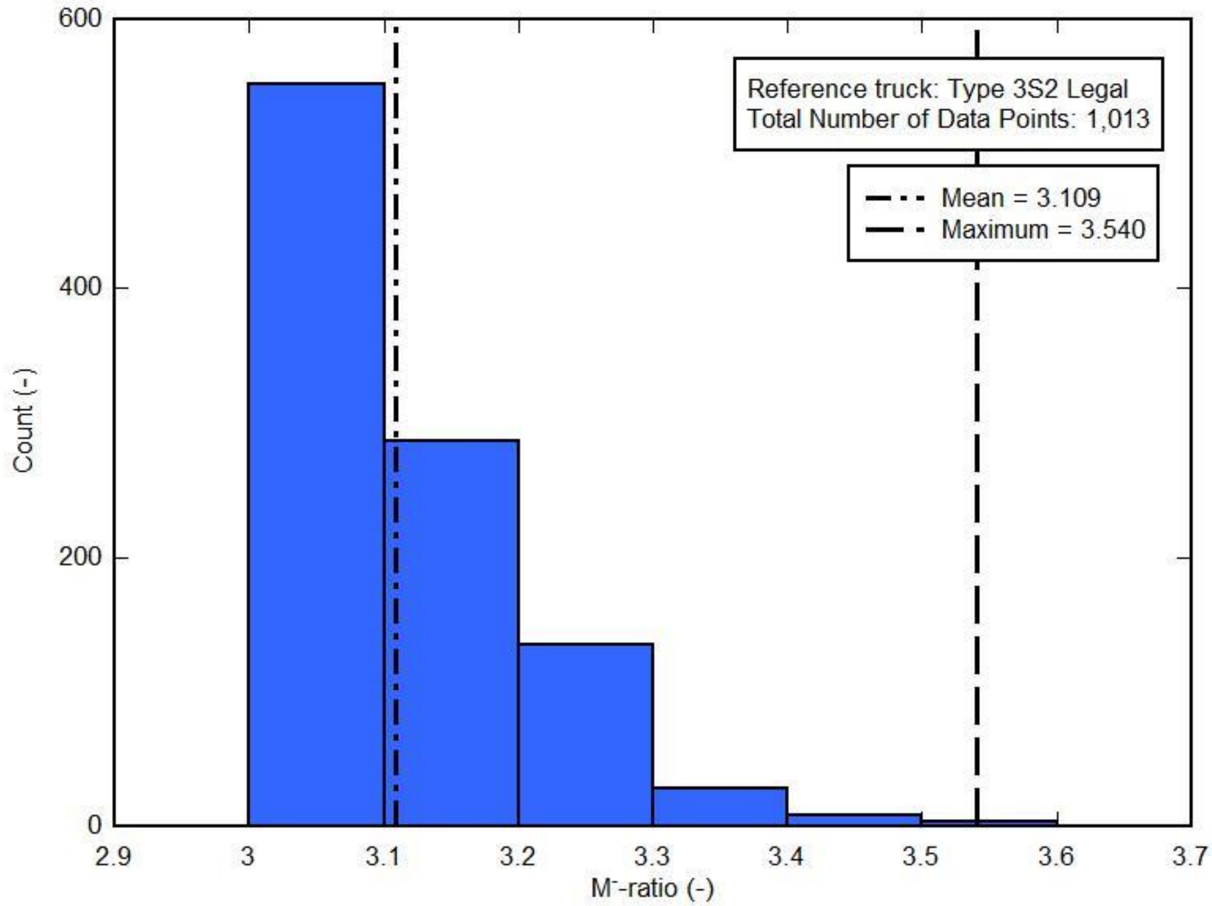


Figure B29. Histogram of maximum negative bending moment ratio (3.0+ ratio) normalized by OR Type 3S2 Legal Truck

Class	***Count***
3.00	552
3.10	286
3.20	135
3.30	28
3.40	8
3.50	4

Figure B30. Count of maximum negative bending moment ratio (3.0+ ratio) normalized by OR Type 3S2 Legal Truck

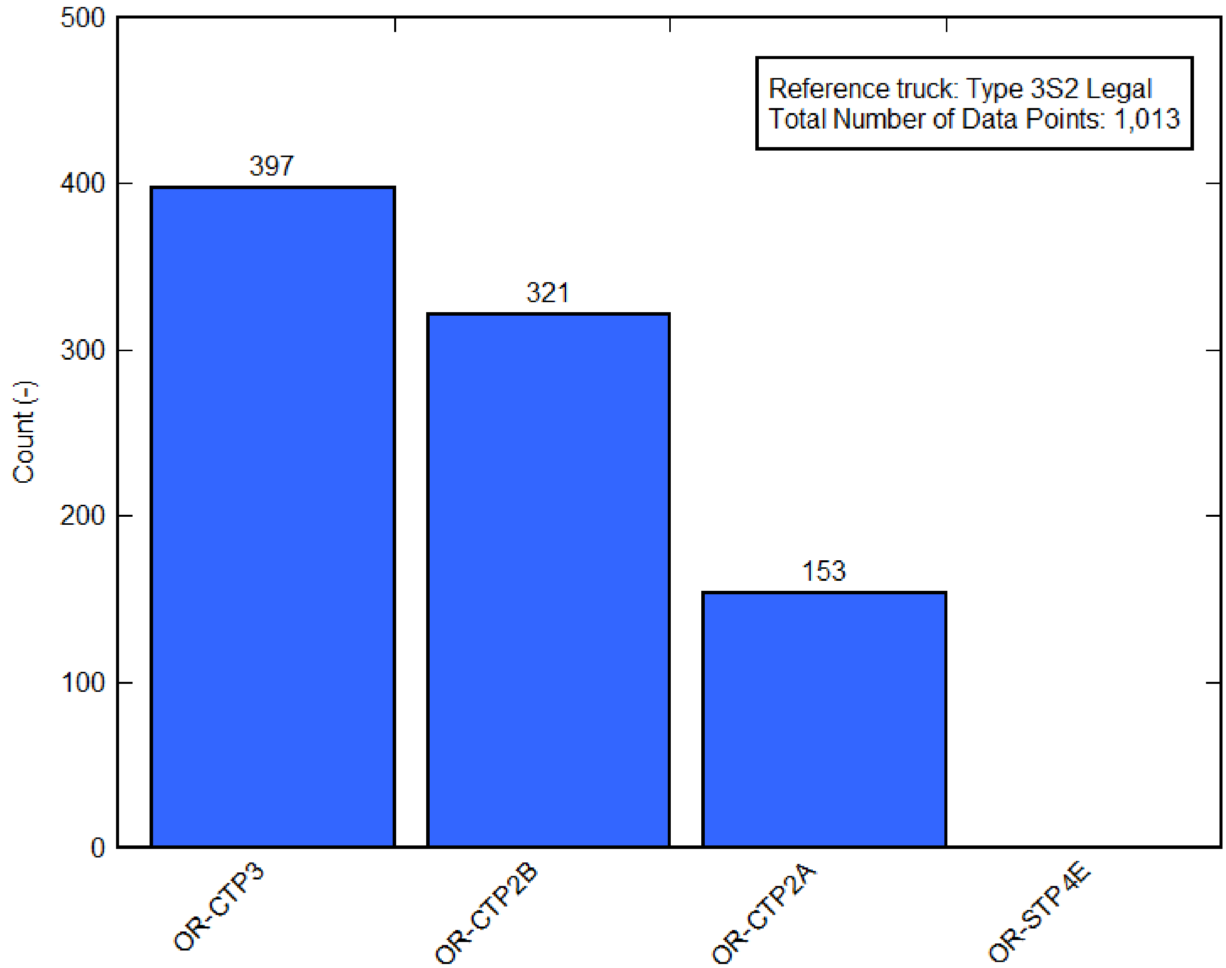


Figure B31. Histogram of maximum negative bending moment (the 95th percentile) normalized by OR Type 3 Legal Truck

Truck Type	***Count***
CTP3	397
CTP2B	321
CTP2A	153
STP4E	142

Figure B32. Count of maximum negative bending moment (the 95th percentile) normalized by OR Type 3 Legal Truck

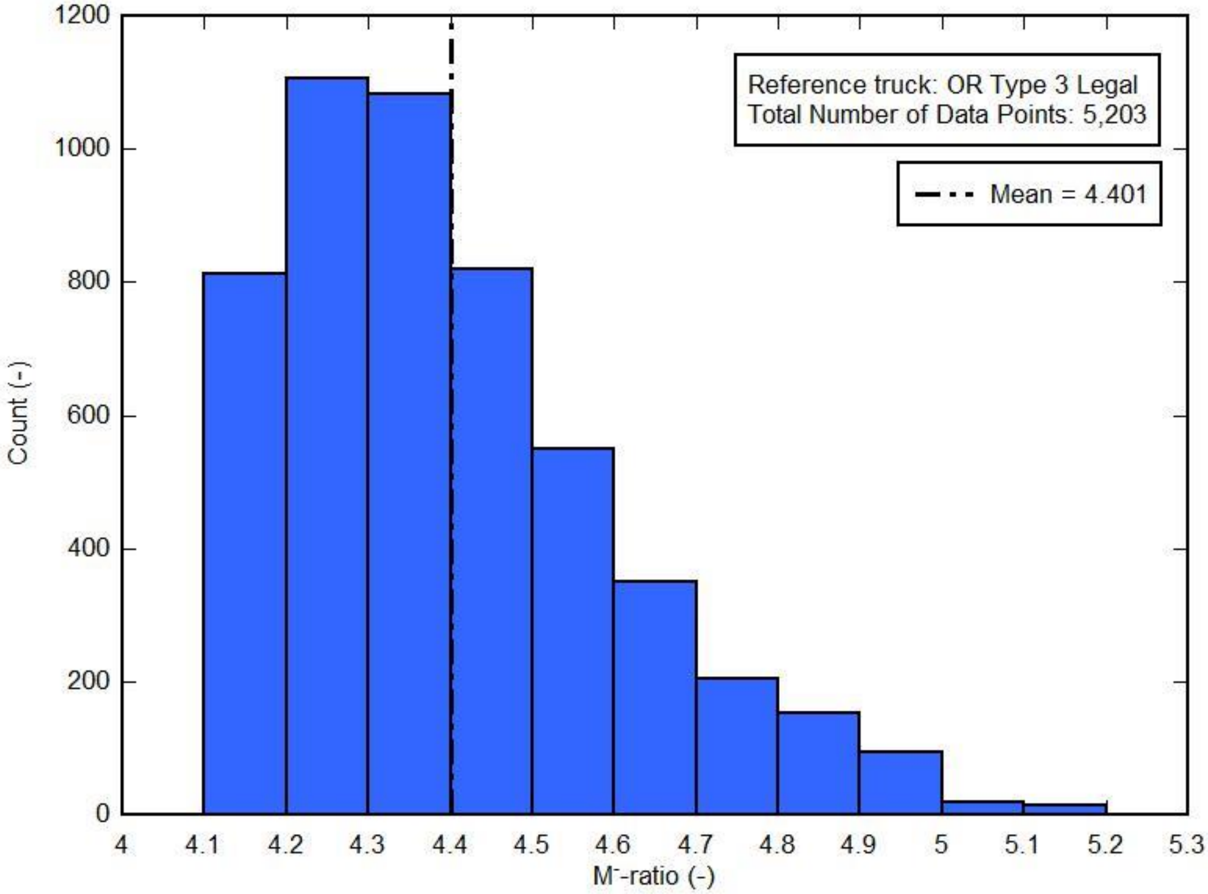


Figure B33. Histogram of maximum negative bending moment (the 95th percentile) normalized by OR Type 3 Legal Truck

Class	*Count*
4.10	812
4.20	1106
4.30	1083
4.40	820
4.50	550
4.60	351
4.70	204
4.80	153
4.90	93
5.00	18
5.10	13

Figure B34. Count of maximum negative bending moment (the 95th percentile) normalized by OR Type 3 Legal Truck

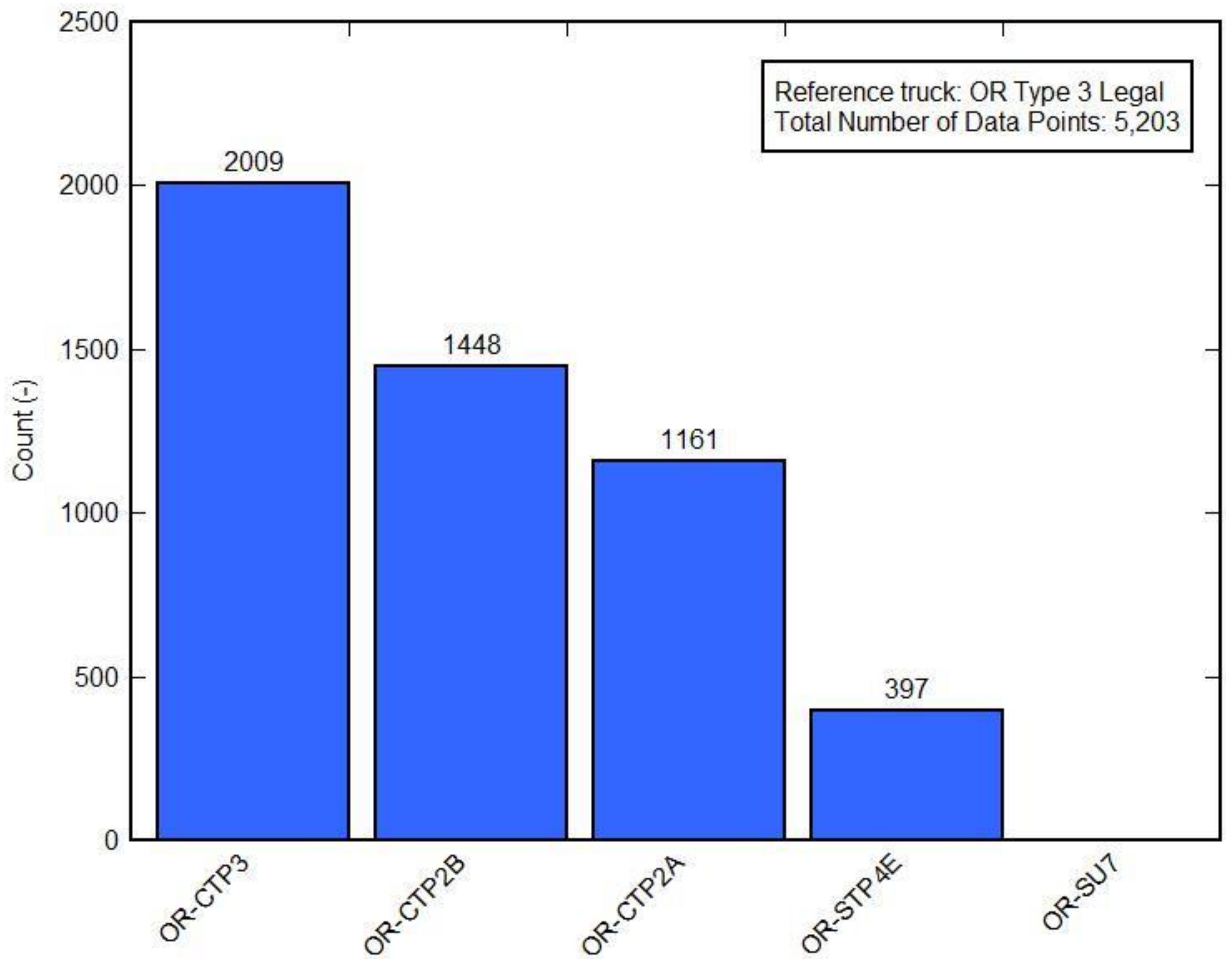


Figure B35. Histogram of maximum negative bending by truck type (the 95th percentile) normalized by OR Type 3 Legal Truck

