Load Posted Bridges and the Timber Transportation Industry

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LOAD POSTED BRIDGES AND THE TIMBER TRANSPORTATION INDUSTRY

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Report Summary

The investigation in this project has found that there is no direct solution for avoiding load posting of bridges on important timber hauling highway routes. The problem arises from the existence of numerous old low load capacity bridges or newer bridges that have been allowed to deteriorate combined with trucks that are carrying heavier loads. Any fix to the problem will have a cost component that the haulers, the local economy and/or the bridge owners will have to bear. In situations with critical load posted bridges, timber haulers might be best served by working with local (county) authorities to define alternate routes or to upgrade essential bridges.

The Problem: The vehicles used to haul materials have greatly increased in both size and weight over the past 40 years. New methods for load rating bridges are being developed as part of this evolution, to insure the continued safety of the highway system for the traveling public.

Simultaneously, the condition of our Nation’s infrastructure is aging and deteriorating - resulting in highway bridges with unsatisfactory load capacity. With regular inspections, there are more load posted bridges. As a result of these load posted bridges, commercial trucks are being forced to take longer alternate routes which cost the industry both time and money.

This report examines the effects of logging vehicles on bridges, the need to control loads on older bridges, possible solutions to permit timber hauling vehicles to use more bridges, and means of improving the capacity of old under-capacity bridges.

Logging Trucks: Based on the weight and axle configurations measured on a series of Wisconsin timber logging trucks, average truck configurations and weights that can be used to predict the effects of these trucks on bridge have been defined as shown on pages 4 and 5.

Effects of Logging Trucks on Bridges: Analyses clearly showed that the average logging trucks overload bridges with spans longer than 59ft to 70ft if the bridges were designed using a modern “design truck” load of 72,000lb. Older bridges, that were design for a 54,000lb
truck, will not be able to carry any of the average logging trucks safely. The truck force analysis results can be seen in Figures 15 and 16.

**2007 Legislative Resolution:** Though a resolution was passed to allow 98,000lb logging trucks on highway bridges, the resolution did not specify axle spacing limits. As a result a 98,000lb truck with 6 very closely spaced axles might cross a bridge and cause significant damage, though a normal 6-axle logging truck would not. To prevent this damage from occurring many bridges have been load posted. Because of an error in the resolution, it has become ineffective and is of little help to the industry.

**Under Capacity Bridges in Wisconsin:** A survey of two counties has lead us to conclude that more than 20% of the bridges in Wisconsin should be expected to be old or deteriorated and have low load capacities requiring load posting.

**Load Posting of Bridges Critical to GLTPA:** Seven load posted bridges that are on important haul routes for logging trucks were examined. Two of the seven bridges were judged to be load rated (in Wisconsin inspection reports) at an inappropriate low level. Overall ½ of the bridges examined appeared to have errors in their load rating procedures.

When the industry encounters a critical bridge that is load posted it would be wise to work with the County or owner to re-examine the bridge and get an up to date load rating. A new load rating may correct mistakes, however it may still be low and prohibit usage by logging trucks.

**Alternate Solution to Avoid Detours:** Where a load posted bridge is on a critical haul route and the detour is very long, it may be effective to run trucks with a lower load to allow use of the bridge. Proposed decreases in loads are shown and listed on pages 35 to 36 of this report.

**Bridge Strengthening:** A quick method of strengthening a concrete bridge is described on pages 41 to 43. The simple strengthening procedure has increased bridge capacities by 30% to 50%. The industry should consider cooperating with the bridge owner in providing cost sharing to strengthen under capacity bridges on critical routes.
Abstract

The logging industry has an important role in the State of Wisconsin’s economy and is dependent on highway transportation of materials. Some of Wisconsin’s highway bridges are deteriorated due to age or lack of funding for maintenance or replacement. As a result, bridges are being load posted which prohibits their use by many commercial vehicles, and particularly logging trucks.

The bridge load posting creates detours for trucks and long hauling routes that are costing the timber industry more money to haul raw timber. The purpose of this project was to look at the effects that logging vehicles have on single span bridges and to investigate the current load ratings of bridges. Following these analyses, solutions to help alleviate some of the challenges the timber industry is experiencing due to load posted bridges were examined.
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Introduction – What Is the Problem?

The transportation industry is constantly evolving. The vehicles used to haul materials have greatly increased in both size and weight over the past century. New methods for load rating bridges are being developed as part of this evolution, to insure the continued safety of the highway system for the traveling public.

Simultaneously the condition of our Nation’s infrastructure is aging and deteriorating, resulting in highway bridges with unsatisfactory load capacity. With regular inspections, there are more load posted bridges. As a result of these load posted bridges, heavy commercial trucks are being forced to take longer alternate routes which cost the industries both time and money.

All of these issues have led to many questions and concerns over accessibility of certain bridges to use by timber hauling vehicles. This report focuses on the effects of logging vehicles on bridges, the need to control loads on older bridges, possible solutions to permit timber hauling vehicles to use more bridges, and means of improving the capacity of old under-designed bridges. The following questions need to be answered:

**Effects of actual timber hauling trucks:** First, how much do timber trucks weigh? What are the actual effects of timber trucks on bridges and how do they compare to the effects of certain specified “design vehicles” which are used to rate bridges and serve as the basis for load posting?

**Load posting:** Do the existing load posted bridges actually require posting?

**Solutions when bridges need load posting:** How can the effects of load posted bridges in causing detours be reduced for the timber hauling industry? Can these load posted bridges be strengthened to allow passage of timber hauling vehicles?
Measured Weights of Logging Trucks

Timber hauling trucks are unique; there is no standard truck configuration. As a result of this, bridge designers and owners may not exactly know how the effects of logging trucks on a highway bridge compare to the effects of their standard “design vehicles” used to rate a bridge’s capacity.

One of the main goals of this project was to compare the effects on bridges of the timber hauling trucks used in Wisconsin to those of the vehicles used in bridge rating and design.

Actual Timber Hauling Truck Weights:
Actual weights and axle configurations of timber hauling trucks were measured as a basis for comparing them to the design vehicles to see if they would have less effect on bridges than the design trucks.

Logging trucks are not mass manufactured and as a result each logging truck’s axle configuration and weight distribution may differ from another truck. The axle weights can vary in day-to-day operation as well. Typically, truck operators use the tire pressure gages as an indicator of weight distribution; some methods are more accurate than others.

Measurements of timber hauling trucks were taken at three different locations in Northern Wisconsin using weigh scales at each site. Information recorded for each truck included gross weight, axle spacing and weight distribution on individual or tandem axles. In total, data on weight and axle spacing was collected for thirty-one trucks.

In terms of axle spacing, four general types of truck configurations were measured:

- five-axle trucks,
- six-axle trucks,
- five-axle truck and pup, and
- six-axle truck and pup.
Table 1 lists the breakdown of the number of trucks measured. Only three six axle truck and pups were measured. The number of measured trucks of this type was not sufficient to accurately represent an average six-axle logging truck and pup configuration.

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Number Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Axle Truck</td>
<td>12</td>
</tr>
<tr>
<td>6 Axle Truck</td>
<td>9</td>
</tr>
<tr>
<td>5 Axle Truck and Pup</td>
<td>7</td>
</tr>
<tr>
<td>6 Axle Truck and Pup</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 1: Type and Quantity of Logging Vehicles Measured**

**Average Timber Hauling Trucks:**
To avoid analyzing the effects of each individual truck on various bridges, representative average trucks were created based on the information obtained from measuring logging trucks in the field. Three average vehicles were created (Figures 1 to 3), a five-axle, six-axle and five-axle truck and pup. Not enough six-axle truck and pup vehicles were measured to use as a basis for creating an average six-axle truck and pup vehicle.

