QUALITY ASSURANCE OF WEIGH-IN-MOTION DATA

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Executive Summary

Background:
Weigh-In-Motion (WIM) systems have been in development since the 1960's and calibration has been, and still is, a major concern. If the calibration is too low, the recorded axle loads are too low resulting in insufficient fatigue calculations, pavement thickness designs that are too thin leading to premature pavement failure. The reverse leads to excessive pavement thickness designs resulting in excessive expenditures at that time—money that might be better used elsewhere.

Inspection of data for eight states incorporating 78 sites revealed extreme differences in axle loads for 5-axle semi-trailer trucks. Additionally, the Long Term Pavement Performance (LTPP) of the Strategic Highway Research Program (SHRP) personnel had privately expressed concerns about the quality of the data for a rather "large" percentage of the data that had been furnished. This research study focused on the development of:

a) a method to determine the quality assurance of the data,
b) develop firm guidelines for making judgment calls, and
c) develop a method to "adjust" the data to fit within the guidelines of (b) above.

Results:
A method was developed using a personal computer spreadsheet program and a detailed step-by-step procedure is provided in Appendix A of this report.

Use:
1. Based on approximately 2,000 data sets, analyses indicate that each data set should be summarized by individual day and the set should have a minimum of 100 5-axle semi-trailer trucks.
2. The following criteria provide firm trends, boundary conditions, and are based upon:

a) the 12,000-lb legal limit load for a steering axle, also manufacturer's maximum load,
b) analyses of static scale data for over 4,000 5-axle semi-trailer trucks,
c) published data from truck-tractor manufacturers based on the vehicle as it sits on the dealer's lot—no driver, no fuel, and no trailer, and
d) providing a tolerance of 50 lbs to a) and c) above in an attempt to account for differences between dynamic and static conditions. The "50 lbs" is an arbitrary number.

3. While a spreadsheet analyses is time-consuming, the process can be installed on a notebook computer, taken to a field site, data retrieved and analyzed at the site to determine if adjustments are needed to the calibration setting.
4. The same program can be used in the office to "adjust" the data to appropriate ranges.

Recommendation:
While the method can be utilized using a spreadsheet program, it is a labor-intensive method. A computer program should be written for the method in Appendix A to permit quick analyses of data sets.

QUALITY ASSURANCE OF WEIGH-IN-MOTION DATA

Background: Historically truck weights have been measured to help in enforcement of loads to prevent overloads on bridges and pavements. Loadings have been measured using portable and/or permanent static scales. In Kentucky, legal regulations state that any fines for overloads must be based on data from permanent static scales. If a truck is found to be overloaded using portable scales, the officer must escort the truck to a permanent static scale before a traffic ticket can be issued.

In Kentucky, research on Weigh-In-Motion (WIM) scales has been made since 1967. The first large platform WIM system was installed on I64-75 at Lexington, Kentucky. Great difficulty was encountered in keeping the electronics in calibration for more than 30 minutes and that WIM was abandoned within a few months. The next WIM system was installed on US 60 in Boyd County on a research project involving six different thicknesses of full-depth asphaltic concrete pavement. About that same time came an onslaught of heavy three-axle coal trucks followed very shortly by four-axle coal trucks. Permanent static scales were not available for determining the magnitudes of these gross and axle loads. Unfortunately, this WIM system was based on gross loads in the range of 90 kips for a five-axle semi-trailer truck and this would mean the tandems might carry 40-kip loads. In the few days that the WIM scales were operable before failure, tandem axle loads of 60 and 65 kips were recorded and the WIM scale simply could not tolerate such loads. The WIM system went through several cycles of redesign, installation, and failure before the manufacturer decided to halt production until a better design could be obtained.

Data collected using WIM scales are dynamic, not static. The question of "accuracy" is one of relative behavior as will be shown under "truck characteristics".

Purpose: How does dynamic WIM data compare with data collected using permanent static scale stations? How "accurate" are WIM data? What variables affect WIM data? How good, or bad, is the calibration of the WIM scale? What can be learned from WIM data? What site factors affect WIM data? What are the effects of installation practices upon WIM data? Many of these questions are interrelated and can be answered rather generically.

Physics: Inspection of WIM data collected from the same scale may reveal rather significant differences.

- **Mass vs Weight**: Mass is mass and cannot change. If a truck has a fixed empty weight, the goods have a fixed weight, why does the WIM scale record different values for the same condition?
- **Temperature**: Scale manufacturers know that temperature affects electronic equipment and data. Measures have been incorporated to account for those temperature effects. What has not been incorporated is the effect of temperature upon the stiffness of flexible pavements. Thus, as the pavement temperature increases, stiffness decreases, and the "opposite and equal reaction" is no longer "equal" as the opposite force to the scale. It is suggested that some of the energy that should be returning to support the WIM sensor is being absorbed by the more flexible pavement material. As the pavement temperature causes the stiffness of the pavement to decrease, the tire load is causing the pavement material to be squeezed laterally as well as vertically resulting in energy being diverted to other directions. It is just that our thinking is not quite coinciding with the actual facts. If mass cannot be destroyed, then energy cannot be lost. The total energy is still total energy, but we may be measuring only a portion of the energy and not the total energy. However, if some of that load is being distributed laterally rather than all vertically as thought, then the vertical energy has to be less than anticipated. The reverse is true if the pavement temperature is less than the pavement

temperature at the time of calibration. In this case the stiffness increases, the lateral distribution of energy is less, and the vertical energy being returned is more than the energy for the pavement temperature at the time of calibration. This results in the WIM sensor recording an axle load that is larger than the actual value. What is not known at this time is the magnitude of these effects.

- **Calibration**: Electronics do "drift" and re-calibration efforts are required.

Truck Characteristics: Truck manufacturers design and build trucks having different characteristics. The following differences were noted.

- **Frame Length:** Frame lengths vary causing different spacings between axles—particularly steering axle to drive axle(s).
- **Tandem Axle Spacing:** Some newer models have tandems spaced at 54 inches with Canadian typically being 60 inches.
- **Fuel Tanks:** Fuel tanks generally are located a) close to the steering tires, b) close to the lead drive axle, or c) mid-way between the steering and lead drive axle.
- **Fifth Wheel:** The fifth-wheel assembly may be fixed, but most likely may be moved as much as two feet. Locations range from 4 to 12 inches for the majority of the tractors.
- **Sleeper Cab:** There may be a sleeper unit that may add 1,500 to 2,000 lbs depending upon style and size.
- **Size:** As the size of the tractor is increased, generally the size and power of the engine, transmission, and differential increase.
- **Off-Center Mounting:** In 1993, for approximately 70 percent of tractors, the engine, transmission, and differential were mounted to the left of center of the truck frame by two inches.
- **Engine Location:** Location of the truck engine might start at the steering axle, or may be nearly centered over the steering axle.
- **Engine Torque:** As the engine torque is increased, the front end rises, the back end sinks, and load is transferred to the drive axles resulting in a different load distribution than that obtained on a permanent static scale.
- **Center of Mass:** The location of the center of mass on the trailer may be along the frame for an empty truck. The center of mass is fairly high up in the body of the truck for a fully loaded truck. When brakes are applied to a fully loaded truck, the dynamic force vector will "lift the rear of the tractor through the fifth wheel" and add load to the steering axle.
- **Suspension:** Type of suspension greatly affects WIM data. Air suspensions are more likely to distribute the load equally between the axles within a tandem set when the truck is accelerating than will steel-leaf springs. When the truck is braking, the variation in load distribution between axles of the tandem and between tandem and steering axle is much larger for air-suspension systems than for steel-leaf suspension systems. Why is there such a difference between air-suspension and steel-leaf spring systems? Steel-leaf springs are rigidly attached to the frame. Air-suspensions involve a rubber bag mounted to the frame and axle. When the force vector is well above the elevation of the fifth-wheel, as is the case for a fully loaded truck, the rubber bag will stretch vertically and will cause some "lifting" of the load off the axle. The rigidity of the steel-leaf spring suspension system reduces the "lifting" of the load off the axles.

WIM Installation Site:

- **Location:** The approach pavement may, or may not, be smooth. If the approach is rough, the dynamic data for the calibration trucks will vary more widely.
- **Vehicle Presence Detectors**: Inaccurate sensor location, and/or, improper installation affect the calculation of the vehicle speed and axle spacings.

- **”Time-out Factor” Setting**: If a second truck is tail-gating another truck, the steering axle load for the second truck may be recorded as an axle load for the first truck. Then the second axle load of the second truck may be recorded as the steering axle load for the second truck.