Truck Type	***Count***
CTP3	2009
CTP2B	1448
CTP2A	1161
STP4E	397
SU7	188

Figure B36. Count of maximum negative bending by truck type (the 95th percentile) normalized by OR Type 3 Legal Truck

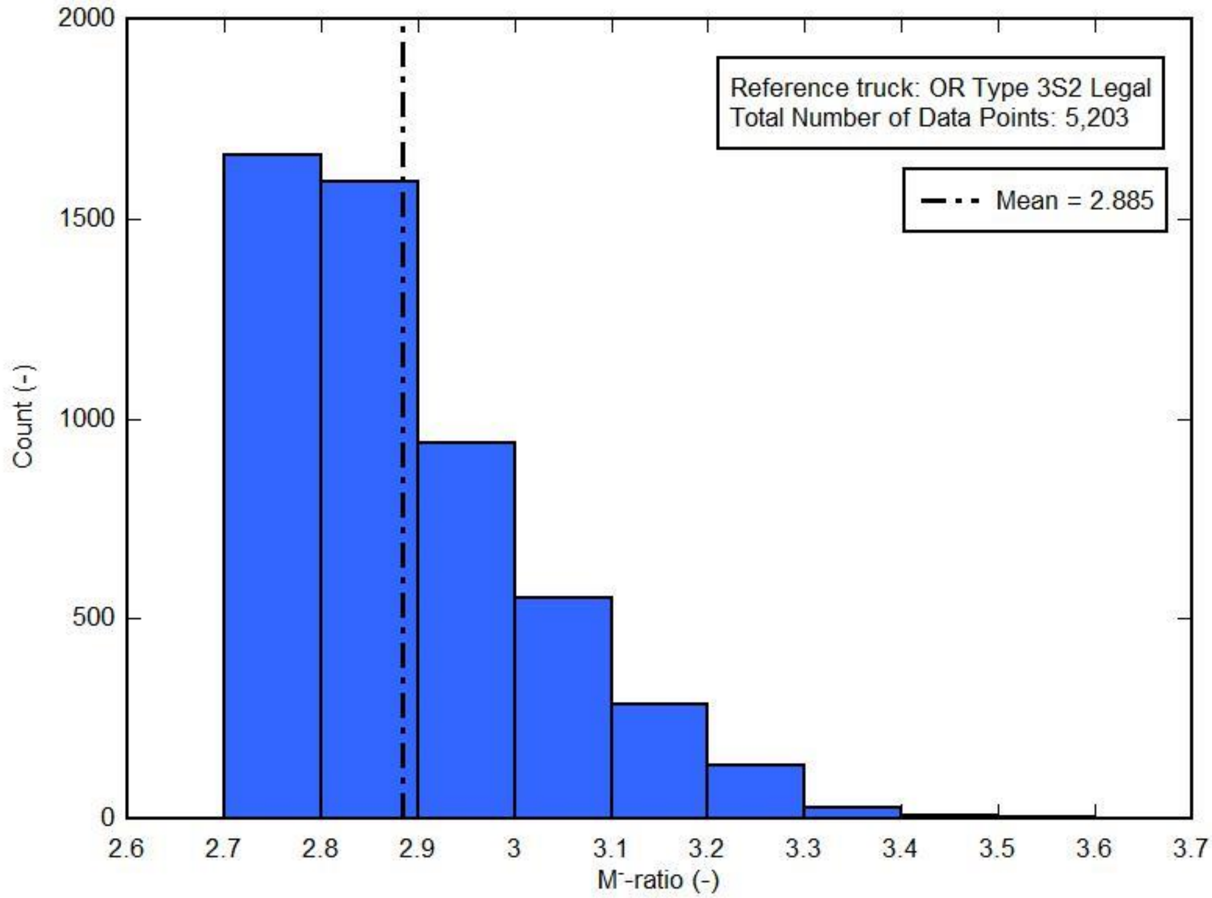


Figure B37. Histogram of maximum negative bending moment (the 95th percentile) normalized by OR Type 3S2 Legal Truck

Class	*Count*
2.70	1661
2.80	1591
2.90	938
3.00	552
3.10	286
3.20	135
3.30	28
3.40	8
3.50	4

Figure B38. Count of maximum negative bending moment (the 95th percentile) normalized by OR Type 3S2 Legal Truck

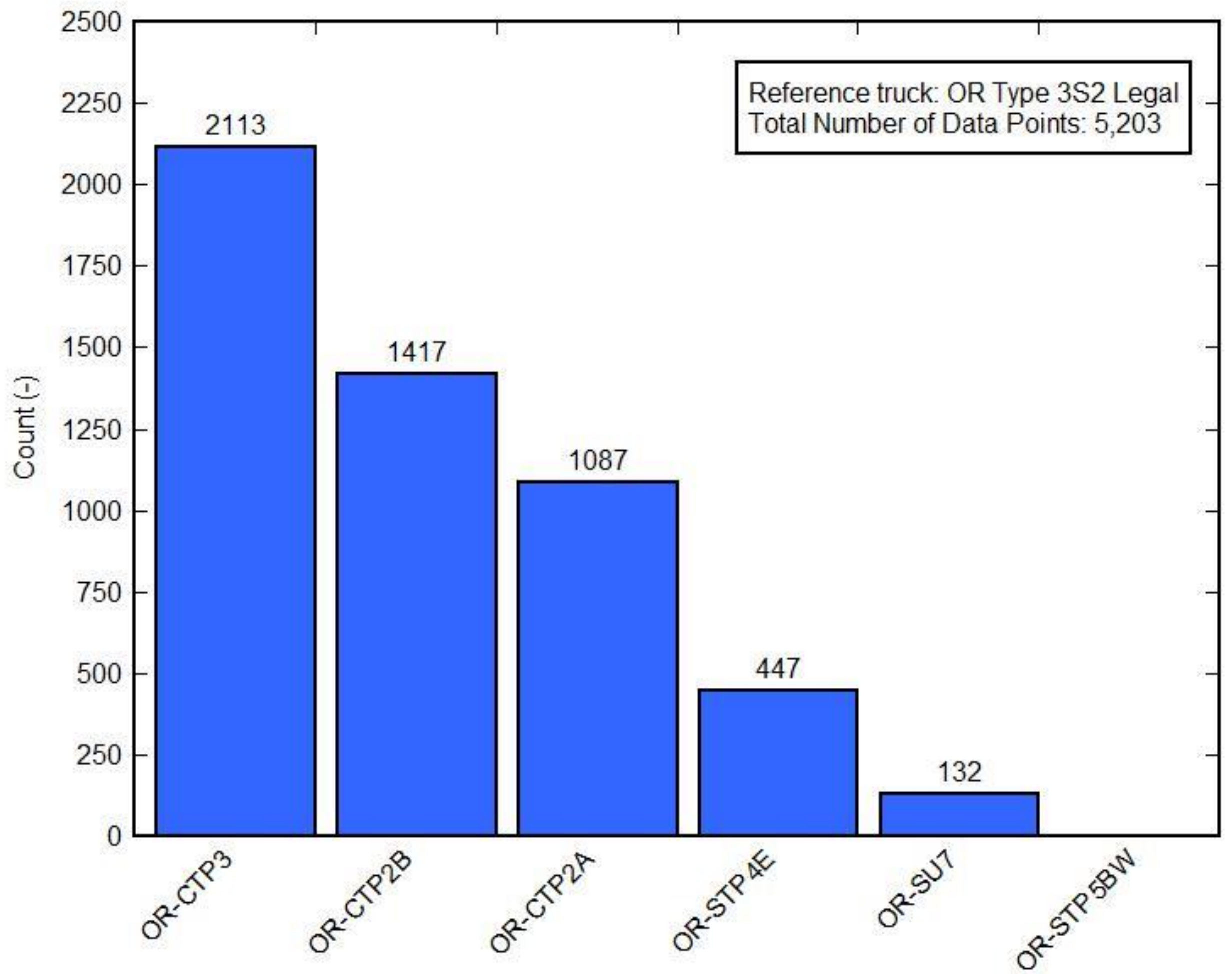


Figure B39. Histogram of maximum negative bending by truck type (the 95th percentile) normalized by OR Type 3S2 Legal Truck

Truck Type	***Count***
CTP3	2113
CTP2B	1417
CTP2A	1087
STP4E	447
SU7	132
STP5BW	7

Figure B40. Count of maximum negative bending by truck type (the 95th percentile) normalized by OR Type 3S2 Legal Truck

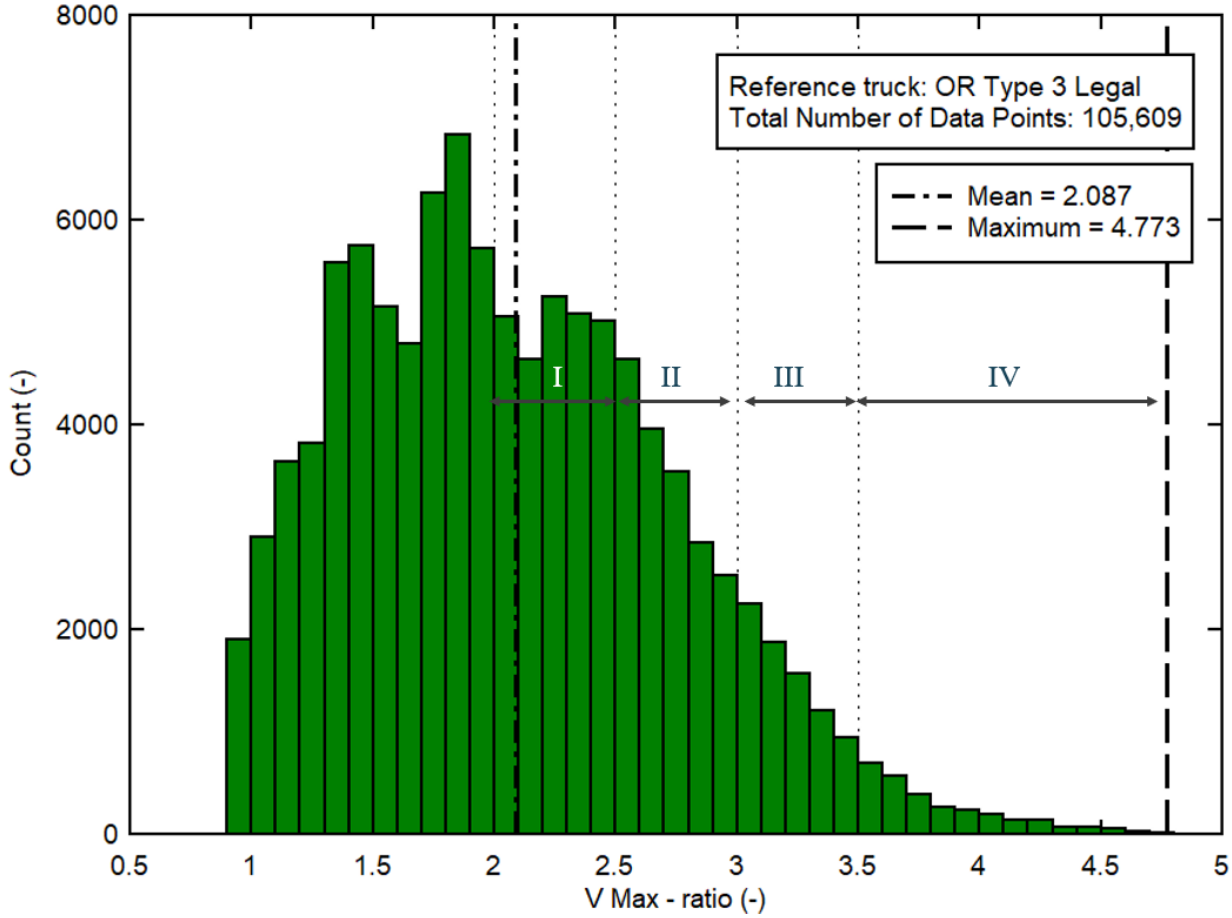


Figure B41. Histogram of maximum shear ratio (full database) normalized by OR Type 3 Legal Truck

Class	*Count*
0.90	1900
1.00	2906
1.10	3645
1.20	3826
1.30	5590
1.40	5744
1.50	5147
1.60	4794
1.70	6257
1.80	6830
1.90	5725
2.00	5052
2.10	4633
2.20	5252
2.30	5077
2.40	5019
2.50	4638
2.60	3956
2.70	3540
2.80	2845
2.90	2534
3.00	2244
3.10	1874
3.20	1570
3.30	1207
3.40	943
3.50	696
3.60	566
3.70	389
3.80	266
3.90	242
4.00	195
4.10	136
4.20	144
4.30	63
4.40	68
4.50	53
4.60	30
4.70	13

Figure B42. Count of maximum shear ratio (full database) normalized by OR Type 3 Legal Truck

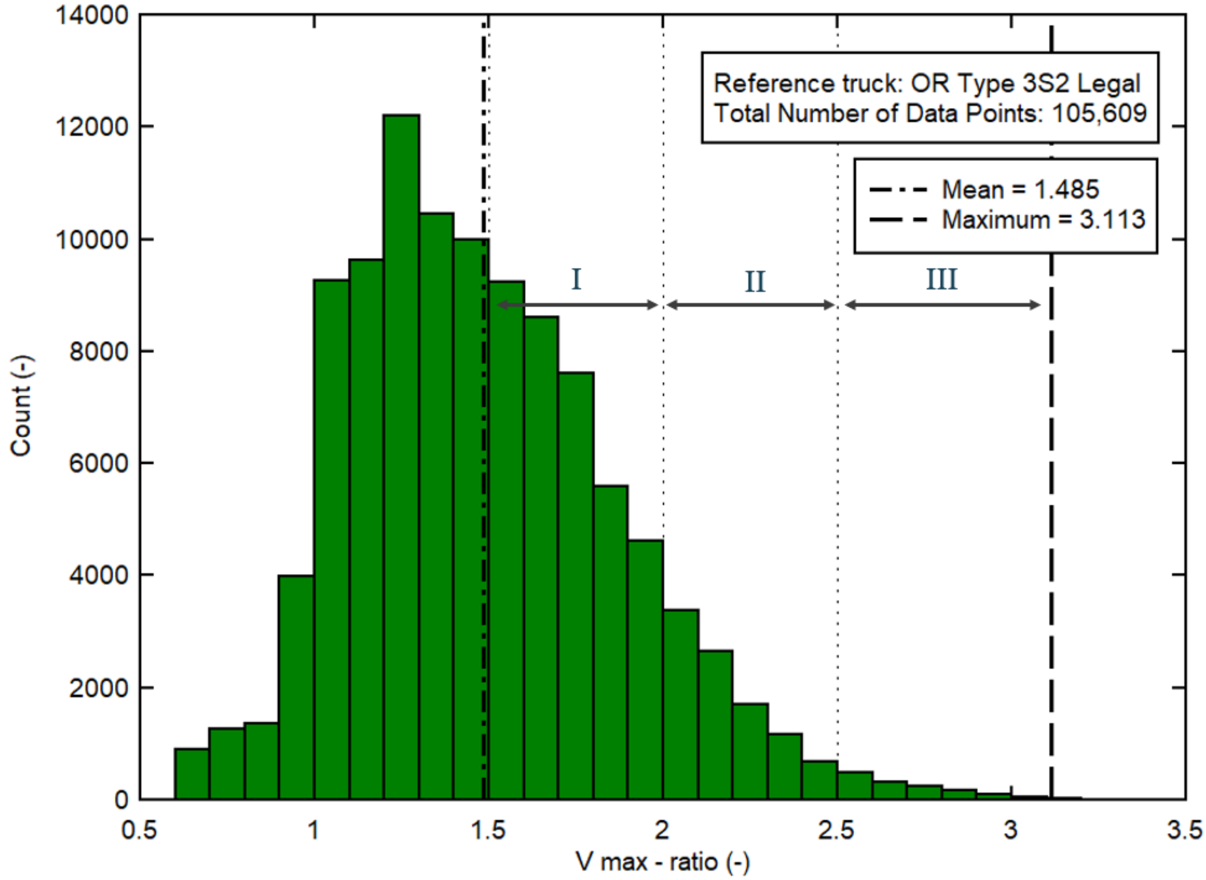


Figure B43. Histogram of maximum shear ratio (full database) normalized by OR Type 3S2 Legal Truck

