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SD Department of Transportation
Office of Research

Truck Weights and the Bridge Formula

Study SD98-08
Final Report

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16. Abstract

Approximately 1,180 South Dakota bridges on the state and Interstate system were analyzed for approximately 200 non-standard truck configurations. A “standard” truck is defined as a vehicle that, if it is a single unit, contains no more than three axles, or, if a semi-trailer unit, contains no more than five axles. Typical standard trucks include the following configurations H, HS, 3S2, T3 or 3-3. All other truck configurations are considered non-standard. The allowable weight of each truck configuration using the current Bridge Gross Weight formula was compared with the analysis. It was found that the current Bridge Gross Weight formula allowed long trucks with a large number of axles to overload a significant number of bridges. Therefore, a modified Bridge Gross Weight formula is proposed. This modified formula has several advantages over the current formula. The number of bridges overloaded is more constant with the number of axles and the overall length of the vehicle. A procedure was developed that would allow an agency to select the constant, C_4, based on agency policy for the amount and percent of overloads allowed. The modified Bridge Gross Weight formula reduces the allowable gross weight for non-standard trucks with a large number of axles and high overall length so the capacity of South Dakota’s bridges is exceeded to a lessor extent than would otherwise be allowed. It increases the gross weight of vehicles with low number of axles and shorter overall length. In addition, the degree of overloading bridges is more uniform and less severe with the modified Bridge Gross Weight formula than with the original one. A procedure was developed to allow the agency to estimate the additional bridge life expected using the modified Bridge Gross Weight formula.

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Executive Summary

Overloading bridges in South Dakota will definitely reduce their expected life. With approximately 1200 bridges on the South Dakota highway system, any reduction in their life could mean a considerable loss of state assets. Since previous research has shown that the bridge weight formula over estimates the capability of bridges to carry long heavy trucks, the present use of the Gross Weight Formula (BGWF) may be significantly reducing the life expectancy of existing bridges. The evaluation of these issues will be examined in this report.

The impact on South Dakota’s bridge system by trucks loaded according to the Bridge Gross Weight Formula has been shown to be unfavorable for extending the service life of bridges. A “standard” truck is defined as a vehicle that, if it is a single unit, contains no more than three axles, or, if a semi-trailer unit, contains no more than five axles. Typical standard trucks include the following configurations H, HS, 3S2, T3 or 3-3. All other truck configurations are considered non-standard. The current Bridge Gross Weight Formula works well for shorter trucks with few axles but allows too much weight on long non-standard trucks with many axles. This causes severe overloading of many bridges, some by nearly 100 percent. Also, the use of non-standard trucks has increased and can be expected to increase further. To maintain expected service life of bridges, it is important to limit the magnitude of overloading caused by trucks, to an acceptable value. Therefore, a new or modified bridge formula is needed to more accurately predict allowable gross vehicle weights.

This study resulted in the development of a modified bridge formula where the user can control how the formula behaves. The modified formula reduces the frequency and magnitude of overloaded bridges when compared to the current Bridge Gross Weight Formula. Therefore the expected service life of bridges was shown to increase when using the modified bridge formula for establishing allowable gross weights for trucks. It does this by decreasing the allowable load on long trucks with a high number of axles to a level acceptable for continued use on bridges. However, for shorter vehicles with a low number of axles, the allowable gross vehicle weight is increased.

The user of the formula is allowed to set the amount of decrease in allowable load. This is done by determining acceptable limits on the number of overloaded bridges for all truck/bridge combinations, the maximum number of overloaded bridges by a single worst truck, the average level of overload for all truck/bridge combinations, and the maximum level of overload by a single worst truck/bridge combination.

The proposed modified bridge formula reduces the allowable loads for non-standard trucks so the operating capacity of South Dakota’s bridges is not exceeded to the extent that would be otherwise be allowed. However, due to the varied strength of bridges, not all the truck/bridge combinations are conservative. Likewise, some truck/bridge combinations will be overly conservative. When determining limits on the formula, one must decide the best method to fairly service the bridges and the trucking industry. One method is to focus on the “worst case” truck/bridge combination, and in doing so, severely reduces the weight of all other trucks. Conversely, the average or majority of truck/bridge combinations could be

focused on, letting the occasional worst case truck/bridge combination be severely overloaded.

The proposed modified BGWF had more consistent results with respect to the number of truck axles and length than the current BGWF. The modified BGWF was developed with a constant, C_4. The impact of selecting the value for C_4 was documented in the report as to the number of bridges overloaded beyond their operating capacity and the level of overloading.

Therefore, the procedure outlined in this report for calculating allowable gross vehicle weights is recommended for adoption. Based on the results of our analysis, a C_4 value between 33 and 37 appears reasonable and is recommended. The selection of a C_4 value in this range allows for an increase in allowable gross vehicle weight for relatively short trucks and a reduction in the allowable gross vehicle weight for long trucks with large numbers of axles when compared to the current bridge formula.

The SDDOT may wish to consider two additional studies before implementing the recommendations of this study. The first supplemental study would consider a more detailed analysis of the bridge system considering the bridges on each route. The state system could be subdivided into various highway classifications, route designations and MRM ranges. The analysis done in this study could be repeated for each highway segment and may result in higher values of C_4 for some highway segments.

The second supplemental study focuses on the costs associated with long, heavy trucks using South Dakota's bridges and highways. The results of the present study demonstrated that implementing the modified BGWF would increase the life of South Dakota's bridge system. The objective of this proposed study would be to develop a methodology for estimating the costs to the state for various truck configurations and gross weights. The results of this study would help guide the state in setting permit fees in the future. The costs to be considered in this study would include bridges, highways and safety.

Problem Statement

Overloading bridges in South Dakota will definitely reduce their expected life. With approximately 1200 bridges on the South Dakota highway system, any reduction in their life could mean a considerable loss of state assets. Since previous research has shown that the bridge weight formula over estimates the capability of bridges to carry long heavy trucks, the present use of the Gross Weight Formula may be significantly reducing the life expectancy of existing bridges. The evaluation of these issues will be examined in this report.

When conducting project, SD 96 - 07, "Feasibility of Automated Routing and Permitting of Oversize/Overweight Vehicles", the Principal Investigator learned that permits in South Dakota were issued, in part, based on the Bridge Gross Weight Formula. A permit is necessary for any truck that exceeds the 80,000 pound gross vehicle weight limit when driving on the Interstate system. For all trucks not traveling on the Interstate system, a permit is not required if the truck configuration satisfies the requirements of the Bridge Gross Weight Formula (BGWF).

In 1964, the Federal Highway Administration developed the Bridge Gross Weight Formula[9] to limit the overloading of bridges and pavements. Many state Department of Transportation agencies use the Bridge Gross Weight Formula for truck permitting applications. The gross vehicle weight of a truck traveling on an Interstate Highway without a permit is limited to 80,000 pounds with the exception of some states that allow greater loads. South Dakota uses the Bridge Gross Weight Formula, which correlates the number of axles and the axle spacing, as a standard of determining the maximum allowable weight for an axle group. All axle group combinations must be satisfied by the formula for the truck to satisfy the Bridge Gross Weight Formula. If the operator wishes to exceed the weight defined by the formula, a special permit application may be issued by the appropriate state agency.

A standard truck is defined as a vehicle that, if it is a single unit, contains no more than three axles, or, if a semi-trailer unit, contains no more than five axles. Typical standard trucks include the following configurations H, HS, 3S2, T3 or 3-3. All other truck configurations are considered non-standard.

With this system, trucking companies in South Dakota operate many different non-standard trucks varying in length and number of axles. Single or straight trucks refer to trucks that are one unit, with no trailers. Combination trucks are trucks that are composed of more than one unit. When counting the pulling unit, a semi-tractor with a trailer has two units, a semi tractor with two trailers has 3 units, a straight truck with a pup has two units. A double is a two trailered truck and a triple is a three trailered truck.

The Bridge Gross Weight Formula is an empirical formula based on correlation of stresses created by axle groups. Since its most recent version, adopted in 1974, the trucking fleet has changed. At the time of the formula's development, the majority of trucks were fairly short with relatively low numbers of axles. The formula was created with these trucks in mind and has worked quite well. Since that time longer trucks with greater numbers of axles have become common in South Dakota. Prior research[2] has shown that the Bridge

Gross Weight Formula does a relatively good job for short trucks, but, based on the operating load rating of each bridge, over-estimates the allowable gross vehicle weight on many longer truck configurations. This causes many non-standard trucks to overload South Dakota bridges.

Project Objective

The objective of this project is to determine the truck configuration limits that should be set so that the life of bridges in South Dakota are not prematurely shortened.

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Task 1 Review and summarize literature relevant to truck loads and their affects on design life

1.1 Literature Review

The purpose of the literature review was twofold: to review previous research related to developing truck weight limiting formulas, and to obtain data describing the truck configurations using the interstate and highway system today. It was desirable to gather information on the trucks that travel through South Dakota or similar rural states, since truck traffic varies greatly depending on the geographic region. In particular, data for trucks traveling on South Dakota interstate and highway system was desired. Also, an effort was made to find the most recent data available. The literature came from two sources: studies carried out by State or Federal government transportation departments, and studies conducted by various universities and research organizations. The following are brief summaries of the literature.

The Ontario Ministry of Transportation and Communications[1] conducted a survey of commercial vehicle weights from 1975 to 1982. Four surveys were done which included weights, axle spacing, and equivalent base lengths of trucks. The surveys found 37 different truck configurations ranging from two to ten axles. There was no evidence to suggest that the heaviest trucks had increased in weight during the time period. However, the frequency of the use of combination trucks with many axles had increased. This data backs the statement that the trucking fleet has changed since the development of the Bridge Gross Weight Formula. More operators are starting to use non-standard combination trucks as a more efficient means of hauling.

Yu and Walton[8] studied characteristics of double and triple trailer truck combinations operating in the United States in 1984. Major types of double and triple trailer combinations in use were identified. The doubles had average wheelbase lengths of up to 60 feet while the triples had average wheel lengths up to 91 feet. The doubles and triples had average gross vehicle weights up to 100,000 pounds and 120,000 pounds, respectively. Combination trucks having two or three trailers made up 20 to 30 percent of the truck traffic, but only 4 to 6 percent of the total traffic, in South Dakota. Although this study is dated, it demonstrates the wide use of non-standard trucks in South Dakota, which are exactly the trucks that are to be focused on in this study.

Meyerburg[3] conducted surveys of truck usage in 1990 and 1991. In each survey, almost 50 percent of the trucks making loaded trips were above their permitted weight limits. Also, eighteen percent of the trucks had five or more axles. This demonstrates the further possibility for damage to bridges through illegally loaded trucks. Along with the increasing number of non-standard trucks, many of them may be overloaded. Many drivers found it more economical to risk the consequences of a fine for the benefit of overloading their vehicle. This increase in efficiency of hauling has to be considered as an additional unknown element effecting bridge overloading and consequently decreasing the bridge service life.

Noel[4], with the Texas Transportation Institute, completed a bridge formula study for the Federal Highway Administration in 1985. The goal was to develop a new bridge formula that limited overstressing of HS-20 bridges to five percent, and H-15 bridges to thirty percent of their design strength. The proposed formula was dependent only on the overall length of the truck. The formula was as follows:

$$W = 1000\,[\,L + 34\,] \quad \text{For } L \leq 56 \text{ feet} \qquad (1.1)$$
$$W = 1000\,[\,L/2 + 62\,] \quad \text{For } L > 56 \text{ feet}$$

W = Gross Weight, Pounds
L = Axle Group Length, ft

The allowable truck weights based on these formulas are very restrictive when compared to the current Bridge Gross Weight Formula. Comments from the trucking industry on this formula were generally negative.

In 1986, the Texas Transportation Institute developed a modified version of their recommended formula referred to as the TTI HS-20 Formula. This formula kept the overstress limit of HS-20 bridges to five percent and dropped the criteria for H-15 bridges. This new formula was as follows:

$$W = 1000\,[\,2L + 26\,] \quad \text{For } L \leq 24 \text{ feet} \qquad (1.2)$$
$$W = 1000\,[\,L/2 + 62\,] \quad \text{For } L > 24 \text{ feet}$$

W = Gross Weight, Pounds
L = Axle Group Length, ft

This modified formula allowed greater weights on shorter trucks than the original TTI formula. However, it is identical to the original formula for trucks longer than 56 feet. With the exception of very short trucks, this formula was still viewed as being overly restrictive for most trucks.

Puckett[7], with the University of Wyoming, developed a method for the evaluation of overload vehicles in a 1989 study. A formula that relates axle weights and spacing to the maximum allowable load was developed through statistical analysis of a sample of trucks and bridges. Twenty trucks and 104 typical bridges in the state of Wyoming were used in this project. Many parameters were studied to find their effects on allowable weight including axle group length, maximum span length, minimum span length, structure type, and number of spans. The only statistically significant parameter was determined to be the axle group length. The number of axles in the axle group was not used as a parameter for testing in this analysis. Allowable weight tables were developed based on axle group length with confidence levels of 90, 95, and 99 percent.

Both the Texas Transportation Institute and the University of Wyoming studies resulted in formulas that only considered length of a truck or axle group. While the methods used in these studies are sound, it will be shown in this report that the number of axles is also a significant factor that affects the maximum allowable load for a truck.

In 1991, a University of Michigan research project by Nowak, Nassif, and DeFrain[5] was conducted to determine the truck load spectra for truck loads in Michigan. Data for over 600,000 trucks was collected using weigh-in-motion instrumentation at two weight stations. The number of axles on the recorded trucks ranged from two to eleven axles. Five axle trucks made up 66 percent of the sample. Trucks with two, three, or four axles made up 26 percent. The remaining eight percent was comprised of trucks with six to eleven axles. The moments on bridges due to the surveyed trucks were normalized with the HS-20 design truck. The maximum observed moments were as high as 2.5 times the HS-20 moment. Although the non-standard trucks still represent a small percent of the total truck population, they are a growing significance to the bridges.

Dr. Nowak was generous in providing truck data from the research for analysis in this project. The data was studied to get a better feel for different configurations of trucks found on Michigan highways. A database of 2,520 vehicles receiving citations from the Highway Patrol was used for examination. Duplicate vehicles, within a defined tolerance, were deleted resulting in a database of 381 unique truck configurations. Vehicles were deemed duplicate if all individual axle spacings were within two feet each other, and the overall truck length was within four feet. Plots were generated for a visual representation of the trucks, and are presented in Task 3.

Specific statistical data for South Dakota was found from the 1992 Census of Transportation[12]. The data is based on a sample of private and commercial trucks registered during 1992. For each truck selected, a survey form was mailed to the owner identified by the State's registration records. A sample of over 150,000 trucks was used in compiling the data.

Data from the 1992 Census was compared with 1987 data and is listed in Table 1-1. As noted in the table, the number of non standard trucks grew in every category in the five year period.

Truck Type and Axle Arrangement	*1992 Trucks (Thousands)*	*1987 Trucks (Thousands)*
Single Unit Trucks	281.9	234.6
2 Axles	275.9	230.7
3 Axles	5.5	3.7
4 Axles or More	.5	.3
Combinations	13.0	9.4
Single Unit Truck with trailer	.6	.3
4 Axles	.3	(S)
5 Axles or More	.3	.2
Truck-Tractor with Single Trailer	6.7	5.5
3 Axles	.3	.2
4 Axles	.7	.9
5 Axles or More	5.7	4.4
Truck-Tractor with Double Trailers	.2	(S)
5 Axles	(S)	(Z)
6 Axles	(Z)	(S)
7 Axles or More	.2	(S)

(S) Withheld because estimate did not meet publication standards on the basis of either the response rate, associated standard error, or a consistency review.

(Z) Represents less than 50 trucks or 0.05 percent, as appropriate for the data column.

Table 1-1 Representative Truck Volume in South Dakota from 1992 Census of Transportation

As a follow up to the 1991 study, Nowak[6], from the University of Michigan, measured actual truck loads on bridges in Detroit, MI in 1994. Observed trucks had up to eleven axles. The observed truck weights were often heavier than legal limits, especially the individual axle weight limit. Eleven axle trucks had the heaviest gross vehicle weights and were the most often overloaded based on the Bridge Gross Weight Formula. This contributes unknown amounts of additional bridge overloading.

The U.S. Department of Transportation Comprehensive Truck Size and Weight Study[10] of 1995 provided information about the U.S. freight hauling truck fleet. The 3S2 (3-axle tractor with 2-axle trailer) is the most common truck. It comprises 78 percent of trucks with five or more axles. Semi-tractors with two trailers (each trailer with three or more axles) represented two percent of trucks with five or more axles. Semi-tractors with triple trailers made up less that one percent of trucks with five or more axles. This data demonstrates that standard five axle trucks are still the most common trucks in use. However, the number of higher axle, non-standard trucks is significant enough that one should give appropriate consideration to them. Unfortunately, these data where not broken down by state.

A 1997 study by Litterick[2], with the University of Kansas, outlined various types of trucks that overloaded bridges when the gross weight was specified by the Bridge Gross Weight Formula. This project used a sample of 17 trucks taken from the Wyoming Highway Department and the Texas Transportation Institute. Many of the 17 trucks, the long trucks with a large number of axles, overloaded many bridges, while the short trucks were fairly conservative, not overloading many bridges. The worst truck, 163 feet long with eleven axles, overloaded 35 percent of the bridges in Kansas when the allowable weight is calculated by the Bridge Gross Weight Formula. The results from this study provide evidence that the long, non-standard trucks are overloading too many bridges when loaded according to the Bridge Gross Weight Formula.

1.2 Conclusions

After reviewing the literature, several conclusions were drawn. There has been a significant amount of research conducted to observe the truck weights and configurations of the trucking fleet, collect large quantities of data on truck weights, and track the use of non-standard trucks. Many studies have shown that the volume of non-standard trucks is steadily growing and represents a significant percentage of the truck population. These non-standard trucks, when loaded according to the Bridge Gross Weight Formula, are a concern to transportation officials responsible for protecting bridge service life.

Although there are many studies measuring the types of non-standard trucks using today's highways as previously described, there are very few studies of the impact on bridge life caused by these non-standard trucks. A small number of projects have proposed a way for reducing the impact of these trucks. The Texas Transportation Institute and the University of Wyoming projects resulted in the development of new bridge weight formulas. Useful knowledge was gained by studying those projects. However, a different approach was adopted for this project. This new approach results in a formula that better fits the goals of this project.

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Task 2 Meet with Technical Panel to review project scope and work plan

A meeting with the Technical Panel was held in Pierre, SD in July 1998 to review the project scope and work plan. A tour of local trucking companies was given by the Highway Patrol and several observations of different truck configurations were made. The truck configurations to be used in the project were generally agreed upon after a discussion with the Technical Panel. Also, it was agreed that the work plan outlined in the proposal would be followed in this project. A meeting was also held with Todd Thompson to discuss the acquisition of bridge data for use in the project. Arrangements were made to obtain the necessary bridge data for all South Dakota Highway and Interstate bridges.

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Task 3 Identify the possible truck configurations to test

3.1 Truck Data

To evaluate the impact of non-standard trucks on South Dakota highways, a representative sample of non-standard trucks that could use the highway system had to be defined. The trucks considered in this study focus on “non-standard” trucks, or trucks with five or more axles. Following a tour of local South Dakota trucking operations, it was evident that an unlimited number of truck types, sizes, and configurations use South Dakota highways. Due to the analysis method used in this study, it was possible to consider a large number of trucks in the project.

The project Technical Panel suggested a database of 199 trucks be considered in this study. Graphic representations of the trucks are found in Appendix A, referenced by Truck ID number. This database includes trucks of differing types and sizes. Single straight trucks refer to trucks that are not articulated, while combination trucks refer to trucks that have one or more articulated joints. Eight single straight trucks (Truck ID’s 136 – 143) ranging in length from 12 to 45 feet and having between 2 and 6 axles were chosen to represent the short single trucks. There are longer combination trucks where single straight trucks use a towbar to pull a trailer or “pup”. The database includes 56 configurations of this type (Truck ID’s 144 – 199) having lengths from 36 to 74 feet and ranging between 4 and 16 axles. A third configuration of truck used in this study is the “triple”. This is a semi-tractor that tows two trailers in series. There are 135 triples in the database (Truck ID’s 1 – 135) with lengths from 86 to 100.5 feet and 6 to 17 axles. In addition to these 199 non-standard trucks, two trucks were included that have the same configuration as the HS-20 rating truck, truck ID’s 200 and 201. One of these trucks had the minimum rear axle spacing with an overall length of 28 feet. The other had the maximum rear axle spacing with an overall length of 44 feet. Both trucks had three axles. These 201 trucks account for a wide array of lengths and axle configurations found on South Dakota Highways and Interstates, with a focus on long, non-standard trucks.

The gross vehicle weights for the study non-standard trucks were determined by the Bridge Gross Weight Formula. For every non-standard truck, the overall truck length and number of axles controlled the allowable load. The maximum allowable individual axle weights were used in determining the distribution of the gross weight to the axles. The maximum axle weights for a single axle and tandem axle are 20,000 and 34,000 pounds, respectively. A tandem axle is defined as two axles not spaced more than 96 inches apart. The maximum axle weights for axle groups with three or more axles, each spaced not more than 96 inches apart, were obtained from the Bridge Gross Weight Formula. Each axle on the non-standard truck was assigned its maximum allowable weight. Although the summation of these axle weights is not the allowable gross vehicle weight, the total was used for determining the percentage of weight each axle could carry. The controlling allowable gross vehicle weight was assigned to each truck, and distributed according to each axle percentage.

A graphic representation of how these non-standard trucks compare to the large sample of trucks obtained from the University of Michigan study [8] is presented in Figures 3-1 and 3-2. The small circles represent axles with the lead axle on the left. The trucks are sorted by axle numbers and by overall length. As shown in the figures, the non-standard trucks in this study are focused on representing the longer non-standard trucks. The trucks with a large number of axles are the longest trucks in the sample, while the lower axle trucks are evenly distributed throughout the Michigan sample. The South Dakota non-standard trucks having twelve or more axles are not shown because the Michigan data only included trucks with a maximum of eleven axles.

3.2 Bridge Data

The method of analysis used in this project made it feasible to consider a large number of bridges in the database. Likewise, to attain the best results in this study, all South Dakota bridges in the database were considered with the exception of truss bridges. By considering all bridges on the South Dakota State Highway and Interstate system, a total of 1,178 bridges were analyzed. Because the formula developed in this project was based on the maximum allowable load given by the operating rating, posted bridges (having restricted limits) were removed from the database. Posted bridges are restricted to levels below the operating rating. They are not considered in this study because non-standard vehicles, based on weight, are not generally allowed on posted bridges. After removing the 26 posted bridges, the final bridge database consisted of 1,152 bridges.

The South Dakota Department of Transportation uses the AASHTO BARS (Bridge Analysis and Rating System) database for analyzing their bridges. The BARS system includes information on design details, current conditions, and load ratings for all bridges. A query of the database was generated to compile the needed information for each bridge. This resulted in a text file that included bridge identification number (BARS number), bridge type, span type, total length, individual span lengths, span material, rating truck, and operating and inventory ratings, along with other miscellaneous information.

The data file was formatted for use with the analysis software. This included parsing the data and attaching codes that identified certain bridge characteristics. The data, for identification number, total length, individual span lengths, and operating ratings, were read directly into the software. Flags were put into the data file to indicate bridge type, span type, span material, and rating truck type.

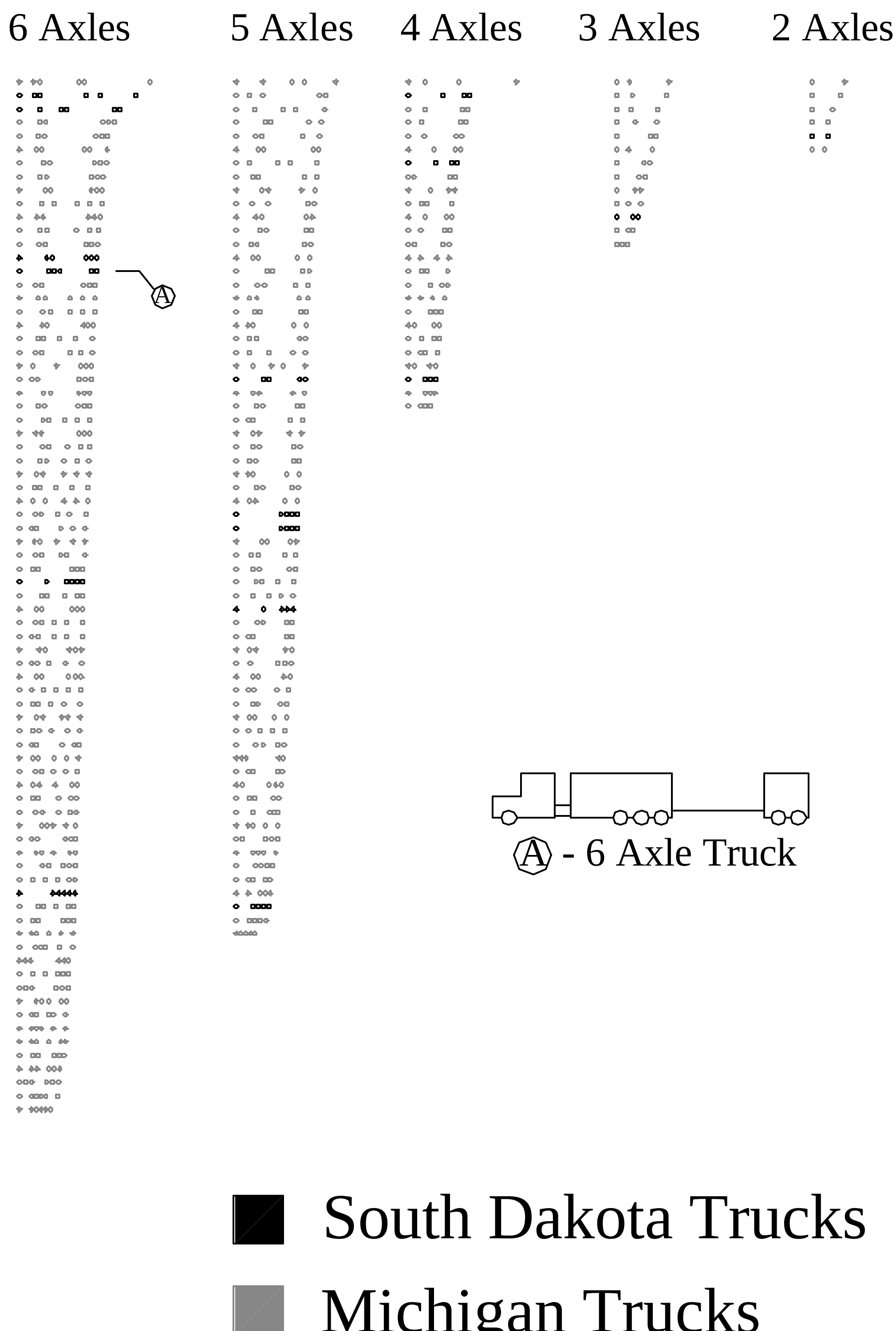

Figure 3-1 South Dakota and Michigan Truck Length Comparisons

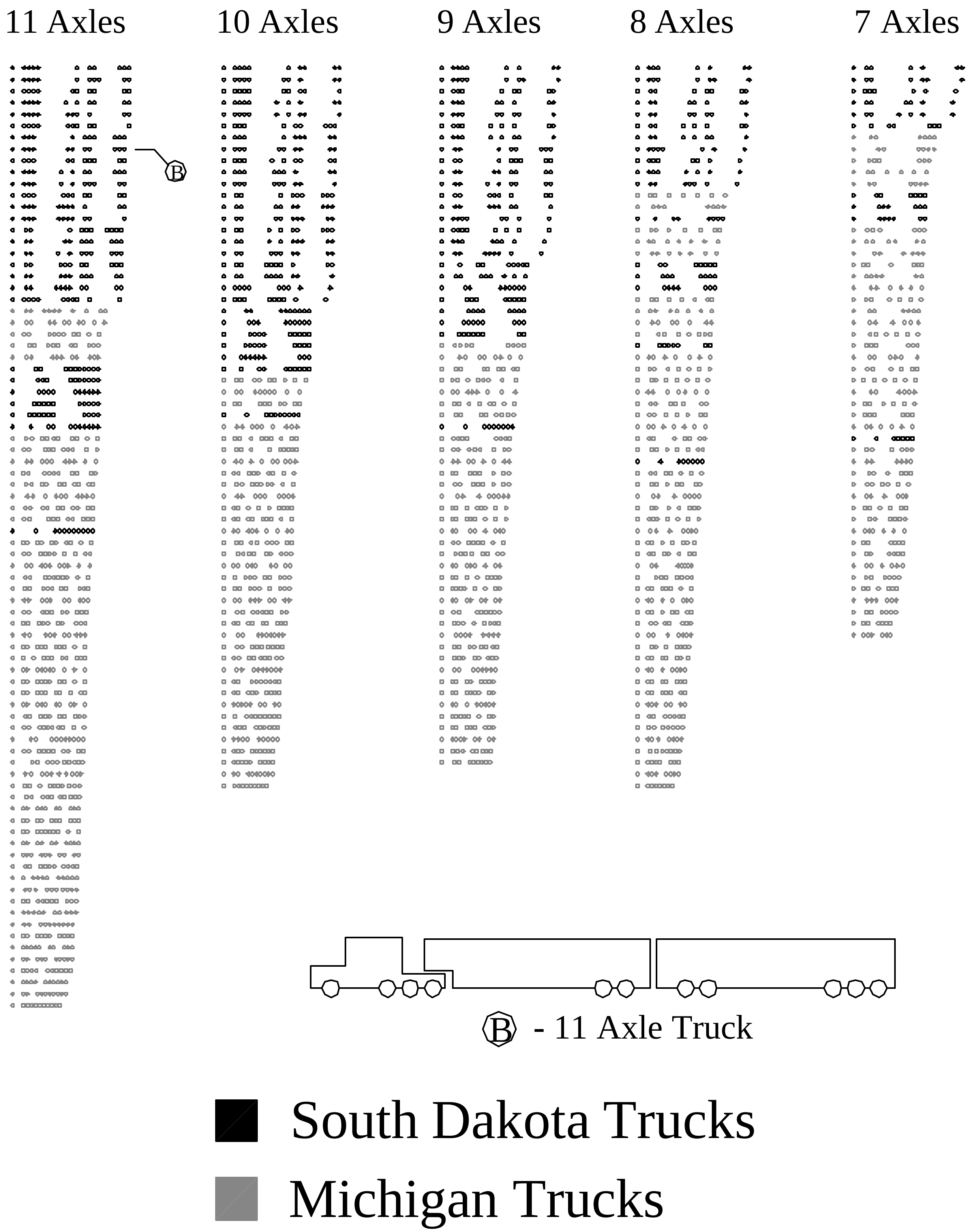

Figure 3-2 South Dakota and Michigan Truck Length Comparisons

Task 4 Perform a structural analysis on a representative sample of bridges and non-standard truck configurations identified in Task Three, for strength capacity and fatigue (serviceability). Bridges to be samples will come from South Dakota's bridge inventory.

4.1 Structural Analysis Approach

When evaluating the strength of bridges, one can use three different values to describe the structural capacity of the bridge. The first value is the design load. This was the load used to design a bridge. It may be a truck configuration and magnitude such as "HS20" or "HS25". After it is built, bridge engineers load rate the bridge at two different levels. In each case, a rating vehicle is used with a predefined axle configuration. The "inventory" rating is defined as the allowable gross weight of the rating vehicle that the rating vehicle can use the bridge without experiencing a reduction in bridge life due to use. At the "operating" rating, the gross weight of the rating vehicle is increased so the bridge is still considered "safe", but if the bridge sees heavy truck traffic, the expected bridge life could be reduced due to use.

Originally, many bridge owners began posting bridges based on the inventory rating. However, the more traditional approach now is to post at the operating rating or somewhere between the inventory and operating rating. Throughout this study, the bridge capacity was based on the bridge operating rating.

As discussed earlier, the following information was extracted from the BARS database: number of spans, length of each span, continuity between spans, rating vehicle, operating rating value. Other data was retrieved to satisfy the requirements of PBRaT such as deck type, material, etc but was not considered in the analysis.

After finalizing the bridge and truck databases, the actual gross vehicle weight each truck could carry on each individual bridge was calculated. The approach used to accomplish this task for a single bridge follows: A structural analysis was performed on the bridge to calculate the moment influence lines at critical moment points. The original rating truck was moved in both directions across the bridge at increments equal to one tenth of the span length. The weight of the rating truck equaled the previously calculated operating rating capacity from the BARS database. The maximum positive and negative moments at critical points were stored. An allowable moment capacity envelope for the bridge at critical locations was calculated.

With the moment capacity envelope for the bridge known, the non-standard truck was also moved incrementally across the bridge at its allowable weight prescribed by the Bridge Gross Weight Formula. The moment envelope created by this loading was calculated and compared to the moment capacity envelope. A ratio of the two moment envelopes was used to determine the magnitude of overload or underload created by the non-standard truck. The allowable gross vehicle weight that the non-standard truck could carry, based on the operating rating, was calculated. This was done for all truck/bridge combinations in the database.

With the databases of 201 trucks and 1,178 bridges, there were 236,778 truck/bridge combinations considered in the study. To perform these calculations, a custom software package, $PBRaT^2$, was used. The software calculates the allowable gross vehicle weights for each truck/bridge combination using the method described above.

Before performing the analysis, the program sorted through the bridge data looking for possible erroneous data that could skew the results. Examples of bad data include invalid structure types, material types, and the sum of the span lengths not equal to the total bridge length. After the invalid data was fixed, the influence lines for each bridge were calculated and stored in a data file. Next, the rating trucks were moved across the bridge to find the moment capacity envelope for each bridge. Finally, each non-standard truck was moved across the bridge, and the allowable gross vehicle weights (based on the bridge operating ratings) were calculated and written to a data file.

Because of this approach, other bridge properties such as dead and impact loads do not need to be considered in this analysis since they were already considered when calculating the original operating rating for the standard rating vehicle.

4.2 Structural Analysis Results

With the extremely large number of data sets considered in this study, one came to several conclusions. It would be nearly impossible to select six to ten bridges to represent the entire South Dakota bridge system. For each truck configuration, a different allowable weight was calculated for every bridge in the system. There were no trends. Also, one truck configuration was not critical for all bridges. When one considers geography with the calculated data, it was obvious that the allowable load for each truck configuration is dependent upon the path taken by a particular truck configuration.

Based on these observations, the project team took an approach of looking at the entire bridge system as a single system. Thus, there are cases were a particular truck might significantly overload a particular bridge. While the degree of overload would be monitored, it would be unduly conservative to base the resulting studies considering the worst truck configuration would only travel over the worst bridge.

Task 5 Determine the extent of usage of non-standard vehicles and the possibility of increased usage.

A list of trucking firms located in South Dakota, or that use South Dakota highways, was provided by the Technical Panel to the project team. Each firm was contacted and asked to fill out a survey questionnaire. A follow up phone call was made to each firm to encourage response to the survey. The purpose of the survey was to determine the current usage and estimated future usage of non-standard trucks.

Two separate survey forms were sent to each company, a detailed form and a summary form. The detailed form was the preferred form, but the summary form was acceptable. Sample detailed and summary forms are included in the following pages.

Four firms responded to the survey. Two companies responded by providing the detailed form and two companies provided the summary form. The data from the survey has been compiled for presentation.

Thirty-two (32) trucks were described in the returned surveys. These trucks ranged from 74 feet to 97 feet in length. Length is defined as the center to center distance from the front axle to the rear most axle. The trucks had from 8 to 15 axles. The specifications for each truck are shown in Table 5-1.

Number of Trucks In Group	*Length (feet)*	*Number of Axles*	*Maximum Gross Weight*	*Total 1998 Mileage*	*Total Estimate 2003 Mileage*
2	74	8	106,000	114,400	120,000
12	76.3	9	117,000	1,089,400	1,198,000
1	94	11	135,000	19,600	50,000
10	94.3	13	148,000	1,228,500	1,351,000
2	91	13	141,000	143,100	145,000
2	95	14	151,000	130,600	135,000
3	97	15	159,000	197,600	205,000

Table 5-1 Survey Results

The survey forms also requested information on the mileage from 1998 and the estimated annual mileage by 2003. The increase in mileage for the five-year period ranged from 1.3 percent to 10.0 percent. Every response indicated an estimated increase in usage of non-standard trucks over the next five years.

EnGraph
4840 W. 15th Street, Suite 1016
Lawrence, KS 66049
(785) 865 – 1436

April 21, 1999

«Name»
«Company»
«Address»
«City», «State» «Zip»

Dear Sir:

EnGraph is presently conducting a research project with the South Dakota Department of Transportation. As one of the tasks, we are required to estimate the present and future travel of commercial vehicles within the state of South Dakota. To accurately accomplish this goal, we solicit your assistance.

To make this questionnaire as convenient as possible, we are providing you with two options. If the data is readily available, the Detail Form is desired. However, if you would like to submit the Summary Form, that is acceptable. Please do **NOT** do both. To make it easier, you may combine your vehicles into groups. For purposes of our research project, a group of trucks would have similar lengths, number of axles, axle spacing and gross vehicle weight when loaded. For each single vehicle, or group, we request the following on the Summary Form: number of vehicles, length between the front and rear axles (or length between axles), gross vehicle weight, actual 1998 Interstate and "other" highway mileage and an estimated mileage in the year 2003. On the Detail Form similar information is requested with the following exception, we would like to know the spacing between each axle.

To make the questionnaire easier, we have prepared a drawing of three typical trucks. The data for each truck is included on the forms.

We would appreciate attachment of your name on the questionnaire for our control purposes. When we compile the results, they will be completely anonymous. In fact, we will not share the raw responses with the SDDOT unless we have your permission. If you have any questions, please do not hesitate to call.

Would you please submit this questionnaire by **MAY 3, 1999**. Thank you for your assistance in our research.

Very truly yours,

Carl E. Kurt
President, EnGraph

Enclosure:

Summary Form				South Dakota Truck Usage					
	Group i *	Group ii *	Group iii *	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Front/Rear Axle Length, ft	49.5	49	97.5						
Number of Axles	5	7	10						
Number of Vehicles in Group	4	5	1						
Maximum Gross Vehicle Weight, lbs	82,000	126,500	125,000						
Actual 1998 Interstate Mileage in South Dakota for Group	255,000	300,500	100,000						
Actual 1998 "Other Highway" Mileage in South Dakota for Group	100,000	155,600	5,000						
Estimated 2003 Total Mileage in South Dakota for Group	400,000	650,000	120,000						

*** See attached Sheet for Examples**

Name	
Company	
Address	
City	
State	SD
ZIP	
Phone	

Return To: Carl E. Kurt
EnGraph
4840 W. 15th Street
Lawrence, KS 66049
(785) 865 - 1436

Please Submit by May 3, 1999

Detail Form South Dakota Truck Usage

Axle ID	Distance Between Axles, feet									
	Group i*	Group ii*	Group iii*	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Axle 1	11.5	12	11.5							
Axle 2	4	4	4							
Axle 3	30	4	26							
Axle 4	4	4	4							
Axle 5		15	4							
Axle 6		10	10							
Axle 7			4							
Axle 8			28							
Axle 9			4							
Axle 10										
Axle 11										
Axle 12										
Axle 13										
Number of Vehicles in Group	4	5	1							
Maximum Gross Vehicle Weight, lbs	82,000	126,500	125,000							
Actual 1998 Interstate Mileage in South Dakota for Group	255,000	300,500	100,000							
Actual 1998 "Other Highway" Mileage in South Dakota for Group	100,000	155,600	5,000							
Estimated 2003 Total Mileage in South Dakota for Group	400,000	650,000	120,000							

Name	
Company	
Address	
City	
State	SD
ZIP	
Phone	

*** See attached sheet for examples**

Return to: Carl E. Kurt
EnGraph
4840 W. 15th Street, Suite 1016
Lawrence, KS 66049
(785) 865 - 1436

Please Submit by **May 1, 1999**

Task 6 Determine limits on weight and axle configuration of vehicles that will better ensure bridges meet their design life

6.1 Evaluation of Current Bridge Gross Weight Formula

Before developing a new formula, the behavior of the current Bridge Gross Weight Formula in screening trucks and the resulting consequences were identified. This was accomplished by comparing the calculated allowable gross vehicle weight found in Task 4 to the estimated gross vehicle weight given by the current bridge formula.