Calibration:
- **Initial Calibration:** Initial calibration of the WIM scale traditionally has been accomplished using trucks of known weight within the normal traffic stream, and/or, dedicated trucks of known weight making repeated trips over the scale.
- **Load:** Loads may be chosen as steering axle, drive and/or trailer tandems, and gross vehicle load.
- **WIM Adjustment Routine:** Some WIM scale manufacturers provide computer routines to adjust the calibration factor based on a moving average of a fixed number of trucks classified under the FHWA system as Vehicle Class (VC) 9.

Advantages for Using Specific Vehicles for Calibration Efforts:
- **Permanent Static Scales:** Sites near permanent static scales have been used to capture static weights and trucks identified for “calibration loads” at the WIM site. These trucks are “free” in that there is no rental cost, or no administrative accounting costs to the organization.
- **Driver Education:** For designated trucks, education of drivers usually becomes an asset when attempting to provide good correlation efforts. Also, characteristics of the truck can be obtained such as suspension type, possible runs for braking and accelerating over the WIM scale.

Disadvantages for Using Specific Vehicles for Calibration Efforts:
- **Calibration Truck(s):** Rental trucks, or those owned by the agency, are difficult to schedule, costly to operate because of turn-around locations and time between runs. These trucks are not representative of the mix of normal traffic at that site.
- **Crew Costs:** Crew costs may be very high if a number of days are involved in calibrating the scale.
- **Vehicle Dynamics:** Normal dynamics of the suspension can provide variations in recorded axle loads as much as +/- 15%.
- **Runs:** Number of calibration runs usually is very limited.
- **Trucks in Traffic Stream:** For trucks in the normal stream, identification and correlation of the truck at the WIM site with data collected at the loadometer station is tricky at best and requires good communication between crews.

Calibration over Time:
- **Moving Average:** Obtaining a moving average of a chosen number of steering axle loads for VC9 trucks has been a procedure used by a number of states.
- **Recorded Load Variation:** Inspection of static scale data has revealed that the gross load of the vehicle may vary by a factor of 2.5 to 3.0 for the same steering axle load. Thus, there is no definitive correlation between steering axle load and gross load.
- **Over Time:** After a period of time, is the site still in calibration, if not, by how much different is it?
- **Data Adjustable?** If the system is out of calibration, can the data be adjusted, and if so, how?

QUALITY ASSURANCE RESEARCH EFFORT

Research efforts under another study for the Travel Monitoring Office, Federal Highway Administration, Washington, D.C. revealed wide variations in axle spacing and axle load data. The need for quality assurance of WIM data became very obvious and this research effort has been focused on determining ways to a) check data validity, and b) to provide a method for adjusting data sets to values approaching "correct" values. The idea of being able to salvage data sets has appeal to the Long Term Pavement Performance (LTPP) program. In this effort, except for Kentucky data, the reader will not be able to identify the location and source of the WIM data.

English or Metric Units?

For most WIM systems in the USA, the manufacturer has furnished a program that provides data conforming to the English system of units. Another reason for using English units in this report is the ease and convenience of using a spreadsheet program to analyze data directly from the WIM computer at the site. Using only one set of "units" greatly simplifies the analysis procedures. After telephone conversations with representatives of several states, states use "in-house" computer programs to convert the WIM data to metric formats specified by The 1995 Traffic Monitoring Guide.

Most truck weight studies historically have been performed and load data have been recorded in English units rather than metric units. Converting massive historical files to metric units would be cumbersome.

Attempting to determine the quality of the WIM data within the data set itself is similar to "incest". While it should not be done, there has not been an independent method to determine the quality of data until this report. The concept of adjusting WIM data requires comparison against an outside source of data, such as static scale data of known quality. However, comparison against static scale data is tricky unless an independent measure of some sort can be used that would be common to both data sets. Figure 1 (next page) illustrates the lack of a definitive relationship between the vehicle gross load and the steering axle load.

For a steering axle load of 10,000 lbs in the top two quadrants of Figure 1, the vehicle gross load varies from approximately 25,000 lbs to 80,000 lbs. In the bottom left quadrant, a steering axle load of 10,000 lbs is above the entire data set. Actually, the data set in the bottom left quadrant has more data than the other three quadrants. This rules out any argument that there is less data and therefore there may be the chance that with more data, the upper ranges would contain additional data points. In the bottom right quadrant, for a steering axle load of 10,000 lbs, the vehicle gross load varies from approximately 25,000 lbs to nearly 100,000 lbs. The conclusion is that 1) a fixed value for the steering axle load has no definitive relationship to vehicle gross load, and 2) within the same data set, does not indicate whether the system is recording good data. It may indicate that the data is consistent. For the reader's benefit, data for the two top quadrants of Figure 1 are very nearly correct. The basis for making this statement is:

a. Steering axle loads range from approximately 6,500 lbs to 12,000 lbs—the same range noted with data collected at static scale sites, and
b. Gross loads range from approximately 25,000 lbs to 80,000 lbs—again the same range noted with data collected at static scale sites.

This leads one to conclude that the calibration of these two WIM scales are nearly correct, the calibration for the WIM scale for the bottom left quadrant is much too low, and the calibration of the WIM scale in the bottom right quadrant is much too high.