Class	*Count*
0.60	892
0.70	1275
0.80	1360
0.90	3984
1.00	9266
1.10	9614
1.20	12202
1.30	10444
1.40	9981
1.50	9229
1.60	8611
1.70	7587
1.80	5602
1.90	4621
2.00	3377
2.10	2662
2.20	1699
2.30	1167
2.40	670
2.50	487
2.60	316
2.70	234
2.80	179
2.90	99
3.00	44
3.10	13

Figure B44. Count of maximum shear ratio (full database) normalized by OR Type 3S2 Legal Truck

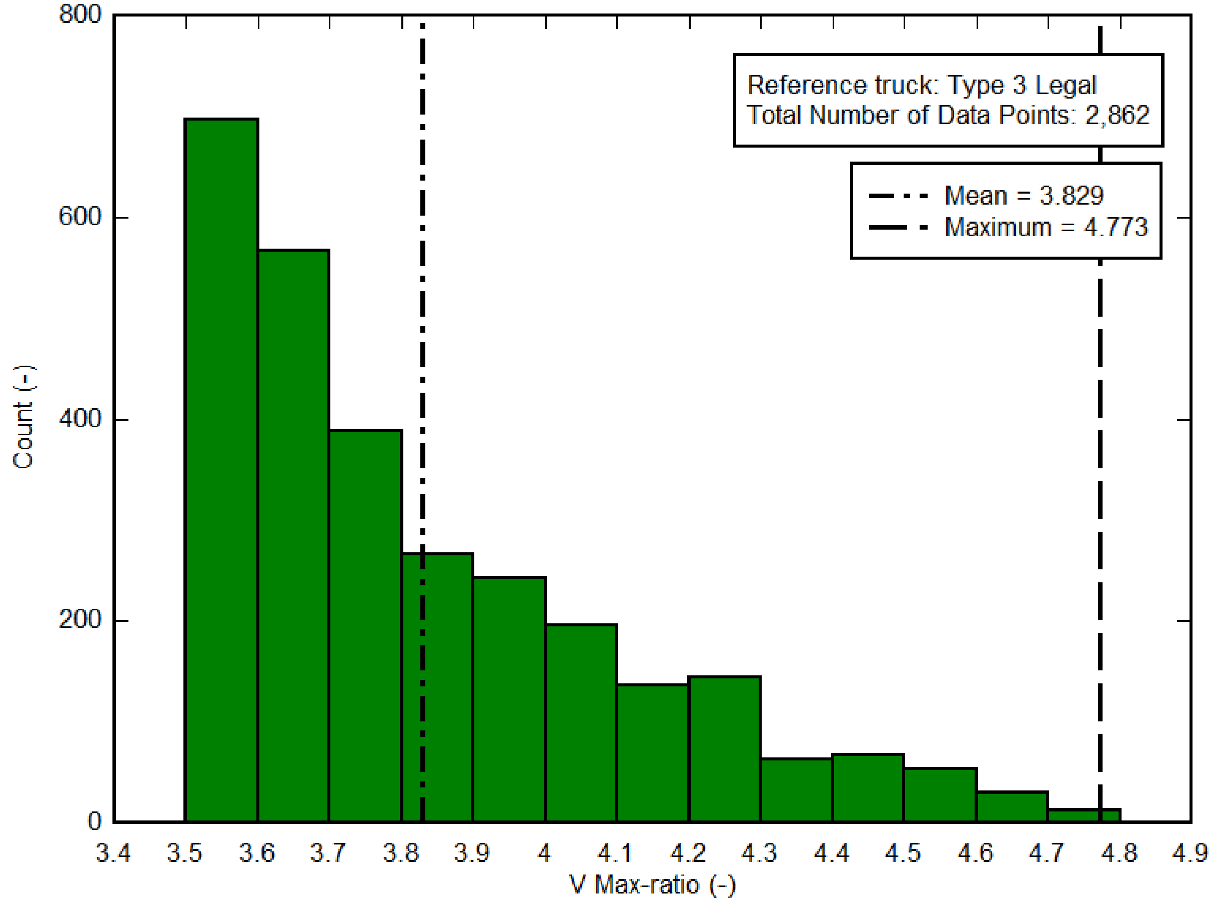


Figure B45. Histogram of maximum shear ratio (3.5+ ratio) normalized by OR Type 3 Legal Truck

Class	***Count***
3.50	697
3.60	566
3.70	389
3.80	266
3.90	242
4.00	195
4.10	136
4.20	144
4.30	63
4.40	68
4.50	53
4.60	30
4.70	13

Figure B46. Count of maximum shear ratio (3.5+ ratio) normalized by OR Type 3 Legal Truck

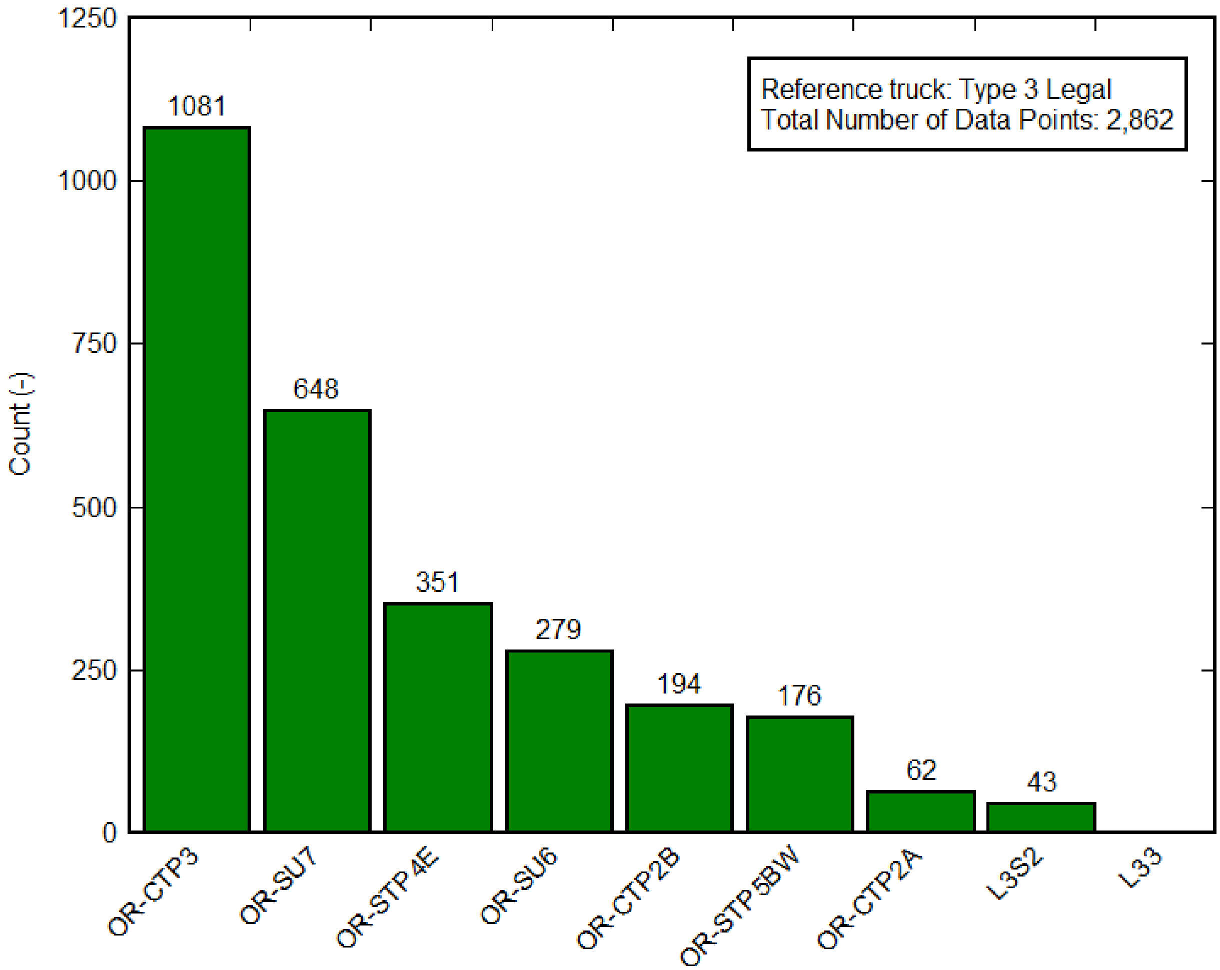


Figure B47. Histogram of maximum shear by truck type (3.5+ ratio) normalized by OR Type 3 Legal Truck

Truck Type	***Count***
CTP3	1081
SU7	648
STP4E	351
SU6	279
CTP2B	194
STP5BW	176
CTP2A	62
Legal3S2	43
Legal33	28

Figure B48. Count of maximum shear by truck type (3.5+ ratio) normalized by OR Type 3 Legal Truck

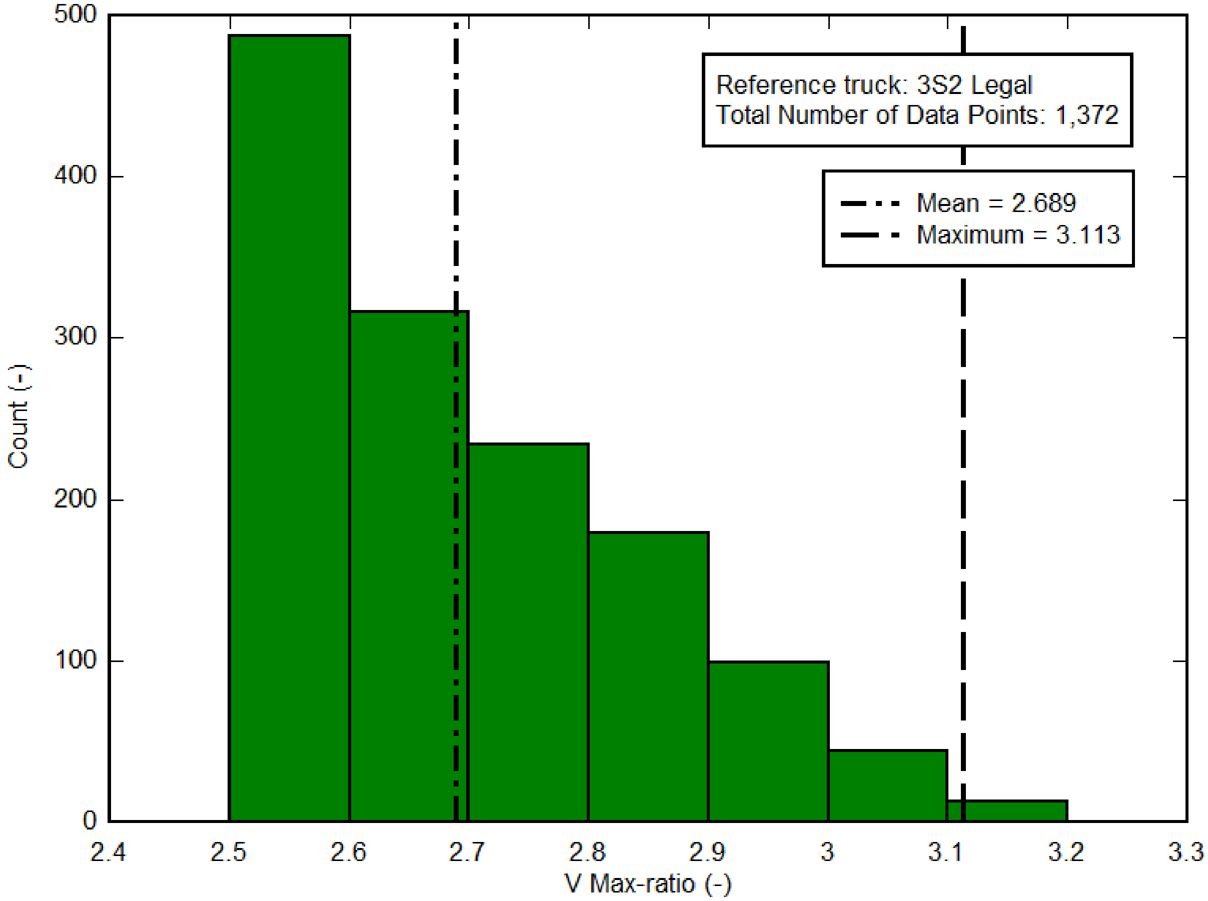


Figure B49. Histogram of maximum shear ratio (2.2+ ratio) normalized by OR Type 3S2 Legal Truck

Class	Count
2.50	487
2.60	316
2.70	234
2.80	179
2.90	99
3.00	44
3.10	13

Figure B50. Count of maximum shear ratio (2.2+ ratio) normalized by OR Type 3S2 Legal Truck

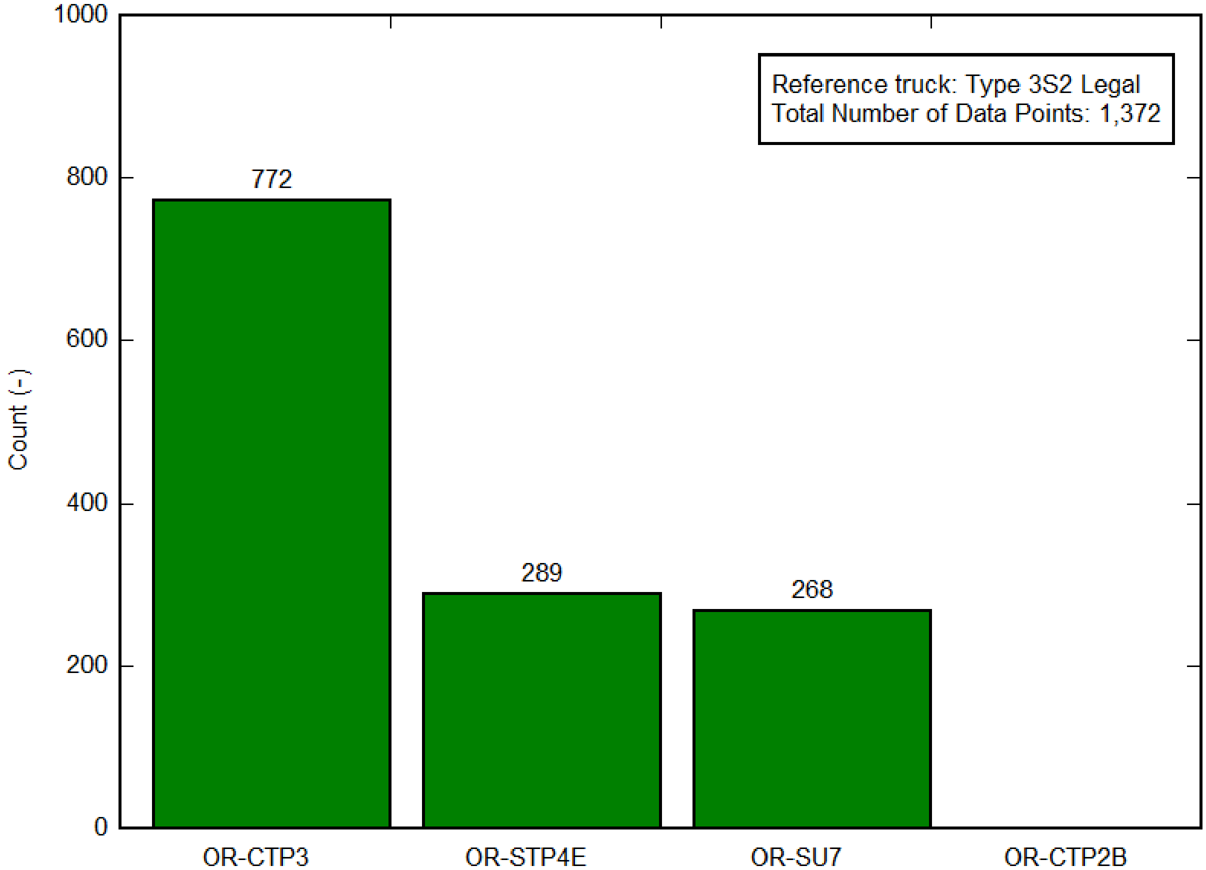


Figure B51. Histogram of maximum shear by truck type (2.5+ ratio) normalized by OR Type 3S2 Legal Truck