As will be justified later, this formula allows too much weight on bridges for many trucks. The general problem is with the longer non-standard trucks. Shorter trucks with fewer axles, like those common at the time of the formula's development, are well served by the formula. They are loaded conservatively in most situations, which is good for extending the bridge life, but limits the service to the trucking industry. The longer non-standard trucks that have emerged since the development of the formula were found to overload many of the existing bridges. The data presented in this section illustrates the problems with the formula, and why a new, or modified formula, is needed to help preserve bridge service life.

There are certain terms used in the presentation of the data that need to be defined. The "average" conditions are based on all 231,552 truck/bridge combinations, while the "maximum" values are obtained from the worst or most critical truck/bridge combination. A bridge is "overloaded" when a truck loads the bridge beyond the specified operating rating. The level of overload is defined as the percent of the actual allowable load that the given truck was overweight. For example, a 110,000 pound truck that is only allowed to carry 100,000 pounds overloads the bridge by ten percent.

The allowable weight based on the Bridge Gross Weight Formula overloaded approximately twelve percent of the truck/bridge combinations in South Dakota. The ten worst trucks, based on the number of bridges overloaded are shown in Table 6-1. The ten worst trucks, based on the maximum level of overload are shown in Table 6-2. In either case, the worst trucks, are long (100.5 feet) with more than 13 or 14 axles.

Truck ID	*Length, ft*	*Number of Axles*	*Number of Bridges Overloaded, %*
99	100.5	14	28.6
98	100.5	13	26.6
108	100.5	15	26.5
107	100.5	14	25.2
54	96.5	13	24.2
126	100.5	16	24.0
63	96.5	14	23.9
53	96.5	12	22.7
97	100.5	12	22.7
125	100.5	15	22.4

Table 6-1 Ten Worst Trucks with Current Bridge Formula Based on Number of Overloaded Bridges

Truck ID	*Length, ft*	*Number of Axles*	*Maximum Level of Overload, %*
108	100.5	15	99.2
99	100.5	14	98.5
126	100.5	16	98.4
135	100.5	17	97.5
88	96.5	14	95.2
117	100.5	15	90.5
125	100.5	15	90.4
90	96.5	16	90.3
107	100.5	14	90.1
98	100.5	13	89.7

Table 6-2 Ten Worst Trucks with Current Bridge Formula Based on Maximum Level of Overloaded

The level of overloading for each truck is shown in Figure 6-1. The average level of overload was approximately fifteen percent. The maximum level of overload, caused by several long trucks with many axles, was ninety-seven percent. This means that the allowable gross vehicle weight using the Bridge Gross Weight Formula was nearly double the allowable gross vehicle weight permitted by the bridge.

The trucks in Figure 6-1 are sorted by increasing length and then by increasing number of axles. It is evident that the short trucks do not create a serious problem for bridges while the long trucks are overloading the bridges beyond an acceptable level. Also, the level of overloading increases as the truck length and number of axles increase.

Another observed trend was that the number of overloaded bridges increases with either increasing truck length or number of axles. The number of bridges overloaded considering all trucks in the database are shown in Figures 6-2 and 6-3, respectively. In Figure 6-2, the number of overloaded bridges is shown to increase with increasing truck length. In Figure 6-3, the number of overloaded bridges also increases with increasing number of axles. As shown in these figures, the allowable load based on the BGWF for one 100.5 foot long truck overloads 28 percent of the bridges in the database.

For a constant truck length, increasing the number of axles results in a greater number of overloaded bridges. As seen in Figure 6-4 for 74 foot long trucks, the trucks with a higher number of axles overloaded more bridges than the trucks with fewer axles. This trend was typical for all length trucks, and can be seen for other truck lengths in Appendix C.

Several conclusions can be drawn from studying the Bridge Gross Weight Formula. First, there are a greater number of overloaded bridges caused by trucks with a large number of axles than by trucks with fewer axles. This implies that the bridge formula allows too much additional weight for the addition of axles. There are also a greater number of overloads for longer trucks than for shorter trucks. The behavior of the formula is not consistent for all truck lengths. This implies that the bridge formula may allow too much additional weight for the addition of length. The Bridge Gross Weight Formula allows too much weight to long trucks, and is conservative for short trucks. Finally, the frequency and level of overloading of bridges is greater than what would be considered reasonable for maintaining bridge life. This means that the formula, in general, allows too much weight on the bridges.

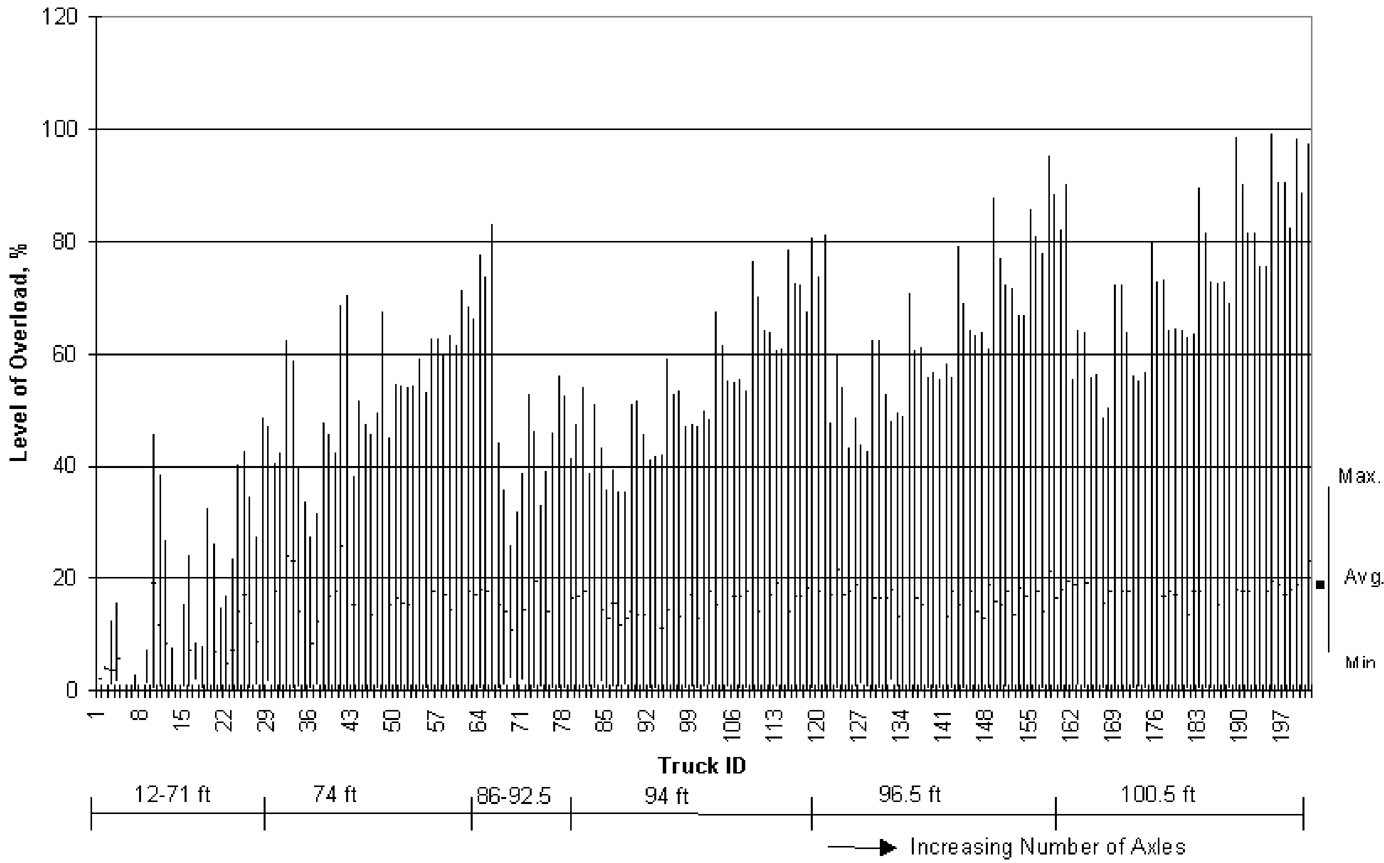

Figure 6-1 Degree of Overloading on South Dakota Bridges Using Current Bridge Gross Weight Formula

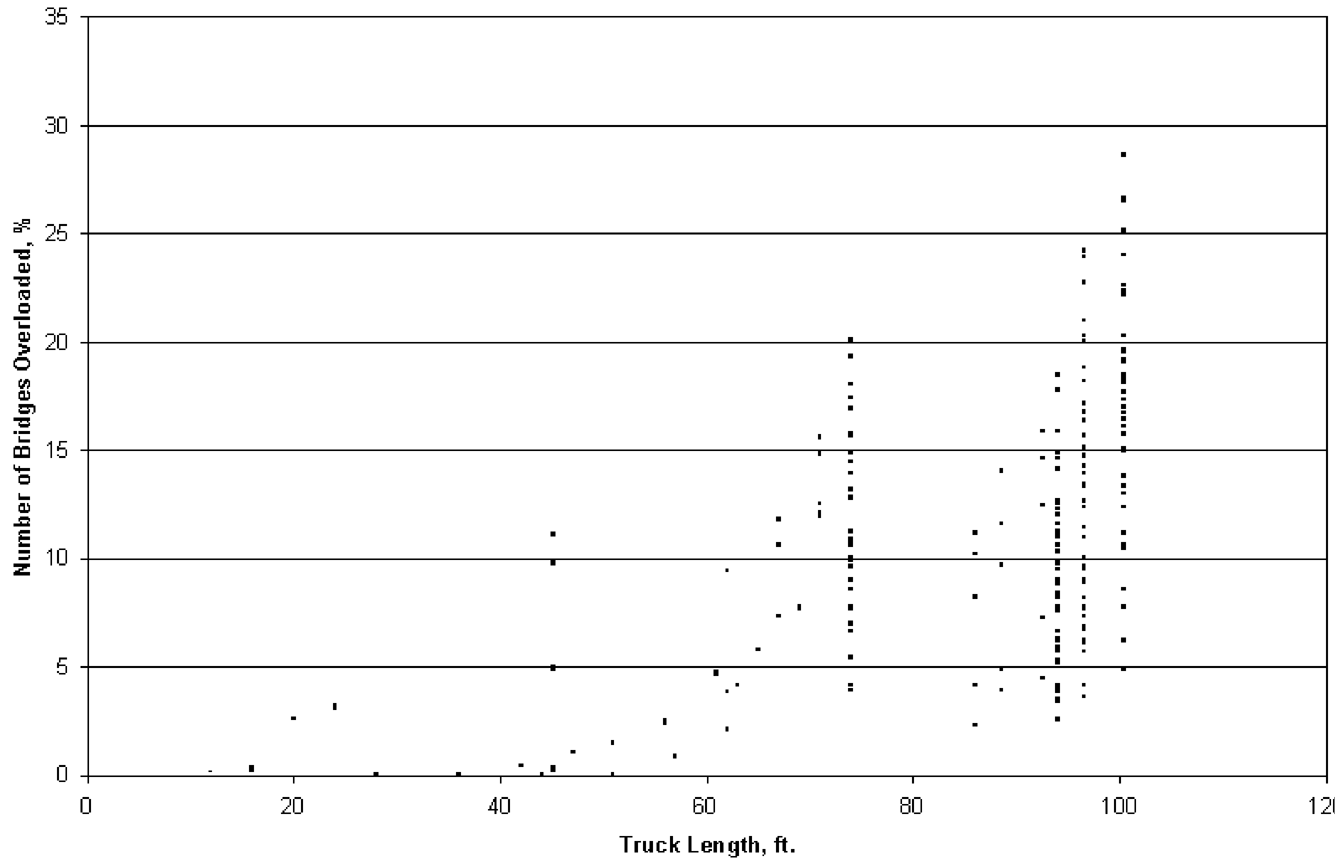

Figure 6-2   Number of Bridges Overloaded By Increasing Truck Length Using Current Bridge Gross Weight Formula

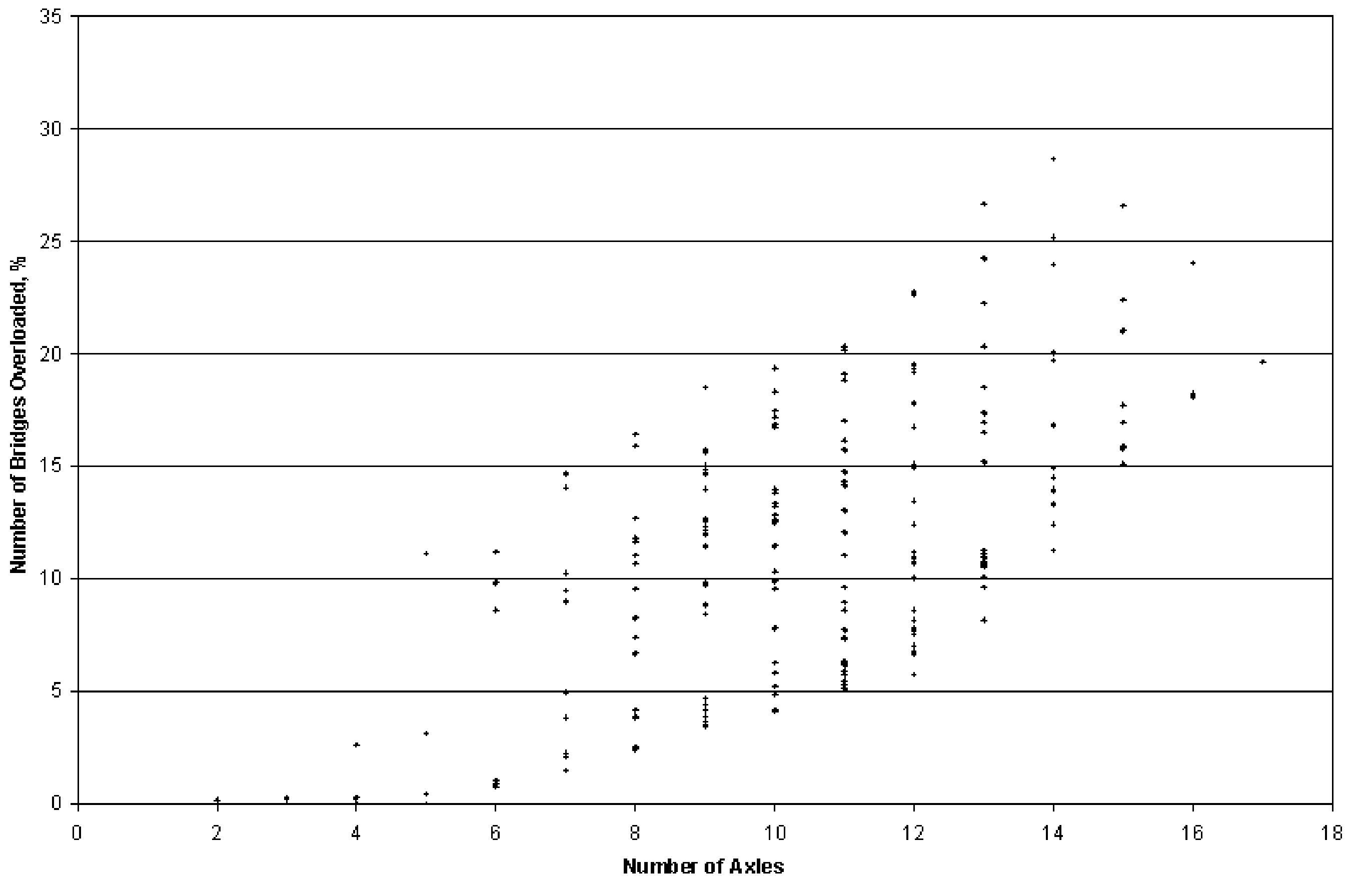

Figure 6-3 Number of Bridges Overloaded By Increasing Number of Axles for All Trucks Using Current Bridge Gross Weight Formula

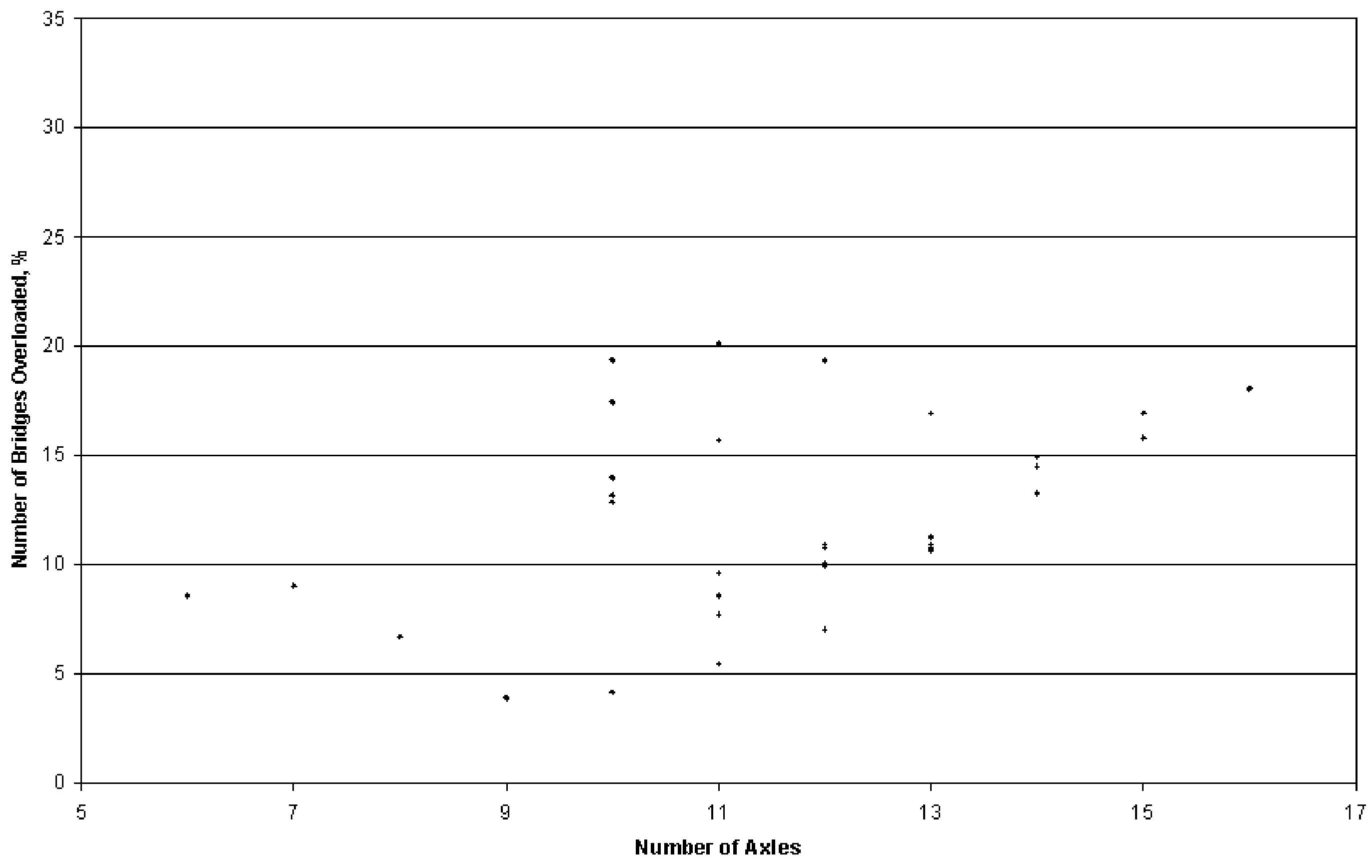

Figure 6-4 Number of Bridges Overloaded By Increasing Number of Axles for 74 foot Trucks Using Current Bridge Gross Weight Formula

Task 7 Recommend practical limits on weight and axle configurations that South Dakota should use for limiting damage caused by non-standard trucks

7.1 Proposed Modified Bridge Formula

Many new formula types were evaluated in the development of the proposed formula. The initial test formulas, for various reasons, were all deemed unusable. The final test formula was modeled after the Bridge Gross Weight Formula, with the constants taken out. New constants would be proposed after optimizing the formula for the desired performance. The generic formula is as follows.

$$W = 1000\ [\ C_1LN/(N+C_2) + C_3N + C_4] \qquad (7.1)$$

L =	Length in feet
N =	Number of axles
C_1-C_4 =	Constants
W =	Gross Weight in pounds

The four constants all have important effects on the formula. A generic plot of the formula is shown in Figure 7-1. The formula is plotted by Gross Weight versus Length. The multiple lines represent different numbers of axles. The constant, $C_{1,}$ determines the initial (unmodified) slope of each line. This determines how much additional weight is allowed for increasing length. The constant, $C_{2,}$ modifies the slope of each line, depending of the number of axles. If C_2 is set at zero, each line has the same slope. If C_2 is greater than zero, the lines have a steeper slope as the number of axles increase. If C_2 is less than zero, the lines have a shallower slope as the number of axles increase. With this constant, the amount of additional weight for additional length can vary for different numbers of axles. The constant, $C_{3,}$ adjusts the spacing between the lines. This determines the additional weight allowed for increasing the number of axles. Finally, the constant, $C_{4,}$ determines the vertical positioning of the group of lines on the graph. This is used to raise or lower the gross vehicle weight on the group as a whole.

Because there is so much variation in the strength of bridges, it is impossible for the formula to exactly predict the allowable weight for every truck on all bridges. However, it is desirable to have a formula where the number of overloads is independent of truck length and number of axles. This goal was accomplished by finding the correct values for the constants in the equation.

The effect that a particular constant has on the equation can be analyzed by varying that particular constant, while holding all other constants unchanged. The first constant tested was C_1. Multiple values of C_1 were tested while holding C_2 and C_3 constant. For each value of C_1, constant C_4 was set so that the number of overloaded truck/bridge combinations was ten percent. This allowed comparison of each variation of the formula. It is shown in Figure 7-2 that setting C_1 equal to 0.5 gives the most constant overloads for all numbers of axles.

Multiple variations of constant C_2 were also tested. Constants C_1 and C_3 were unchanged and C_4 was again set so that each variation overloaded ten percent of truck/bridge combinations. The overloads are most constant for all numbers of axles when C_2 is equal to –1, shown in Figure 7-3.

Constant C_3 was tested by holding C_1 and C_2 unchanged. For each different C_3, the value of C_4 was set to overload ten percent of truck/bridge combinations. It was found that using C_3 equal to 3 gives the most constant number of overloads for all numbers of axles, shown in Figure 7-4.

Finally, constant C_4 is used to set the number of allowable percentage of overloads. As shown in Figure 7-5, with the constants C_1 – C_3 set as described above, the amount of overloaded bridges is nearly constant for all numbers of axles at each value of C_4.

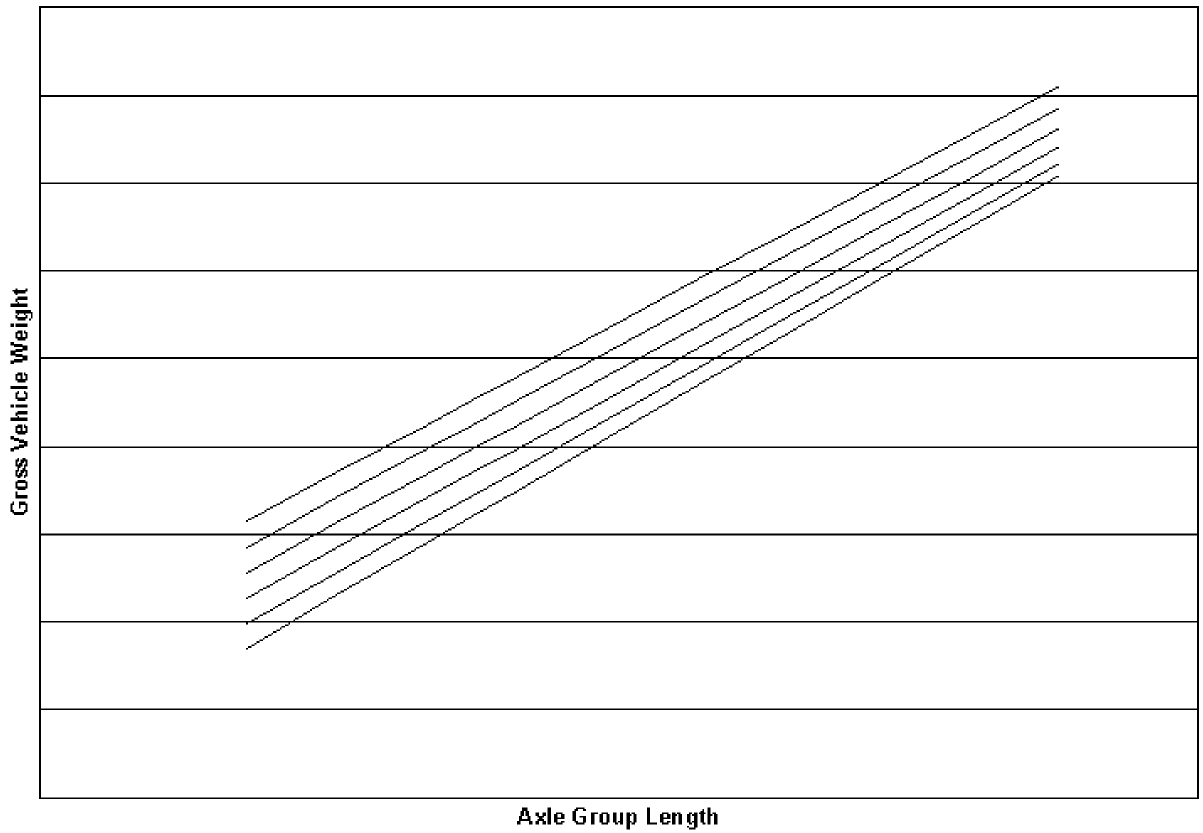

Figure 7-1 Generic Proposed Formula Type

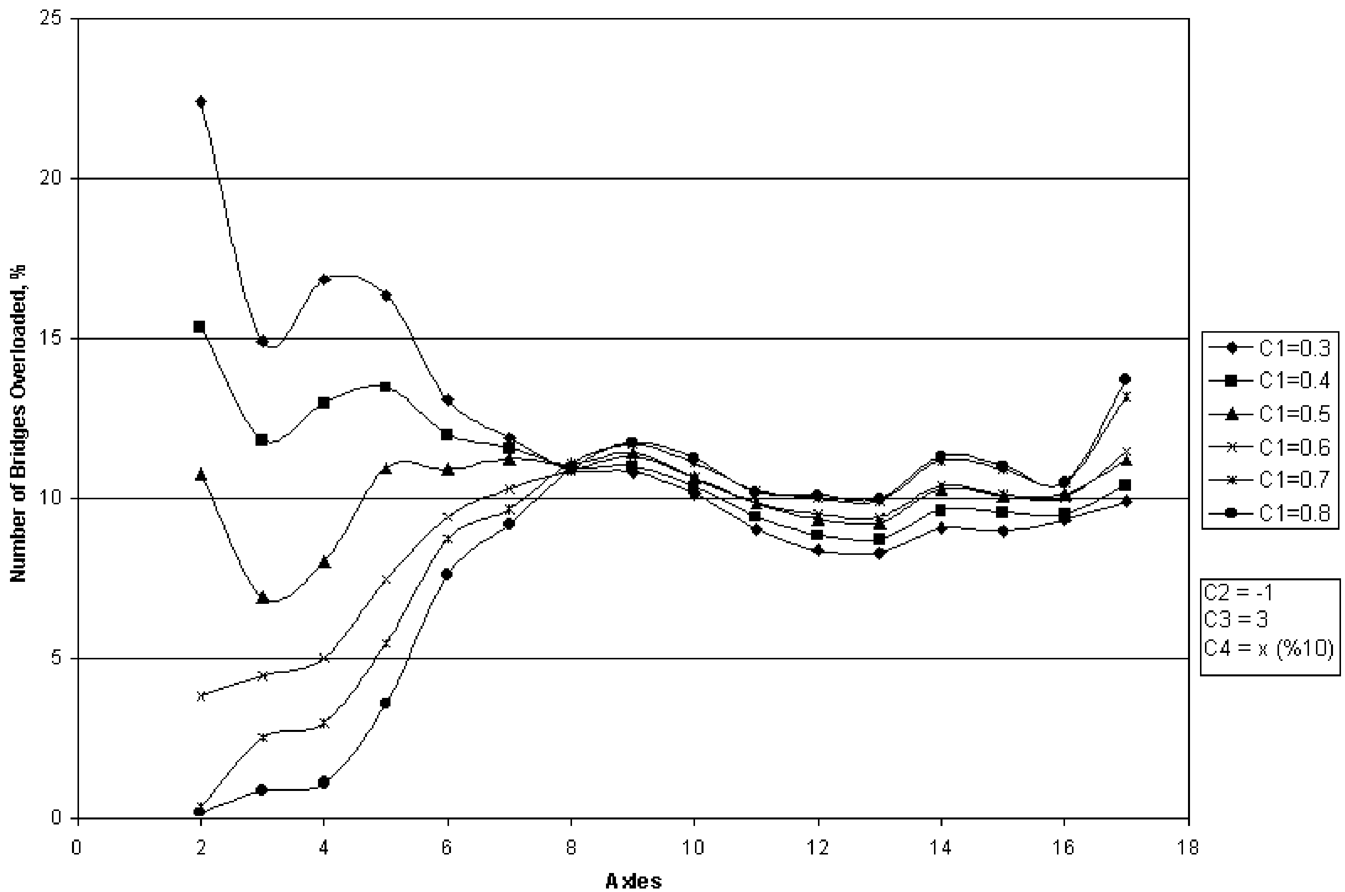

Figure 7-2 Optimization of Coefficient C1

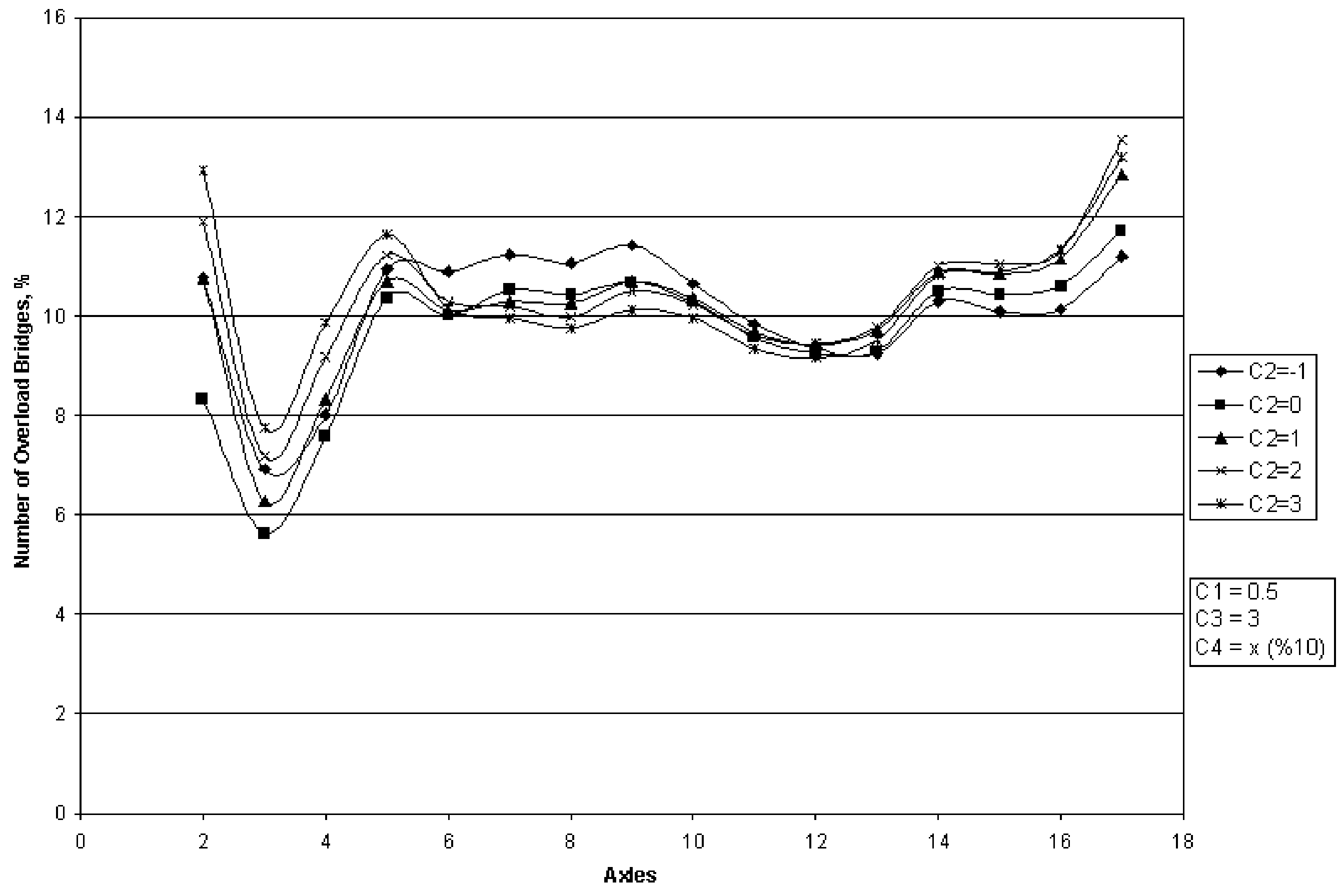

Figure7-3 Optimization of Coefficient C2

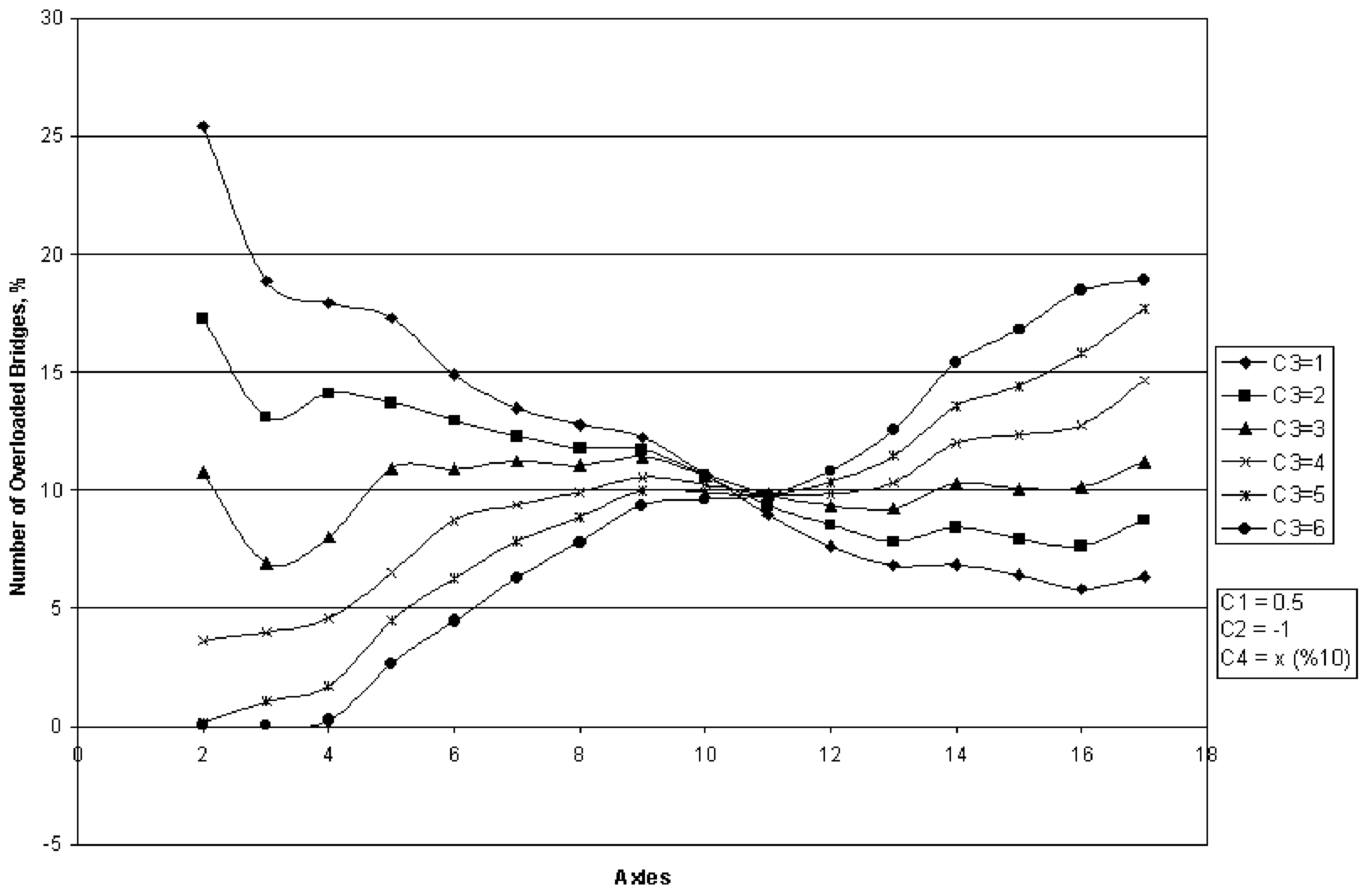

Figure 7-4 Optimization of Coefficient C3

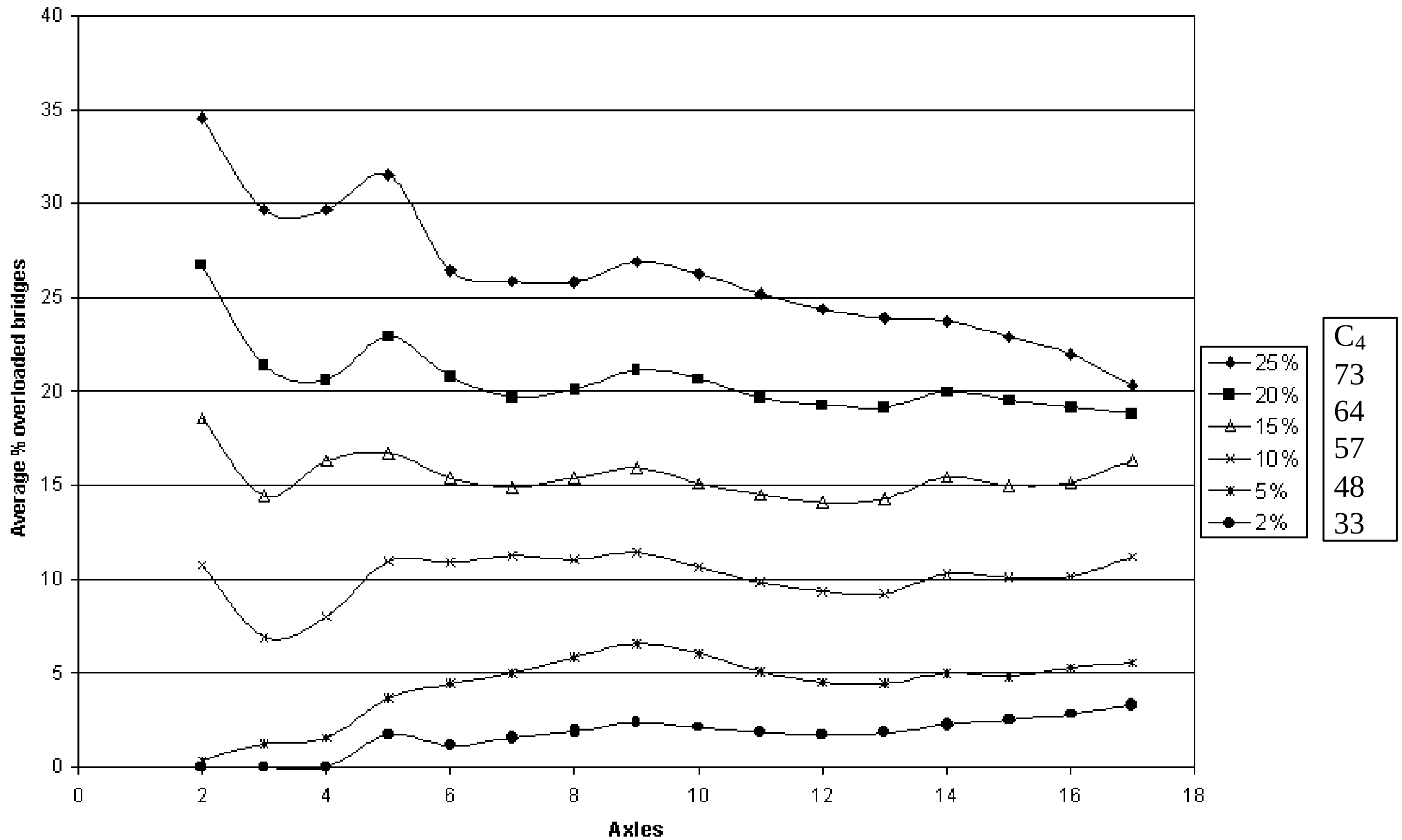

Figure 7-5 Consistent Number of Overloaded Bridges at Various Values of C4

The recommended constants C_1, C_2, and C_3 are 0.5, -1, and 3.0, respectively. These values were determined by optimizing the formula to give a known number of overloaded bridges that is nearly independent of the number of axles on a truck. The proposed formula is as follows:

$$W = 1000 [0.5LN/(N-1) + 3N + C_4] \qquad (7.2)$$

L = Length in feet
N = Number of axles
C_4 = Constant for overloading
W = Gross Weight in pounds

With this formula, the constant C_4, is chosen based on allowable limits for the percentage of overloaded bridges, the average level of overload, and the maximum level of overload. The relationship between constant C_4, and the percent of overloaded bridges is shown in Figure 7-6. For example, if it were decided that a permissible amount of overloading was five percent of truck/bridge combinations, constant C_4 would be set to 33. This means that considering all truck/bridge combinations in the database, five percent were overloaded. However, there are some trucks that overload more than five percent, while others overload less than five percent. It was found that the error was approximately a difference of ten percent, meaning that there is at least one truck that may overload fifteen percent of the bridges.

