Interpretation of Computer Analyses of Traffic Data Using FHWA's VTRIS Computer Program

By

Herbert F. Southgate
Consulting Engineer

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Federal Highway Administration
Office of Highway Information Management
400 Seventh Street, S. W.
Washington, D.C. 20590

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Preface

Under Order No. DTFH61-97-P-00724, Federal Highway Administration, authorized research for this study to develop ways to use output from the Vehicle Travel Information Service (VTRIS) Computer Program for both Weigh-In-Motion (WIM) and Automated Vehicle Classifier (AVC) data. The study was monitored by Ralph Gillmann, COTR, Travel Monitoring Division, Federal Highway Administration, Department of Transportation. As a part of the Order, the Travel Monitoring Division furnished all data used in these analyses.

The author wishes to acknowledge the tremendous cooperation of Ralph Gillmann and David Jones, Travel Monitoring Division, Federal Highway Administration for their help, Barbara Hertzog and Mark Finch of Washington DOT, and Curtis Dahlin, Minnesota DOT for their help during the course of this research. Thanks also to Bill McCall, Iowa State University Transportation Center, and Mark Gardner, Brent Rahut Engineers, Austin, TX for reviewing and commenting on the report.

EXECUTIVE SUMMARY

The purpose of this research was to develop ways to use and interpret the results from the VTRIS computer program developed by the Federal Highway Administration (FHWA) Office of Highway Information Management. The basic assignment was to develop methodologies for analyzing Weigh-In-Motion (WIM) data, vehicle classification data, axle count data and how to tie all these data together. The common factor between the equipment designed to count axles, classify the traffic into vehicle classifications, and to classify and weigh axles is "axles". Analyses were made using data provided by FHWA for four states. The basic premise for analyzing WIM data is based on calculating AASHTO ESALs for each truck and counting the number of axles. Each of the two values are summed for the truck traffic over a 24-hour period. Data were converted and expressed as "ESALs per Axle" resulting in reduction of massive variations into manageable comparisons. Analyses have been made for "ESAL per Axle" by functional class of highway, seasonal variations, lane, direction, and vehicle classification for WIM data. Automated vehicle classification (AVC) data for 24-hour periods were converted to number of axles and then to percent for each vehicle classification. This permits estimating the traffic makeup using axle count data. For individual sites, percent of Vehicle Class 9 axles were plotted against the Vehicle Class 2 axles. Possibly a better method would be to combine the number of axles for Vehicle Classes 1-3 as the X axis. Literature review shows that vehicle classification equipment has great difficulty in determining if the vehicle should be placed in vehicle classifications 2 or 3. Of course, as the sophistication of the equipment decreases, so does the accuracy of application to results from lesser-sophisticated equipment. Yet, it at least permits rough estimates that are better than none.

Figure 16 illustrates the hazard of using one week of WIM data to predict annual ESALs. The second week of August for this site turned out to be one of the lower truck traffic weeks of the year. Thus, the annual prediction would result in much too low an estimate of accumulated ESALs.

One outstanding result is that there is a large difference in both ESALs and truck axle counts between "Weekday and Weekend" traffic. If the average for "weekday" is used for the seven days in the week, the result will be an excessively high estimate for that type of data. Weekday vs weekend may have more influence than seasonal variations. For most of the sites investigated during this research effort, either volumes or percentages of axles stratified into a group of weekdays for Monday through Friday. However for one site, the data appeared to form two groups—one group for "weekdays" defined as Sunday through Thursday and the other group as the "weekend" defined as Friday and Saturday. Perhaps even a better stratification might be made if it could be determined that the day "began and ended at noon" rather than at midnight. This investigation could not be made during this research effort.

Some additional uses might be to determine if calibration of WIM equipment is drifting from the calibration at the time of installation and/or determining that the scales are good but that particular truck classifications may be the problem such as quarry operations where dump trucks are empty in one direction and loaded in the other. Suspect results may be investigated by looking at the raw WIM data files. In one location, the lead trailer axle weighed approximately 70 % of the trailing axle within the trailer tandem. One possible scenario, but certainly not the only one, for this condition is that the lead axle is an air-lift axle while the rear axle has a steel leaf-spring suspension.

In summary, VTRIS can be used to quickly determine trends and identification of peculiar situations for use in Planning and Pavement Design.

By sorting sites into regional areas, ESALs may be calculated for each region, a total obtained for all regions, and then converting the regional ESALs into percentages. This would show which areas are being subjected to traffic intensities and the percentages applied by the administration office to a total budget to determine money allocations by regions.

Chapter 1

Background

For years the Federal Highway Administration (FHWA) has requested states and Metropolitan Planning Organizations (MPO) to collect and report traffic data characteristics such as the number of trucks by vehicle classification and axle loads. Initiation of the Strategic Highway Research Program (SHRP) and particularly the Long Term Pavement Performance (LTPP) study resulted in additional requirements for traffic data. These data should permit estimation of pavement fatigue and rates of fatigue applications. As technology advances, one prominent question is how to coordinate and utilize data obtained by less sophisticated equipment with data using the most sophisticated equipment available.

Original efforts focused on axle counts and axle loads using portable scales and/or static scales at permanent Loadometer Stations because they were the only equipment available. The simplest equipment for monitoring traffic flow is the axle counter that is attached to a sensor placed on the surface of the lane. One typical sensor is the hollow rubber tube. When the tire(s) cross over the tube, a momentary impulse of increased air pressure within the tube trips the counter device to increase the count by "one".

"Second generation" traffic monitoring equipment is called a "vehicle classifier" that utilizes in-pavement sensors, such as loops of wire or piezo cables, to detect the presence of a vehicle. By using two sensors separated by a specified distance, the number of axles and time between them permit identification of the vehicle and records that vehicle by increasing the appropriate counter as determined by a standard set of specifications such as the FHWA 13 class scheme.

Technological advancement permitted development of equipment now employed by state DOTs and Metropolitan Planning Offices (MPO) to measure dynamic axle loads at normal traffic speeds using Weigh-In-Motion (WIM) devices. Some of these devices are portable pads placed on the pavement surfaces, some are plates installed in the pavement so the surfaces are flush and even, and some are piezo cables placed in the pavement and flush with the surface. These devices obtain axle loads and axle spacings that permit defining the style of vehicle, such as a five-axle semi-trailer truck. All of these devices are relatively expensive, both initially and operationally. Retrieval of these data take one of two methodologies, a) personnel must visit the site, or b) data are obtained remotely using telephone lines or other more sophisticated methods.

Historical Data Usage

Monitoring of traffic started by counting axles only. As equipment became more sophisticated and affordable, vehicles were counted and classified using the number of axles and spacing between axles. The more recent developments include WIM devices permitting capture of axle loads combined with vehicle classification data.

Traditional use of traffic data has included the determination of space requirements for various vehicle lengths. As the speed limit and number of vehicles increase, so does the proportion of required space for each vehicle to maintain safety. As required space increases, eventually additional lanes will be required. When the number of lanes increases, traffic flow characteristics change accordingly. For example, recorded traffic for two and three lanes in one direction indicate that the vast majority of trucks travel in the outer lane until the traffic volume increases and the number of trucks in each lane approach equality. For three-lane facilities, truck traffic may be nearly equal in the outer two lanes and minimal in the median lane. One known exception to the above statements is that in heavy municipal traffic, trucks may travel in the middle and/or inner lane to avoid traffic leaving and entering at interchanges. There are known instances where traffic signing dictates that through trucks must travel in the left lanes rather than in the right lanes. There have been cases where pavement life of the right lane has been nearly depleted by heavy trucks and the state DOT has opted to require that trucks travel in the left lane in hopes of postponing major reconstruction.

Initial and Overlay Pavement Thickness Designs

Traffic estimates based on traffic volume data, vehicle classification data, and Equivalent Single Axle Loads (ESALs) are critical items used in determining initial pavement thickness designs for new pavements. Depending on how the analyses are made, results can be very influential on determining pavement type and life-cycle costs. For rehabilitation considerations, traffic characteristics, particularly fatigue calculations, may be very influential in determining the need for upgrading an/or reconstruction versus simply a cosmetic or skid resistant treatment. Significant differences may result if data for all lanes are combined before analyses. The lane receiving the greatest fatigue due to heavy traffic should be the only lane considered in overlay thickness requirements. All other lanes will receive the same thickness so that there are no differential elevations between lanes. Thus, combining data for a number of lanes will result in excessive thickness requirements, either initially or for overlays.

Some version of the VTRIS computer program has been in existence for over 30 years. FHWA, or the Bureau of Public Roads (BPR), its predecessor, published tables containing traffic data and computed ESALs using that data. Information from those tables were used in the Interstate Rehabilitation Cost Estimates of the mid 1970's by Kentucky DOT and other state DOTs. Further use was made of them in the early days of the formation of the SHRP while putting together data requirements at state DOT levels.

FHWA has been requested to develop ways and methods that make further use of the W-2 and W-4 Traffic Summary Tables. Additionally, determine ways to incorporate automated vehicle classification (AVC) and tube counts with WIM data but not to solve all the problems for the four states. These goals are the subject of this research effort. The one common factor between the three types of data sets is the number of axles. Thus, the focus of this research is to relate pavement fatigue through using the "average ESAL per vehicle" and the number of vehicles weighed over time, vehicle classification, and tube counts to axles.

Specific subjects to be undertaken in this research were:

a) development of a simplified analysis of WIM data,
b) application of the simplified analysis procedure to a sample of data from one state,
c) similarity of sites with that sample state's data,
d) analysis of data from three other states,
e) analysis of weekday data versus weekend data,
f) use of data collected by vehicle classification equipment,
g) use of data collected by axle counters, and
h) examples of appropriate and inappropriate data set analyses.

Chapter 2

Weigh-In-Motion Data

Initially, the original proposal included the development of a computer program to analyze each vehicle and process the results to appropriate accumulators. The FHWA VTRIS computer program proved to be adequate for sophisticated analyses and negated the need to develop other computer programs. There are four options included in VTRIS for processing the data to give average daily values for:

a) annual period,
b) semi-annual period,
c) monthly, and
d) custom.

All analyses were made for this report using the custom option that permits entering the beginning and ending date. This permitted analyses for an individual day, a combination of days such as Monday through Friday (week days) and Saturday and Sunday (weekend). Normal analyses by FHWA and State DOTs are made to obtain the average ESAL for each of the 13 vehicle classifications specified in the FHWA Traffic Monitoring Guide (TMG). The W-2 Report provides the number of vehicles analyzed for the specified time period, and calculates the percent volume for each vehicle class within that particular data set. Figure 1 contains the information used in this research effort. The FHWA VTRIS Summary Report is published in a "landscape" format and could not be imported to this report. The same information has been used but created in a "portrait" format. The W-4 Summary Report , provides the number of vehicles weighed and the calculated average "ESAL per Vehicle" for each vehicle class for both rigid and flexible load equivalency relationships adopted by the American Association of State and Highway Officials (AASHTO). The TMG specifies the "number of axles" which, multiplied by the average ESAL per vehicle for each vehicle classification yields the total ESALs for the traffic stream in that data set. Inspection of many W-4 Summary Tables indicated the average ESAL per vehicle for vehicle classification number 4 (buses) was relatively as large as for vehicle classes 5, or more. Because the pavement "knows only the effects of load", the decision was made to include the ESALs and axles for buses as a category of "truck". Summing the total product of the number of axles per class and the number of weighed vehicles provides the total axles for the heavy traffic stream for vehicle classes 4-13. Summing the product of the number of weighed vehicles and the average "ESAL per Vehicle" provides the total ESALs for vehicle classifications 4-13. These two sums may be plotted as a data pair where the X axis is the number of axles and the Y axis is the respective number of ESALs as shown in Figure 2. Strictly as a helpful aid to understanding the relationship of ESALs to Axles, a grid of "ESAL per Axle" values has been superimposed over the data. Choosing 0.20 as an individual grid line means that anywhere on that line the division of ESALs by Axles yields that value, i.e. 1,000 ESALs divided by 5,000 Axles equals 0.2. Figure 2 also represents results of the TMG requirement of data collected for 24 hours per day for one week which is also one requirement for traffic information by LTPP. However, only seven data points is highly frowned upon statistically. Most statistics tables indicate that at least 35 pairs of data should be obtained to assure that there is no real bias due to sparseness of data. The Washington DOT was requested to furnish continuous data for 60 days for one of their sites to determine the validity of the approach. Their cooperation is most appreciated and the results for Site P6 are shown in Figure 3. Regression analyses were made for each direction and the equations are shown on the respective plots. The equations for the individual lanes for Site P6N (N for north-bound traffic) were so close that the data for both lanes for Site P6S (S for south-bound traffic) were combined to obtain one regression equation. The lower graph for Site P6S also illustrates the stratification of data at this site for the effects of weekday and weekend as identified by a calendar.

AASHTO Rigid and Flexible Load Equivalency Equations Applied to the Same Traffic Stream

Figure 4 compares rigid and flexible ESALs computed by VTRIS for the same traffic stream for a given day. The only difference that can occur is directly related to any difference between the two sets of equations. The top figure shows number of truck axles versus ESALs flexible pavements, the middle figure to the rigid pavement ESALs, and the bottom is a direct comparison of flexible to rigid ESALs for the same truck traffic stream. The bottom figure shows that there is such a direct relationship that the decision was made to calculate only one set of ESALs. The AASHTO pavement load equivalency relationships are based upon the results from the AASHO Road Test for both flexible and rigid pavements. The quantity of data from the AASHO Road Test for flexible pavements was much greater than for the rigid pavements. Admittedly this comparison is shown for one site, but a short comparison was made for other sites and the results were equally as good. Thus, the decision was made that for this research, the ESALs should be computed using the flexible pavement load equivalency relationships. As a word of caution, it is conceivable that ESAL calculations for unusual truck-axle configurations may result in wider scatter, but not much wider. The reader is cautioned to make his/her own comparison of the two sets of ESALs before accepting the results of Figure 4 for general use.

Analyses of Traffic Data for Sites Within the Same Functional Class of Highway

As a part of Task C, the simplified ESAL-Axle procedure was applied to data for sites within the same Functional Class of Highway. Figure 5 is a compilation of results for seven sites within Functional Class 2 for 1995 in Washington State. Thus the "+" data points corresponding to Site P23 show an ESALs/Axle ratio of nearly 0.4 while those for Site B02 (solid circles in the 3,000 to 4,000 range of axles) is less than 0.2, yet they are both in the same Functional Class of Highway. This indicates that trucks at Site P23 were more heavily loaded than those at Site B02. Three questions arise:

1) are the scales in calibration, and if so,
2) what is the difference in truck styles, or usage, that cause such a difference?
3) Are the trucks of the same vehicle classification but empty at Site B02 and loaded at Site P23?

Thus, this approach can serve as a useful tool to state planners and traffic analyses personnel to help understand site specific differences, or to compare recent results to earlier results to determine if equipment is still within calibration, or to other factors.

Analyses of Traffic Stream by Lane Designation

Results were combined for all sites within the same functional class and the process repeated for several functional classes using the data set for 1996 as furnished to FHWA by the Washington DOT. Figure 6 illustrates the results for Functional Classes 1, 2, 11, and 12. The lower left figure of Figure 6 shows the results for Functional Class 11 and illustrates a broader band of data compared to the other three figures, particularly in the range of 8,000 to 10,000 truck axles. Closer inspection revealed that each of the three small groups of data within the 8,000 to 10,000 range belonged to a separate site. In particular, one group corresponded to trucks in the outer lane and another to trucks in the inner lane at the same Kilometer Post, and the third group represented a site on another route. Results for other functional classes and other states indicate that grouping sites together to provide a relationship for "Functional Class" is not always appropriate. Assignment of sites by Functional Class is specified by the Traffic Monitoring Guide (TMG) and other political factors such as funding allotments provided by FHWA. These constraints will continue to exist. However, early in this research effort, a conclusion was made that the only really valid comparison could be made for each lane because each lane has its own instrumentation and that requires each set of equipment to have its own calibration—particularly for WIM scales. Just because the same "type" of equipment is used at various sites does not mean that each piece of equipment has exactly the same calibration characteristics at each site. As a corollary statement, if this were not true, why would a factory use statistical quality control procedures to test their products? Thus, the reader is requested to look closely at the appropriate figures that follow to see the differences between lanes at the same site, directional differences, different sites, and seasons.

Analyses for Seasonal Effects

For example, Figure 7 illustrates the results for the same sites as shown in Figure 6 except that the data in Figure 7 were obtained in August 1996 and that of Figure 6 were obtained in May 1996. In particular, look at the upper right figure corresponding to Functional Class 2 in Figures 6 and 7. The number of truck axles are within approximately the same range, but the number of ESALs in Figure 7 is nearly 3 times that of Figure 6. In the upper left portion of Figure 7 (Functional Class 1), there is a group of data in the 4,000 to 5,000 range of axles that is nearly twice that shown in Figure 6. The conclusion is that something is different between the two time periods! While not shown here, further analyses indicated that results for the October data set were nearly within the same range as shown in Figure 6. Is it possible that the results shown in Figure 7 corresponded to a harvest season? The answer is not known at the time of writing this report. Equally as interesting is the comparison of data in the lower right portions of Figures 6 and 7. While there is a slight difference between the two data sets, the overall results are nearly the same. Note that this corresponds to an Urban Arterial route and suggests that traffic does not vary that much according to season.

Figure 8 compares the results of data taken for one week in each of four months. For Lane 2 (circles), there is an increase of approximately 1,000 truck axles per day for August and October compared to February and May, but the ESAL/Axle remain approximately the same. For Lane 2 (diamonds), the number of truck axles per day are approximately the same in February and October, but the ESALs/Axle is slightly higher in February than in October. However, Lane 1 data for May and August are higher for both the number of truck axles and ESALs/Axle in May and August than in February and October. Thus, one might conclude that there are some seasonal effects at this site. Site P6S is classified as a Functional Class 2 site and is a SHRP site.

Figure 9 presents the same sort of analyses shown in Figure 8 except that Site P3S is located on Interstate 5. The main difference in these figures is between lanes. Note that for each figure, the number of truck axles is always greater for Lane 2 (circles) than for Lane 1 (diamonds), the total ESALS are nearly the same except for October, but that the “ESALs/Axle” (or rate of applied ESALs) is higher for Lane 1 than

Lane 2. Another way of saying it is that trucks in Lane 1 are more heavily loaded than those in Lane 2. There are minor differences between seasons.

Analysis Procedures Applied to Data from Four States

Figure 10 presents the results of ESALs vs Axles for four states. The purpose for each of the four figures is different for each state, but the overall conclusion is that the process can be applied to each state. The upper left figure is repeated from Figure 9. The upper right figure shows the very large difference between weekday and weekend truck traffic for Site 1611 in Ohio. The lower left figure shows the very large difference between inner and outer lanes at Site 1 on a California interstate route. This figure also shows that the regression equation appears to be valid for the combined inner and outer lanes and the difference is associated with the number of truck axles per 24 hours. The lower right figure shows the tremendous influence of season, particularly month, for Site 40 in Minnesota. Note the large effect between directions for a given month and then between months. A part of these differences can be explained because Minnesota permits much higher axle loads while the subgrades are frozen and lower load limits when the subgrades thaw. A very close inspection also reveals the differences between weekday and weekend, though not as prominently as for the Ohio figure at the upper right.

Figure 11 illustrates the combined effect of seasonal and lane distribution effects. For Site 1051 in California, there is decidedly less seasonal effect than for the Minnesota data shown in the lower right figure of Figure 10. It seems obvious that the weather variation in California is much less than for Minnesota and that effects of harvesting is less severe because harvesting is much nearer to being an "around-the-clock" operation in warm climates. The bottom figure is a combination of the two upper figures and simply emphasizes the effect of lane distribution.

Figure 12, Site 39 in California, does show more seasonal effects than for Site 10 in Figure 11. There seems to be a decreasing trend in truck usage and resulting ESALs as the seasons go by. This is more noticeable in the middle figure where data for September is the least, June a little greater, and March has the highest ESALs per Axle. However, combining the data for the upper two figures into one as shown in the bottom figure simply shows that trucks in the eastbound outer lane are more consistent overall than for those in the westbound outer lane.

Figure 13 illustrates the effect of season on each of four sites on Functional Class 2 Highways. Seasonal effects are highly dependent upon site. For example Site B02 (upper left) exhibits a fairly tight band of data compared to Site P01 (upper right). For Site P01, ESALs for August (+) are much greater for the same number of truck axles than for October (*). Though not to the same degree, the same comment can be made for Site P20 that is the lower right figure. However, for Site P03 (lower left), comparison of August versus October shows more difference than for Site P20, but less difference than for Site P01. The obvious conclusion is that each site should be treated individually.

Figure 14, California Site 4471, illustrates the combination of season and weekday vs weekend data. The most obvious influence is the weekday vs weekend variation. Effects of season and weekday vs weekend were investigated for four additional sites in California as shown in Figure 15.

Figures 8-12, either totally or in part, illustrate the effects of ESALs vs truck axles for 24 hours but primarily for a one-week time period. Of the four data sets provided by FHWA for this research, only Minnesota had sufficient data to be able to truly look at the effects over a full year. Figure 16 provides very interesting relationships. In the upper figure, a "best-fit line by eye" has been drawn from the origin through the upper data group. This same line is superimposed on both the middle and lower figures to illustrate a point. The middle figure is the compilation of data for August and September and the data in the upper figure is a part of the middle figure. All the data in both the upper and middle figures are included in the bottom figure that represents data for 10 of the 12 months. Note: 1) the increasing scatter of data with the inclusion of more months of data, and 2) the location of the superimposed "best-fit line" from the top figure. The obvious conclusion is that trying to use one week of data to represent an entire year can yield results that truly do not represent the entire year. Thus, the user **MUST** be very careful in making definite conclusions. While not shown specifically, other sites showed there are large variations in data scatter and those relationships are a direct function of the particular site. Trying to make general conclusions concerning particular Functional Classes of Highways is very risky. There is one obvious conclusion for Figure 16: 1) the effects of weekday vs weekend are distinct in all three figures, and 2) the general slope for weekend data is separate and steeper than for weekday data. One <u>might</u> conclude that trucks might be more heavily loaded over the weekend because there might be less chance of being caught by enforcement officers. That may not be true at all, but does provide food for thought!

Diagnostic Evaluations

Figure 17, Ohio Site 20, also illustrates effects of both lane distribution and weekday vs weekend. There is a slight difference in ESAL/Axle for weekend vs weekday for the outside lane. Figure 18, Ohio Site 11, clearly separates weekend truck axles from weekday truck axles for the months of January, February, and March. Additionally, direction 5 (southbound) data as a whole is greater than direction 1 data (northbound). This raises two obvious possibilities:

1) economic influences truly reflect differences in direction, and
2) one, or both, scales may be out of calibration.

Thus, this procedure might be used to flag suspect sites for possible problems.

Figure 19, Ohio Site 9, contain weekday data only for January, February, and March 1996. The top left figure represents southbound data and the bottom left figure represents northbound data. The pattern for the southbound data obviously has a steeper slope than for the northbound data. The first investigative effort was to look at the average "ESAL per Vehicle" values on the W-4 Summary Reports. The criteria to be applied was that either the "ESAL per Vehicle" for each vehicle classification was greater for the southbound data than for the northbound data indicating a scale possibly out of calibration, or a few vehicle classifications had approximately the same values for both directions and values for other vehicle classifications were quite different according to direction. An additional criteria was that there had to be data for each direction for the same calendar date. The total ESALs were calculated and summed for each day and the total number of axles were computed and summed for each day for both directions. The average ESAL per Axle was calculated for both directions for the same date and then the ratio of southbound average ESALs to northbound average ESALs was calculated. The upper right figure illustrates the results for January and the bottom right figure correspond to data for March. In the upper right figure, note that the ratio for vehicle classification 9 (five-axle semi-trailer truck) is nearly 1.0, yet the ratio for vehicle classifications 6 and 7 are much greater than 1.0. In the lower right figure, ratios for vehicle classifications 5 and 9 are nearly 1.0, ratios for vehicle classification 7 are a little greater than 1.0, and the ratios for vehicle classification 6 are much greater than 1.0. This suggested that the WIM records should be investigated for verification. Spot checks of the WIM data showed that axle loads were very light for northbound vehicle classifications 6 and 7 and very heavy with uneven load distributions for the same southbound vehicle types. Intuitively, this suggests the possibility of a quarry, asphalt plant, and/or concrete plant operation, or a combination of operations. These industries typically utilize vehicle classification 6 and 7 trucks.