Truck Type	***Count***
CTP3	772
STP4E	289
SU7	268
CTP2B	43

Figure B52. Count of maximum shear by truck type (2.5+ ratio) normalized by OR Type 3S2 Legal Truck

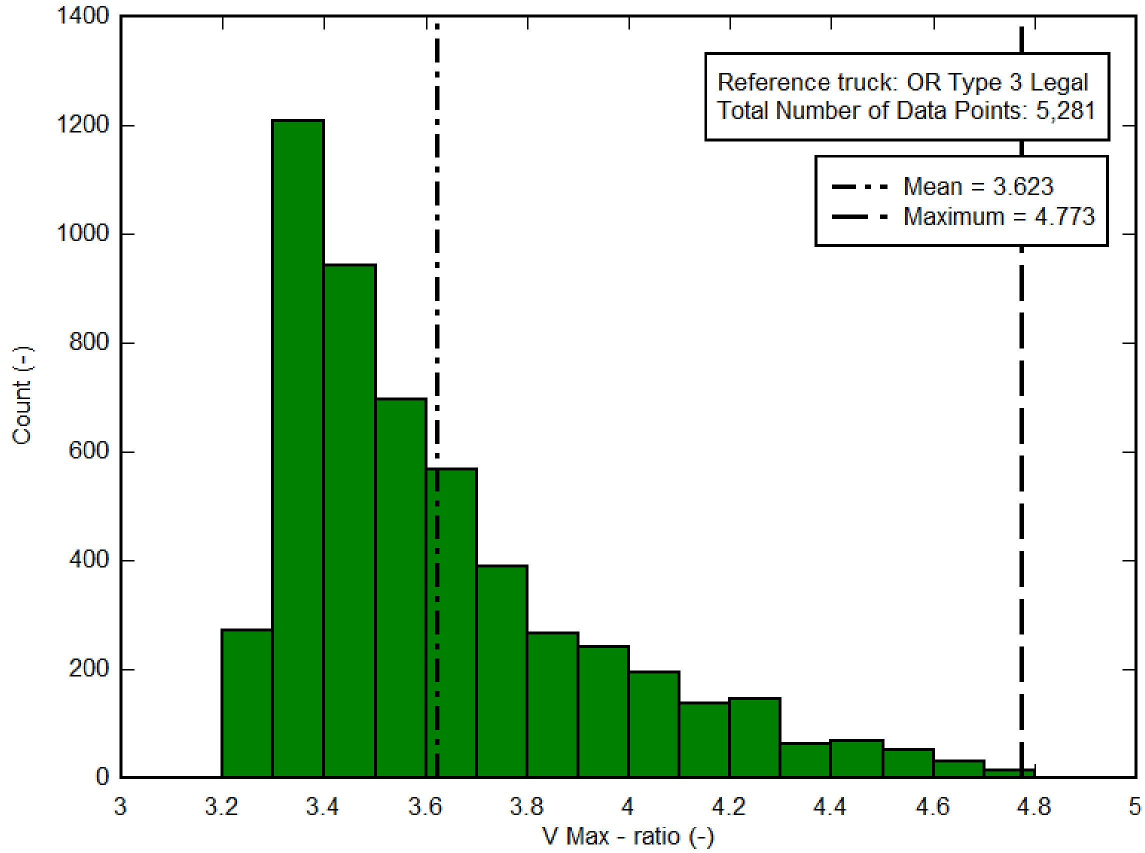


Figure B53. Histogram of maximum shear (the 95th percentile) normalized by OR Type 3 Legal Truck

Class	Count
3.20	271
3.30	1207
3.40	943
3.50	696
3.60	566
3.70	389
3.80	266
3.90	242
4.00	195
4.10	136
4.20	144
4.30	63
4.40	68
4.50	53
4.60	30
4.70	13

Figure B54. Count of maximum shear (the 95th percentile) normalized by OR Type 3 Legal Truck

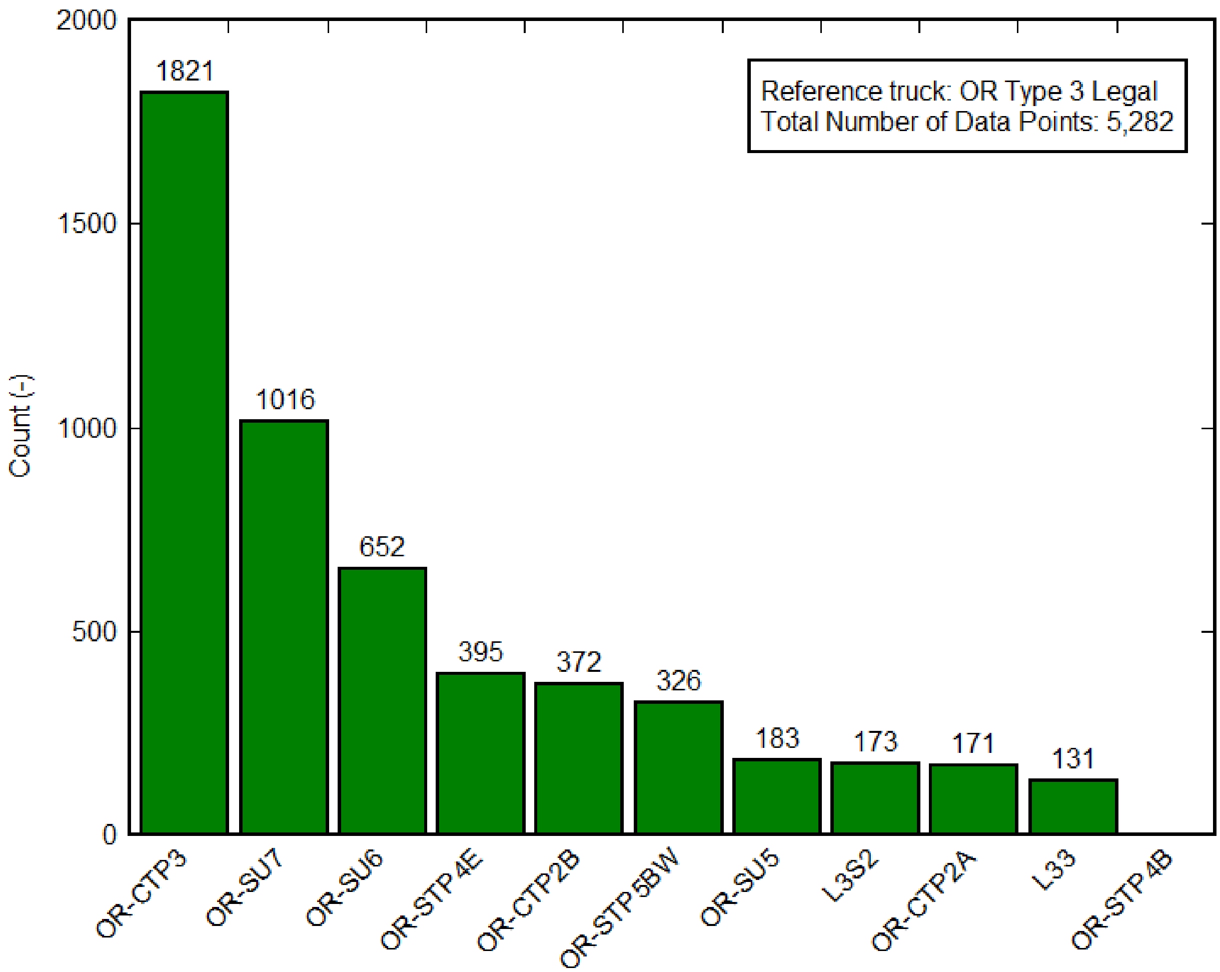


Figure B55. Histogram of maximum shear by truck type (the 95th percentile) normalized by OR Type 3 Legal Truck

Truck Type	***Count***
CTP3	1821
SU7	1016
SU6	652
STP4E	395
CTP2B	372
STP5BW	326
SU5	183
Legal3S2	173
CTP2A	171
Legal33	131
STP4B	42

Figure B56. Count of maximum shear by truck type (the 95th percentile) normalized by OR Type 3 Legal Truck

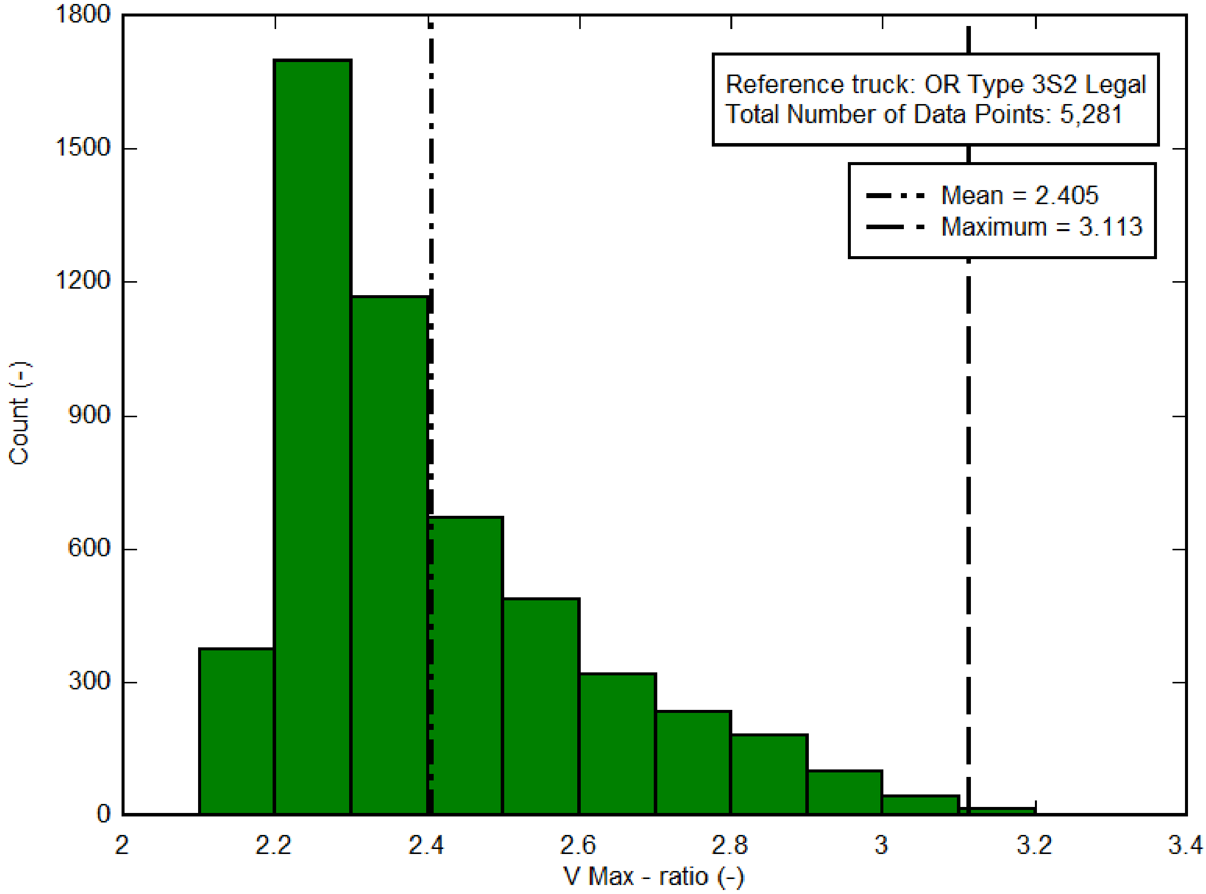


Figure B57. Histogram of maximum shear (the 95th percentile) normalized by OR Type 3S2 Legal Truck

Class	*Count*
2.10	373
2.20	1699
2.30	1167
2.40	670
2.50	487
2.60	316
2.70	234
2.80	179
2.90	99
3.00	44
3.10	13

Figure 58. Count of maximum shear (the 95th percentile) normalized by OR Type 3S2 Legal Truck

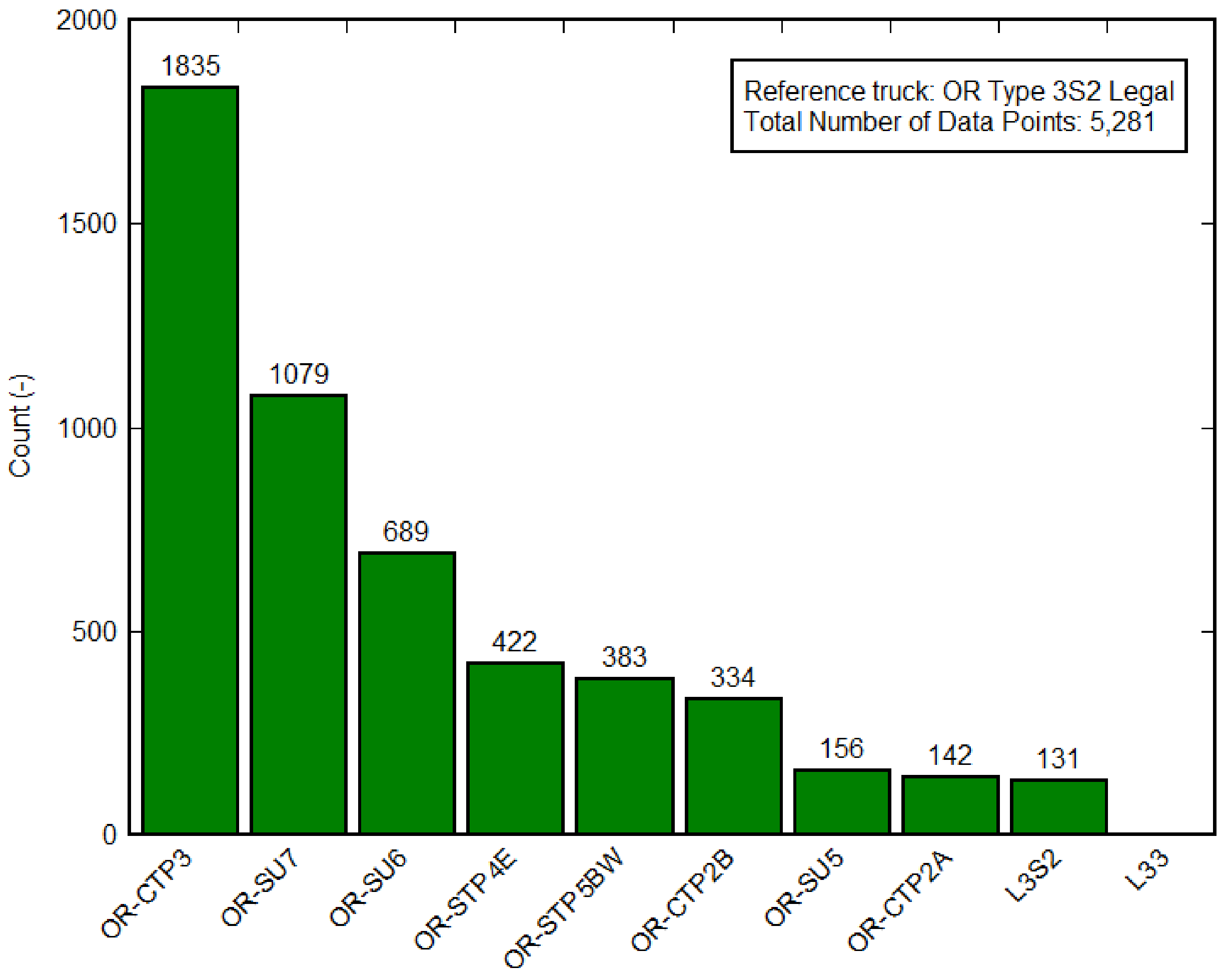


Figure B59. Histogram of maximum shear by truck type (the 95th percentile) normalized by OR Type 3S2 Legal Truck

