Final Technical Report

TRUCK LOADING PATTERNS FOR USE IN THE NCHRP 1-37A SOFTWARE FOR MONTANA ROADWAYS

by

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FINAL TECHNICAL REPORT

TRUCK LOADING PATTERNS FOR USE IN THE NCHRP 1-37A SOFTWARE FOR MONTANA ROADWAYS

This report describes the results of a review of 15 months of Montana truck volume and weight data. The purpose of this review was to develop recommendations and traffic load data sets for use with the NCHRP 1-37A pavement design software.

The 15 months of data (May 2000 through July 2001) were collected at 21 Montana weigh-in-motion (WIM) sites and provided to the project team by the Montana Department of Transportation (DOT). Weight data were available for all 21 sites. Extensive data on volume by vehicle classification were also provided for 19 of those sites. These two types of data were used to determine general pavement loading patterns in the state of Montana.

Patterns were developed for seasonal variation in both truck volumes and weights. Conclusions were then drawn about how Montana should apply its knowledge of these patterns within its pavement design process.

Because of the extremely limited funding for this task, this analysis was very limited in scope. No significant data quality review was performed. If concerns about data accuracy arose in the analysis process, these concerns are described in this report. (Concerns most commonly centered on the validity of WIM scale calibration; however, it is also distinctly possible that some of the outlier values for seasonal truck volume trends resulted from data quality problems.) Insufficient funding existed for this analysis to confirm the reliability of these estimates.

Conclusions were also made about the traffic patterns observed; however, these conclusions need to be carefully reviewed by Montana DOT staff familiar with the state's weight laws and economic activity patterns. The traffic analyst who performed this analysis does not have knowledge of local Montana truck travel patterns, which could lead to different conclusions about traffic loading patterns in Montana (and/or about the likelihood that data used were, in fact, erroneous). In addition, accurate local knowledge is necessary to expand the application of the general patterns described in this report to all roads within the state, since the vast majority of Montana roads were not covered by the limited data set available for this report.

GENERAL LOADING PATTERNS

Traffic loading is a function of the number of trucks (by type/class of truck) and the axle weights of each of those trucks. The damage caused by traffic increases with both the volume of heavy trucks and the weight of those trucks. Therefore, to design a pavement requires that the analyst understand how many trucks of each type use a particular road, and the load distribution of each of those types of trucks.

A strong, project-specific counting program (vehicle classification counts done at or near each pavement project location specifically to collect data on the volume and classification of trucks using the roadway) will provide the basic truck volume data necessary for each pavement design. What the general Montana count program needs to provide is an understanding of how those truck volumes vary over time, and what type of loads are carried by each kind of truck.

This project reviewed the loading patterns and truck volumes at 21 Montana WIM sites to determine the variability of truck volumes and loading patterns across the state. The intent was to create a limited number of "groups" that describe the variation in truck volumes that can be expected at any given project location, as well as the types of loads that can be expected.

In creating these groups, the analyst emphasized FHWA truck classes 9, and 13. This decision was based on the fact that at the vast majority of Montana test sites, most load (accounting for both volumes and weights) is applied by a combination of Class 9 and Class 13 vehicles. Class 9 trucks generally contribute the vast majority of traffic load, with Class 13 vehicles supplying a significant but secondary load.

The exception to this rule of thumb was found at the two sites with the lowest volumes,[1] where Class 6 vehicles made up a significant portion of the traffic load.

Interestingly, these two sites were the only "county" roads in the data set. (All other roads were Interstates, U.S. signed highways, or Montana state highways.) This suggests that roads that serve primarily local truck traffic can expect a greater proportion of load to be supplied by Class 6 trucks, and therefore, for pavement design purposes, they may need to be treated somewhat differently than larger routes.

In a few cases, vehicles from classes 5 and 10 contributed slightly more than 10 percent of the total traffic load, but in most cases these trucks contributed only modestly in terms of load. Class 5 trucks were ignored for this effort because they tend to be quite light and, therefore, contribute relatively minor amounts of pavement damage, even when they are a large portion of total volume. Class 10 vehicles may be of more significance. Class 10 vehicles are tractor-semi-trailers with six- or more axles. This usually means a

[1] These sites are Site 102 on S-314 near Decker, and Site 109 on S-273 near Galen.

conventional, heavy duty, three-axle tractor pulling a single trailer with a tridem or quad axle. These trucks can be quite heavy, and therefore, their presence, while relatively low in number, may be of interest for specific routes.

Table 1 shows the three most "significant" vehicle classes in terms of load[2] for each of the data collection sites for which both volume by class and truck weight information were present.

Table 1: Percentage of Load Caused by Primary Truck Classes

Site	Vehicle Class	Percentage of Load Applied by That Class
101: US 12 Townsend	9	43%
	13	32%
	10	8%
102: S 314 Decker	13	33%
	9	24%
	6	19%
103: I-94 Bad Route	9	82%
	13	9%
	10	2%
104: I-90 Manhattan	9	79%
	13	9%
	10	4%
105: US 93 Arlee	9	41%
	13	37%
	10	9%
106: US 191 Four Corners	9	63%
	13	16%
	5	7%
107: US 19 Galatin	9	69%
	13	10%
	5	6%
108: I-90 Big Timber	9	80%
	13	8%
	5	4%
109: S 273 Galen	6	41%

2 For this table, "load" was calculated using a traditional ESAL calculation for flexible pavements. This is a simple method for judging the relative damage cause by different types of trucks.

	9 5	32% 18%
110: MT 3 Broadview	9 13 10	69% 13% 12%
111: US 12 Miles City East	9 13 10	62% 21% 8%
112: I-15 Ulm	9 13 10	65% 19% 7%
113: US 12 Ryegate	9 13 10	67% 15% 11%
114: US 87 Stanford	9 13 10	64% 19% 9%
115: US 87 Fort Benton	9 13 10	37% 32% 8%
116: US 2 Havre	9 13 5	45% 24% 12%
118: MT 200 Paradise	9 13 10	49% 23% 11%
202: I-15 Lima	9 13 10	70% 18% 5%
203: I-90 Mossmain Pre-pass	9 13 5	74% 14% 4%

Concentrating on these classes created some minor biases in the traffic load estimate, but those biases were very small because they were produced by truck classes that cause very little pavement damage.

TRUCK VOLUME PATTERNS

Because significant numbers of double-bottom trailers use Montana highways, these trucks need to be tracked separately from combination trucks. As a result, it is recommended that Montana use three truck categories to create and apply seasonal adjustment factors for truck volumes when using the NCHRP 1-37A software. The three recommended truck classes are

- single unit trucks (SU)
- combination trucks (Comb.)
- multi-trailer trucks (Multi.).

The category of single unit trucks should contain all trucks in FHWA classes 5, 6, and 7. Combination trucks should include all vehicles in classes 8, 9, and 10. Multi-trailer trucks should include all trucks in FHWA classes 11, 12 and 13.

Only three truck classes are recommended for seasonal factoring because at many Montana road sites the number of trucks in many of the FHWA vehicle categories was quite small. When small volumes of vehicles are present, seasonal and day-of-week adjustment factors become unstable, and unstable factors do not improve the accuracy of pavement loading estimates. By aggregating FHWA truck classes into three broader categories, Montana will be able to apply seasonal patterns to its design process while both limiting the work involved in that effort and the effects that truck classes with low volumes would have on the accuracy of those factors.

In most cases, one specific FHWA vehicle class will contribute the vast majority of trucks within each of these aggregated truck categories. For example, in the data set reviewed, the vast majority of the trucks included in the "combination" category comprised FHWA Class 9 vehicles. Most multi-trailer trucks were from FHWA Class 13, and the single unit category was primarily made up of Class 5 trucks. (However, in

The seasonal patterns in the data made available to the project team varied by type of truck. Figure 1 shows the mean seasonal patterns for all sites combined. (This figure represents "Montana's basic seasonal truck pattern.") Table 2 shows the numerical factors and the standard deviation for each factor.