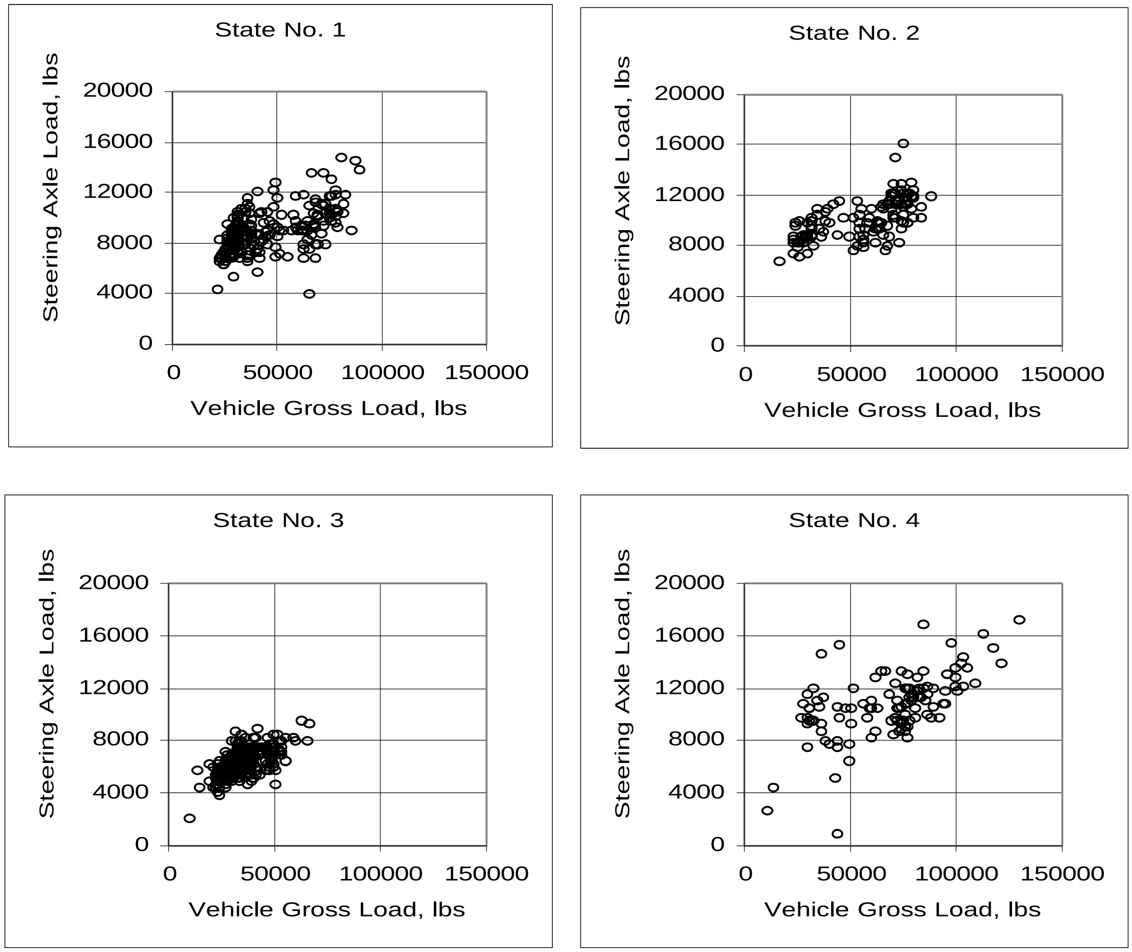


Figure 1: Vehicle Gross Load Compared to Steering Axle Load

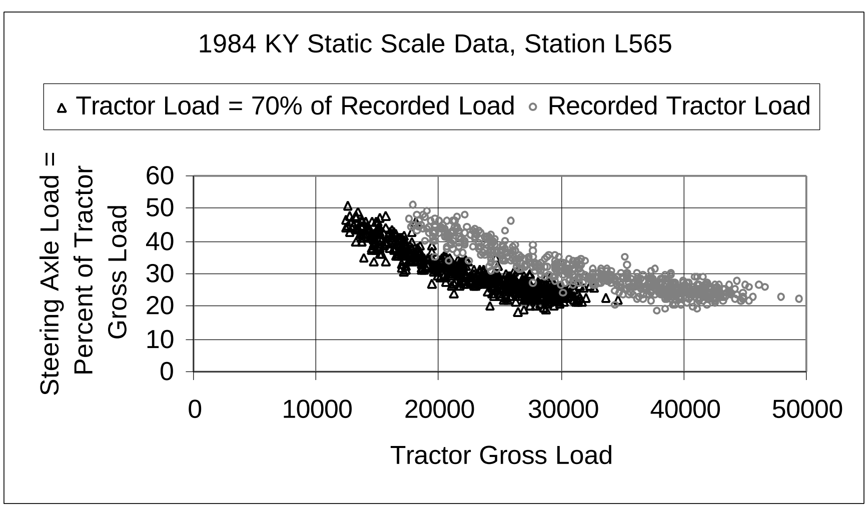


Figure 2: Recorded Data vs. Recorded Data Reduced by 30 Percent to Show Scalar Concept

If the WIM calibration factor is incorrect, the WIM scale still is obtaining a proportionately valid data set which can be justified. Figure 2 illustrates this concept for a set of static scale weight data for VC9 trucks and then reducing each vehicle to 70% of the value in the original data set. Note in the graph the original data extends over a longer range of tractor gross load than does the data set simulating a calibration factor being 70% of the true value and confirms that the scalar principle is just an "adjustment factor".

Figure 1 shows a limited variation in magnitude of steering axle load for a wide range in total vehicle gross load, is there another relationship that might help define a better measure of the variability of steering axle load? In an unpublished research effort, a relationship was determined between load per tire on the steering axle divided by load per tire on the drive tandem vs. total tractor load. The results showed that the ratio of tire loads may be as high as 3.5 for an empty truck, to 1.1 for a legally loaded truck, and had a curved pattern. Coupling this idea with the notion that the length of the tractor ought to have some influence upon the load on the steering axle prompted the idea of investigating a relationship between steering axle load and the distance between the steering axle and the lead drive axle of a three-axle tractor. A suggestion was made to plot that ratio versus wheelbase that is defined as the distance between the steering axle and the center point between the two axles of the drive tandem. Because the WIM data records the distance between axles, the idea of wheelbase was modified to axle space, thus dealing strictly with "measured" parameters. However, the question still arises about the validity of the magnitude of the calibration factor for the WIM scale. Are the data within, above, or below, the expected actual range of axle loads. An independent measure is required to make that assessment.

Independent Criteria—Legal Axle Load Limit

In the FHWA Traffic Monitoring Guide, the data format assigns specific columns for axle loads and axle spacings. "AS1" is an acronym for "Axle Space No. 1". Axle Space No. 1 has been used throughout this report.

At the beginning of this study, the author was under the impression that most states had a legal limit of 12 kips for a two-tired axle (steering axle). Within the last few years, statutes may have been changed to read "20,000 lbs for a single axle." Some states have an additional clause stating that the load also is dependent upon a certain number of pounds per tire width. In Kentucky, a value of 700 lbs per inch or tire width is used.

The more appropriate definition of a maximum load for the steering axle is the truck manufacturers' stated maximum allowable load. For all the tractors for which data were obtained for this study, the manufacturers' limiting load was 12,000 lbs for the steering axle.

Dividing 12 kips by the recorded "axle space number 1" provides an upper guideline that can be used as an indicator of validity. This is not to say that all loads above 12 kips are illegal because the issuance of overload permits allows the steering axle to have a load greater than 12 kips. However, those loads will constitute a rather low percentage of the total truck traffic. Thus, "excessive" number of observations above the 12-kip legal limit may be indicative of:

- the calibration factor for the WIM is set at too high a value,
- the "time-out" factor entered into the computer for the WIM scale is too long allowing an axle from the previous truck to be assumed as the load on the steering axle of a truck that is "tail-gating" too close to the previous truck. This situation has been verified as the trouble by inspecting a suspected problem site. Reducing the time-out setting eliminated the recording of extremely high steering axle loads; or

- the site is in a location where trucks are braking, or decellarating (including traffic congestion).

Independent Criteria—Physical Characteristics of Truck Tractors

Is there a lower limit for steering axle loads? The idea of an empty tractor prompted visits to local truck dealers to obtain manufacturers' specifications for tractors as they sat on the dealers lot—no fuel, no driver, and no trailer. Data showed rather wide ranges in both steering axle load and wheelbase. Also, as the model size increased, the steering axle load for the empty truck increased as the wheelbase increased, but more prominently because the engine and drive train size and weight increased. Another factor may be if the engine is centered over the axle or the front end of the engine is over the axle and the remainder of the engine extends toward the drive axles. Collecting data for a number of tractor models from five truck dealers allowed the compilation of data indicating a lower boundary of "steering axle loads per foot of distance between the steering axle and the lead drive axle". Using truck manufacturers' minimum steering axle load data suggests that the ratio of "(steering axle load) / (axle space number 1) should provide a "hard" lower boundary. Three conditions may occur that result in the recorded data being less than the "truck manufacturers' minimum specifications" line:

- the calibration factor for the WIM scale is set too low,
- the driver may be changing lanes such that the presence detectors are triggered and the spacing and speed data are calculated correctly, but only one side of the truck is passing over the WIM scale. It may be also that only a portion of the tires on that one side are passing over the scale resulting in data that is even less than half the actual axle load, or
- the truck may be accelerating or climbing a grade.

Independent Criteria—Permanent Static Scale Data

What should the shape of the data be and where should it be relative to the 12-kip limiting line divided by axle space number 1 and the truck manufacturers' minimum specification for steering axle load divided by axle space number 1? Should the data be midway between the two lines, closer to one than the other, parallel to the two lines, or possibly skewed in some manner?

Kentucky permanent static scale data recorded in 1984, the last year these stations were used to collect axle load data for Federal Highway Administration (FHWA), were obtained for all permanent stations resulting in some 14,000 records. Data were sorted by permanent station, the ratio of steering axle load to axle space number 1 were calculated, and a regression equation calculated using the form:

$$\mathrm{Log10}(Y) = a + b*\log10(X) \qquad 1$$

where,

Y = (steering axle load) / (axle space no. 1), and
X = axle space no. 1 in feet.

Table 1 provides the constants and statistics for equations having the form of Equation 1 above and expressing the limiting value of 12,000 lbs as a function of axle space no. 1. A reviewer requested that the regression equations for the full set of data and the set resulting from the elimination of 115 vehicles be given. Both sets of values for slope, intercept, R^2, and STEYX are included in Table 1. It is noted that for the shortest axle space no. 1, the difference in the two equations was approximately 13 lbs/ft. For the longest axle space no. 1, the difference was less than 1 lb/ft.

This emphasizes that while Kentucky static scale data has been used in these analyses, a user may desire to substitute an equation developed from the same type of static scale data that may be more appropriate for that specific state or locality.

One reviewer also commented that the R^2 values "were pretty low". Yes, the number might "be low" but it does reflect the large variability within the truck fleet when considering the variability in fifth-wheel location, fuel tank location, the way the driver applied the brakes while on the scale platform, whether the tractor has a sleeper and if so what size and weight, location of pumps, etc.

Table 1. Constants and Regression Statistics

Description	"a"	"b"	R^2	STEYX	Constant
Recorded Static					
Scale Data w/ 115 pts.	3.928361	-0.952182	0.644309	0.046159	
Scale Data w/o 115 pts.	3.910316	-0.941031	0.541135	0.056453	
Truck Manufacturers'					
Minimum					
Specifications	3.942369	-1.075085	0.945302	0.020775	-50 lbs/ft
12-kip Legal Limit					
Line, also Known as					
Truck Manufacturer's					
Maximum Steering					
Axle Load:		12 kips / (axle space)			+ 50 lbs/ft
		(Note: Not an equation, just simple arithmetic.)			