Truck Type	Count
CTP3	1835
SU7	1079
SU6	689
STP4E	422
STP5BW	383
CTP2B	334
SU5	156
CTP2A	142
Legal3S2	131
Legal33	110

Figure B60. Count of maximum shear by truck type (the 95th percentile) normalized by OR Type 3S2 Legal Truck

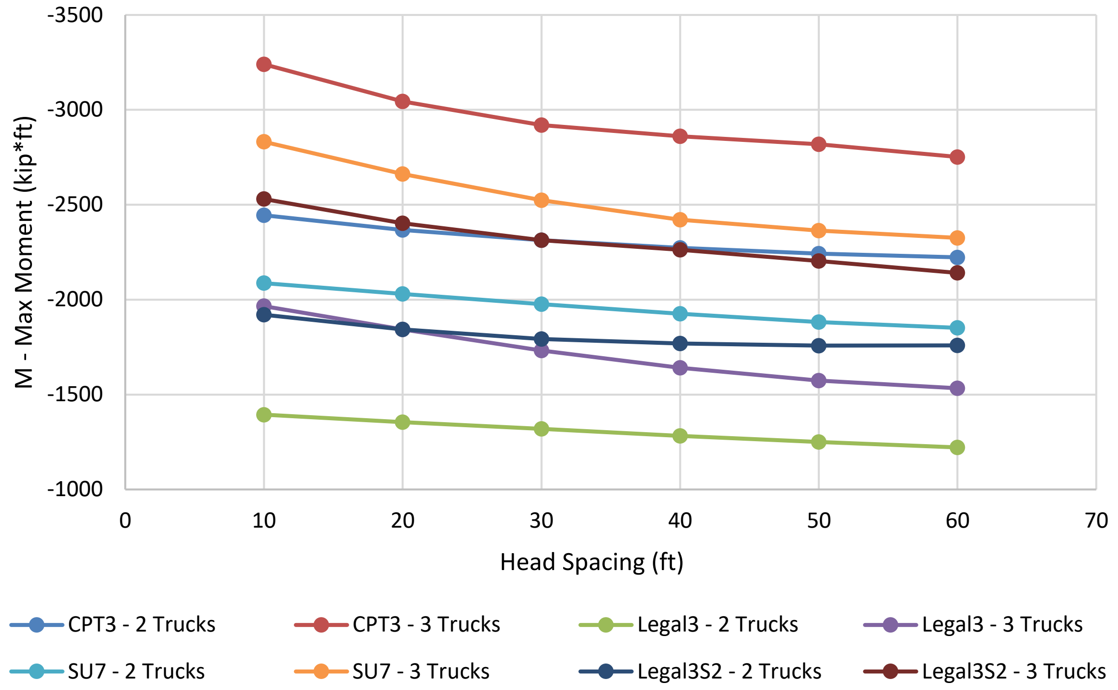
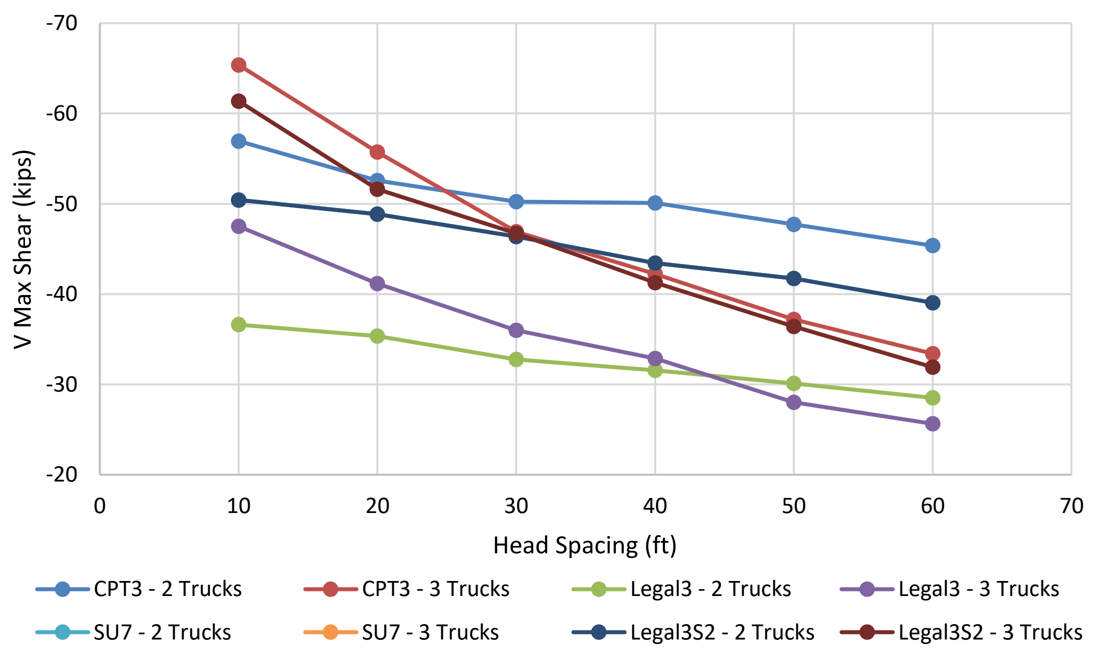


Figure B61: Effect of Head Spacing on Average Max Negative Moment of Two versus Three-Truck Platoons



igure B62: Effect of Head Spacing on Average Max Shear of Two versus Three-Truck Platoons

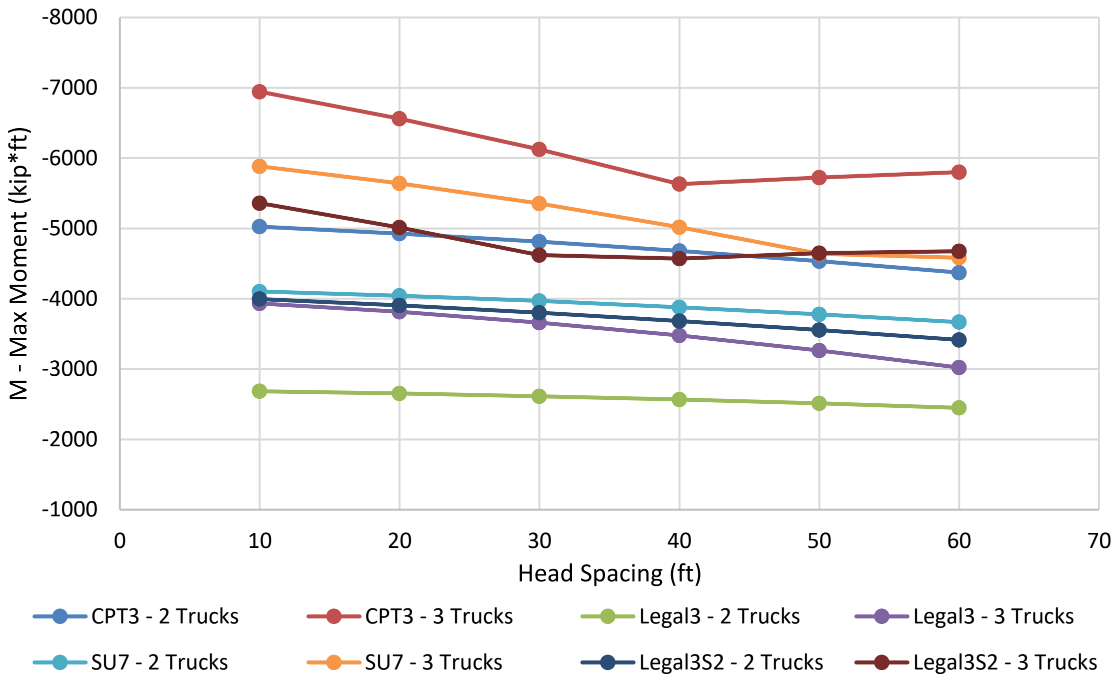


Figure B63: Effect of Head Spacing on Max Negative Moment of Two versus Three-Truck Platoons

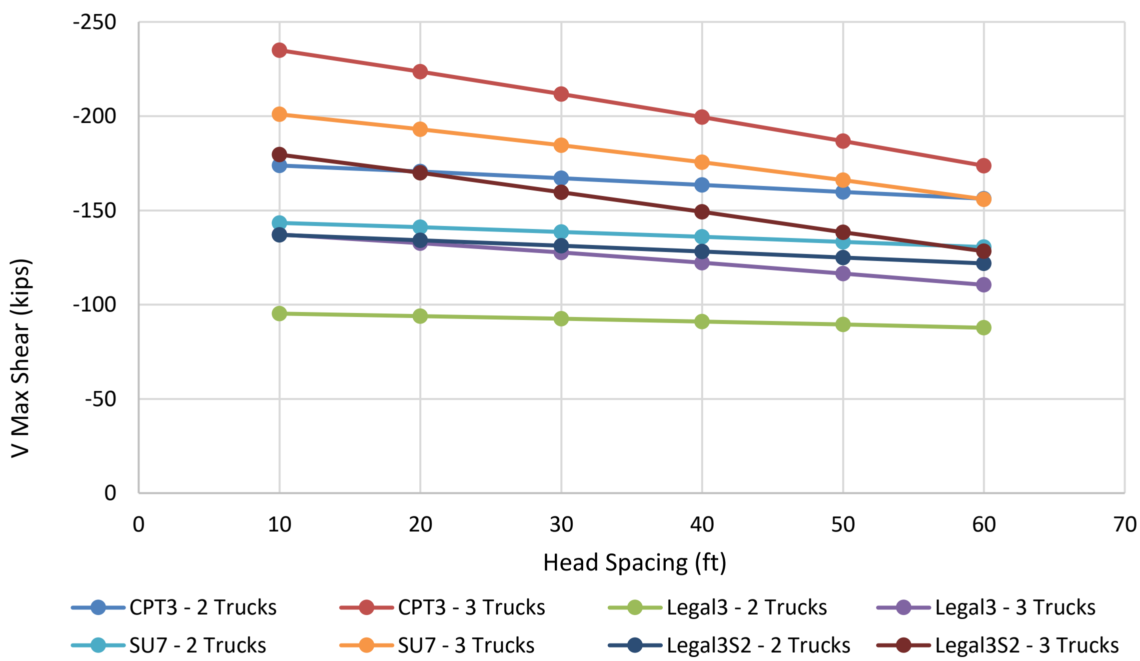


Figure B64: Effect of Head Spacing on Max Shear Moment of Two versus Three-Truck Platoons

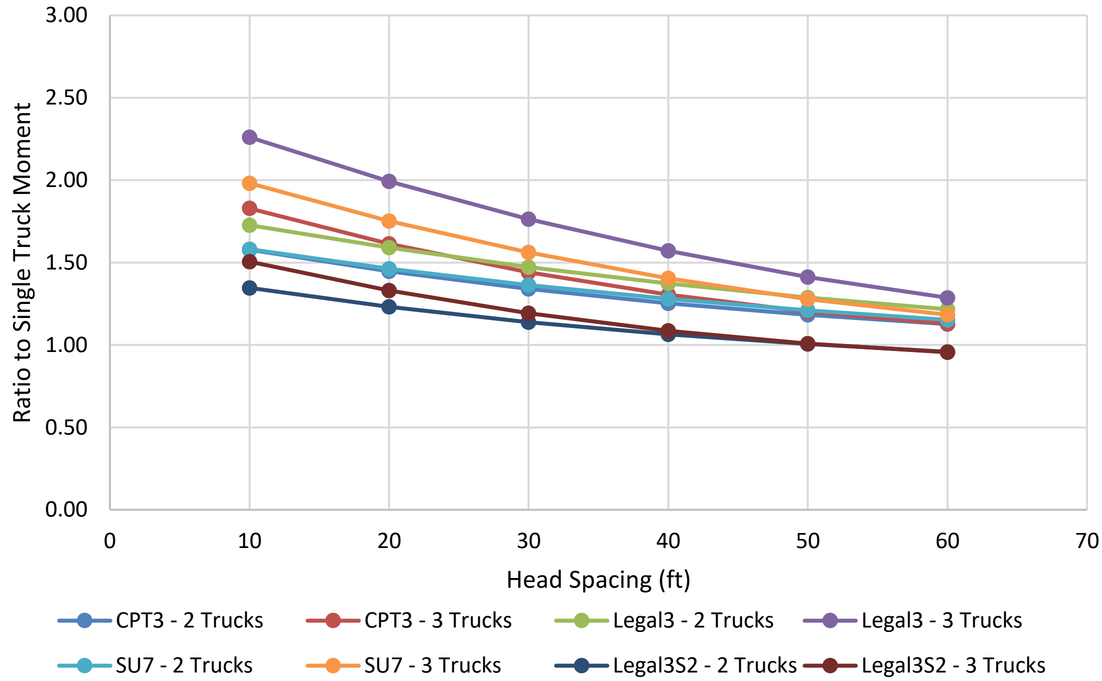


Figure B65: Effect of Head Spacing on Average Max Positive Moment of Single Truck Platoon Ratios for Two versus Three-Truck Platoons