- For the average five-axle vehicle a gross weight of 94,000 lbs. was used. The measured gross weights of this type of truck ranged from 84,040 lbs. to 96,660 lbs.
- For the average six-axle vehicle the maximum allowable permit gross weight of 98,000 lbs. was assigned. The nine six-axle vehicles that were measured had gross weights ranging from 89,080 lbs. to 98,280 lbs.
- For the average five-axle truck and pup the gross weight was taken as 94,000 lbs. The actual measured gross weights varied from 89,500 lbs. to 94,620 lbs. The axle configuration and distribution of weight is shown in Figure 7.
Figure 1. Average Five-axle Tractor Trailer (photo: GLTPA, 2009)
( “k” = 1000lbs, 12.9k = 12,900lbs)

Figure 2. Average Six-axle Tractor Trailer (photo: GLTPA, 2009)
( “k” = 1000lbs, 12.1k = 12,100lbs)
The Wisconsin statutes state that five-axle vehicles with permits carrying raw forest products are allowed a gross weight of 90,000 lbs., however the majority of the five-axle vehicles measured had a gross weight close to 94,000 lbs. This weight was chosen for an “average” truck because it provides a representation of the logging trucks measured. The maximum allowable permit weight for the 6 axle trucks is 98,000 lbs and this matched the measured trucks.

The axle locations of the average vehicles were taken as the average of axle dimensions measured in the thirty-one trucks (Figures 1 to 3). The total weight of the truck was distributed across the axles in the same proportions as the average results from the measured trucks.

Thus, the “average trucks” represent the average of the measured trucks in axle locations and weight distribution. The average truck can be compared to the bridge design vehicles that are described in Appendix A.
Effects of Trucks on Bridges

Vehicle Effects on Bridges:
The set of trucks described above, and the standard vehicles described in Appendix A, were used in a set of highway bridge force analyses. The analyses compared the forces created in bridges by timber hauling vehicles with those created by the standard bridge design trucks. A computer program “drives” each truck across a bridge and measures the forces that the truck creates in the bridge beams.

A set of single span bridges ranging from 20ft to 170ft in length were investigated under the truck loads. Two types of forces inside the bridge beams or girders were measured: “moment” and “shear”.

\[
\text{MOMENT} = \text{the force in a girder that bends the girder downward:}
\]

\[
\text{SHEAR} = \text{force that breaks a girder:}
\]

Comparison of Design Vehicle Effects on Bridges

Before looking in depth at how logging trucks affect bridges, the effects of standard design and special State vehicles were examined. Figure 5 compares the maximum moment caused in a single span bridge by four of the “design trucks”. The basic “design truck” that
has been used for bridge design over the past 60 years is the HS20 truck weighing 72,000lbs. A second design truck weighing 54,000lbs, referred to as an HS15, was used extensively for bridge design before the 1950’s. The “tandem” is a two axle design load weighing 50,000lbs. The newest standard truck used for bridge design, the HL-93, weighs 72,000lbs but is combined with a continuous load of 640lbs per foot of bridge length. The HL-93 has been used in bridge design since 1994.

Two additional truck loadings used in Wisconsin to evaluate bridges are the Wisconsin permit vehicle and the statute vehicle. The moment forces created in bridges by these trucks are also shown in Figure 5. All of these vehicles are described in Appendix A.

A similar comparison is shown in Figure 6 with the shear effects caused by the standard trucks for bridges of various span lengths.

![Figure 5. Maximum bridge moments caused by official standard trucks.](image-url)
The Figures clearly show that the effects of the new bridge design truck, the HL-93, surpass the effects of all previous design vehicles used. New bridges are being designed to carry higher loads to ideally encompass the larger vehicles using the roadways today.

In contrast, the HS15 vehicle produces relatively small moment and shear effects. Many bridges today were originally designed for or are still load rated as HS15 and the trend lines for the HS15 represent the maximum moment and shear effects those bridges are capable of withstanding. That large difference between the HL-93 and the HS15 forces represents how variable the loading capacities of different Wisconsin bridges may be.
Effects of Actual Timber Hauling Trucks

5-Axle Logging Truck Effect on Bridges

A 94,000lb 5-axle logging truck can pass over bridges that are 68ft. long or shorter without creating larger internal forces than the Wisconsin HS20 design truck. They can pass over bridges that are 85ft. long or shorter without creating larger forces than are created by the 80,000lb State design permit truck.

The 5-axle logging truck creates both shear and bending moment forces in highway bridges. If those forces are less than the bridge capacity, then the 5-axle logging truck can safely cross the bridge.

The shear force created in bridges of various lengths is shown in Figure 7. The shears are given as a % of the shear force that would be created by the HS20 “design truck”. The 5-axle logging truck can safely cross well designed bridges, based on the shear force, where the % of load shown is less than 100% or spans of less than 68ft.

Shear from 5-Axle Truck as % of Design Truck

Figure 7. Shear force created by 5-axle logging trucks as a % of HS20 design truck.
A similar evaluation of the effect of the 5-axle logging truck in creating shear force is compared to the 80,000lb State design permit truck as shown in Figure 8. The 5-axle logging truck has less of a load effect than the permit truck wherever the shear % is less than 100%, in spans less than 85ft.

![Shear from 5-Axle Truck as % of Permit Truck](image)

Figure 8. Shear force created by 5-axle logging trucks as a % of Wis. permit truck.

The moment bending force created in bridges of various lengths is shown in Figure 9. The moments are given as a % of the moment force that would be created by the HS20 “design truck”. The 5-axle logging truck can safely cross well designed bridges, based on the moment force, where the % of load shown is less than 100% or spans less than 84ft.

Bending created in bridges by the 94,000lb 5-axle logging truck is compared with the amount of bending from the State 80,000lb permit truck in Figure 10. Again values less than 100% indicate that the logging trucks have less effect on the bridge than the standard permit truck. The range of acceptable bridge lengths in this case is up to 113ft.
Figure 9. Moment force created by 5-axle logging trucks as a % of HS20 design truck.

Figure 10. Moment force created by 5-axle logging trucks as a % of State permit truck.
In comparing Figures 7&9, it is evident that the range of bridges that the 94,000lb 5-axle logging truck can cross without exceeding the force caused by the “design truck” is controlled by the size of shear force created. The shear force limit of 100% of the “design truck” is exceeded for spans greater than 68ft. From Figure 9 the bending moment effect isn’t exceeded until a bridge length of 84ft. is crossed, which is longer than the limit for shear.

In comparing Figures 8&10 in a similar manner, the size of shear force also controls the span length (85ft.) where the effects of the 94,000lb 5-axle logging truck exceed the forces that are acceptable for the Wisconsin 80,000 permit truck.

6-Axle Logging Truck Effect on Bridges

The bridge analyses showed that a 98,000lb 6-axle logging truck can pass over bridges that are 59ft. long or shorter without creating larger internal forces than the Wisconsin HS20 design truck. They can pass over bridges that are 74ft. long or shorter without creating larger forces than are created by the 80,000lb State permit truck.

The shear force effects caused by the 6-axle logging truck are compared with the effects of the HS20 State “design truck” and the 80,000lb State permit truck in Figures 11&12. The shear force caused by the logging truck is less than the State trucks for spans less than 59ft when equated to the HS20 truck and 74ft. when equated to the permit truck.

The moment force effects are not as critical as the shear effects in controlling the load that can be applied to bridges by the 6-axle logging trucks. Figures 13&14 show that the 6-axle logging trucks would be limited to spans less than 80ft long to keep moments less than the HS20 “design truck” creates, and less than 110ft long to have moments less than created by the State permit truck. The shorter limits noted above, based on the shear force, are the controlling span lengths for the 6-axle logging truck.
Figure 11. Shear force created by 6-axle logging trucks as a % of HS20 design truck.

Figure 12. Shear force created by 6-axle logging trucks as a % of State permit truck.
Figure 13. Moment force created by 6-axle logging trucks as a % of HS20 design truck.