Figure 20 contains summary data for Minnesota Site 40. The top figure illustrates the monthly average ESAL per Axle for eastbound trucks (star) and westbound (solid circle) and the two are distinctly different. Again, the W-4 Summary Reports were investigated to compare the average ESALs per Vehicle for both directions on the same day. The average ESAL per Vehicle for buses (+) could be considered as approximately equal, particularly when compared to values for vehicle classifications 9 and

10 (stars and open circles, respectively). The difference was confirmed verbally by a Mr. Dahlin, Minnesota, who said that these were trucks hauling grain to Duluth and returning empty. Again, the procedure was used as a diagnostic tool.

Figure 21 contains monthly average ESAL per Axle for each of five sites in Minnesota. For Site 5531 (open circle) is in the Functional Class 1 category and Site 3311 (solid triangle) is in the Functional Class 11 category. Note that the average ESAL per Axle values are relatively constant throughout the year. Functional Class 6, Site 2911, is highly variable compared to Functional Class 1 and 11 sites above. Since this is a rural agricultural site, it is possible that the winter values will be low, spring higher than winter and mid-summer, and then increase during the harvest season. However, in his review of the first draft, Mr. Dahlin said, and permission was given to quote him:

> "Site 2911 was a piezo cable site in flexible pavement. One of the cables was near a major crack in the pavement, so we never were able to collect good data at that site. It was highly variable, but this was due to site problems."

The reader is reminded that the Minnesota data were collected in 1992 and Mr. Dahlin and his crew would have had a chance to investigate site conditions long before this research effort. From the point of view of this research effort, the erratic AASHTO ESALs vs monthly relationships would have served its purpose by simply raising a flag to alert someone to check all conditions—regardless of the actual cause. Site 25171 (solid diamond) and Site 4031 (+) are in Functional Class 2, and follow the same basic pattern—high in winter when the ground is frozen, lower in the spring and summer, then increases during the fall. Site 4031 is the same as shown in Figure 20.

Figure 22 illustrates another way to use the W-4 Summary Reports for the same five sites shown in Figure 21. Figure 22 shows the relationship of time and the average number of axles per truck. The average number of axles per truck for Functional Class 1 and 11 remain nearly constant for the year, but for Functional Class 2, the average decreases during the crop growing season of May through October. The supposition is that the increase in trucks hauling crop related materials such as fertilizer, weed control chemicals, etc, increase and "dilutes" the average number of axles per truck compared to Functional Class 1. Note for Functional Class 6, the average number axles per truck increased rather dramatically in October—harvest time!

Chapter 3

AVC Data Compared to WIM Data

Numbers of axles are the common link between WIM, AVC, and axle counters. However, the number of axles should be adjusted for several reasons. The first reason is that the number of axles counted and assigned to appropriate vehicle classifications from the AVC equipment should be compared to the same traffic stream weighed and classified by WIM equipment. The AVC counts probably will be higher than the WIM counts because the WIM computer program has a minimum weight assigned as a threshold value before the vehicle is assigned to appropriate counters. Thus, empty trucks may not be recorded by WIM equipment but could be recorded by AVC equipment. In his review, Mr. Dahlin stated:

> "I have a different view on the issue of AVC data compared to WIM data as discussed (above). Mn/DOT's and most or all other department's WIM systems, have WIM and AVC (vehicle identification) as a part of the same system. AVC counts from these systems are typically higher than the counts from vehicles weighed because all vehicles are not properly weighed for a variety of reasons. However, the system was able to classify most of those that were not weighed. Consequently, the 'AVC classification' is a better representation of what is there than the 'WIM classification'. (The report) may be correct in that with a weight threshold in the WIM system, some empty trucks may not be recorded by the system. But I feel that the other issue which I cite above far overshadows the light truck issue and I do not think we have an issue of too many heavy axles...AVC as collected by stand alone systems which are not WIM systems would need to be checked to see that they do not have any bias."

After receiving Mr. Dahlin's comments above, a telephone conversation showed why there was some disagreement with this report.

1) Mr. Dahlin said that MNDOT has attempted to instrument the LTPP sites with permanent WIM systems and to collect data continuously. This is not the case for many states. LTPP specifies a general criteria that approximately 1/3 of the sites should be instrumented with WIM equipment on a three-year cycle with the remaining sites instrumented with AVC equipment. For the above, data is to be collected for at least one week. Thus, Minnesota is obtaining a more complete data set than most states.
2) For some States such as Kentucky, the WIM equipment does have a minimum weight threshold entered into the equipment that is a value high enough to exclude pickup trucks, Vehicle Classification 3.

3) The author emphasized the point that the main reason for adjusting the number of axles obtained by the AVC counters is to assure that the number of axles of the heavier traffic stream are of the same magnitude as would have been recorded by WIM equipment. This is to assure that the estimated ESALs developed by WIM equipment would not result in an over estimation of accumulated ESALs. There is no argument between the author and Mr. Dahlin that the actual traffic stream is better captured by AVC equipment IF THE COUNTERS HAVE BEEN PROPERLY CALIBRATED. More about counter calibration will be discussed later in this report.

Figure 23 shows the relationship for California Site 1 and Figure 24 is for Minnesota Site 55. Note that the two regression equations are not the same although they are fairly close. The two equations serve to indicate that each user should determine the relationship between the two sets of equipment because there may be different threshold weights for the user's WIM equipment, particularly compared to equipment used by another agency. Another possibility for the difference in the two regression equations stems from Mr. Dahlin's comments above. If CADOT WIM equipment utilized a different AVC counter than MNDOT's WIM, then there possibly exists a different correlation. As for this research effort, a correlation between the two sets of equipment should be made if one has not been done.

Why should a regression equation be developed by the user? Processing AVC data to determine the number of truck axles (heavy axles) to use as the entry value to estimate ESALs per day will result in higher values than would be obtained had the WIM equipment been used for the same traffic stream. Thus, the number of heavy axles should be reduced to an equivalent number that The WIM equipment would have recorded and would be a more appropriate estimate for that traffic stream.

The second reason for adjusting the number of axles is to be able to determine the proportionate number of axles for vehicle classes 1-3. Each site will have percentages appropriate to the traffic traveling over that site. Some sites may have similar characteristics with other sites and definitely not with other sites. Each location may have its own peculiarities that need to be recognized. Economics and industries may dictate prominent use of certain vehicle classifications and the lack, or minimization, of others.

AVC Counts as a Function of Day of Week

Day of the week seems to have a prominent influence upon AVC counts as shown in Figure 25 for Ohio Site 15. Vehicle Classes 2 and 9 have the higher proportions of the traffic stream and these two have been concentrated upon to illustrate certain relationships. The data are plotted in terms of number of axles. In the upper left figure, note the rather sharp curvatures from Monday to Friday providing the basic form of a "fish". The upper right figure shows the average values for each day of the week, the bottom left figure shows the average of all values for Monday through Friday, and separate values for Saturday and Sunday. The bottom right figure is a compilation of the other three figures. Note that the vertical axes in all figures are expressed in terms of the number of axles. Also note that there is a fair degree of spread in the number of axles on certain days of the week, or weekend.

Figure 26 displays the same data as shown in Figure 25 but axle volumes have been changed to percentages of the total axles recorded for that day by AVC equipment. Note the flatter curvatures in the upper left and lower right figures. Also note the reduced scatter of points for a given day compared to Figure 25. This suggests that converting the number of axles to percentages should improve the estimated number of axles by vehicle classification where the total volume of vehicles fluctuates greatly. Also note that Figures 25 and 26 represent a Functional Class 1 site.

Figure 27 illustrates relationships for Ohio Site 956 on a Functional Class 2 highway. The upper figure expresses the axles in volumes and the same data as percentages in the lower figure. Also note the rather different patterns compared to Figures 25 and 26. Again, percentages appear to reduce the scatter in the daily data values.

During this research, a comment was made that there had been difficulty determining if a vehicle should be placed in vehicle classification 2 or 3 (cars or pickups, respectively). While investigating vehicle classification data, it was noted:

1) that there were very few counts for vehicle classification 1 (motorcycles), and
2) the vehicle classification 9 (five-axle semi-trailer truck) composed the vast majority of the balance of the vehicles.

Vehicle counts were converted to axles, summing the axles for vehicle classifications 1-3 and 4-13, and changing the sums to percentages. The percentages for each "Day" were averaged and the results are shown in Figure 28 that contains figures for January, February, March, and December for Ohio Site 9. There is a distinct difference between weekdays and weekends. Site 9 is designated as a Functional Class 2 highway. Figure 29 shows the similar results for Ohio Site 16 that is designated as a Functional Class 12 highway.

Weekdays and Weekends—Conventional versus "Traffic"

For most sites, truck traffic is usually higher on Mondays through Fridays than for Saturday or Sunday. Is this always true, or are there sites where the greater truck traffic occurs on a different grouping of "days"? Figure 30 suggests Ohio Site 15 traffic departs from the usual pattern of "Monday through Friday" versus "Saturday and Sunday".

Figure 30 displays four figures. The left two figures have data grouped into:

1) the conventional assignment of Monday through Friday as "Weekday", and
2) Saturday and Sunday as "Weekend".

Closer inspection of data in the two left figures show that Friday and Saturday data are more nearly the same than data for Saturday and Sunday. For Ohio Site 15, the data suggests that a more appropriate grouping of days should be "Sunday through Thursday" as "weekdays" and "Friday and Saturday" as "weekends" as shown in the right two figures.

Traffic Volume

During this research, total daily traffic seemed to be nearly the same regardless of the day of the week. The difference between "weekdays" and "weekends" occurs in vehicle usage during those days. For example, for most sites, car and pickup truck volumes (vehicle classifications 2 and 3) are less during Mondays through Fridays and more on Saturdays and Sundays while the reverse is true for heavy vehicles (vehicle classifications 4-13). Is this usage pattern always true? Figure 31 suggests that there are sites such as this one where there are differences in total volume. The upper figure is displayed as volume of axles and the lower figure shows the same data in terms of percentages. Figure 31 suggests that each site might need to be investigated to determine which pattern is more correct—relatively equal or different volumes.

Percent Axles as Function of Daily Total Axles

Figure 32 contains two figures for California sites. The top figure represents a compilation of data for seven sites on designated Functional Class 1 highways. The bottom figure is a compilation of data for two sites on designated Functional Class 2 highways. The basic pattern is the same for the two figures. The bottom figure is chosen for discussion because the pattern is easier to see. For a given site, the percentage of axles for vehicle classifications 2 and 9 are assigned different symbols for "weekend" and "weekday" data. While there appears to be a distinct pattern of percent axles vs total axle volume in the bottom figure, the top figure suggests that extreme caution be used before saying that there is a distinct pattern for each Functional Class of highway. Data for Functional Class 11 sites in California were grouped in the same manner as shown in Figure 32. The top figure contains data for the outer lane at four sites. The middle and bottom figures contain data for five other sites, but separated into figures for "Inner Lane" and "Outer Lane" (middle and bottom figures, respectively). The same comments for Figure 32 apply to Figure 33. Figure 34 presents the same analyses for three California sites on Functional Class 12 highways and the same patterns are shown as in Figures 32 and 33. In his review, Mr. Dahlin stated, "...some of the data are shown for individual lanes. Data for individual lanes speak to the issue of distribution of traffic by lane. However, lane data should not be used in analysis of functional class." He may be very true, but for some sites, lane data may be all that is available for a particular functional class. For example, in Kentucky, many highways in Functional Class 2 are two-lane pavements, yet some have three or four lanes. This example also points out that a better grouping of sites might include a method that also recognizes the number of lanes.

Data for each site should be analyzed before saying that there is a distinct pattern for that site. After analyzing the data for various sites, it might be possible to sort the sites into distinct patterns, but the grouping of sites might cross over Functional Class designations. This conclusion simply supports the concept that highways are assigned to various Functional Classifications primarily, but not necessarily, according to "political, or budget" groups. Such assignations are necessary for other DOT operations but may not be the most appropriate in terms of "traffic characteristics". Developing a category of groupings by traffic characteristics is beyond the scope of this investigation but does provide an interesting idea for future research.

Percent Axles for Various Vehicle Classifications vs Percent Axles for Vehicle Classifications 1-3 Combined

Data were collected almost continually for Minnesota Site 55 January through December 1992 except for a few days scattered throughout. The month of June was missing entirely. Data for the five months of January through May were grouped by:

1) vehicle classifications 1-3 combined,
2) vehicle classification 2,
3) vehicle classification 9,
4) vehicle classification 4-13 (excluding 9), and
5) vehicle classification 4-13 (including 9).

Figure 35 contains three figures. The top figure represents data for January, the middle figure for February and March combined, and the bottom figure for April and May combined. In addition, data by groupings 1-3 and 5 above were separated into "Weekday" and "Weekend" groupings and are shown by different symbols in the three figures. A distinct pattern is shown in all three figures but the bottom figure is easier to see and has been chosen for the following discussion. For Vehicle Classification 9 (five-axle semi-trailer truck), the "open circle" symbol and the "+" symbol represent "Weekday" and "Weekend" data, respectively. For "Weekend" data, the percentage of axles for VC 1-3 generally are higher than for "Weekdays". Also, a trend line could be drawn through the "+" points that would be distinctly different than a similar line through the "open circle" points. For discussion purposes, for a VC 1-3 percentage of 70 percent, the "+" symbol is approximately four percent greater than for the "open circle" point. It seems logical that the axle percentage for VC 9 classifications should be higher on weekends because the number of larger vehicles decreases more proportionately than for VC 9. Another explanation is that VC 9 trucks are more apt to be long-haul trucks and the other large vehicles are used more for "local" hauling. The exception to this might be for a portion of the VC 11 and 12 vehicles if the site is on a Functional Class 1 highway. Even then, their usage decreases over the weekend. Movement of goods also helps explain the drop in usage of VC 11 and 12 over a weekend. For example, an industry may need to ship goods that would not fill a full-sized semi-trailer (say a 48-foot trailer), but would fill a short single-axle trailer (28-foot) that may be combined with another short trailer to produce a VC 11 or 12 vehicle. An imaginary trip might consist of two short trailers being fully loaded in Seattle, WA with one designated to go to the Portland, OR area and the other to go to San Francisco, CA area. A typical run might be to pull the two trailers to the Portland terminal where they would be separated. Another short trailer might be fully loaded in Portland for a San Francisco area business. The San Francisco trailer from Seattle could be combined with the San Francisco trailer loaded at Portland and the two pulled to San Francisco. This run might occur during a weekday or a weekend depending upon the particular trucking firm. Some trucking firms have scheduled runs over the weekend and other firms never run over the weekend. This pattern has been observed on interstate routes in Kentucky. The obvious advantage is that once the trailer is loaded, it does not require the load to be unloaded and reloaded at an intermediate terminal. This amounts to savings in time and money.

For verification of the concept employed in Figure 35, three tables of AVC vehicle count data were processed identically to the method used to obtain Figure 35. The three tables were published in the Georgia DOT Report No. GDOT 9210, June 1995, "Accuracy of Traffic Monitoring Equipment". The three tables were Nos. VII, XVII, and XXIV and are data for equipment from three different manufacturers.

	Percent Axles	Percent Axles
Table No.	VC 1-3	VC 9
VII	62.0	30.5
XVII	61.2	29.5
XXIV	63.4	24.8

Considering that the test month is not known, these results agree remarkably well with the bottom figure in Figure 35 and suggest that the approach is valid. For another classifier, the calculated percent axles for VC 1-3 vs percent axles for VC 9 very nearly matched for both "ground truth" data and the classifier, but both points did not fall within the band of data shown on the bottom figure of Figure 35. Inspection of the data in that table showed that the traffic stream was very different from the one corresponding to the bottom figure of Figure 35. Thus, the correlation for that one classifier was very good, but just not comparable to the other three classifiers or to the data in Figure 35 , but that is just fine.

Other tables in the Georgia Report do not give as good agreement but neither was the accuracy of the equipment compared to "ground truth" data that was obtained by a camera. The Georgia Report No. 9210 contained data for 14 counter-classifiers taken over a 7-day period. These data were converted to axles and Figure 36 shows the results. Note that the total axles for six counters had accuracies of approximately 90 % or more. What is the definition of "ground truth data" used in the Georgia Report? As an integral part of that study, a video camera was used to record the same traffic stream classified and recorded by each classifier. Accuracy of the counter was determined as a function of the stream recorded by the video camera.

Figure 36 illustrates the tremendous lack of correlation between "ground truth" data and data obtained by most of the counters for Vehicle Classifications 2 and 3. It is not surprising that there is a poor correlation for VC 2 and 3 because these classifications are based on the number of axles and the spacing between them. Both of these types, cars and pickups, have very similar spacings. Therefore, for this study, data for VC 1, 2, and 3 were combined. VC 1 was combined because usually there are so few in the traffic stream that their effect is negligible. However, the surprise came in the lack of correlation of results for VC 9, five-axle semi-trailer trucks, for most counters. Note that for one counter, not a single VC 9 vehicle was recorded by the classifier. For VC 1-3 (diamond points) nine of the fourteen had accuracies less than 75 percent. One might conclude that calculating historical traffic streams is an act of frustration if the counter cannot have any better accuracy than that shown in Figure 36. It is no wonder that most state DOT agencies have trouble estimating when pavements need structural overlays if those schedules are based on traffic forecasts that are based upon counter data. AVC counter data is the real backbone of most DOT data collection efforts because the equipment is far less expensive than WIM equipment. Long Term Pavement Performance (LTPP), a part of SHRP, requires State DOTs to collect data one week per year once every three years. If the data collected has no better accuracy than most of the counters displayed in Figure 36, LTPP personnel are really going to be frustrated. Figure 36 illustrates the real requirement for equipment calibration efforts. **It is very necessary to ensure that data recorded by the classifier is correctly entered into the computer file. However, it is far more important that the classifier record what is in the traffic stream. Bad data is almost worse than no data because it can be so misleading.**

Chapter 4

Conclusions

The VTRIS Computer Program has been proven to be a very valuable tool for the following.

1) To reduce vast amounts of traffic volumes and related ESALs to manageable quantities.
2) To convert vehicle volumes to number of axles for each vehicle classification and obtaining totals for that time period.
3) To produce average ESALs per vehicle for vehicle classifications 4 through 13.
4) To calculate the total ESALs for that time period.
5) To review the average ESALs per vehicle to determine peculiarities at a site for:
    a. unusual usage of a particular vehicle classification,
    b. to flag unusually high ESALs that may be a direct function of commodity,
    c. to determine if a scale has drifted out of calibration, particularly of there is another site installation in the other direction, and
    d. comparing ESAL per Axle for particular vehicle classifications to evaluate the classification that produces the most and/or least fatigue per trip.
6) To determine relationships by lane, and direction.
7) To develope ESAL vs Axle relationships for weekdays and weekends that have been proven in this research to be one of the most influential variables.
8) To analyze average ESALs per day by day of week to determine the combination of days that make up a "traffic weekday" and a "traffic weekend" that may be different than the usual "Monday through Friday" week and "Saturday and Sunday" weekend.
9) To use the "ESAL per Axle" grid system to:
    a. evaluate daily values, and
    b. determine if there are seasonal effects due to unusual axle loads, and
    c. to show differences between, and within, Functional Class Highways.
10) To develop various comparisons of traffic volume and vehicle classifications such as:
    a. converting volumes of axles to percent of total axles for each vehicle classification,
    b. development of percent axles for a class vs total volume of axles for each day,
    c. development of percent of axles for the sum of vehicle classes 1-3 vs percent axles for other vehicle classifications, and
    d. permitting the possibility of comparing those relationships in 10c above by Functional Class of Highway for significant variations. These comparisons were not

made during this study, but the concept shown in Figure 35 certainly permit these analyses. However, such analyses do require the collection of data for far more than one week or even one month. If seasonal effects may be involved, then the comparison of results by Functional Classes must be for the same time period. It is very conceivable that results will and should be different according to characteristics of the traffic stream. For instance, routes primarily used by cars, pickups, and lighter delivery trucks will have a different traffic stream than those for which large trucks that serve quarry or grain operations. Thus, percent axles for these vehicle classifications will be less or more, respectively for the same traffic volume.

11) To convert AVC data to percent axles allows the development of distribution factors that may be applied to axle count data to make rough estimates of vehicle classification percentages.
12) To make a **rough estimate** of the number of truck axles to estimate corresponding ESALs.

Mr. Dahlin took exception to 5c above. "I disagree with this statement. VTRIS can indicate when patterns change, but this change may or may not have actually taken place. In my opinion, the calibration issue can be addressed either by using a test truck, and even this has problems, or by using front axle weights and/or distribution of gross weights for Type 9's." After our conversation, Mr. Dahlin understood that this research again is simply an attempt to flag some possible problem area, but the true problem may not have been identified. Also, agreement was reached that another possibility would be the addition of an industry or some other economic factor was added since the previous data collection effort. For this report, item 5c above should be true if the "ESAL per Vehicle" in one direction for all vehicle classifications is different from the opposite direction. Mr. Dahlin would be very correct if the ESAL per Vehicle in one direction were the same for some vehicle classifications but different for others in the other direction. Regardless, VTRIS can be used to determine if something is different—whatever the cause.

Mr. Dahlin also states, "Some types of analysis may be simpler to do by looking at vehicle types" and that is true. However, Mr. Dahlin was reminded that one major goal of this effort was to be able to utilize axle count data with results from analyses of WIM data. The only real advantage of converting to axles is that in dealing with vehicles, the scatter may be a relatively short rectangle with fair scatter while converting to axles would lengthen the rectangle in only one direction. Thus, some increase in "accuracy" might be achieved.

For AVC data, in this study it appears that converting the number of axles for each vehicle classification to percentages reduces errors in extrapolation that may occur by using volumes of axles. Applying percentages to total volume of axles should minimize potential incorrect estimates that might occur when dealing with just volumes of axles.

Data for each site should be analyzed before saying that there is a distinct pattern for that site. After analyzing the data for various sites, it might be possible to sort the sites into distinct pattern, but the grouping of sites might cross over Highway Functional Class designations. As an illustration, an urban interstate traffic stream for moving economic goods will be very different than one for primarily moving commuters. Likewise, for Functional Class 2 highways, an older route that is paralleled by a rural interstate may have a totally different traffic stream than one serving an outlying industry such as quarries or large warehousing and distribution centers. Such groupings to permit better analyses of similar traffic streams should be more beneficial in helping make budget estimates within each Functional Class of Highway. Estimates of pavement fatigue and future maintenance or reconstruction needs might be made to establish priorities for various sections within the same Functional Class of Highways.

Subjects Requiring Local Analyses Before Use by VTRIS

ESAL calculations for unusual truck-axle configurations may result in wider scatter, but not much wider.

The reader is cautioned to make his/her own comparison of the two sets of ESALs before accepting the results of Figure 4 for general use.

Each lane has its own instrumentation and both AVC and WIM require each set of equipment to have its own calibration for both AVC and WIM.

Seasonal effects are highly dependent upon the site and should be treated individually.

Trying to use one week of "ESAL vs Axle" data to represent an entire year can yield results that truly may not represent the entire year. Also, trying to make general conclusions about traffic and pavement fatigue for particular Functional Classes of highways is very risky. This research showed that there is not one trend for a rural interstate, but that relationships for a lane are site specific.

The number of axles calculated from AVC data should be adjusted to an "equivalent" number of axles appropriate to WIM data to prevent calculating an excessive number of ESALs.