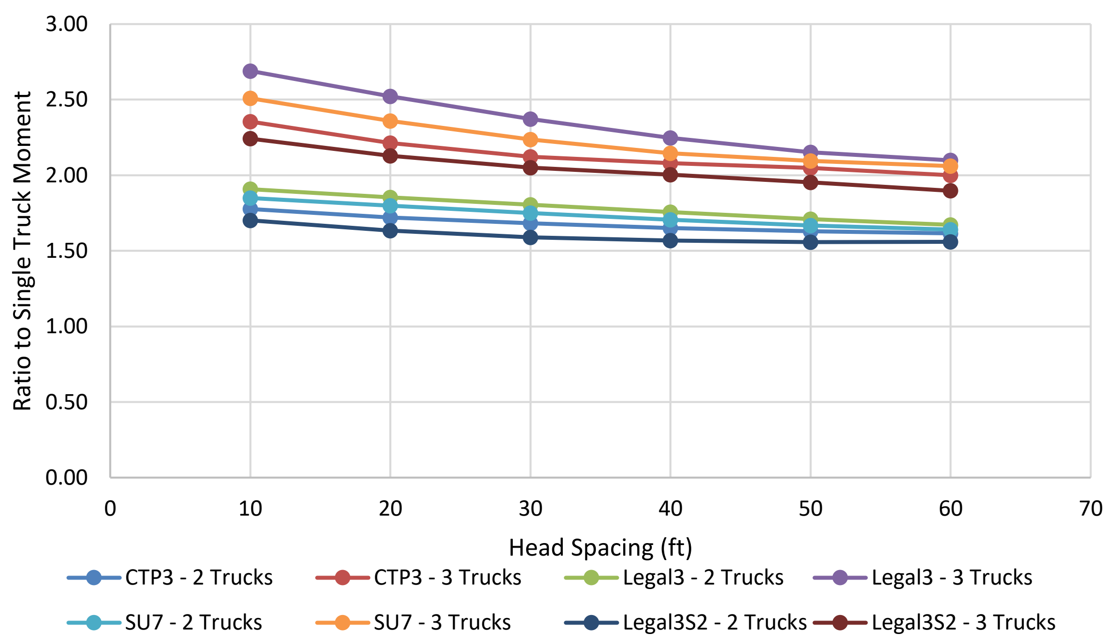


Figure B66: Effect of Head Spacing on Average Max Negative Moment of Single Truck Platoon Ratios for Two versus Three-Truck Platoons

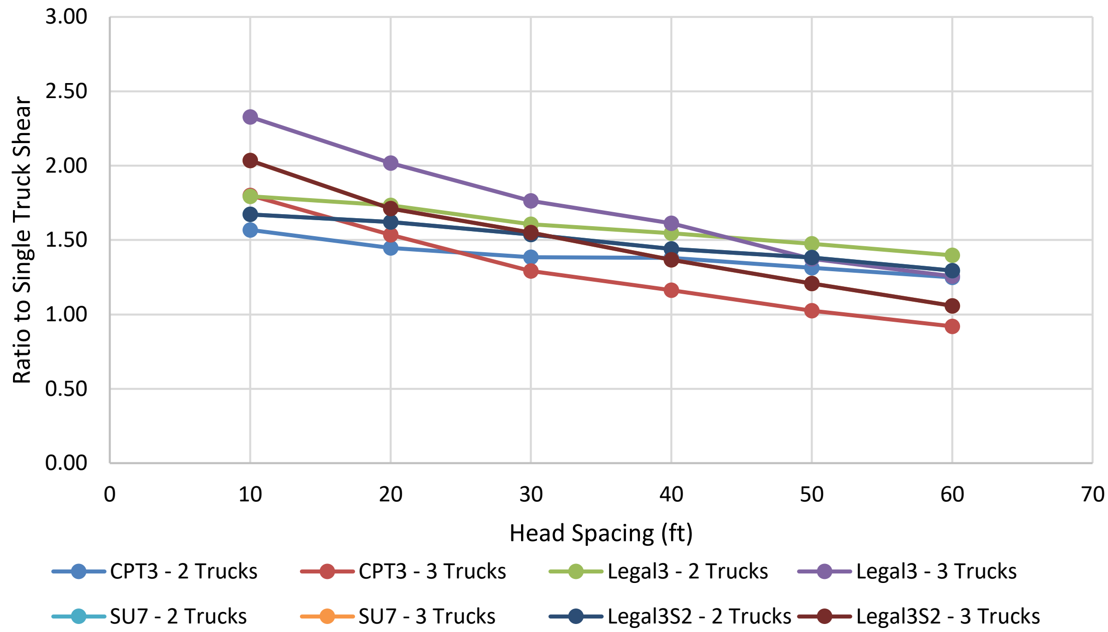


Figure B67: Effect of Head Spacing on Average Max Shear of Single Truck Platoon Ratios for Two versus Three-Truck Platoons

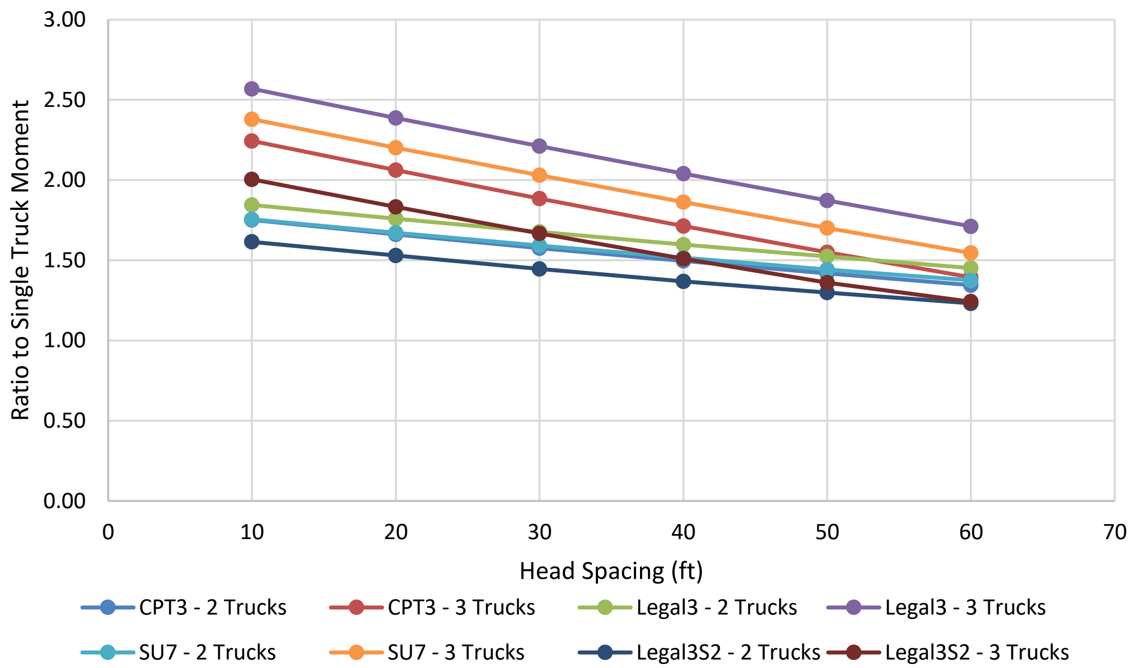


Figure B68: Effect of Head Spacing on Max Positive Moment of Single Truck Platoon Ratios for Two versus Three-Truck Platoons

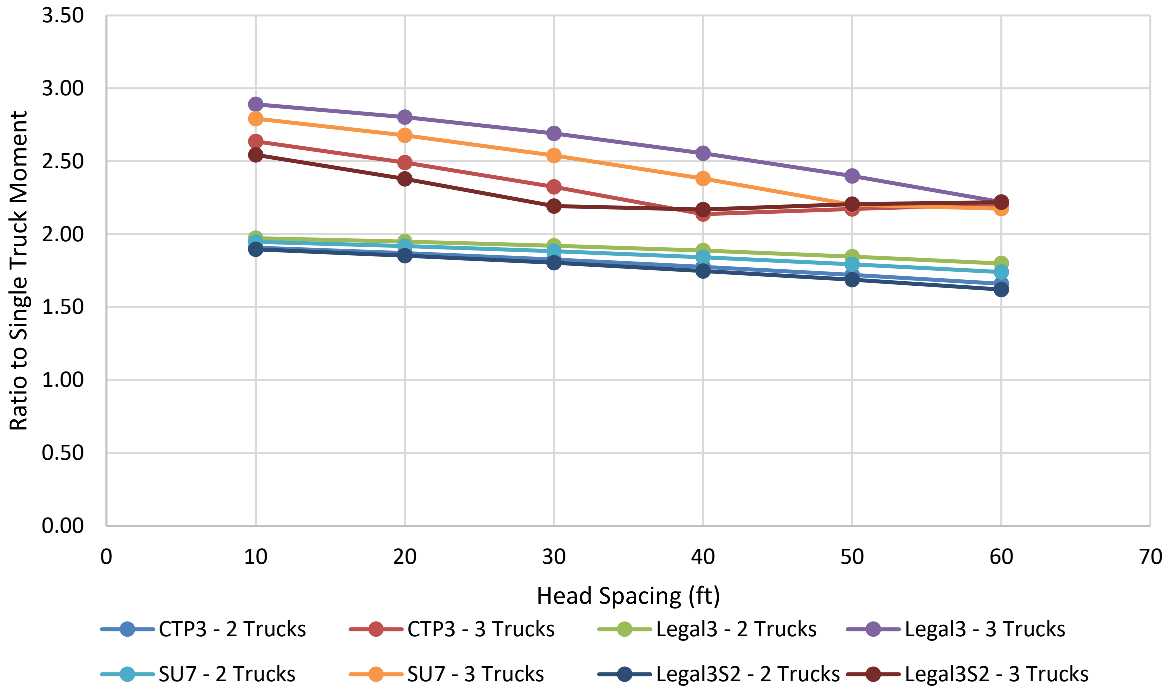


Figure B69: Effect of Head Spacing on Max Negative Moment of Single Truck Platoon Ratios for Two versus Three-Truck Platoons

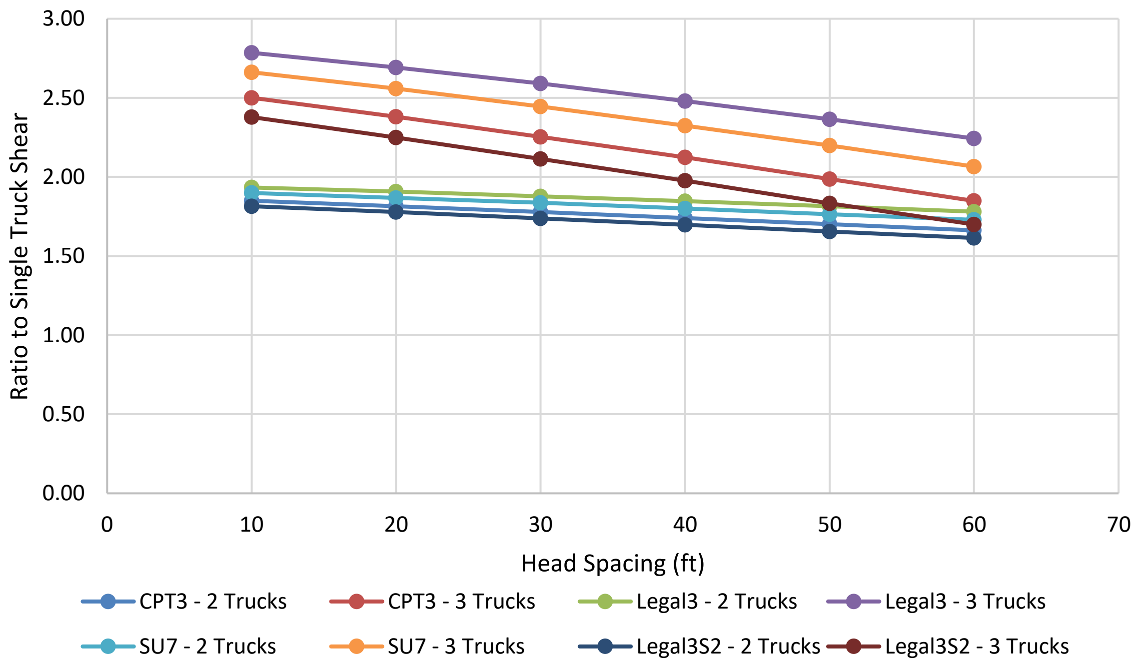


Figure B70: Effect of Head Spacing on Max Shear of Single Truck Platoon Ratios for Two versus Three-Truck Platoons

OREGON D.O.T. BRIDGE SECTION

TIER-2 LOAD RATING SUMMARY REPORT (PAGE 1)

Latest Revision 10/13/2010

BRIDGE DATA...

BRIDGE #: 20026 | NBI FEATURE: UPRR Main Line
BRIDGE NAME: Hwy 1 over UPRR Main Line
HIGHWAY NAME: Pacific Hwy | HIGHWAY #: 001
REGION: 2 | DIST: 03 | COUNTY: Marion | MILEPOST: 252.13

YEAR BUILT: 2006 | DESIGN LOADING: HL93 | OWNER: ODOT
SPAN DESCR: 1-91'10", 1-142'9" RCDG Prest Bulb-T
OTHER DESCR: 15-DgSkw

LOAD RATING ENGINEER DATA...

RATING DATE: 1/6/11 | FIRM: ODOT | LOAD RATER: JPM | CALCULATION BOOK: -

LATEST INSPECTION DATA...

INSP. DATE: 8/5/10 | ADT: 64,100 | ADTT: 10,897 | YEAR of ADT (2 digits): 08 | A.C. DEPTH, INCHES: 0.0

CONDITION RATINGS ----> DECK: 7 | SUPERSTR.: 8 | SUBSTR.: 8 | IMPACT ASSESSMENT (Elem. 325): CS1 | WEAR. SURFACE (Elem. 326): CS1

RATING DATA...

LRFR FACTORS: IMPACT 1+I: 1.10 | γ_{DC} 1.25 | γ_{DW} 1.25
LRFR RATINGS FOR N.B.I. : INVENTORY (Item 66): Tons 54.7 | OPERATING (Item 64): Tons 70.9
SECTIONS EVALUATED: 85 | COMMENTS:

NBI STATUS ITEMS:
Operational Status (Item 41): A
Bridge Posting Status (Item 70): #NAME?
Temporary Status (Item 103):

<----------1st rating control---------->

LOAD:	γ_L	R.F.	Limit State	Force Type	Φ	CONTROLLING... MEMBER	SPAN	LOCATION
DESIGN & LEGAL VEHICLES								
HL93 (INVENTORY)	1.750	1.52	St1	+M	1.000	Int. Girder	1 of 2	0.5L
TYPE 3 (50K)	1.400	4.36	St1	+M	1.000	Int. Girder	1 of 2	0.5L
TYPE 3S2 (80K)	1.400	3.78	St1	+M	1.000	Int. Girder	1 of 2	0.45L
TYPE 3-3 (80K)	1.400	3.67	St1	+M	1.000	Int. Girder	1 of 2	0.5L
TYPE 3-3 & LEGAL LANE	1.400							
TYPE 3-3 TRAIN & LEGAL LANE	1.400	5.68	St1	+M	0.900	Bent 2 XB	2 of 5	0.4L
SU4 TRUCK (54K)	1.400	3.91	St1	+M	1.000	Int. Girder	1 of 2	0.5L
SU5 TRUCK (62K)	1.400	3.50	St1	+M	1.000	Int. Girder	1 of 2	0.5L
SU6 TRUCK (69.5K)	1.400	3.14	St1	+M	1.000	Int. Girder	1 of 2	0.5L
SU7 TRUCK (77.5K)	1.400	2.86	St1	+M	1.000	Int. Girder	1 of 2	0.5L
CTP VEHICLE, MULTI-LANE								
OR-CTP-2A (105.5K)	1.350	3.40	St2	+M	1.000	Int. Girder	2 of 2	0.5L
OR-CTP-2B (105.5K)	1.350	3.64	St2	+M	1.000	Int. Girder	2 of 2	0.45L
OR-CTP-3 (98K)	1.450	2.67	St2	+M	1.000	Int. Girder	1 of 2	0.45L
STP VEHICLE, MULTI-LANE								
OR-STP-3(120.5K)	1.250	3.14	St2	+M	1.000	Int. Girder	1 of 2	0.45L
OR-STP-4A (99K)	1.400	2.62	St2	+M	1.000	Int. Girder	1 of 2	0.45L
OR-STP-4B (185K)	1.000	3.14	St2	+M	1.000	Int. Girder	2 of 2	0.45L
OR-STP-4C (150.5K)	1.100	2.91	St2	+M	1.000	Int. Girder	2 of 2	0.45L
OR-STP-4D (162.5K)	1.050	2.51	St2	+M	1.000	Int. Girder	1 of 2	0.5L
OR-STP-4E (258K)	1.000	2.72	St2	+M	1.000	Int. Girder	1 of 2	0.5L
OR-STP-5BW (204K)	1.000	2.76	St2	+M	1.000	Int. Girder	2 of 2	0.45L
SPECIAL	1.000							
STP VEHICLE, SINGLE LANE W/ESCORT								
OR-STP-3(120.5K)	1.150	4.33	St2	+M	1.000	Ext. Girder	2 of 2	0.45L
OR-STP-4A (99K)	1.150	4.45	St2	+M	1.000	Ext. Girder	1 of 2	0.45L
OR-STP-4B (185K)	1.150	3.48	St2	+M	1.000	Ext. Girder	2 of 2	0.45L
OR-STP-4C (150.5K)	1.150	3.54	St2	+M	1.000	Ext. Girder	2 of 2	0.45L
OR-STP-4D (162.5K)	1.150	3.02	St2	+M	1.000	Ext. Girder	2 of 2	0.5L
OR-STP-4E (258K)	1.150	3.10	St2	+M	1.000	Ext. Girder	2 of 2	0.5L
OR-STP-5BW (204K)	1.150	3.05	St2	+M	1.000	Ext. Girder	2 of 2	0.45L
SPECIAL	1.150							