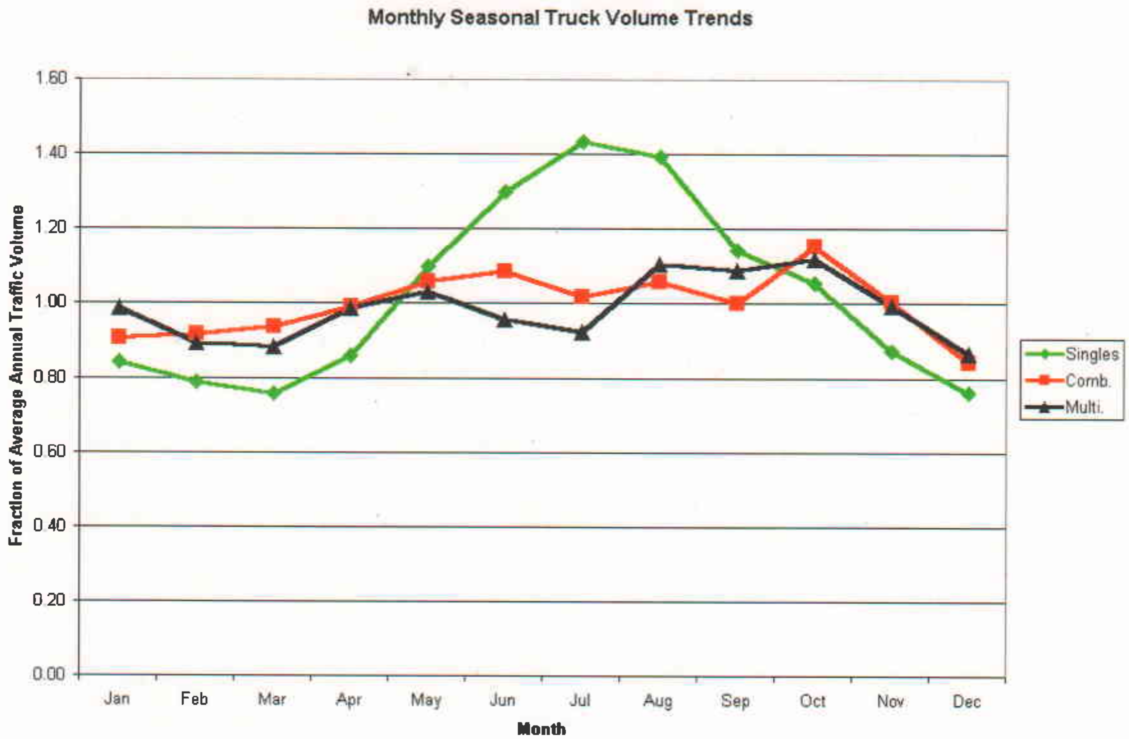

Figure 1: Truck Seasonal Patterns for All Sites Combined

Generally, combination trucks had the least seasonal variation, while single unit trucks had the greatest seasonal variation. Multi-trailer trucks showed a seasonal pattern that was reasonably similar to that of combination trucks. Both showed an increase in volume in late summer and early fall as shippers sent products to stores before the start of the holiday shopping period. However, multi-trailer trucks experienced a decline in truck volumes in the summer that was not seen in combination trucks and started their "holiday increase" earlier than combination trucks. Conversely, single unit trucks showed a volumes in the summer that was not seen in combination trucks and started their "holiday increase" earlier than combination trucks. Conversely, single unit trucks showed a substantial volume increase in summer, with significantly lower volumes during the winter and spring.

Table 2: Monthly Volume Factors[3]

	Single Units		Combinations		Multi-trailer	
	Monthly factor	Standard Deviation	Monthly factor	Standard Deviation	Monthly factor	Standard Deviation
January	0.84	0.16	0.91	0.06	0.99	0.19
February	0.79	0.17	0.92	0.06	0.89	0.18
March	0.76	0.14	0.94	0.12	0.88	0.19
April	0.86	0.12	0.99	0.07	0.99	0.20
May	1.10	0.18	1.06	0.08	1.03	0.37
June	1.30	0.31	1.09	0.08	0.96	0.35
July	1.43	0.29	1.02	0.10	0.92	0.25
August	1.39	0.29	1.06	0.09	1.11	0.26
September	1.14	0.16	1.00	0.14	1.09	0.24
October	1.06	0.14	1.15	0.12	1.12	0.10
November	0.87	0.13	1.00	0.10	1.00	0.11
December	0.76	0.15	0.84	0.07	0.87	0.17

3 Monthly Volume Factors are computed by dividing Average Monthly Truck Volume by Average Annual Truck Volumes

Individual data collection sites may frequently have volume patterns that differ, sometimes significantly, from these "average" patterns. In the data sets supplied by Montana DOT, there was considerable diversity in both the single unit truck and multi-trailer truck patterns. Diversity in truck volume patterns is caused in part by differences in the timing of seasonal commodity movements and in part by changes in the volume of commodities carried as changes in both the national and local economy affect the number of truck trips.

On some truck routes, local economic conditions and shipping patterns tend to dominate truck travel patterns. On other roads (particularly Interstates dominated by through-truck traffic), national economic trends and shipping patterns may overshadow local effects. Without direct knowledge of the nature of local commodities and their flows, it is not possible to comment accurately on the relative causes of the diversity in truck volume patterns observed at specific sites.

Some of the variation observed in the computed average monthly truck volumes at specific Montana sites appeared to be caused by short duration economic activity. For example, a major construction project may have created a substantial increase in heavy truck traffic on a road that served that construction site. This temporary increase in truck volumes may have significantly skewed the average monthly truck volumes for the month when natural resources were moved into or out of the construction site. Some of these dramatic seasonal peaks may also have been caused by minor problems in the data collection hardware (for example, misclassification of recreational vehicles pulling cars behind them as a combination truck).

Some of the diversity in observed truck volume patterns is explored in the subsections below. However, a far more substantial analysis is required before definitive statements about truck travel patterns within Montana can be made. What is obvious from the data available to the project team is that truck volumes can vary considerably from site to site, and from year to year at individual sites. Until a more detailed analysis (including input from people familiar with commodity flows within the state and the basic shipping patterns associated with those key commodities) can be performed to create a more definitive approach to seasonal factoring, it is recommended that Montana DOT adopt a fairly simplistic approach to seasonal truck volume adjustments.

Seasonal Patterns for Single Unit Trucks

As noted above, single unit trucks had the most seasonal variation of the three truck classes. In addition, site-specific travel patterns for single units trucks were not very consistent across sites. The average standard deviation associated with the mean monthly factors, illustrated in Figure 1 and shown in Table 2, averaged just under 0.18, which corresponds to a coefficient of variation of about 18 percent.

Figure 2 illustrates the diversity of seasonal adjustment factors computed from the 15 months of 2000 and 2001 data provided by the Montana DOT.[4] Peak monthly factors[5] for single unit trucks were often greater than 1.50 or less than 0.7 (meaning that the average-day-of-month single unit truck volume ranged between 50 percent more than the average annual day to 30 percent less than the average annual day).

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[4] Note that these factors are computed from 15 consecutive months of data, but those 15 months do not include a complete calendar year. All 15 months are illustrated in Figure 2 to show the truck volume changes that can occur at sites from year to year.

[5] To estimate average annual conditions from a short duration count, the short duration count would be divided by these factors.

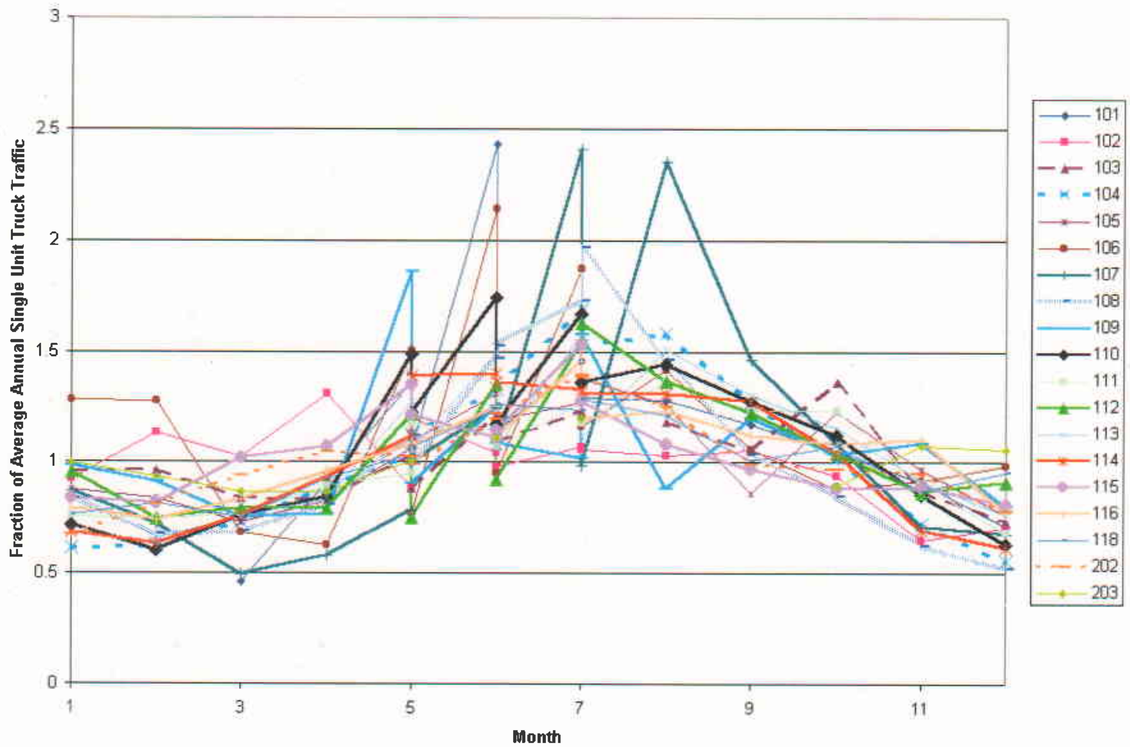

Figure 2: Seasonal Traffic Patterns for Single Unit Trucks

It is apparent from this figure that the basic shape of the seasonal distribution of single unit truck volumes was fairly consistent across the 18 sites for which data were provided. However, the actual seasonal adjustment factor for a given month at a given site varied considerably from the average statistic for all sites. The standard deviation of each monthly factor was generally equal to the size of the adjustment being made for that month. This means that while use of the factors would improve the accuracy of traffic load estimates, the adjusted load volumes were not extremely precise.