Each site should be analyzed to determine the combination of days that constitute a "traffic weekday" and a "traffic weekend" because the combination of calendar days may be other than the traditional "Monday through Friday" and "Saturday and Sunday", respectively.

Figure 32 shows that an analyses of percent axles vs total axle volumes should be made to determine if there is a distinct pattern for each Functional Class of Highway.

It cannot be emphasized enough that calibration at the time of installation all equipment is absolutely essential to obtain good data. Equally important is to monitor the recorded to determine if patterns have changed for whatever reason, one of which might be a requirement of re-calibration. VTRIS has been shown to be a valuable tool to determine if patterns have changed. Some logical reasons have been presented for obvious changes in the patterns of the data. However the suggested reasons may not be the actual reason. Minnesota site 2911 is a perfect example—seasonal changes had been suggested initially, but actual field inspection had revealed a large crack in the pavement that affected the piezo sensor and the recorded data.

W-4 TABLE
EQUIVALENCY FACTORS
By Lane

State: MN
Period: 06/01/92 To 06/01/92
Functional Class: 11
Averaging Method: Hour of Day

Axle Grouping Method: Vehicle Size & Weight
Station Code(s): 3311

Rigid Pavement P = 2.50 D = 228 mm

Vehicle Class No.	ESALs Per Vehicle	Percent Distribution Using Average Daily Count
3	0	0
4	0.5055	1.07
5	0.0686	2.07
6	0.6471	4.38
7	1.5018	1.31
8	0.3444	2.46
9	1.7001	81.65
10	0.806	1.21
11	1.3543	4.75
12	1.0644	1.06
13	3.5448	0

Flexible Pavement P = 2.50 SN = 127 mm

Vehicle Class No.	ESALs Per Vehicle	Percent Distribution Using Average Daily Count
3	0	0
4	0.469	1.49
5	0.0701	3.17
6	1.4029	4.09
7	1.2189	1.6
8	0.3313	3.55
9	1.0592	76.26
10	0.5037	1.13
11	1.3925	7.33
12	0.8948	1.34
13	2.3455	0

Vehicle Class No.	AVERAGE VEHICLES WEIGHED	AVERAGE VEHICLES COUNTED	Percent Distribution OF AVERAGE DAILY COUNT BY TRUCK TYPE
3	0	2,172	
4	15	17	
5	215	241	30.51
6	52	54	6.84
7	8	7	0.89
8	51	57	7.22
9	361	383	48.48
10	8	12	1.52
11	27	28	3.54
12	8	8	1.01
13	2	0	0

	TOTAL
AVERAGE VEHICLES WEIGHED =	747
AXLES =	2,902
RIGID PAVEMENT ESALs =	757.9145
FLEXIBLE PAVEMENT ESALs =	505.5525

Note: 20-Year ESAL Estimate Growth Rate Tables have been purposely omitted from this Figure, but are a part of the W-4 Table output from VTRIS.

Figure 1. W-4 Table Equivalency Factors

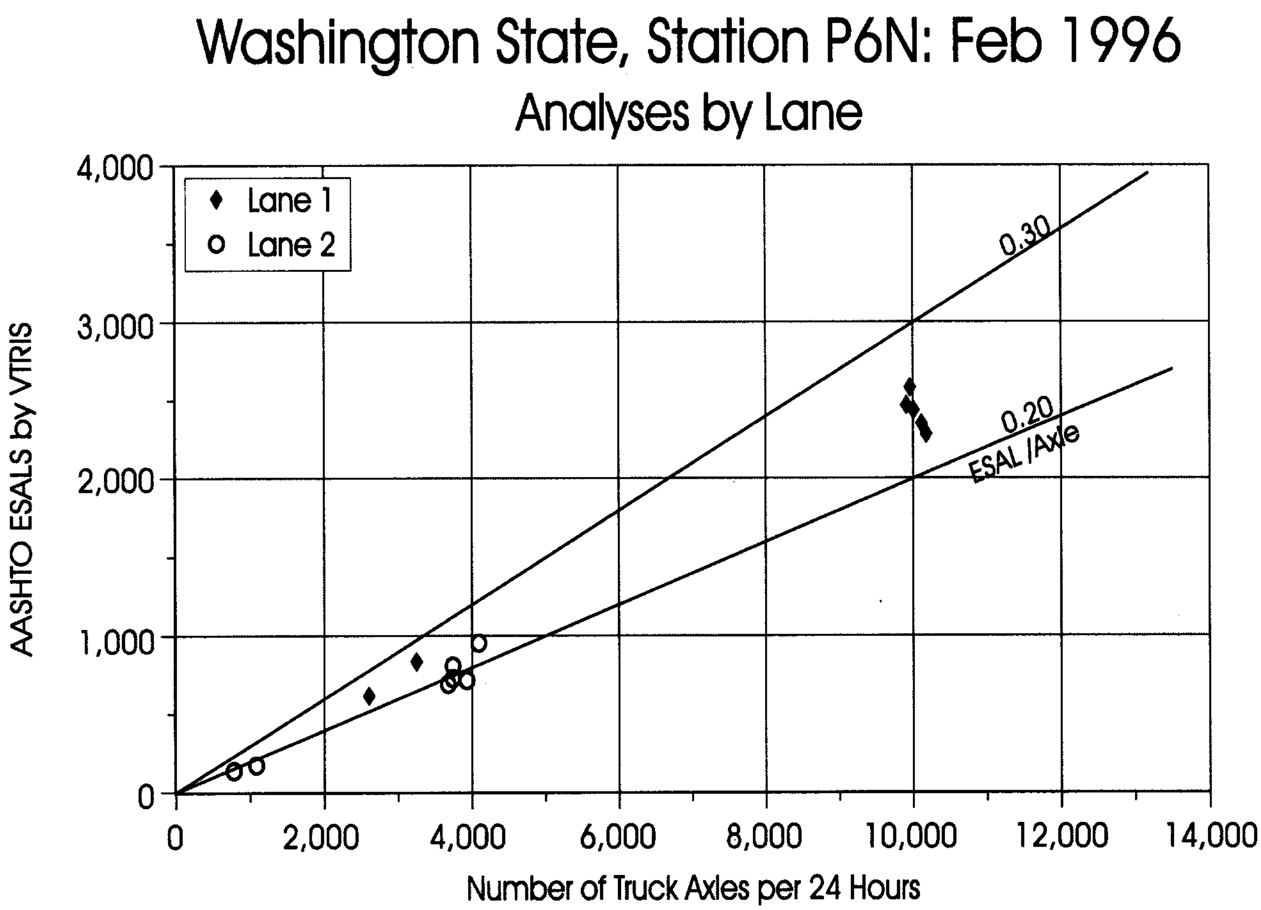
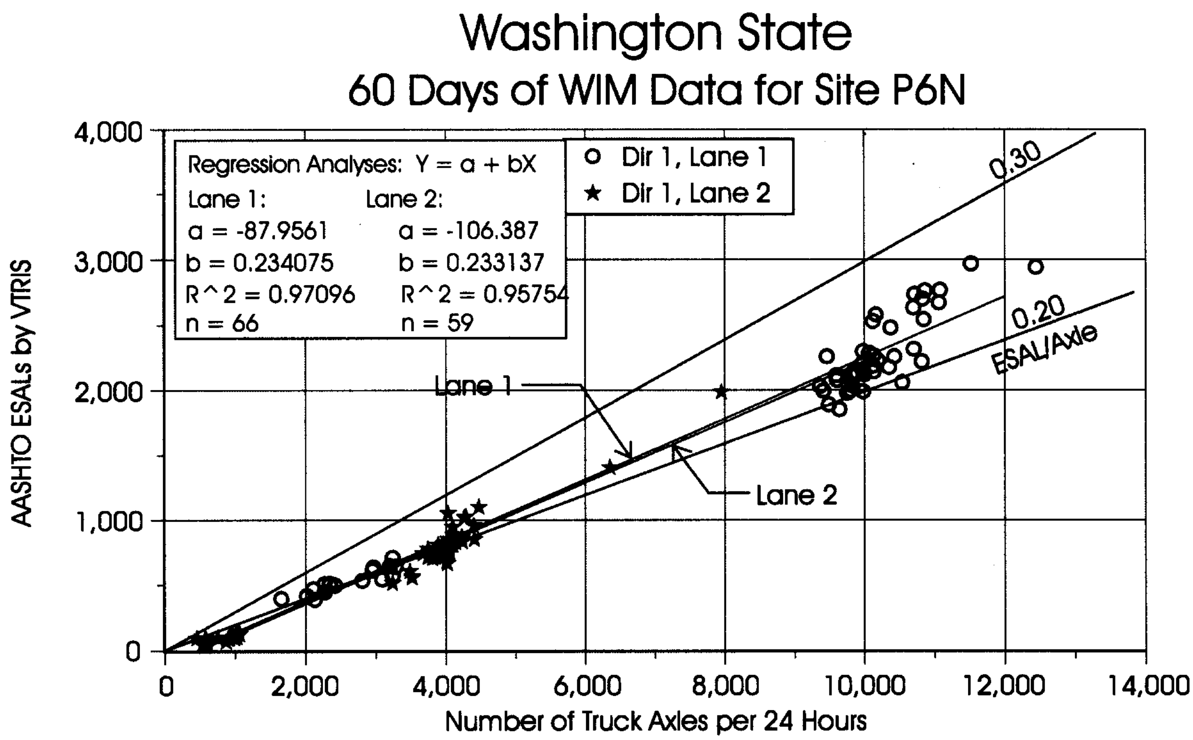


Figure 2. Washington DOT Site P6N, One Week of Data per Lane



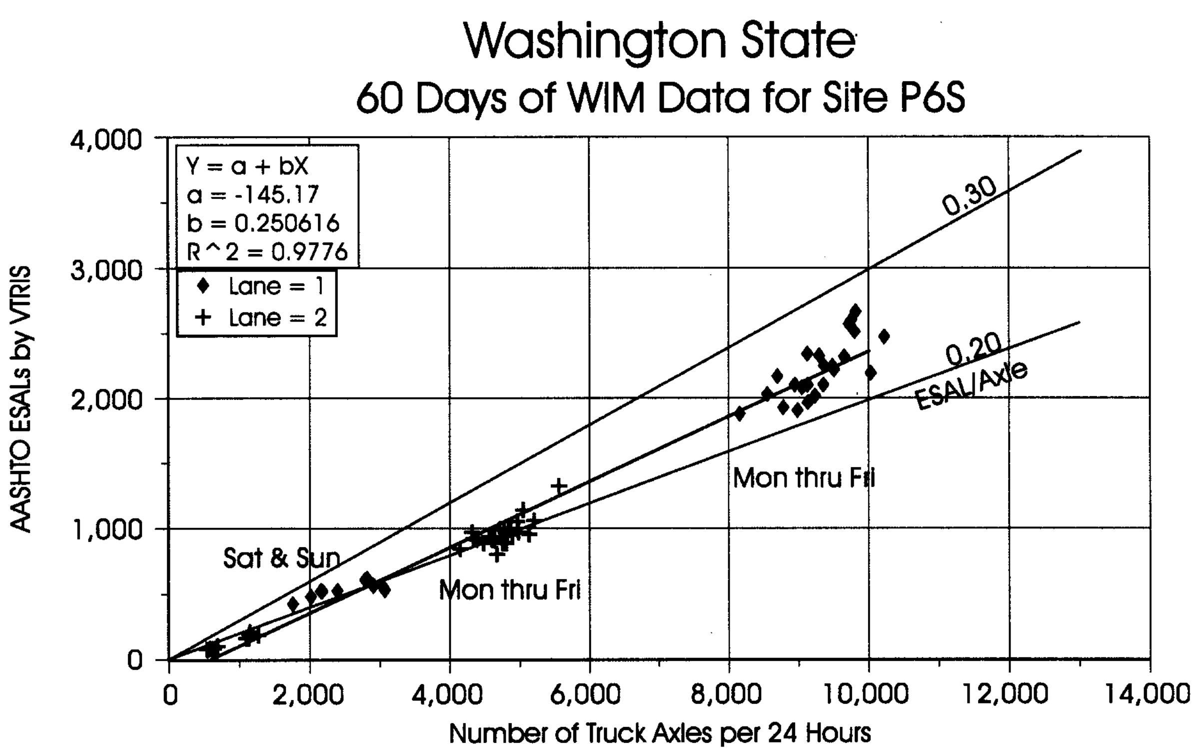
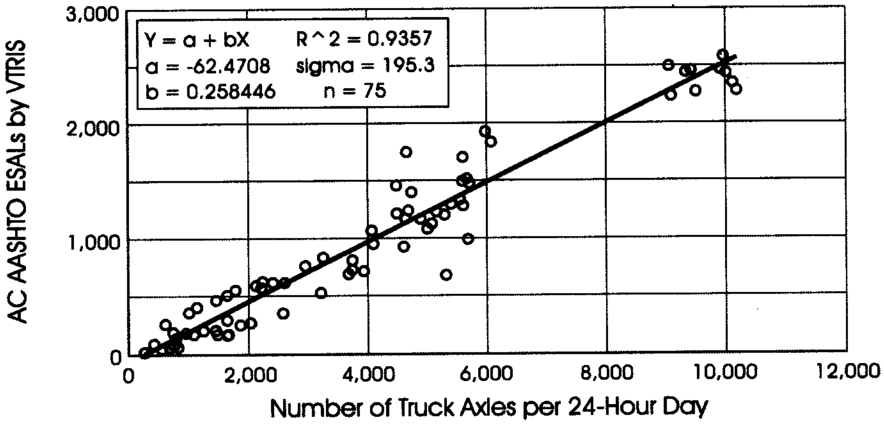
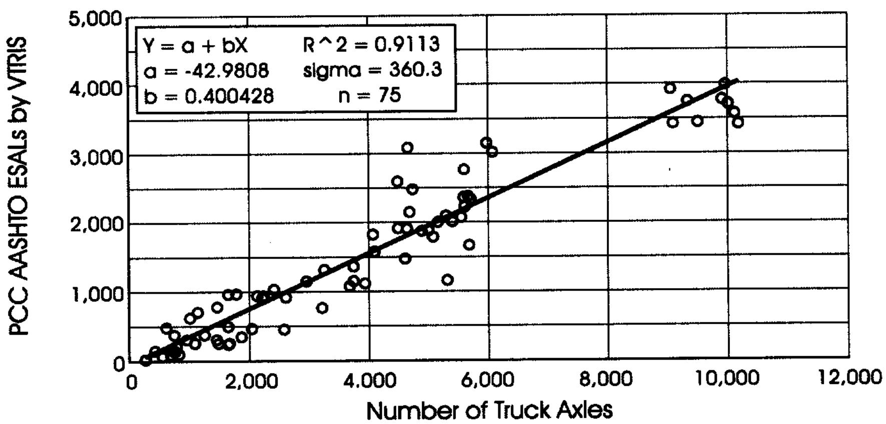


Figure 3. ESALs vs Axles Relationships for 60 Days of Data

Washington State
Functional Class 12, February 1996



Washington State
Functional Class 12, February 1996



Washington State
Functional Class 12, February 1996

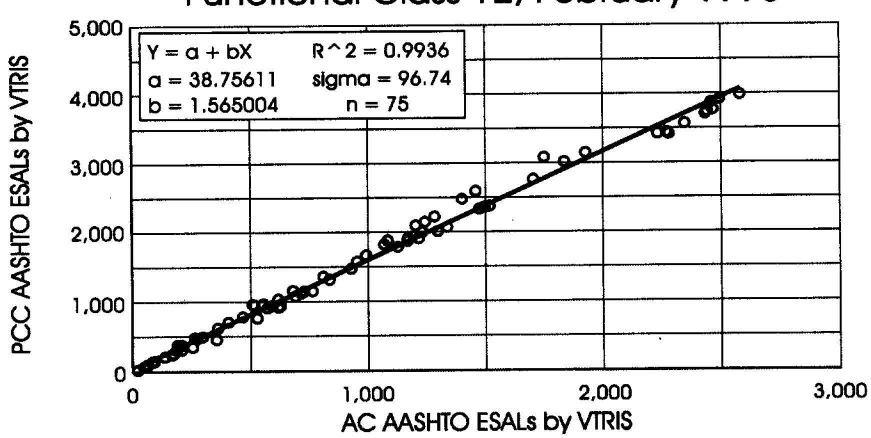


Figure 4. Relationship of Flexible to Rigid ESALs

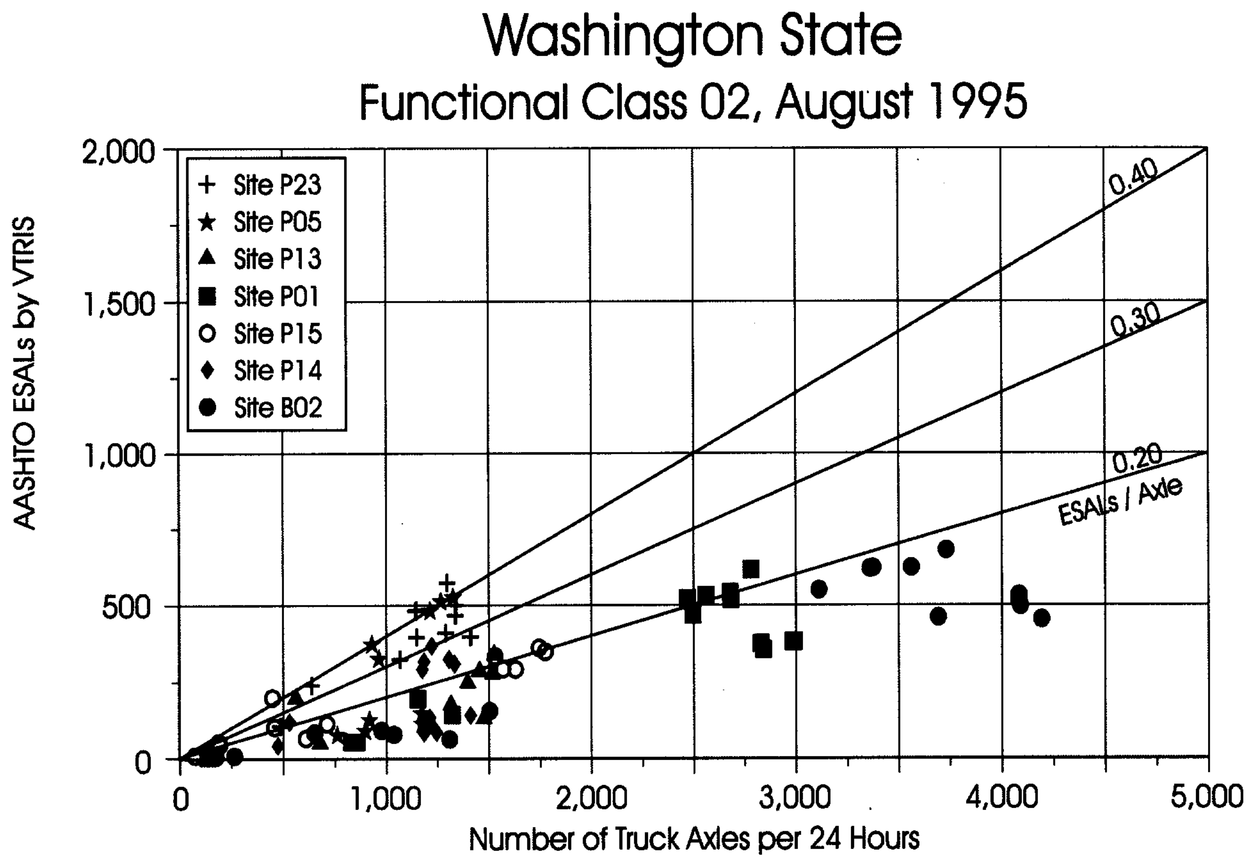


Figure 5. ESALs vs Axles for August 1995 for Functional Class 2 Sites, WADOT

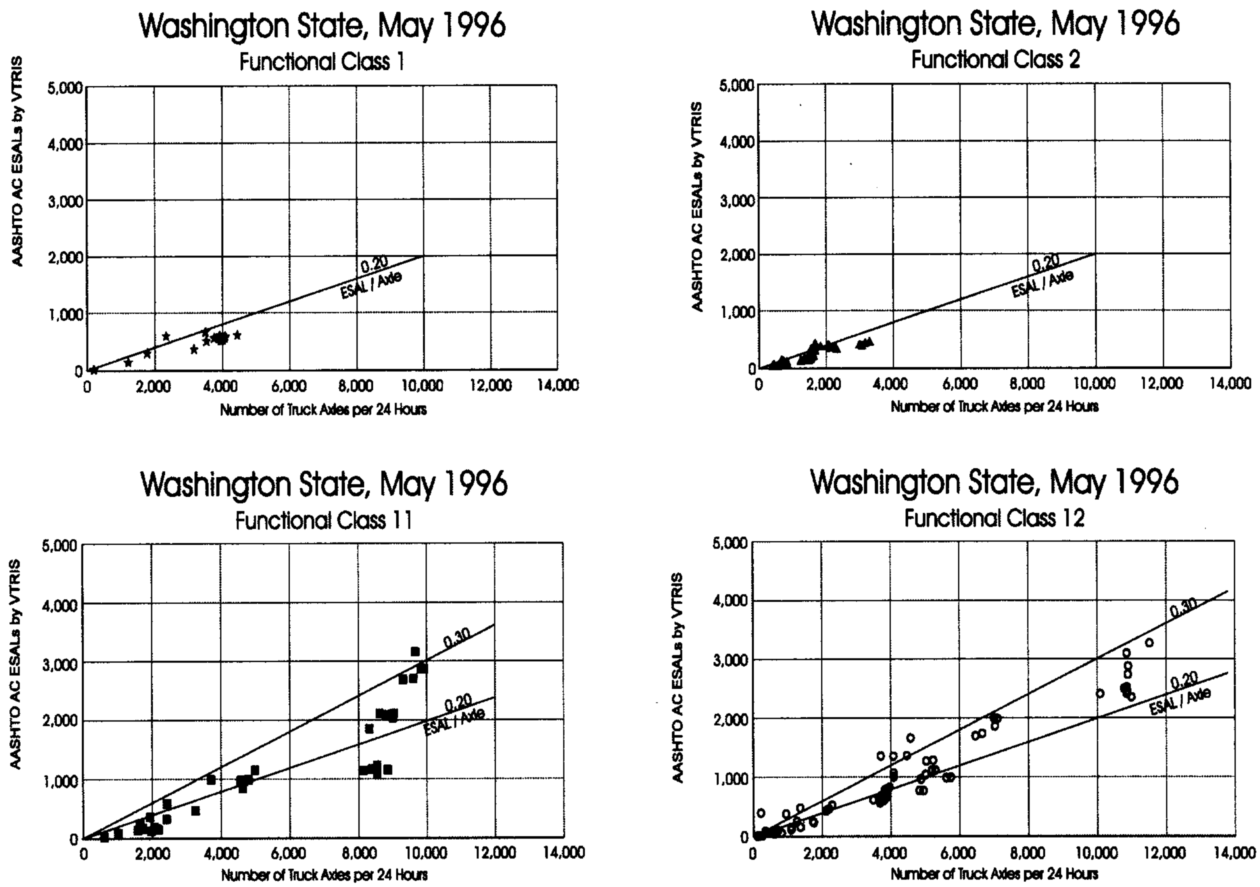


Figure 6. WADOT May 1996 Data: ESALs vs Axles for Functional Classes 1, 2, 11, and 12