Figure 14. Moment force created by 6-axle logging trucks as a % of State permit truck.
5-Axle Truck and Pup Logging Truck Effect on Bridges

Similar analyses were conducted for the 5-axle truck and pup configuration.

The truck and pup vehicle caused force effects higher than those from the HS20 “design truck” on any bridge spans longer than 71ft and force effects higher than the State permit truck for bridge spans longer than 89ft.

Comparison of Bridge Forces from Various Trucks:

A full comparison of the bridge forces caused by the various logging trucks and the “design trucks” or rating trucks used by the State is provided in Figures 15&16.

Examining the bending moment forces shown in Figure 15 and the shear forces in Figure 16, it may be clearly detected that the design forces caused by the new HL-93 “design truck” exceed the effects of the logging trucks for all bridge span lengths between 20ft. and 170ft. Logging trucks should be able to easily pass over the new bridges.

Comparing the logging truck effects to the effects of the HS20 “design truck”, as was already done in the Figures of the previous section, shows that the logging trucks create high shear forces. For bridges that were designed (between 1945 and 2007) to carry the HS20 truck, and still have that capacity, the 5-axle logging truck can pass over any bridge less than 68ft in length, the 6-axle truck can pass any bridge less than 59ft in length, and the truck and pup can pass over any bridge less than 71ft.

It is evident, however, that the shear effects caused by the average 5-axle, 6-axle and truck+pup logging trucks greatly exceed the effects caused by the HS15 “design truck” for all bridges with lengths from 20ft to 140ft. Additionally, based on the trend shown, the average logging truck shear effects will exceed the HS15 “design truck” effects for any span length.
Summary of Acceptable Logging Truck Bridge Usage

In general, it should be expected that the force effects of logging trucks will be unacceptably high on most bridges designed before 1945. Those bridges will likely be load posted to prevent passage of heavy trucks.

Logging trucks should be able to use most bridges that are less than 60ft. in length if the bridge was designed after the 1940’s and the bridges have been well maintained to prevent deterioration. The trucks should be able to pass over any bridge designed after 2007, regardless of bridge length.
Figure 15. Maximum moment created in bridge vs. span length comparison for trucks.
Figure 16. Maximum shear created in bridge vs. span length comparison for trucks.
Comparison with New Wisconsin Truck Size and Weight Study Proposed Truck

Six new candidate vehicles for permitting were described as part of the Wisconsin Truck Size and Weight study completed on January 1, 2009. Of these six vehicles, two had similar configurations to the logging trucks measured in the field for this project. Those two configurations are the six-axle 98,000-lb. tractor semi-trailer and the six-axle 98,000-lb. straight truck and pup trailer.

For the 98,000-lb, six-axle tractor semi-trailer (see Appendix A), comparisons were made with the average six-axle logging vehicle as well as the HS20 and the Wisconsin permit vehicle. Figure 17 shows the maximum bending moment created in bridges vs. bridge span length for four different reference trucks. The “average six axle” is the measured average logging truck in Wisconsin. The new proposed vehicle has the same effects as the 6-axle logging truck.

![Graph showing maximum bending moment vs. bridge span for different vehicles](image)

**Figure 17. Moments created in bridges with the new 6-axle proposed truck.**

Shear force comparisons were made between the same four vehicles as shown in Figure 18. The proposed truck produces a higher shear force up to span lengths of approximately 40ft and from then on the average six-axle logging vehicle produces a higher shear force.
Wisconsin Legislature: 2007-2008 Resolution to Increase Gross Weight Limit of Six-axle Trucks to 98,000lbs

Increased Load Resolution:

As a means of improving freight commerce and allowing transportation over more bridges, a Wisconsin statute was passed in 2007/2008 which allowed six-axle trucks carrying “raw forest products” to have a maximum gross weight not exceeding the gross weight limitations by more than 18,000 lbs. (Wisconsin State Legislature, 2007). The gross weight limitation without a permit for a six-axle vehicle is 80,000lb so this statute allows six-axle timber vehicles to carry a maximum load of 98,000 lbs. with a permit. In addition to the gross weight limitations, the statutes also state that a single axle can’t exceed a weight of 18,000 lbs. and every axle must carry at least eight percent of the gross vehicle weight.
The main flaw in this statute was that there was no specification regarding the axle spacings or minimum truck length. This means that any six-axle 98,000lb truck, regardless of whether all the axles are spaced at 4ft on center or 15ft on center, should be allowed on bridges. It is clear that the truck with axles closely spaced will have a much larger, and very likely unsafe, impact on a bridge.

**Current Bridge Load Limit Postings:**

After the resolution, the Great Lakes Timber Professionals Association noted that more bridges were load posted. Some bridges may have been posted due to a concern that trucks with close axle spacings would induce damage even though the total weight meets the 98,000lb limit. This situation might have been avoided if the legislative resolution had included well defined axle spacing limits. Other bridges may be load posted as a safety precaution because funds are not available to conduct an accurate load rating study to check the true bridge capacity.

**Wisconsin Bridge Load Posting Procedures**

A standard rating procedure is used to determine the capacity of highway bridges. The common Load Factor Rating (LFR) procedure examines a number of factors related to the bridge and its ability to carry the forces created by certain standard trucks and results in a rating number being defined for the bridge. In the Load and Resistance Factor Rating method (LRFR), a need for load restrictions is indicated when an operating rating of less than 1.0 is calculated.

There are nine standard vehicles used for load rating and posting of highway bridges. Three of the vehicles are the commercial AASHTO vehicles which include the Type 3, Type 3-3 and Type 3S2. Four AASHTO Specialized Hauling Vehicles are also used in determining whether load posting is necessary. These four vehicles are all single-unit trucks.
with four, five, six and seven axles. The final two vehicles used in load posting are Wisconsin DOT Specialized Annual Permit Vehicles. One of these vehicles is a six-axle truck and pup configuration and the other is a six-axle tractor trailer combination. Both vehicles have a gross weight of 98 kip. Exact weight distribution and axle configuration for all of these vehicles can be found in Chapter 45 of the Wisconsin Bridge Manual (Wisconsin Department of Transportation, 2008).

**Review of Current Load Ratings of Bridges in Two Wisconsin Counties**

An examination of bridges in Marathon and Lincoln Counties found that an average of 20% of the bridges had a capacity less than the HS20 “design truck” and might not be able to carry the loads of logging trucks.

Based on the truck analyses discussed previously it is obvious that for certain span ranges the moment and shear effects of the logging trucks were less than the HS20 design vehicle. It was also clear that the logging trucks would always exceed the allowable moment and shear effects in a bridge designed for an HS15 vehicle. How many bridges might then be unavailable to the logging industry because of a load rating less than the HS20 design truck?

To go through inspection reports for all bridges in the State of Wisconsin was outside the scope of this project, however, two counties that have a good deal of logging traffic were chosen to assess the condition of their bridges. Marathon County and Lincoln County were examined and inventory ratings for the bridges in each of these counties were tabulated and analyzed.

Marathon County has a total of 360 bridges according to the Wisconsin Highway Structures Information (HSI) system database. Of the 360 bridges, 96 had an inventory rating less than an HS20. This is equal to 27% of the bridges. Figure 19 shows the breakdown of
the inventory ratings for every bridge in the county. The bottom axis lists the equivalent load capacity, i.e. HS16-17 indicates the inventory capacity is between an HS16 an HS17 truck load. If in the capacity indication the number, i.e. 16 in HS16, is multiplied by 3.6 the total weight of the truck can be found (16 x 3.6 = 57.6 thousand lbs).

Figure 19. Marathon County Bridge Inventory Ratings

Lincoln County was also chosen because it doesn’t contain any large cities such as Wausau in Marathon County. A total of 121 bridges are reported in the HSI database for Lincoln County. Of these 121 bridges, only 22 were found to have load ratings less than HS20. This is equivalent to 18% of the County bridges. Figure 20 shows the break down of the inventory load rating for bridges in Lincoln County.