Remember that all trucks considered in the study travel across all bridges determined these percentages. In reality, this may not happen. Considering that the weakest bridges are usually not on the main highways and interstates, there is a chance that the “worst” trucks may not travel across the weakest bridges. There is also a chance that the worst truck may travel across the weakest bridge. Also, it is important to realize that these heavily loaded non-standard trucks are only a small percent of the total spectrum of vehicles found on bridges. Setting C_4 to overload five percent of truck/bridge combinations means that a non-standard truck will, on average, overload five percent of bridges. It does not mean that all traffic will overload five percent of bridges.

The relationship between constant C_4 and the level of overloading is shown in Figure 7-7. In this example, considering only the five percent of truck/bridge combinations overloaded, the average level of overload is approximately 10 percent. The maximum level of overload caused by the worst truck/bridge combination is approximately 62 percent.

The distribution of the levels of overloading is also important. The number of truck/bridge combinations that are overloaded greater than 10, 20, 30, and 40 percent are shown in Figure 7-8. For example, if C_4 is 33, the percent of truck/bridge combinations overloaded beyond 10, 20, 30, and 40 percent are 2.5, 1.1, 0.35, and 0.08 percent, respectively. These numbers are based on all truck/bridge combinations. Looking at the maximum case, the number of bridges that exceed 10, 20, 30, and 40 percent overloading by the worst truck are shown in Figure 7-9. Again, with C_4 equal to 33, the number of bridges overloaded greater than forty percent by the worst truck is only 0.78 percent, or nine bridges.

The modified formula overloads a nearly consistent number of bridges for all truck lengths and axle numbers, no matter what value is used for constant C_4. These numbers, however, are based on the averages of all trucks with the same number of axles. Due to the varied strengths of bridges in the population, there will always be some that are greatly overloaded while others are overloaded less than the average. The maximum observed error was approximately ten percent, as shown in Figure 7-10 for C_4 equal to 33. In other words, if the formula is set so that the average percent of overloaded bridges is 5 percent, there will be a truck that overloads 15 percent of bridges. Conversely, there will be trucks that do not overload any bridges at all. Graphs of these errors for other values of C_4 are included in Appendix D.

When deciding the value at which to set constant C_4, it is important to recall the basis of the analysis. The calculated critical gross vehicle weights for these trucks were based on the operating rating of each bridge. Recall that the operating rating is the level of loading where the bridge is considered safe. However, fatigue may occur over time with constant use at this loading. Therefore, it is recommended not to exceed this level by a large amount. Note that the current Bridge Gross Weight Formula exceeds this level by a considerable amount.

7.2 Comparison to the Bridge Gross Weight Formula

Any change made to the Bridge Gross Weight Formula will be met with scrutiny from the bridge owners and users. It is important to see how the proposed formula differs from the status quo. The difference between the current formula and the proposed formula is in the constants C_3 and C_4. Constant C_3 changed from six in the current formula to three in the proposed formula, a reduction of three thousand pounds per axle. This means that instead of gaining an additional six thousand pounds per axle, a gain of three thousand pounds is proposed.

Depending on the value of C_4, there are reductions and increases from the weights given by the Bridge Gross Weight Formula. For example, if C_4 is 33 there is an increase in allowable weight for trucks with less than five axles. Conversely, there is a decrease in allowable weight for trucks with more than five axles. There is no difference between the allowable weights for trucks with five axles. The amount of reduction or increase is entirely dependent on the value of constant C_4. Charts that show the change from the current bridge formula for various levels of C_4 are included in Appendix E.

An evaluation of the types of trucks that are overloading the bridges is shown in Tables 7 – 1 and 7 – 2 using a C_4 value of 33. With regard to the number of bridges being overloaded, with the proposed formula, the worst trucks are not necessarily the ones with a large number of axles. Also, with this value of C_4 the number of bridges being overloaded is reduced from the current bridge formula and is more consistent. In Table 7 – 2, one sees that the level of overloading has been reduced when compared to the original bridge formula. If other values of C_4 were used, the results would be similar but adjusted up or down based on the value of C_4 used. These tables can be compared with Tables 6-1 and 6-2 for the Current Bridge Formula.

Truck ID	*Length, ft*	*Number of Axles*	*Number of Bridges Overloaded, %*
93	100.5	9	14.3
48	96.5	8	14.2
185	74	10	13.9
91	92.5	8	12.6
178	74	10	11.9
186	74	11	11.6
46	88.5	7	11.5
184	71	9	11.5
94	100.5	10	11.4
3	94	7	11.3

Table 7-1 Ten Worst Trucks with Proposed Bridge Formula Using C_4 = 33 Based on Number of Overloaded Bridges

Truck ID	*Length, ft*	*Number of Axles*	*Maximum Level of Overload, %*
99	100.5	14	64.3
108	100.5	15	62.1
88	96.5	14	61.0
126	100.5	16	59.4
98	100.5	13	59.4
107	100.5	14	57.3
54	96.5	13	57.1
135	100.5	17	56.4
117	100.5	15	55.1
125	100.5	15	55.0

Table 7-2 Ten Worst Trucks with Proposed Bridge Formula Using C_4 = 33 Based on Maximum Level of Overload

Using the example where C_4 is set to 33, the following figures show the improvement over the Current Bridge Gross Weight Formula. In Figure 7-11, the level of overloading is reduced as compared to Figure 6.1, an equivalent chart for the Bridge Gross Weight Formula. The average level of overload is approximately ten percent, a 33 percent decrease from the Bridge Gross Weight Formula. The maximum level of overload dropped from nearly 100 percent to 62 percent, approximately a 40 percent decrease. As shown in Figure 7-12 the number of overloaded bridges is reduced and more constant for all truck lengths as compared to the Bridge Gross Weight Formula. The worst truck overloads 14 percent of bridges, half the number overloaded with the Bridge Gross Weight Formula. As shown in Figure 7-13, the number of overloaded bridges is also more constant for all numbers of axles, with the average being set by the value of C_4. Figure 7-14 illustrates that the number of overloaded bridges for different 74 foot trucks is more constant as compared to Figure 6-4, an equivalent chart for the Bridge Gross Weight Formula. Similar plots of different length trucks are included in Appendix C.

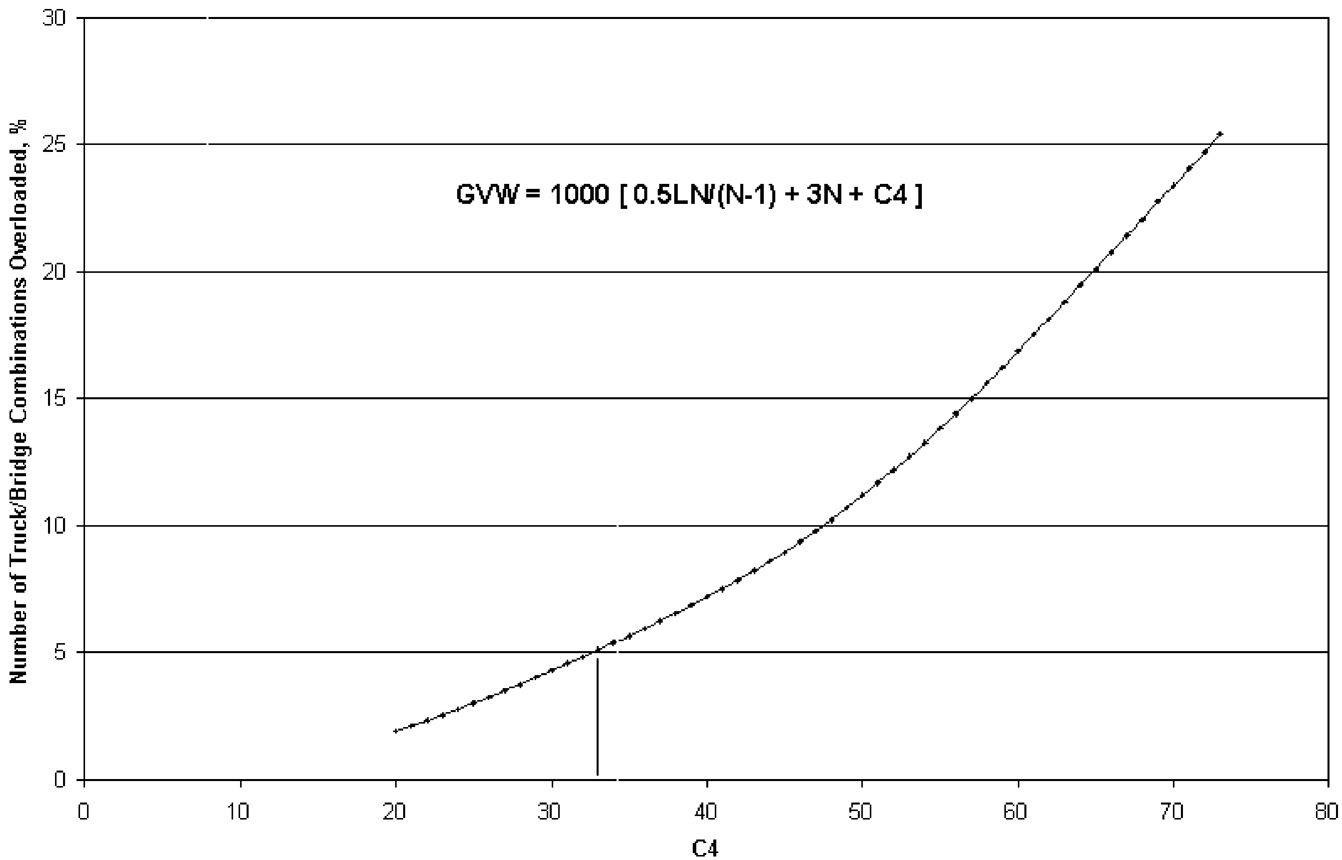

Figure 7-6 Impact of C4 on the Number of Bridges Overloaded Considering All Truck/Bridge Combinations

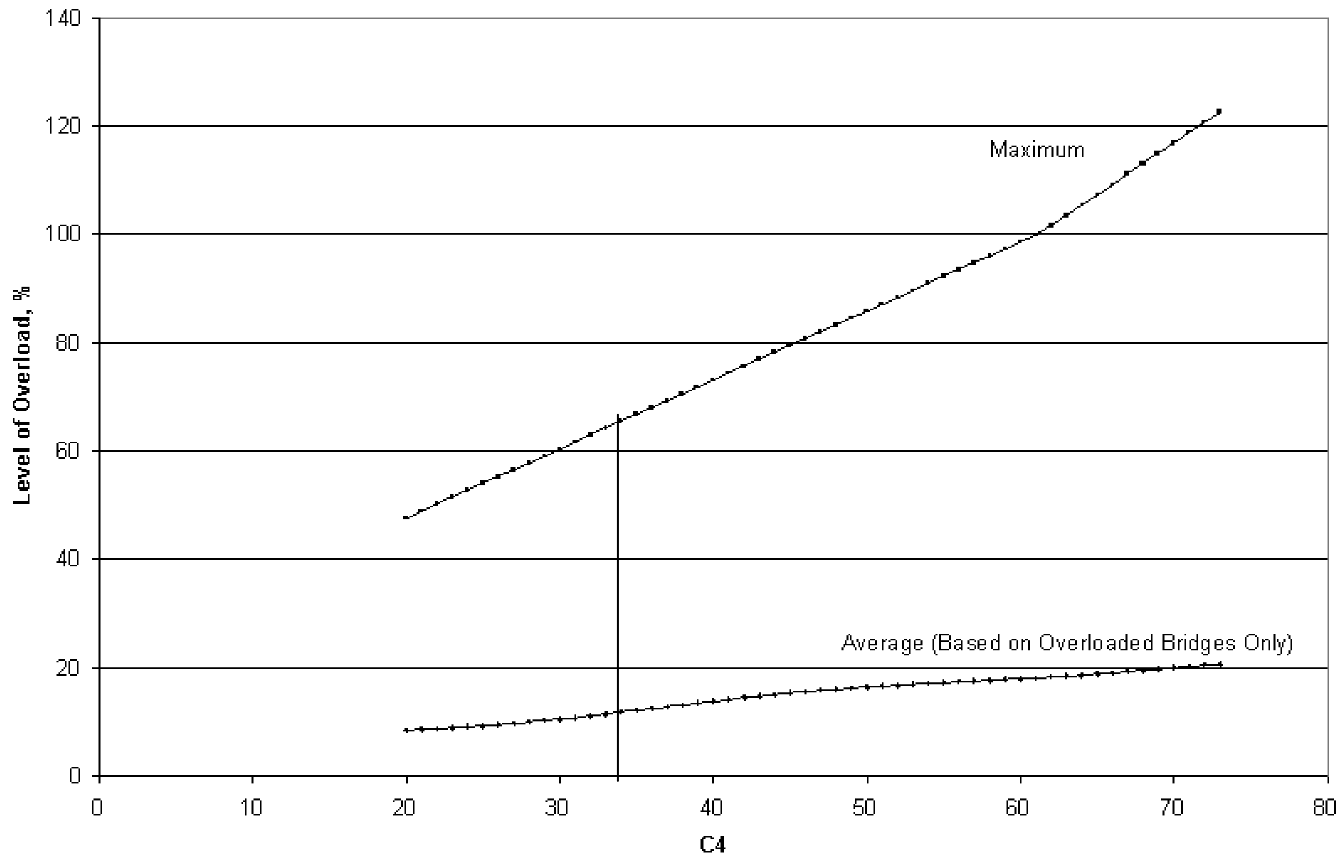

Figure 7-7 Average and Maximum Level of Overload Increasesas C4 Increases

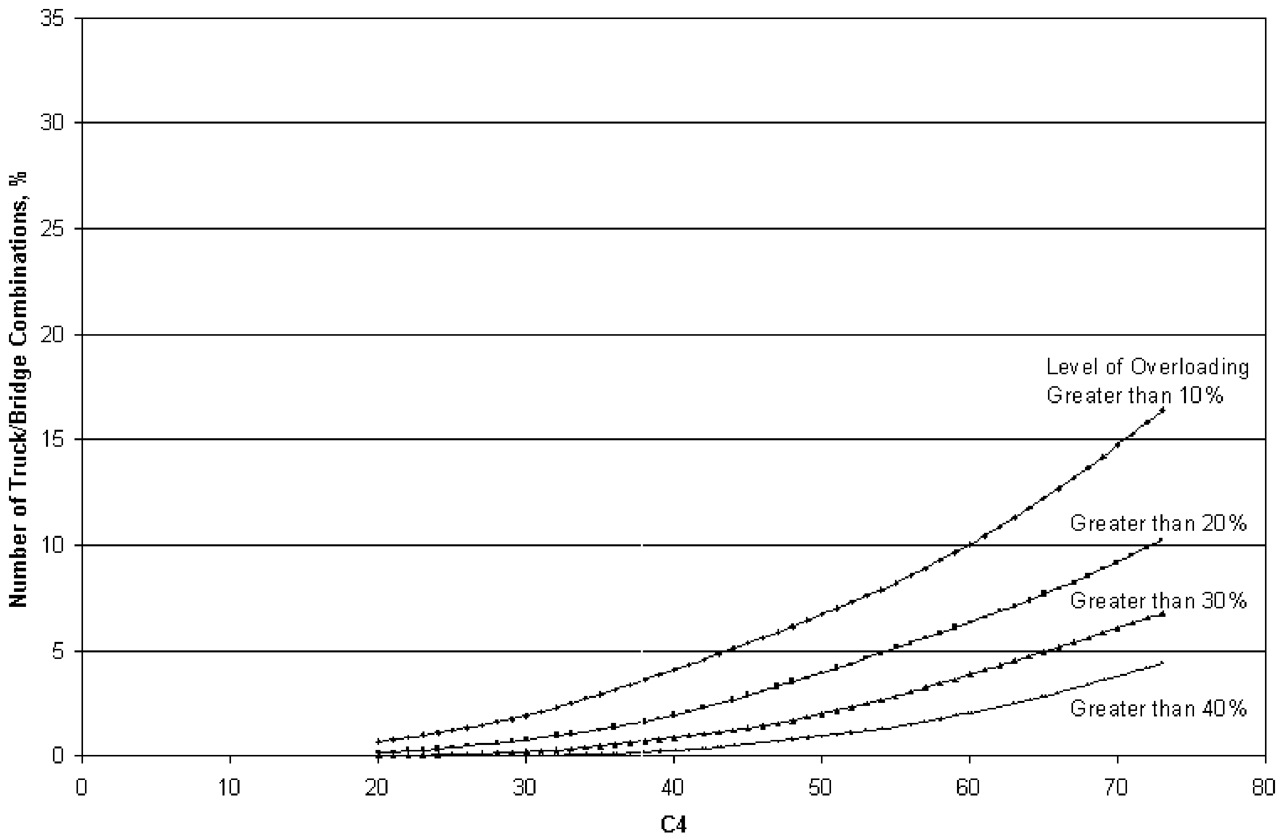

Figure 7-8 Impact of C4 on the Number of Truck/Bridge Combinations Overloaded Greater than 10%, 20%, 30%, and 40%

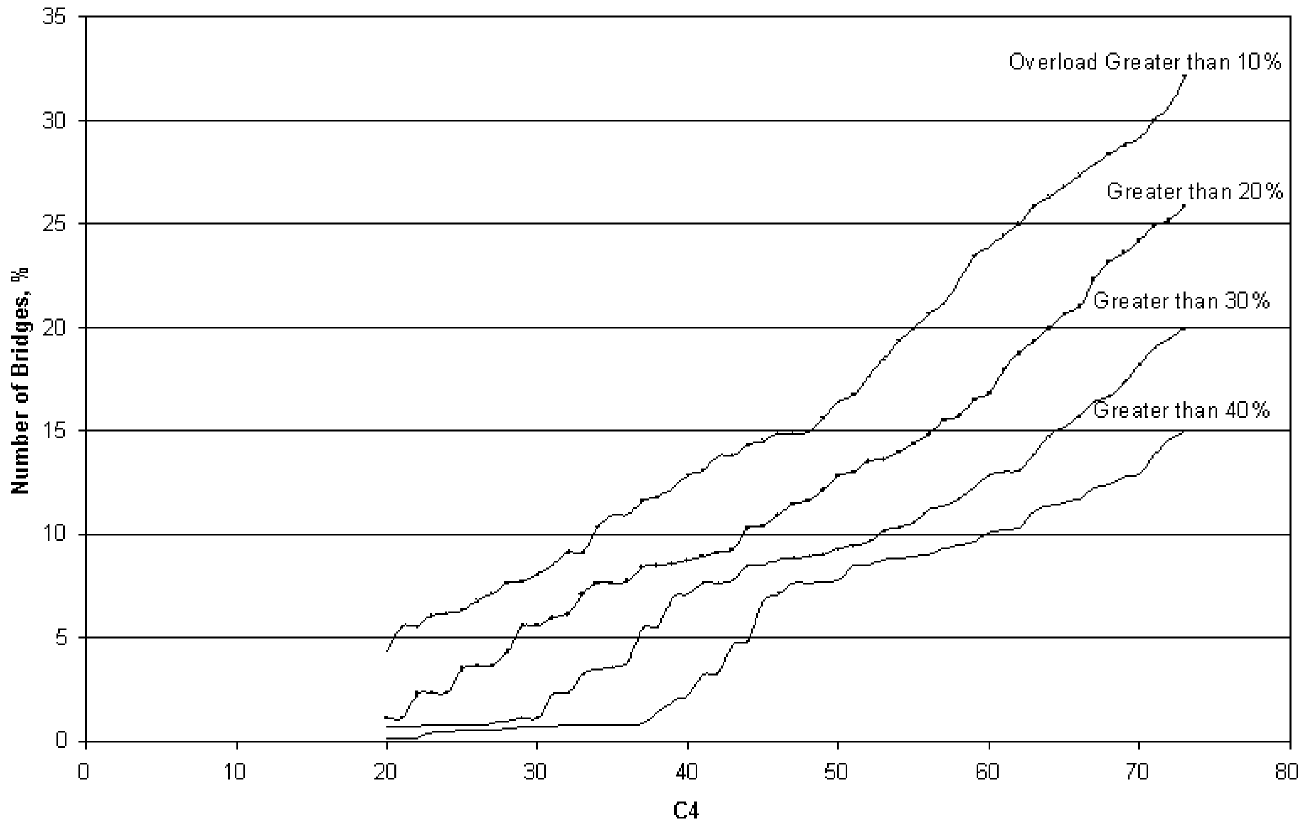

Figure 7-9 **Impact of C4 on the Number of Bridges Overloaded Greater than 10%, 20%, 30%, and 40% by the Worst Truck**

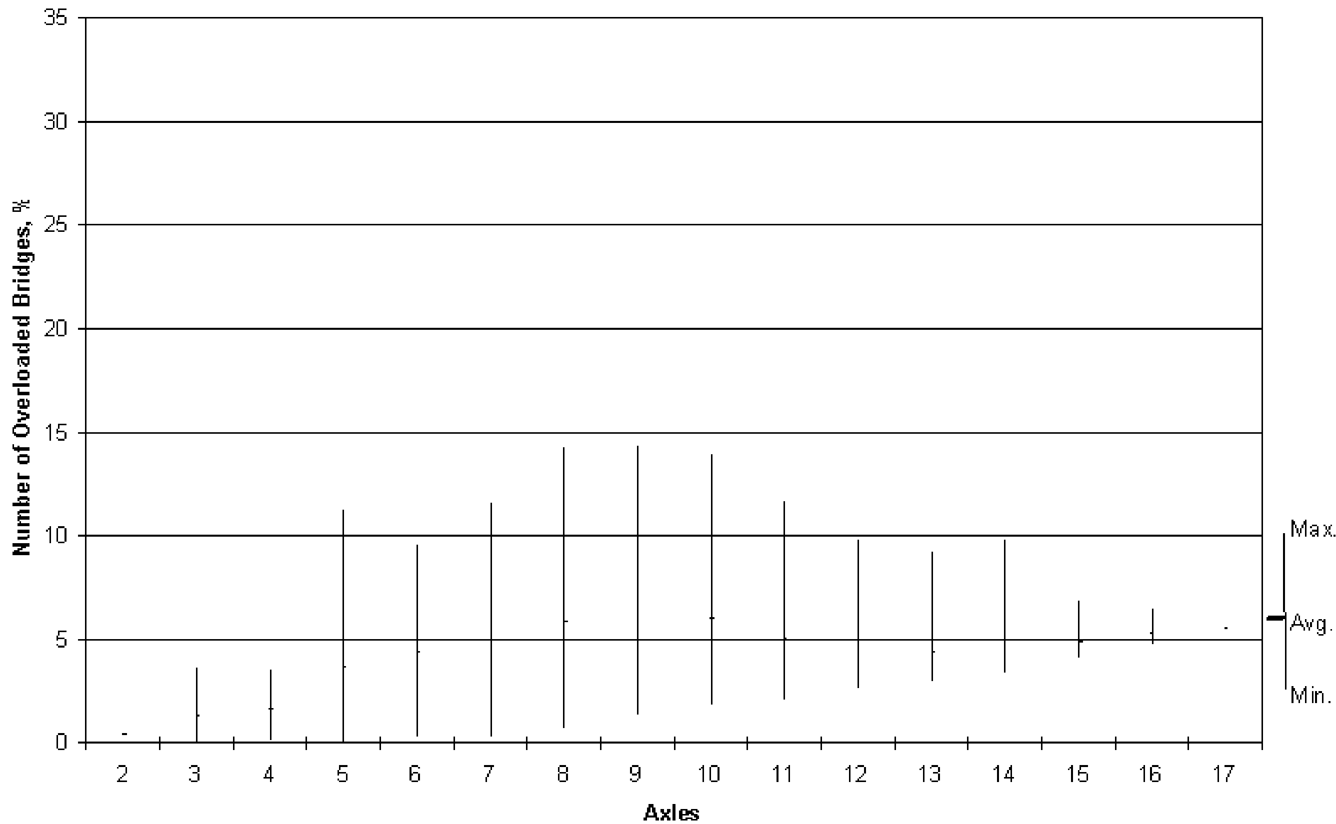

Figure 7-10 Number of Overloaded Bridges Considering all Trucks, C4=33 (5%)

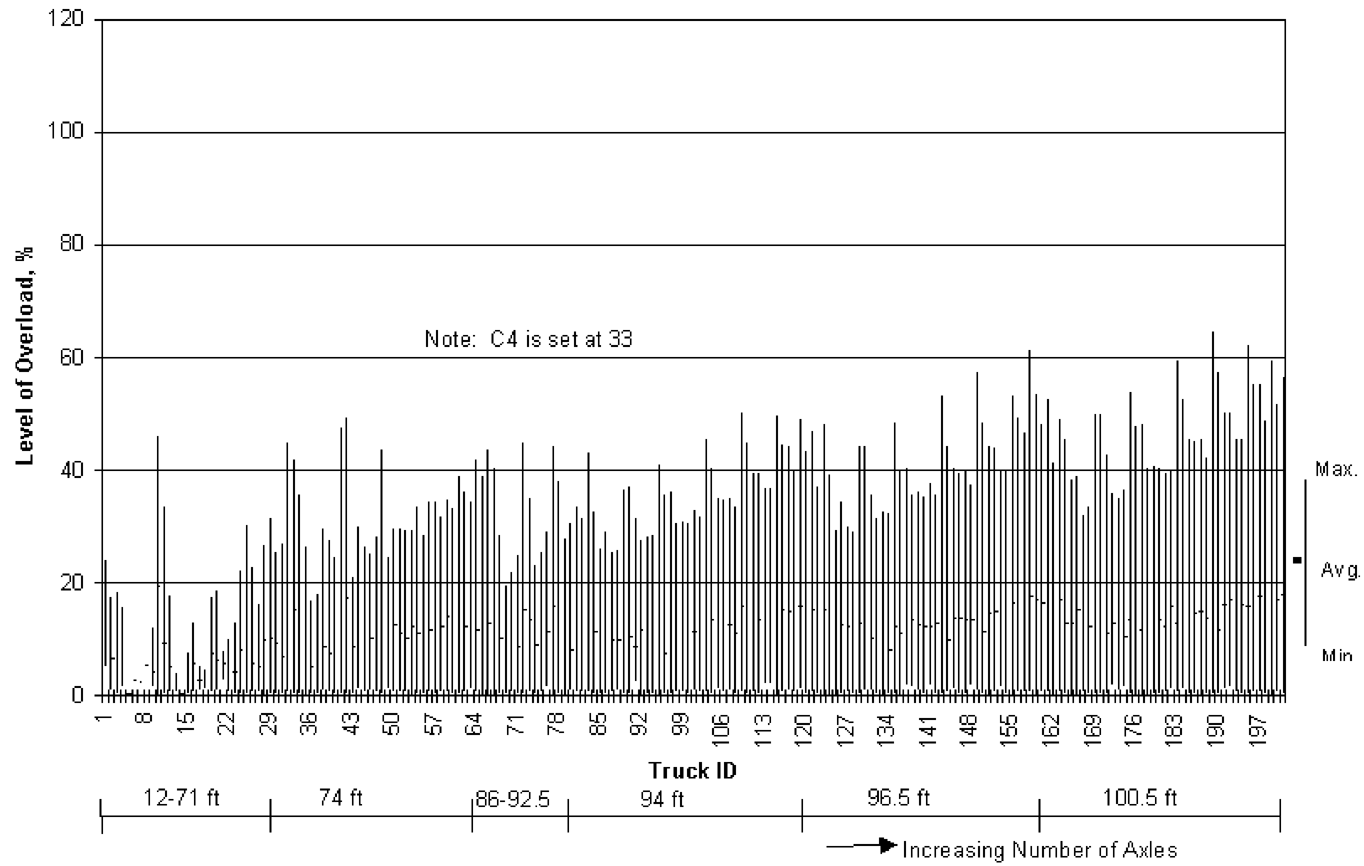

Figure 7-11 Average and Range of Level of Overloading on Bridges Using Modified Bridge Weight Formula

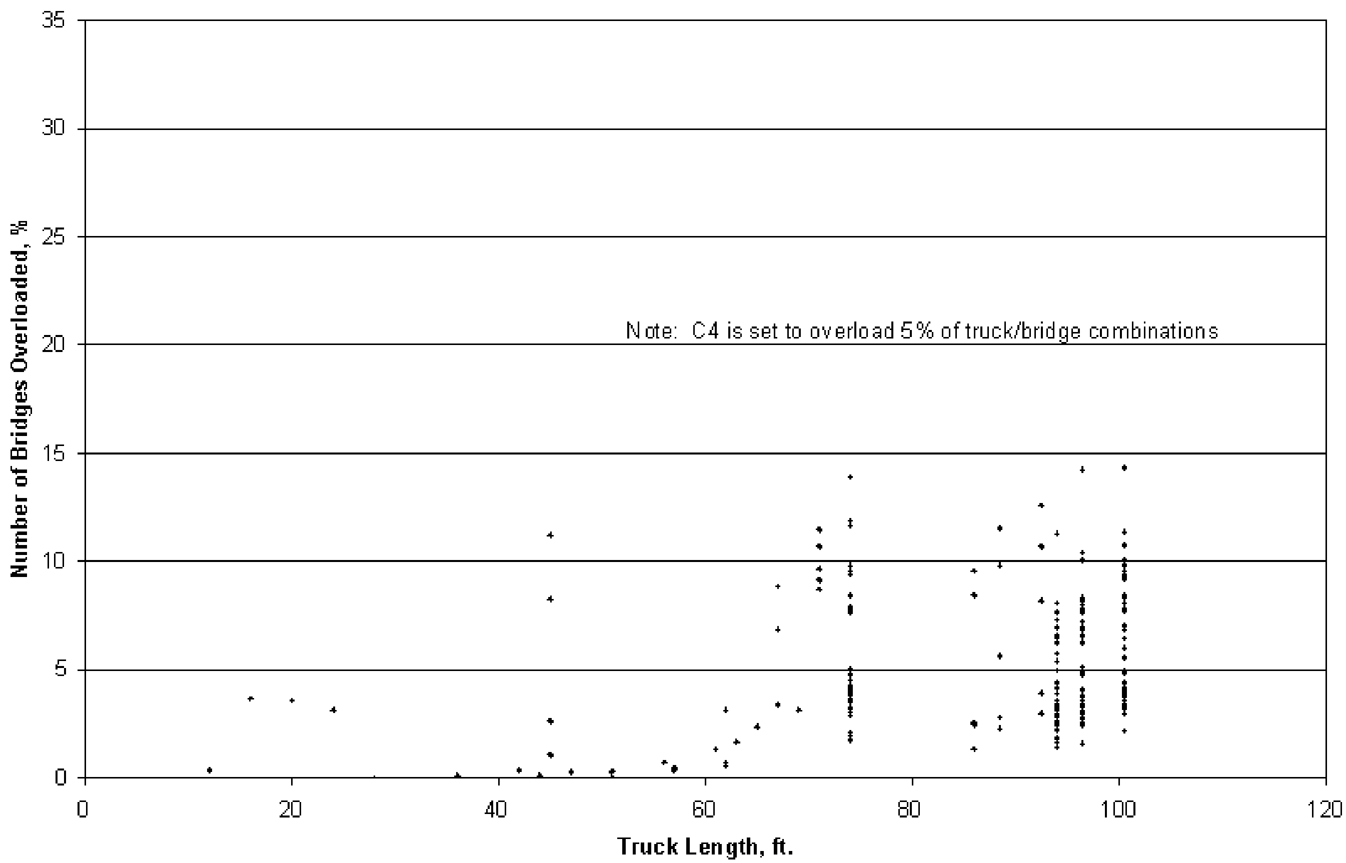

Figure 7-12 Number of Bridges Overloaded Considering All Trucks Using Modified Gross Weight Formula

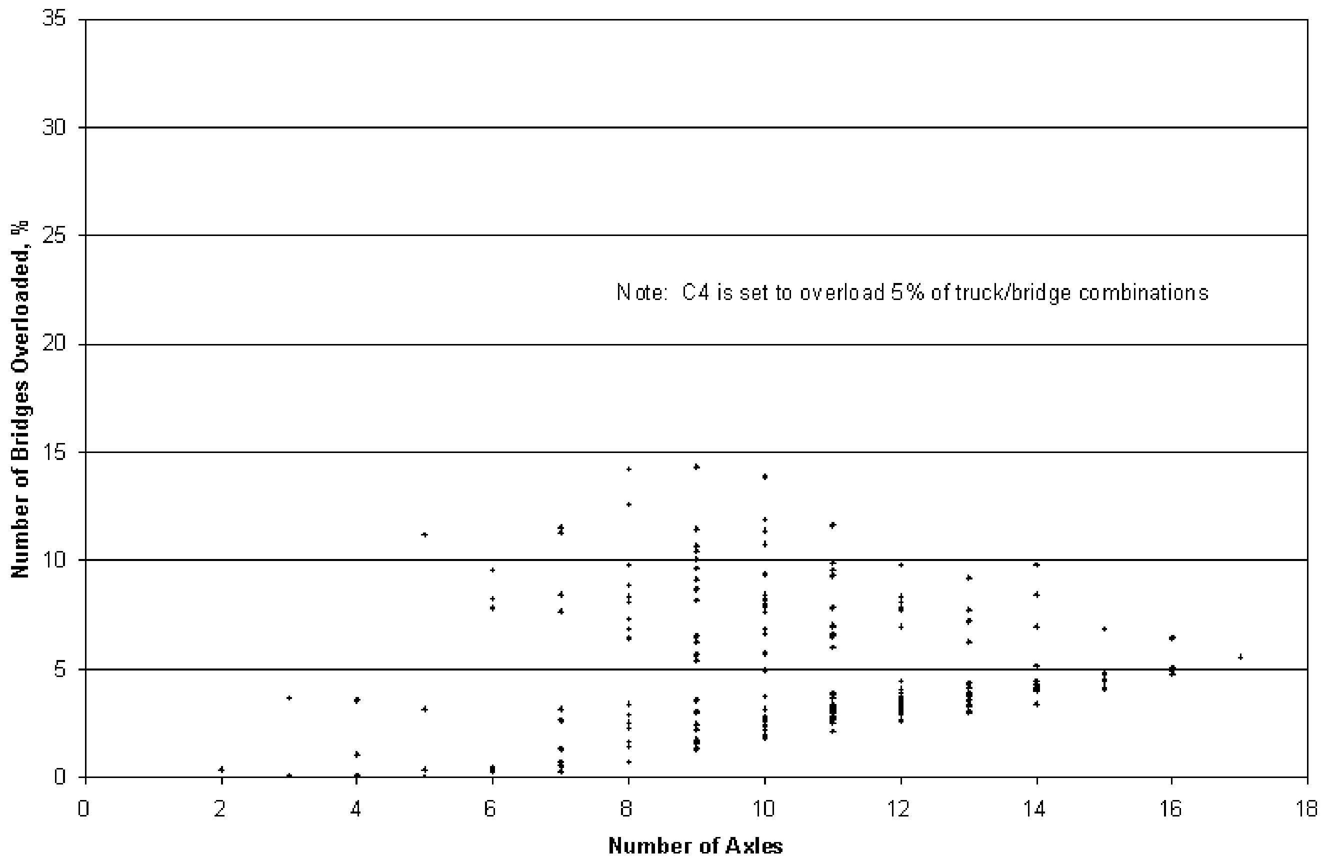

Figure 7-13 **Number of Bridges Overloaded Independent of Number of Axles for all Trucks Using Modified Gross Bridge Formula**

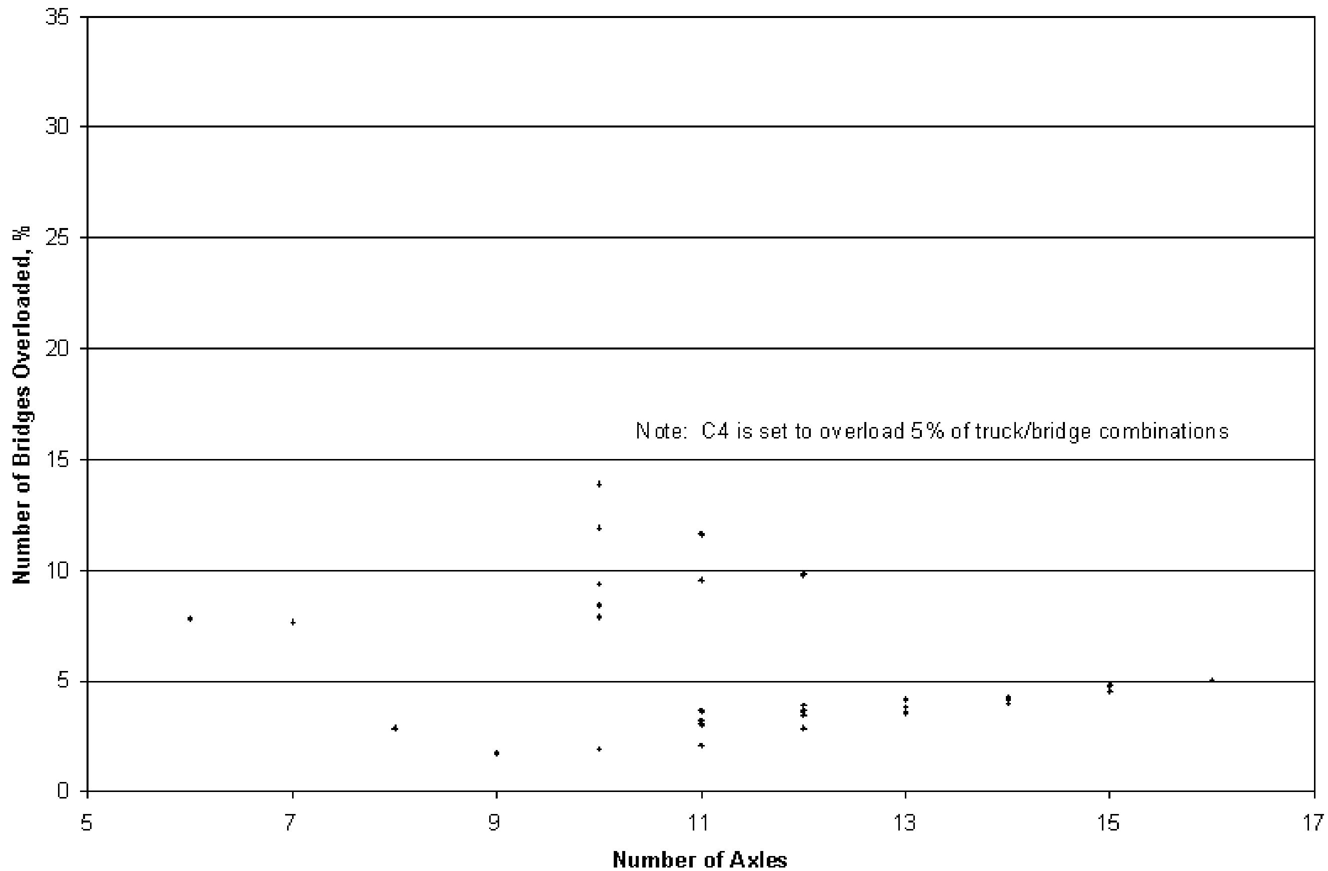

Figure 7-14 **Number of Bridges Overloaded Nearly Consistent for All Number of Axles on 74 ft. Trucks Using the Modified Bridge Gross Formula**

7.3 Impact Analysis

To evaluate the impact of the proposed formula, the truck configurations that were reported in the survey were used for analysis. A new "survey truck" database was built and used to analyze all South Dakota bridges. The exact individual axle spacing and axle weights were known for the trucks reported on the survey Detailed Form. These trucks were built exactly as reported. For trucks on the Summary Form, only the overall length, number of axles, and gross weights were reported. Therefore, assumptions had to be made as to the individual axle spacing. All trucks in the "non-standard truck" database that had the same overall length and number of axles as the survey trucks were included into the new database. There were 20 trucks in the survey truck database, which are presented in Appendix B.