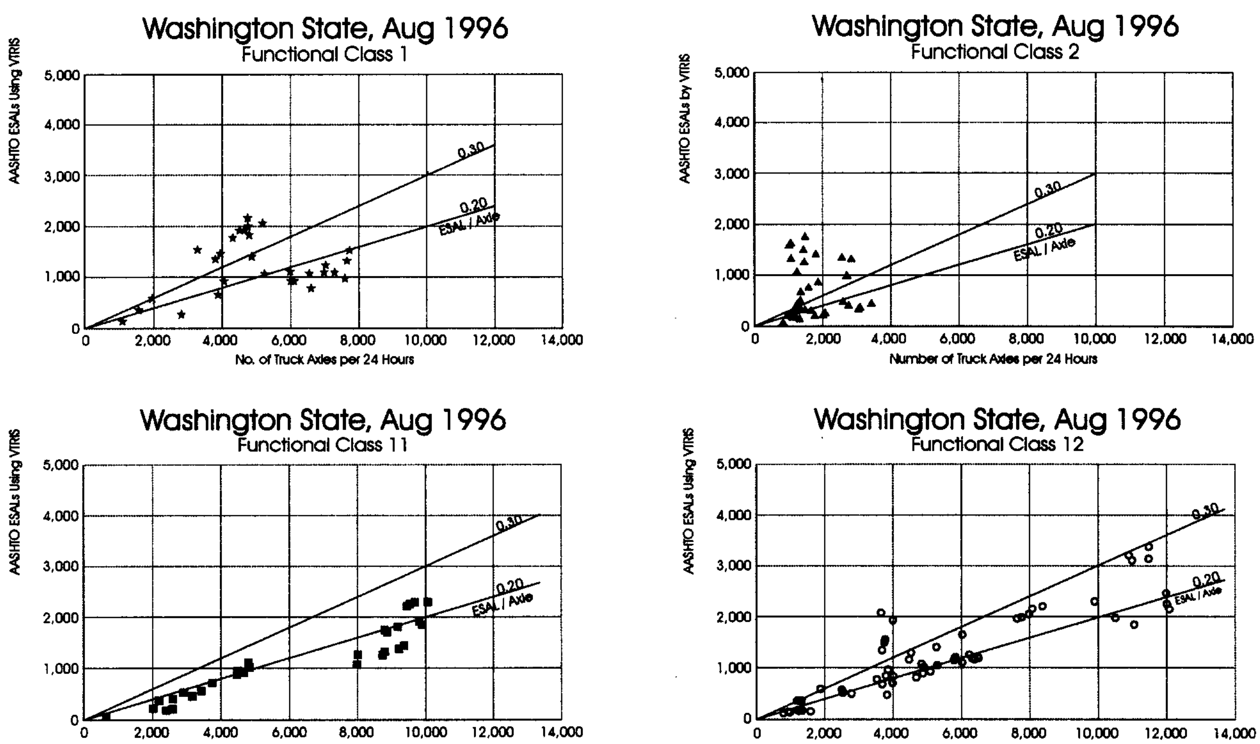


Figure 7. WADOT August 1996 Data: ESALs vs Axles for Functional Classes 1, 2, 11, and 12

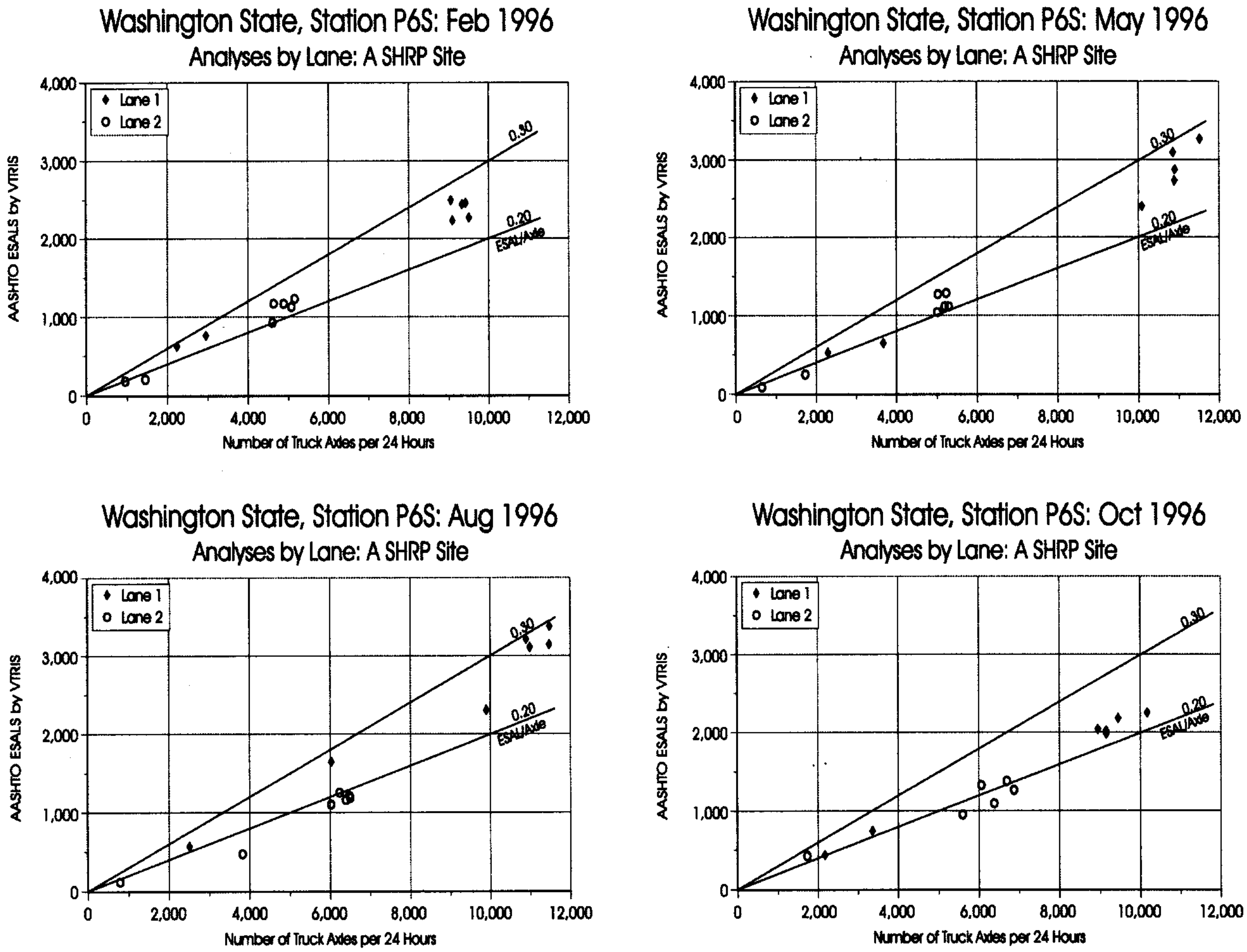


Figure 8. Analyses by Lane for SHRP WADOT Site P6S

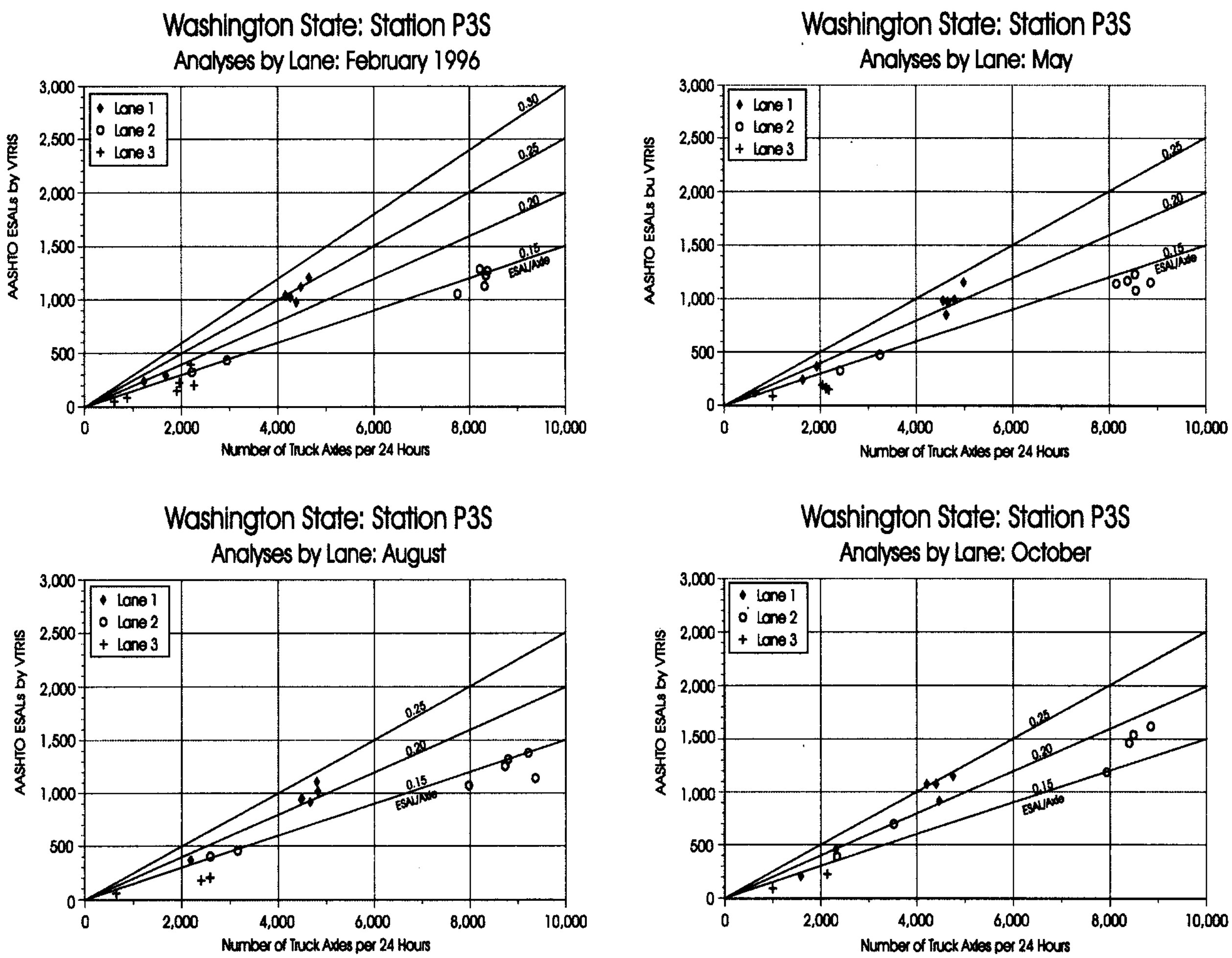


Figure 9. Analyses by Lane for WADOT Site P3S

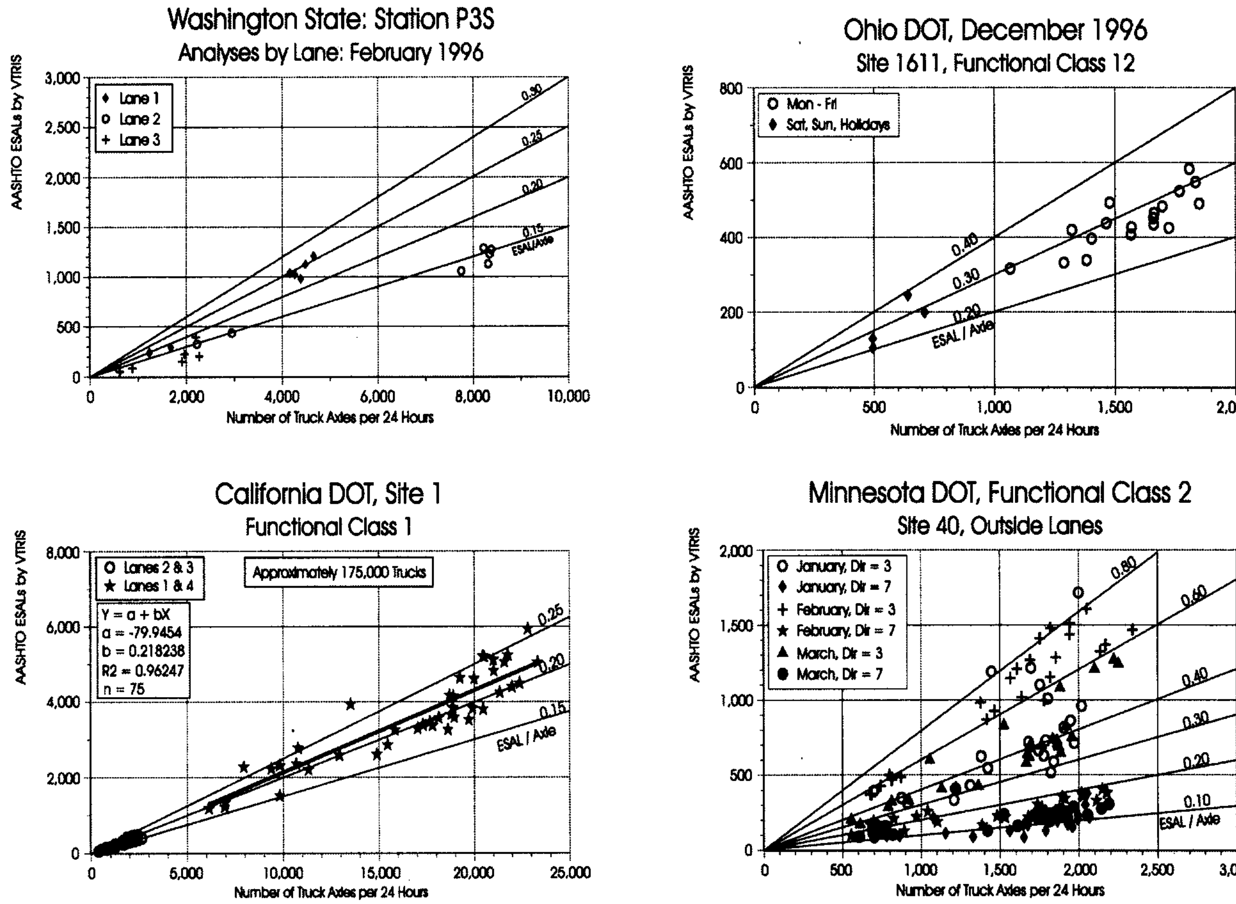


Figure 10. ESAL vs Axle Relationships for Ohio, Washington, California, and Minnesota

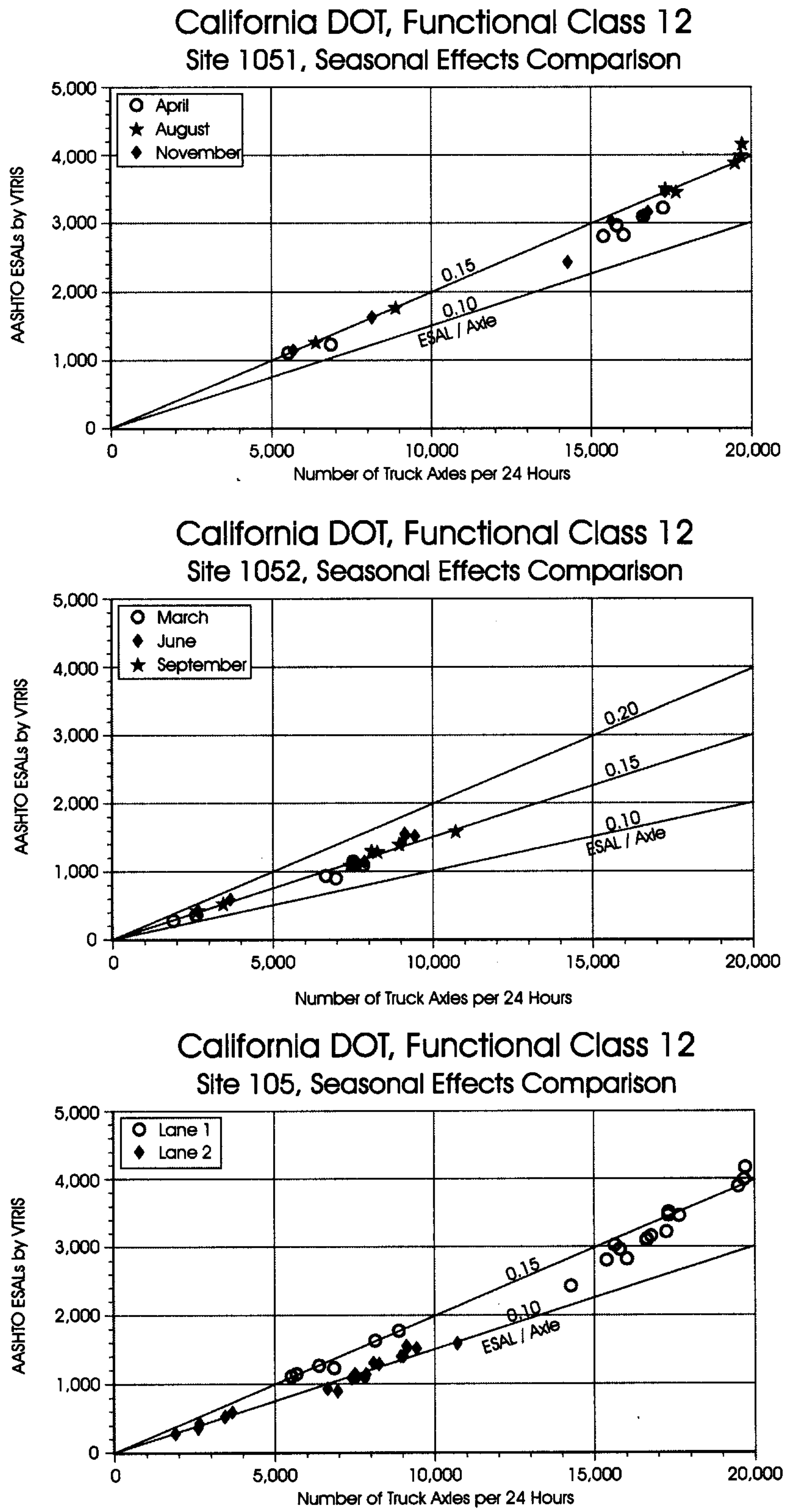
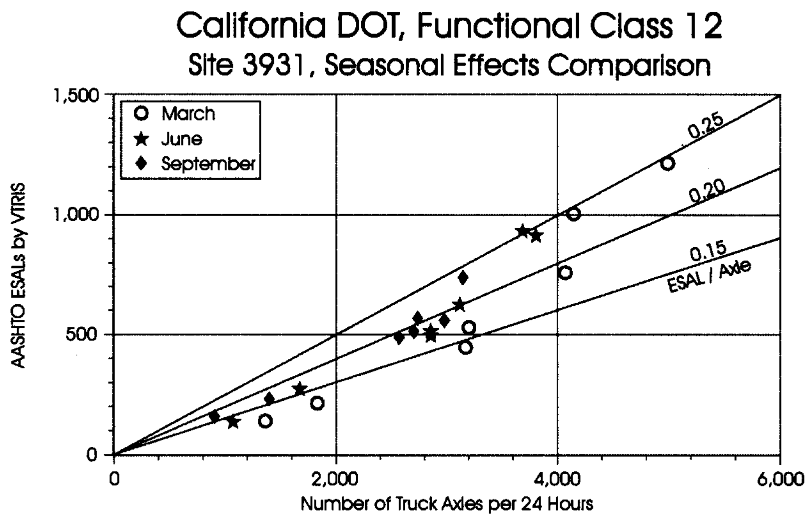
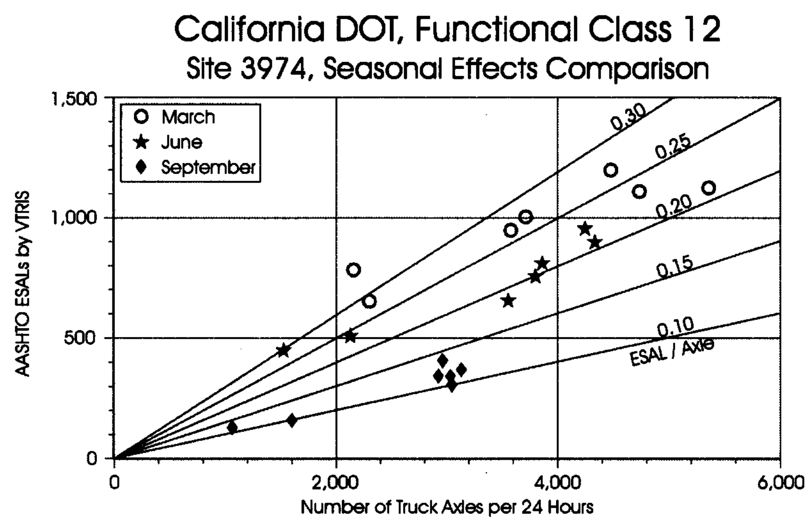


Figure 11. Seasonal Effects Upon ESALs vs Axles Relationship for CADOT Site 10





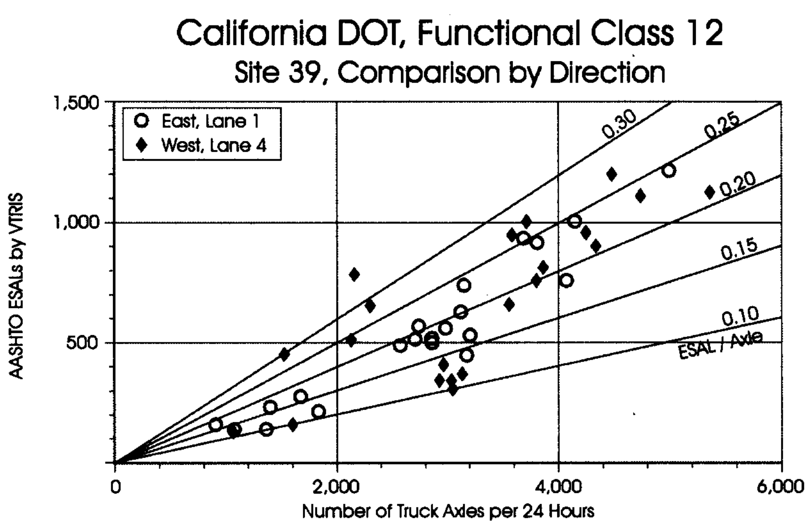


Figure 12. Effects of Season and Direction upon ESAL vs Axle Relationships, CADOT Site 39