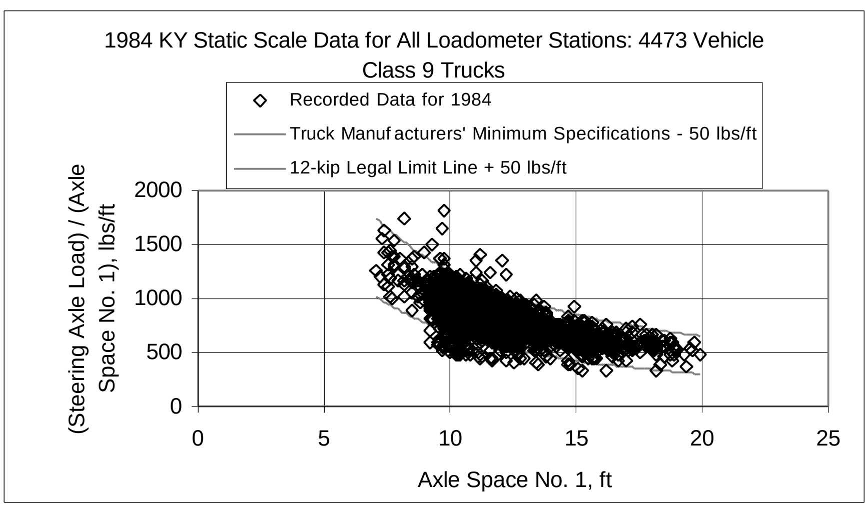


Figure 3a: Loadometer Data Analyzed as (Steering Axle Load) / (Axle Space No. 1)

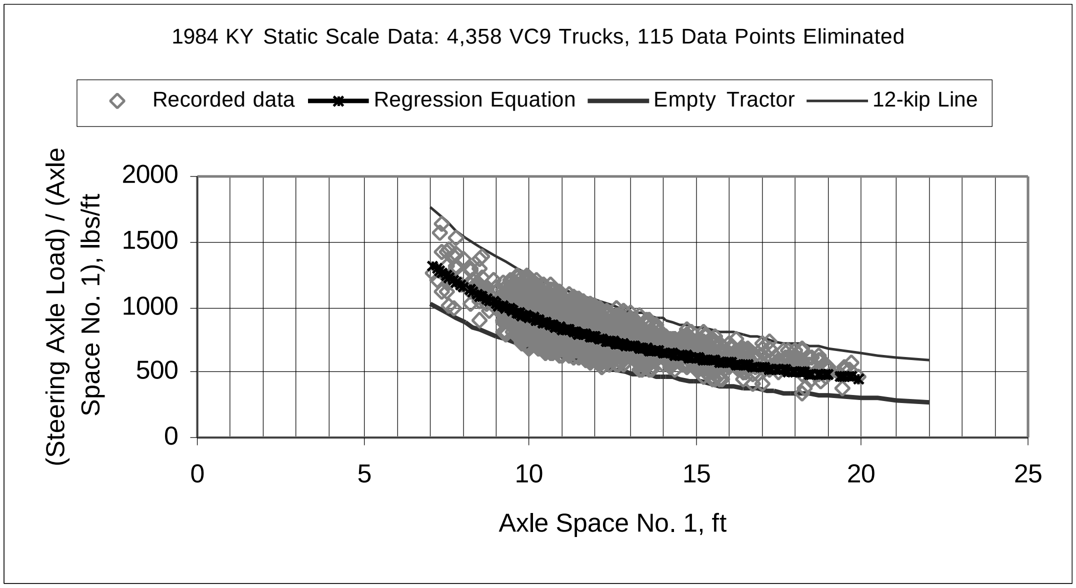


Figure 3b: Loadometer Data Analyzed as (Steering Axle Load) / (Axle Space No. 1)

Figure 3a shows data collected in 1984 at Kentucky Permanent Stations. Of the 4,473 vehicle class (VC) 9 records for 1984 shown in Figure 3a, the ratio of steering axle load to axle space no. 1 for 115 records were outside the 12-kip legal limit line (also known as the truck manufacturer's maximum allowable load) or the truck manufacturers' minimum specification line. Figure 3b is the same as Figure 3a except for the elimination of the 115 vehicles.

Inspection of Figures 3a and 3b show that 50 lbs/ft has been added to the 12-kip limiting line (also known as the truck manufacturer's maximum allowable load) and also subtracted from the truck manufacturers' minimum specification line. The logic is that the upper and lower guide lines without the 50 lbs/ft adjustments correspond to static conditions while WIM data are dynamic loading conditions.

The question has been raised concering the format of Equation 1. It is true that the data may be described as a second degree polynomial. The answer is "YES". Why divide the steering axle load by the value of axle space no. 1? Why use logarithms instead of the arithmetic values? Let's address the last question first. Even after dividing the recorded steering axle load by the recorded axle space no. 1, the resulting form of the data is still a slight curve. Using logarithms provides the opportunity of expressing the regression as a straight line in log-log form. The driving force for using the format of Equation 1 is that most spreadsheet programs provide built-in routines for linear regression and calculating the log of an arithmetic number. The routine developed herein coupled with linear regression capabilities contained in lap-top computers permits a user to take the lap-top computer to the field, tie into the WIM computer at the site, record data, and determine rather quickly if adjustments need to be made to the calibration setting. Most lap-top computers do not have routines available for regression anlalyses involving polynomial equation formats. Thus**, ease of use is the primary driving force** behind the decision to use the form provided in Equation 1.

Note that the basic shape of the data in Figures 3a and 3b have a skew at the right end corresponding to a longer axle space value. This makes logical sense because this represents a large tractor that will weigh more than a “cabover” model resulting in the steering axle load being closer to the 12-kip limit. Thus, the regression equation also should have a skew and close scrutiny of Figure 3 reveals that there is a slight skew.

WIM Sites

Converting WIM data to “(Steering Axle Load) / (Axle Space No. 1)” and plotting them vs. “Axle space No. 1” results in the data having a slightly bent shape similar to a banana. The log-log equation closely approximates this bent shape. If the calibration factor setting is correct, the regression equation for the recorded data will be almost identical, if not identical, to the regression equation for the static scale data. Appendix A contains a step-by-step listing for performing the analyses described herein.

Because the recorded data represents a true set of vehicles, the question becomes, “Is it accurate?” To compare two data sets, each must be converted to identical relationships. The following process has been adopted in these analyses. The steering axle load is divided by the first axle space recorded for that tractor. A log-log regression equation is obtained for the static scale and dynamic WIM data sets using the format of Equation 1. A graph is made where the first axle space is the “X” value and the “steering axle load divided by the first axle space” is the “Y” value. The regression equations for the static scale data and dynamic data are superimposed. If the regression equation for the dynamic WIM data is less than the regression equation for the static scale data, the calibration adjustment factor for the dynamic WIM data was set too low and vice versa. The ratio of static to dynamic values from the two regression equations for the same axle space was calculated for each truck in the dynamic data set. After the ratio was calculated for each truck contained in the dynamic WIM data set, an average of the ratios is obtained and this corresponds to the adjustment factor to be applied to all vehicles for all vehicle classifications. The result is the adjustment of WIM data to the same range of values that would be, or has been, weighed for a stream of 5-axle semi-trailer trucks at a permanent static scale site. In summary, if the average adjustment factor is greater than 1.0, the calibration factor for the WIM scale had been set too low and the recorded data values had to be increased. Conversely, if the average adjustment factor is less than 1.0, the calibration factor for the WIM scale had been set too high and the recorded data values had to be reduced.

WIM Site—Good Calibration

A set of recorded data is shown in Figure 4 and the results of adjusting the same data set is shown in Figure 5. There may be data lying outside the limiting lines, but the average adjustment factor will be very nearly 1.00.