It was originally expected that a higher percentage of bridges would have inventory load ratings less than an HS20 and be closed to logging trucks. A major highway with new bridges and overpasses, US-51, runs directly through both of these counties. The new bridges on this route may skew the results toward more bridges with an HS20 rating. In order to check this hypothesis both of the County’s bridges were tabulated again excluding bridges on US-51. Looking at the results from Marathon County, the percentage of bridges with inventory ratings less than an HS20 decreased to 24%, down from 27%.
The inventory ratings of bridges in Lincoln County were re-analyzed in a similar manner. The results yielded 20% of the 79 bridges had a rating of less than an HS20, up from the 18%. This was just over two percent higher than the percentage when US-51 bridges were included.

Looking at bridge ratings, it should be expected that as much as 20% of the highway bridges in any county might be posted with load limits that could exclude logging trucks from passing over.

**Examination of a Set of Specific Bridges of Interest to the Timber Industry: The Need for Load Posting**

The Great Lakes Timber Professionals Association (GLTPA) provided a description of seventeen bridges that were load posted and affecting logging truck haul routes. Based on these descriptions and using the Highway Structures Information (HSI) system, attempts were made to match each bridge description with a bridge identification number.
Bridge descriptions which could not be matched to a bridge identification number were eliminated from a list of bridges to examine further. Bridge plans were then sought for the bridges with ID numbers. Some of the bridges were found to be county owned and the State HSI database did not have plans for these bridges. Bridges without plan sets were also eliminated from the original list.

A final list of seven bridges was chosen to be investigated in more detail and load rate. The final seven bridges were chosen based on their importance for the GLTPA and their current load posting limits. The list included some bridges with inventory ratings as low as HS09 (32,400lbs) and up to one bridge with a rating of HS41 (147,000lbs). This wide range was chosen to verify the existing load postings on some of the bridges.

Table 1 provides information on each of the seven bridges to be load rated. The current posting on the bridge indicates whether or not the bridge is posted either for dimensions or weight limits. A load posting of 45ton means that the maximum gross weight allowed on the bridge is 45ton (90,000lbs). The average five and six-axle logging vehicles have gross weights of 47ton and 49ton respectively. These logging vehicles exceed the posted weight limit and would not be allowed on the bridges posted at 45ton.

Additionally, the inventory and operating load factor ratings were taken from the most current routine inspection information from the Wisconsin Department of Transportation. The trucks named in ratings, (i.e. HS41) are related to the HS20 design vehicle described earlier. For example, the HS41 vehicle has the same axle configuration as the HS20 except it has higher loads on each axle.

The “Inventory Rating” is the maximum load that the bridge could sustain indefinitely without experiencing any permanent damage, assuming it is maintained. The “Operating Rating” is the absolute maximum permissible load possible for the bridge.

National Bridge Inventory (NBI) ratings are based on visual inspections and determined by a bridge inspector. Ratings for the seven bridges were taken from the most
recent inspection report. Ratings are on a scale of 0-9. Table 2 shows the relationship between the NBI condition rating and the actual condition of the bridge.

### Table 1. Seven Bridges from the Great Lakes Timber Professionals Association

<table>
<thead>
<tr>
<th>ID #</th>
<th>No. Span</th>
<th>Length (ft)</th>
<th>Structural Material</th>
<th>Year Built</th>
<th>Current Posting</th>
<th>Current Inventory Rating</th>
<th>Current Operating Rating</th>
<th>NBI Rating (deck/superstr)</th>
</tr>
</thead>
<tbody>
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<td>B06-0013</td>
<td>2</td>
<td>41.8</td>
<td>Continuous Steel Girders</td>
<td>1951</td>
<td>45Ton</td>
<td>HS41</td>
<td>HS58</td>
<td>7/6</td>
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<tr>
<td>B26-0002</td>
<td>1</td>
<td>61.5</td>
<td>Steel Girders</td>
<td>1948</td>
<td>45Ton</td>
<td>HS21.6</td>
<td>HS36</td>
<td>6/5</td>
</tr>
<tr>
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<td>2</td>
<td>54</td>
<td>Continuous Steel Girders</td>
<td>1962</td>
<td>---</td>
<td>HS15</td>
<td>HS24</td>
<td>8/5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>54</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>B37-0043</td>
<td>2</td>
<td>92</td>
<td>Continuous Steel Girders</td>
<td>1958</td>
<td>Narrow bridge</td>
<td>HS13</td>
<td>HS21</td>
<td>5/4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B60-0005</td>
<td>2</td>
<td>45</td>
<td>Continuous Steel Girders</td>
<td>1960</td>
<td>Narrow bridge</td>
<td>HS14</td>
<td>HS27</td>
<td>6/6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B37-0006</td>
<td>1</td>
<td>51.5</td>
<td>Steel Girders</td>
<td>1951</td>
<td>---</td>
<td>HS19</td>
<td>HS32</td>
<td>8/8</td>
</tr>
<tr>
<td>B38-0513</td>
<td>1</td>
<td>43</td>
<td>Concrete Girders</td>
<td>1925</td>
<td>45Ton</td>
<td>HS09</td>
<td>HS24</td>
<td>7/6</td>
</tr>
</tbody>
</table>

### Table 2. Description of National Bridge Inventory (NBI) Condition Ratings

<table>
<thead>
<tr>
<th>Rating</th>
<th>Condition</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Very Good</td>
<td>No problems noted</td>
</tr>
<tr>
<td>7</td>
<td>Good</td>
<td>Some minor problems</td>
</tr>
<tr>
<td>6</td>
<td>Satisfactory</td>
<td>Structural elements show some minor deterioration</td>
</tr>
<tr>
<td>5</td>
<td>Fair</td>
<td>All primary structural elements are sound but may have minor section loss, cracking, spalling or scour</td>
</tr>
<tr>
<td>4</td>
<td>Poor</td>
<td>Advanced section loss, deterioration, spalling or scour</td>
</tr>
<tr>
<td>3</td>
<td>Serious</td>
<td>Loss of section, deterioration, spalling or scour have seriously affected primary structural components</td>
</tr>
<tr>
<td>2</td>
<td>Critical</td>
<td>Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken</td>
</tr>
<tr>
<td>1</td>
<td>&quot;Imminent&quot; Failure</td>
<td>Major deterioration or section less present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service</td>
</tr>
<tr>
<td>0</td>
<td>Failed</td>
<td>Out of service, beyond corrective action</td>
</tr>
</tbody>
</table>
Special Notes:

Bridge Number B06-0013

The current existing posting on the bridge is 45ton. The inspection inventory and operating load factor ratings were HS41 and HS58 respectively. If these ratings are correct, then load posting of this bridge would not be necessary as the gross weight of the inventory rating of HS41 is over 70ton. This discrepancy between the rating and the posting is one of the main reasons this bridge was chosen for a new load rating.

Bridge Number B26-0002

The current posting for the bridge is 45ton. The inventory and operating load factor ratings from the most current inspection report are HS21.6 and HS36 respectively. In checking the load rating, the capacity of this bridge will be taken as the capacity of the girders alone with no composite contribution from the concrete deck.

Bridge Number B38-0513

This bridge was originally built in 1925 and is a single span concrete T-girder bridge. When the bridge was originally constructed in 1925, this bridge consisted of six concrete girders which were 40ft long. Major reconstruction was completed on the bridge in 1948. The structure was widened with five new girders and a new deck was poured. The new girders are of various lengths as shown in Figure 21. Because of the complexity of this bridge a very careful load rating procedure was used. Standard methods of estimating the force that a truck creates in individual girders could not be employed because of the various girder lengths. An accurate analysis of the bridge was accomplished using a detailed finite element model built using the software package SAP2000. The truck loadings were applied to this model and the actual forces developed in the girders were calculated and compared with the girder force capacities in bending moment and shear to define load ratings.
Length of Bridges Compared to Truck Effects

Whether the three logging trucks (5-axle, 6-axle, 5-axle with pup) should be able to cross any of the bridges depends on the bridge span length as was shown earlier. The seven bridges were examined to see where they fall relative to the span limitations defined earlier for the logging trucks.