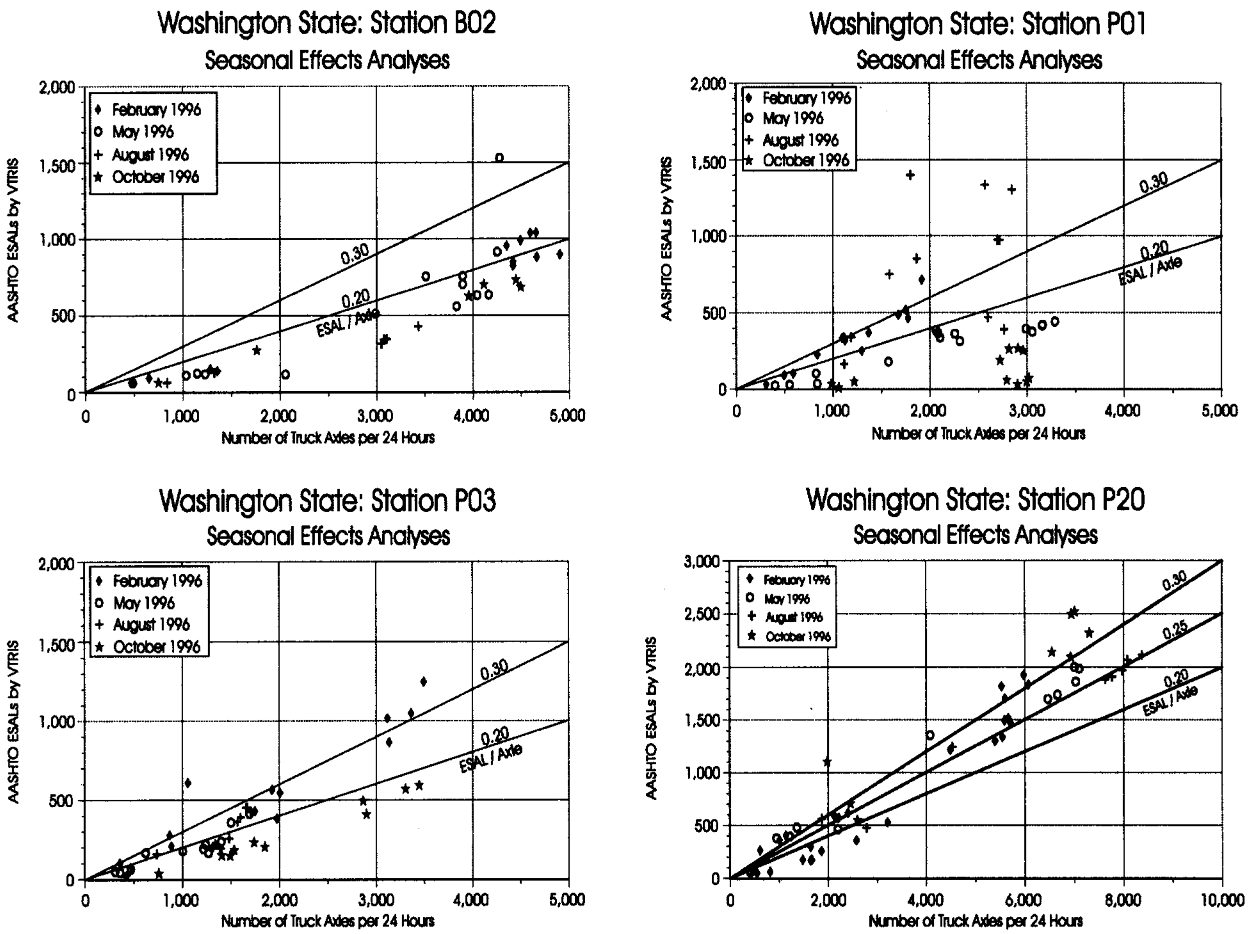


Figure 13. Seasonal Analyses for Sites B02, P01, P03, and P20

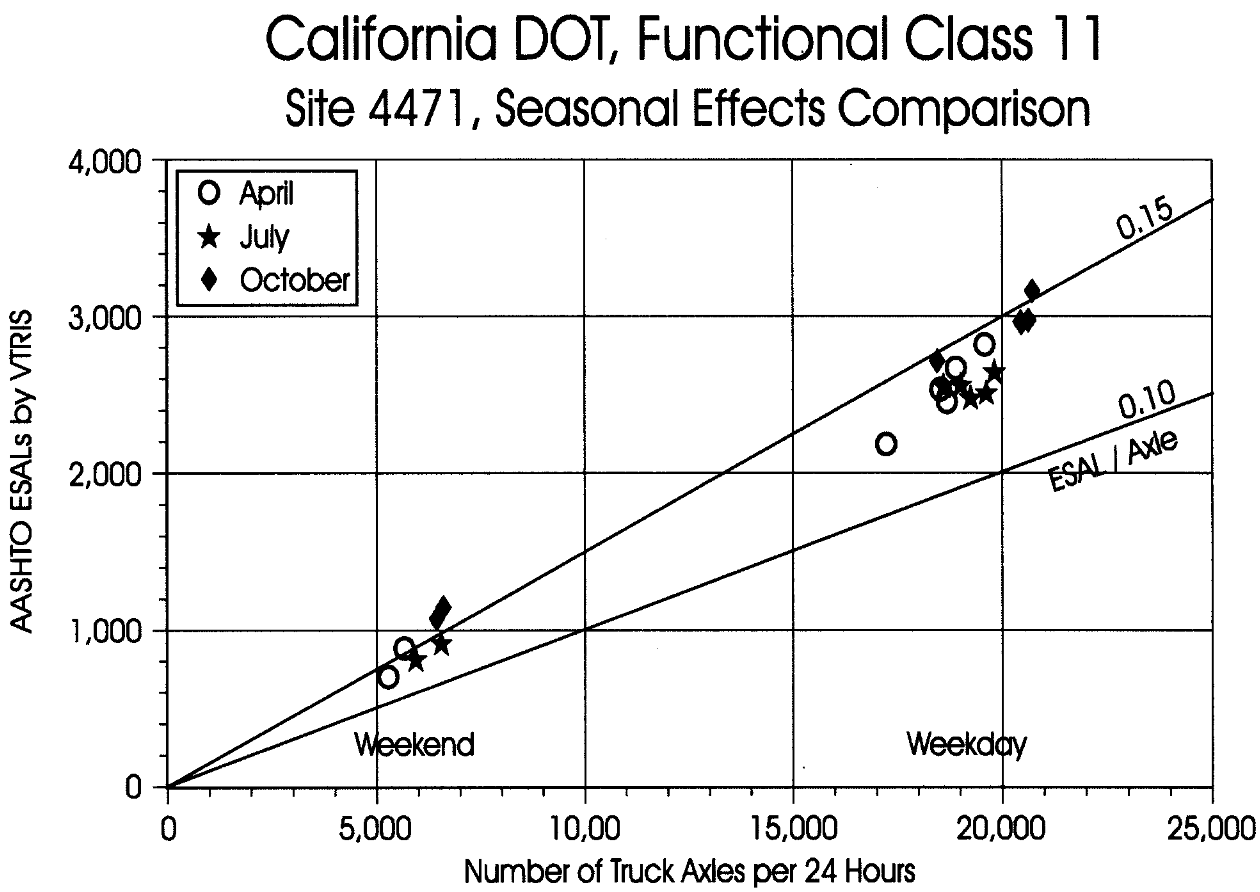


Figure 14. ESAL vs Axle Relationship for CADOT Functional Class 11, Site 44

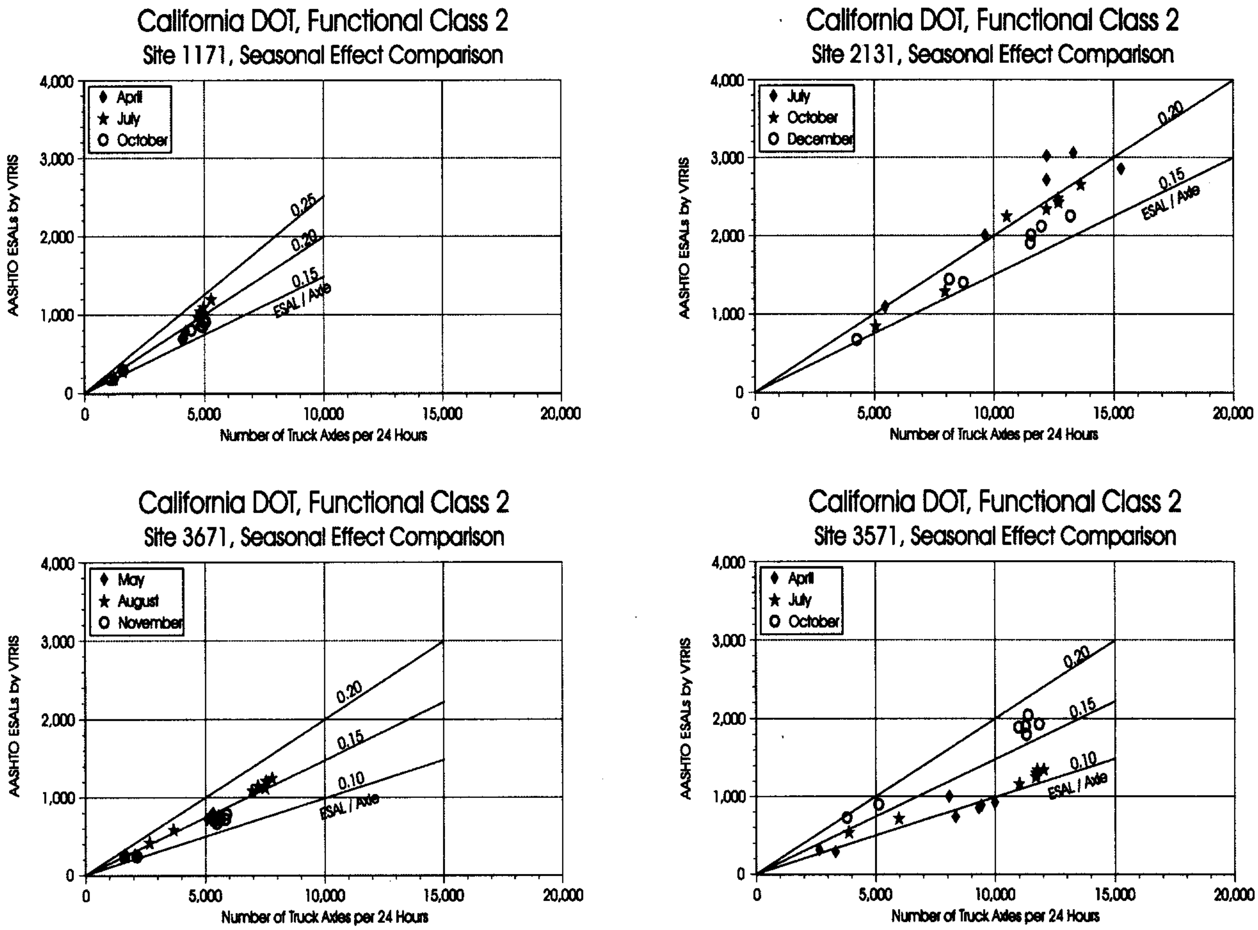


Figure 15. Seasonal Effects Upon ESALs vs Axle Relationships for Four CADOT Functional Class 2 Sites

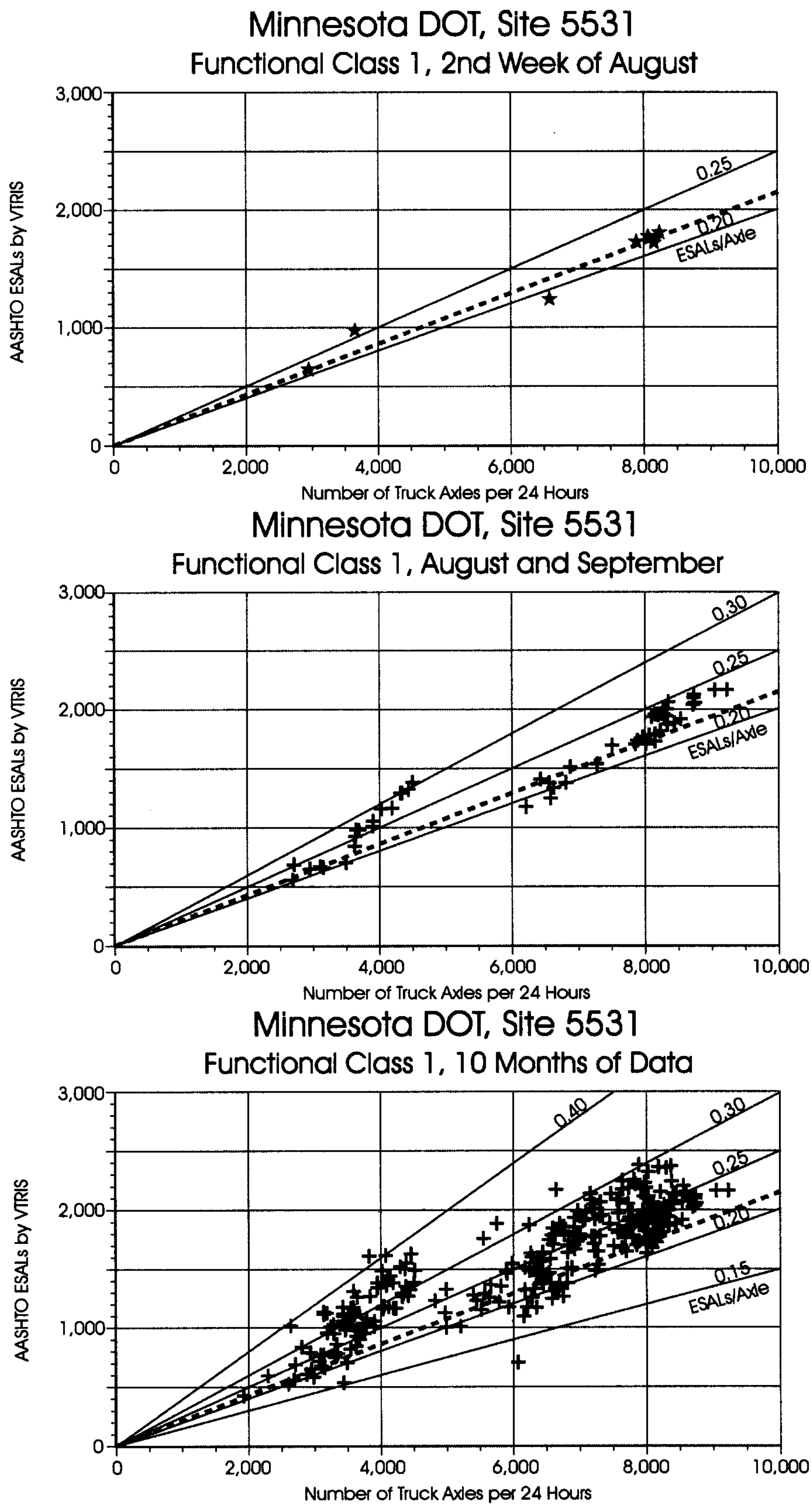


Figure 16. Variation in Traffic Data With Time

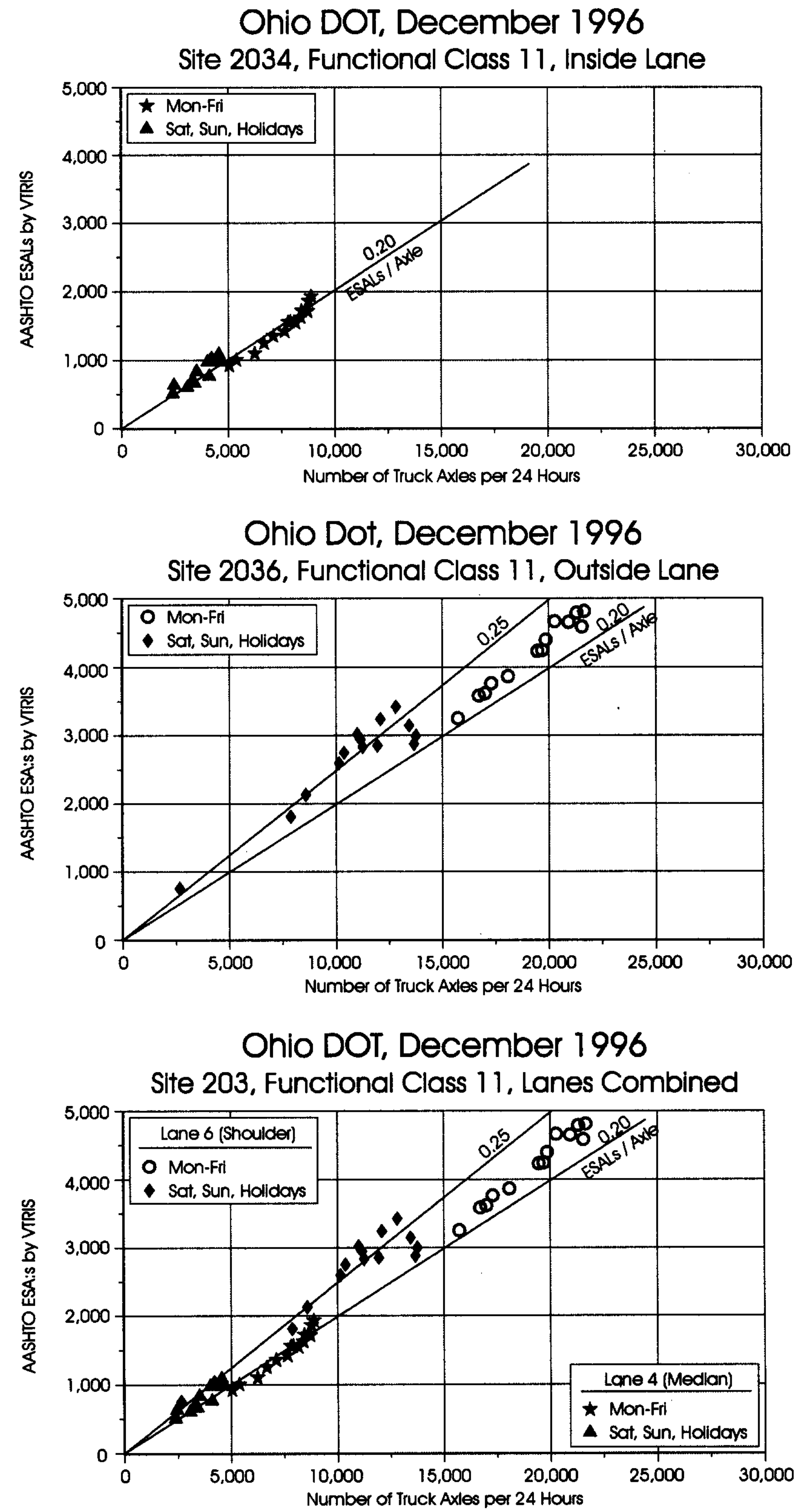


Figure 17. ESALs vs Axle Relationship for OHDOT Functional Class 11 Site 20, Weekday vs Weekend

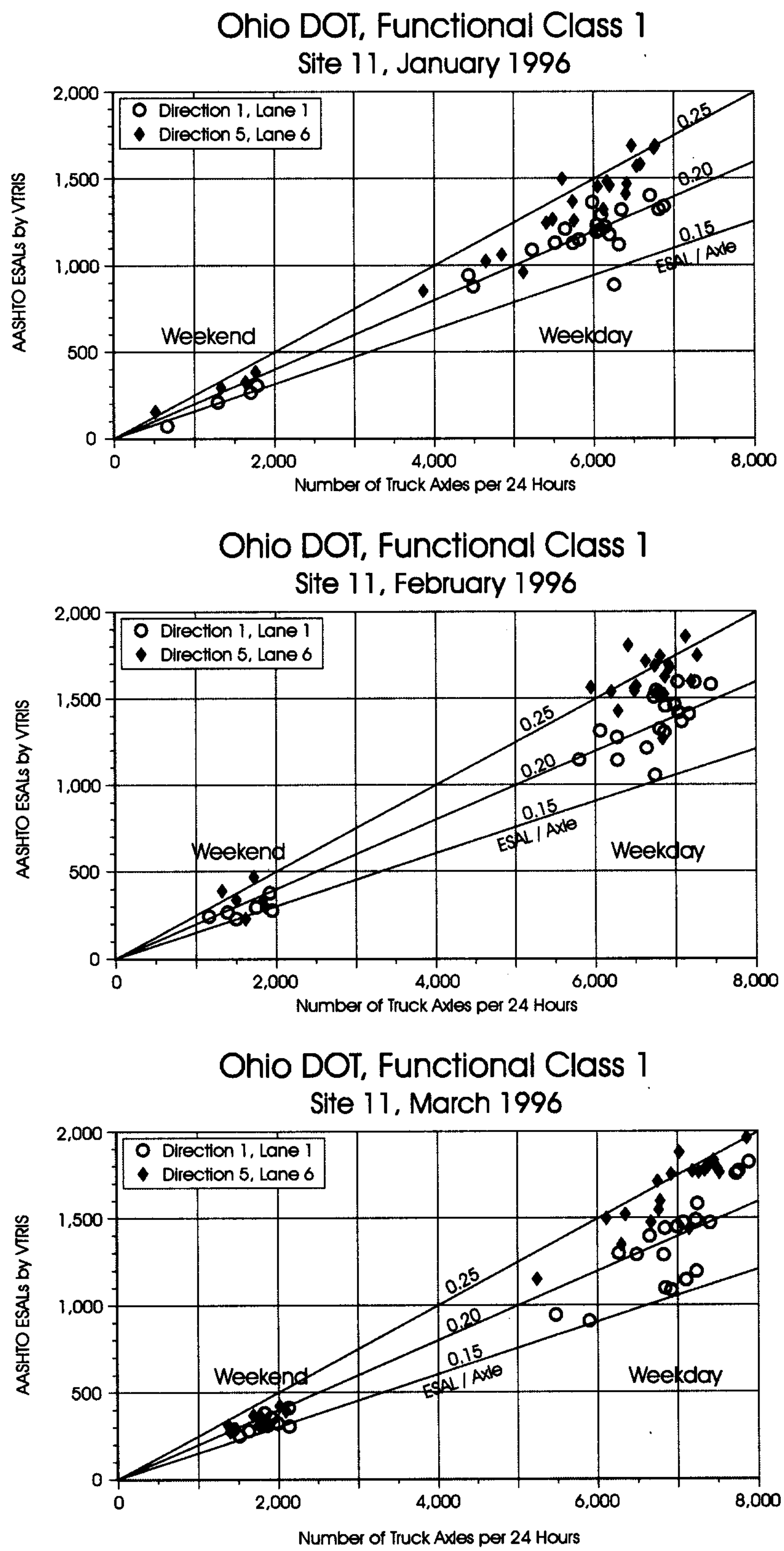


Figure 18. ESALs vs Axle Relationship for OHDOT Relationships for Functional Class 1 Site 11