An attempt was made to group the 18 stations into "regional" travel time patterns. Unfortunately, the variation both from month to month and from site to site was so large that the resulting "regional monthly factors" did not provide a significantly better estimation of seasonal trends than use of the average condition for all pavement loading analyses not located near a road with a permanent vehicle classification counter.

Because the single unit truck volume patterns were primarily influenced by Class 5 trucks, which cause relatively little pavement damage, a test was also performed to ensure that the single unit monthly factors were applicable to Class 6 trucks.

Figure 3 shows that Class 5 and Class 6 volume patterns were generally quite similar. The standard deviations for each of the monthly factors for both classes were also reasonably similar in size, averaging around 0.2. (Class 6 factors were slightly more variable than those of Class 5, in large part because Class 6 volumes were lower and thus less stable than Class 5 volumes.)

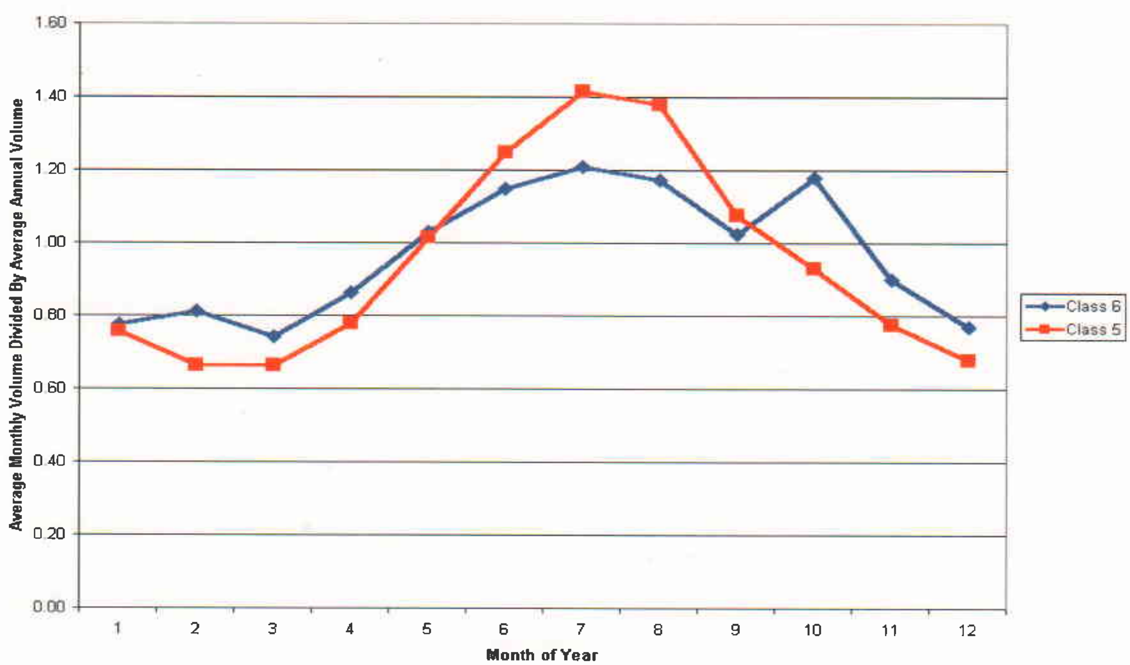

Figure 3: FHWA Class 5 and Class 6 Monthly Volume Patterns

Because low volumes are inherently unstable and because the two patterns were quite similar, it is recommended that seasonality for Class 6 trucks remains within the combined single unit truck factor. Furthermore, it is recommended that for Montana's initial truck seasonality computations, only one single unit truck seasonal factor group be used.

Seasonal Patterns for Multi-Trailer Trucks

The multi-trailer truck classification is predominately made up of FHWA Class 13 vehicles. On Montana's high volume roadways, between 10 to 15 percent of all multi-trailer trucks may have been from FHWA classes 11 or 12, but the remaining 85 to 90 percent were FHWA Class 13.

For all sites combined, multi-trailer trucks had the most "flat" seasonal pattern of the three truck classes; however, as with the single unit truck factors, individual sites frequently exhibited seasonal fluctuations that were substantial. These large fluctuations were caused by a combination of small volumes of very large trucks and changes in local conditions. From the limited number of months of data provided by Montana, it is impossible to determine whether the significant volume fluctuations observed at specific sites were part of a consistent trend (agricultural harvests), or whether they were caused by unusual or one-time occurrences such as construction projects.

A review of the seasonal patterns for multi-trailer trucks at each site showed that three sites (102, 111, and 109) had multi-trailer truck volumes that were too low to produce stable seasonal adjustment factors. (Site 109 had less than 1 per day. Site 111 averaged just over 11 multi-trailer trucks per day, and although Site 102 averaged just under 20 multi-trailer trucks per day on an annual basis, without the four high volume months between September and December, it too averaged 11 trucks per day.) As a result of the low average annual truck volume, all three of these sites had relatively unstable seasonal factors for multi-trailer trucks and were removed from most truck volume seasonal analyses.

Site 102, however, is an excellent illustration of both the importance and difficulty of using seasonal factors for truck volumes in pavement design. During the four-month period from September to December, this site averaged almost 30 multi-trailer trucks per day, with a seasonal peak in September of over 45 trucks per day. During the rest of the year, the site experienced just over 11, while in the summer monthly multi-trailer truck volumes fell to 5 or 6. So an unadjusted vehicle classification count taken in the middle of the summer (June/July) would underestimate the average annual daily load applied by multi-trailer truck on this road by a factor of roughly three to four.[6] A count taken in September would over-estimate average annual load by a factor of roughly two.

Although most sites did not have quite this extreme level of seasonality for multi-trailer trucks, as shown in Figure 4, data for many of the sites showed monthly "surges" in heavy truck traffic.

The result of these periodic fluctuations in multi-trailer truck volumes was that the standard deviation of the seasonal factors was fairly high. Unfortunately, attempts to create factor groups based on geographic location and/or roadway type were not very successful.

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[6] That same count would under estimate average annual combination truck volumes by roughly 50 percent.

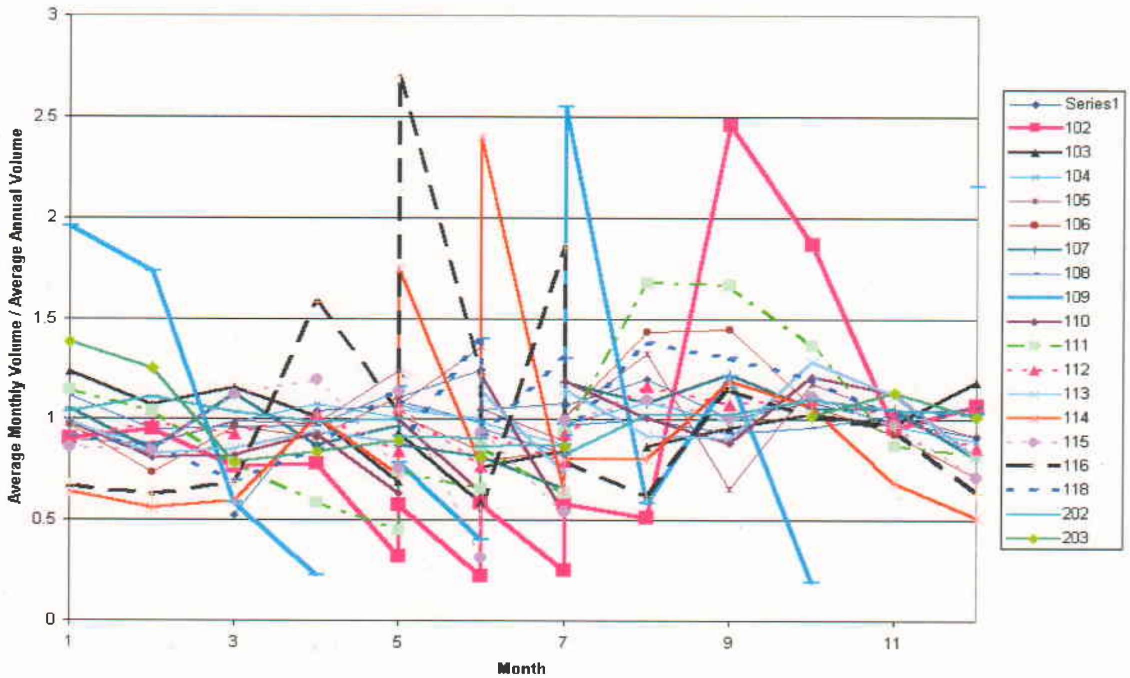

Figure 4: Monthly Multi-Trailer Truck Volume Patterns by Site

For example, a review of the January and February factors showed that most of the sites that exhibited January multi-trailer truck volumes that exceeded average annual conditions were located towards the eastern portion of the state (sites 103 and 111) or at least are farther east than most of the other WIM sites (sites 108 and 203). Creating a factor group of these four sites resulted in a marginally better factor group than a group consisting of all valid sites for the state.[7] The remaining sites in the state were then grouped together