Figure 22 shows the moment effects of the logging trucks along with some of the standard “design trucks”. The vertical black lines represent the span lengths of the seven bridges being examined. From this Figure it can be noted that all the bridges, except one, have spans less than 59ft and the logging trucks could pass if the bridges were capable of carrying the HS20 “design truck”. The one bridge with a 61.5ft span would be slightly overloaded in shear force by the 6-axle truck. All spans are OK if the bridges can carry the permit truck.
Load Rating of Bridges

Each of these seven bridges was individually load rated using two methods. These methods, the Load Factor Rating (LFR) method and the Load and Resistance Factor Rating (LRFR) method are both used today in practice. The LRFR method is the newer method and was created in conjunction with the LRFD design method.

The LRFR inventory rating differs from the LFR in that it isn’t an HS truck but rather a number around 1.0. An inventory rating of 1.0 means that the bridge can handle loads equal to the HL-93 indefinitely without permanent damage. A value less than 1.0 indicates that the bridge can only sustain loads lower than the HL-93 indefinitely without damage.

The legal load rating is a third type of rating. For this project, nine vehicles were used for the legal load rating. These vehicles are the same vehicles that are used by the State of Wisconsin to determine load posting of bridges using the LRFR method.
Due to constraints associated with this research project, visual inspections of the bridges could not be completed as part of the load rating procedure. As a result, inspection reports were used to obtain necessary information about the current state of the bridge including NBI ratings.

For each bridge, a minimum of two girders must be analyzed for load rating. In the case of a single span bridge, an interior girder and an exterior girder were analyzed. In the cases of multi span continuous bridges, one interior and one exterior girder were checked for both positive and negative moment load effects.

**Load Rating Results for the Selected Bridges**

The load rating and posting results for six of the bridges are shown in Table 3. Based on the LRFR ratings, four of the six bridges had legal load ratings which were less than one. This means they require load posting. Determining the load posting for each bridge was completed based on the Wisconsin Bridge Manual methods (Wisconsin Department of Transportation, 2008).

Bridge B38-0513 was not checked for legal load posting, due to the complex geometry of the bridge. Inventory and operating ratings, however, were calculated for the bridge. The LRFR method inventory rating was 0.74 based on moment capacity and 0.24 based on shear capacity. LRFR operating ratings were 0.98 and 0.31 based on moment and shear. The LFR method inventory ratings were HS21 and HS04 from moment and shear. LFR operating ratings were HS36 and HS07 based on moment and shear. The shear capacity of this bridge is sub-standard with the HS07 corresponding to a 25,200lb truck weight.

Five of the bridges were evaluated as requiring posting with weight limits of 5.1 to 32.4 ton. Bridge B37-0094 had the lowest posting at just over five ton. One thing to note is if the WisDOT semi vehicle (Figure 23) were excluded from the rating procedure, the posting weight could be almost doubled. This truck has back axle weights similar to the 6-axle logging truck of Figure 2, but much closer together – creating higher forces in the
bridges. This is an excellent example of how certain configurations can have much more adverse effects on a bridge and why posting solely based on gross weight is not always beneficial to all truck configurations.

Table 3. Load Posting Results

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Controlling Vehicle</th>
<th>Gross Weight of Vehicle (ton)</th>
<th>LRFR Rating</th>
<th>Posting (Ton)</th>
<th>Bridge Posting (Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B37-0006</td>
<td>SU6</td>
<td>34.75</td>
<td>0.905</td>
<td>30.0339</td>
<td>29.51</td>
</tr>
<tr>
<td></td>
<td>SU7</td>
<td>38.75</td>
<td>0.833</td>
<td>29.5054</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PUP</td>
<td>49</td>
<td>0.86</td>
<td>39.2</td>
<td></td>
</tr>
<tr>
<td>B60-0005</td>
<td>Type 3S2</td>
<td>36</td>
<td>0.75</td>
<td>23.1429</td>
<td>16.38</td>
</tr>
<tr>
<td></td>
<td>Type 3-3</td>
<td>40</td>
<td>0.747</td>
<td>25.5429</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SU4</td>
<td>27</td>
<td>0.985</td>
<td>26.4214</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SU5</td>
<td>31</td>
<td>0.898</td>
<td>26.4829</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SU6</td>
<td>34.75</td>
<td>0.811</td>
<td>25.3675</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SU7</td>
<td>38.75</td>
<td>0.75</td>
<td>24.9107</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pup</td>
<td>49</td>
<td>0.665</td>
<td>25.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semi</td>
<td>49</td>
<td>0.534</td>
<td>16.38</td>
<td></td>
</tr>
<tr>
<td>B60-0013</td>
<td>SU6</td>
<td>34.75</td>
<td>0.981</td>
<td>33.8068</td>
<td>32.44</td>
</tr>
<tr>
<td></td>
<td>SU7</td>
<td>38.75</td>
<td>0.886</td>
<td>32.4393</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pup</td>
<td>49</td>
<td>0.772</td>
<td>33.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semi</td>
<td>49</td>
<td>0.808</td>
<td>35.56</td>
<td></td>
</tr>
<tr>
<td>B37-0043</td>
<td>Type 3</td>
<td>25</td>
<td>0.732</td>
<td>15.4286</td>
<td>5.11</td>
</tr>
<tr>
<td></td>
<td>Type 3S2</td>
<td>36</td>
<td>0.542</td>
<td>12.4457</td>
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</tr>
<tr>
<td></td>
<td>Type 3-3</td>
<td>40</td>
<td>0.51</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SU4</td>
<td>27</td>
<td>0.657</td>
<td>13.77</td>
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</tr>
<tr>
<td></td>
<td>SU5</td>
<td>31</td>
<td>0.586</td>
<td>12.6657</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SU6</td>
<td>34.75</td>
<td>0.528</td>
<td>11.3186</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SU7</td>
<td>38.75</td>
<td>0.483</td>
<td>10.1304</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pup</td>
<td>49</td>
<td>0.435</td>
<td>9.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semi</td>
<td>49</td>
<td>0.373</td>
<td>5.11</td>
<td></td>
</tr>
</tbody>
</table>
Summary of Rating Results

The load ratings recorded in the State inspection records do not appear to be accurate for all of the bridges that were important for the GLTPA and the logging industry. It may be in the industry’s best interest to request a special rating procedure for critical load posted bridges. Table 4 lists the controlling LFR load rating results for each bridge along with the LFR results from the most recent State inspection report (labeled as “Inspection Report”).

Load ratings for three of the bridges matched up very closely to the inspection report ratings (shaded columns in Table 4). The maximum inventory rating difference found in those three bridges was 9400lbs and this small variance is expected due to differences and assumptions made in the load rating process. Four of the bridges had a higher than expected rating in the State inspection report, and three had a rating that appeared too low.