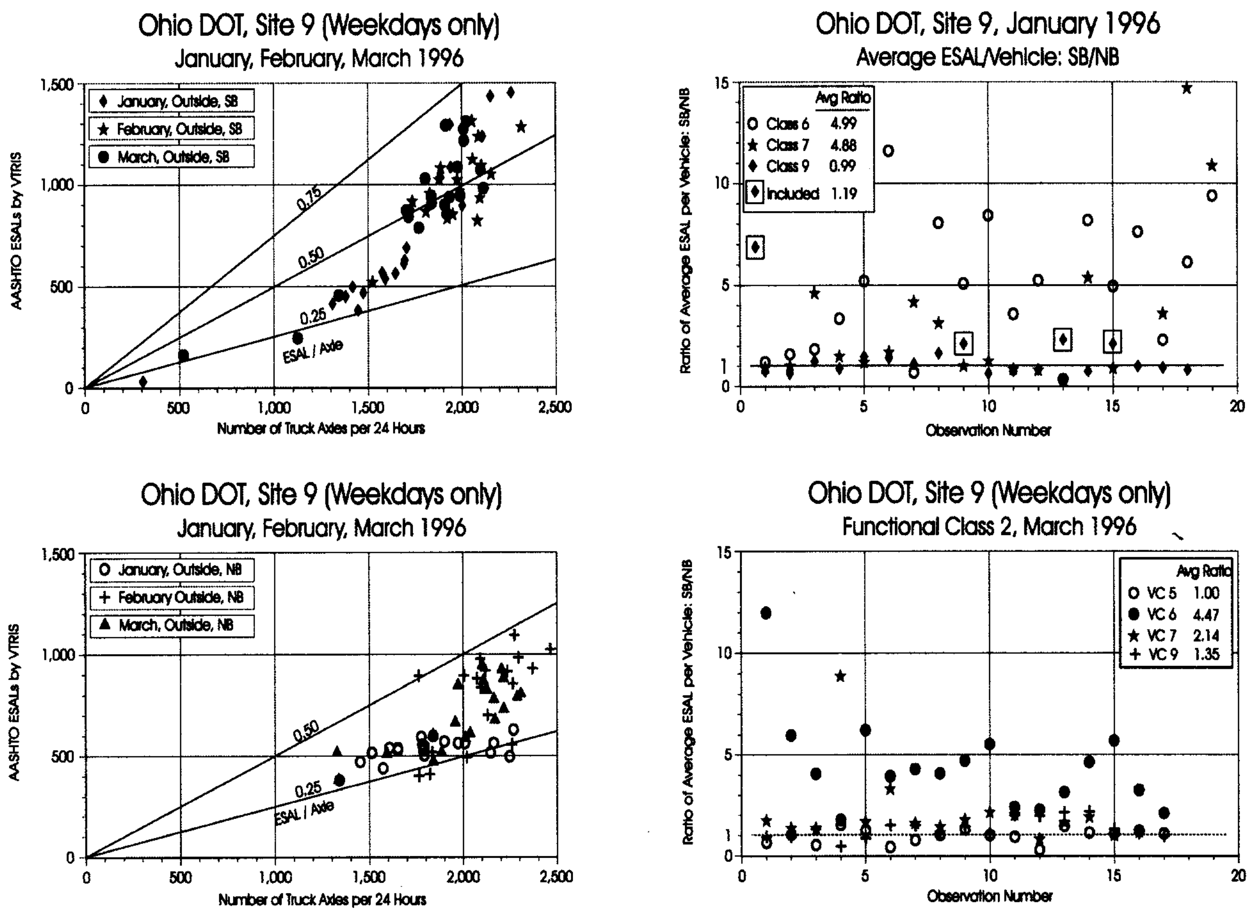
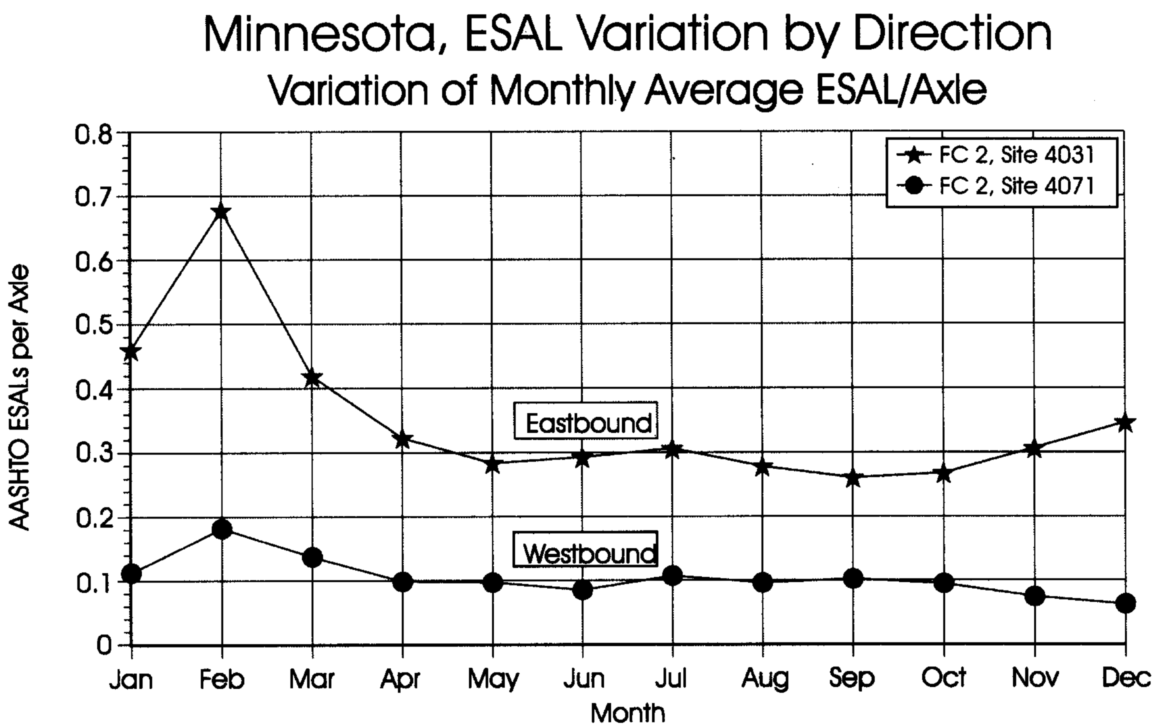


Figure 19. ESALs vs Axle Relationships Used as Diagnostic Investigative Tool for OHDOT Site 9



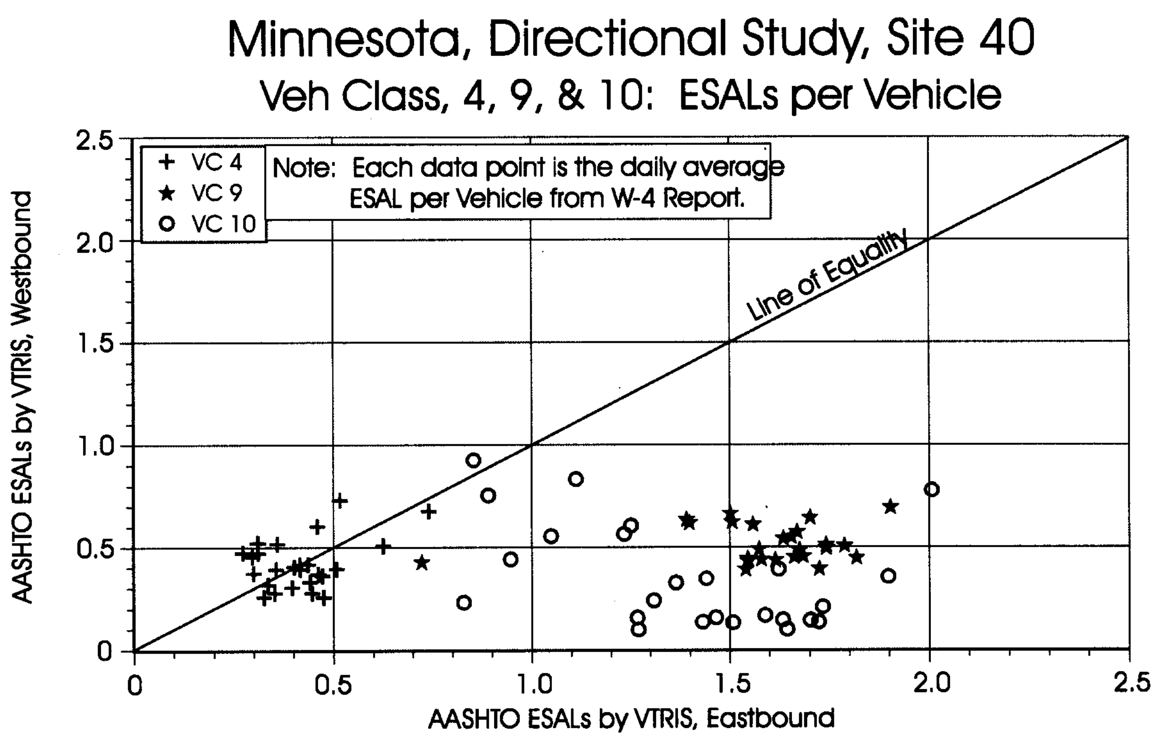


Figure 20. Monthly Variation of ESAL per Axle and Using ESALs per Vehicle as Diagnostic Tool for Directional Differences at MNDOT Site 40

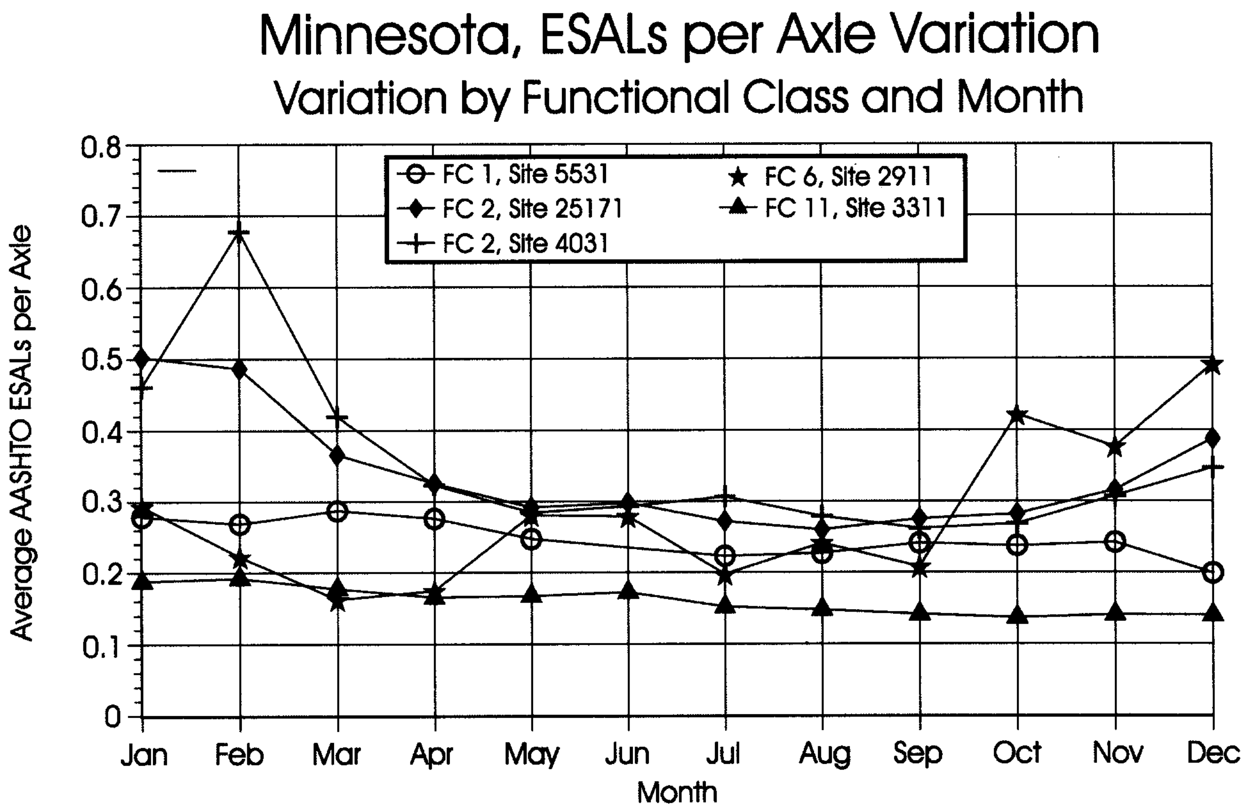


Figure 21. Five MNDOT Sites Analyzed to Show Effects of Time and Functional Class Variations on Pavement Fatigue Expressed as ESALs per Axle

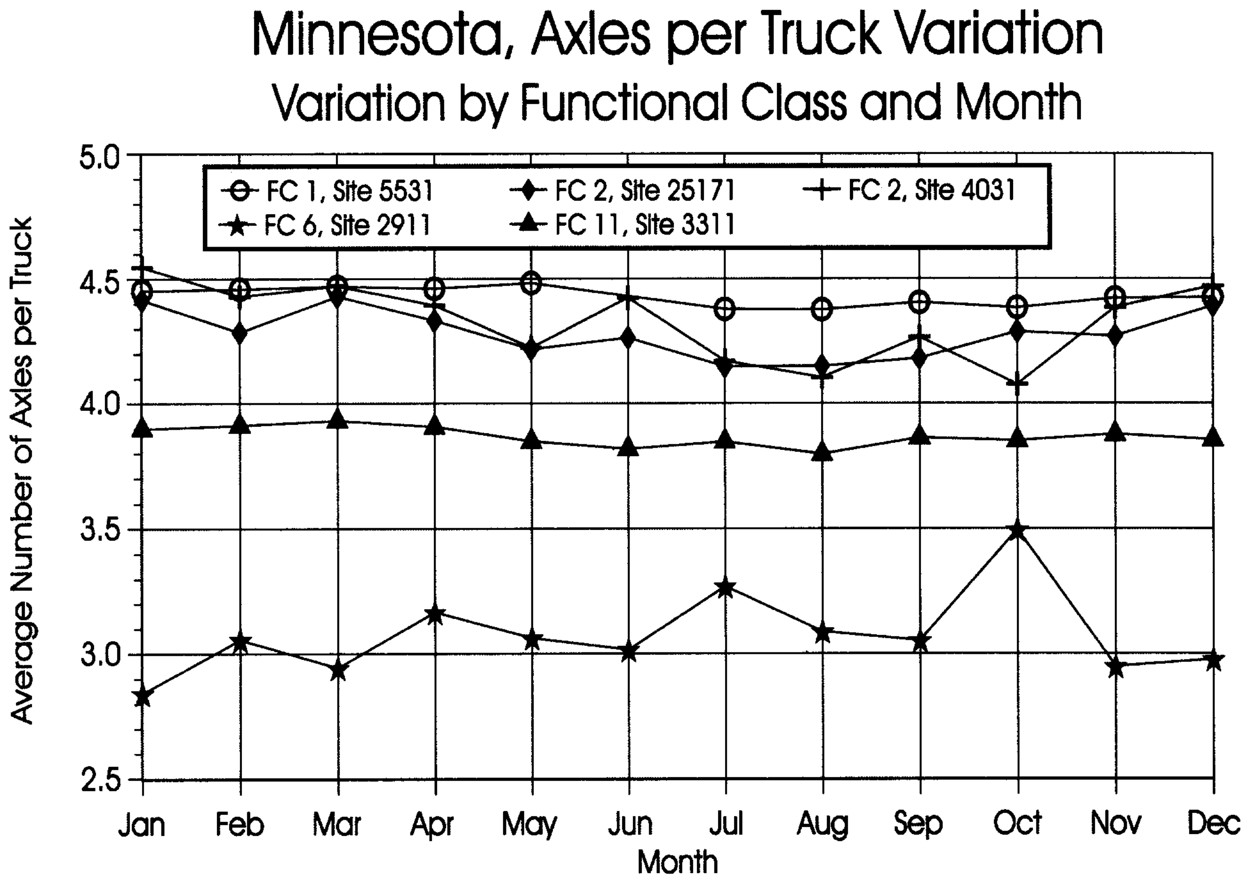


Figure 22. Using "Axles per Truck" to Study Variations due to Time and Functional Class

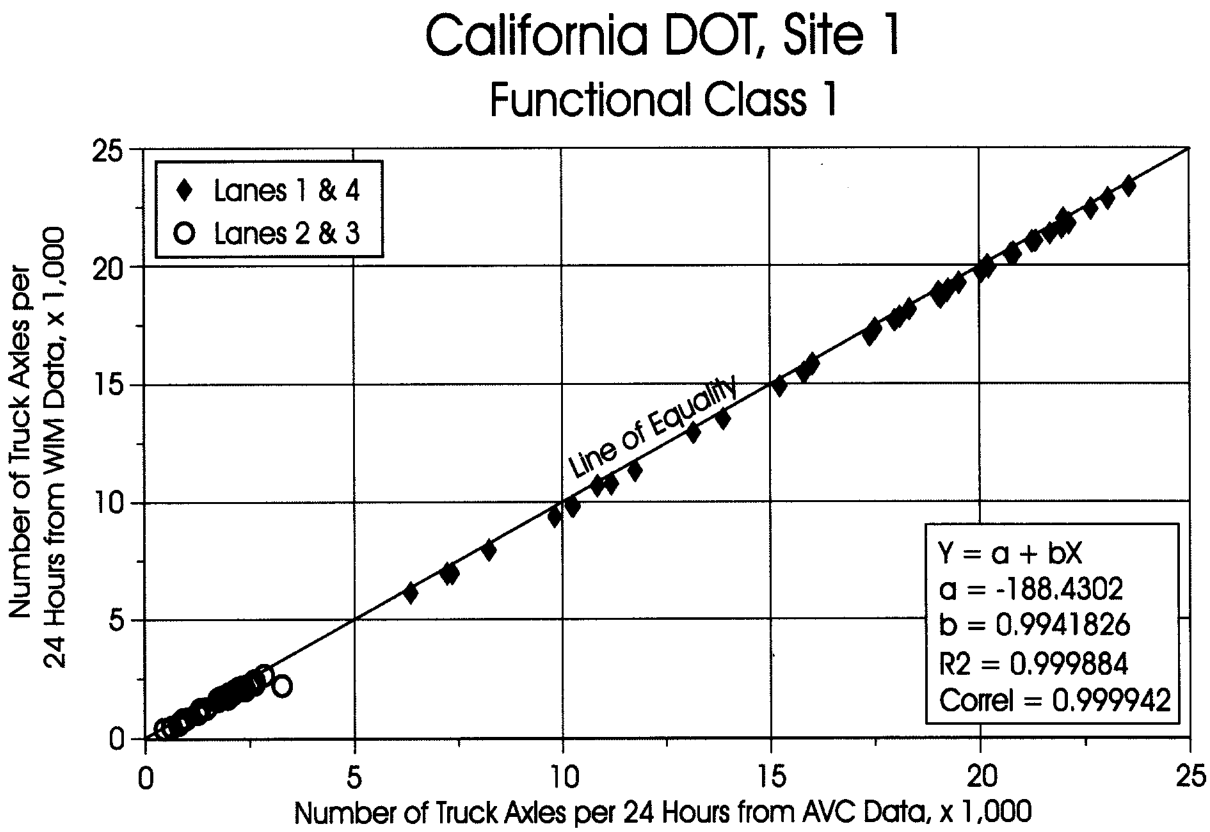


Figure 23. Correlation of Number of Truck Axles Per Day from AVC and WIM Equipment Used at CADOT Site 1

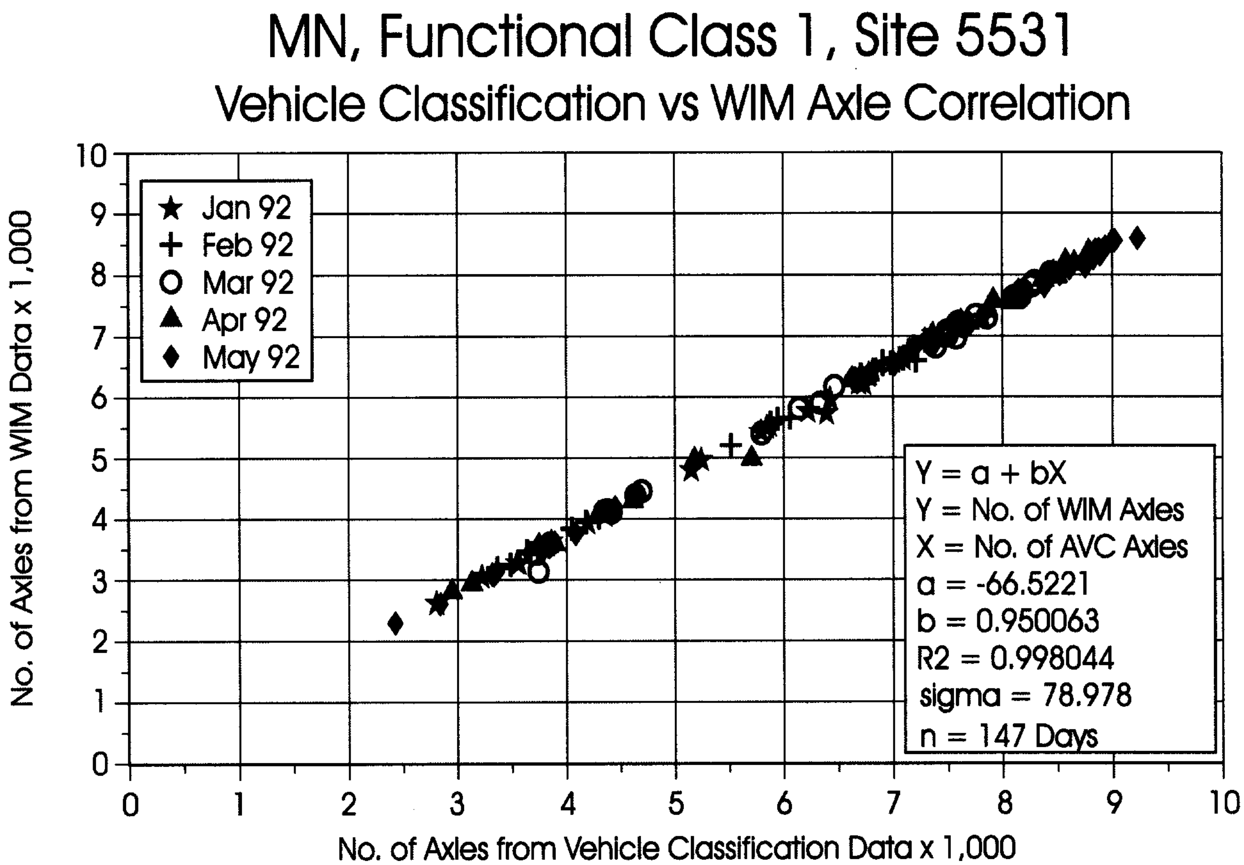


Figure 24. Correlation of Number of Truck Axles Per Day from AVC and WIM Equipment Used at MNDOT Site 55

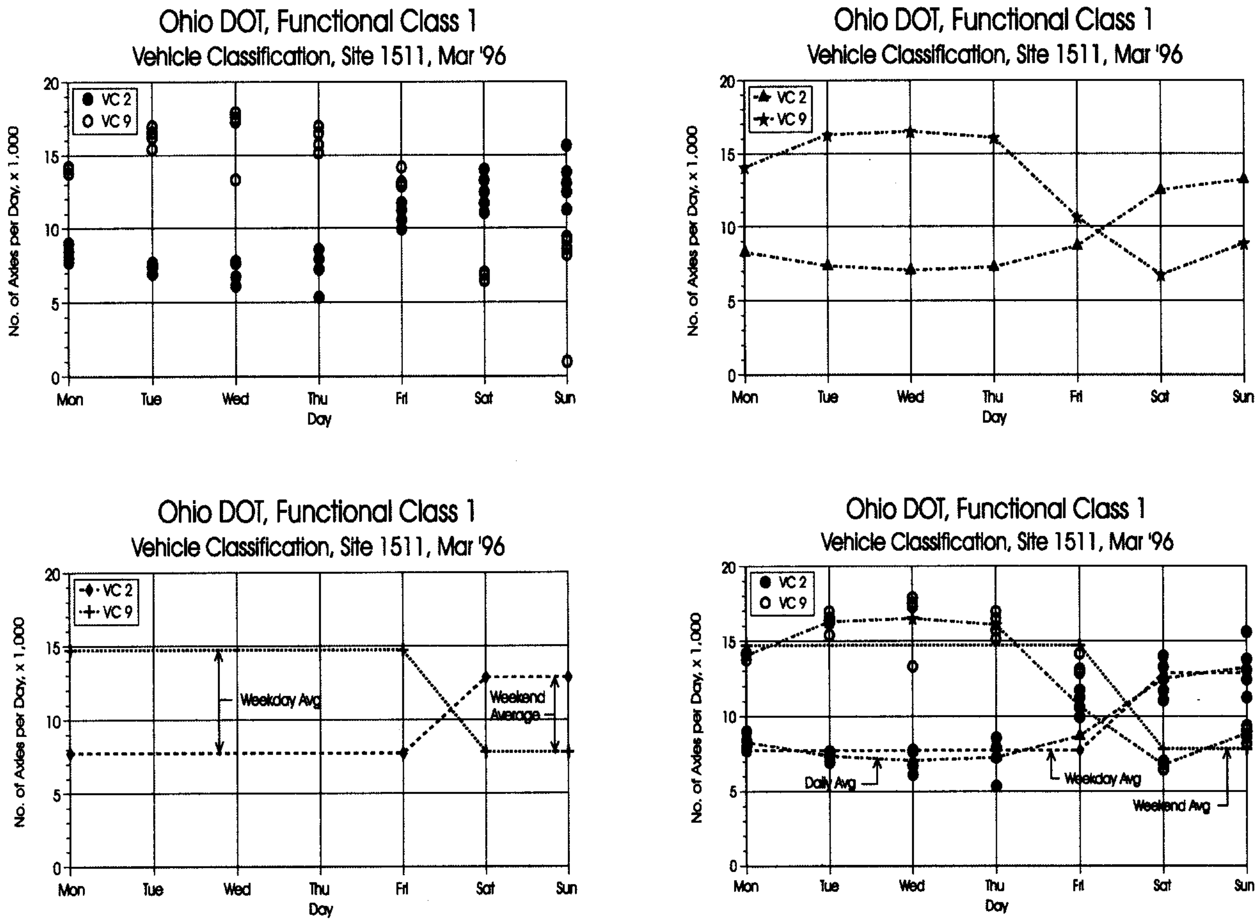


Figure 25. Day of Week vs Volume of Axles per Day for OHDOT Functional Class 1 Site 15