With the real truck data obtained from the survey, an analysis was performed with the Bridge Gross Weight Formula and the Modified Bridge Weight Formula. The Modified Bridge Weight Formula was set with C_4 equal to 33 for this evaluation. At this level, referring to the Figures 7-6 and 7-7, a truck should overload five percent of bridges on average. The maximum level of overload by the worst truck/bridge combination should not exceed 62 percent.

The results of this analysis are presented in Table 7-3. The data shows the reduction in allowable gross weight, number of overloaded bridges, and worst level of overload using the Modified Bridge Weight Formula versus the Bridge Gross Weight Formula. The number of overloaded bridges with the Bridge Gross Weight Formula is highly varied, whereas the number of overloaded bridges for all trucks with the Modified Bridge Weight Formula is near five percent. Also, the maximum level of overload with the Bridge Gross Weight Formula is 95 percent, whereas it is 61 percent with the Modified Bridge Weight Formula. This shows a consistent rate of bridge overloading and a consistent reduction in the level of overload for all of the trucks.

A histogram of the operating capacity for the South Dakota bridge system is shown in Figure 7-15. The operating capacity for all bridges with an operating capacity greater than 20 Tons for the HS Truck is shown in the figure.

	Bridge Gross Weight Formula			Modified Bridge Weight Formula C_4=33		
Survey Truck ID	Reported Gross Weight	Number of Overloaded Bridges, %	Worst Level of Overload, %	Allowable Gross Weight by MBWF	Number of Overloaded Bridges, %	Worst Level of Overload, %
S1	135500	10.1	57.3	117500	3.5	36.5
S2	117000	15.0	46.0	103000	8.3	30.7
S3	148000	10.0	67.6	123000	3.4	40.2
S4	70500	(1 Bridge)	10.0	70500	(1 Bridge)	10.0
S5	106000	6.7	27.4	99285	2.9	16.6
S6	147000	18.5	78.7	123000	4.3	49.4
S7	147000	10.7	72.6	123000	3.3	44.3
S8	147000	11.1	72.3	123000	3.6	44.0
S9	147000	8.2	67.3	123000	3.0	39.9
S10	152500	14.9	80.7	125500	4.2	48.9
S11	152500	11.3	73.9	125500	3.4	43.2
S12	154000	24.0	85.6	127000	5.1	53.0
S13	154000	14.0	80.8	127000	4.1	49.1
S14	154000	16.8	77.8	127000	4.1	46.6
S15	154000	20.1	95.3	127000	6.9	61.0
S16	159500	21.0	88.4	129500	4.9	53.2
S17	159500	15.1	82.0	129500	4.1	48.0
S18	162000	17.7	90.5	132000	4.9	55.1
S19	162000	22.4	90.5	132000	4.9	55.0
S20	162000	15.8	82.4	132000	4.4	48.4

Table 7-3 Allowable Gross Weights for Survey Trucks using Current and Modified Gross Weight Formulas

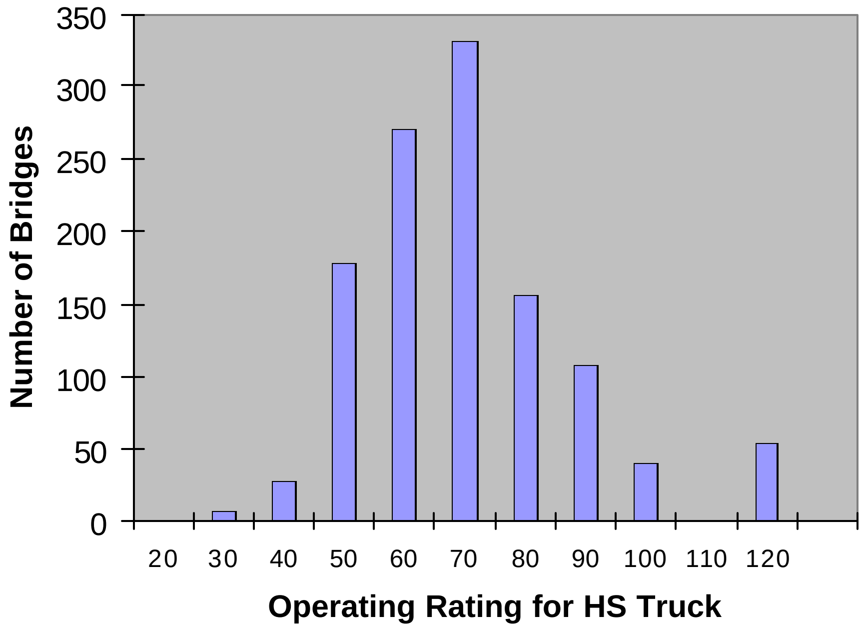

Figure 7-15 Histogram of South Dakota Bridge System

7.4 Bridge Service Life Analysis

As requested by the Technical Panel, an analysis was conducted to estimate the effect on bridge service life by the modified bridge formula. The analysis was conducted for the South Dakota bridge system as a "whole", and for selected individual bridges in South Dakota. The service life was estimated using the Bridge Gross Weight Formula and the modified bridge formula at various levels of C_4.

To generate the data for cycles on the bridges, the Technical Panel provided data concerning the Annual Average Daily Traffic Volumes (ADT) for all classifications of road type, the total lengths of road types, and the composition of ADT by vehicle types. Using this data, the ADT for each vehicle type and each road classification was generated. These ADT's would be used as the daily number of cycles on bridges. ADTs used in the study are presented in Table 7-4.

Vehicle Classification	ADT (% of Total) per Highway Classification			
	1	2	11	14
5	1.3	1.2	1.3	0.6
6	1.1	1.3	1.3	0.6
7	0.3	0.3	0.3	0.3
8	4.2	2.4	3.6	2.8
9	8.8	3.7	6.6	1.2
10	1.1	1.1	1.2	0.4
11	0.6	0.7	0.6	0.5
12	0.3	0.1	0.2	0.1
13	1.4	1.0	1.8	0.7

Table 7-4 Composite ADT for each Highway Classification

Non-standard trucks were chosen from the database to represent each vehicle category. The vehicle categories, along with the trucks chosen to represent them, are shown in Table 7-5.

Classification	Vehicle Type	Non-standard Truck ID	Number of Axles
5	Single Truck – 2 axle / 6 tire	136	2
6	Single Truck – 3 axle	200	3
7	Single Truck – 4 axle	143	4
8	Single Trailer Truck – 4 axle or less	144	4
9	Single Trailer Truck – 5 axle	152	5
10	Single Trailer Truck – 6 axle or more	169	8
11	Multi-Trailer Truck – 5 axle or less	202*	5
12	Multi-Trailer Truck – 6 axle	1	6
13	Multi-Trailer Truck – 7 axle or more	88	14

* No truck of this type was in original database. A new truck was created.

Table 7-5 Assumed Truck Configurations for Each Vehicle Classification

Certain assumptions were necessary in developing the method for estimating the bridge system service life. Stress ranges were needed to determine the number of cycles remaining in the bridge life. A Category C weld design detail was chosen for use in estimating service life. Of detail Categories A – F, the category C is the lowest recommended for use in designing bridges. Category C details represent weldments of stiffeners and short attachments.

For a Category C detail, the allowable fatigue stress range is 10 ksi except for transverse stiffener welds on girder webs or flanges where the allowable fatigue stress range is 12 ksi. If the live load stresses due to trucks is kept below this value, the theoretical service life is infinite. An assumption was made that at the operating rating a live load stress range of 10 ksi would occur in the bridge. Any loading in excess of the operating rating would result in a higher stress range, and contribute to shortened service life. For all occurrences of bridge overloading, the stress range caused by the overloading was calculated based on the level of overload. For example, if a bridge was overloaded by 30 percent, a stress range of 13 ksi was calculated.

Miner's Law for fatigue was used to estimate the service life of the bridge system based on the occurrence of calculated stress ranges by all truck categories and the average daily cycles on the bridges. This law states that the sum of the cycles at each stress range divided by the allowable cycles at that range must equal one, as shown in Formula 7-3. The allowable cycles for Category C at each stress range were obtained from the AASHTO S-N design curves (stress range vs. cycles).

$$\Sigma(n_i/N_i) = 1 \qquad (7.3)$$

n = number of cycles at stress range i
N = allowable cycles at stress range i

The results of the service life analysis for the South Dakota bridge system as a whole are presented in Table 7-6. Many of the bridges on the system are not overloaded by any of the trucks due to their high strength. The large amount of these bridges had the effect of raising the expected life of the system to high values. From the ADT's provided by the Technical Panel, an average annual traffic growth was calculated. This calculation was based on an 18 year span from 1980 to 1998. There were many different growth percentages ranging from 0.7 percent to 11.3 percent yearly, depending on the location of the count station. The average of all count stations was approximately 4 percent.

Annual Traffic Growth Rate	*Estimated Life of Bridge System in Years*				
	BGWF	MBWF C4=21	MBWF C4=33	MBWF C4=37	MBWF C4=48
1%	142	235	203	179	117
2%	93	162	126	113	79
3%	71	119	94	85	61
4%	58	95	76	69	51
5%	50	80	64	59	44

Table 7-6 Estimated System Life for Various Values of C_4

Because the analysis was conducted considering the entire bridge system, the estimated service life could be viewed as an "average" of all the bridges. It is important to also know the effects on single bridges. Therefore, a second service life analysis was conducted for selected bridges with low operating ratings. This allowed comparison of the formulas for bridges that are nearing the end of their service life. Two bridges were selected, one from a rural highway and the other from an urban Interstate. The analysis was conducted using the same methodology as described above. The results of the analysis are presented in Table 7-7.

BARS Number		044140	090354
Location		US12 1.4 E. of Jct. US281 N.	I-90 1.6 E. of St. Pat Str. Intrch.
Operating Rating		41.2	43.2
ADT		6032	21421
Estimated Bridge Service Life in Years	BGWF	16.5	4.3
	MBWF C_4=21	18.1	5.1
	MBWF C_4=33	18.0	5.0
	MBWF C_4=37	17.9	4.9
	MBWF C_4=48	17.2	4.6

Table 7-7 Estimated Life for Two Typical Bridges using Various Values of C_4

Task 8 Prepare a final report and executive summary of the literature review, research methodology, findings, conclusions and recommendations

This document composes the final report for this project. The findings and methods have been described in the discussions of each task. The remainder of this report focuses on the conclusions and recommendations at the project level.

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Summary and Conclusions

The impact on South Dakota's bridge system by trucks loaded according to the Bridge Gross Weight Formula has been shown to be unfavorable for extending the service life of bridges. The formula works well for shorter trucks with few axles but allows too much weight on long non-standard trucks with many axles. This causes severe overloading of many bridges, some by nearly 100 percent. Also, the use of non-standard trucks has increased and can be expected to increase further. To maintain expected service life of bridges, it is important to limit the magnitude of overloading caused by trucks to an acceptable value. Therefore, a new or modified bridge formula is needed to more accurately predict allowable truck loads.

This study resulted in the development of a modified bridge formula where the user can control how conservative the formula behaves. The modified formula reduces the frequency and magnitude of overloaded bridges, as compared to the Bridge Gross Weight Formula. As a consequence, use of the modified formula can extend the expected service life of the bridges in South Dakota. It does this by decreasing the allowable load on trucks to a level acceptable for continued use on bridges. The modified formula can be set based upon the policies set by the department. This is done by determining acceptable limits on the number of overloaded bridges for all truck/bridge combinations, the maximum number of overloaded bridges by a single worst truck, the average level of overload for all truck/bridge combinations, and the maximum level of overload by a single worst truck/bridge combination.

The resulting formula is more consistent in loading all trucks closer to their actual allowable weight than the Bridge Gross Weight Formula. However, due to the varied strength of bridges not all the truck/bridge combinations will be conservative. Likewise, some truck/bridge combinations will be overly conservative.

When determining limits on the formula, one must decide the best method to fairly service the bridges and the trucking industry. One method is to focus on the "worst case" truck/bridge combination, and in doing so severely reduce the weight of all other trucks. Conversely, the average or majority of truck/bridge combinations could be focused on, letting the occasional worst case truck/bridge combination be severely overloaded. An option of tying the formula to a specific route was proposed.

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Recommendations

Since long trucks with high number of axles were found to overload a large number of South Dakota bridges using the current BGWF, the project team recommends the adoption of the modified BGWF outlined in this report. In addition, the most critical bridge/truck combination using the current BGWF overloaded one bridge to nearly twice the operating capacity of the bridge. From a safety perspective, that level of bridge overloading is very high.

The proposed modified BGWF had more consistent results with respect to the number of truck axles and length than the current BGWF. The modified BGWF was developed with a constant, C_4. The impact of selecting the value for C_4 was documented in the report as to the number of bridges overloaded beyond their operating capacity and the level of overloading.

Based on the results of our analysis, a C_4 value between 33 and 37 appears reasonable and is recommended. Selection of the values of C_4 will increase the allowable gross vehicle weight for relatively short trucks and reduce the allowable gross vehicle weight for long trucks with large numbers of axles.

The SDDOT may wish to consider two additional studies before implementing the recommendations of this study. The first supplemental study would consider a more detailed analysis of the bridge system considering the bridges on each route. The state system could be subdivided into various highway classifications, route designations and MRM ranges. The analysis done in this study could be repeated for each highway subdivision and may result in higher values of C_4 for some highway segments.

The second supplemental study focuses on the costs associated with long, heavy trucks using South Dakota's bridges and highways. The results of the present study demonstrated that implementing the modified BGWF would increase the life of South Dakota's bridge system. The objective of this proposed study would be to develop a methodology for estimating the costs to the state for various truck configurations and gross weights. The results of this study would help guide the state in setting permit fees in the future. The costs to be considered in this study would include bridges, highways and safety.

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Appendix A

The non-standard trucks are graphically shown on the following pages. The circles represent wheels with the lead (steering) axle on the left. The values in-between the wheels indicate the axle spacing in feet. The values above the wheels give the percentage of the total gross vehicle weight that is distributed to the axle. Truck IDs 1 – 135 are "triples", a semi-tractor towing two trailers in series. Truck IDs 136 – 143 are single trucks. Truck IDs 144 – 199 are single trucks that tow a "pup". Truck IDs 200 and 201 are the short and long extremes of an HS-20 rating truck.

The weight was distributed by axle groups based on the current bridge formula. A single axle weight was limited to 20k. A dual axle weight was limited to 38k. After the group weights were determined, the total weight was calculated and the percentage of the total weight was assigned to each axle. The total percentages for each vehicle add up to 100.

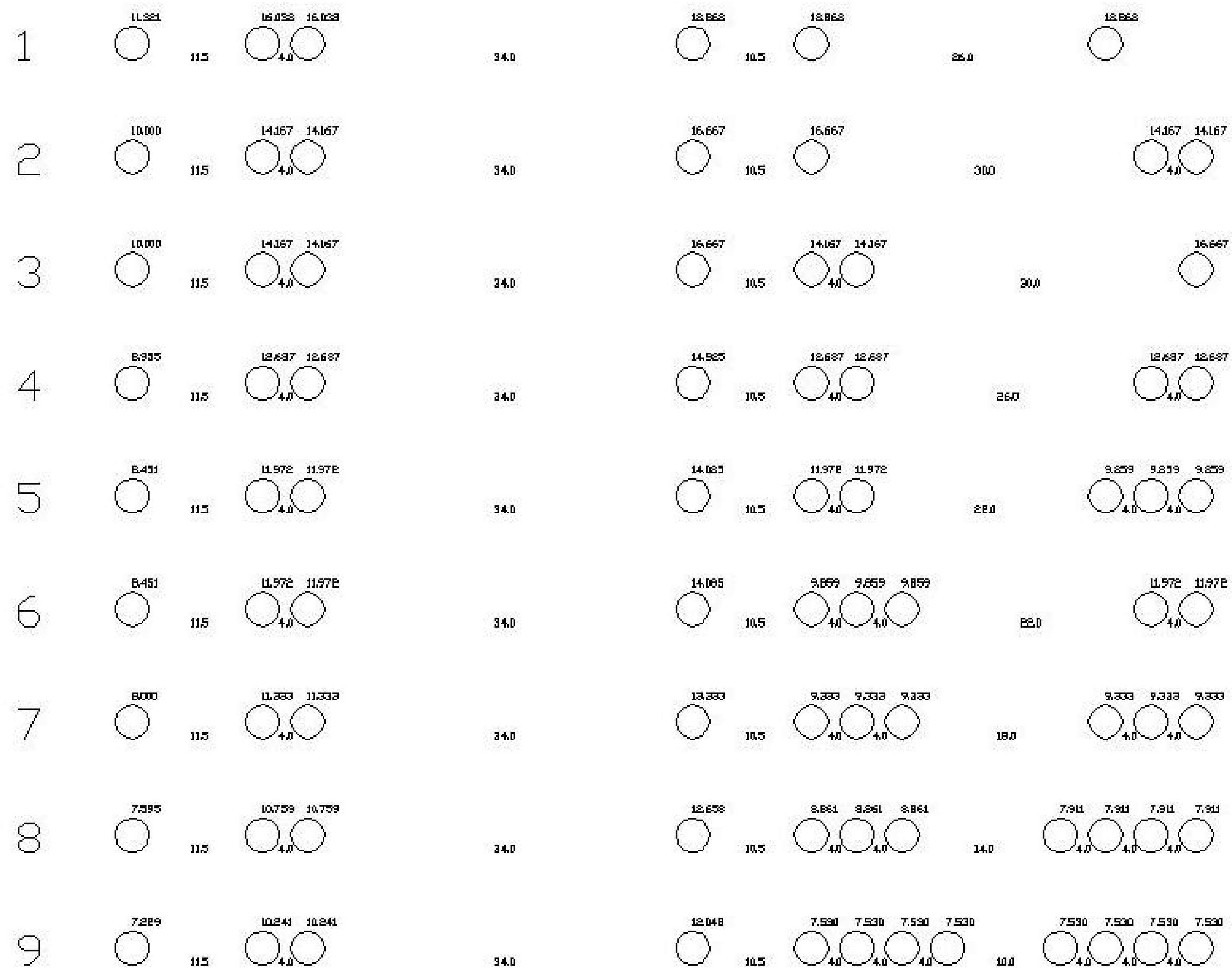


Figure A-1 Non-Standard Trucks

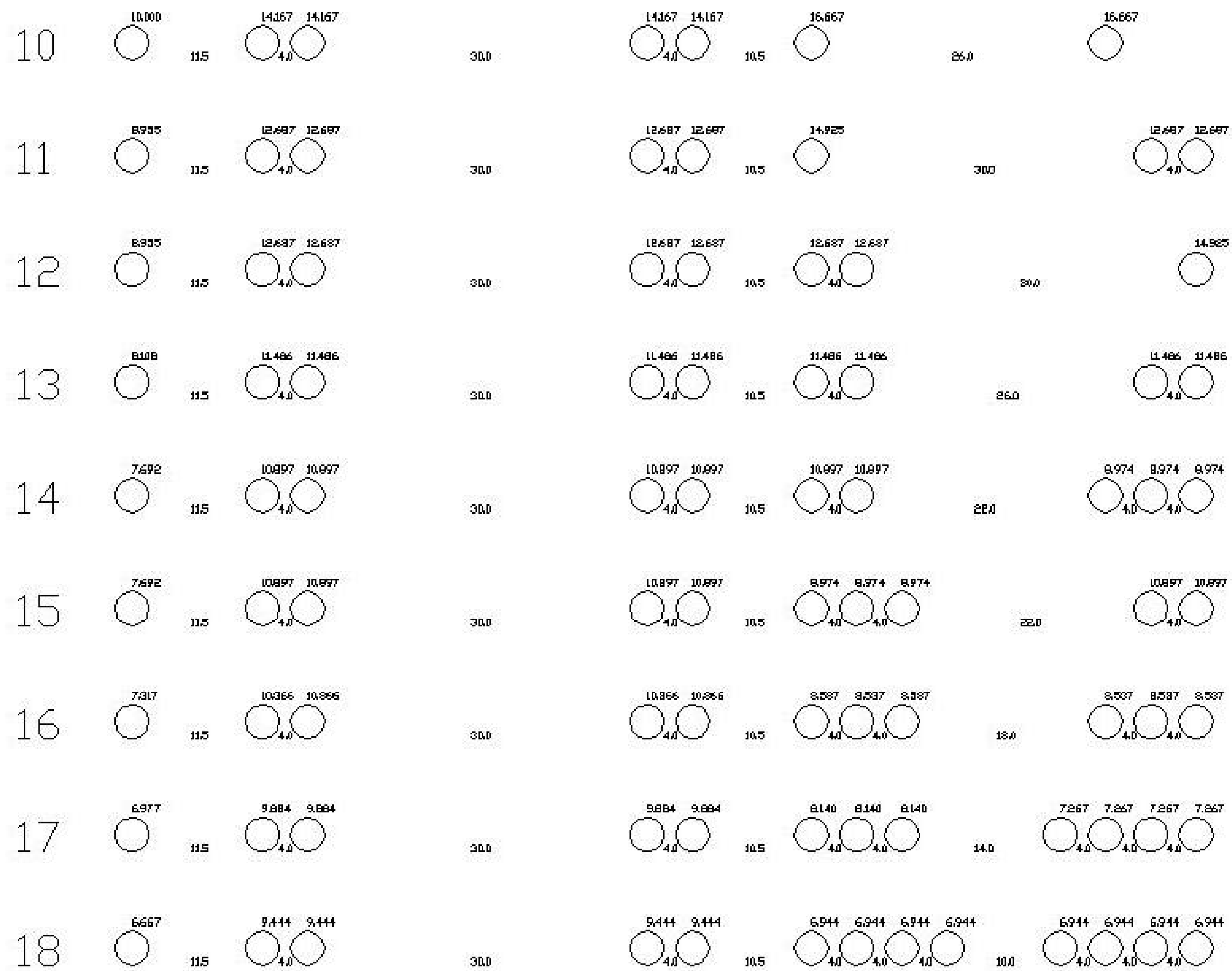
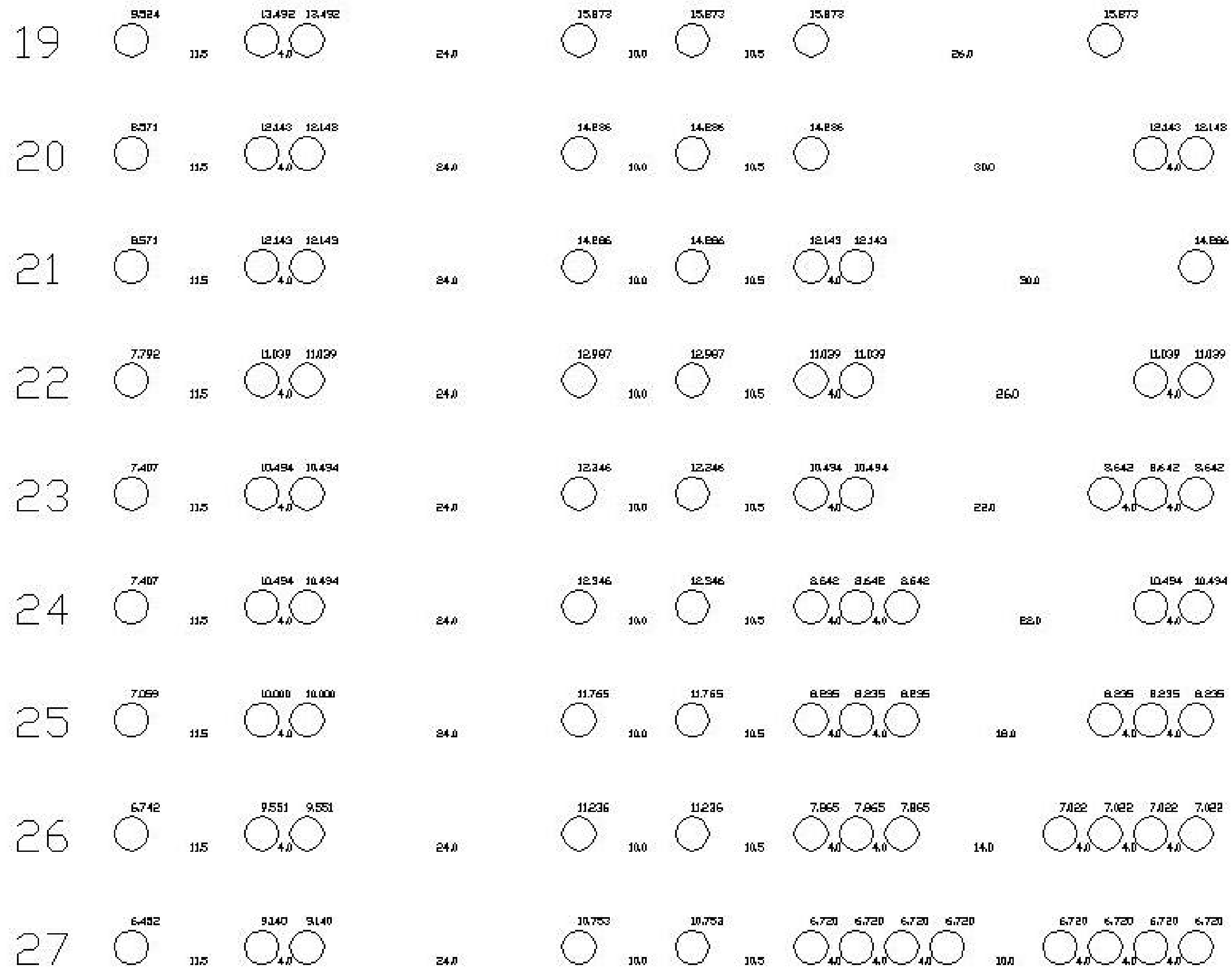


Figure A-1 Non-Standard Trucks (Continued)



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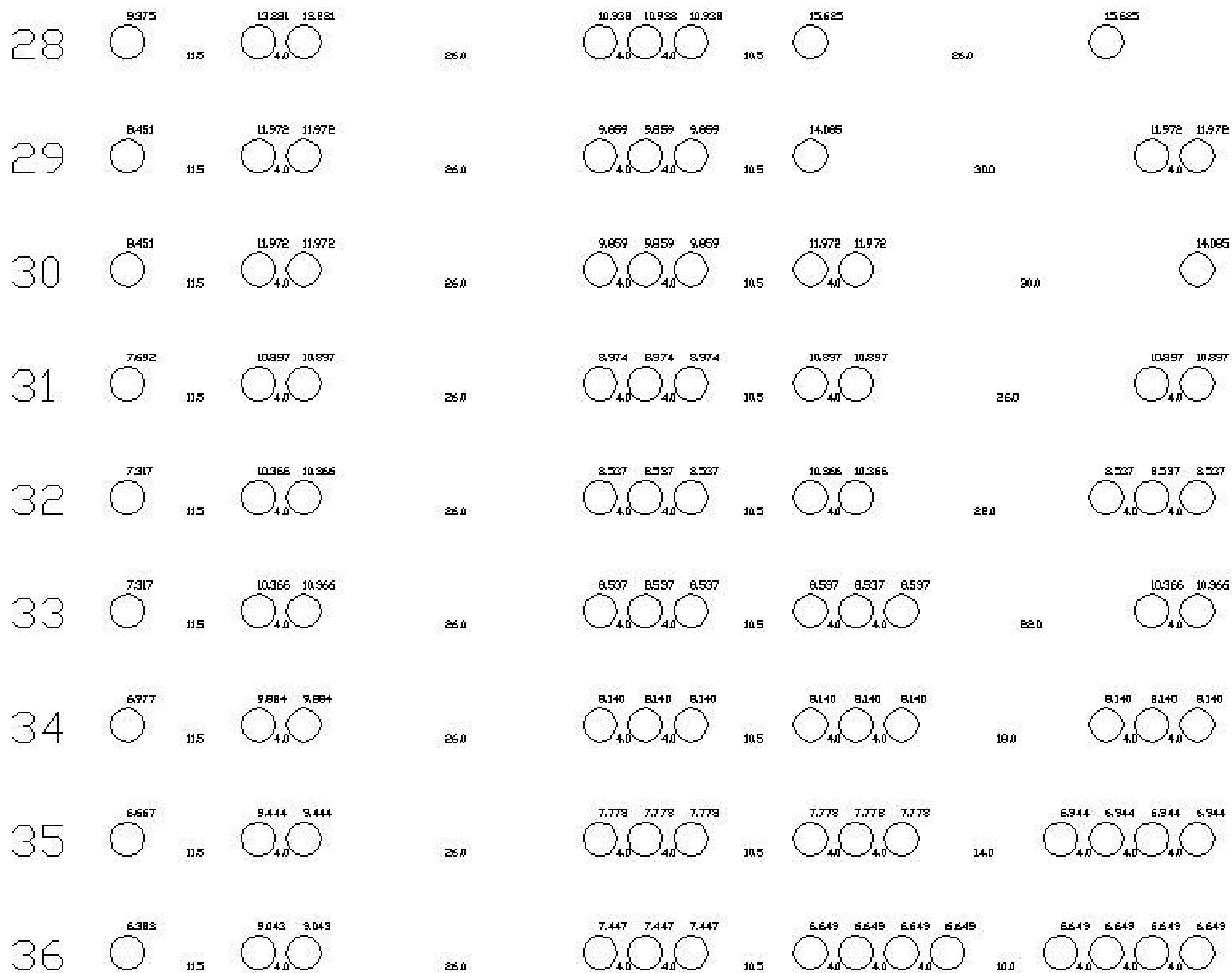

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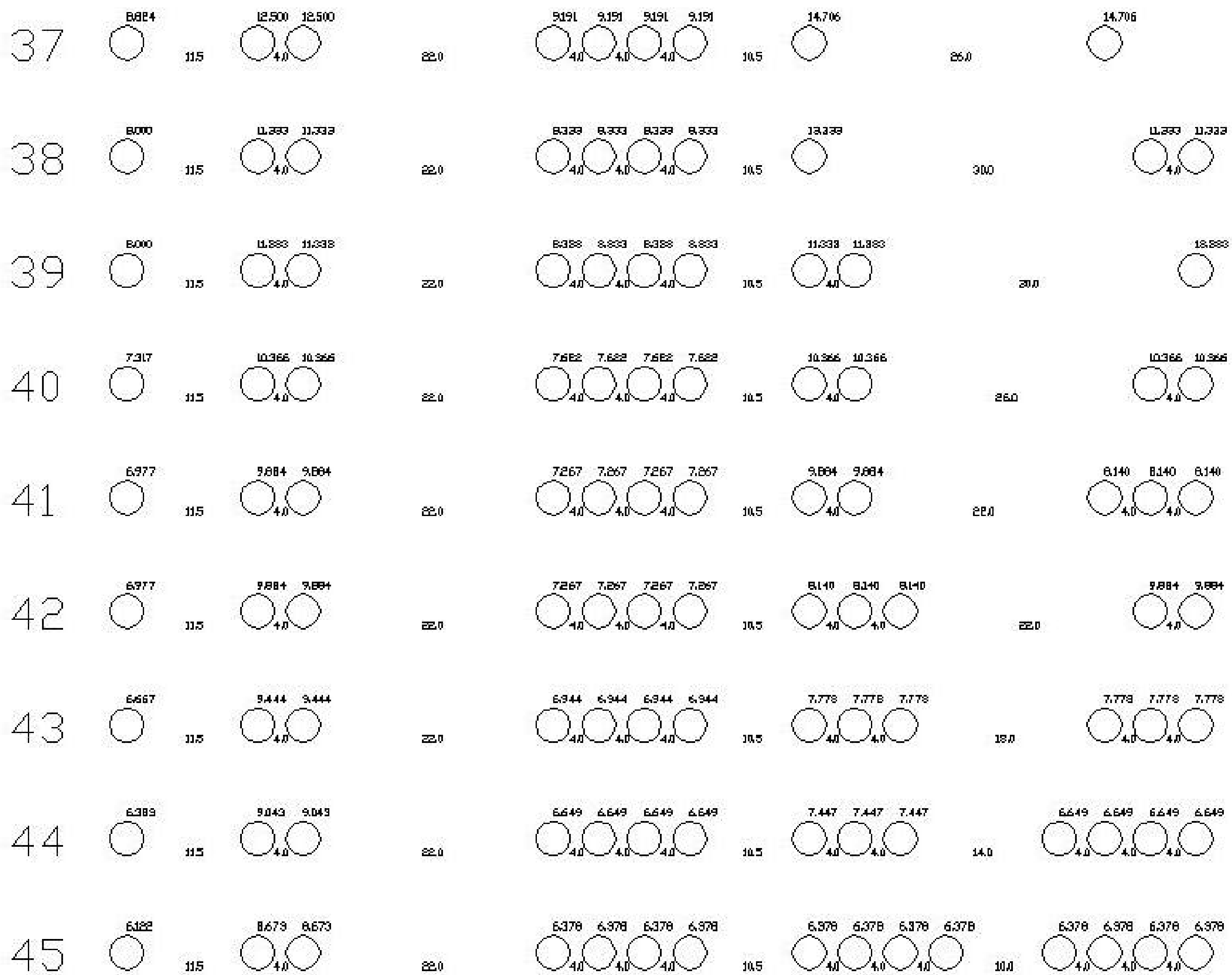

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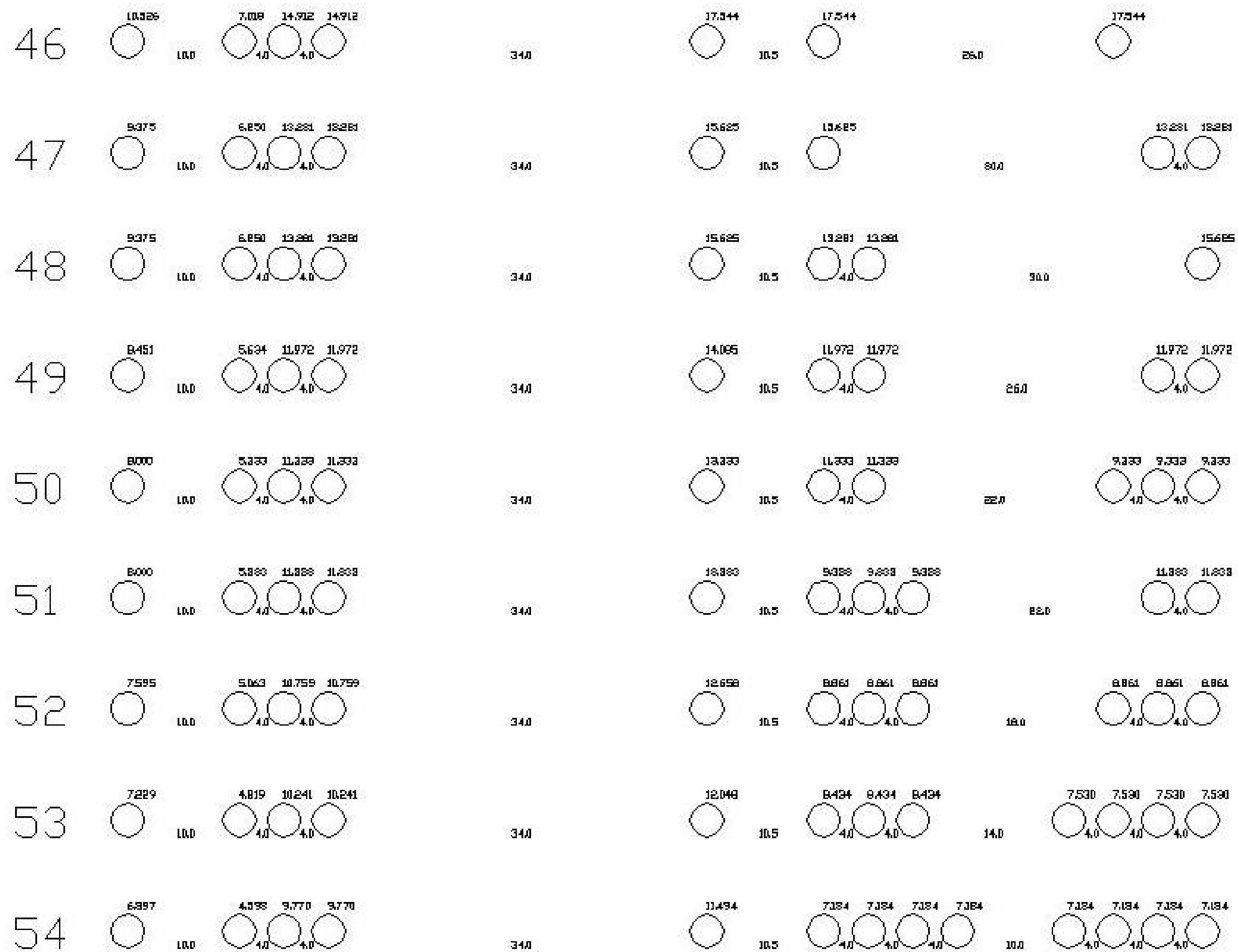

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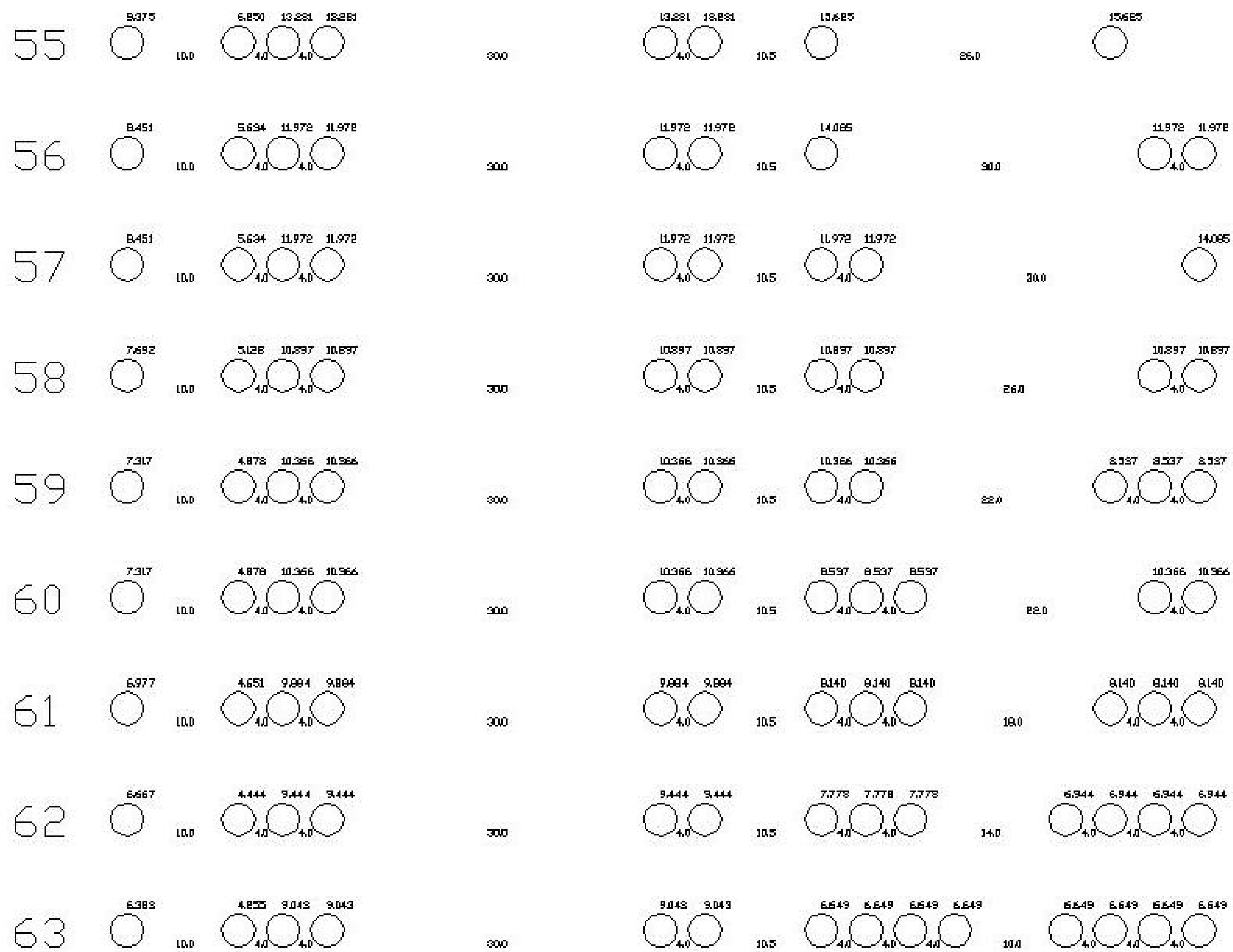