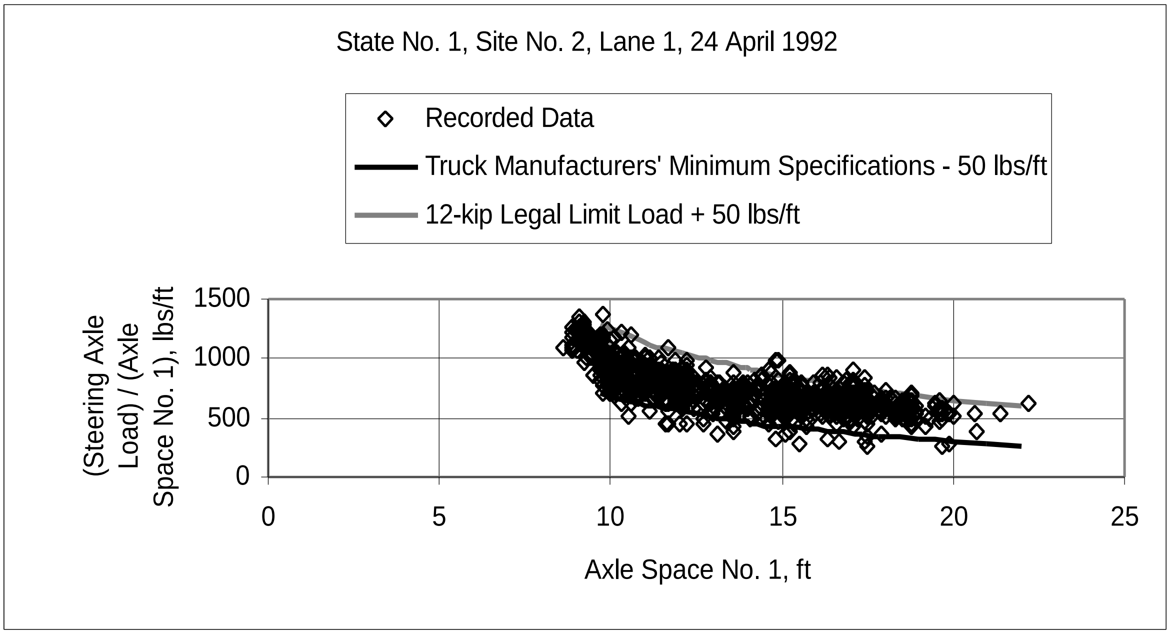


Figure 4. Recorded Data for State No. 1, Site No. 2, Lane 1, 24 April 1992

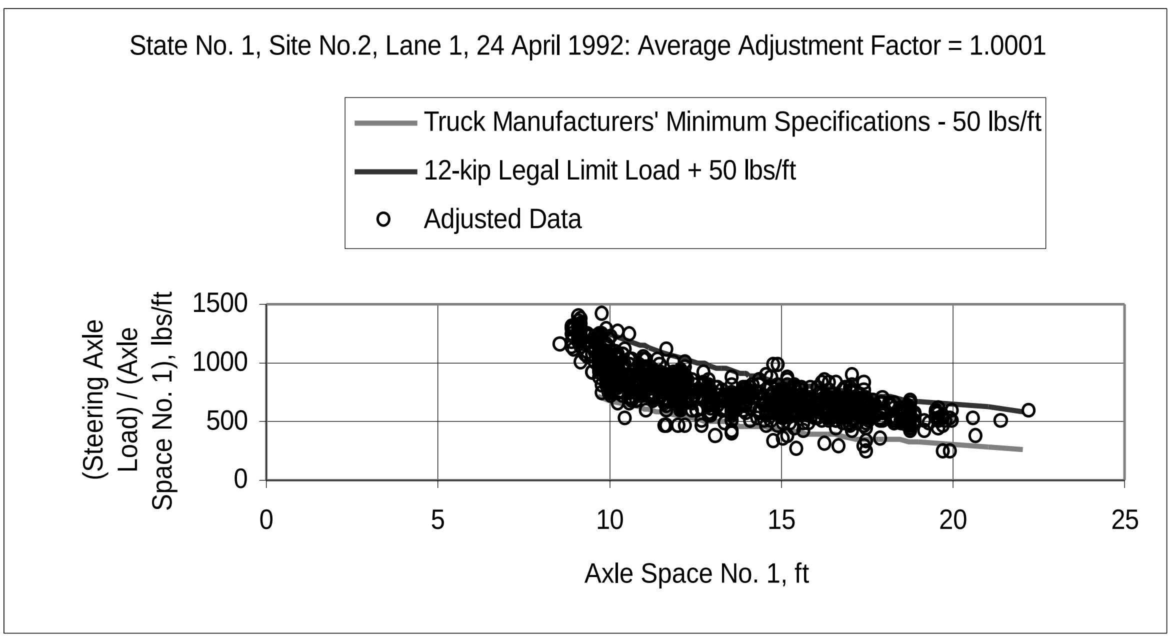


Figure 5. Adjusted Data for State No. 1, Site No. 2, Lane 1, 24 April 1992 as shown in Figure 4

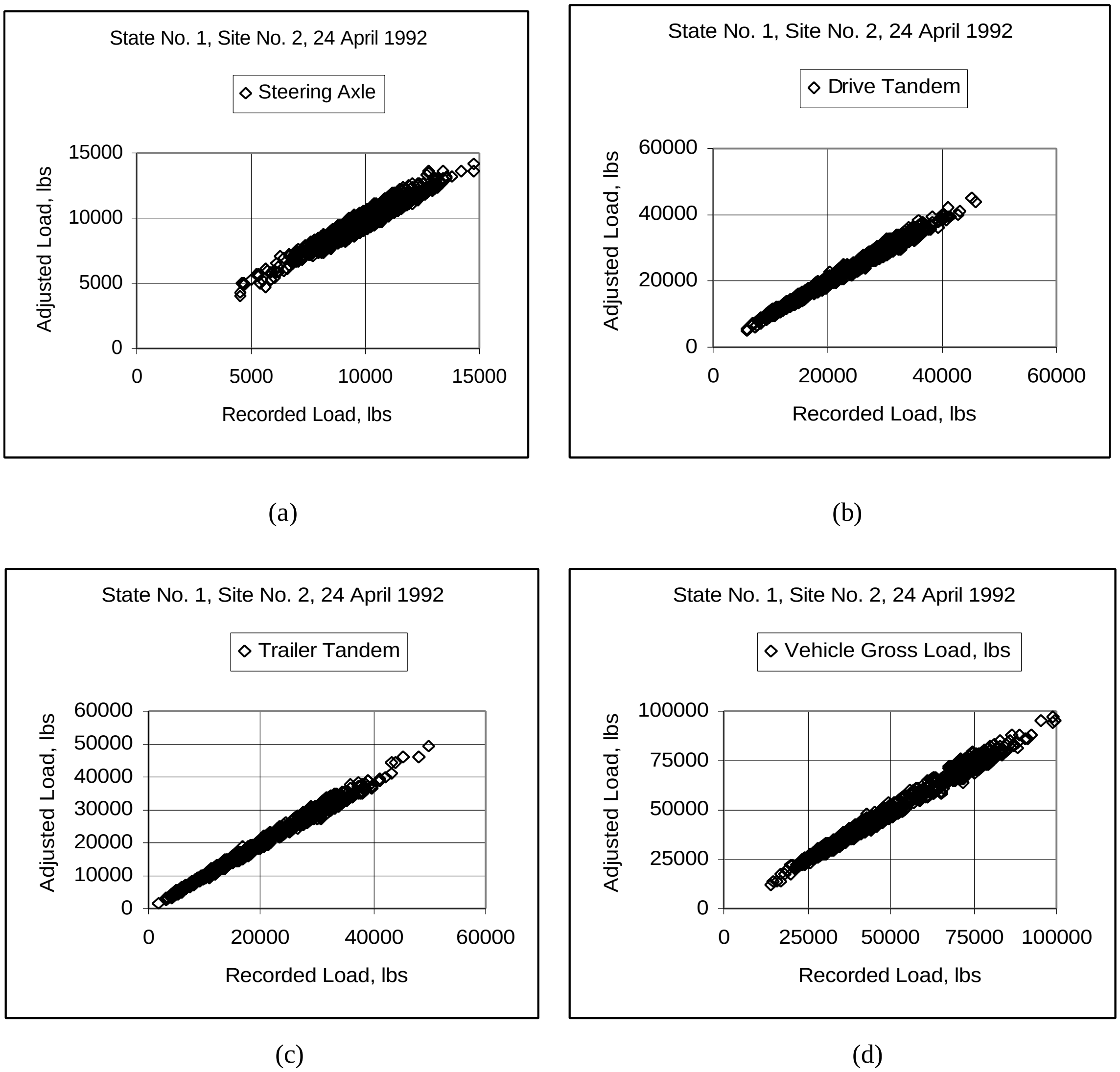


Figure 6. Recorded vs. Adjusted Data for State No. 1, Site No.2, Lane 1, 24 April 1992, Average Adjustment Factor = 0.9877

Figure 6 compares the recorded data versus the adjusted data for (a) steering axle load, (b) drive tandem, (c) trailer tandem, and (d) gross load where each data point is a specific truck in the data set shown in Figures 4 and 5.

WIM Site—Calibration Set Too Low

Data recorded at a WIM site appeared to be unreasonably low as shown in Figure 7. The DOT was contacted and their representative visited the site. He called three days later and said that the presence detectors had been installed at the wrong spacing and the calibration setting was way too low. He made some adjustments and appeared to be obtaining good data.

Figure 7 shows that both conditions did exist and can be detected using the suggested procedure provided in Appendix A. When compared to the two criteria lines, the data is much too low. Very few tractors are manufactured with an axle space no. 1 exceeding 22 feet. Axle spacing data in Figure 7 starts at approximately 9.5 ft and extends to 24 ft. Most data sets analyzed within this research range from 8 to 20 ft. Figure 8 shows the same data after being processed by the method given in Appendix A.