The result was one pattern with a minor volume peak between December and February, and a second with a minor peak between April and May (see Figure 5). Both patterns showed increased volumes during September and October, when shipping picked

7 The mean standard deviation for a monthly factor of the "east" factor group was 0.20, while the "all sites in the state" factor group had a mean standard deviation of just under 0.22. The "non-eastern" group of sites had an average monthly factor standard deviation of 0.20.

up to meet holiday season demands. In addition, both patterns were marginally more homogeneous than the "average for the state pattern." However, creating two patterns would mean that Montana DOT would need a mechanism for determining which roadways in the state fell into which of these two patterns. For example, at what point would a milepost on I-90 stop being in the "eastern" factor group and start belonging to the "other parts of the state" group?

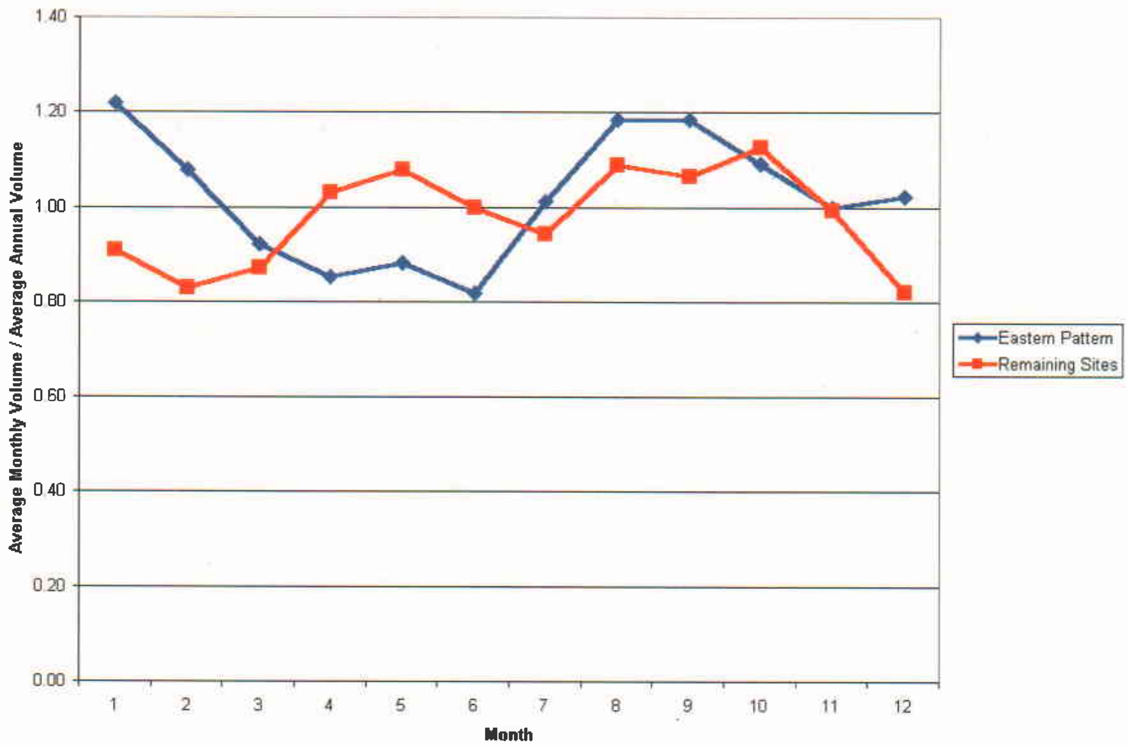

Figure 5: Comparison of Eastern and Non-Eastern Monthly Seasonal Patterns for Multi-Trailer Trucks

Without detailed knowledge of the commodity flows occurring on Montana's highways, it is not possible for this analysis to determine which of these approaches is truly better. If freeze thaw damage due to loads were a concern in either February or

April, then the differences in seasonal adjustments produced by using these two groups, instead of a single group, might justify the additional effort of determining which factor group each Montana road should belong to. If freeze thaw were not an issue, then the benefit might not exceed the cost of the more complex procedures necessary to apply seasonal adjustments with more than one "pattern."

Monthly Seasonal Factors for Combination Trucks

The seasonal patterns for combination trucks were dominated by the travel patterns of FHWA Class 9 trucks. Class 9 trucks (tractor semi-trailers) generally make up between 70 and 90 percent of all combination trucks and generally account for 40 to 70 percent of all pavement loadings.

The "average" combination truck seasonal pattern was quite similar to the average pattern for multi-trailer trucks. It was reasonably flat, with modest increases in volume during the summer and early fall and modest decreases in volume during the winter months. However, unlike multi-trailer trucks, the combination truck volume patterns were fairly stable from site to site and from month to month. Figure 6 illustrates the range of seasonal factors at all sites for which data were provided.

While a large number of Montana sites had monthly multi-trailer factors of less than 0.5 or greater than 1.5, relatively few sites had monthly factors for combination trucks that were less than 0.8 or greater than 1.3. In addition, when taken as a single state-wide factor group, the average standard deviation for monthly combination factors (0.09) was less than half that of the corresponding value for either single unit or multi-trailer trucks.

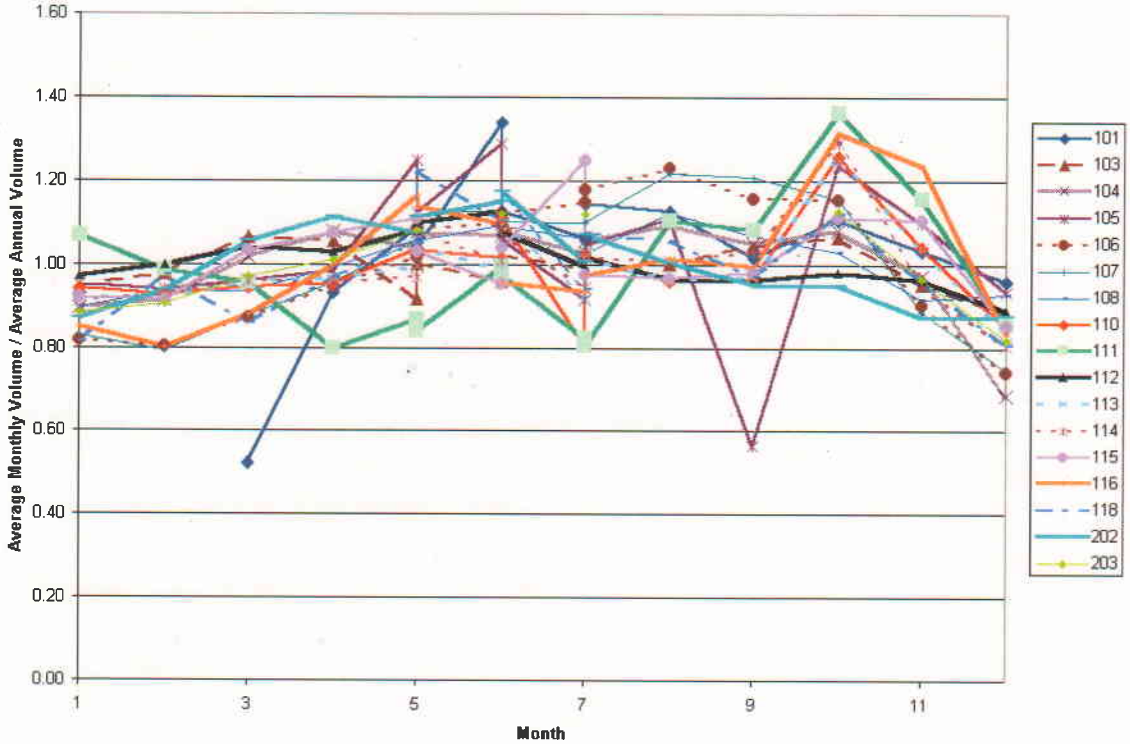

Figure 6: Monthly Seasonal Factors for Combination Trucks

The project team believes that the majority of the exceptionally high or low points seen in Figure 6 were the result of problems with the data collection equipment rather than the result of real changes in truck travel behavior.