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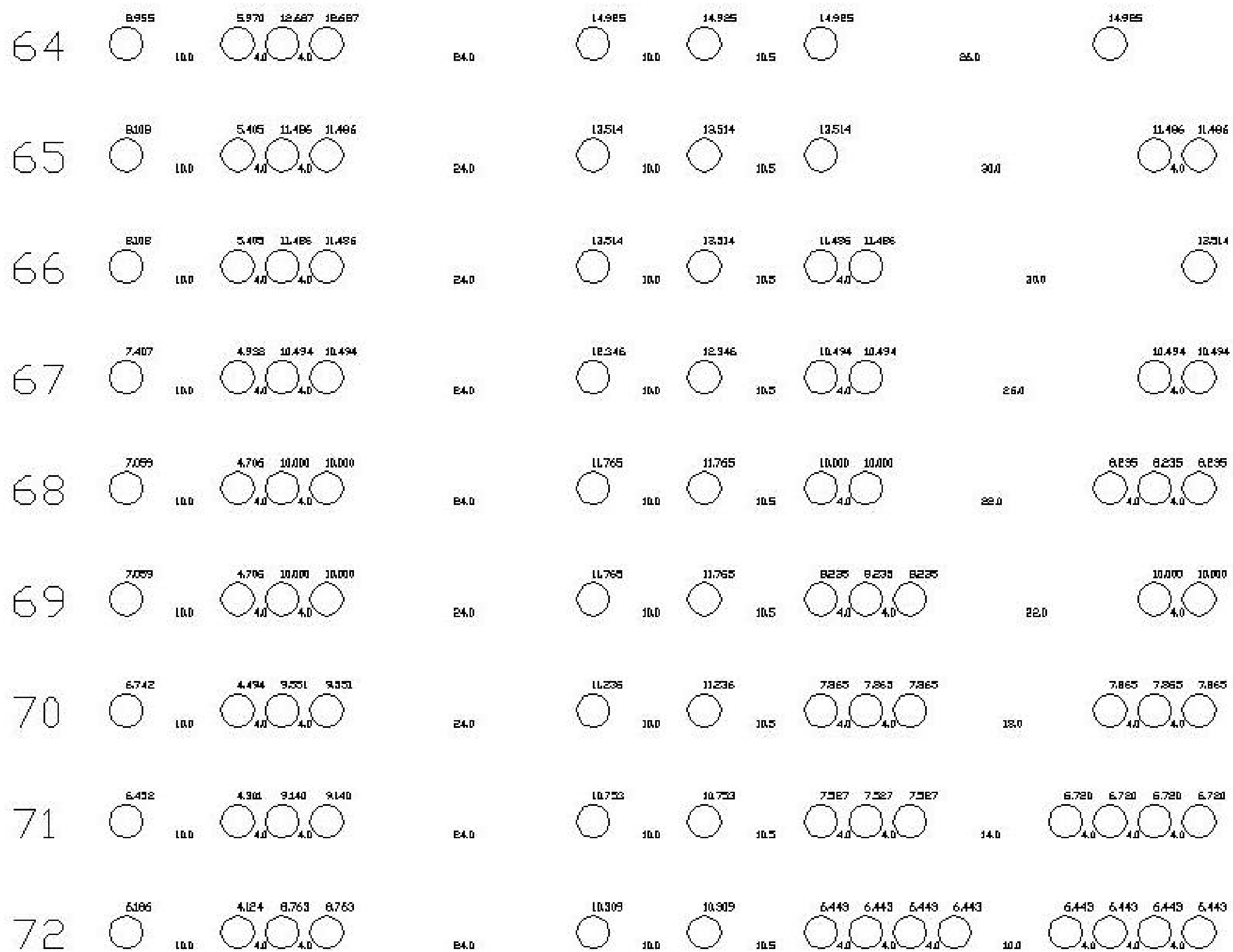

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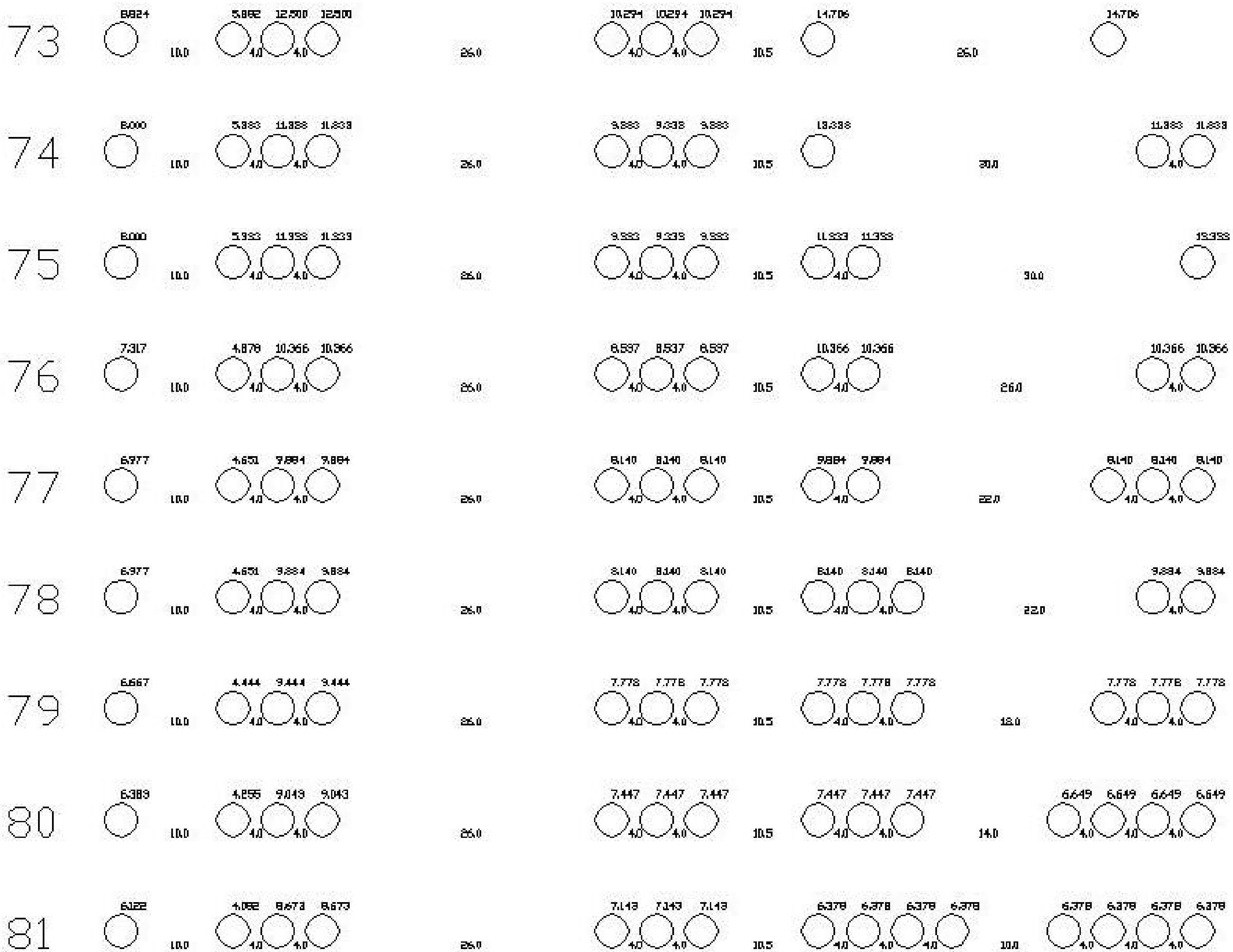

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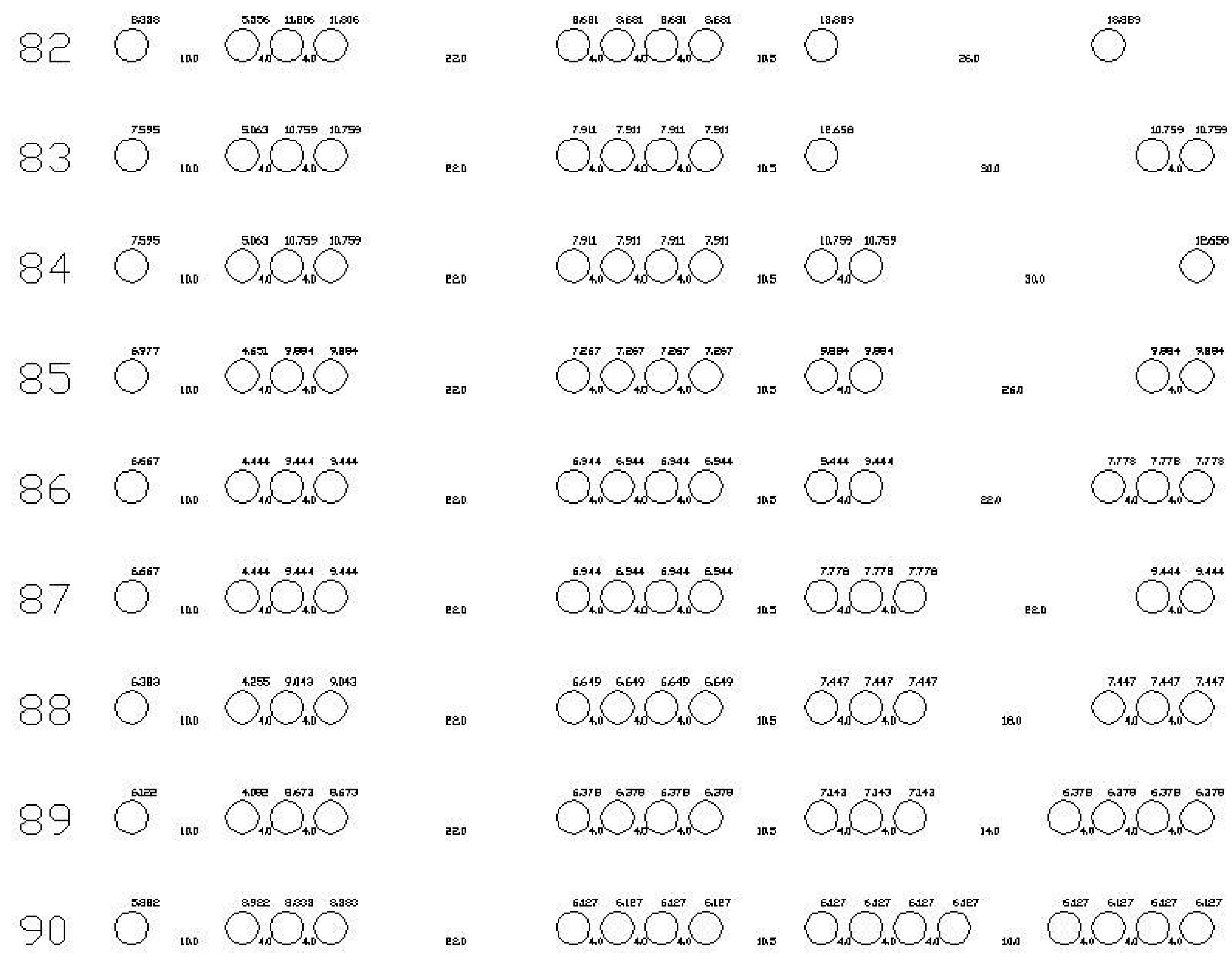

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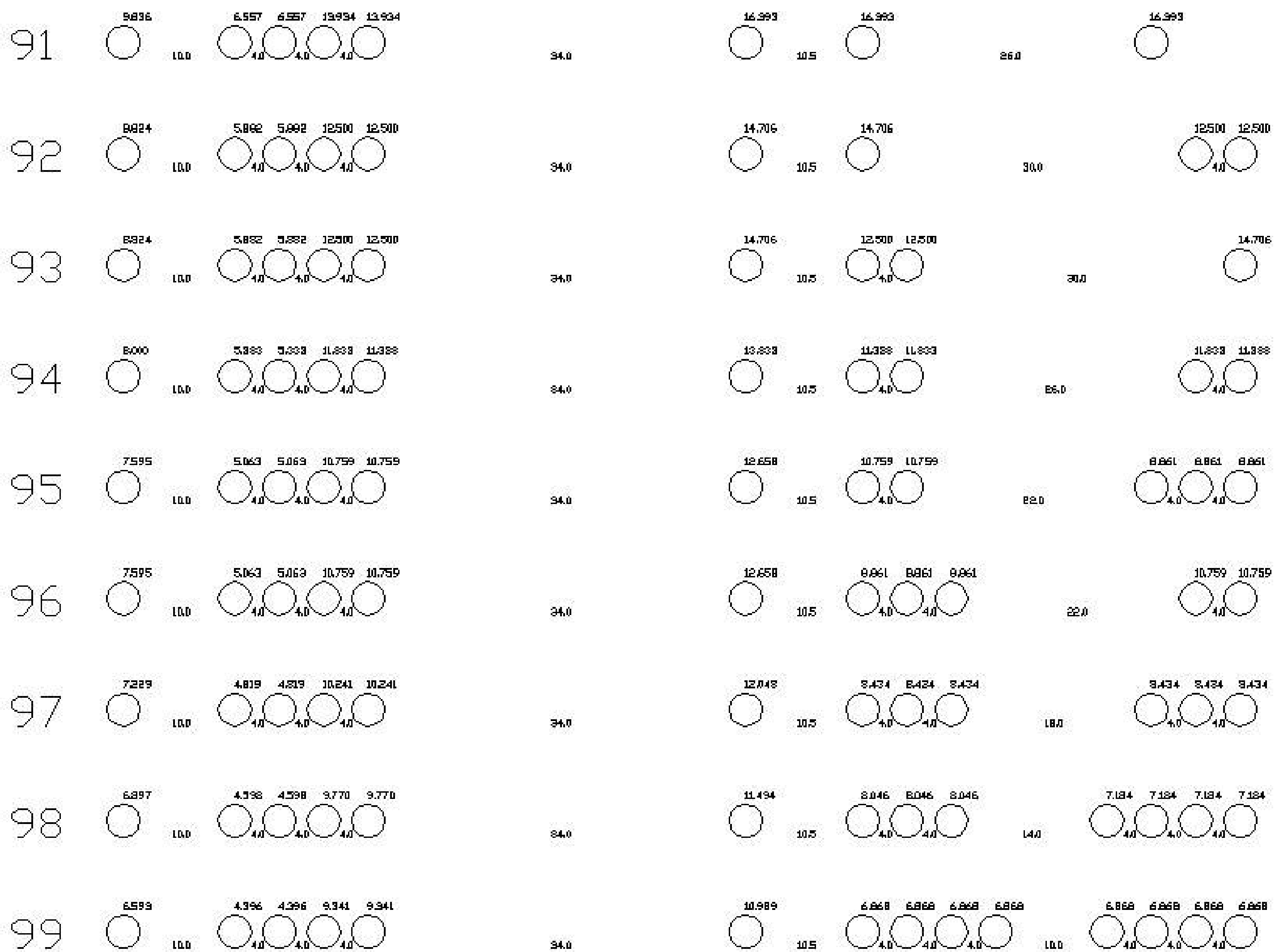

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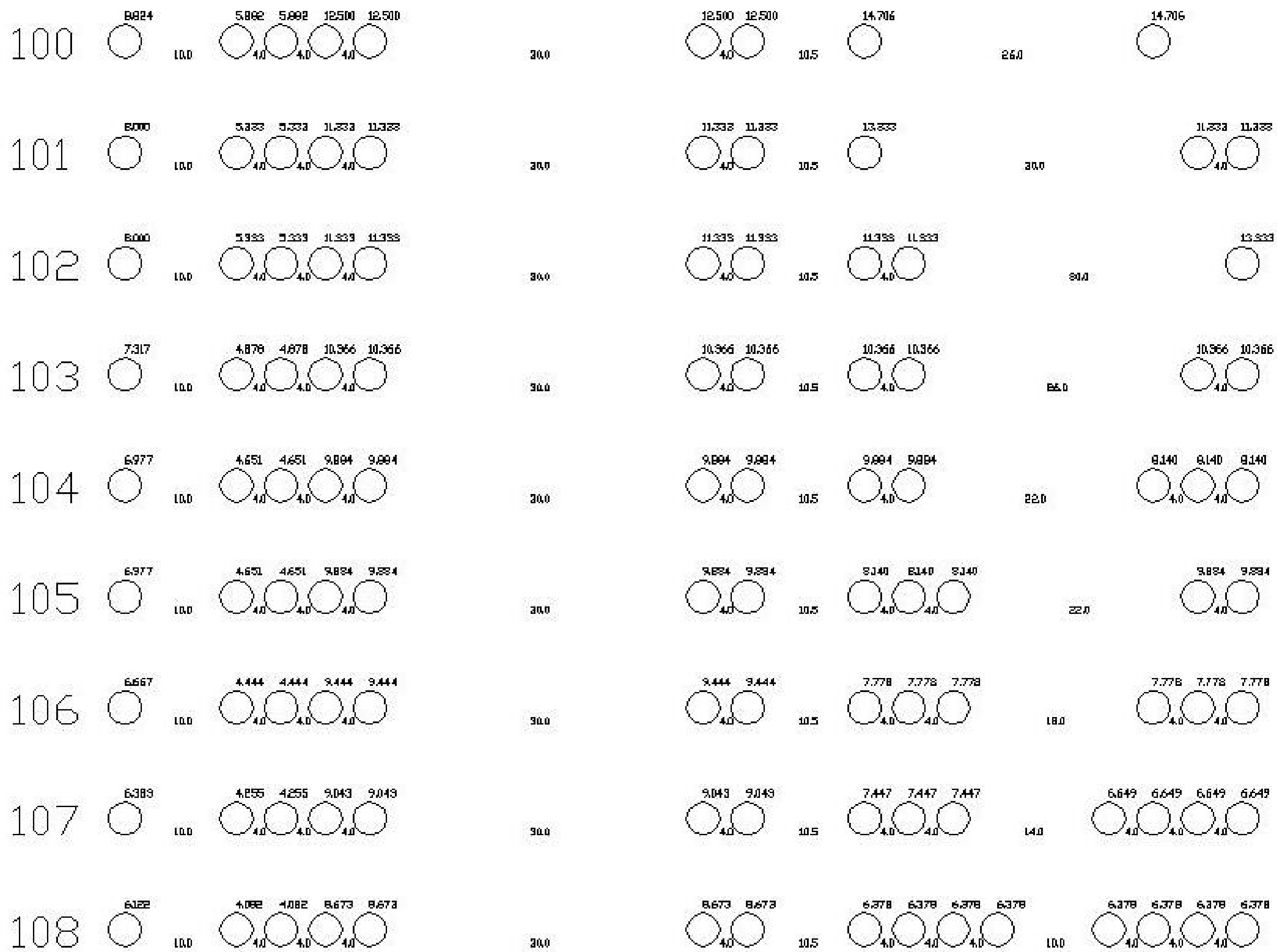

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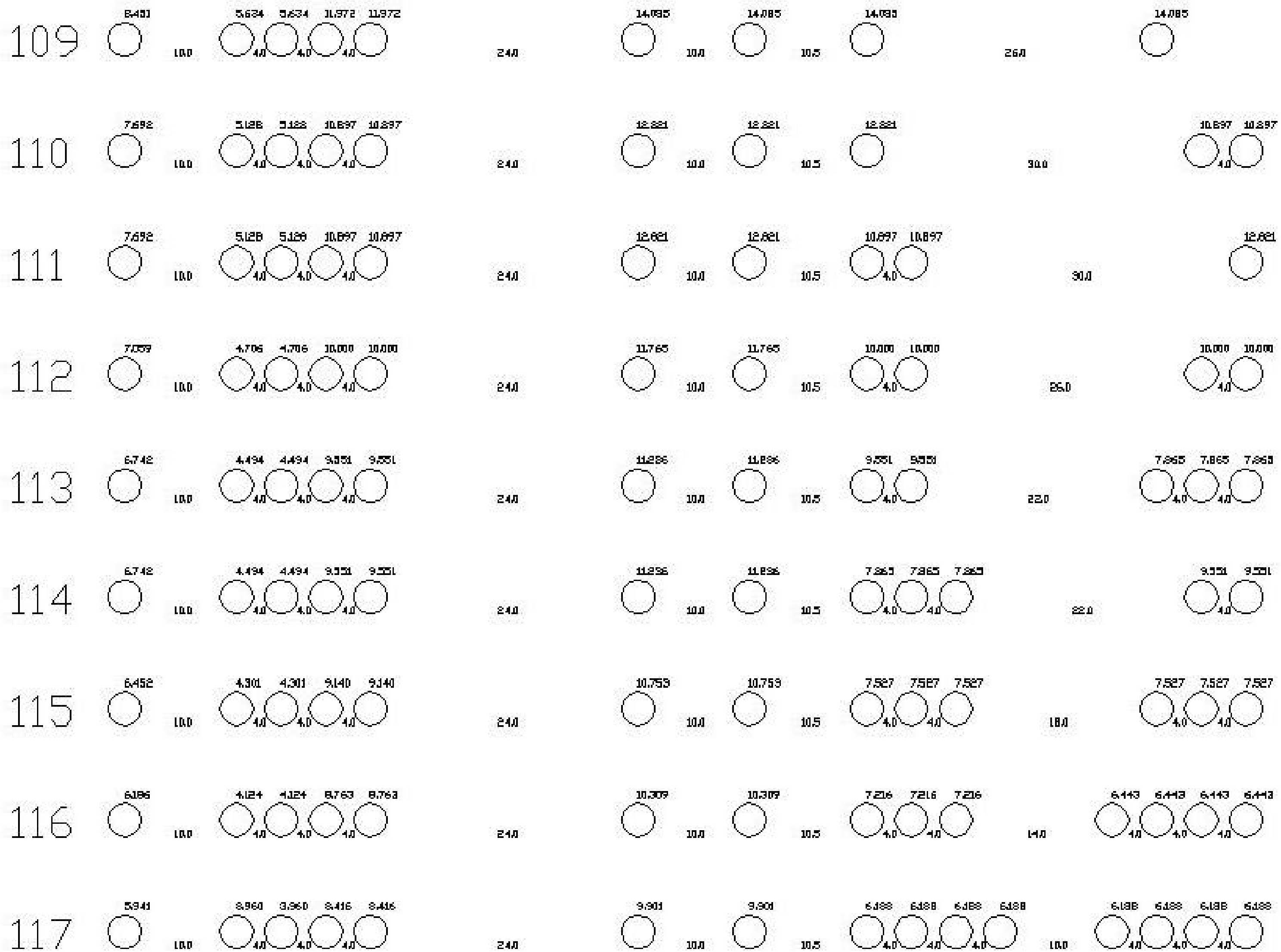

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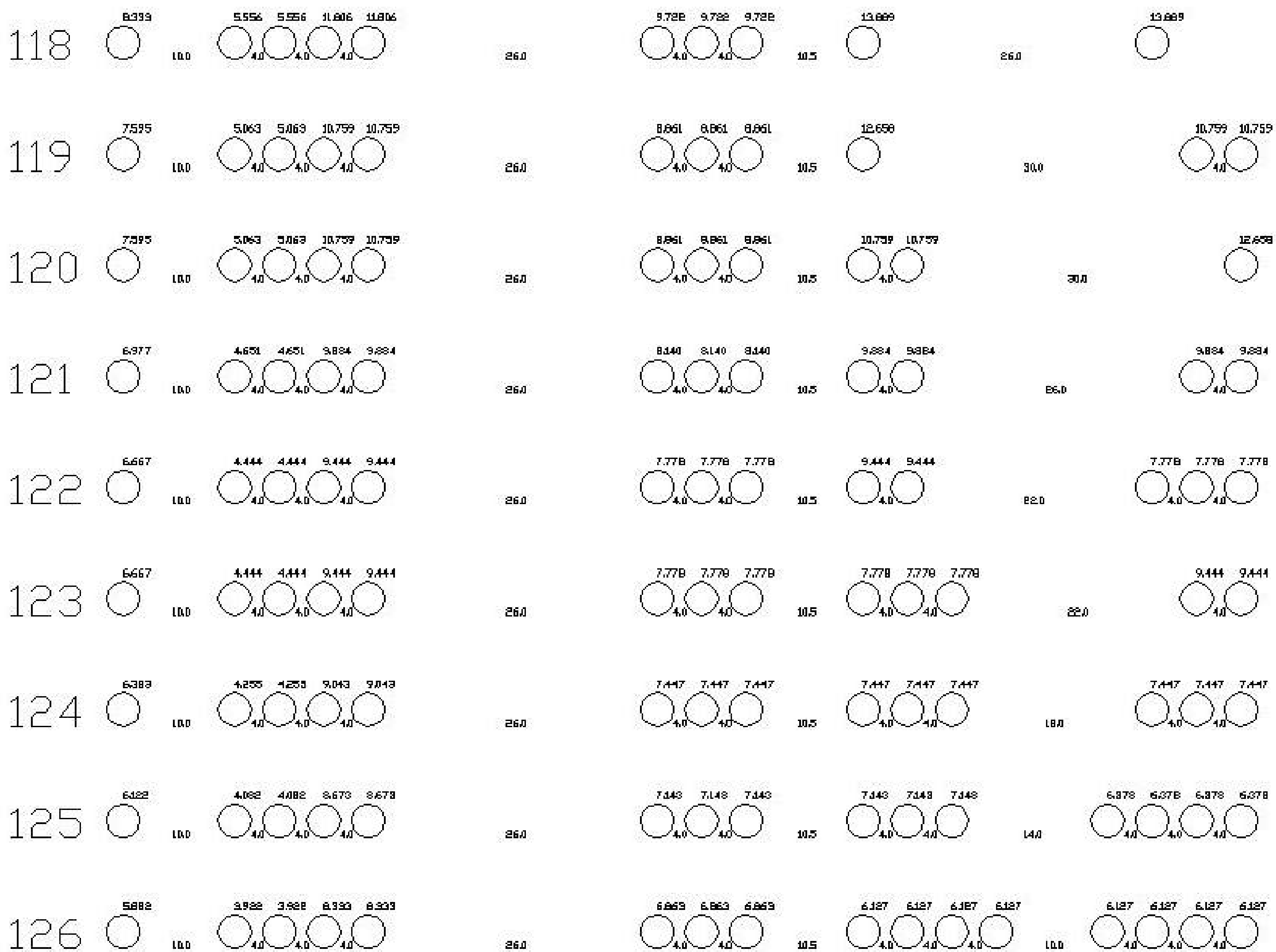

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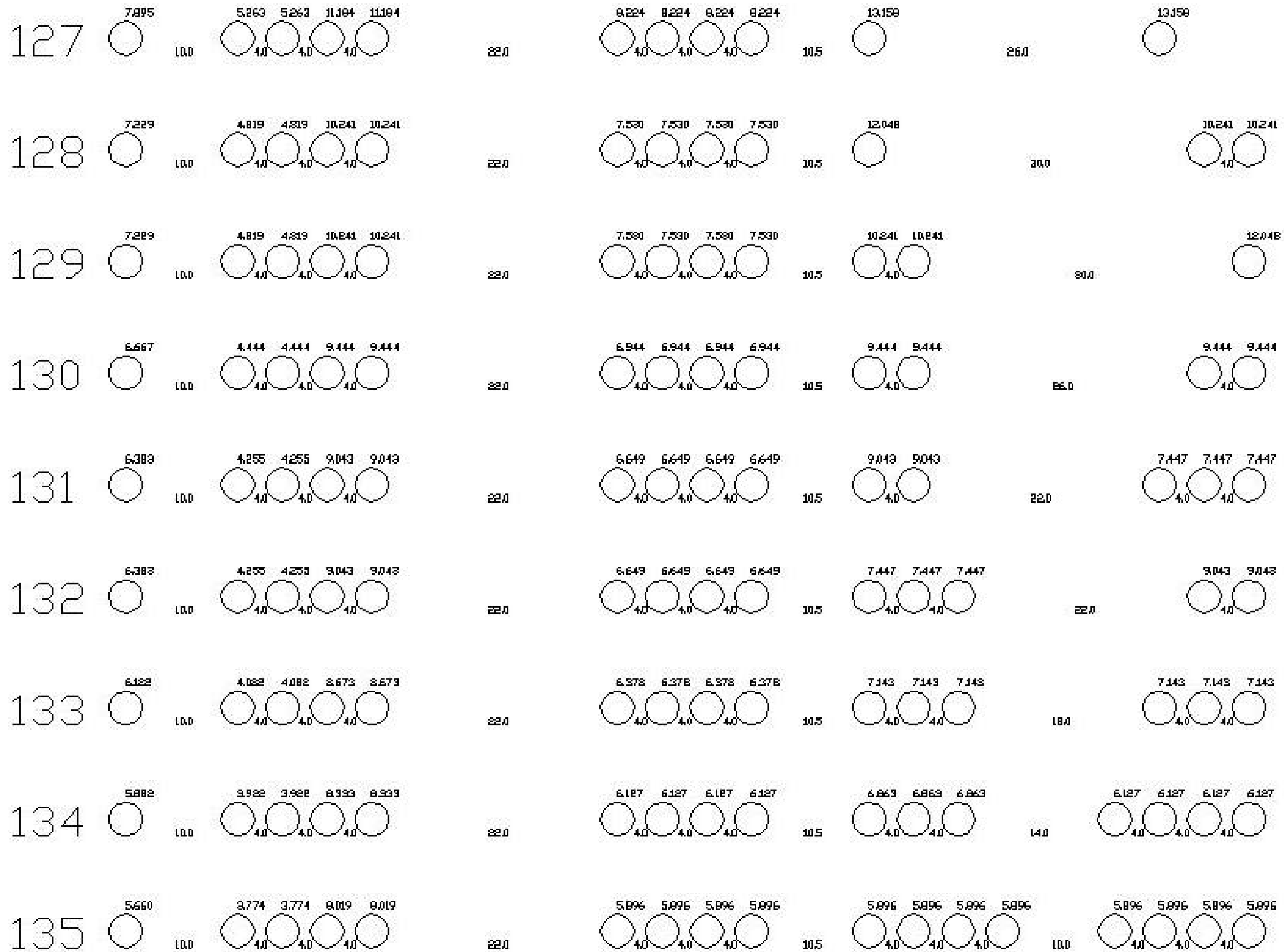

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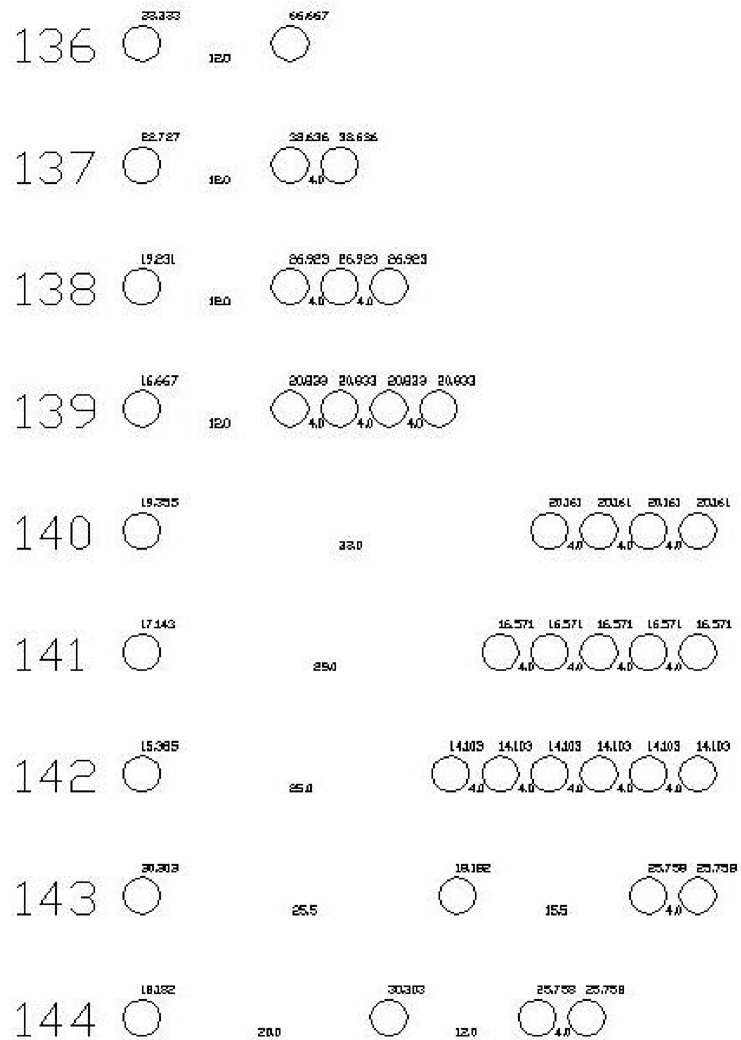

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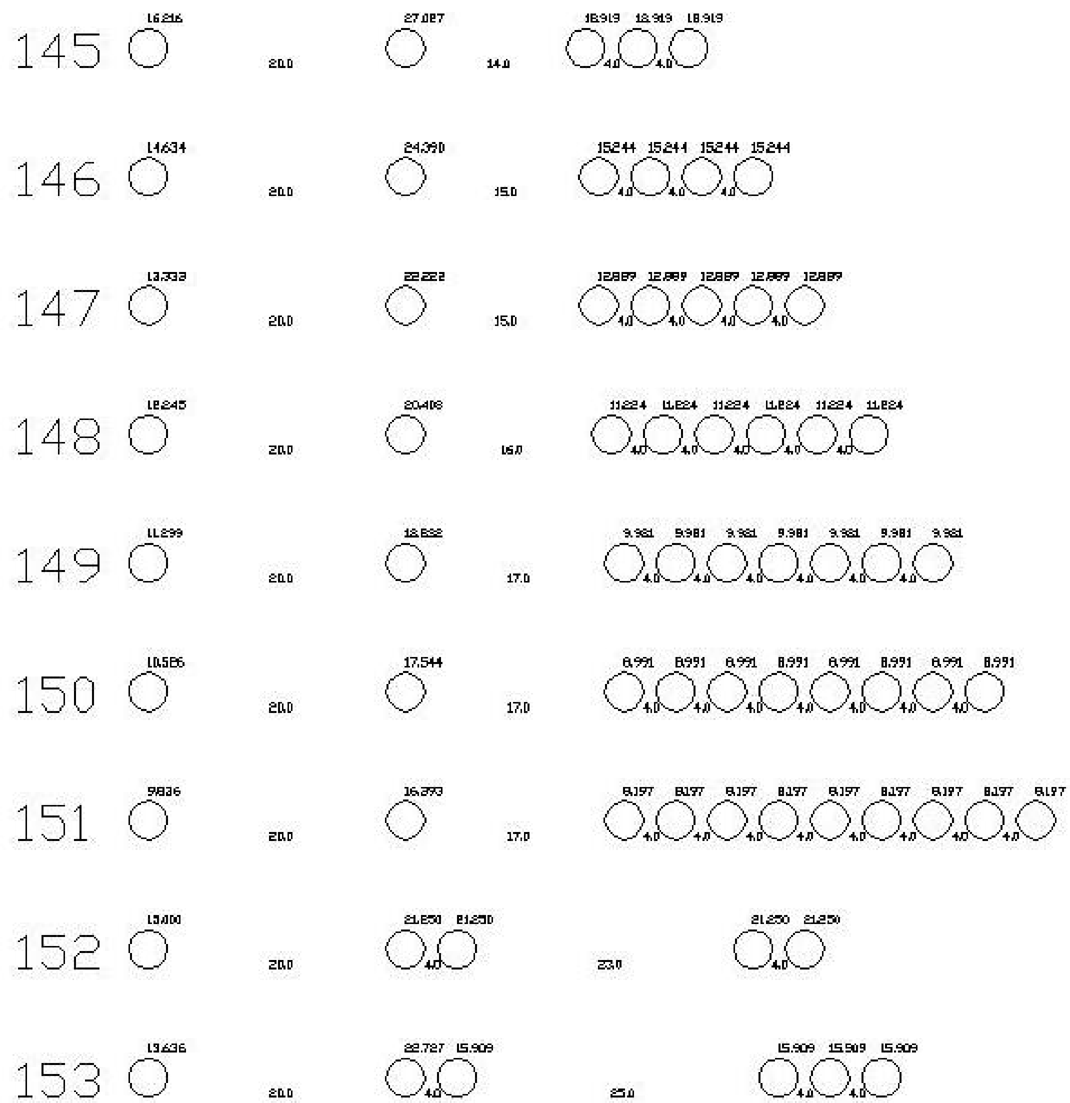

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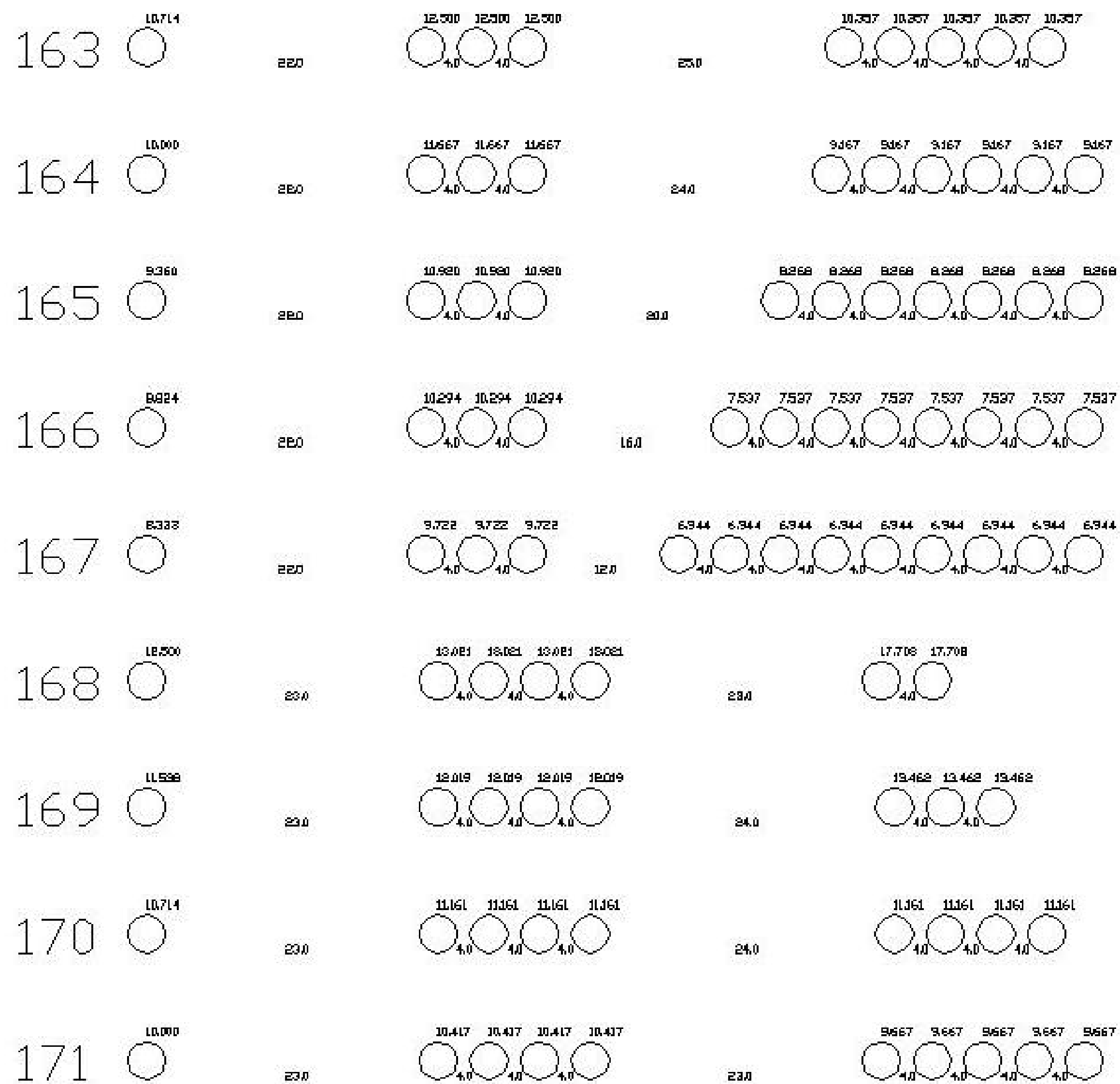