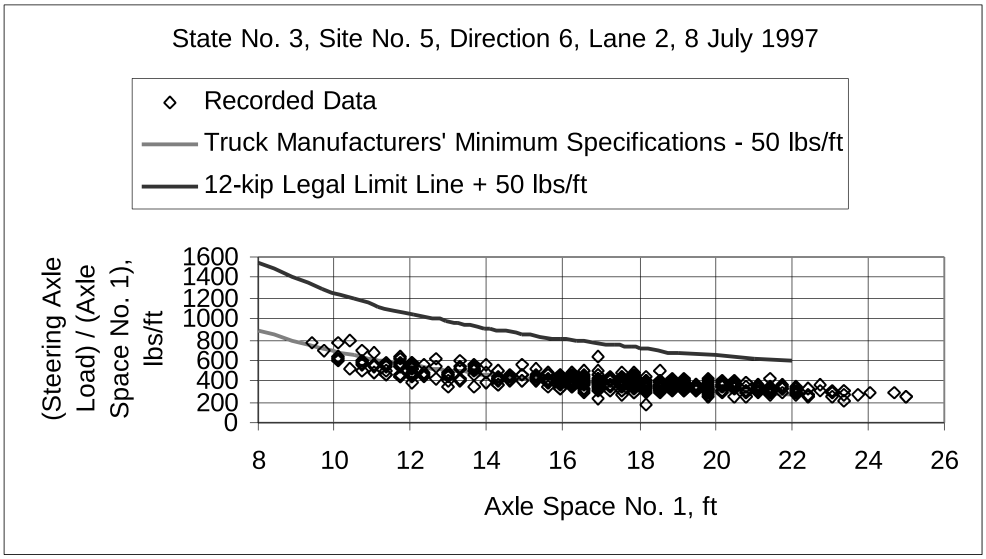


Figure 7. State No. 3, Site No. 5, Direction 6, Lane 2, 8 July 1997—Recorded Data

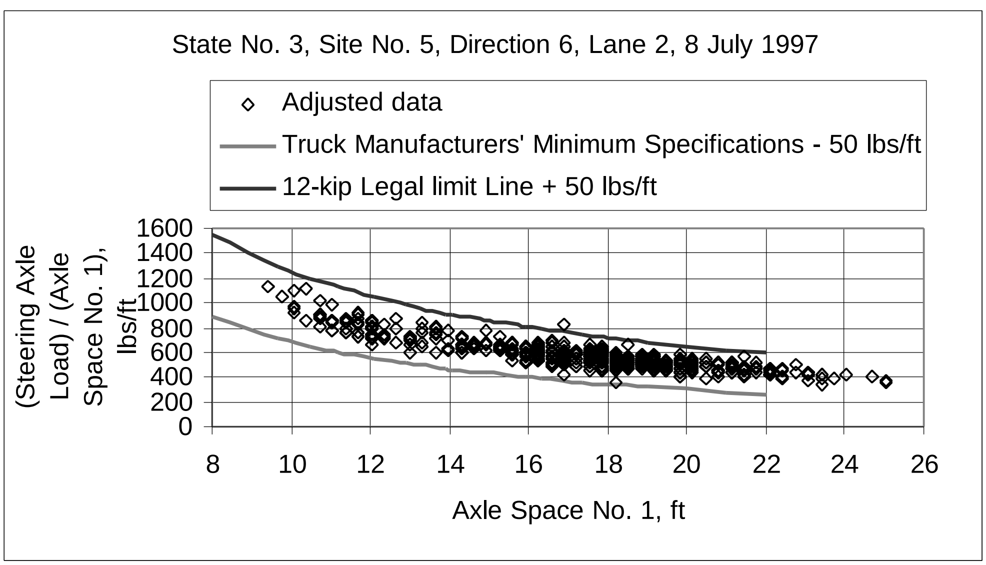
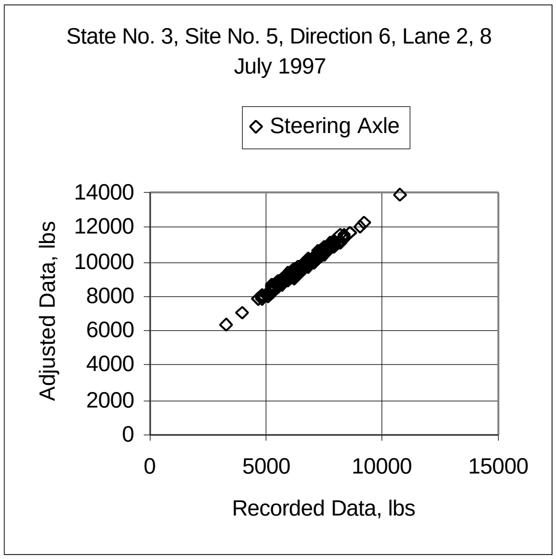
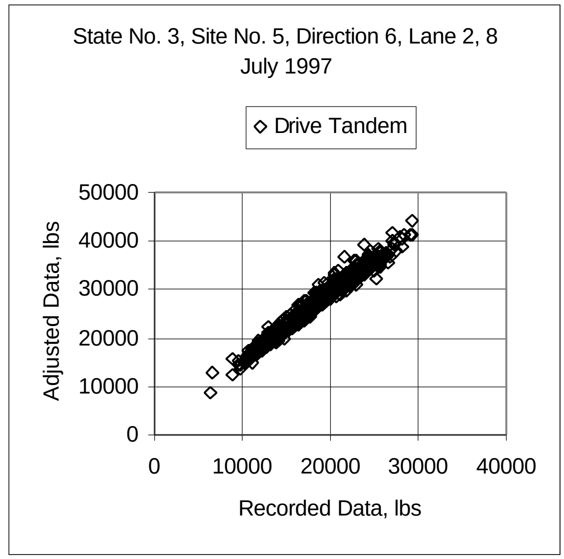


Figure 8. State No. 3, Site No. 5, Direction 6, Lane 2, 8 July 1997—Adjusted Data

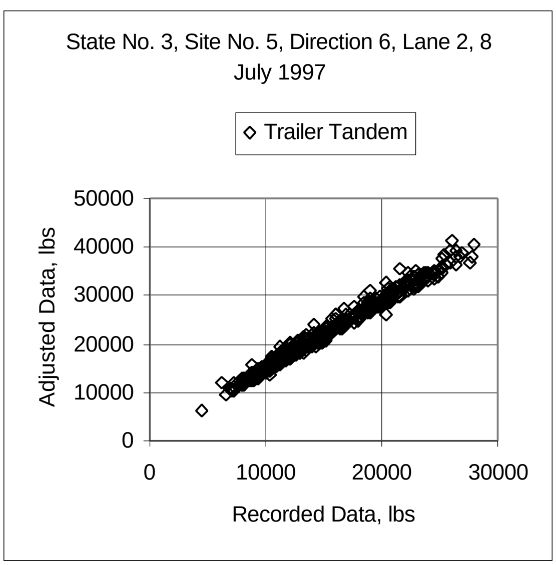
Comparison of Recorded and Adjusted Data for Axle Groups and Gross Load
Figure 9 contains the comparison of recorded and adjusted loadings for the same data shown in Figures 7 and 8 for (a) steering axle, (b) drive tandem, (c) trailer tandem, and (d) gross load, respectively. With the exception of one truck, the adjusted data appear to be quite reasonable.



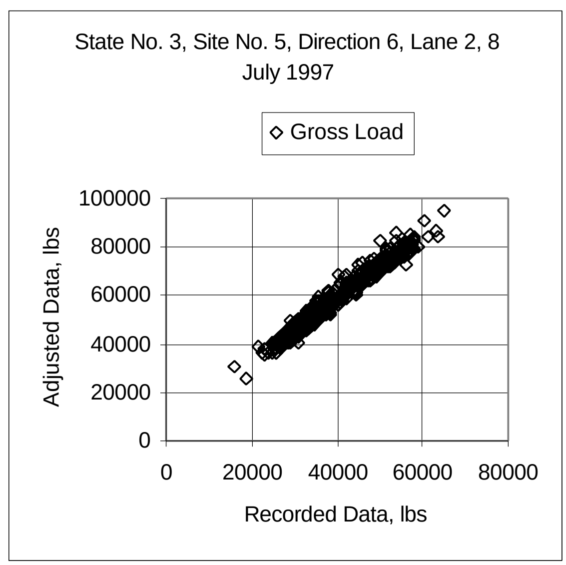
(a)



(b)



(c)



(d)

Figure 9. Recorded vs. Adjusted Data for WIM Site 18, Direction 6, Lane 2, 8 July 1997

WIM—Calibration Set Too High

Data recorded at a WIM site in another state appeared to be unreasonably high as shown in Figure 10. However, there does not appear to be a problem with the axle space no. 1 data at this site as there was in Figure 7. Figure 11 illustrates the results after applying the procedure in Appendix A for adjusting the data.