<----------2nd rating control---------->

LOAD:	R.F.	Limit State	Force Type	Φ	CONTROLLING... MEMBER	SPAN	LOCATION
DESIGN & LEGAL VEHICLES							
HL93 (INVENTORY)	1.54	St1	+M	1.000	Int. Girder	1 of 2	0.45L
TYPE 3 (50K)	4.40	St1	+M	1.000	Int. Girder	1 of 2	0.45L
TYPE 3S2 (80K)	3.85	St1	+M	1.000	Int. Girder	1 of 2	0.5L
TYPE 3-3 (80K)	3.71	St1	+M	1.000	Int. Girder	1 of 2	0.45L
TYPE 3-3 & LEGAL LANE							
TYPE 3-3 TRAIN & LEGAL LANE	5.78	St1	+M	0.900	Bent 2 XB	4 of 5	0.59L
SU4 TRUCK (54K)	3.96	St1	+M	1.000	Int. Girder	1 of 2	0.45L
SU5 TRUCK (62K)	3.54	St1	+M	1.000	Int. Girder	1 of 2	0.45L
SU6 TRUCK (69.5K)	3.18	St1	+M	1.000	Int. Girder	1 of 2	0.45L
SU7 TRUCK (77.5K)	2.90	St1	+M	1.000	Int. Girder	1 of 2	0.45L
CTP VEHICLE, MULTI-LANE							
OR-CTP-2A (105.5K)	3.42	St2	+M	1.000	Int. Girder	2 of 2	0.45L
OR-CTP-2B (105.5K)	3.68	St2	+M	1.000	Int. Girder	2 of 2	0.5L
OR-CTP-3 (98K)	2.68	St2	+M	1.000	Int. Girder	1 of 2	0.5L
STP VEHICLE, MULTI-LANE							
OR-STP-3(120.5K)	3.14	St2	+M	1.000	Int. Girder	2 of 2	0.45L
OR-STP-4A (99K)	2.62	St2	+M	1.000	Int. Girder	1 of 2	0.5L
OR-STP-4B (185K)	3.17	St2	+M	1.000	Int. Girder	2 of 2	0.5L
OR-STP-4C (150.5K)	2.92	St2	+M	1.000	Int. Girder	2 of 2	0.5L
OR-STP-4D (162.5K)	2.54	St2	+M	1.000	Int. Girder	1 of 2	0.45L
OR-STP-4E (258K)	2.75	St2	+M	1.000	Int. Girder	1 of 2	0.45L
OR-STP-5BW (204K)	2.77	St2	+M	1.000	Int. Girder	2 of 2	0.5L
SPECIAL							
STP VEHICLE, SINGLE LANE W/ESCORT							
OR-STP-3(120.5K)	4.34	St2	+M	1.000	Ext. Girder	2 of 2	0.5L
OR-STP-4A (99K)	4.46	St2	+M	1.000	Ext. Girder	1 of 2	0.5L
OR-STP-4B (185K)	3.52	St2	+M	1.000	Ext. Girder	2 of 2	0.5L
OR-STP-4C (150.5K)	3.56	St2	+M	1.000	Ext. Girder	2 of 2	0.5L
OR-STP-4D (162.5K)	3.07	St2	+M	1.000	Ext. Girder	2 of 2	0.45L
OR-STP-4E (258K)	3.11	St2	+M	1.000	Ext. Girder	2 of 2	0.45L
OR-STP-5BW (204K)	3.07	St2	+M	1.000	Ext. Girder	2 of 2	0.5L
SPECIAL							

Figure B71: ODOT Bridge Section Tier 2 Load Rating Summary Report for Bridge 20026