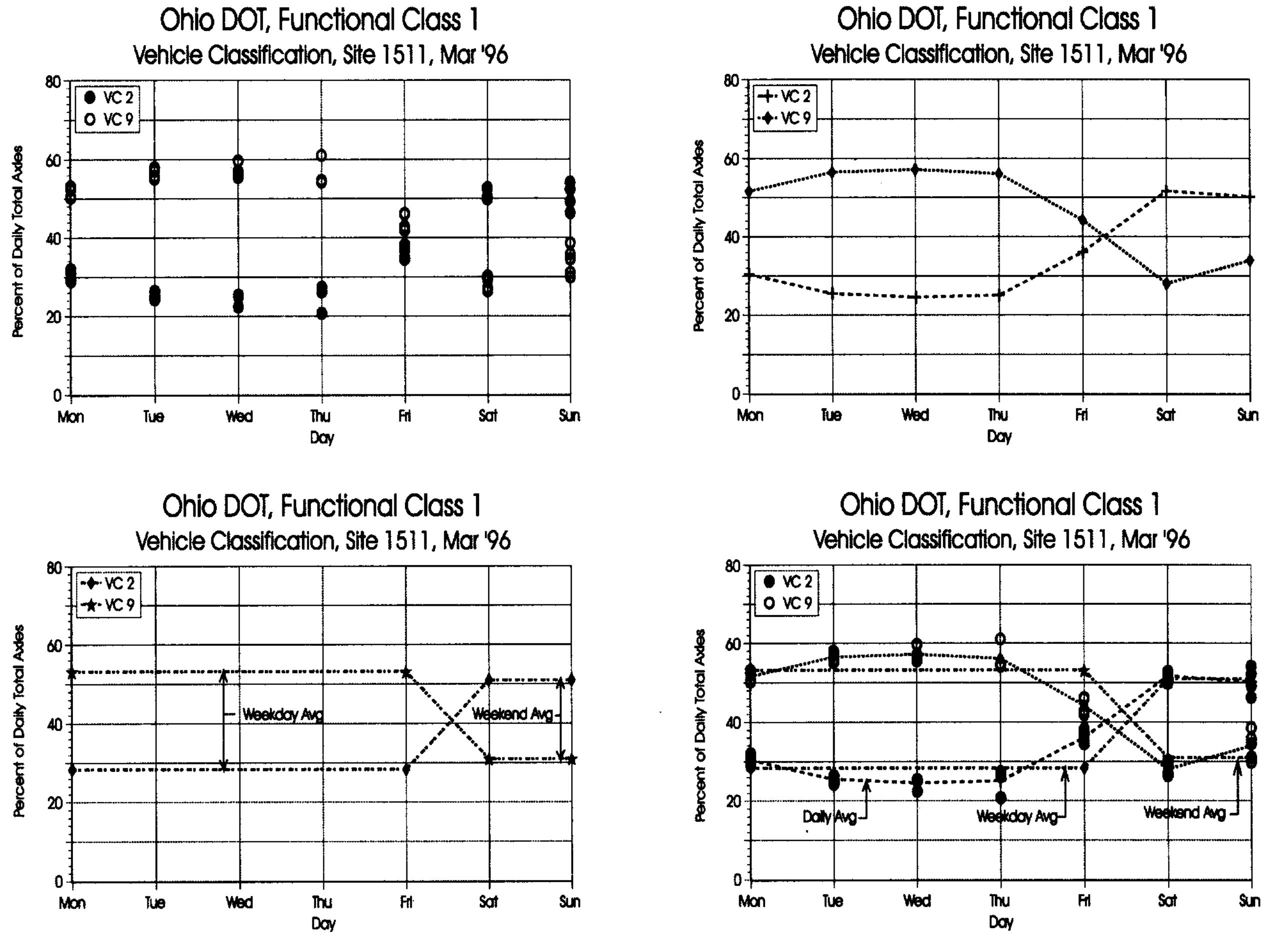
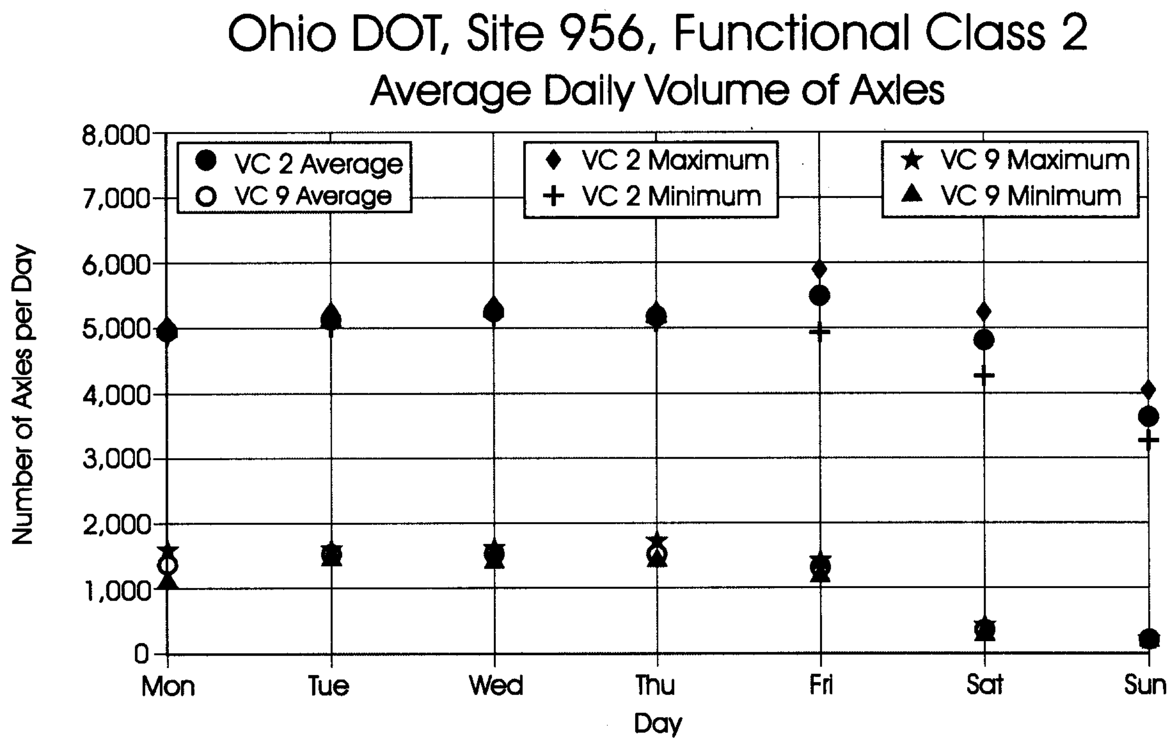


Figure 26. Day of Week vs Percent of Axles per Day for OHDOT Functional Class 1 Site 15



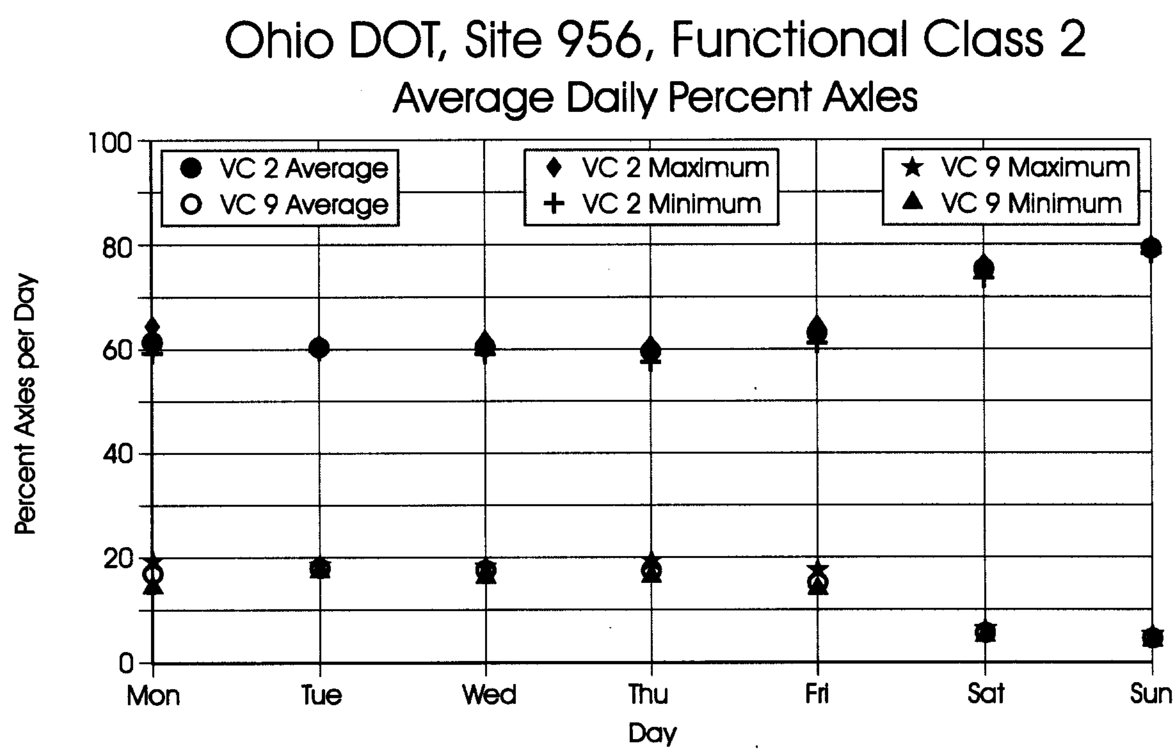


Figure 27. Day of Week vs Volume or Percent of Axles per day for OHDOT Functional Class 2 Site 9

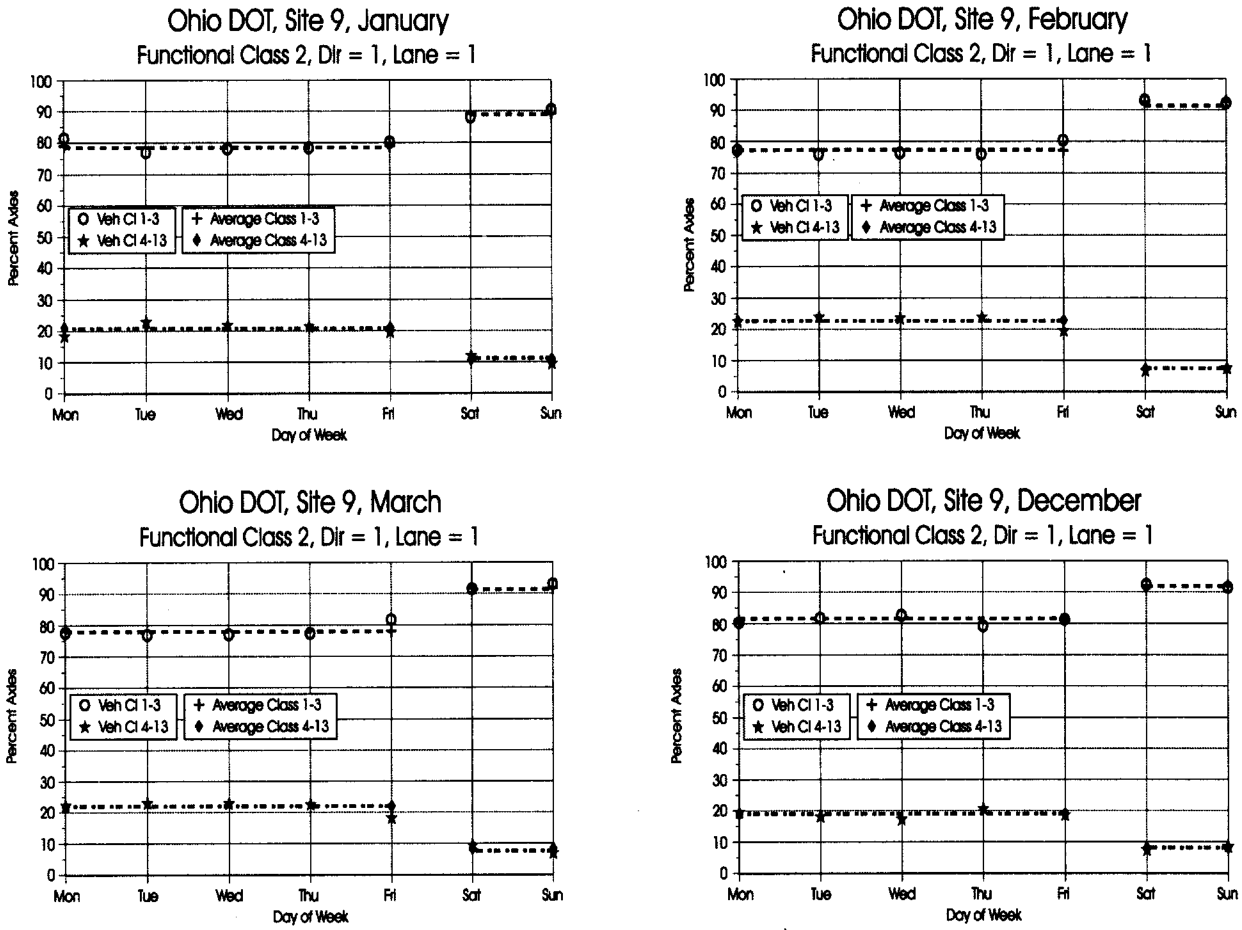


Figure 28. Monthly Variation Upon Percent Axles vs Day of Week for OHDOT Functional Class 2 Site 9

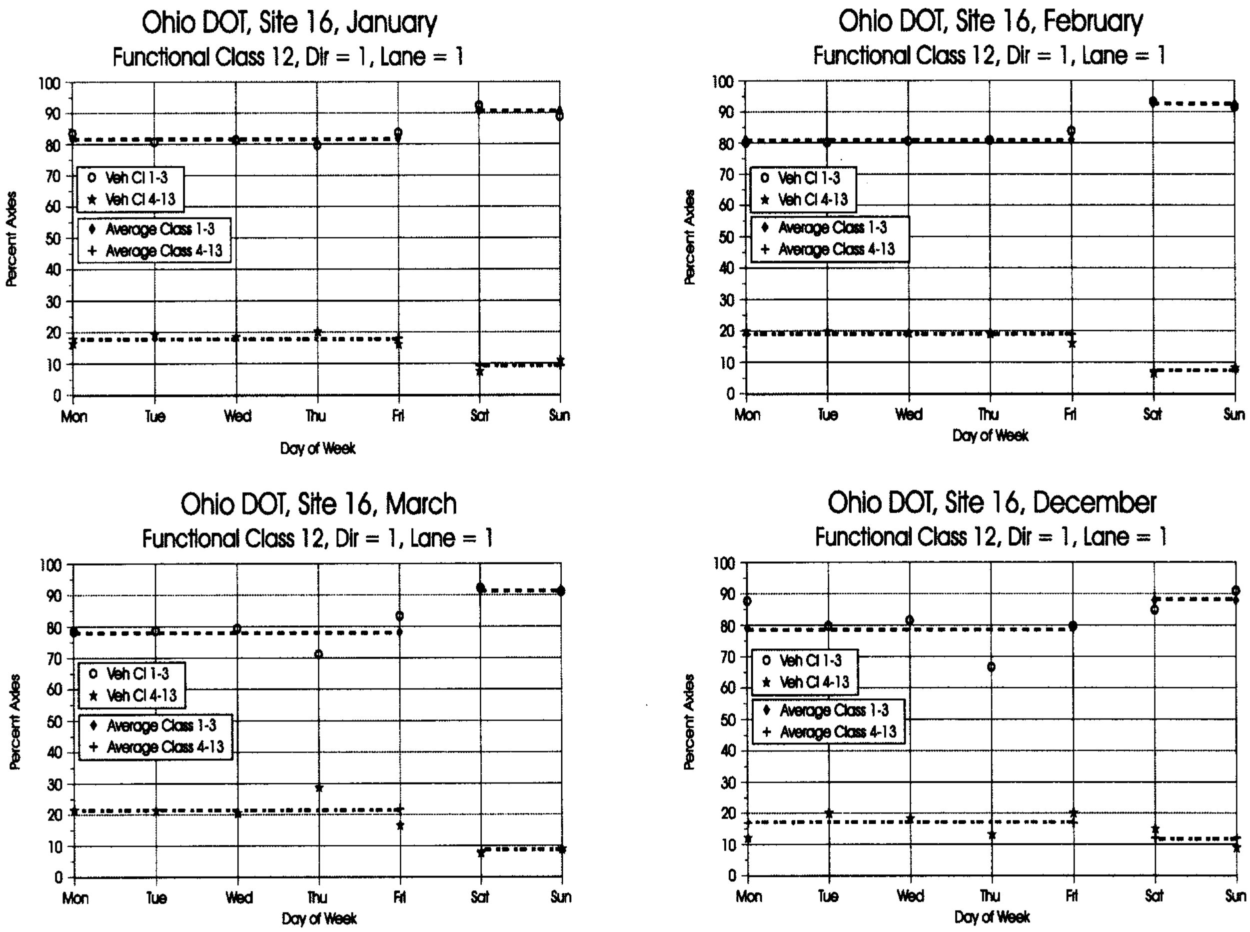


Figure 29. Monthly Variation Upon Percent Axles vs Day of Week for OHDOT Functional Class 12 Site 16

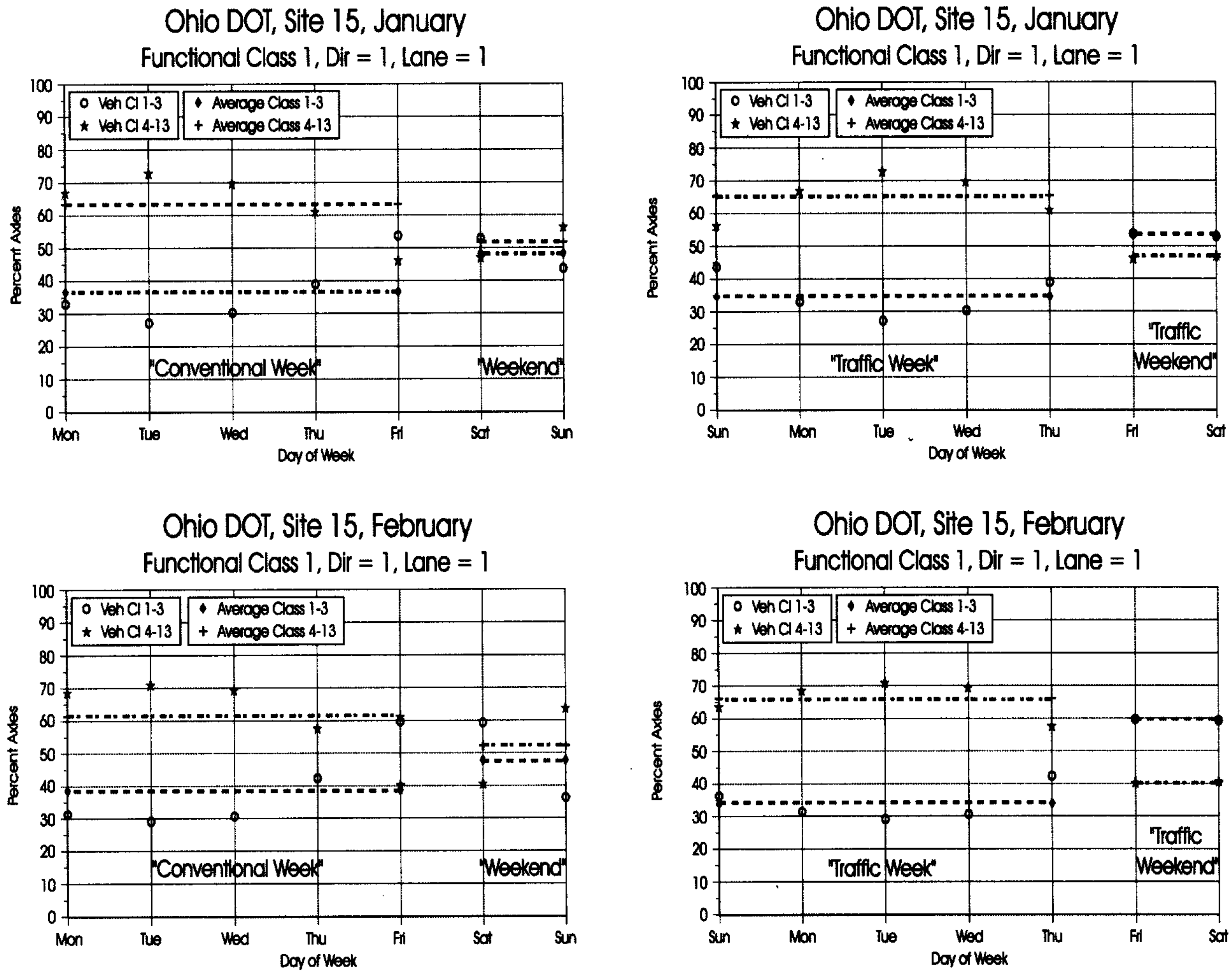
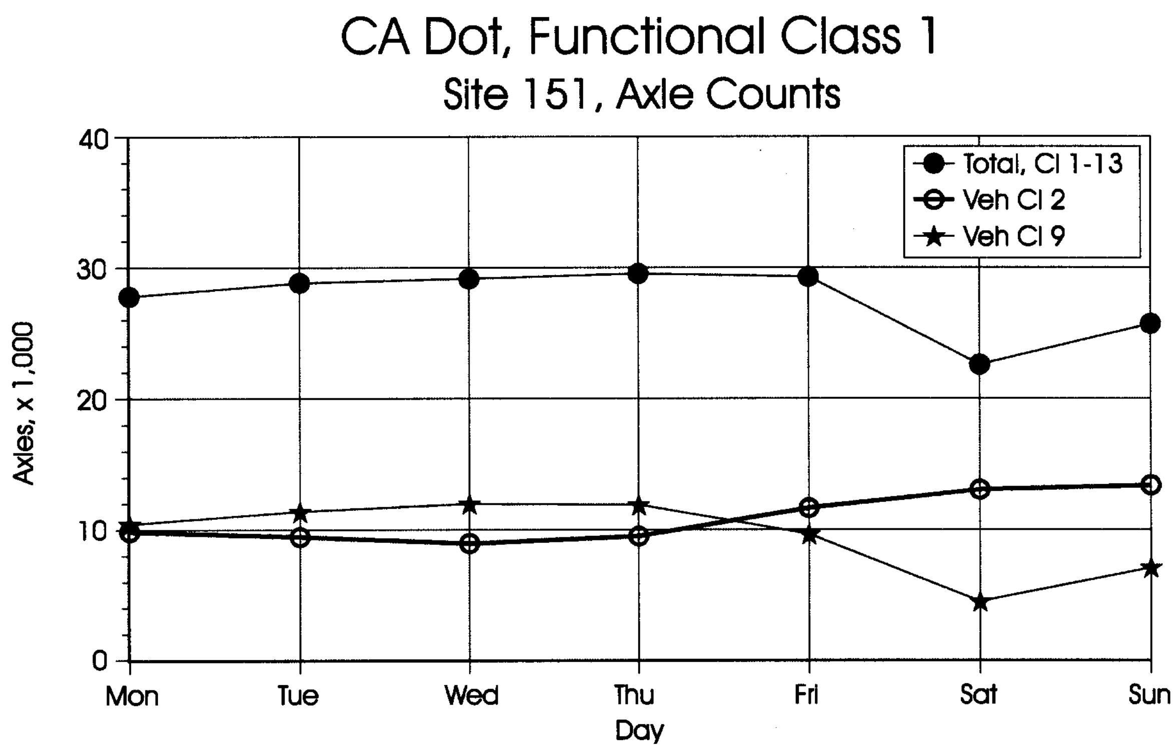


Figure 30. AVC Data - "Conventional Week" vs "Traffic Week"