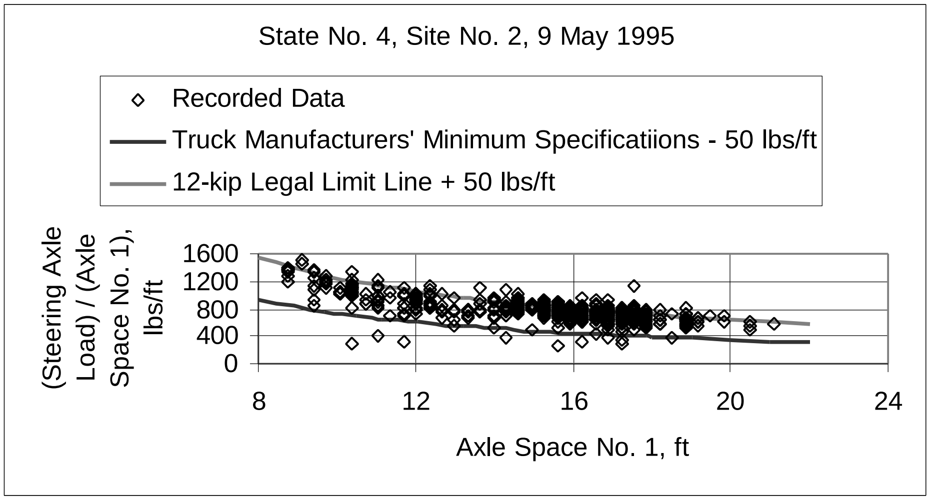


Figure 10. Recorded Data for State No. 4, Site No. 2, 9 May 1995

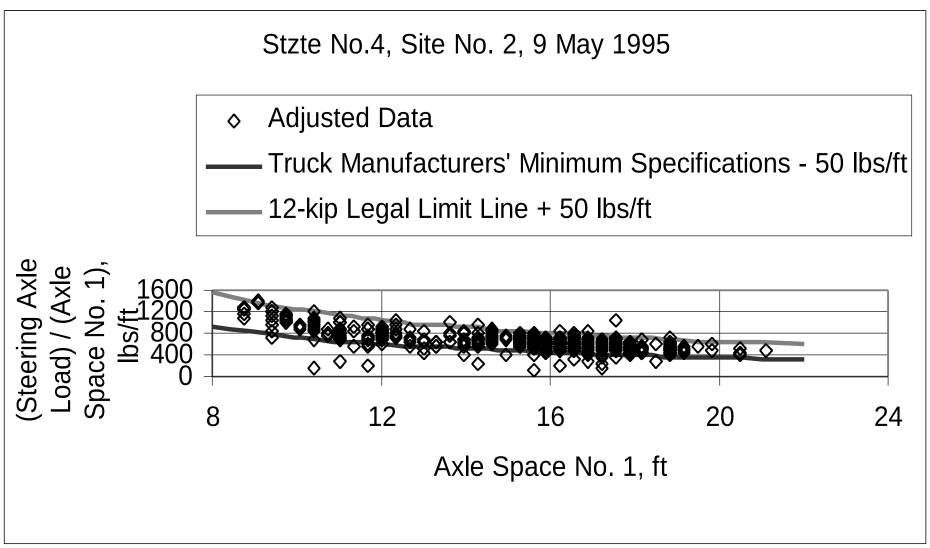
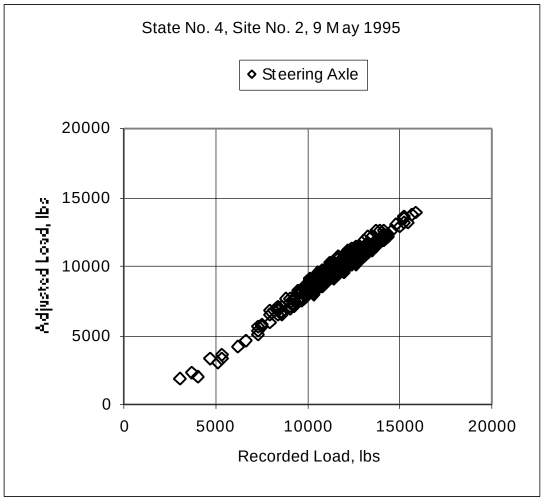
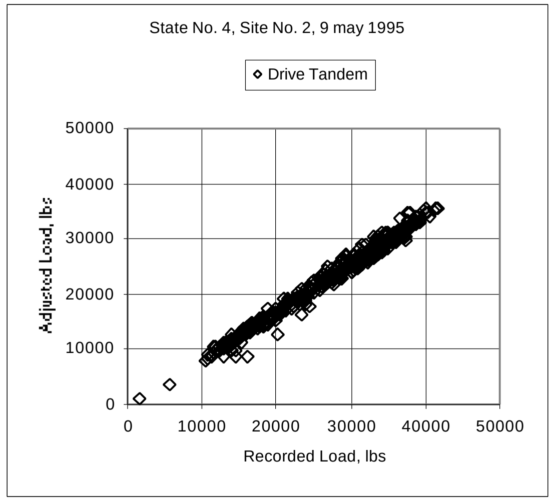


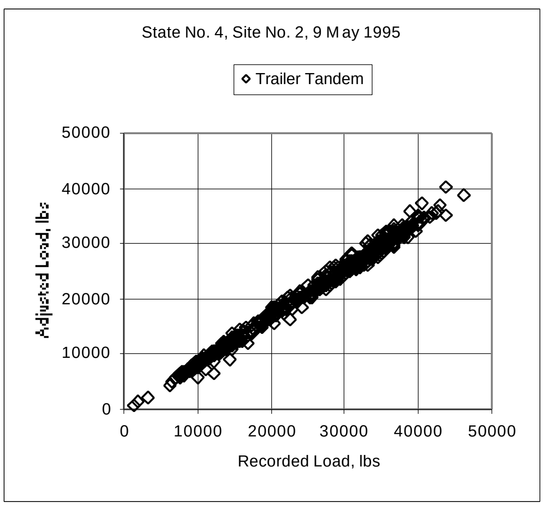
Figure 11. Adjusted Data for State No. 4, Site No. 2, 9 May 1995--Same Data Set as in Figure 10



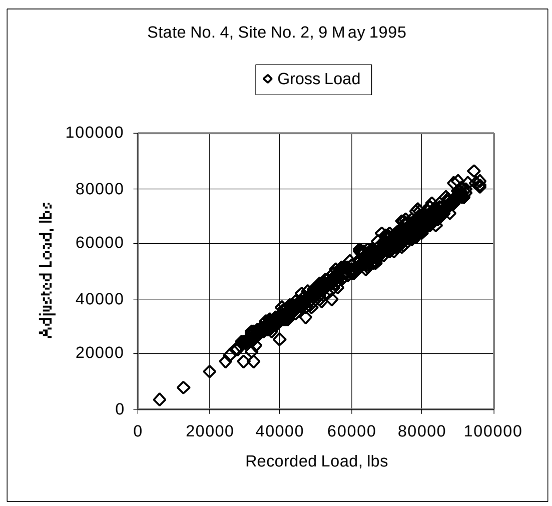
(a)



(b)



(c)



(d)

Figure 12. Recorded versus Adjusted Data for State No. 4, Site No. 2, 9 May 1995

Figure 12 contains the comparison of recorded and adjusted loadings for the same data shown in Figures 10 and 11 for (a) steering axle, (b) drive tandem, (c) trailer tandem, and (d) gross load, respectively.

Does the adjustment methodology produce reasonable results? Figure 12d suggests that the answer be “yes”. The main concentration of data appears to end at approximately 91 kips for the recorded value and approximately 81 kips for the adjusted data.

Adjustment Variations over Time:
During the analyses of WIM data from many sites, several conditions became evident that can be either detrimental or enlightening depending upon the increments used in the analyses. One pitfall is to include data spanning several days. At one site, data for an entire week were plotted in the format of Figure 10. The spread in the data exceeded the two limiting guide lines. Applying the adjustment methodology did not improve anything. The data were separated into calendar dates and the adjustment methodology applied to each day's set of data with results shown in Figure 13.