Table 4. Comparison of Load Factor Rating Results for GLTPA Bridges

<table>
<thead>
<tr>
<th>Bridge number:</th>
<th>B370006</th>
<th>B600005</th>
<th>B260002</th>
<th>B060013</th>
<th>B370043</th>
<th>B370094</th>
<th>B380513</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inventory Rating</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection Report</td>
<td>HS19</td>
<td>HS21.6</td>
<td>HS14</td>
<td>HS41</td>
<td>HS13</td>
<td>HS15</td>
<td>HS09</td>
</tr>
<tr>
<td>Current Result</td>
<td>HS27</td>
<td>HS19</td>
<td>HS16</td>
<td>HS22</td>
<td>HS25</td>
<td>HS13</td>
<td>HS04</td>
</tr>
<tr>
<td><strong>Operating Rating</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection Report</td>
<td>HS32</td>
<td>HS36</td>
<td>HS27</td>
<td>HS58</td>
<td>HS43</td>
<td>HS24</td>
<td>HS24</td>
</tr>
<tr>
<td>Current Result</td>
<td>HS46</td>
<td>HS32</td>
<td>HS27</td>
<td>HS37</td>
<td>HS43</td>
<td>HS22</td>
<td>HS07</td>
</tr>
</tbody>
</table>

*Note: number in bold indicates the higher rating given in each category.*
The inspection rating of bridge B37-0006 appeared to have a serious error. It is expected that this was due to a mistake in the inspection report ratings. The bridge was widened in 1997 and it is possible these new girders were not included in the most recent State inspection rating.

Bridge B06-0013 exhibited an enormous discrepancy in ratings, a 75,600lb weight difference in the operating rating. It is very unlikely that a bridge built in 1951 would have an inventory rating of HS41 (147,600lb capacity). Incredibly, this bridge is posted at 40ton (80,000lbs).

The final bridge that was load rated was B38-0513. This bridge matched up fairly closely for the inventory ratings, however, the operating ratings were very different. Again, the quality of the ratings listed in the State inspection record is suspicious in the large difference between the inspection report’s inventory and operating ratings.

From the inspection reports, three of the seven bridges that were load rated were load posted at 45ton. Bridge B06-0013 is a load posted bridge at 45ton which does not require posting based on the load ratings completed for this project.

Using the LRFR rating results from this project, all but two of the bridges would require load posting or strengthening as indicated in Table 3.

Bridge B38-0513 was not load rated for legal loads due to the complicated geometry. Only the HL-93 vehicle was used in the LRFR ratings so it is unknown how the nine legal vehicles would affect the bridge. The load ratings that were completed using the HL-93 were very low and it is likely the legal load ratings which use the AASHTO commercial vehicles would also be less than one, meaning load posting would be necessary.
Optimizing the Logging Truck Configuration to Reduce Bridge Effects

There are long spans, over 60ft, beyond which the force effects from the average logging truck on a bridge may exceed the design vehicle effects. The force effects of the average logging truck are always greater than those of the 54,000lb HS15 “design truck” used on older bridges, regardless of span length. Those conclusions clearly indicate that there are bridges that the average logging truck will not be able to use.

One possible solution to this dilemma is to decrease the effects the logging vehicles have on bridges. This could occur if optimization of the logging vehicle shape and/or weight decreased the moment and shear effects the trucks will have on bridges. Three different possible optimization options were examined and are described below.

Option 1: Reduce the Gross Vehicle Weight to Reduce Effects on Bridges

One possible solution for reducing the effects the logging trucks have on bridges is to reduce the gross weight of the vehicle. This would only be a viable solution if the reduction of load was minimal so that it was still economical to use the vehicles.

The HS20 and HS15 design vehicles were used in this analysis as a basis of comparison because many bridges have load ratings which accept these design vehicles. Weights of the logging trucks were adjusted to match the shear force created in a bridge by those two design vehicles (since shear force was found to be the controlling force).

The gross weights of the vehicles were reduced with the same proportion on each axle. This assumption simplifies the analysis but in reality the weight of the front two axles would not change much even if the pay load weight decreased. The front two axles support the cab of the truck and don’t carry much of the weight from the timber.
Figure 24 shows a series of analysis results for the shear created in a bridge by the 5-axle (94,000lb) logging truck compared to the HS20 (72,000lb) “design truck”. The gross weight of the logging truck would have to be reduced by 15%, or to 85% of its original weight, to have shear effects less than the HS20 for spans up to 170ft.

Figure 25 shows similar analyses with comparisons to the lighter HS15 (54,000lb) “design truck”. The gross weight of the 5-axle logging truck would have to be reduced by 40%, to 56,400lbs, in order to have less of a shear effect than the HS15 “design truck” on a 170ft span bridge.

![Graph showing shear force effects created in bridges by reduced weight logging trucks.](image)

**Figure 24.** Shear force effects created in bridges by reduced weight logging trucks. *(Percentages refer to a % of the gross weight of the 5-axle logging truck.)*
Other analyses were done for the average six-axle logging truck and the average five-axle truck and pup. Table 5 summarizes the results and percentage of reduction that would be needed in order to meet or be less than the design load limits of HS20 and HS15.

Table 5. Summary of Gross Weight Reduction Analysis Results-
(reduced truck weights needed to meet bridge design load limits)

<table>
<thead>
<tr>
<th>Span Length</th>
<th>HS20 load limit</th>
<th>HS15 load limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moment 170ft</td>
<td>Shear 140ft</td>
</tr>
<tr>
<td>5 Axle</td>
<td>85%</td>
<td>85%</td>
</tr>
<tr>
<td>6 Axle</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>5 Axle T&amp;P</td>
<td>80%</td>
<td>85%</td>
</tr>
</tbody>
</table>

It is evident from Table 5 that regardless of the truck configuration, the percent reduction in gross weight is fairly consistent for either of the design load limits. To meet the capacity limits of a bridge with an HS15 rating the logging trucks would have to reduce their loads by 40%. This would be an unacceptable solution since it would not be economical for the haulers.
Logging trucks could use bridges rated as HS20 if their loads were reduced by 15% to 20%. Depending on the length of the detour to avoid a posted bridge, it may or may not be economically logical to reduce the truck load. Reducing truck weight will probably not be cost effective for the timber haulers for either of the HS15 or HS20 bridge cases.

**Option 2: Change the Weight Distribution on Truck Axles to Reduce Bridge Effects**

The next possible solution was to reduce the effects of the logging vehicles on bridges by changing the vehicle gross weight distribution among the individual axles, but not changing the total weight. The average five-axle vehicle was used as a base model for this analysis as shown in Figure 26.

![Figure 26. Average Five-axle Logging Vehicle](image)

**Constraints:** The first step in this analysis was to determine constraints. The first two axles typically carry the load from the cab of the vehicle and it would be difficult to distribute the haul load to those axles. Additionally, based on the measurements taken in the field, the weight distributed to the first and second axles seemed fairly consistent for all vehicles. For these reasons, the weight distributed on axles A and B were held constant at 12.85kip (14%) and 19.87kip (21%) respectively.

Secondly, the changes allowed in axle weights were limited to the range of axle weights measured in the logging truck field study. Table 6 shows the maximum and minimum percentages of weights allowed on the third, fourth and fifth axles based on the measured five-axle truck variations.
A final constraint was that the overall gross weight must remain at 94,000lbs. Additionally, the effects of all trial trucks were analyzed for an eighty foot bridge span.

Table 6. Variation in Percentage of Weight Observed with Five-axle Logging Trucks

<table>
<thead>
<tr>
<th></th>
<th>3rd Axle</th>
<th>4th Axle</th>
<th>5th Axle</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN %:</td>
<td>19.75%</td>
<td>20.66%</td>
<td>16.23%</td>
</tr>
<tr>
<td>MAX %:</td>
<td>22.57%</td>
<td>24.00%</td>
<td>23.29%</td>
</tr>
</tbody>
</table>

Results: The goal of this analysis was to find the weight distribution which had that lowest effect on the bridge, meaning the lowest moment and shear effects. Six trials were run in total, each aimed at maximizing the weight on certain axles. The results shown in Table 7 indicate that these variations actually have little effect on the forces in the bridge.