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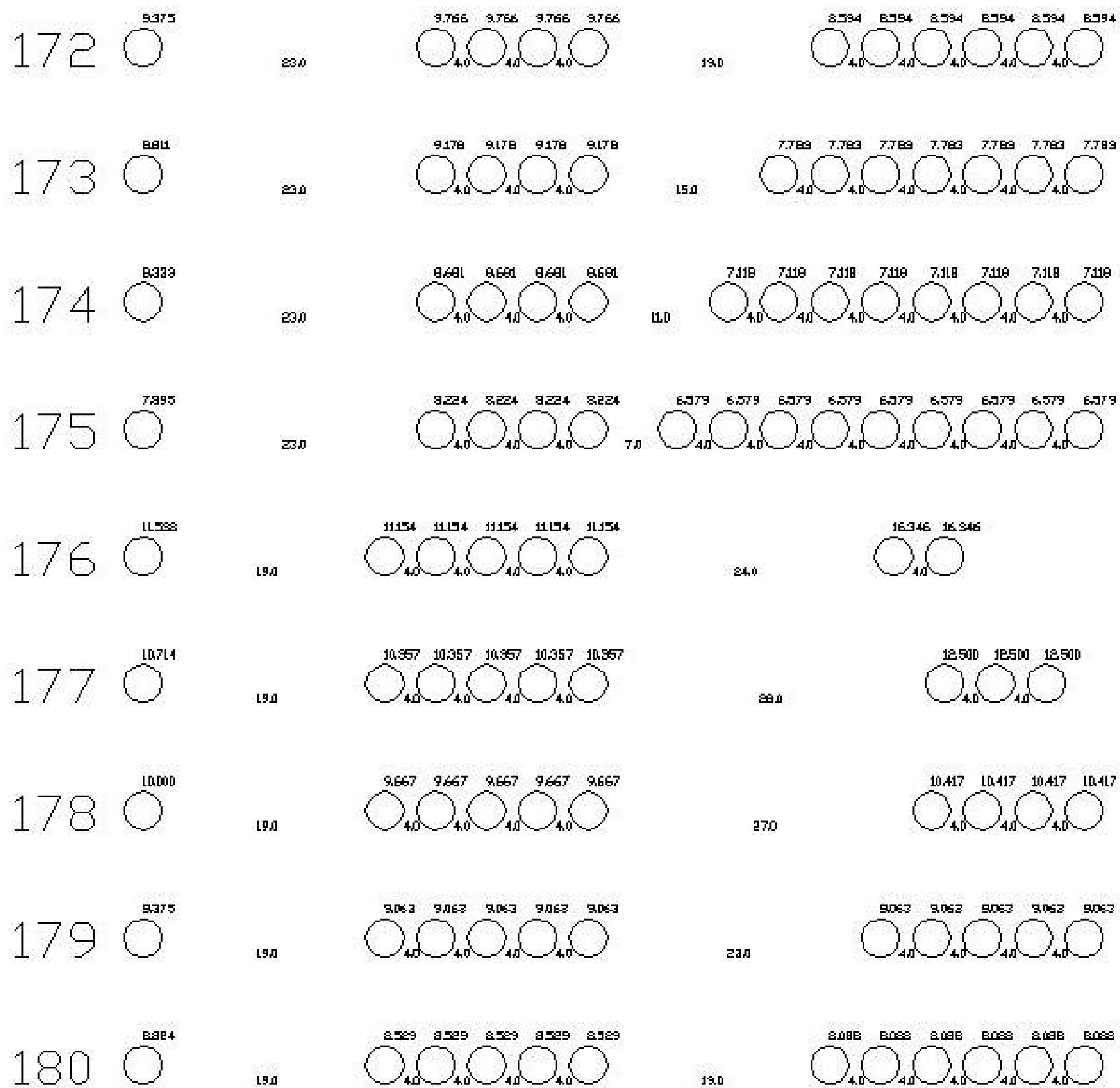

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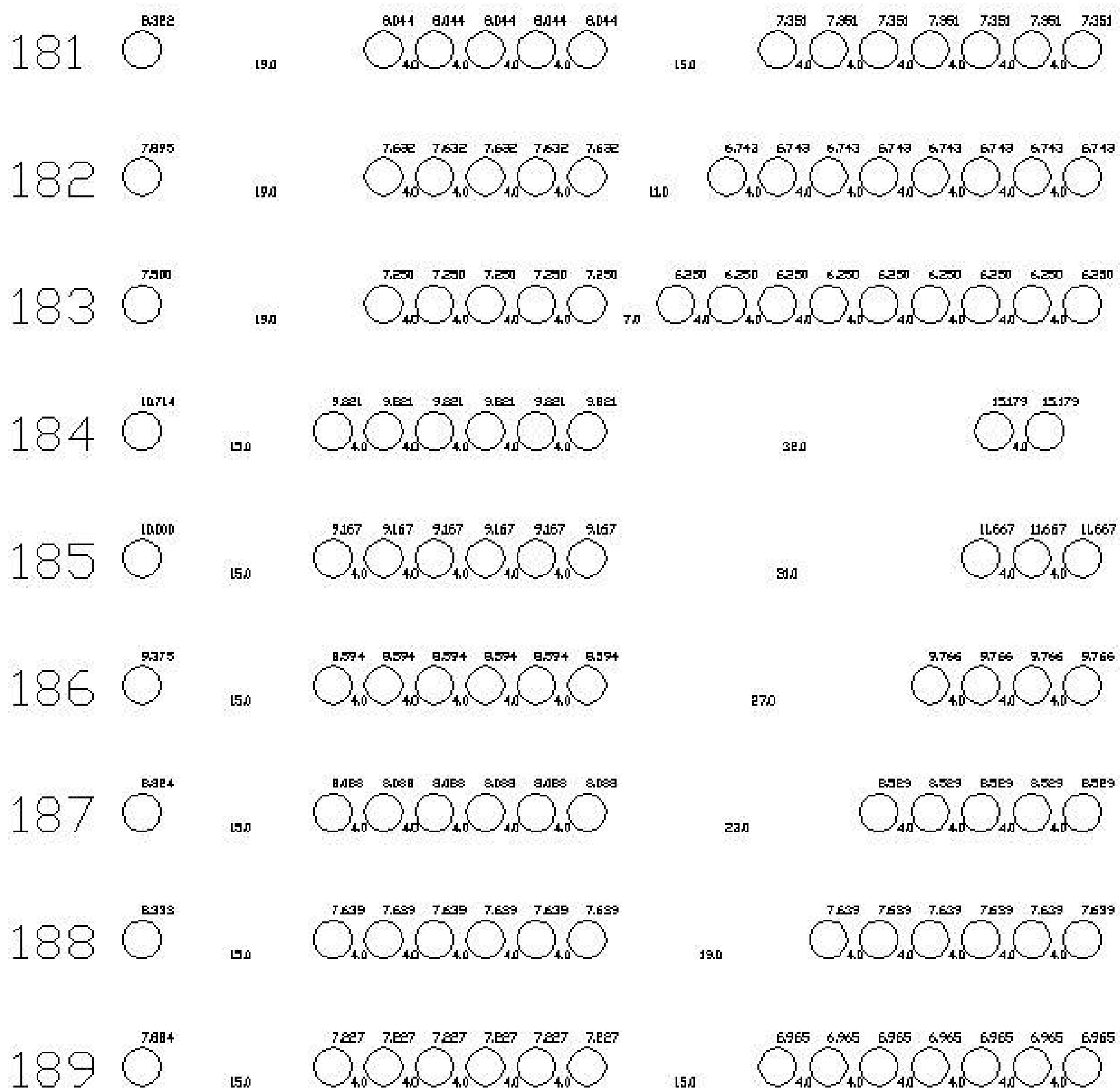

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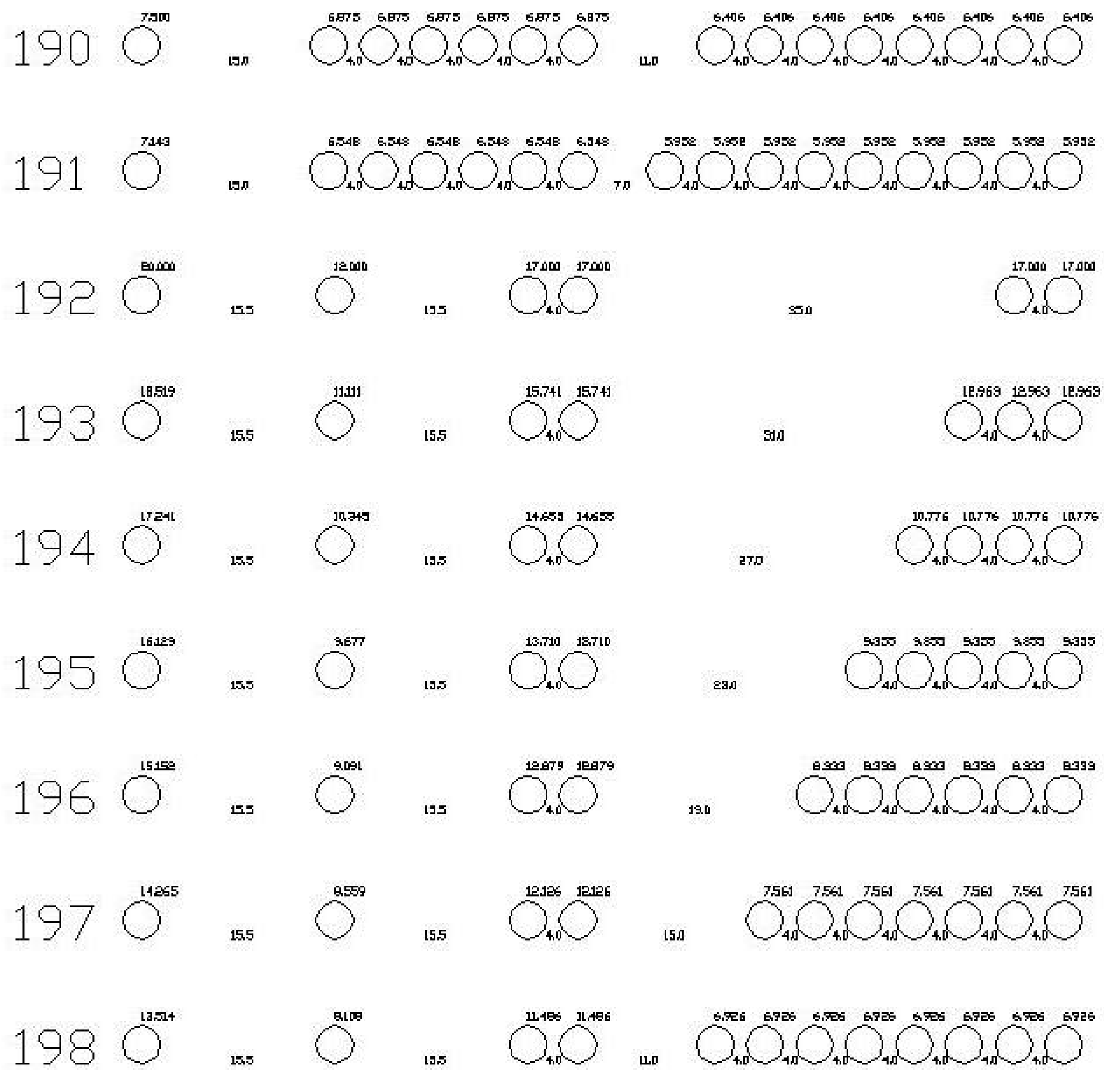

Figure A–1   Non-Standard Trucks (Continued)

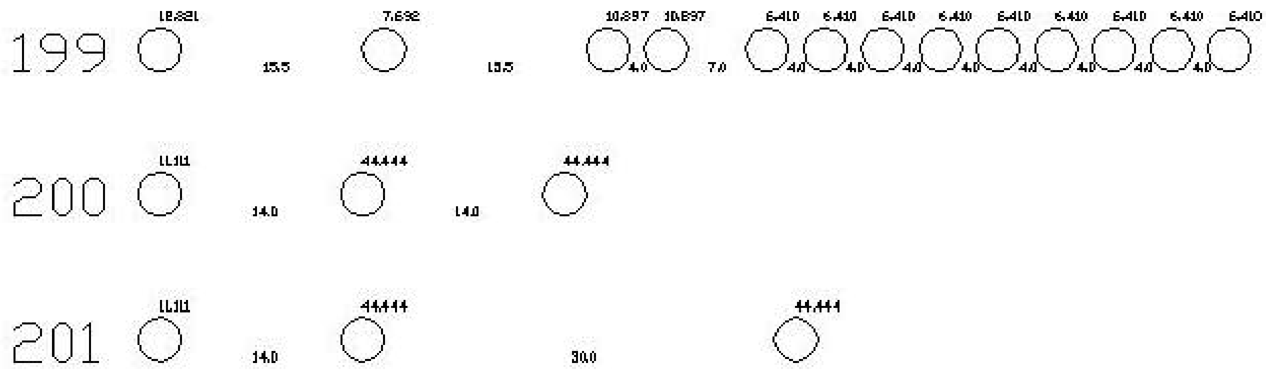

Figure A–1 Non-Standard Trucks (Continued)

For each of the non-standard trucks considered in the study, the gross vehicle weight using the current bridge formula was calculated. The results of this calculation are found in Table A-1. For example, for the truck with Truck ID equal to one, the following calculations were made.

Case 1

Axle 1	20k	
Axle 2-3 @ 4’	38k	
Axle 4-5 @ 10.5’	40k	
Axle 6	20k	
Total All Axle Groups		118k

Case 2

Axle 1-3 @ 15.5’	47.5k	
Axle 4-5 @ 10.5’	40k	
Axle 6	20k	
Total All Axle Groups		107.5k

Case 3

Axle 1-6 @ 86’	105.5k	
Total All Axle Groups		105.5k

Allowable Gross Vehicle Weight 105.5k

Truck	Axles	Length	BWF	Truck	Axles	Length	BWF
1	6	86	105500	56	9	96.5	126500
2	7	94	115000	57	9	96.5	126500
3	7	94	115000	58	10	96.5	131500
4	8	94	119500	59	11	96.5	137000
5	9	94	125000	60	11	96.5	137000
6	9	94	125000	61	12	96.5	142500
7	10	94	130000	62	13	96.5	148500
8	11	94	135500	63	14	96.5	154000
9	12	94	141500	64	8	88.5	116500
10	7	86	110000	65	9	96.5	126500
11	8	94	119500	66	9	96.5	126500
12	8	94	119500	67	10	96.5	131500
13	9	94	125000	68	11	96.5	137000
14	10	94	130000	69	11	96.5	137000
15	10	94	130000	70	12	96.5	142500
16	11	94	135500	71	13	96.5	148500
17	12	94	141500	72	14	96.5	154000
18	13	94	147000	73	9	88.5	122000
19	7	86	110000	74	10	96.5	131500
20	8	94	119500	75	10	96.5	131500
21	8	94	119500	76	11	96.5	137000
22	9	94	125000	77	12	96.5	142500
23	10	94	130000	78	12	96.5	142500
24	10	94	130000	79	13	96.5	148500
25	11	94	135500	80	14	96.5	154000
26	12	94	141500	81	15	96.5	159500
27	13	94	147000	82	10	88.5	127000
28	8	86	115000	83	11	96.5	137000
29	9	94	125000	84	11	96.5	137000
30	9	94	125000	85	12	96.5	142500
31	10	94	130000	86	13	96.5	148500
32	11	94	135500	87	13	96.5	148500
33	11	94	135500	88	14	96.5	154000
34	12	94	141500	89	15	96.5	159500
35	13	94	147000	90	16	96.5	165500
36	14	94	152500	91	8	92.5	119000
37	9	86	120500	92	9	100.5	128500
38	10	94	130000	93	9	100.5	128500
39	10	94	130000	94	10	100.5	134000
40	11	94	135500	95	11	100.5	139500
41	12	94	141500	96	11	100.5	139500
42	12	94	141500	97	12	100.5	145000
43	13	94	147000	98	13	100.5	150500
44	14	94	152500	99	14	100.5	156000
45	15	94	158500	100	9	92.5	124000
46	7	88.5	111500	101	10	100.5	134000
47	8	96.5	121000	102	10	100.5	134000
48	8	96.5	121000	103	11	100.5	139500
49	9	96.5	126500	104	12	100.5	145000
50	10	96.5	131500	105	12	100.5	145000
51	10	96.5	131500	106	13	100.5	150500
52	11	96.5	137000	107	14	100.5	156000
53	12	96.5	142500	108	15	100.5	162000
54	13	96.5	148500	109	9	92.5	124000
55	8	88.5	116500	110	10	100.5	134000

Table A-1 Allowable Gross Vehicle Weight using Current Bridge Formula

Truck	Axles	Length	BWF	Truck	Axles	Length	BWF
111	10	100.5	134000	166	12	74	130500
112	11	100.5	139500	167	13	74	136000
113	12	100.5	145000	168	7	62	96000
114	12	100.5	145000	169	8	67	104500
115	13	100.5	150500	170	9	71	112000
116	14	100.5	156000	171	10	74	119000
117	15	100.5	162000	172	11	74	124500
118	10	92.5	129500	173	12	74	130500
119	11	100.5	139500	174	13	74	136000
120	11	100.5	139500	175	14	74	142000
121	12	100.5	145000	176	8	63	102000
122	13	100.5	150500	177	9	71	112000
123	13	100.5	150500	178	10	74	119000
124	14	100.5	156000	179	11	74	124500
125	15	100.5	162000	180	12	74	130500
126	16	100.5	167500	181	13	74	136000
127	11	92.5	135000	182	14	74	142000
128	12	100.5	145000	183	15	74	147500
129	12	100.5	145000	184	9	71	112000
130	13	100.5	150500	185	10	74	119000
131	14	100.5	156000	186	11	74	124500
132	14	100.5	156000	187	12	74	130500
133	15	100.5	162000	188	13	74	136000
134	16	100.5	167500	189	14	74	142000
135	17	100.5	173500	190	15	74	147500
136	2	12	42000	191	16	74	153500
137	3	16	48000	192	6	74	98500
138	4	20	55500	193	7	74	103000
139	5	24	63000	194	8	74	108500
140	5	45	76000	195	9	74	113500
141	6	45	81000	196	10	74	119000
142	7	45	86500	197	11	74	124500
143	4	45	72000	198	12	74	130500
144	4	36	66000	199	13	74	136000
145	5	42	74500	200	3	28	57000
146	6	47	82000	201	3	44	69000
147	7	51	90000				
148	8	56	98000				
149	9	61	106500				
150	10	65	114000				
151	11	69	122000				
152	5	51	80000				
153	6	57	88000				
154	7	62	96000				
155	8	67	104500				
156	9	71	112000				
157	10	74	119000				
158	11	74	124500				
159	12	74	130500				
160	6	57	88000				
161	7	62	96000				
162	8	67	104500				
163	9	71	112000				
164	10	74	119000				
165	11	74	124500				

Table A-1 Allowable Gross Vehicle Weight using Current Bridge Formula (Con't)

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Appendix B

Appendix B is a listing of the 20 Survey Trucks. They are shown in the same format as the non-standard trucks.

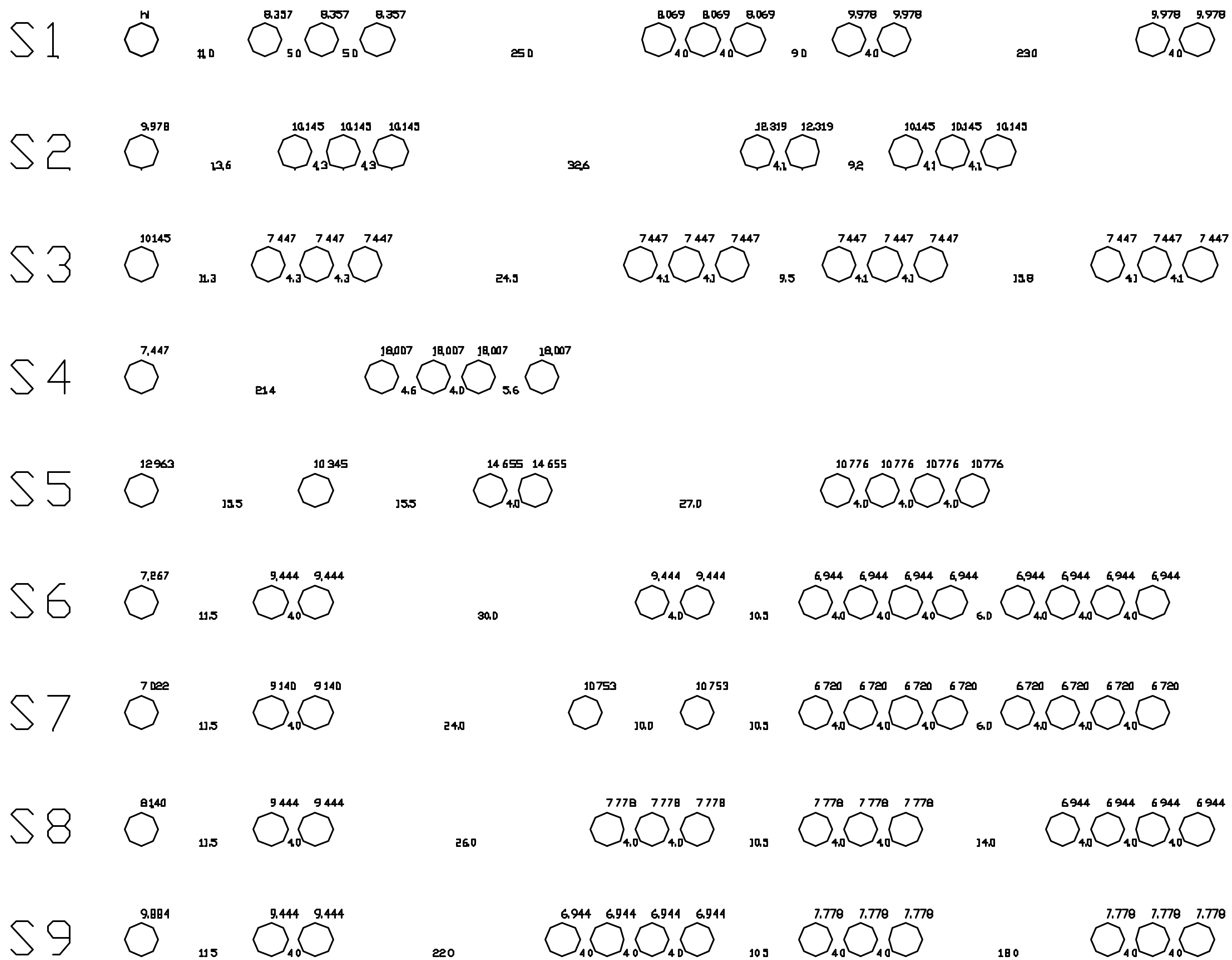

Figure B-1 Survey Trucks

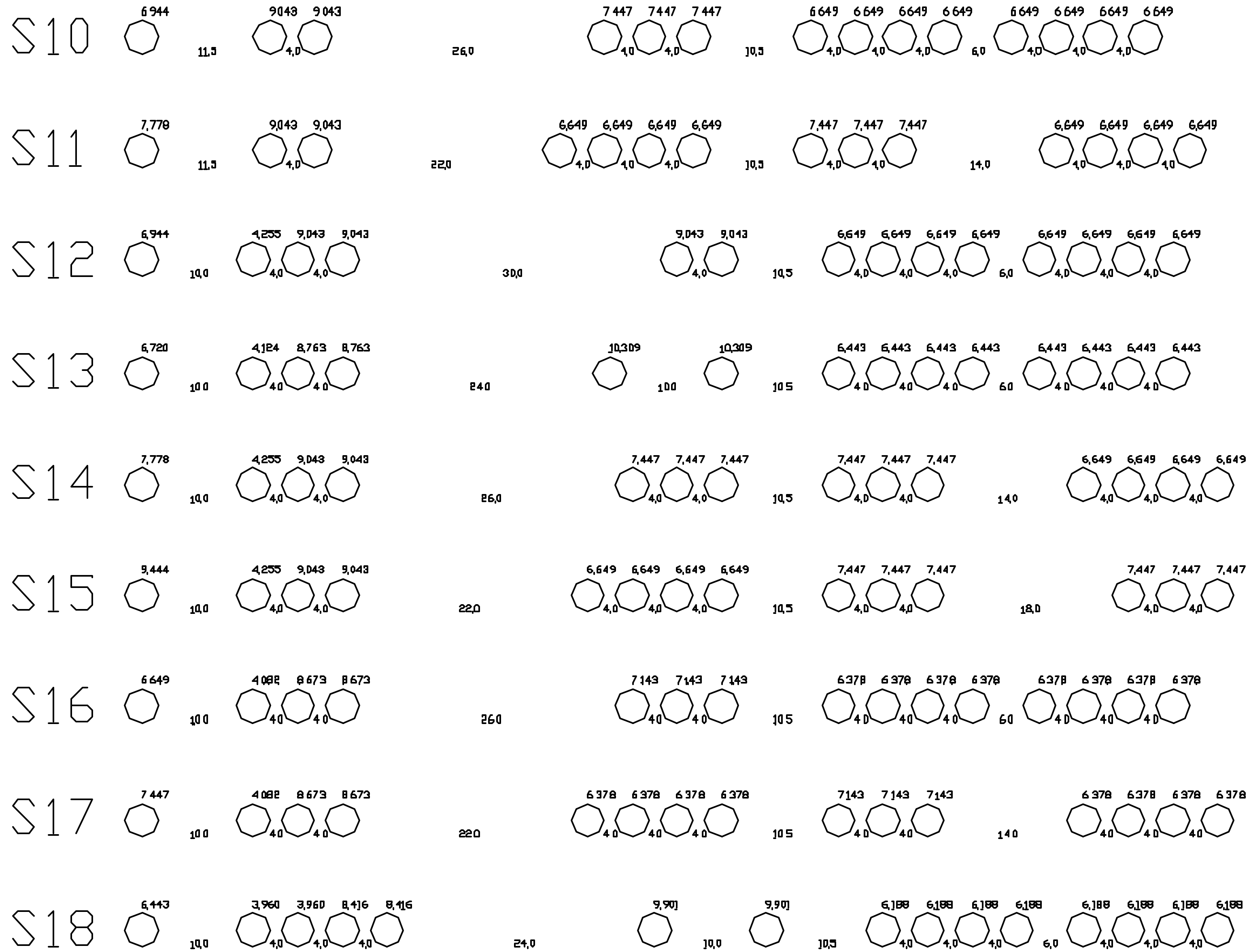

Figure B-2 Survey Trucks Continued

Figure B-3 Survey Trucks Continued

Appendix C

The number of bridges overloaded by trucks of the same length for both the Bridge Gross Weight Formula and the Modified Bridge Weight Formula are shown in Appendix B.

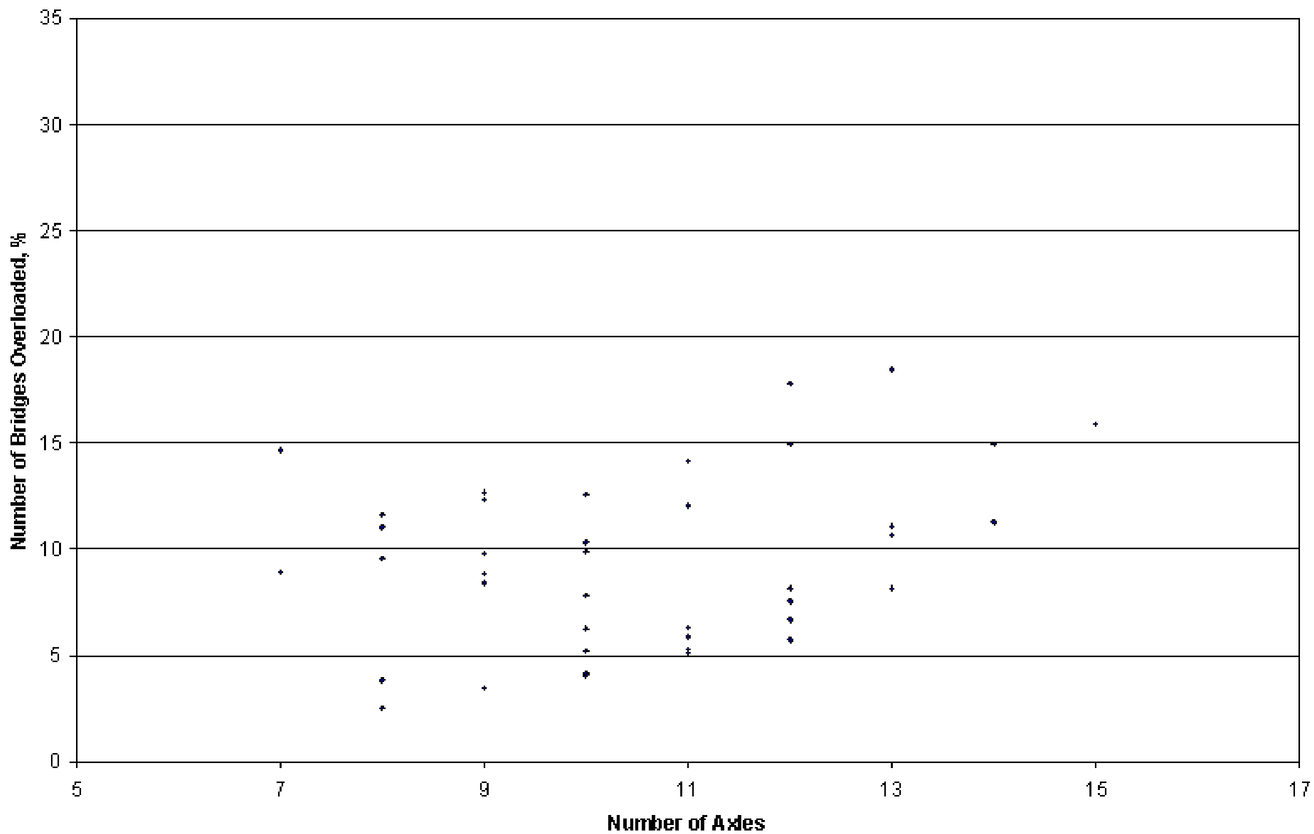

Figure C-1 Number of Bridges Overloaded By Increasing Number of Axles for 94 ft. Trucks Using the Bridge Gross Weight Formula

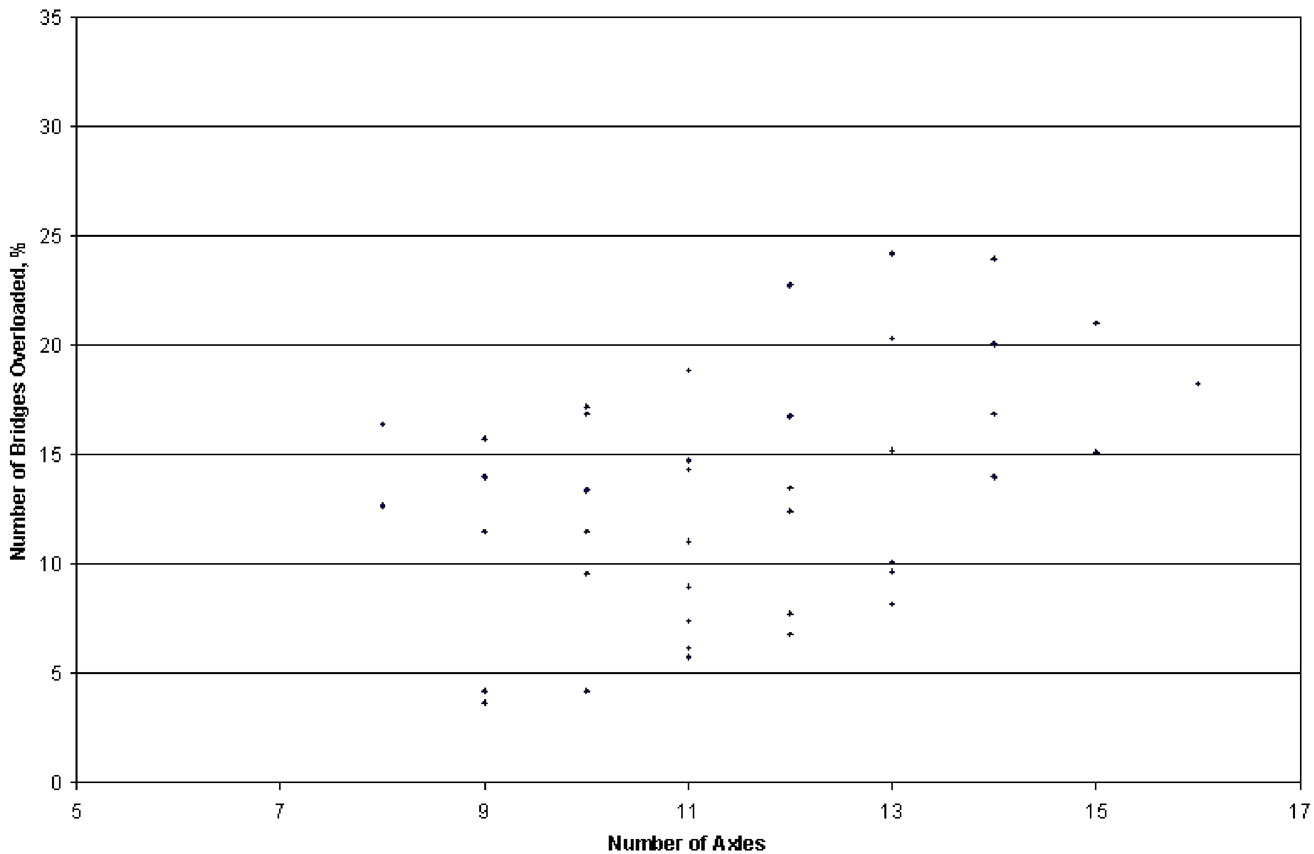

Figure C-2 Number of Bridges Overloaded By Increasing Number of Axles for 96.5 ft. Trucks Using the Bridge Gross Weight Formula

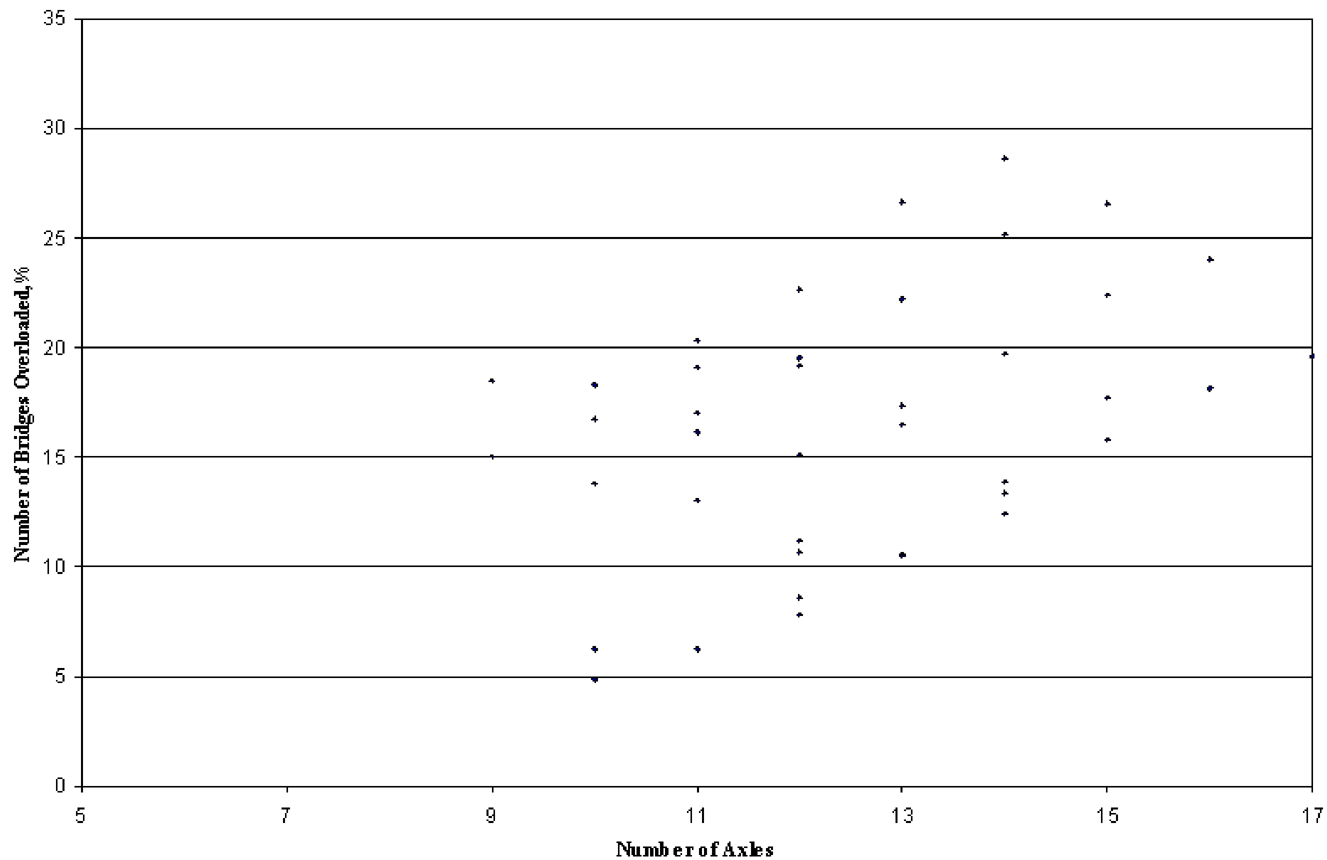

Figure C-3 **Number of Bridges Overloaded By Increasing Number of Axles for 100.5 ft. Trucks Using the Bridge Gross Weight Formula**