One set of "exceptional" seasonality that did appear to be "real" was the relatively high peak in truck volumes at about one-third of the sites in October. These data collection sites experienced October combination truck volumes that were more than 20 percent above average annual conditions. These sites included 105, 110, 111, 113, 114, and 116. It might make sense to create a single factor group from these sites to try to capture these heavy seasonal volumes.

If these sites were called a "group" and all remaining sites with good data were grouped in a second seasonal factor group, the average standard deviation for monthly factors would decline slightly for both groups (from 0.9 for the statewide group to 0.8 for both new groups). Thus, dividing these sites into groups would provide a slightly more homogeneous set of monthly factors.

However, this group would be completely different than the seasonal factor group that was discussed for multi-trailer trucks. A review of the sites with high October volumes showed that they were geographically spread throughout the state of Montana. Interestingly, every one of the sites was located on a U.S. signed route (e.g., Site 105 was located on U.S. 93). In fact, all but three of the data collection sites located on U.S. signed routes in Montana were in the above list, and those three sites (106, 107, and 115) all had October seasonal factors above 1.10 and, therefore, could be added to this seasonal grouping without changing the homogeneity of the factor group significantly. Such an approach would allow any U.S. signed route to be associated with that seasonal factor group. All other roads in the state would be associated with the "rest of the state" group.

As with the multi-trailer truck factors, it is not clear whether use of this "split" factor group would actually be better than using a single statewide group. Unlike the two multi-trailer truck factor groups, the seasonal patterns for these two groups were fairly minor except for the months immediately surrounding October.

Better knowledge of the economic activity and commodity movements taking place within Montana is needed to judge the merits of the "split" factor approach to combination factors.

Recommendations for Seasonal Truck Volume Factoring

For the initial testing and calibration of the new pavement design guide, it is recommended that either statewide average seasonal factors be used or that factors for site-specific WIM locations be used. While minor improvement in the accuracy of truck volume estimates might be gained by using multiple seasonal factor groups, the complexity that such an approach would bring to the traffic load estimation process does not appear to be warranted at this time.

To apply multiple seasonal truck factor groups, Montana would have to track and apply more than one set of factor groups for each pavement design. This would likely be a complex process to develop, implement, and maintain. Given the high level of truck volume variability already present as a result of day-to-day volume fluctuations in truck volumes by class, as well as the difficult task of defining the road segments that should be associated with specific seasonal patterns observed at WIM sites, the benefits in accuracy that would result from the application of multiple factor groups do not appear to be substantial.

Consequently, we recommend that Montana continue to analyze its growing archive of truck volume data. In addition to the mathematical analysis of those data, the Montana DOT should consult experts who understand the economic activity patterns of the state and can provide explanations of what is occurring in the observed patterns and help develop more rational and easier to apply factor groups.

TRUCK WEIGHT PATTERNS

The same 15 months of weigh-in-motion data that were used to analyze seasonal volume factors were reviewed for truck weight information. Because the resources to perform this task were heavily constrained, very limited quality control was performed in the review of the truck weight data. Multiple cases of possible WIM scale calibration drift were noted (and are discussed briefly in this section); except in extreme cases, these data were not removed or adjusted during this analysis. (Suspected calibration drift at Site 113 makes it impossible to classify this site into a truck weight group. Consequently, this site was removed from the data.) Essentially, the majority of the analysis performed for this project assumed that the data supplied by Montana were valid.

Note that this analysis did *not* attempt to compare weights by lane or direction. It is distinctly possible that axle weight will vary by lane and by direction. (Lighter trucks may be more likely to use the "fast lane," whereas heavier trucks may be more likely to use the right or "slow" lane.) Similarly, experience with data submitted to the Long-Term Pavement Performance (LTPP) program indicates that directional loading (trucks are loaded and heavy in one direction but empty and light in the reverse direction) can occur at many sites. Montana DOT may wish to extend this research by performing such an analysis as it progresses in the deployment of the new pavement design guide.

For this analysis, truck weight records (W-card records) were obtained from Montana DOT. The data were run through a Beta version of the NCHRP 1-39 software as part of the 1-39 software testing program. Monthly load distributions were then examined for tandem and single axles. The majority of effort was spent examining load distributions for FHWA Class 9 trucks because those trucks were responsible for far more traffic loading in Montana than any other classification of vehicle.

It was determined that in many but not all cases, sites with similar Class 9 tandem load axle distributions had similar Class 13 tandem axle load distributions, and that Class

6 tandem axle load distributions for those sites were also reasonably similar. (That is, if Site 1 and Site 2 had Class 9 tandem axle loads with similar shapes, then the Class 13 tandem axle load distributions at those two sites would also have similar shapes.) As a result of this finding, the grouping of Montana WIM sites was based on the observed patterns of Class 9 tandem axle loads.[8] The groups were named after the shape of these load distribution patterns, and only a minor amount of analysis was given to the axle load distributions of the other vehicle types.

One other finding of the analysis of multiple vehicle classes was that sites that tended to have "heavy" axle load distributions relative to other sites in their group for one Class of vehicles tended to have "heavy" axle load distributions for all classes of trucks. This finding led to the speculation that these trends were primarily the result of minor WIM scale calibration problems, rather than truly different trucking load characteristics. Additional work by Montana DOT is needed to confirm this speculation.

General Axle Load Distribution Findings

Five basic patterns of truck axle weight distributions were observed in Montana's data for FHWA Class 9 trucks. Montana WIM sites could be grouped into fairly homogeneous loading patterns using these five basic patterns. For pavement design, individual roadway segments would then be assigned to one of these groups on the basis of the nature of truck travel on that road segment, and the axle load distribution for that group would then be used, along with the number of trucks by classification of truck, to determine the expected pavement load on that roadway.

[8] The axle load distribution histograms were based on the input axle weight categories used by the NCHRP 1-37A software. The axle weight boundaries associated with these categories are given in Appendix A for this report.

These five Truck Weight Road Groups were based on the shape of the tandem axle load distribution found for Class 9 trucks. The five groups are

- primarily loaded trucks
- bimodal loading condition, with more heavy than light trucks
- bimodal loading condition with an even distribution between loaded and unloaded trucks
- lightly loaded condition (primarily empty trucks).
- flat distribution.

Each of these basic patterns is discussed in more detail below.

A brief review of monthly changes in axle load distributions was conducted for each of the WIM sites for which data were provided. That review indicated that WIM scale calibration drift may have significantly affected the loading rates described in this report. A thorough investigation of those concerns was beyond the scope of this analysis effort. However, Montana DOT is encouraged to perform such an analysis, as the new pavement design guide uses monthly axle load distributions, and the variation observed in the data at many WIM sites would be large enough to affect some pavement designs.

Four Excel files have been transmitted to the prime contractor for this project. Those files contain the loading patterns, by month, for both individual sites and the truck weight load groups defined in this section. Montana DOT may include these data in the pavement design and performance analysis process.

Primarily Loaded Trucks

The first truck weight road group identified in this report is called "Primarily Loaded." It represents sites where the vast majority of Class 9 trucks operating on that roadway carried a significant load. For Class 9 trucks at these sites, only one obvious peak was observed in the tandem axle load distribution. (See Figure 7, which shows the average of the 12 monthly load distributions for each of the seven sites grouped into this truck weight road group.)