Table 7. Weight Distribution Optimization Results

<table>
<thead>
<tr>
<th>Trials</th>
<th>Moment (kip*ft)</th>
<th>Shear (kip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base*</td>
<td>Average 5 Axle Vehicle</td>
<td>1143.00</td>
</tr>
<tr>
<td>1</td>
<td>Maximize 3rd Axle Load</td>
<td>1153.80</td>
</tr>
<tr>
<td>2</td>
<td>Maximize 4th Axle Load</td>
<td>1125.80</td>
</tr>
<tr>
<td>3</td>
<td>Maximum 5th Axle Load</td>
<td>1135.70</td>
</tr>
<tr>
<td>4</td>
<td>Maximize 4th Axle; equalize 3rd and 5th Axle Loads</td>
<td>1132.5</td>
</tr>
<tr>
<td>5</td>
<td>Maximize 4th Axle; minimize 3rd Axle</td>
<td>1189.1</td>
</tr>
<tr>
<td>6</td>
<td>Maximizes 3rd and 4th Axles; minimize 5th as much as possible</td>
<td>1223.3</td>
</tr>
</tbody>
</table>

* “Base” refers to the case with the original average 5-axle truck condition.

38
Option 3: Change Axle Positions to Reduce Truck Effects on Bridges

The force effects created in a bridge are very sensitive to large loads spaced closely together. The final option for reducing effects of logging trucks could involve changing the axle positions on the trucks to spread loads apart. The bridge force effects caused by a five-axle logging truck were used as a basis for comparison.

**Constraints:** The overall length of the 5-axle truck was held constant at 52.3ft. This is the total length of the average five-axle vehicle. The axle spacing between the first two axles was fixed at 16ft. The first two axles typically support the cab of the truck and therefore this spacing can not be easily adjusted. A bridge with a fifty foot span was used to examine the effects of the trial vehicles.

**Results:** Table 8 shows the spacings used between the axles and the maximum bending moment and shear force effects the trucks created in a fifty foot span bridge. Two different axle configurations were found as optimal – “trial 4” reduced the moments and “trial 20” reduced the shear. But the reductions in moment and shear were only 5%, making the effort of changing axle spacing pointless. In essence, the current axle spacing found in the measured trucks is near to an optimum value.
Table 8. Axle Spacing Optimization Results
(“BC”, “CD”, and “DE” refer to axles labeled in Figure 26)

<table>
<thead>
<tr>
<th>Trial</th>
<th>BC spacing (ft)</th>
<th>CD spacing (ft)</th>
<th>DE spacing (ft)</th>
<th>Maximum Moment (kip*ft)</th>
<th>Maximum Shear (kip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base*</td>
<td>4.39</td>
<td>25.99</td>
<td>5.97</td>
<td>521.60</td>
<td>51.70</td>
</tr>
<tr>
<td>2</td>
<td>3.00</td>
<td>25.00</td>
<td>8.34</td>
<td>532.30</td>
<td>53.00</td>
</tr>
<tr>
<td>3</td>
<td>5.00</td>
<td>24.00</td>
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* Base – refers to the original 5-axle logging truck configuration of Figure 1.

Logging Truck Optimization Conclusions

The only modification to the current logging truck configuration and weight that can provide a significant reduction in the effect the trucks have on highway bridges is related to the truck weight. Logging trucks could pass over bridges with low capacity, but a reduction of up to 35% or more of the normal total gross weight could be required. This might be a feasible alternative when the detour route is very long, but will not generally be an economical option.

Changing the proportional weight distribution to the truck axles or the spacing of the truck axles has little impact on the size of force created in a bridge and does not provide a solution.
Temporary Strengthening of Bridges to Carry Larger Truck Loads

The logging industry may be able to avoid the use of detours around a load posted bridge by simply strengthening the critical structure. This may be a more economical alternative to long detours or reduced truck loads.

Mechanically Fastened FRP Strips for Bridge Strengthening

An examination of different options for bridge strengthening was conducted as an alternative solution strategy for the load posted bridge problem. As a quick, economical method of strengthening – a method involving attachment of fiber reinforced polymer (FRP) strips was identified as a feasible approach for temporarily strengthening concrete bridges. External post-tensioning has already been shown by others to be an alternative for steel bridges.

Mechanically-fastened fiber reinforced polymer strips have been attached to the bottom side of concrete girders and concrete decks in projects conducted by the University of Wisconsin, WisDOT, the University of Missouri-Rolla and the State of Missouri.

The FRP strips are commercially produced and are typically composed of glass, carbon or aramid fibers and vinyl, ester, polyester or epoxy resins produced in thicknesses of 1/8in -1/4in and various widths from 4in to 12in. The strips can be quickly attached to the concrete bridge using a powder actuated mechanical fastener system such as provided by Hilti, or by threaded fasteners in drilled holes.
One of the large benefits to using this method is that the concrete surface requires very little preparation before installation. The strips can be applied by semi-skilled laborers, often county employees. The system is quickly applied and cost effective.

**Example Application of FRP Strips:** A concrete slab bridge in the city of Edgerton, WI was strengthened using mechanically fastened FRP Strips in August of 2002. This bridge was built in 1930 and was a load posted structurally deficient short span bridge. The bridge had an inventory load rating of HS17.6 (63,000lb) before strengthening. The bridge was twenty-three feet long with a twenty inch reinforced concrete deck.

The goal of the strengthening project was to increase the LFR inventory rating to HS25 (90,000lb). The bridge strengthening had a total material cost of $7572 and was completed over the course of three days. The design included FRP strips fastened 12” on center using forty fasteners spaced three inches on center. An anchor bolt was placed on each end of the strip.

The bridge was subsequently tested to failure to verify the strengthening. Failure occurred with about eight inches of deflection.

An increase of capacity by 30% was detected resulting in an effective rating of HS23 (82,000lb), higher than the normal bridge design capacity. Based on the test results, it was evident that the MF-FRP strips did add strength to the deck. Three other bridges were strengthened in Missouri using similar FRP strips and averaged $480/ft of span length for materials and labor.

An alternate solution for low capacity bridges is to complete a quick economical strengthening procedure. If the bridge has a low moment capacity, then application of mechanically fastened FRP strips may provide a relatively economical increase in load capacity and allow the bridge to be used by heavy logging trucks. The cost of the procedure, however, is not trivial. Strengthening a 60ft span bridge could cost $30,000 for materials and labor. The timber industry might be willing to compromise with the bridge owner, town, county or State, in a cost-sharing arrangement that could benefit the industry and the local
economy. The procedure can be accomplished quickly, in all weather conditions, and more economically if the owner’s own labor force is used.
Summary and Conclusions

Logging Trucks … Three different types of logging truck weights and axle configurations were measured to provide a standard reference for the loading effect that these trucks create on highway bridges. These three average logging trucks included a five-axle tractor trailer, a six-axle tractor trailer and a five-axle truck and pup vehicle with gross weights of 94,000lb, 98,000lb and 94,000lb respectively.

Effect of Logging Trucks on Bridges … Analyses clearly showed that there were bridge spans where the logging trucks would create an overload condition. The effects that the logging trucks have on a bridge depend on the bridge’s condition and strength. If a bridge has the capacity to carry the standard HS20 (72,000lb) “design truck” that has been used for the past 50 years then the three trucks can cross bridges with the following span lengths without causing overload conditions:

- 5-axle logging truck …. max bridge span = 68ft.
- 6-axle logging truck …. max bridge span = 59ft.
- 5-axle truck and pup …. max bridge span = 71ft.

The analyses also showed that if an older bridge with lower load capacity is encountered like an HS15 (54,000lb) that was used for design before the 1940’s, then all of the trucks would cause an overload condition regardless of the span length. These bridges will be load posted to prevent passage of heavy trucks.