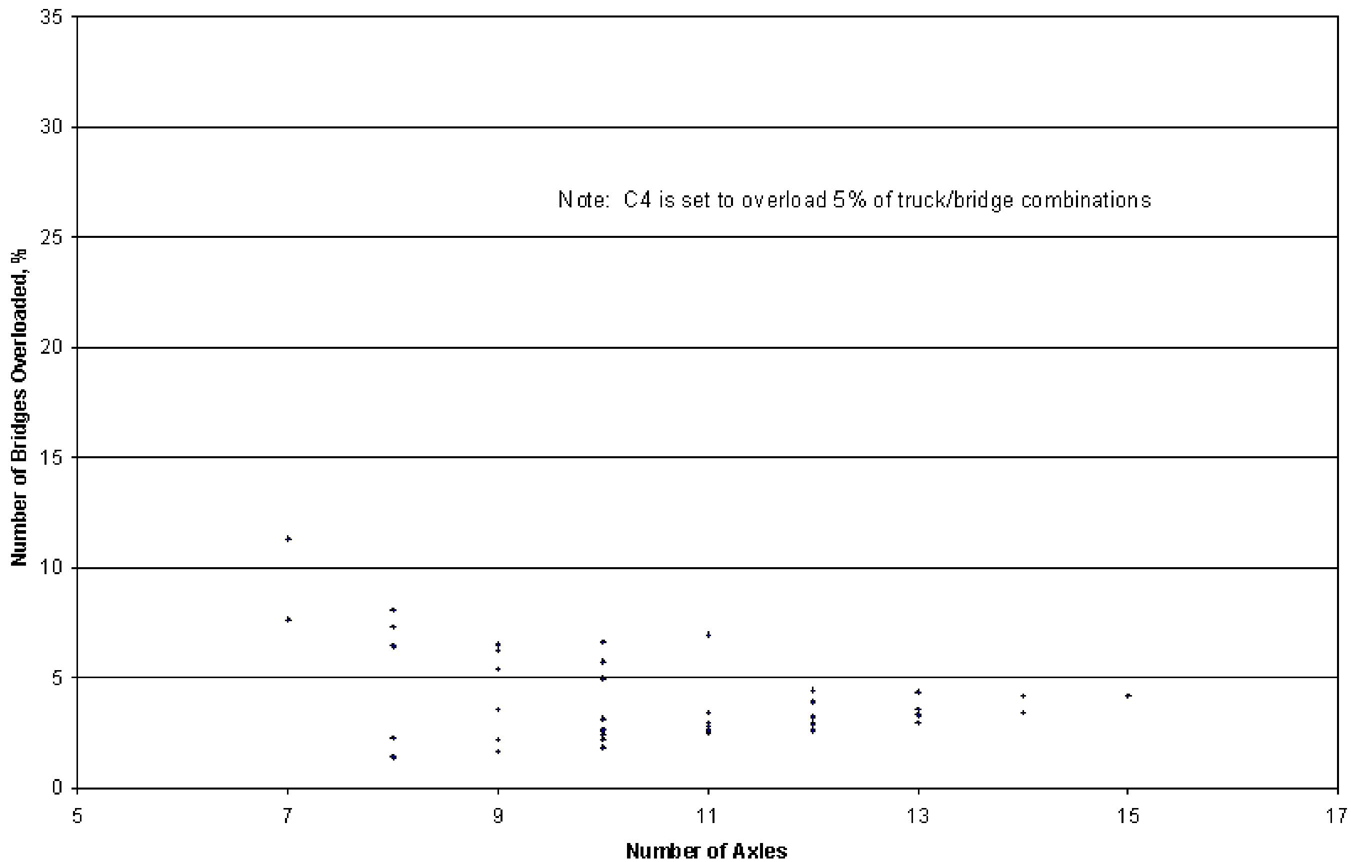

Figure C-4 Number of Bridges Overloaded for All 94 ft. Trucks Using the Modified Bridge Gross Formula

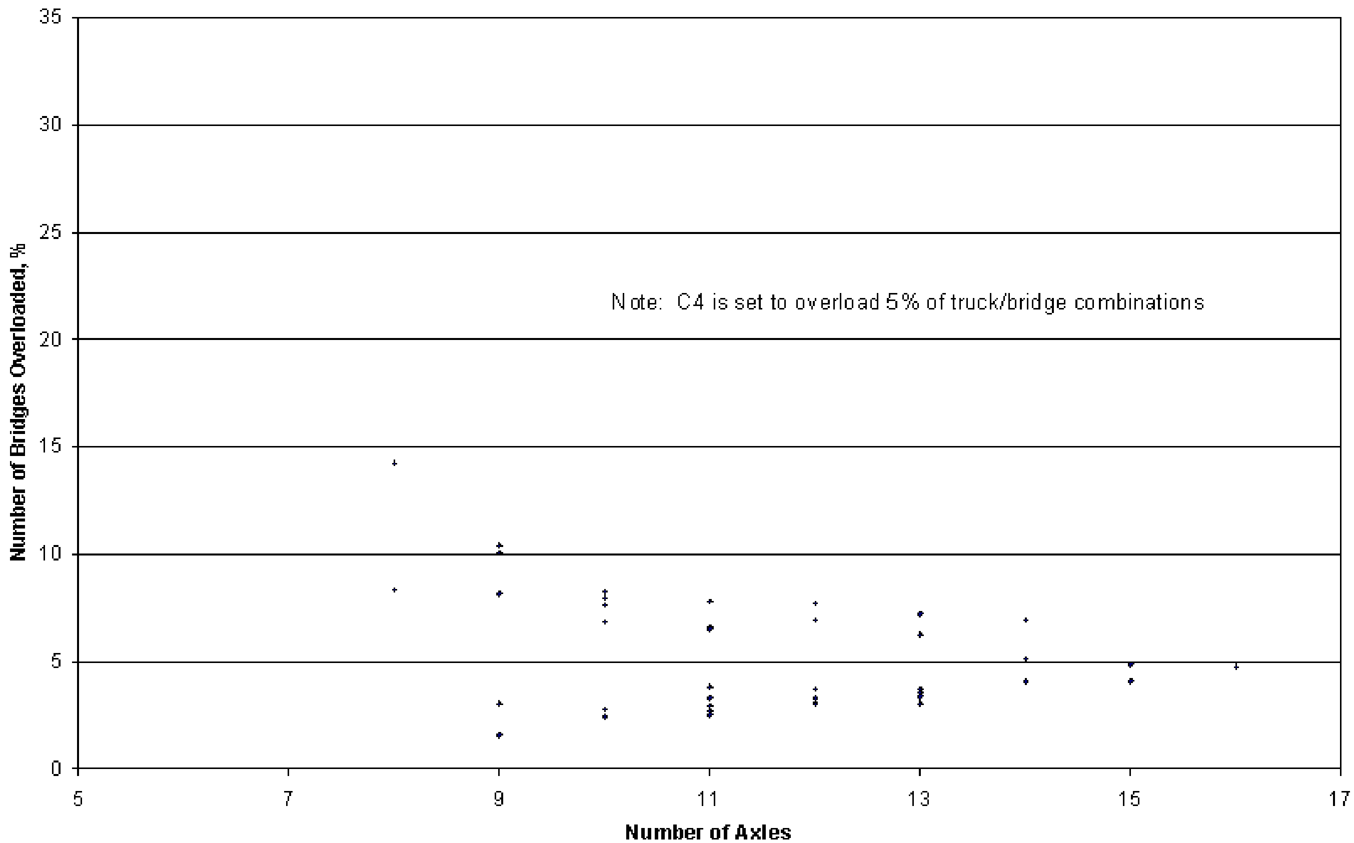

Figure C-5 Number of Bridges Overloaded for All 96.5 ft. Trucks Using the Modified Bridge Gross Formula

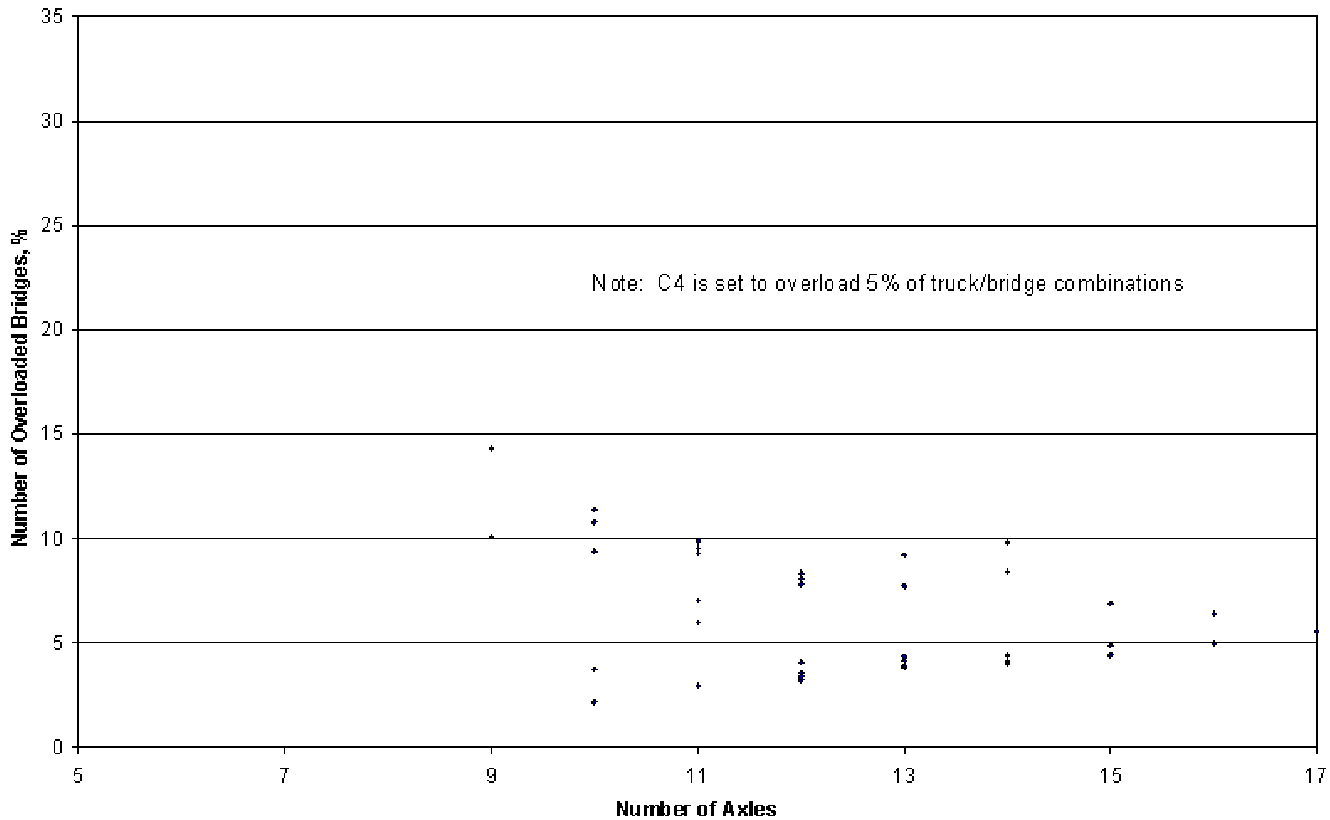

Figure C-6 Number of Bridges Overloaded for All 100.5 ft. Trucks Using the Modified Bridge Gross Formula

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Appendix D

The graphs in Appendix D illustrate the varying amounts of overloaded bridges caused by all trucks at different values of C_4.

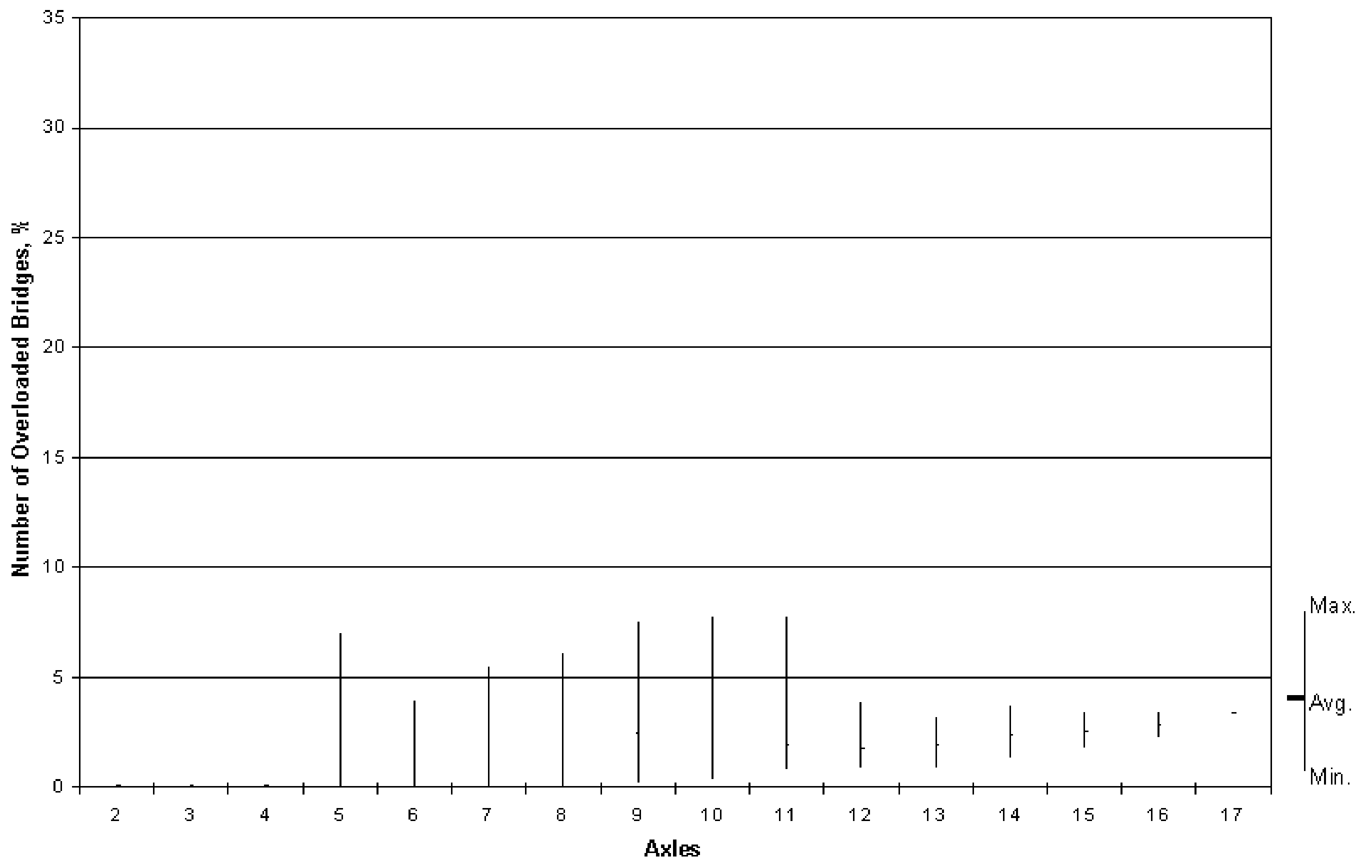

Figure D-1 **The Number of Overloaded Bridges by All Trucks - C4 = 21 (2%)**

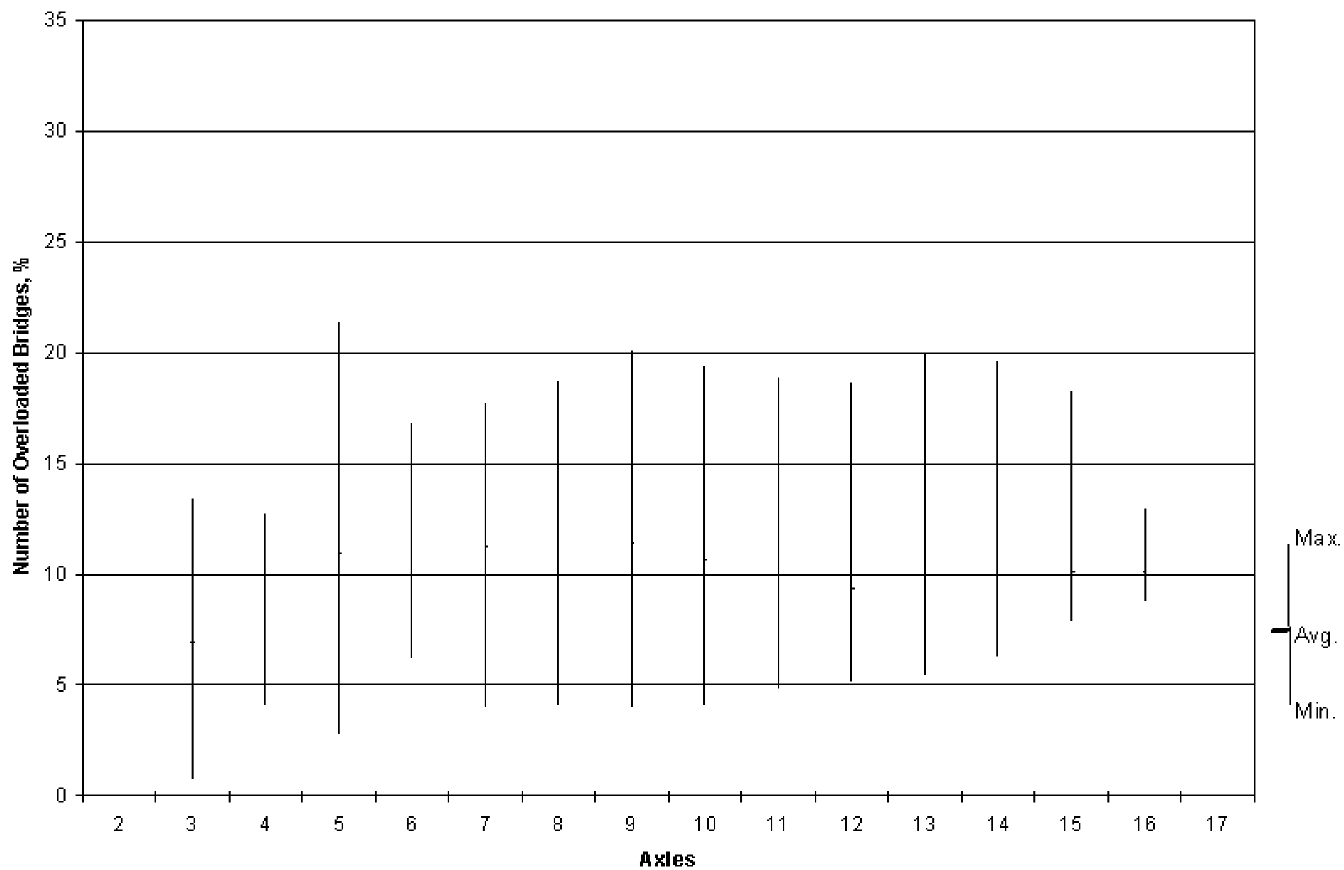

Figure D-2 The Number of Overloaded Bridges by All Trucks - C4 = 48 (10%)

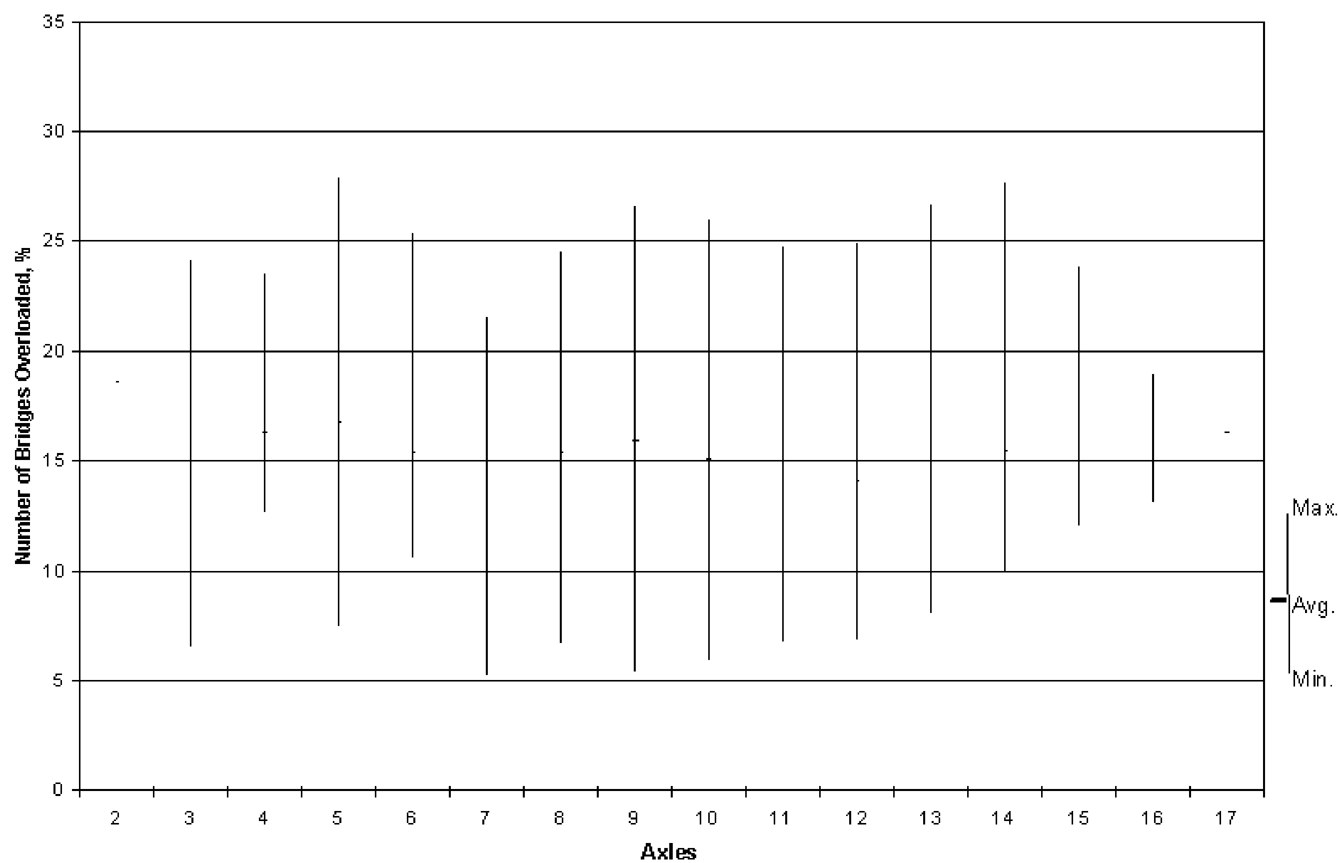

Figure D-3 **The Number of Overloaded Bridges by All Trucks - C4 = 57 (15%)**

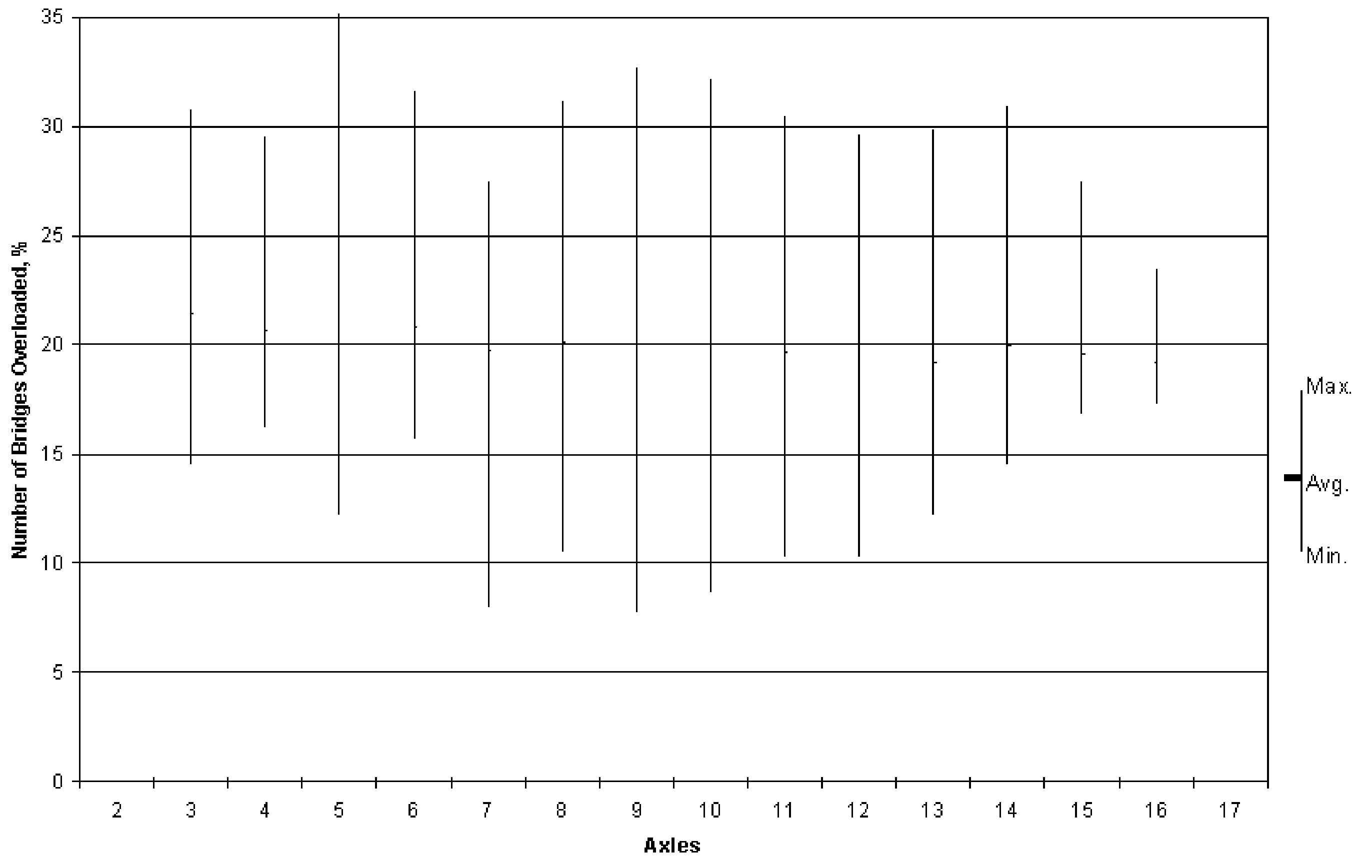

Figure D-4 The Number of Overloaded Bridges by All Trucks - C4 = 65 (20%)

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Appendix E

Appendix E includes tables of the Modified Bridge Formula at different levels of C_4. Also included are tables showing the difference between the Bridge Gross Weight Formula and the Modified Bridge Formula at those levels of C_4. Positive values indicate an addition of weight from the Bridge Gross Weight Formula. Negative values indicate a reduction from the Bridge Gross Weight Formula.

	c4 = 57		(15%)		Number of Axles							
Axle	2	3	4	5	6	7	8	9	10	11	12	13
Spacing		Difference Between Current BGWF and Proposed BGWF - Pounds										
9	1000	17500										
10	0	16500	27000									
11	0	16000	27000									
12	0	15000	27000									
13	0	14500	27000									
14	0	13500	27000	24000								
15	0	13000	27000	24000								
16	0	12000	27000	24000								
17	0	11500	26500	24000	21000							
18	0	10500	26000	24000	21000							
19	0	10000	25500	24000	21000							
20	0	9000	24500	24000	21000	18000						
21	0	8500	24000	24000	21000	18000						
22	0	7500	23500	24000	21000	18000						
23	0	7000	22500	24000	21000	18000						
24	0	6000	22000	24000	21000	18000	15000					
25	0	5500	21500	24000	21000	18000	15000					
26	0	4500	20500	24000	21000	18000	15000					
27	0	4000	20000	24000	21000	18000	15000	12000				
28	0	3000	19500	24000	21000	18000	15000	12000				
29	0	2500	18500	24000	21000	18000	15000	12000				
30	0	1500	18000	24000	21000	18000	15000	12000	9000			
31	0	1000	17500	24000	21000	18000	15000	12000	9000			
32	0	0	16500	24000	21000	18000	15000	12000	9000			
33	0	0	16000	24000	21000	18000	15000	12000	9000			
34	0	0	15500	24000	21000	18000	15000	12000	9000	6000		
35	0	0	14500	24000	21000	18000	15000	12000	9000	6000		
36	0	0	14000	24000	21000	18000	15000	12000	9000	6000		
37	0	0	13500	24000	21000	18000	15000	12000	9000	6000	3000	
38	0	0	12500	24000	21000	18000	15000	12000	9000	6000	3000	
39	0	0	12000	24000	21000	18000	15000	12000	9000	6000	3000	
40	0	0	11500	24000	21000	18000	15000	12000	9000	6000	3000	0
41	0	0	10500	24000	21000	18000	15000	12000	9000	6000	3000	0
42	0	0	10000	24000	21000	18000	15000	12000	9000	6000	3000	0
43	0	0	9500	24000	21000	18000	15000	12000	9000	6000	3000	0
44	0	0	8500	24000	21000	18000	15000	12000	9000	6000	3000	0
45	0	0	8000	24000	21000	18000	15000	12000	9000	6000	3000	0
46	0	0	7500	23500	21000	18000	15000	12000	9000	6000	3000	0
47	0	0	6500	22500	21000	18000	15000	12000	9000	6000	3000	0
48	0	0	6000	22000	21000	18000	15000	12000	9000	6000	3000	0
49	0	0	5500	21500	21000	18000	15000	12000	9000	6000	3000	0
50	0	0	4500	21000	21000	18000	15000	12000	9000	6000	3000	0
51	0	0	4000	20000	21000	18000	15000	12000	9000	6000	3000	0
52	0	0	3500	19500	21000	18000	15000	12000	9000	6000	3000	0
53	0	0	2500	19000	21000	18000	15000	12000	9000	6000	3000	0
54	0	0	2000	18500	21000	18000	15000	12000	9000	6000	3000	0
55	0	0	1500	17500	21000	18000	15000	12000	9000	6000	3000	0
56	0	0	500	17000	21000	18000	15000	12000	9000	6000	3000	0
57	0	0	0	16500	21000	18000	15000	12000	9000	6000	3000	0
58	0	0	0	16000	21000	18000	15000	12000	9000	6000	3000	0
59	0	0	0	15000	21000	18000	15000	12000	9000	6000	3000	0
60	0	0	0	14500	21000	18000	15000	12000	9000	6000	3000	0
61	0	0	0	14000	21000	18000	15000	12000	9000	6000	3000	0
62	0	0	0	13500	21000	18000	15000	12000	9000	6000	3000	0
63	0	0	0	12500	21000	18000	15000	12000	9000	6000	3000	0
64	0	0	0	12000	21000	18000	15000	12000	9000	6000	3000	0

	c4 = 57		(15%)		Number of Axles							
Axle	2	3	4	5	6	7	8	9	10	11	12	13
Spacing		Difference Between Current BGWF and Proposed BGWF - Pounds										
65	0	0	0	11500	21000	18000	15000	12000	9000	6000	3000	0
66	0	0	0	11000	21000	18000	15000	12000	9000	6000	3000	0
67	0	0	0	10000	21000	18000	15000	12000	9000	6000	3000	0
68	0	0	0	9500	21000	18000	15000	12000	9000	6000	3000	0
69	0	0	0	9000	21000	18000	15000	12000	9000	6000	3000	0
70	0	0	0	8500	21000	18000	15000	12000	9000	6000	3000	0
71	0	0	0	7500	21000	18000	15000	12000	9000	6000	3000	0
72	0	0	0	7000	21000	18000	15000	12000	9000	6000	3000	0
73	0	0	0	6500	21000	18000	15000	12000	9000	6000	3000	0
74	0	0	0	6000	21000	18000	15000	12000	9000	6000	3000	0
75	0	0	0	5000	21000	18000	15000	12000	9000	6000	3000	0
76	0	0	0	4500	20500	18000	15000	12000	9000	6000	3000	0
77	0	0	0	4000	20000	18000	15000	12000	9000	6000	3000	0
78	0	0	0	3500	19000	18000	15000	12000	9000	6000	3000	0
79	0	0	0	2500	18500	18000	15000	12000	9000	6000	3000	0
80	0	0	0	2000	18000	18000	15000	12000	9000	6000	3000	0
81	0	0	0	1500	17500	18000	15000	12000	9000	6000	3000	0
82	0	0	0	1000	17000	18000	15000	12000	9000	6000	3000	0
83	0	0	0	0	16000	18000	15000	12000	9000	6000	3000	0
84	0	0	0	0	15500	18000	15000	12000	9000	6000	3000	0
85	0	0	0	0	15000	18000	15000	12000	9000	6000	3000	0
86	0	0	0	0	14500	18000	15000	12000	9000	6000	3000	0
87	0	0	0	0	14000	18000	15000	12000	9000	6000	3000	0
88	0	0	0	0	13000	18000	15000	12000	9000	6000	3000	0
89	0	0	0	0	12500	18000	15000	12000	9000	6000	3000	0
90	0	0	0	0	12000	18000	15000	12000	9000	6000	3000	0
91	0	0	0	0	11500	18000	15000	12000	9000	6000	3000	0
92	0	0	0	0	11000	18000	15000	12000	9000	6000	3000	0
93	0	0	0	0	10000	18000	15000	12000	9000	6000	3000	0
94	0	0	0	0	9500	18000	15000	12000	9000	6000	3000	0
95	0	0	0	0	9000	18000	15000	12000	9000	6000	3000	0
96	0	0	0	0	8500	18000	15000	12000	9000	6000	3000	0
97	0	0	0	0	8000	18000	15000	12000	9000	6000	3000	0
98	0	0	0	0	7000	18000	15000	12000	9000	6000	3000	0
99	0	0	0	0	6500	18000	15000	12000	9000	6000	3000	0
100	0	0	0	0	6000	18000	15000	12000	9000	6000	3000	0
101	0	0	0	0	5500	18000	15000	12000	9000	6000	3000	0
102	0	0	0	0	5000	18000	15000	12000	9000	6000	3000	0
103	0	0	0	0	4000	18000	15000	12000	9000	6000	3000	0
104	0	0	0	0	3500	18000	15000	12000	9000	6000	3000	0
105	0	0	0	0	3000	18000	15000	12000	9000	6000	3000	0
106	0	0	0	0	2500	18000	15000	12000	9000	6000	3000	0
107	0	0	0	0	2000	17500	15000	12000	9000	6000	3000	0
108	0	0	0	0	1000	17000	15000	12000	9000	6000	3000	0
109	0	0	0	0	500	16500	15000	12000	9000	6000	3000	0
110	0	0	0	0	0	16000	15000	12000	9000	6000	3000	0

Table E-1 Difference Between Current BGWF and Modified Formula with C4 = 57

Axle Spacing	c4 = 57, 2	3	(15%) 4	5	6	7	8	9	10	11	12	13
	Number of Axles											
	Maximum Gross Weight - Pounds											
9	40000	60000										
10	40000	60000	75500									
11	40000	60000	76500									
12	40000	60000	77000									
13	40000	60000	77500									
14	40000	60000	78500	80500								
15	40000	60000	79000	81500								
16	40000	60000	79500	82000								
17	40000	60000	80000	82500	85000							
18	40000	60000	80000	83000	86000							
19	40000	60000	80000	84000	86500							
20	40000	60000	80000	84500	87000	89500						
21	40000	60000	80000	85000	87500	90000						
22	40000	60000	80000	85500	88000	91000						
23	40000	60000	80000	86500	89000	91500						
24	40000	60000	80000	87000	89500	92000	94500					
25	40000	60000	80000	87500	90000	92500	95500					
26	40000	60000	80000	88000	90500	93000	96000					
27	40000	60000	80000	89000	91000	93500	96500	99000				
28	40000	60000	80000	89500	92000	94500	97000	99500				
29	40000	60000	80000	90000	92500	95000	97500	100500				
30	40000	60000	80000	90500	93000	95500	98000	101000	103500			
31	40000	60000	80000	91500	93500	96000	98500	101500	104000			
32	40000	60000	80000	92000	94000	96500	99500	102000	105000			
33	40000	60000	80000	92500	95000	97000	100000	102500	105500			
34	40000	60000	80000	93000	95500	98000	100500	103000	106000	108500		
35	40000	60000	80000	94000	96000	98500	101000	103500	106500	109000		
36	40000	60000	80000	94500	96500	99000	101500	104000	107000	110000		
37	40000	60000	80000	95000	97000	99500	102000	105000	107500	110500	113000	
38	40000	60000	80000	95500	98000	100000	102500	105500	108000	111000	113500	
39	40000	60000	80000	96500	98500	100500	103500	106000	108500	111500	114500	
40	40000	60000	80000	97000	99000	101500	104000	106500	109000	112000	115000	117500
41	40000	60000	80000	97500	99500	102000	104500	107000	110000	112500	115500	118000
42	40000	60000	80000	98000	100000	102500	105000	107500	110500	113000	116000	118500
43	40000	60000	80000	99000	101000	103000	105500	108000	111000	113500	116500	119500
44	40000	60000	80000	99500	101500	103500	106000	108500	111500	114000	117000	120000
45	40000	60000	80000	100000	102000	104000	106500	109500	112000	114500	117500	120500
46	40000	60000	80000	100000	102500	105000	107500	110000	112500	115500	118000	121000
47	40000	60000	80000	100000	103000	105500	108000	110500	113000	116000	118500	121500
48	40000	60000	80000	100000	104000	106000	108500	111000	113500	116500	119000	122000
49	40000	60000	80000	100000	104500	106500	109000	111500	114000	117000	119500	122500
50	40000	60000	80000	100000	105000	107000	109500	112000	115000	117500	120500	123000
51	40000	60000	80000	100000	105500	107500	110000	112500	115500	118000	121000	123500
52	40000	60000	80000	100000	106000	108500	110500	113000	116000	118500	121500	124000
53	40000	60000	80000	100000	107000	109000	111500	114000	116500	119000	122000	124500
54	40000	60000	80000	100000	107500	109500	112000	114500	117000	119500	122500	125000
55	40000	60000	80000	100000	108000	110000	112500	115000	117500	120000	123000	126000
56	40000	60000	80000	100000	108500	110500	113000	115500	118000	121000	123500	126500
57	40000	60000	80000	100000	109000	111000	113500	116000	118500	121500	124000	127000
58	40000	60000	80000	100000	110000	112000	114000	116500	119000	122000	124500	127500
59	40000	60000	80000	100000	110500	112500	114500	117000	120000	122500	125000	128000
60	40000	60000	80000	100000	111000	113000	115500	117500	120500	123000	125500	128500
61	40000	60000	80000	100000	111500	113500	116000	118500	121000	123500	126500	129000
62	40000	60000	80000	100000	112000	114000	116500	119000	121500	124000	127000	129500
63	40000	60000	80000	100000	113000	114500	117000	119500	122000	124500	127500	130000
64	40000	60000	80000	100000	113500	115500	117500	120000	122500	125000	128000	130500

Axle Spacing	c4 = 57, 2	3	(15%) 4	5	6	7	8	9	10	11	12	13
	Number of Axles											
	Maximum Gross Weight - Pounds											
65	40000	60000	80000	100000	114000	116000	118000	120500	123000	125500	128500	131000
66	40000	60000	80000	100000	114500	116500	118500	121000	123500	126500	129000	131500
67	40000	60000	80000	100000	115000	117000	119500	121500	124000	127000	129500	132500
68	40000	60000	80000	100000	116000	117500	120000	122000	125000	127500	130000	133000
69	40000	60000	80000	100000	116500	118000	120500	123000	125500	128000	130500	133500
70	40000	60000	80000	100000	117000	119000	121000	123500	126000	128500	131000	134000
71	40000	60000	80000	100000	117500	119500	121500	124000	126500	129000	131500	134500
72	40000	60000	80000	100000	118000	120000	122000	124500	127000	129500	132500	135000
73	40000	60000	80000	100000	119000	120500	122500	125000	127500	130000	133000	135500
74	40000	60000	80000	100000	119500	121000	123500	125500	128000	130500	133500	136000
75	40000	60000	80000	100000	120000	121500	124000	126000	128500	131000	134000	136500
76	40000	60000	80000	100000	120000	122500	124500	126500	129000	132000	134500	137000
77	40000	60000	80000	100000	120000	123000	125000	127500	130000	132500	135000	137500
78	40000	60000	80000	100000	120000	123500	125500	128000	130500	133000	135500	138000
79	40000	60000	80000	100000	120000	124000	126000	128500	131000	133500	136000	139000
80	40000	60000	80000	100000	120000	124500	126500	129000	131500	134000	136500	139500
81	40000	60000	80000	100000	120000	125000	127500	129500	132000	134500	137000	140000
82	40000	60000	80000	100000	120000	126000	128000	130000	132500	135000	137500	140500
83	40000	60000	80000	100000	120000	126500	128500	130500	133000	135500	138500	141000
84	40000	60000	80000	100000	120000	127000	129000	131000	133500	136000	139000	141500
85	40000	60000	80000	100000	120000	127500	129500	132000	134000	136500	139500	142000
86	40000	60000	80000	100000	120000	128000	130000	132500	135000	137500	140000	142500
87	40000	60000	80000	100000	120000	128500	130500	133000	135500	138000	140500	143000
88	40000	60000	80000	100000	120000	129500	131500	133500	136000	138500	141000	143500
89	40000	60000	80000	100000	120000	130000	132000	134000	136500	139000	141500	144000
90	40000	60000	80000	100000	120000	130500	132500	134500	137000	139500	142000	144500
91	40000	60000	80000	100000	120000	131000	133000	135000	137500	140000	142500	145500
92	40000	60000	80000	100000	120000	131500	133500	135500	138000	140500	143000	146000
93	40000	60000	80000	100000	120000	132000	134000	136500	138500	141000	143500	146500
94	40000	60000	80000	100000	120000	133000	134500	137000	139000	141500	144500	147000
95	40000	60000	80000	100000	120000	133500	135500	137500	140000	142000	145000	147500
96	40000	60000	80000	100000	120000	134000	136000	138000	140500	143000	145500	148000
97	40000	60000	80000	100000	120000	134500	136500	138500	141000	143500	146000	148500
98	40000	60000	80000	100000	120000	135000	137000	139000	141500	144000	146500	149000
99	40000	60000	80000	100000	120000	135500	137500	139500	142000	144500	147000	149500
100	40000	60000	80000	100000	120000	136500	138000	140000	142500	145000	147500	150000
101	40000	60000	80000	100000	120000	137000	138500	141000	143000	145500	148000	150500
102	40000	60000	80000	100000	120000	137500	139500	141500	143500	146000	148500	151000
103	40000	60000	80000	100000	120000	138000	140000	142000	144000	146500	149000	152000
104	40000	60000	80000	100000	120000	138500	140500	142500	145000	147000	149500	152500
105	40000	60000	80000	100000	120000	139000	141000	143000	145500	147500	150500	153000
106	40000	60000	80000	100000	120000	140000	141500	143500	146000	148500	151000	153500
107	40000	60000	80000	100000	120000	140000	142000	144000	146500	149000	151500	154000
108	40000	60000	80000	100000	120000	140000	142500	144500	147000	149500	152000	154500
109	40000	60000	80000	100000	120000	140000	143500	145500	147500	150000	152500	155000
110	40000	60000	80000	100000	120000	140000	144000	146000	148000	150500	153000	155500