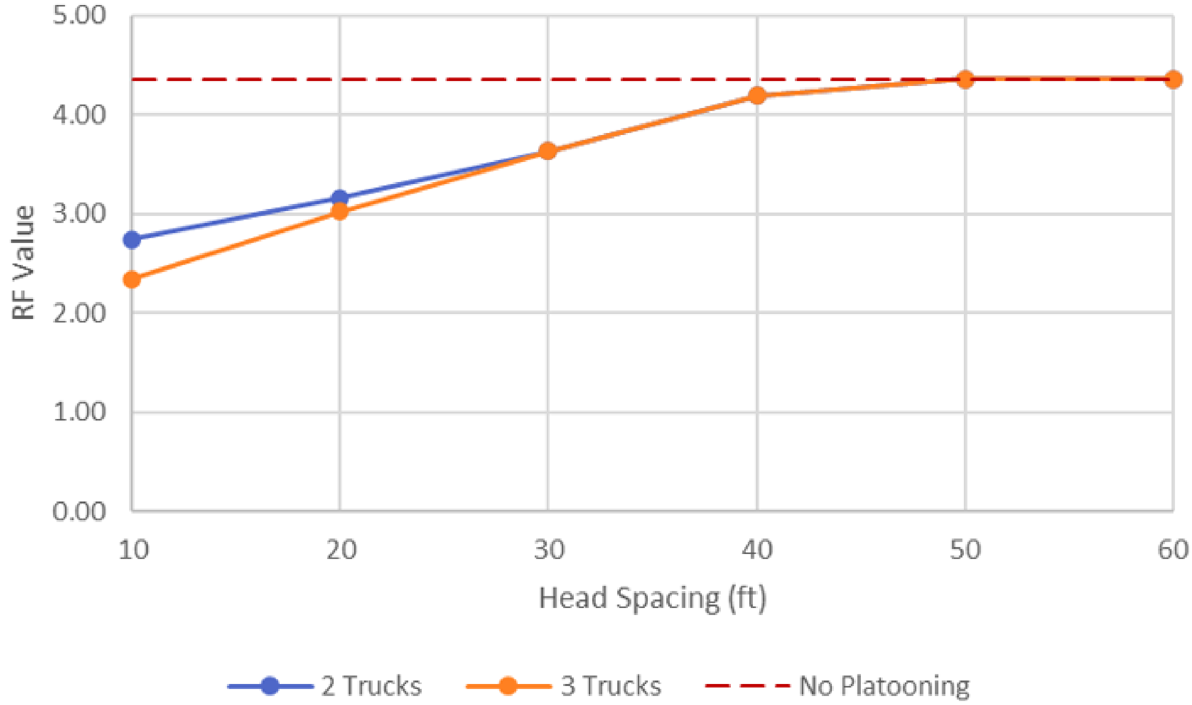


Figure B72: Rating Factor versus Head Spacing for the OR Type 3 Legal Truck

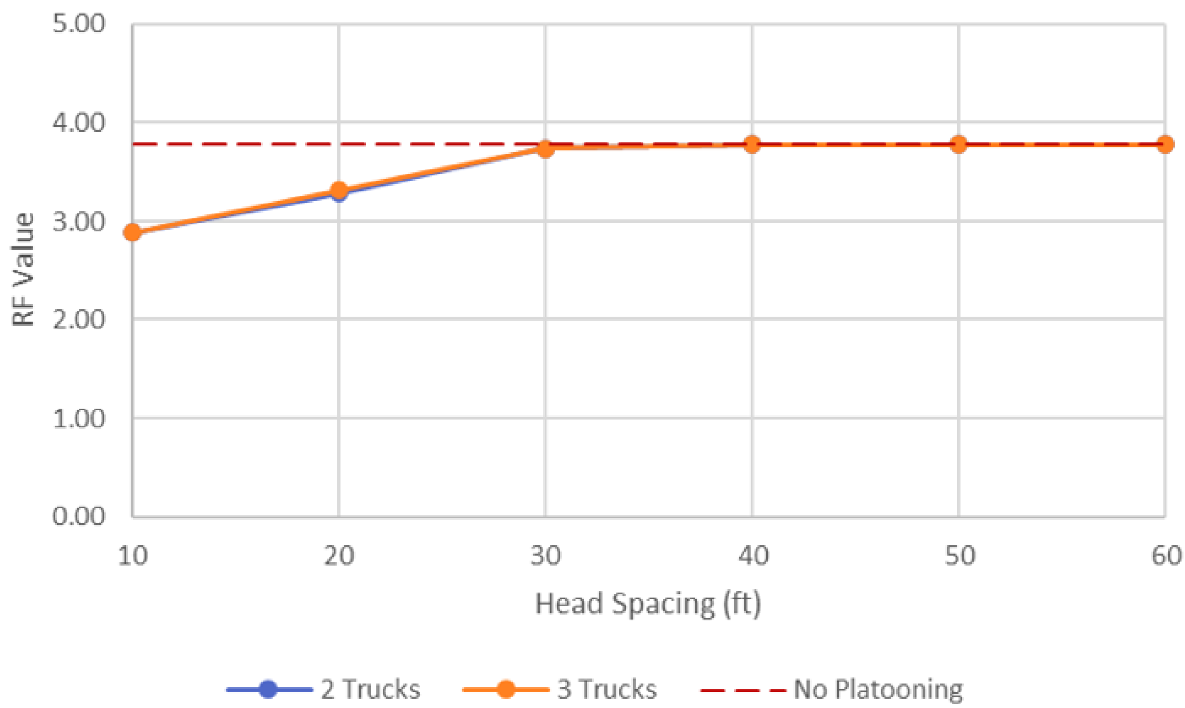


Figure B73: Rating Factor versus Head Spacing for the OR Type 3S2 Legal Truck

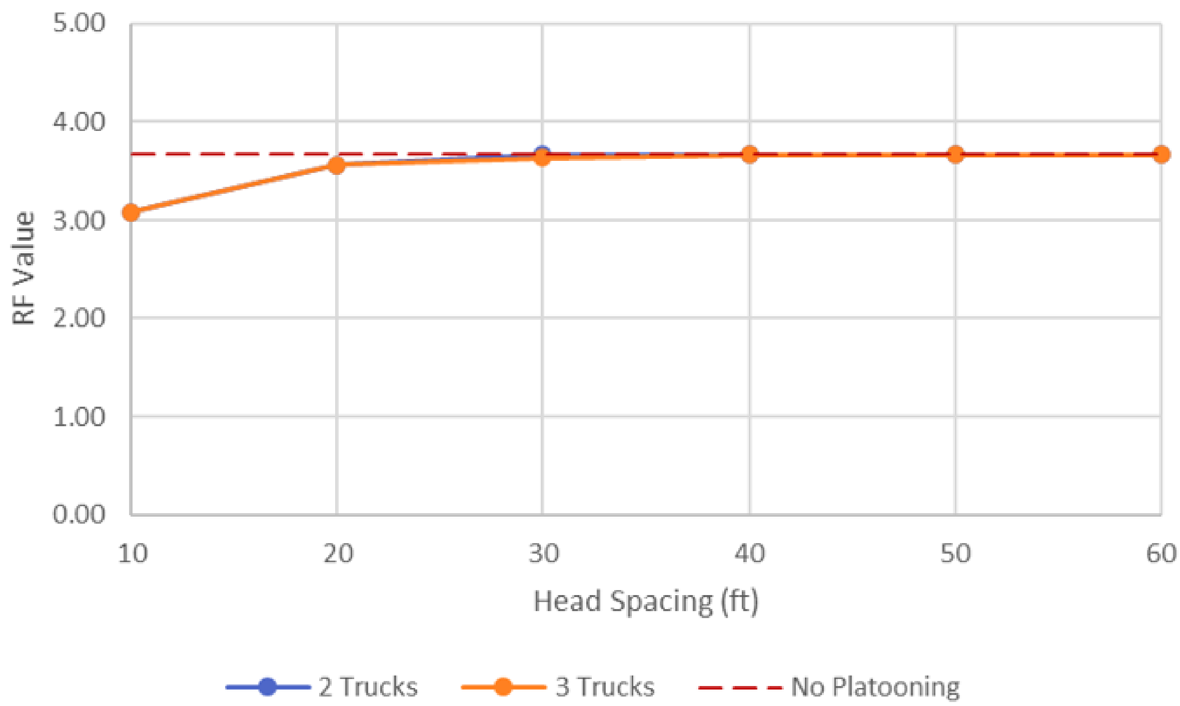


Figure B74: Rating Factor versus Head Spacing for the Type 3-3 Legal Truck

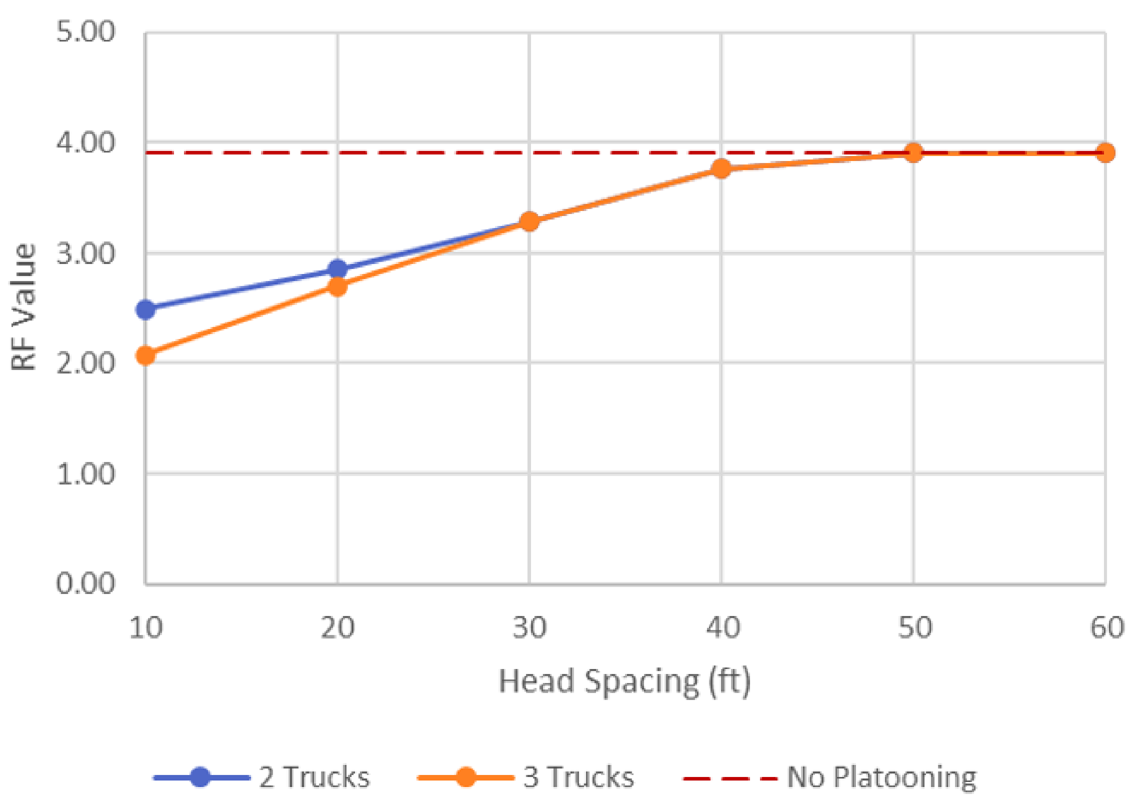


Figure B75: Rating Factor versus Head Spacing for the OR SU4 Truck

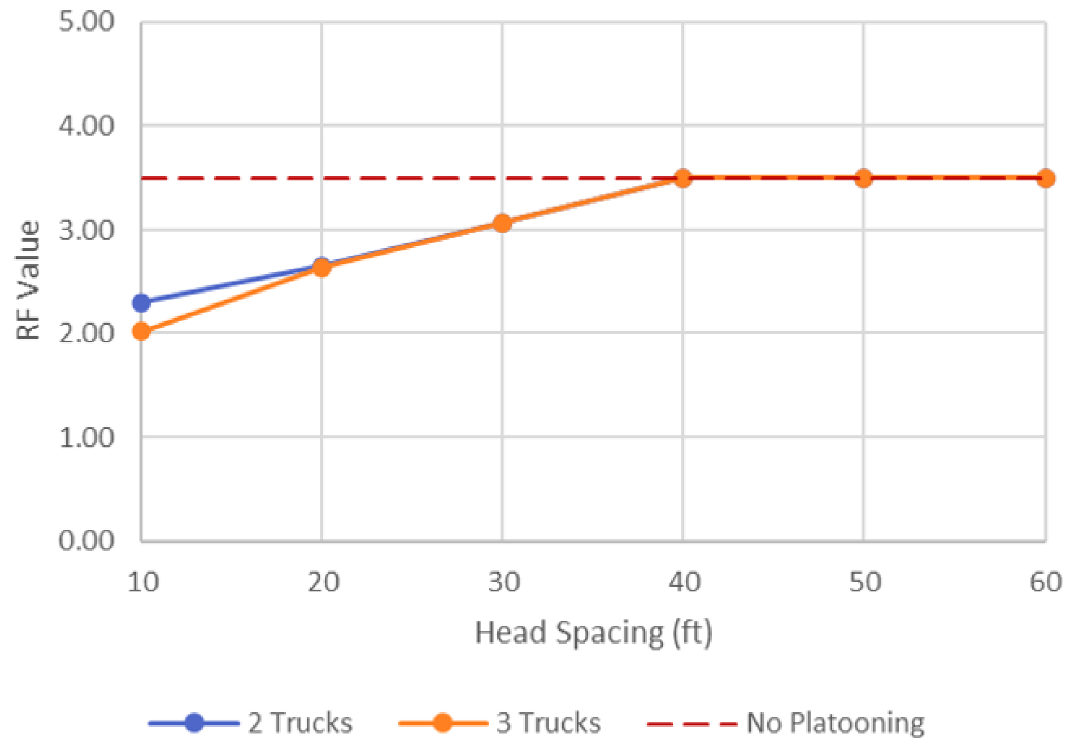


Figure B76: Rating Factor versus Head Spacing for the OR SU5 Truck

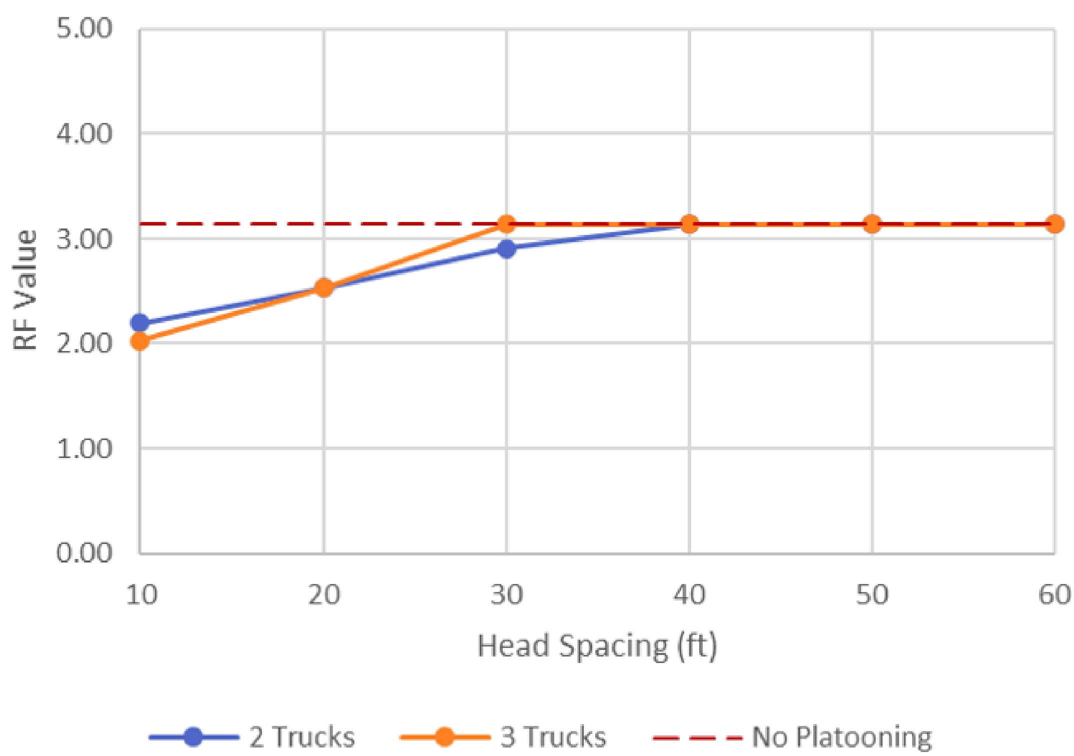


Figure B77: Rating Factor versus Head Spacing for the OR SU6 Truck

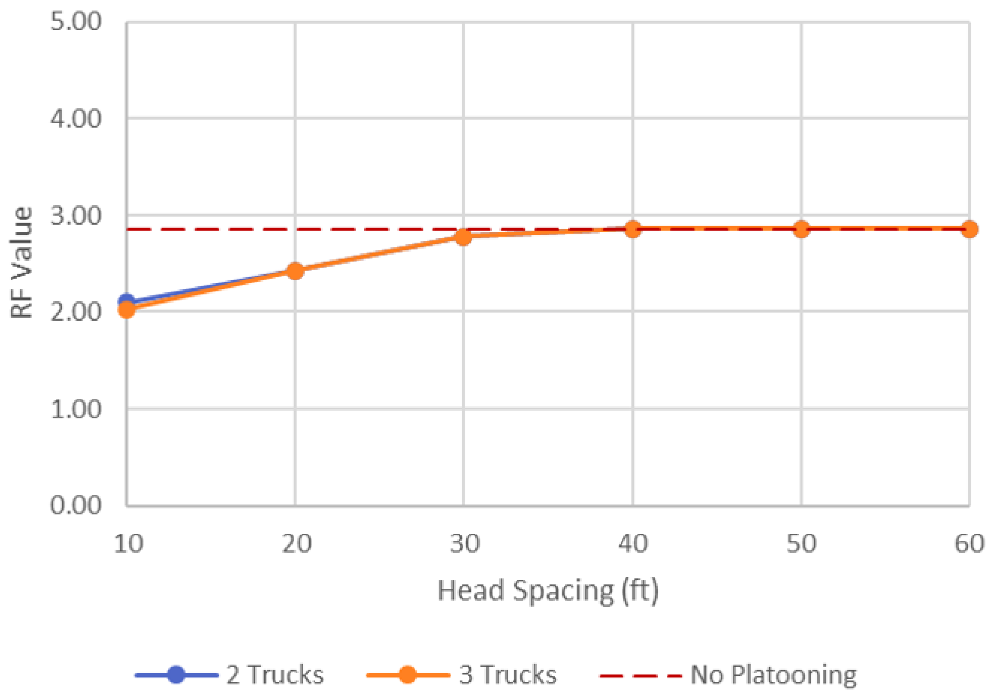


Figure B78: Rating Factor versus Head Spacing for the OR SU7 Truck

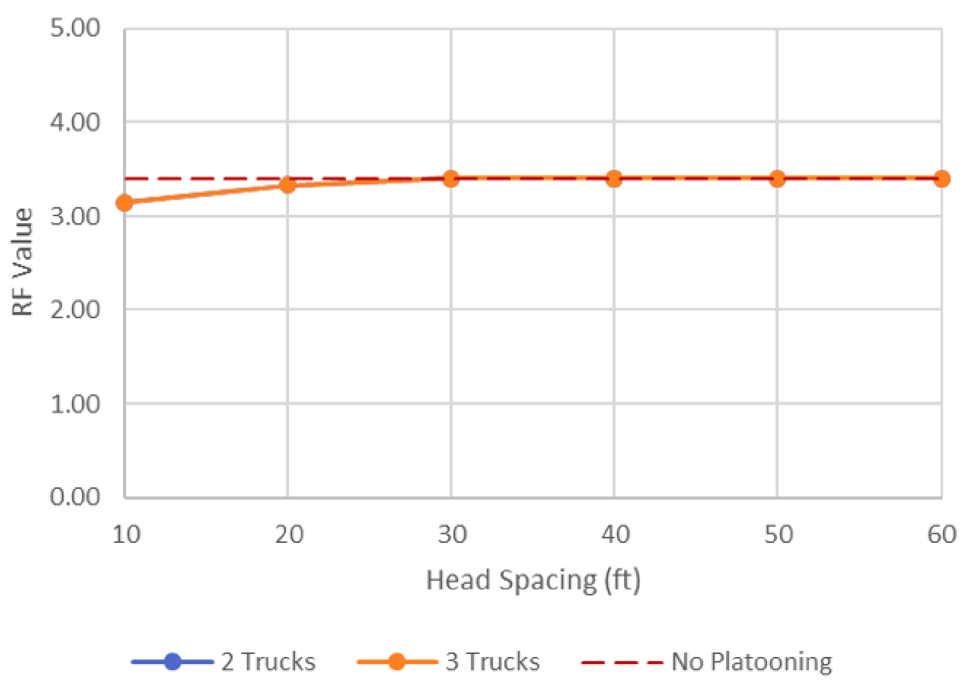


Figure B79: Rating Factor versus Head Spacing for the Type OR CTP-2A Truck

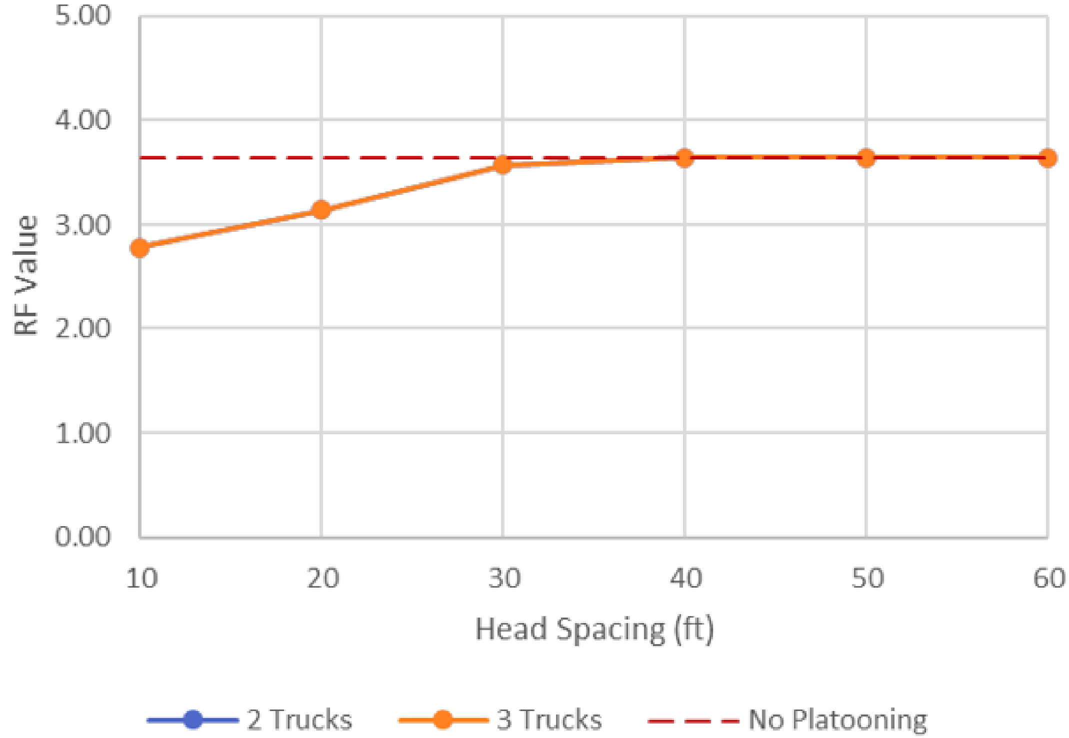


Figure B80: Rating Factor versus Head Spacing for the Type OR CTP-2B Truck

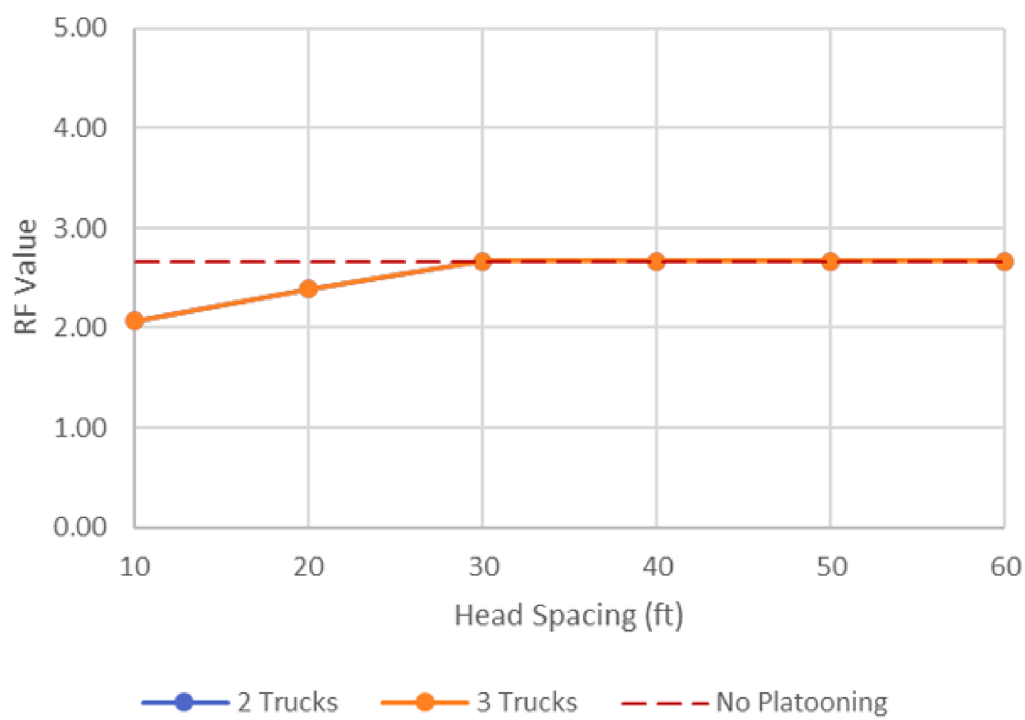


Figure B81: Rating Factor versus Head Spacing for the Type OR CTP-3 Truck