New Design Trucks … The State is considering the adoption of new truck configurations for bridge design and rating (Truck Size and Weight Study). One of the new configurations is a 6-axle semi weighing 98,000lb. Unfortunately analyses indicate that the 6-axle logging truck will have slightly larger force effects on bridges than the new proposed “design truck” so the new truck will not help solve overload problems in the future.
2007 Legislative Resolution … Though the legislature passed a resolution in 2007 authorizing 98,000lb logging trucks on highways, this has not improved the load posting problem. Since the legislature did not specify an axle spacing configuration for the 98,000lb truck it is possible that a truck could have 3 very closely spaced axles and easily overload and damage a bridge, even though the total load is less than 98,000lb. As a result bridge owners are still load posting bridges to control damage.

Number of Under Capacity Bridges … All of the bridges in two Wisconsin counties were examined to see how many bridges have a rated capacity less than the normal HS20 (72,000lb) “design truck” amount. The State bridge inventory showed that 20% of the bridges in any county could be expected to have low load capacities – due to age, low initial design strength or deterioration. That translates to an expectation that for more than 20% of the State bridges, log haulers can expect to see load postings.

Load Posting of Bridges Critical to GLTPA … Seven bridges that are on critical log hauling routes and are load posted were examined to check their load capacities. The load capacities were also compared to the reported rated capacities on State bridge inspection records. Two of the seven bridges appeared to be load rated at an inappropriate low level and probably should not have been load posted. Overall ½ of the bridges examined appeared to have errors in the recorded State load ratings.

When the industry encounters a critical bridge that is load posted, the bridge owner should be requested to examine the load rating and possibly re-rate the bridge. The cost of re-rating might be shared by the industry as a compromise on critical bridges. There may be a 50% chance that the original rating is incorrect, but a new rating may still not allow usage of the bridge by heavy trucks.

Alternate Solutions to Avoid Detours … Three alternate solutions that might help haulers avoid detours around load posted bridges were evaluated. The only effective solution is in reducing the load on the truck. This solution should be considered when the detour route is long and the bridge is just slightly below capacity. A decrease of load by 15% - 20% would allow logging trucks to cross any bridge of any length rated at HS20 (72,000lbs)
without causing an overload. This solution may only be cost efficient with long detour routes and would not work with bridges designed for low loads such as HS15 (54,000lbs).

**Bridge Strengthening**  … One method of quick bridge strengthening was described. Fiber reinforced polymer strips can be easily mechanically fastened to concrete bridges and have been shown to increase the capacity by 30% to 50%. The cost of this procedure, including materials and labor, may be in the range of $500 per foot of length of a bridge. In critical situations the industry might cooperate with the bridge owner in providing cost sharing for this type of quick strengthening. The total process can usually be completed in approximately one week with an inexperienced work crew.

**Summary:**

The three types of measured logging trucks create forces in bridges that are generally larger than those assumed in bridges that were designed before 2007 when a new design specification became effective. It is possible that some of these bridges will be load posted to insure their continued safety.

It is almost certain that any bridge older than 55 years was designed to carry substantially lower loads then current bridge designs. Most of these bridges will definitely be load posted preventing usage by normal timber hauling trucks.

A review of bridges in two Wisconsin counties showed that 20% of the bridges had a rated capacity less than the HS20 (72,000lb) “design truck”. That, in general, indicates that timber haulers could expect more than 20% of the bridges in Wisconsin to be posted in some fashion limiting truck usage.

Though the Wisconsin Legislature passed a 2007 resolution regarding logging trucks up to 98,000lbs on highway bridges, the resolution was flawed in that specific axle spacings for the trucks were not defined. Trucks with close axle spacings and a 98,000lb gross weight could cause serious permanent damage to bridges. As a result, any reasonable bridge owner might still load post critical bridges to prevent such damage.
A review of seven critical log hauling bridges showed that more than half of the rated capacities specified on bridge inspection reports of the State appeared to be inaccurate. Load posting of bridges is related to visual inspections and calculated bridge capacity. Thus load postings may be done in error, based on faulty State or local inspection records. It would behoove the timber industry to cooperate with bridge owners in obtaining new accurate bridge ratings for critical bridges with capacities just below the logging truck weight that are load posted. This might involve a form of cost sharing for the rating procedure.

Logging trucks could still use load posted bridges, where the detour routes are extremely long, by reducing their load weights. Analyses completed here show that any bridge rated at HS20 (72,000lbs) could carry the average logging trucks, regardless of span length, if the load weight was reduced 15% to 20%. This would only be an economical alternative when the detour route around a load posted bridge is very long.

A second alternative to the load posting problem is for timber haulers and the forest industry, possibly in league with other freight movers such as the dairy industry, to cooperate with bridge owners in sharing the cost of strengthening critical bridges to increase the load capacity and remove posting. Quick strengthening methods, such as the attachment of durable fiber reinforced polymer (FRP) strips to bridge components can economically increase bridge capacity by 30% to 50%.

There is no simple solution to load posted bridges on important timber hauling highway routes. The problem is in the existence of numerous old low load capacity bridges or newer bridges that have been allowed to deteriorate in our infrastructure system, combined with trucks that are carrying heavier loads. Any fix to the problem will have a cost component that the haulers, the local economy and/or the bridge owners will have to bear. In situations with critical load posted bridges timber haulers might be best served by working with local (county) authorities to define alternate routes or to upgrade essential bridges.
Appendix A
Bridge Design Vehicles

Highway designers use “standard” vehicles in the design and load rating of highway bridges. The standard trucks are intended to create the same size forces in a bridge as actual expected trucks. Five standard design vehicles are described below.

1.) HS20-44
   The first standard truck is referred to as an “HS20-44” design vehicle, which has a gross weight of 72,000lbs. Though the HS20 vehicle was defined more than 60 years ago, it is part of the current “HL-93” loading used in bridge design. Figure A-1 shows the configuration and weight for the HS20-44 design vehicle.

![Figure A-1. Current HS20-44 Design Truck Configuration](AASHO, 2004)

(“kip” = 1000lbs, 8.0kip = 8,000lbs)

2.) HS15-44
   An “HS15-44” truck was also used in the past for design of older bridges. The gross weight of the HS15 is 75% of the gross weight of the HS20, equal to 27 tons. The weight distribution is 6,000 lbs. on the first axle and 24,000 lbs. on each of the back two axles with the same axle spacing as the HS20. Many old, deteriorating bridges are currently load rated at HS-15 so this vehicle is a good representation of the loads these bridges can currently withstand or for older bridges, it may be what they were designed to originally withstand.
3.) **Tandem**

A third current design vehicle is the “tandem”, which was created in 1956 to represent military vehicles. This vehicle consists of only two axles closely spaced at 4ft on center and each axle has a concentrated weight of 25,000lbs as shown in Figure A-2.

![Figure A-2. Current Tandem Design Vehicle Configuration](image)

(“kip” = 1000lbs, 25kip = 25,000lbs)

4.) **HL-93**

The newest design truck in use is the “HL-93”. This design truck consists of a uniform continuous load along the roadway of 640lbs per linear foot simultaneous with the larger of the maximum effects created by either the HS20 or the Tandem Vehicle.

5.) **Wisconsin Permit Vehicle**

A fourth vehicle is the “Wisconsin permit vehicle”. The permit vehicle has the same axle configuration as the HS20 with a gross weight three tons heavier. The axle weight distribution is shown in Figure A-3 (C: Maximum Weight by Annual Permit).

![Figure A-3. Wisconsin Department of Transportation Statute and Permit Vehicle Configurations](image)
6.) Proposed 6-axle 98,000lb truck

As part of Wisconsin’s recent truck and weight study a new proposed 6-axle 98,000lb was suggested for consideration as a design/rating basis in Wisconsin. The layout of the struck is shown in Figure A-4. Note that the spacing between the back axles is closer than the average 6-axle logging truck – which should result in larger shear force effects on short span bridges. The spacing between the front axle set and the back axle set, 37ft., is greater than the 22.7ft. distance in the logging trucks – so the average 6-axle logging trucks would be expect to have larger force effects in long span bridges.

Figure A-4. Proposed Wisconsin 6-axle 98,000lb truck.