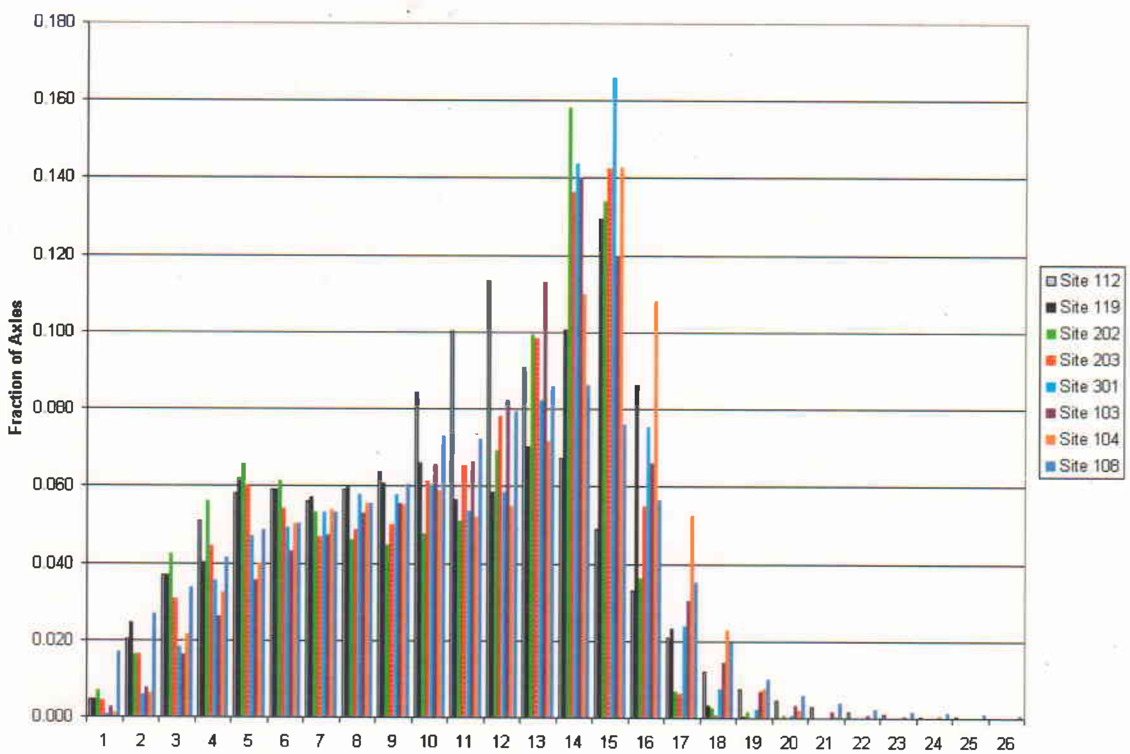

Figure 7: Average Annual Tandem Axle Load Distribution for Class 9 Trucks, Primarily Loaded Truck Weight Road Group[9]

The only significant peak in the tandem axle load distribution shown in Figure 7 corresponds to tandem axle loads near the legal limit. These axles weigh roughly 30,000 to 32,000 pounds and are associated with fully loaded, 5-axle, tractor semi-trailers.

9 See Appendix A for the weights associated with each category of axle loads

An axle load distribution of this type indicates that heavy trucks on these roads are loaded to near their legal limits, and that the majority of Class 9 trucks using these roads are fully loaded. This is a pattern common to Interstate highways in rural areas that serve significant long-haul truck movements. Not surprisingly, all but one of the Montana WIM sites associated with this truck weight group were on rural Interstates. The one site not on an interstate highway was site 301, which is on U.S. 2 near Malta in the north central portion of Montana. All WIM sites located on Montana's Interstate system were classified within this group, although sites 119, 202, and 112 had enough of an unloaded peak that they might have been included in the Bimodal-Heavy group.

Interestingly, the Class 13 tandem axle load distributions for the different sites in this truck weight road group were not nearly as uniform as those for Class 9 trucks (compare Figure 8 with Figure 7). Unlike Class 9 trucks, Class 13 trucks weighed at five of the eight sites in this group had both loaded and unloaded peaks. For example, sites 108 and 119 had very substantial peaks in the first two histogram ranges, which corresponded to tandem axles below 6,000 pounds and between 6,000 and 8,000 pounds. However, the size and relative position of the unloaded peaks differed from site to site. Sites 103, 104, and 203 had no substantial unloaded peak in the Class 13 tandem axle distribution for this group.

The fact that there were unloaded peaks in the tandem axle distribution indicates that a significant portion of these trucks were most likely operating with trip origins and destinations within roughly four hours or less of each other. Thus, a significant portion of the Class 13 trips at these sites were likely not long distance hauls, which are uneconomical if the reverse haul must be made empty, whereas the majority of the Class 9 trucks were probably in long haul service.

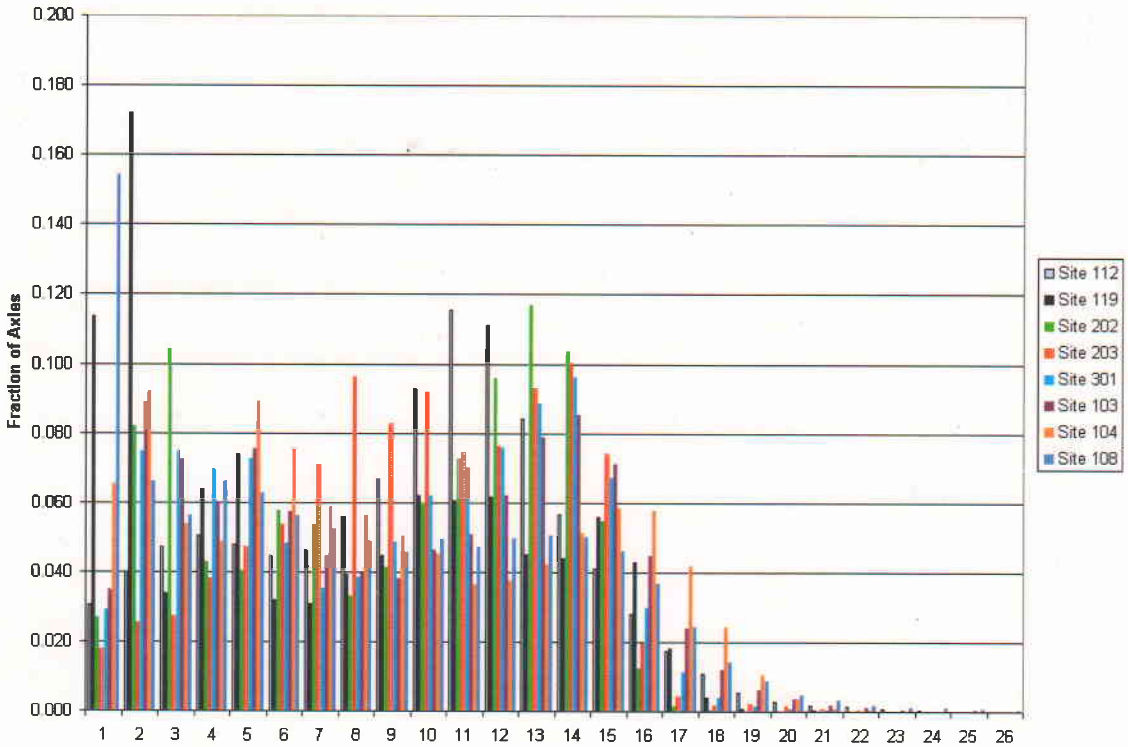

Figure 8: Average Annual Tandem Axle Load Distribution for Class 13 Trucks, Primarily Loaded Truck Weight Road Group

The variability seen in the axle load distribution for Class 13 trucks means that the "group average" axle load distribution would not be as accurate a load estimate for any one site associated with this group as it would be for the Class 9 load distribution. For some of these sites (e.g., Site 108), the "group average" would over-estimate loads applied by Class 13 trucks, while at other sites (e.g., site 203) the group average would underestimate actual loads. Because the Class 9 load estimates were much more similar when compared between sites, these errors would be much less common and/or pronounced for Class 9 trucks.

Figure 9 shows the tandem axle weight distribution for Class 6 trucks for this site. The axle load distribution for Class 6 trucks was more uniform than that for Class 13, but less uniform than that for Class 9. The biggest discrepancy in the uniformity of this axle load distribution group was the unusually large number of very lightly loaded axles for sites 108 and 203, as well as the very light "loaded peak" for site 202.