Table E-2 Maximum Gross Weight Using Modified Formula with C4 = 57

Axle	c4 = 48		(10%)		Number of Axles							
	2	3	4	5	6	7	8	9	10	11	12	13
Spacing		Difference Between Current BGWF and Proposed BGWF - Pounds										
9	1000	17500										
10	0	16500	18000									
11	0	16000	18000									
12	0	15000	18000									
13	0	14500	18000									
14	0	13500	18000	15000								
15	0	13000	18000	15000								
16	0	12000	18000	15000								
17	0	11500	18000	15000	12000							
18	0	10500	18000	15000	12000							
19	0	10000	18000	15000	12000							
20	0	9000	18000	15000	12000	9000						
21	0	8500	18000	15000	12000	9000						
22	0	7500	18000	15000	12000	9000						
23	0	7000	18000	15000	12000	9000						
24	0	6000	18000	15000	12000	9000	6000					
25	0	5500	18000	15000	12000	9000	6000					
26	0	4500	18000	15000	12000	9000	6000					
27	0	4000	18000	15000	12000	9000	6000	3000				
28	0	3000	18000	15000	12000	9000	6000	3000				
29	0	2500	18000	15000	12000	9000	6000	3000				
30	0	1500	18000	15000	12000	9000	6000	3000	0			
31	0	1000	17500	15000	12000	9000	6000	3000	0			
32	0	0	16500	15000	12000	9000	6000	3000	0			
33	0	0	16000	15000	12000	9000	6000	3000	0			
34	0	0	15500	15000	12000	9000	6000	3000	0	-3000		
35	0	0	14500	15000	12000	9000	6000	3000	0	-3000		
36	0	0	14000	15000	12000	9000	6000	3000	0	-3000		
37	0	0	13500	15000	12000	9000	6000	3000	0	-3000	-6000	
38	0	0	12500	15000	12000	9000	6000	3000	0	-3000	-6000	
39	0	0	12000	15000	12000	9000	6000	3000	0	-3000	-6000	
40	0	0	11500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
41	0	0	10500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
42	0	0	10000	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
43	0	0	9500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
44	0	0	8500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
45	0	0	8000	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
46	0	0	7500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
47	0	0	6500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
48	0	0	6000	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
49	0	0	5500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
50	0	0	4500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
51	0	0	4000	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
52	0	0	3500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
53	0	0	2500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
54	0	0	2000	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
55	0	0	1500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
56	0	0	500	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
57	0	0	0	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
58	0	0	0	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
59	0	0	0	15000	12000	9000	6000	3000	0	-3000	-6000	-9000
60	0	0	0	14500	12000	9000	6000	3000	0	-3000	-6000	-9000
61	0	0	0	14000	12000	9000	6000	3000	0	-3000	-6000	-9000
62	0	0	0	13500	12000	9000	6000	3000	0	-3000	-6000	-9000
63	0	0	0	12500	12000	9000	6000	3000	0	-3000	-6000	-9000
64	0	0	0	12000	12000	9000	6000	3000	0	-3000	-6000	-9000

Axle	c4 = 48		(10%)		Number of Axles							
	2	3	4	5	6	7	8	9	10	11	12	13
Spacing		Difference Between Current BGWF and Proposed BGWF - Pounds										
65	0	0	0	11500	12000	9000	6000	3000	0	-3000	-6000	-9000
66	0	0	0	11000	12000	9000	6000	3000	0	-3000	-6000	-9000
67	0	0	0	10000	12000	9000	6000	3000	0	-3000	-6000	-9000
68	0	0	0	9500	12000	9000	6000	3000	0	-3000	-6000	-9000
69	0	0	0	9000	12000	9000	6000	3000	0	-3000	-6000	-9000
70	0	0	0	8500	12000	9000	6000	3000	0	-3000	-6000	-9000
71	0	0	0	7500	12000	9000	6000	3000	0	-3000	-6000	-9000
72	0	0	0	7000	12000	9000	6000	3000	0	-3000	-6000	-9000
73	0	0	0	6500	12000	9000	6000	3000	0	-3000	-6000	-9000
74	0	0	0	6000	12000	9000	6000	3000	0	-3000	-6000	-9000
75	0	0	0	5000	12000	9000	6000	3000	0	-3000	-6000	-9000
76	0	0	0	4500	12000	9000	6000	3000	0	-3000	-6000	-9000
77	0	0	0	4000	12000	9000	6000	3000	0	-3000	-6000	-9000
78	0	0	0	3500	12000	9000	6000	3000	0	-3000	-6000	-9000
79	0	0	0	2500	12000	9000	6000	3000	0	-3000	-6000	-9000
80	0	0	0	2000	12000	9000	6000	3000	0	-3000	-6000	-9000
81	0	0	0	1500	12000	9000	6000	3000	0	-3000	-6000	-9000
82	0	0	0	1000	12000	9000	6000	3000	0	-3000	-6000	-9000
83	0	0	0	0	12000	9000	6000	3000	0	-3000	-6000	-9000
84	0	0	0	0	12000	9000	6000	3000	0	-3000	-6000	-9000
85	0	0	0	0	12000	9000	6000	3000	0	-3000	-6000	-9000
86	0	0	0	0	12000	9000	6000	3000	0	-3000	-6000	-9000
87	0	0	0	0	12000	9000	6000	3000	0	-3000	-6000	-9000
88	0	0	0	0	12000	9000	6000	3000	0	-3000	-6000	-9000
89	0	0	0	0	12000	9000	6000	3000	0	-3000	-6000	-9000
90	0	0	0	0	12000	9000	6000	3000	0	-3000	-6000	-9000
91	0	0	0	0	11500	9000	6000	3000	0	-3000	-6000	-9000
92	0	0	0	0	11000	9000	6000	3000	0	-3000	-6000	-9000
93	0	0	0	0	10000	9000	6000	3000	0	-3000	-6000	-9000
94	0	0	0	0	9500	9000	6000	3000	0	-3000	-6000	-9000
95	0	0	0	0	9000	9000	6000	3000	0	-3000	-6000	-9000
96	0	0	0	0	8500	9000	6000	3000	0	-3000	-6000	-9000
97	0	0	0	0	8000	9000	6000	3000	0	-3000	-6000	-9000
98	0	0	0	0	7000	9000	6000	3000	0	-3000	-6000	-9000
99	0	0	0	0	6500	9000	6000	3000	0	-3000	-6000	-9000
100	0	0	0	0	6000	9000	6000	3000	0	-3000	-6000	-9000
101	0	0	0	0	5500	9000	6000	3000	0	-3000	-6000	-9000
102	0	0	0	0	5000	9000	6000	3000	0	-3000	-6000	-9000
103	0	0	0	0	4000	9000	6000	3000	0	-3000	-6000	-9000
104	0	0	0	0	3500	9000	6000	3000	0	-3000	-6000	-9000
105	0	0	0	0	3000	9000	6000	3000	0	-3000	-6000	-9000
106	0	0	0	0	2500	9000	6000	3000	0	-3000	-6000	-9000
107	0	0	0	0	2000	9000	6000	3000	0	-3000	-6000	-9000
108	0	0	0	0	1000	9000	6000	3000	0	-3000	-6000	-9000
109	0	0	0	0	500	9000	6000	3000	0	-3000	-6000	-9000
110	0	0	0	0	0	9000	6000	3000	0	-3000	-6000	-9000

Table E-3 Difference Between Current BGWF and Modified Formula with C4 = 48

	c4 = 48		(10%)		Number of Axles							
Axle	2	3	4	5	6	7	8	9	10	11	12	13
Spacing	Maximum Gross Weight - Pounds											
9	40000	60000										
10	40000	60000	66500									
11	40000	60000	67500									
12	40000	60000	68000									
13	40000	60000	68500									
14	40000	60000	69500	71500								
15	40000	60000	70000	72500								
16	40000	60000	70500	73000								
17	40000	60000	71500	73500	76000							
18	40000	60000	72000	74000	77000							
19	40000	60000	72500	75000	77500							
20	40000	60000	73500	75500	78000	80500						
21	40000	60000	74000	76000	78500	81000						
22	40000	60000	74500	76500	79000	82000						
23	40000	60000	75500	77500	80000	82500						
24	40000	60000	76000	78000	80500	83000	85500					
25	40000	60000	76500	78500	81000	83500	86500					
26	40000	60000	77500	79000	81500	84000	87000					
27	40000	60000	78000	80000	82000	84500	87500	90000				
28	40000	60000	78500	80500	83000	85500	88000	90500				
29	40000	60000	79500	81000	83500	86000	88500	91500				
30	40000	60000	80000	81500	84000	86500	89000	92000	94500			
31	40000	60000	80000	82500	84500	87000	89500	92500	95000			
32	40000	60000	80000	83000	85000	87500	90500	93000	96000			
33	40000	60000	80000	83500	86000	88000	91000	93500	96500			
34	40000	60000	80000	84000	86500	89000	91500	94000	97000	99500		
35	40000	60000	80000	85000	87000	89500	92000	94500	97500	100000		
36	40000	60000	80000	85500	87500	90000	92500	95000	98000	101000		
37	40000	60000	80000	86000	88000	90500	93000	96000	98500	101500	104000	
38	40000	60000	80000	86500	89000	91000	93500	96500	99000	102000	104500	
39	40000	60000	80000	87500	89500	91500	94500	97000	99500	102500	105500	
40	40000	60000	80000	88000	90000	92500	95000	97500	100000	103000	106000	108500
41	40000	60000	80000	88500	90500	93000	95500	98000	101000	103500	106500	109000
42	40000	60000	80000	89000	91000	93500	96000	98500	101500	104000	107000	109500
43	40000	60000	80000	90000	92000	94000	96500	99000	102000	104500	107500	110500
44	40000	60000	80000	90500	92500	94500	97000	99500	102500	105000	108000	111000
45	40000	60000	80000	91000	93000	95000	97500	100500	103000	105500	108500	111500
46	40000	60000	80000	91500	93500	96000	98500	101000	103500	106500	109000	112000
47	40000	60000	80000	92500	94000	96500	99000	101500	104000	107000	109500	112500
48	40000	60000	80000	93000	95000	97000	99500	102000	104500	107500	110000	113000
49	40000	60000	80000	93500	95500	97500	100000	102500	105000	108000	110500	113500
50	40000	60000	80000	94000	96000	98000	100500	103000	106000	108500	111500	114000
51	40000	60000	80000	95000	96500	98500	101000	103500	106500	109000	112000	114500
52	40000	60000	80000	95500	97000	99500	101500	104000	107000	109500	112500	115000
53	40000	60000	80000	96000	98000	100000	102500	105000	107500	110000	113000	115500
54	40000	60000	80000	96500	98500	100500	103000	105500	108000	110500	113500	116000
55	40000	60000	80000	97500	99000	101000	103500	106000	108500	111000	114000	117000
56	40000	60000	80000	98000	99500	101500	104000	106500	109000	112000	114500	117500
57	40000	60000	80000	98500	100000	102000	104500	107000	109500	112500	115000	118000
58	40000	60000	80000	99000	101000	103000	105000	107500	110000	113000	115500	118500
59	40000	60000	80000	100000	101500	103500	105500	108000	111000	113500	116000	119000
60	40000	60000	80000	100000	102000	104000	106500	108500	111500	114000	116500	119500
61	40000	60000	80000	100000	102500	104500	107000	109500	112000	114500	117500	120000
62	40000	60000	80000	100000	103000	105000	107500	110000	112500	115000	118000	120500
63	40000	60000	80000	100000	104000	105500	108000	110500	113000	115500	118500	121000
64	40000	60000	80000	100000	104500	106500	108500	111000	113500	116000	119000	121500
65	40000	60000	80000	100000	105000	107000	109000	111500	114000	116500	119500	122000
66	40000	60000	80000	100000	105500	107500	109500	112000	114500	117500	120000	122500
67	40000	60000	80000	100000	106000	108000	110500	112500	115000	118000	120500	123500
68	40000	60000	80000	100000	107000	108500	111000	113000	116000	118500	121000	124000
69	40000	60000	80000	100000	107500	109000	111500	114000	116500	119000	121500	124500
70	40000	60000	80000	100000	108000	110000	112000	114500	117000	119500	122000	125000
71	40000	60000	80000	100000	108500	110500	112500	115000	117500	120000	122500	125500
72	40000	60000	80000	100000	109000	111000	113000	115500	118000	120500	123500	126000
73	40000	60000	80000	100000	110000	111500	113500	116000	118500	121000	124000	126500
74	40000	60000	80000	100000	110500	112000	114500	116500	119000	121500	124500	127000
75	40000	60000	80000	100000	111000	112500	115000	117000	119500	122000	125000	127500
76	40000	60000	80000	100000	111500	113500	115500	117500	120000	123000	125500	128000
77	40000	60000	80000	100000	112000	114000	116000	118500	121000	123500	126000	128500
78	40000	60000	80000	100000	113000	114500	116500	119000	121500	124000	126500	129000
79	40000	60000	80000	100000	113500	115000	117000	119500	122000	124500	127000	130000
80	40000	60000	80000	100000	114000	115500	117500	120000	122500	125000	127500	130500
81	40000	60000	80000	100000	114500	116000	118500	120500	123000	125500	128000	131000
82	40000	60000	80000	100000	115000	117000	119000	121000	123500	126000	128500	131500
83	40000	60000	80000	100000	116000	117500	119500	121500	124000	126500	129500	132000
84	40000	60000	80000	100000	116500	118000	120000	122000	124500	127000	130000	132500
85	40000	60000	80000	100000	117000	118500	120500	123000	125000	127500	130500	133000
86	40000	60000	80000	100000	117500	119000	121000	123500	126000	128500	131000	133500
87	40000	60000	80000	100000	118000	119500	121500	124000	126500	129000	131500	134000
88	40000	60000	80000	100000	119000	120500	122500	124500	127000	129500	132000	134500
89	40000	60000	80000	100000	119500	121000	123000	125000	127500	130000	132500	135000
90	40000	60000	80000	100000	120000	121500	123500	125500	128000	130500	133000	135500
91	40000	60000	80000	100000	120000	122000	124000	126000	128500	131000	133500	136500
92	40000	60000	80000	100000	120000	122500	124500	126500	129000	131500	134000	137000
93	40000	60000	80000	100000	120000	123000	125000	127500	129500	132000	134500	137500
94	40000	60000	80000	100000	120000	124000	125500	128000	130000	132500	135500	138000
95	40000	60000	80000	100000	120000	124500	126500	128500	131000	133000	136000	138500
96	40000	60000	80000	100000	120000	125000	127000	129000	131500	134000	136500	139000
97	40000	60000	80000	100000	120000	125500	127500	129500	132000	134500	137000	139500
98	40000	60000	80000	100000	120000	126000	128000	130000	132500	135000	137500	140000
99	40000	60000	80000	100000	120000	126500	128500	130500	133000	135500	138000	140500
100	40000	60000	80000	100000	120000	127500	129000	131000	133500	136000	138500	141000
101	40000	60000	80000	100000	120000	128000	129500	132000	134000	136500	139000	141500
102	40000	60000	80000	100000	120000	128500	130500	132500	134500	137000	139500	142000
103	40000	60000	80000	100000	120000	129000	131000	133000	135000	137500	140000	143000
104	40000	60000	80000	100000	120000	129500	131500	133500	136000	138000	140500	143500
105	40000	60000	80000	100000	120000	130000	132000	134000	136500	138500	141500	144000
106	40000	60000	80000	100000	120000	131000	132500	134500	137000	139500	142000	144500
107	40000	60000	80000	100000	120000	131500	133000	135000	137500	140000	142500	145000
108	40000	60000	80000	100000	120000	132000	133500	135500	138000	140500	143000	145500
109	40000	60000	80000	100000	120000	132500	134500	136500	138500	141000	143500	146000
110	40000	60000	80000	100000	120000	133000	135000	137000	139000	141500	144000	146500

Table E-4 Maximum Gross Weight using Modified Formula with C4 = 48

	c4 =	33	(5%)		Number of Axles							
Axle	2	3	4	5	6	7	8	9	10	11	12	13
Spacing	Difference Between Current BGWF and Proposed BGWF - Pounds											
9	1000	6000										
10	0	6000	3000									
11	0	6000	3000									
12	0	6000	3000									
13	0	6000	3000									
14	0	6000	3000	0								
15	0	6000	3000	0								
16	0	6000	3000	0								
17	0	6000	3000	0	-3000							
18	0	6000	3000	0	-3000							
19	0	6000	3000	0	-3000							
20	0	6000	3000	0	-3000	-6000						
21	0	6000	3000	0	-3000	-6000						
22	0	6000	3000	0	-3000	-6000						
23	0	6000	3000	0	-3000	-6000						
24	0	6000	3000	0	-3000	-6000	-9000					
25	0	5500	3000	0	-3000	-6000	-9000					
26	0	4500	3000	0	-3000	-6000	-9000					
27	0	4000	3000	0	-3000	-6000	-9000	-12000				
28	0	3000	3000	0	-3000	-6000	-9000	-12000				
29	0	2500	3000	0	-3000	-6000	-9000	-12000				
30	0	1500	3000	0	-3000	-6000	-9000	-12000	-15000			
31	0	1000	3000	0	-3000	-6000	-9000	-12000	-15000			
32	0	0	3000	0	-3000	-6000	-9000	-12000	-15000			
33	0	0	3000	0	-3000	-6000	-9000	-12000	-15000			
34	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000		
35	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000		
36	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000		
37	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	
38	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	
39	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	
40	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
41	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
42	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
43	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
44	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
45	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
46	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
47	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
48	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
49	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
50	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
51	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
52	0	0	3000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
53	0	0	2500	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
54	0	0	2000	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
55	0	0	1500	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
56	0	0	500	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
57	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
58	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
59	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
60	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
61	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
62	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
63	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
64	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000

	c4 =	33	(5%)		Number of Axles							
Axle	2	3	4	5	6	7	8	9	10	11	12	13
Spacing	Difference Between Current BGWF and Proposed BGWF - Pounds											
65	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
66	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
67	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
68	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
69	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
70	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
71	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
72	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
73	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
74	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
75	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
76	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
77	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
78	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
79	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
80	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
81	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
82	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
83	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
84	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
85	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
86	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
87	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
88	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
89	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
90	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
91	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
92	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
93	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
94	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
95	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
96	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
97	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
98	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
99	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
100	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
101	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
102	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
103	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
104	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
105	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
106	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
107	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
108	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
109	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000
110	0	0	0	0	-3000	-6000	-9000	-12000	-15000	-18000	-21000	-24000

Table E-5 Difference Between Current BGWF and Modified Formula with C4 = 33

Axle	c4 = 33		(5%)	Number of Axles								
Axle Spacing	2	3	4	5	6	7	8	9	10	11	12	13
	Maximum Gross Weight - Pounds											
9	40000	48500										
10	40000	49500	51500									
11	40000	50000	52500									
12	40000	51000	53000									
13	40000	51500	53500									
14	40000	52500	54500	56500								
15	40000	53000	55000	57500								
16	40000	54000	55500	58000								
17	40000	54500	56500	58500	61000							
18	40000	55500	57000	59000	62000							
19	40000	56000	57500	60000	62500							
20	40000	57000	58500	60500	63000	65500						
21	40000	57500	59000	61000	63500	66000						
22	40000	58500	59500	61500	64000	67000						
23	40000	59000	60500	62500	65000	67500						
24	40000	60000	61000	63000	65500	68000	70500					
25	40000	60000	61500	63500	66000	68500	71500					
26	40000	60000	62500	64000	66500	69000	72000					
27	40000	60000	63000	65000	67000	69500	72500	75000				
28	40000	60000	63500	65500	68000	70500	73000	75500				
29	40000	60000	64500	66000	68500	71000	73500	76500				
30	40000	60000	65000	66500	69000	71500	74000	77000	79500			
31	40000	60000	65500	67500	69500	72000	74500	77500	80000			
32	40000	60000	66500	68000	70000	72500	75500	78000	81000			
33	40000	60000	67000	68500	71000	73000	76000	78500	81500			
34	40000	60000	67500	69000	71500	74000	76500	79000	82000	84500		
35	40000	60000	68500	70000	72000	74500	77000	79500	82500	85000		
36	40000	60000	69000	70500	72500	75000	77500	80000	83000	86000		
37	40000	60000	69500	71000	73000	75500	78000	81000	83500	86500	89000	
38	40000	60000	70500	71500	74000	76000	78500	81500	84000	87000	89500	
39	40000	60000	71000	72500	74500	76500	79500	82000	84500	87500	90500	
40	40000	60000	71500	73000	75000	77500	80000	82500	85000	88000	91000	93500
41	40000	60000	72500	73500	75500	78000	80500	83000	86000	88500	91500	94000
42	40000	60000	73000	74000	76000	78500	81000	83500	86500	89000	92000	94500
43	40000	60000	73500	75000	77000	79000	81500	84000	87000	89500	92500	95500
44	40000	60000	74500	75500	77500	79500	82000	84500	87500	90000	93000	96000
45	40000	60000	75000	76000	78000	80000	82500	85500	88000	90500	93500	96500
46	40000	60000	75500	76500	78500	81000	83500	86000	88500	91500	94000	97000
47	40000	60000	76500	77500	79000	81500	84000	86500	89000	92000	94500	97500
48	40000	60000	77000	78000	80000	82000	84500	87000	89500	92500	95000	98000
49	40000	60000	77500	78500	80500	82500	85000	87500	90000	93000	95500	98500
50	40000	60000	78500	79000	81000	83000	85500	88000	91000	93500	96500	99000
51	40000	60000	79000	80000	81500	83500	86000	88500	91500	94000	97000	99500
52	40000	60000	79500	80500	82000	84500	86500	89000	92000	94500	97500	100000
53	40000	60000	80000	81000	83000	85000	87500	90000	92500	95000	98000	100500
54	40000	60000	80000	81500	83500	85500	88000	90500	93000	95500	98500	101000
55	40000	60000	80000	82500	84000	86000	88500	91000	93500	96000	99000	102000
56	40000	60000	80000	83000	84500	86500	89000	91500	94000	97000	99500	102500
57	40000	60000	80000	83500	85000	87000	89500	92000	94500	97500	100000	103000
58	40000	60000	80000	84000	86000	88000	90000	92500	95000	98000	100500	103500
59	40000	60000	80000	85000	86500	88500	90500	93000	96000	98500	101000	104000
60	40000	60000	80000	85500	87000	89000	91500	93500	96500	99000	101500	104500
61	40000	60000	80000	86000	87500	89500	92000	94500	97000	99500	102500	105000
62	40000	60000	80000	86500	88000	90000	92500	95000	97500	100000	103000	105500
63	40000	60000	80000	87500	89000	90500	93000	95500	98000	100500	103500	106000
64	40000	60000	80000	88000	89500	91500	93500	96000	98500	101000	104000	106500
65	40000	60000	80000	88500	90000	92000	94000	96500	99000	101500	104500	107000
66	40000	60000	80000	89000	90500	92500	94500	97000	99500	102500	105000	107500
67	40000	60000	80000	90000	91000	93000	95500	97500	100000	103000	105500	108500
68	40000	60000	80000	90500	92000	93500	96000	98000	101000	103500	106000	109000
69	40000	60000	80000	91000	92500	94000	96500	99000	101500	104000	106500	109500
70	40000	60000	80000	91500	93000	95000	97000	99500	102000	104500	107000	110000
71	40000	60000	80000	92500	93500	95500	97500	100000	102500	105000	107500	110500
72	40000	60000	80000	93000	94000	96000	98000	100500	103000	105500	108500	111000
73	40000	60000	80000	93500	95000	96500	98500	101000	103500	106000	109000	111500
74	40000	60000	80000	94000	95500	97000	99500	101500	104000	106500	109500	112000
75	40000	60000	80000	95000	96000	97500	100000	102000	104500	107000	110000	112500
76	40000	60000	80000	95500	96500	98500	100500	102500	105000	108000	110500	113000
77	40000	60000	80000	96000	97000	99000	101000	103500	106000	108500	111000	113500
78	40000	60000	80000	96500	98000	99500	101500	104000	106500	109000	111500	114000
79	40000	60000	80000	97500	98500	100000	102000	104500	107000	109500	112000	115000
80	40000	60000	80000	98000	99000	100500	102500	105000	107500	110000	112500	115500
81	40000	60000	80000	98500	99500	101000	103500	105500	108000	110500	113000	116000
82	40000	60000	80000	99000	100000	102000	104000	106000	108500	111000	113500	116500
83	40000	60000	80000	100000	101000	102500	104500	106500	109000	111500	114500	117000
84	40000	60000	80000	100000	101500	103000	105000	107000	109500	112000	115000	117500
85	40000	60000	80000	100000	102000	103500	105500	108000	110000	112500	115500	118000
86	40000	60000	80000	100000	102500	104000	106000	108500	111000	113500	116000	118500
87	40000	60000	80000	100000	103000	104500	106500	109000	111500	114000	116500	119000
88	40000	60000	80000	100000	104000	105500	107500	109500	112000	114500	117000	119500
89	40000	60000	80000	100000	104500	106000	108000	110000	112500	115000	117500	120000
90	40000	60000	80000	100000	105000	106500	108500	110500	113000	115500	118000	120500
91	40000	60000	80000	100000	105500	107000	109000	111000	113500	116000	118500	121500
92	40000	60000	80000	100000	106000	107500	109500	111500	114000	116500	119000	122000
93	40000	60000	80000	100000	107000	108000	110000	112500	114500	117000	119500	122500
94	40000	60000	80000	100000	107500	109000	110500	113000	115000	117500	120500	123000
95	40000	60000	80000	100000	108000	109500	111500	113500	116000	118000	121000	123500
96	40000	60000	80000	100000	108500	110000	112000	114000	116500	119000	121500	124000
97	40000	60000	80000	100000	109000	110500	112500	114500	117000	119500	122000	124500
98	40000	60000	80000	100000	110000	111000	113000	115000	117500	120000	122500	125000
99	40000	60000	80000	100000	110500	111500	113500	115500	118000	120500	123000	125500
100	40000	60000	80000	100000	111000	112500	114000	116000	118500	121000	123500	126000
101	40000	60000	80000	100000	111500	113000	114500	117000	119000	121500	124000	126500
102	40000	60000	80000	100000	112000	113500	115500	117500	119500	122000	124500	127000
103	40000	60000	80000	100000	113000	114000	116000	118000	120000	122500	125000	128000
104	40000	60000	80000	100000	113500	114500	116500	118500	121000	123000	125500	128500
105	40000	60000	80000	100000	114000	115000	117000	119000	121500	123500	126500	129000
106	40000	60000	80000	100000	114500	116000	117500	119500	122000	124500	127000	129500
107	40000	60000	80000	100000	115000	116500	118000	120000	122500	125000	127500	130000
108	40000	60000	80000	100000	116000	117000	118500	120500	123000	125500	128000	130500
109	40000	60000	80000	100000	116500	117500	119500	121500	123500	126000	128500	131000
110	40000	60000	80000	100000	117000	118000	120000	122000	124000	126500	129000	131500

Table E-6 Maximum Gross Weight using Modified Formula with C4 = 33

	c4 =	21	(2%)		Number of Axles							
Axle	2	3	4	5	6	7	8	9	10	11	12	13
Spacing			Difference Between Current BGWF and Proposed BGWF - Pounds									
9	-3000	-6000										
10	-3000	-6000	-9000									
11	-2000	-6000	-9000									
12	-1000	-6000	-9000									
13	0	-6000	-9000									
14	0	-6000	-9000	-12000								
15	0	-6000	-9000	-12000								
16	0	-6000	-9000	-12000								
17	0	-6000	-9000	-12000	-15000							
18	0	-6000	-9000	-12000	-15000							
19	0	-6000	-9000	-12000	-15000							
20	0	-6000	-9000	-12000	-15000	-18000						
21	0	-6000	-9000	-12000	-15000	-18000						
22	0	-6000	-9000	-12000	-15000	-18000						
23	0	-6000	-9000	-12000	-15000	-18000						
24	0	-6000	-9000	-12000	-15000	-18000	-21000					
25	0	-6000	-9000	-12000	-15000	-18000	-21000					
26	0	-6000	-9000	-12000	-15000	-18000	-21000					
27	0	-6000	-9000	-12000	-15000	-18000	-21000	-24000				
28	0	-6000	-9000	-12000	-15000	-18000	-21000	-24000				
29	0	-6000	-9000	-12000	-15000	-18000	-21000	-24000				
30	0	-6000	-9000	-12000	-15000	-18000	-21000	-24000	-27000			
31	0	-6000	-9000	-12000	-15000	-18000	-21000	-24000	-27000			
32	0	-6000	-9000	-12000	-15000	-18000	-21000	-24000	-27000			
33	0	-5500	-9000	-12000	-15000	-18000	-21000	-24000	-27000			
34	0	-4500	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000		
35	0	-4000	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000		
36	0	-3000	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000		
37	0	-2500	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	
38	0	-1500	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	
39	0	-1000	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	
40	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
41	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
42	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
43	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
44	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
45	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
46	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
47	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
48	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
49	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
50	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
51	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
52	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
53	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
54	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
55	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
56	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
57	0	0	-9000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
58	0	0	-8500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
59	0	0	-7500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
60	0	0	-7000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
61	0	0	-6500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
62	0	0	-5500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
63	0	0	-5000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
64	0	0	-4500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
65	0	0	-3500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
66	0	0	-3000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
67	0	0	-2500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
68	0	0	-1500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
69	0	0	-1000	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
70	0	0	-500	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
71	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
72	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
73	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
74	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
75	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
76	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
77	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
78	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
79	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
80	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
81	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
82	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
83	0	0	0	-12000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
84	0	0	0	-11500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
85	0	0	0	-11000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
86	0	0	0	-10500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
87	0	0	0	-9500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
88	0	0	0	-9000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
89	0	0	0	-8500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
90	0	0	0	-8000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
91	0	0	0	-7000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
92	0	0	0	-6500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
93	0	0	0	-6000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
94	0	0	0	-5500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
95	0	0	0	-4500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
96	0	0	0	-4000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
97	0	0	0	-3500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
98	0	0	0	-3000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
99	0	0	0	-2000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
100	0	0	0	-1500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
101	0	0	0	-1000	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
102	0	0	0	-500	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
103	0	0	0	0	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
104	0	0	0	0	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
105	0	0	0	0	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
106	0	0	0	0	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
107	0	0	0	0	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
108	0	0	0	0	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
109	0	0	0	0	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000
110	0	0	0	0	-15000	-18000	-21000	-24000	-27000	-30000	-33000	-36000

Table E-7   Difference Between Current BGWF and Modified Formula with C4 = 21

Axle	c4 = 21		(2%)	Number of Axles								
Axle	2	3	4	5	6	7	8	9	10	11	12	13
Spacing	Maximum Gross Weight - Pounds											
9	36000	36500										
10	37000	37500	39500									
11	38000	38000	40500									
12	39000	39000	41000									
13	40000	39500	41500									
14	40000	40500	42500	44500								
15	40000	41000	43000	45500								
16	40000	42000	43500	46000								
17	40000	42500	44500	46500	49000							
18	40000	43500	45000	47000	50000							
19	40000	44000	45500	48000	50500							
20	40000	45000	46500	48500	51000	53500						
21	40000	45500	47000	49000	51500	54000						
22	40000	46500	47500	49500	52000	55000						
23	40000	47000	48500	50500	53000	55500						
24	40000	48000	49000	51000	53500	56000	58500					
25	40000	48500	49500	51500	54000	56500	59500					
26	40000	49500	50500	52000	54500	57000	60000					
27	40000	50000	51000	53000	55000	57500	60500	63000				
28	40000	51000	51500	53500	56000	58500	61000	63500				
29	40000	51500	52500	54000	56500	59000	61500	64500				
30	40000	52500	53000	54500	57000	59500	62000	65000	67500			
31	40000	53000	53500	55500	57500	60000	62500	65500	68000			
32	40000	54000	54500	56000	58000	60500	63500	66000	69000			
33	40000	54500	55000	56500	59000	61000	64000	66500	69500			
34	40000	55500	55500	57000	59500	62000	64500	67000	70000	72500		
35	40000	56000	56500	58000	60000	62500	65000	67500	70500	73000		
36	40000	57000	57000	58500	60500	63000	65500	68000	71000	74000		
37	40000	57500	57500	59000	61000	63500	66000	69000	71500	74500	77000	
38	40000	58500	58500	59500	62000	64000	66500	69500	72000	75000	77500	
39	40000	59000	59000	60500	62500	64500	67500	70000	72500	75500	78500	
40	40000	60000	59500	61000	63000	65500	68000	70500	73000	76000	79000	81500
41	40000	60000	60500	61500	63500	66000	68500	71000	74000	76500	79500	82000
42	40000	60000	61000	62000	64000	66500	69000	71500	74500	77000	80000	82500
43	40000	60000	61500	63000	65000	67000	69500	72000	75000	77500	80500	83500
44	40000	60000	62500	63500	65500	67500	70000	72500	75500	78000	81000	84000
45	40000	60000	63000	64000	66000	68000	70500	73500	76000	78500	81500	84500
46	40000	60000	63500	64500	66500	69000	71500	74000	76500	79500	82000	85000
47	40000	60000	64500	65500	67000	69500	72000	74500	77000	80000	82500	85500
48	40000	60000	65000	66000	68000	70000	72500	75000	77500	80500	83000	86000
49	40000	60000	65500	66500	68500	70500	73000	75500	78000	81000	83500	86500
50	40000	60000	66500	67000	69000	71000	73500	76000	79000	81500	84500	87000
51	40000	60000	67000	68000	69500	71500	74000	76500	79500	82000	85000	87500
52	40000	60000	67500	68500	70000	72500	74500	77000	80000	82500	85500	88000
53	40000	60000	68500	69000	71000	73000	75500	78000	80500	83000	86000	88500
54	40000	60000	69000	69500	71500	73500	76000	78500	81000	83500	86500	89000
55	40000	60000	69500	70500	72000	74000	76500	79000	81500	84000	87000	90000
56	40000	60000	70500	71000	72500	74500	77000	79500	82000	85000	87500	90500
57	40000	60000	71000	71500	73000	75000	77500	80000	82500	85500	88000	91000
58	40000	60000	71500	72000	74000	76000	78000	80500	83000	86000	88500	91500
59	40000	60000	72500	73000	74500	76500	78500	81000	84000	86500	89000	92000
60	40000	60000	73000	73500	75000	77000	79500	81500	84500	87000	89500	92500
61	40000	60000	73500	74000	75500	77500	80000	82500	85000	87500	90500	93000
62	40000	60000	74500	74500	76000	78000	80500	83000	85500	88000	91000	93500
63	40000	60000	75000	75500	77000	78500	81000	83500	86000	88500	91500	94000
64	40000	60000	75500	76000	77500	79500	81500	84000	86500	89000	92000	94500
65	40000	60000	76500	76500	78000	80000	82000	84500	87000	89500	92500	95000
66	40000	60000	77000	77000	78500	80500	82500	85000	87500	90500	93000	95500
67	40000	60000	77500	78000	79000	81000	83500	85500	88000	91000	93500	96500
68	40000	60000	78500	78500	80000	81500	84000	86000	89000	91500	94000	97000
69	40000	60000	79000	79000	80500	82000	84500	87000	89500	92000	94500	97500
70	40000	60000	79500	79500	81000	83000	85000	87500	90000	92500	95000	98000
71	40000	60000	80000	80500	81500	83500	85500	88000	90500	93000	95500	98500
72	40000	60000	80000	81000	82000	84000	86000	88500	91000	93500	96500	99000
73	40000	60000	80000	81500	83000	84500	86500	89000	91500	94000	97000	99500
74	40000	60000	80000	82000	83500	85000	87500	89500	92000	94500	97500	100000
75	40000	60000	80000	83000	84000	85500	88000	90000	92500	95000	98000	100500
76	40000	60000	80000	83500	84500	86500	88500	90500	93000	96000	98500	101000
77	40000	60000	80000	84000	85000	87000	89000	91500	94000	96500	99000	101500
78	40000	60000	80000	84500	86000	87500	89500	92000	94500	97000	99500	102000
79	40000	60000	80000	85500	86500	88000	90000	92500	95000	97500	100000	103000
80	40000	60000	80000	86000	87000	88500	90500	93000	95500	98000	100500	103500
81	40000	60000	80000	86500	87500	89000	91500	93500	96000	98500	101000	104000
82	40000	60000	80000	87000	88000	90000	92000	94000	96500	99000	101500	104500
83	40000	60000	80000	88000	89000	90500	92500	94500	97000	99500	102500	105000
84	40000	60000	80000	88500	89500	91000	93000	95000	97500	100000	103000	105500
85	40000	60000	80000	89000	90000	91500	93500	96000	98000	100500	103500	106000
86	40000	60000	80000	89500	90500	92000	94000	96500	99000	101500	104000	106500
87	40000	60000	80000	90500	91000	92500	94500	97000	99500	102000	104500	107000
88	40000	60000	80000	91000	92000	93500	95500	97500	100000	102500	105000	107500
89	40000	60000	80000	91500	92500	94000	96000	98000	100500	103000	105500	108000
90	40000	60000	80000	92000	93000	94500	96500	98500	101000	103500	106000	108500
91	40000	60000	80000	93000	93500	95000	97000	99000	101500	104000	106500	109500
92	40000	60000	80000	93500	94000	95500	97500	99500	102000	104500	107000	110000
93	40000	60000	80000	94000	95000	96000	98000	100500	102500	105000	107500	110500
94	40000	60000	80000	94500	95500	97000	98500	101000	103000	105500	108500	111000
95	40000	60000	80000	95500	96000	97500	99500	101500	104000	106000	109000	111500
96	40000	60000	80000	96000	96500	98000	100000	102000	104500	107000	109500	112000
97	40000	60000	80000	96500	97000	98500	100500	102500	105000	107500	110000	112500
98	40000	60000	80000	97000	98000	99000	101000	103000	105500	108000	110500	113000
99	40000	60000	80000	98000	98500	99500	101500	103500	106000	108500	111000	113500
100	40000	60000	80000	98500	99000	100500	102000	104000	106500	109000	111500	114000
101	40000	60000	80000	99000	99500	101000	102500	105000	107000	109500	112000	114500
102	40000	60000	80000	99500	100000	101500	103500	105500	107500	110000	112500	115000
103	40000	60000	80000	100000	101000	102000	104000	106000	108000	110500	113000	116000
104	40000	60000	80000	100000	101500	102500	104500	106500	109000	111000	113500	116500
105	40000	60000	80000	100000	102000	103000	105000	107000	109500	111500	114500	117000
106	40000	60000	80000	100000	102500	104000	105500	107500	110000	112500	115000	117500
107	40000	60000	80000	100000	103000	104500	106000	108000	110500	113000	115500	118000
108	40000	60000	80000	100000	104000	105000	106500	108500	111000	113500	116000	118500
109	40000	60000	80000	100000	104500	105500	107500	109500	111500	114000	116500	119000
110	40000	60000	80000	100000	105000	106000	108000	110000	112000	114500	117000	119500

Table E-8 Maximum Gross Weight using Modified Formula with C4 = 21