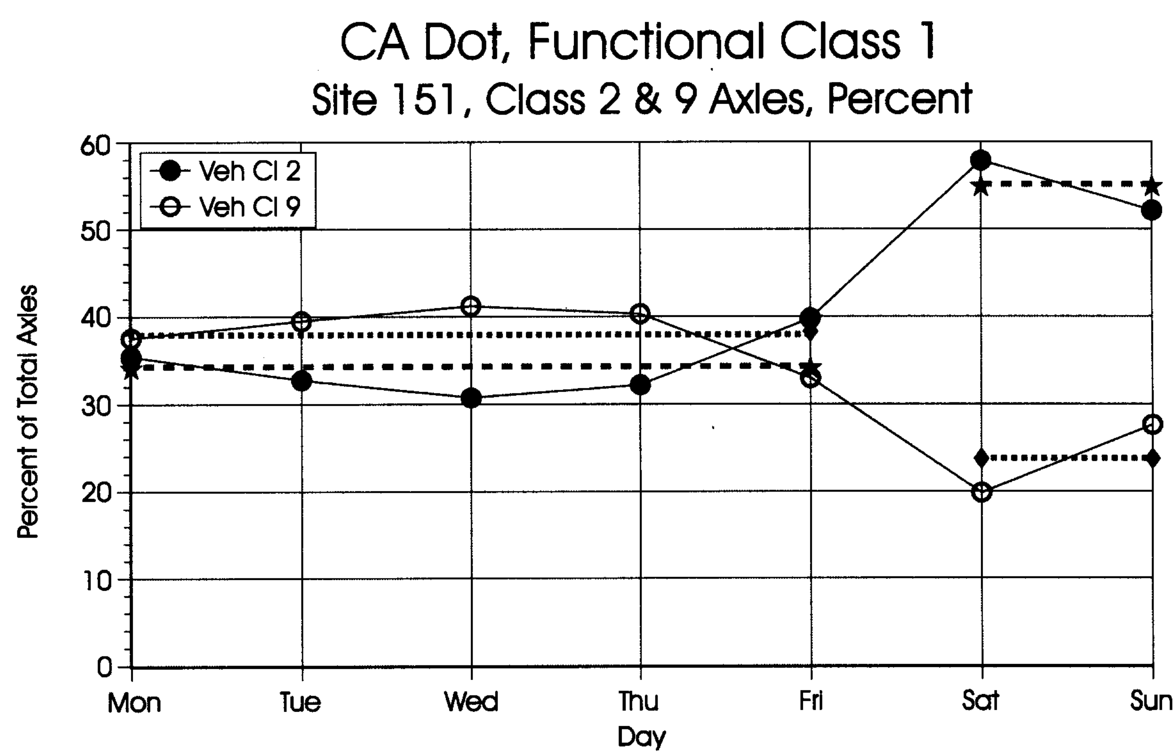
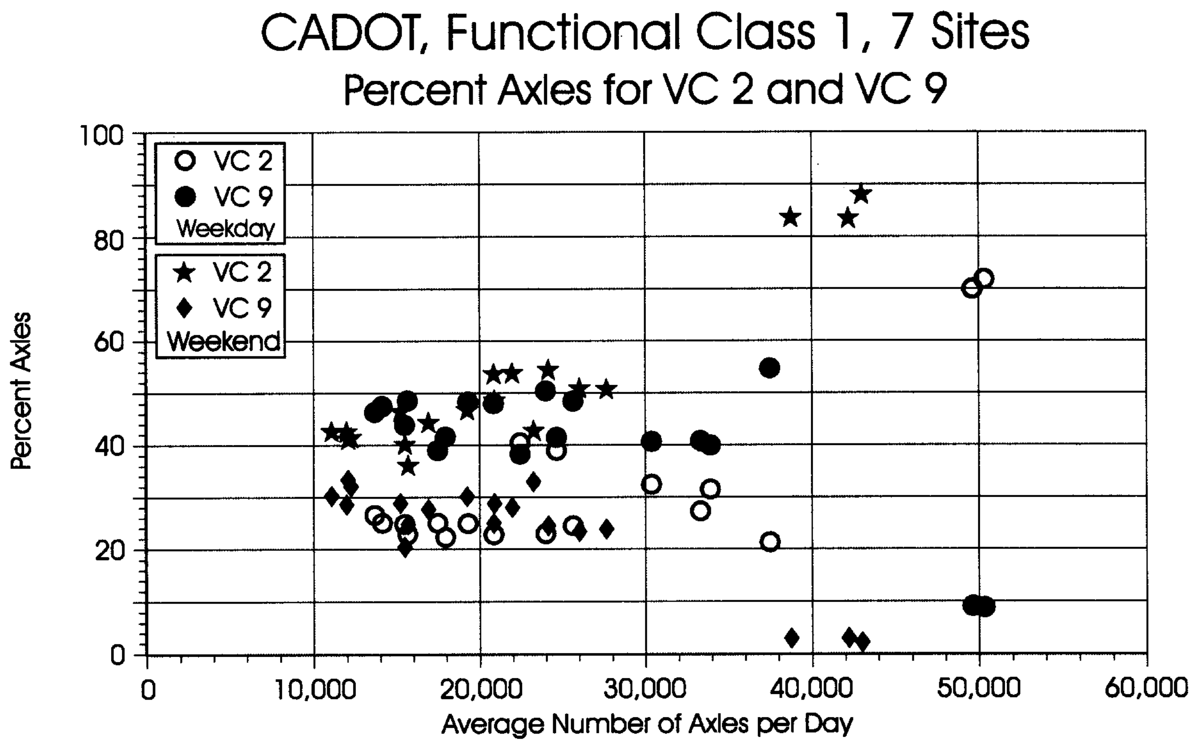


Figure 31. Day of Week vs Volume or Percent Axles for CADOT Functional Class 1 Site 1



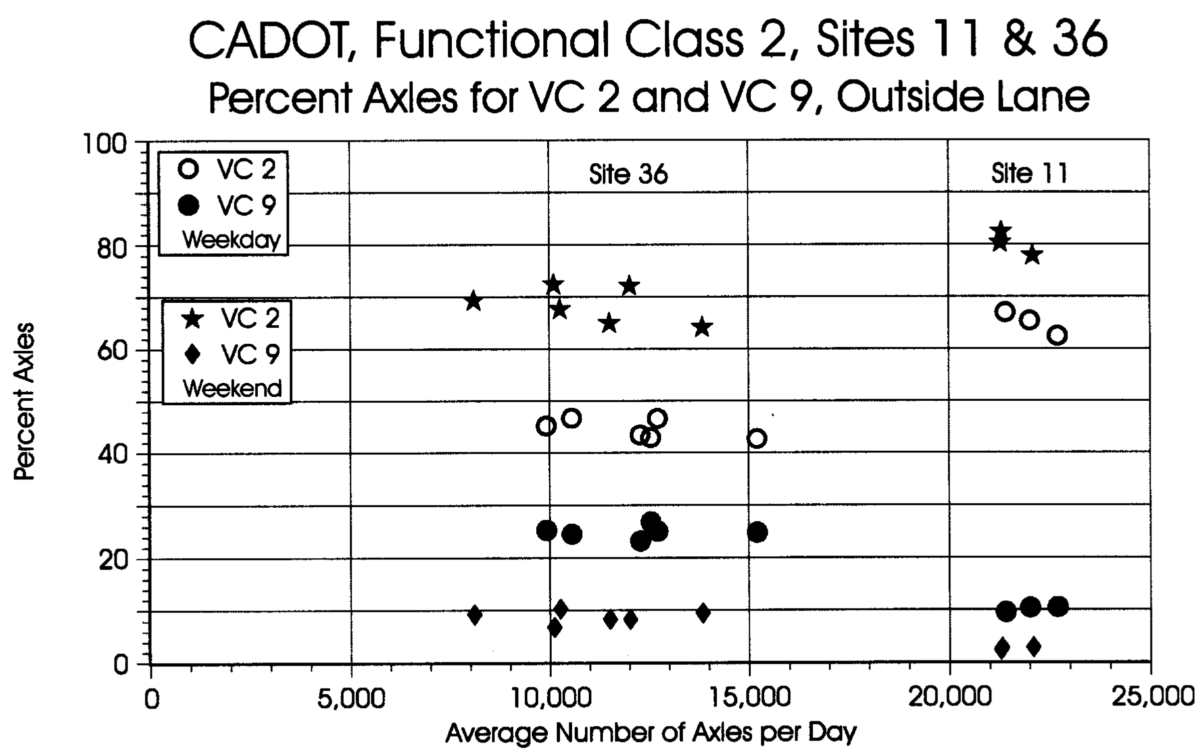


Figure 32. Percent Axles vs Average No. of Axles per Day for CADOT Functional CLass 1 and 2 Sites

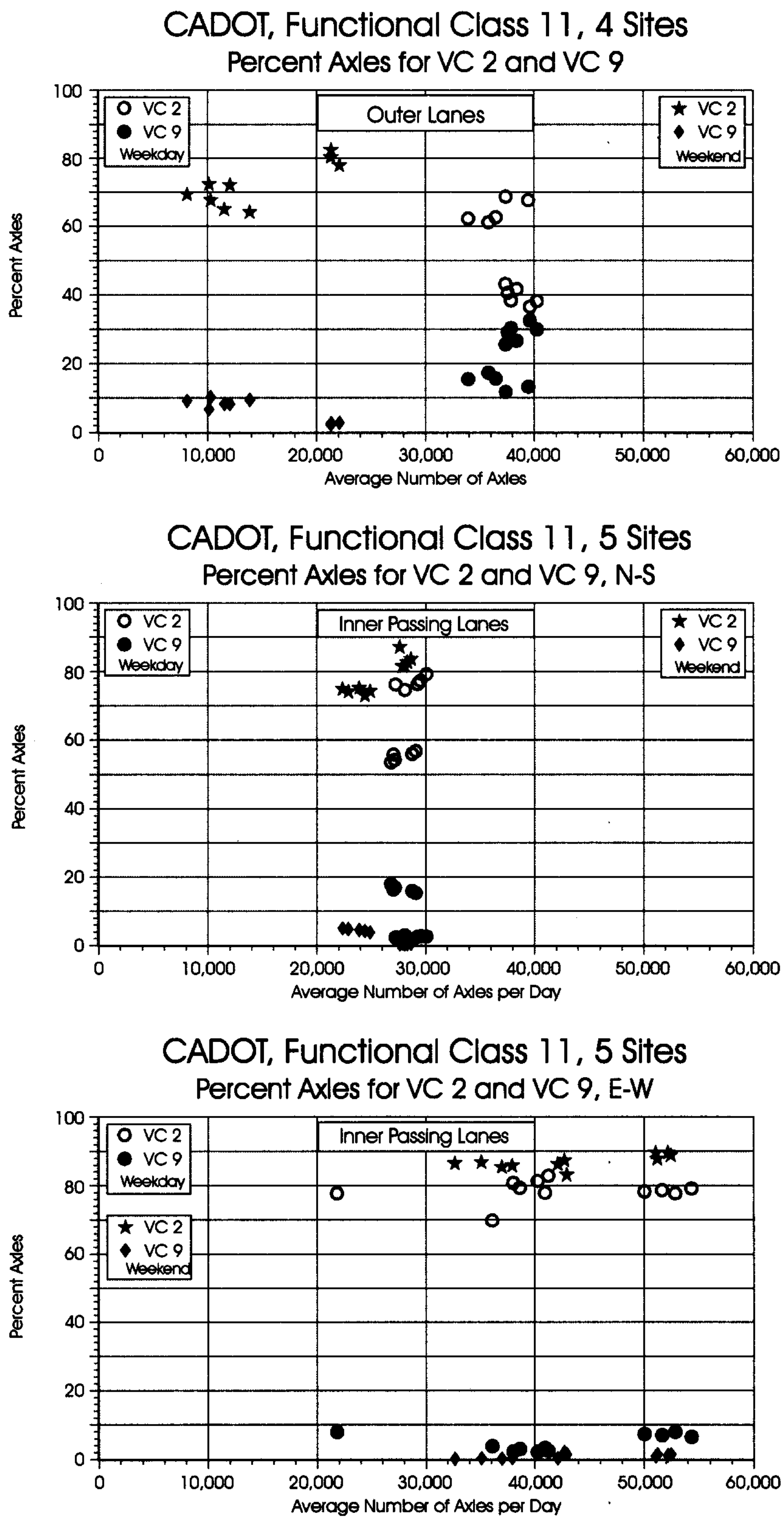


Figure 33. Percent Axles vs Average No. of Axles per Day for CADOT Functional Class 11 Sites

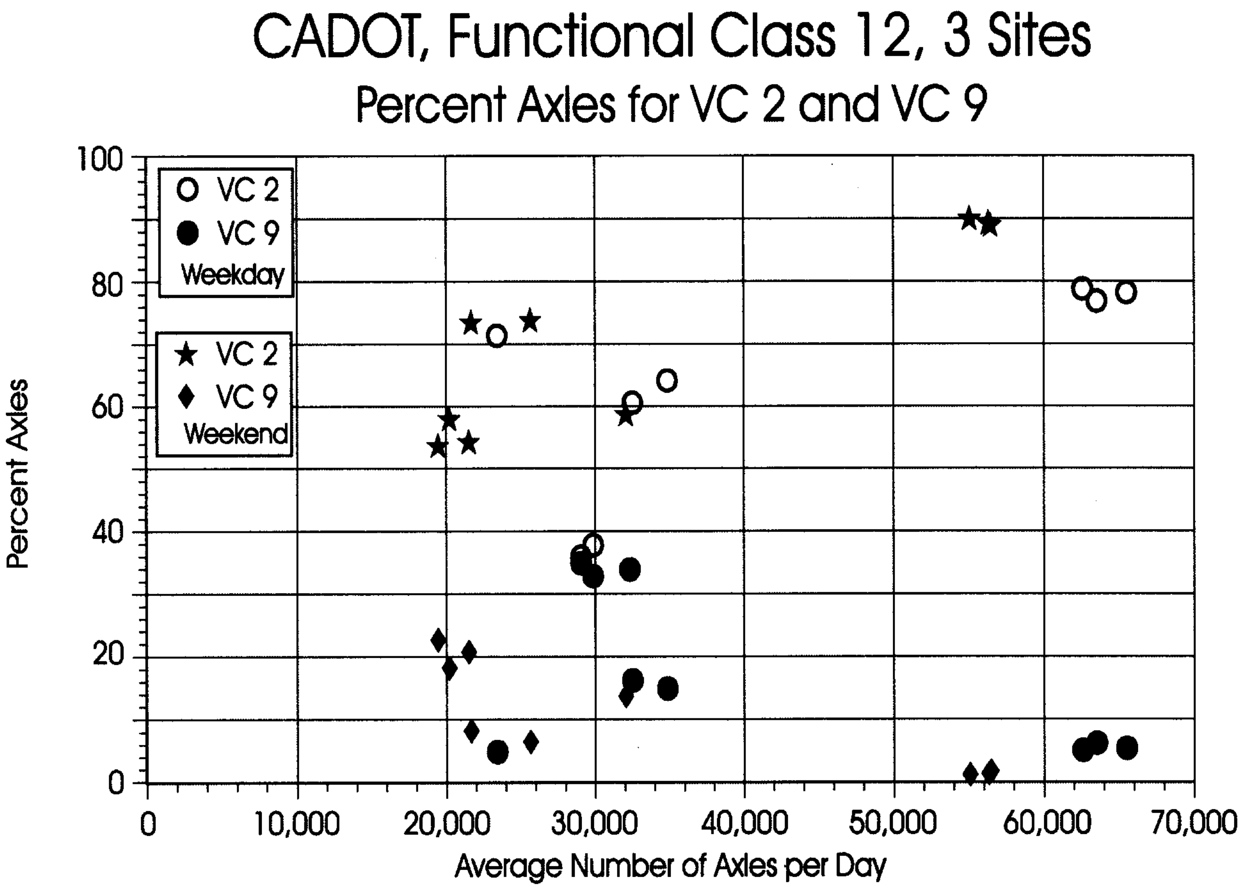
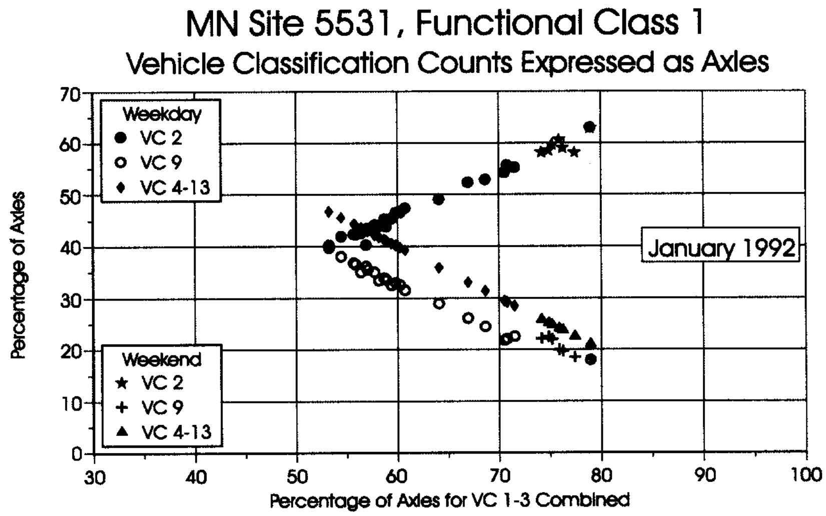
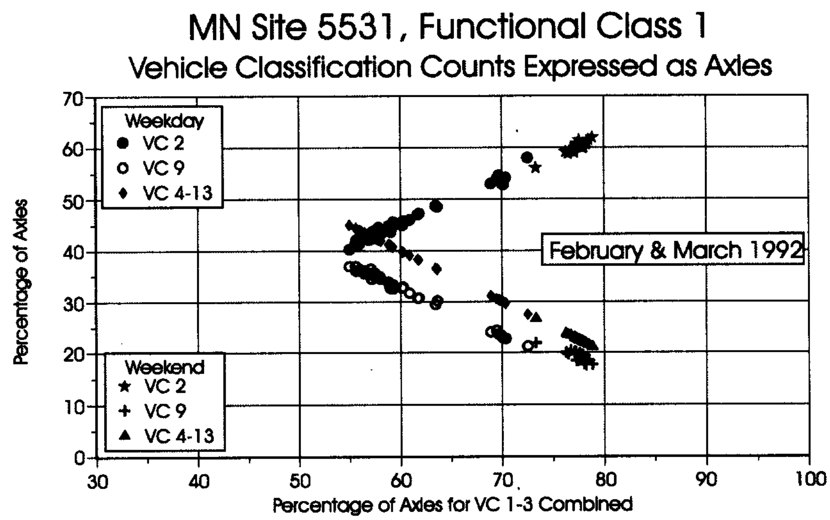


Figure 34. Percent Axles vs Average Number of Axles per Day for CADOT Functional Class 12 Sites





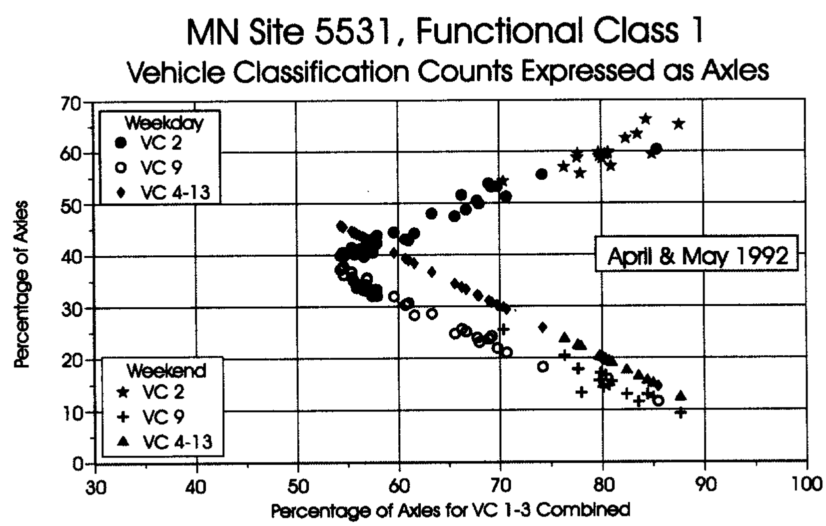


Figure 35. Vehicle Classsification Counts Expressed as Percent of Axles

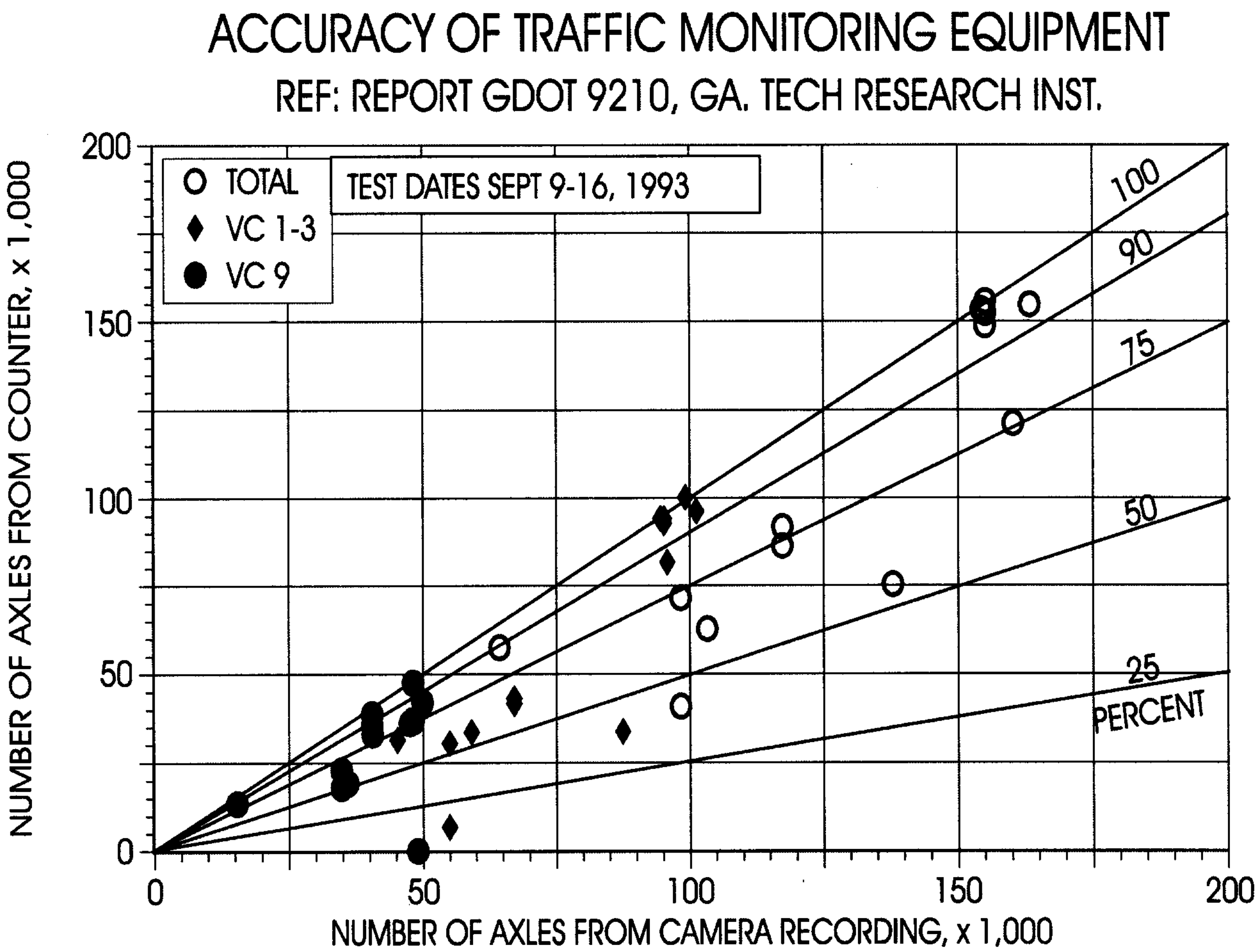


Figure 36. Georgia Counter Accuracy Test, 1993