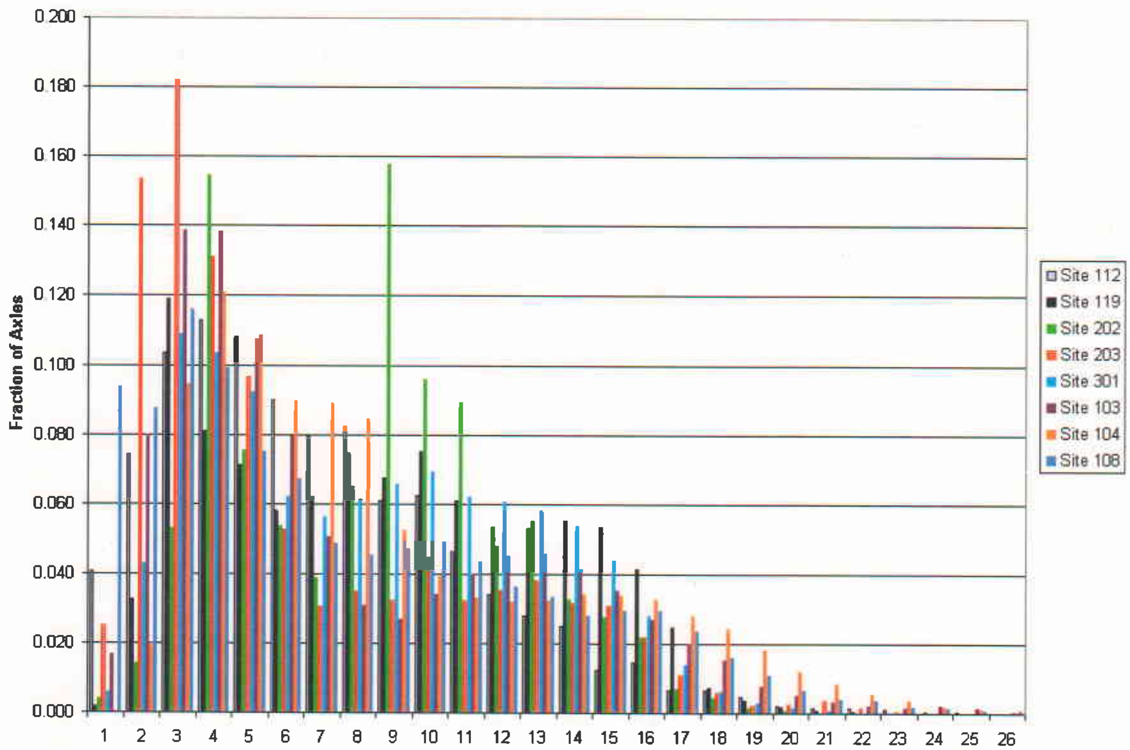

Figure 9: Average Annual Tandem Axle Load Distribution for Class 6 Trucks, Primarily Loaded Truck Weight Road Group

Also of interest in the Class 6 graphic is the fact that roughly 1 percent of tandem axles at sites 103, 104, and 108 were 40,000 pounds or greater (histogram categories 19 and up). These very heavy axles were not nearly as prevalent in the other five sites in this group. These very heavy axles would be likely to have a substantial impact on pavement life and, consequently, pavement design.

When figures 7, 8, and 9 are taken together, they do suggest some scale calibration concerns. For example, the locations of both loaded and unloaded peaks in the tandem axle distributions for Site 202 were generally lighter than those of the other six sites. Conversely, sites 103 and 104 generally had heavier loaded and unloaded peaks (and more very heavy axles) than the other six sites. These consistent differences may have been caused by minor differences in scale calibration at the different sites.

Site 108 tended to have both relatively high numbers of very heavy axles and very light axles in comparison to the other sites. This could indicate that truck dynamic motion was higher at this site than at the other sites in the group, which normally means that the pavement near the scale is not smooth, causing high levels of dynamic vehicle motion. This in turn leads to "abnormally high" numbers of very light and very heavy axles being reported. It also means that the pavement loading estimate based on axle distributions from this site may overestimate actual traffic loading, because very heavy axles have a disproportionate effect on pavement design than very light axles.

Using an average axle load distribution for the entire group of sites, rather than the load spectra for a single site, would dampen the effects of these potential scale problems. It is therefore recommended that Montana DOT use an average load spectra for the group as a whole for all pavement design efforts.

Bimodal Loading Condition – Heavy Distribution

The second distribution group examined was very similar to the first in that there was a significant loaded peak in the tandem axle load distribution for Class 9 trucks. The primary difference between this group and the last one is that sites in this group had a higher level of "unloaded" Class 9 truck traffic. This resulted in a more noticeable unloaded peak in the axle load distribution (see Figure 10). However, as with all grouping efforts, the boundaries between this group and the "Primarily Loaded" group were somewhat arbitrary.

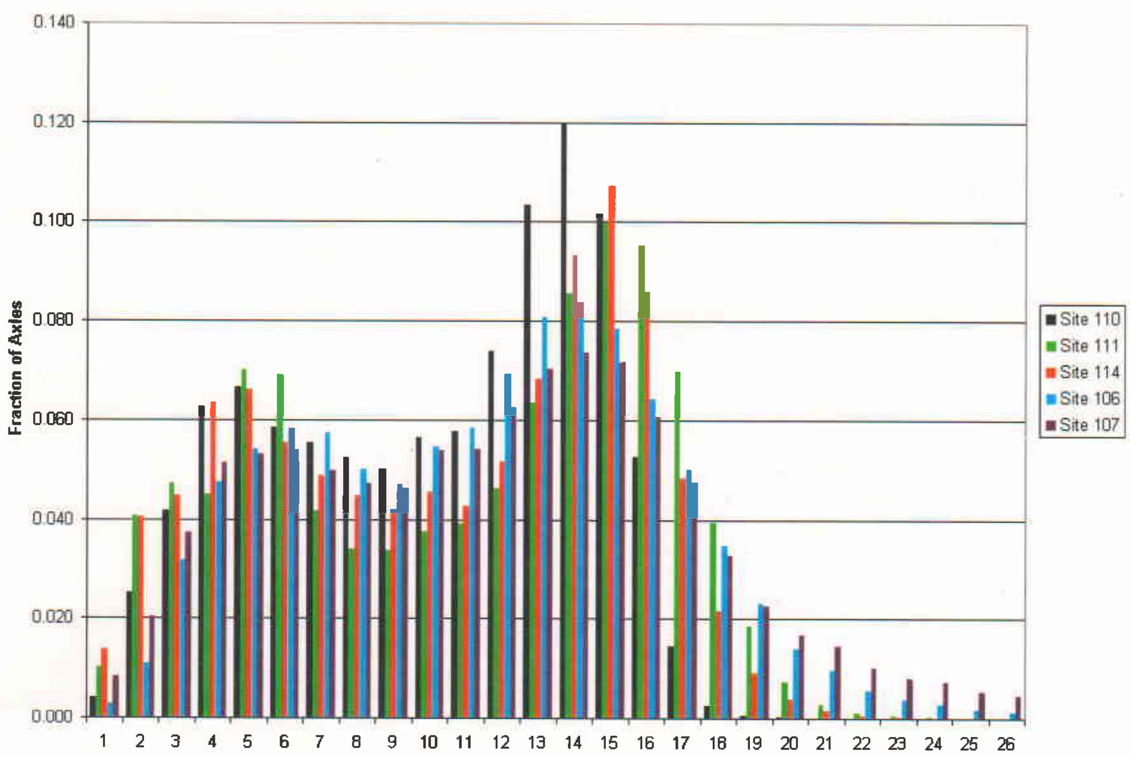

Figure 10: Average Annual Tandem Axle Load Distribution for Class 9 Trucks, Heavy-Bimodal Truck Weight Road Group

Interestingly, none of these sites were Interstates. Instead four were U.S. routes and one was a Montana state route. They were not geographically related, although sites

106 and 107 were only 8 miles apart on U.S. 191. They appear to represent sites with generally heavy truck movements, but with a modest number of empty trucks mixed in with the heavily loaded trucks.

Of particular interest in Figure 10 is the significant number of very heavy tandem axles at sites 106 and 107. It is not clear whether this resulted from scale calibration problems or is an indication of over-loaded axles at these two sites (they were only 8 miles apart).

Very heavy tandem axles were also present at these two sites for both Class 13 and Class 6 trucks (see figures 11 and 12). Very heavy axles were also present in Class 6 trucks at site 114, but only to a modest extent for Class 13 trucks at that site.

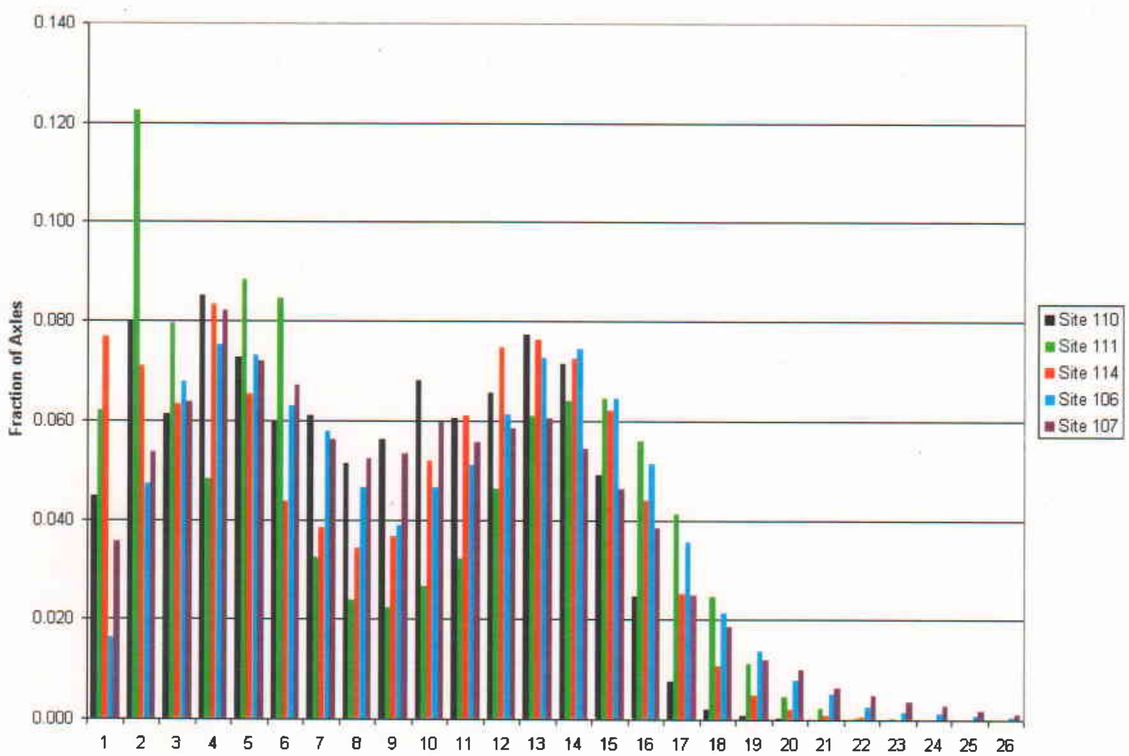

Figure 11: Average Annual Tandem Axle Load Distribution for Class 13 Trucks, Heavy-Bimodal Truck Weight Road Group