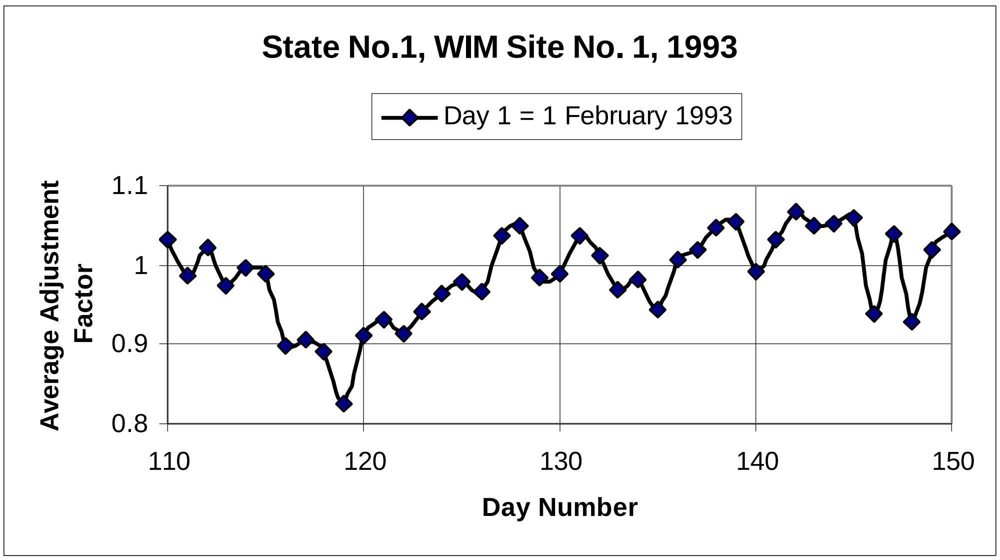


Figure 13. Variation in Adjustment Factor Over Time

The WIM system at another site contains a temperature adjustment procedure provided by the manufacturer for adjusting the electronic signal from the sensor. Figure 13 shows how the daily adjustment factor may vary for consecutive days of data. The author suggests that the variation in Figure 13 is caused by the variation in pavement stiffness due to temperature of the pavement beneath the WIM system and this variation is separate from temperature effects upon the signal from the sensor. The additional effect is a function of the supporting media under the scale. While the following example is a bit ridiculous, the concept is the important issue. In classical physics, for every action there is an equal and opposite reaction. If the scale is supported by a huge block of steel, a given force upon the WIM sensor will result in a stronger signal than if the sensor is supported by a huge block of foam rubber. A large data set was found that permitted separating the data by hour within the same date and each hour had at least 100 WIM records. The variation in adjustment factor by hour of the day also indicated a possible variation due to temperature variation within the pavement. Thus, it is suggested that the data be separated into groups corresponding to calendar dates.

After analyzing approximately 2,000 days of data, the conclusion was reached that the adjustment methodology given in Appendix A may not be appropriate for data sets having less that 100 VC9 records per day.

Summary

- Using the concept of "Steering Axle Load per Foot of Space Between Steering Axle and Leading Axle of Drive Tandem versus Axle Space" combined with limiting lines corresponding to the 12-kip limit and the truck manufacturers' minimum specifications as guides provide a method to determine if the recorded data are reasonable, or should be adjusted. The results may be used to determine if the site needs to be inspected for unusual conditions that may have arisen due to time, or unseen initial installation problems.
- The adjustment methodology is straight-forward and is adaptable to computer spreadsheet programs such as Lotus or Excel. All analyses performed under this study were accomplished using Excel.
- A portable computer with a spreadsheet may be used at a WIM site to collect data in real time and to determine if the data for at least 100 VC9 records is reasonable. If not, the results indicate what type of adjustment may be needed.
- While this method may be used by a spread-sheet computer program, it is not recommended for "production" analyses on a massive scale. The procedure is very labor intensive and requires too much time for massive analyses.
- A computer program needs to be written for automated analyses based upon the suggested methodology in Appendix A.
- It is suggested that this adjustment method might be used by LTPP to improve the quality of the data already in the data bank as well as data sets received in the future.

Acknowledgements

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Appendix A

The following method has been used on over 2,000 daily sets of recorded WIM data from eight states. It is not recommended to use data sets covering more than one day because of the effects of temperature within the pavement upon the WIM sensor. The following is the proposed method:

1. Convert metric units to english units for compatibility with historical data.
2. Divide the Steering Axle Load by Axle Space No. 1.
3. Obtain a linear regression equation for the "recorded data" where Y = log10((Steering Axle Load) / (Axle Space No. 1)), and X = log10(Axle Space No. 1).
4. A "reference equation" is a linear log-log regression equation fitted to the 1984 KY Static Scale Data for All Permanent Stations without 115 data points outside the 12-kip Limiting Line + 50 lbs/ft Line and the Truck Manufacturers' Minimum Specifications – 50 lbs/ft line, and where X and Y have the same definitions as in Step 3. The equation for the reference line is: log10(Y) = 3.925361 – 0.952182*log10(X), also given in Table 1.
5. For an individual truck, use the recorded Axle Space No. 1 and evaluate the regression equation from Step 3 and the "reference equation" in Step 4.
6. Calculate the algebraic differences obtained in Step 4. Add this difference algebraically to the recorded (Steering Axle Load) / (Axle Space No. 1) in Step 2. This is the "Adjusted (Steering Axle Load) / (Axle Space No. 1)" value.
7. To obtain the Adjusted Steering Axle Load, multiply the result of Step 6 by the recorded value for Axle Space No. 1.
8. Divide the adjusted Steering Axle Load by the Recorded Steering Axle Load. This ratio represents the needed adjustment to be applied to the remaining axles for this truck.
9. Multiply the remaining axle loads by the ratio from Step 8 to obtain the Adjusted Drive Tandem and Trailer Tandem.
10. Add the Adjusted Axle Loads to obtain the Adjusted Gross Load. Likewise, add the Recorded Axle Loads to obtain the Recorded Gross Load.
11. After all calculations for all VC 9 Trucks have been made, calculate the average ratio for all ratios in Step 8 for the entire data set used in these calculations (for that day). This is the multiplying adjustment factor to be used for all other vehicle classes for that calendar day. It is the same as the "scale adjustment factor".
12. The following steps may be made if visual results are desired. The author strongly suggests that graphs be made at least until the user feels comfortable with the procedure. Make the following XY scatter plots to provide graphs for visual assessment of the method and results:
    a. Recorded (Steering Axle Load) / (Axle Space No. 1) versus (Axle Space No. 1).
    b. Superimpose the Adjusted (Steering Axle Load) / (Axle Space No. 1) versus (Axle Space No. 1) (Step 6.)
    c. Superimpose the (12-kip) / (Axle Space No. 1) versus (Axle Space No. 1) reference line (Step 4).
    d. Superimpose the Truck Manufacturers' Minimum Specification Line that is the (minimum Steering Axle Load) / (Axle Space No. 1) for the tractor as it sits on a dealer's lot without fuel, driver, or trailer. These values were obtained from the truck manufacturers' dealers. The Equation is: log10(Y) = 3.942369 – 1.07509*log10(Axle Space No. 1).
    e. Adjusted Steering Axle Load versus Recorded Steering Axle Load.
    f. Adjusted Drive Tandem Load versus Recorded Tandem Load.
    g. Adjusted Trailer Tandem Load versus Recorded Tandem Load, and
    h. Adjusted Gross Load versus Recorded Gross Load.

Notes:

1. There will still be outliers above the 12-kip limiting line and they may be very legitimate considering that some companies purchase overload permits. Conversely, there may be those that are very close to, but below, the Truck Manufacturers' Minimum Specification Line that may reflect suspension activity. Another scenario might be that a driver is changing lanes such that one side of the truck travels over the scale but the other side does not.
2. Data that extend beyond the limits of Axle Space No. 1 of 9.67 ft and 22 ft should be evaluated for possible mislocation of the vehicle presence sensor(s), or the wrong value of that spacing inserted into the computer at the WIM site. There may be a few trucks that will exceed 22 ft, but very few. Cabover 3-axle tractors should not be less that 8.67 ft.
3. Out of the 2,000 data sets investigated, the following patterns have been determined as "typical":
   a. Data sets that nearly perfectly fit between the 12-kip and Truck Manufacturers' Minimum Specification lines. In these cases, "if it ain't broke, don't fix it."
   b. Data sets that nearly fitted between the two criteria lines but the data set was skewed.
   c. Sets that were too high—the 12-kip line penetrating too far into the data set, and
   d. Sets that were too low—the Truck Manufacturers' Minimum Specification line penetrating too far into the data set.
   e. In some cases, a data set combining an interval of one week extended outside both limiting lines. After breaking this data set into individual days, each day's set fell into one of the four in 3a-d above.
   f. In the figures of the report, you will note that the Truck Manufacturers' Minimum Specification Line has an additional 50 lbs/ft subtracted from the original regression equation, and conversely, 50 lbs/ft has been added to the 12-kip limiting line. This additional "cushion" has been added to account for possible dynamic effects within the suspension system considering that both lines were obtained for totally static conditions. Also, the "50 lbs/ft" is an arbitrary value selected for the purpose of illustration. The user should feel free to change this constant to a value that better suits the particular condition or location. For instance, if the approach is smooth, the constant might be reduced. Conversely, for a rough approach to the scale, the constant might be increased.