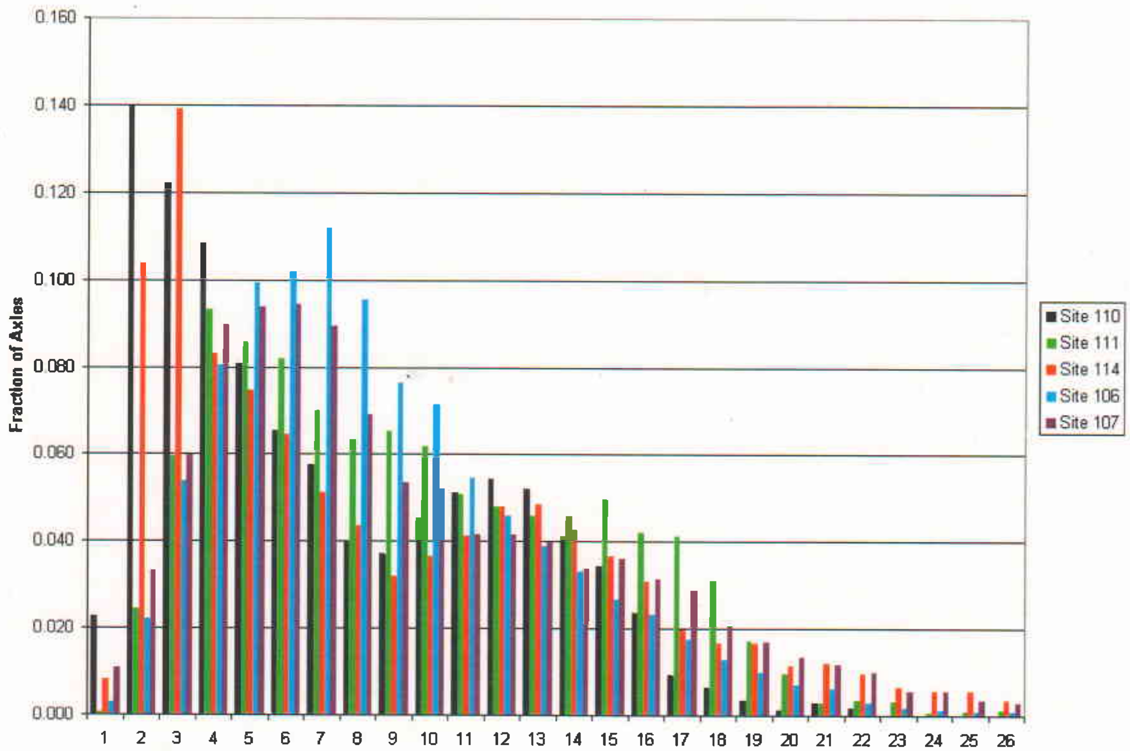

Figure 12: Average Annual Tandem Axle Load Distribution for Class 6 Trucks, Heavy-Bimodal Truck Weight Road Group

Other than the differences in the extent of overloaded axles observed, the tandem axle distributions measured at the sites within this "heavy bimodal" group tended to be more homogeneous for most classes of trucks than those observed in the Primarily Loaded group of Interstate sites. Thus, the group averages are generally an excellent descriptor of the loads carried at sites within these groups.

The two difficulties associated with this truck weight road group are 1) that the group itself may be hard to define (which roads within Montana should be associated with this group?) and 2) the fact that the presence of overloaded axles in some but not all sites would result in very different pavement loading rates for those sites, even though the shape of the two distributions are quite similar. Overloaded axles in pavement design can be so important to pavement design that if overloading is as prevalent as suggested by these data, Montana might want to consider developing a truck weight road group specifically to handle roads with this level of overloading. The only issue then would be to determine which road segments the "frequent overload" truck weight group should be applied to.

Without having better local knowledge of the prevalence of overloads, it is initially recommended that this be treated as a single group. Averaging of the axle load distribution patterns for the five sites will dilute the effect of the overloaded axles somewhat, but it will also result in a fairly conservative loading design for non-Interstate Montana roadways that are carrying loaded heavy trucks.

Bimodal Loading Condition – Even Distribution

The third truck weight road group had a very balanced tandem axle load distribution. For sites in this group, the loaded and unloaded peaks were roughly equal in height (see Figure 13). This signifies that the numbers of loaded and unloaded trucks on these roads were roughly equal.

As with the heavy bimodal group, the WIM sites allocated to this group were all U.S. or Montana state routes. (Site 102 was on S 314, where it carried only 10 to 25 Class 9 trucks per day.) They, too, were spread geographically around the state.

Of significant interest for this group is what appears to be an overloaded condition for Site 102. All three major truck categories (classes 6, 9, and 13) showed very heavy tandem axles at this site, but not at the other four sites in this group (see figures 14 and 15). The project team does not know whether the large number of overloaded axles was the result of a high percentage of overloaded vehicles or poor scale calibration at this low volume WIM scale.

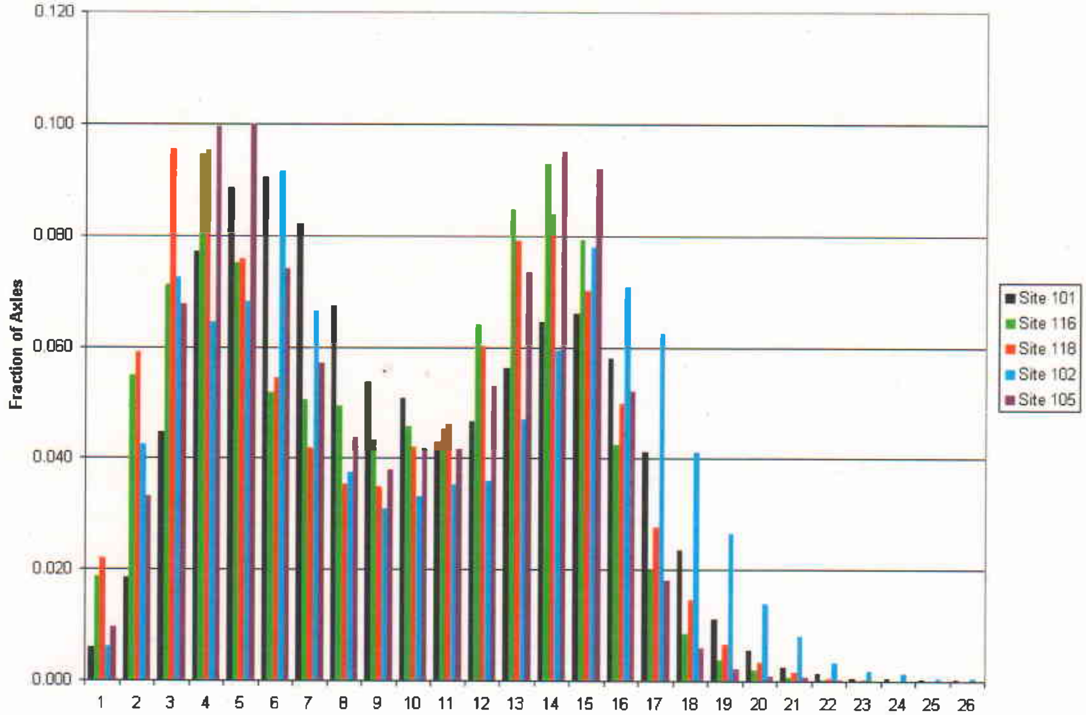

Figure 13: Average Annual Tandem Axle Load Distribution for Class 9 Trucks, Bimodal Truck Weight Road Group

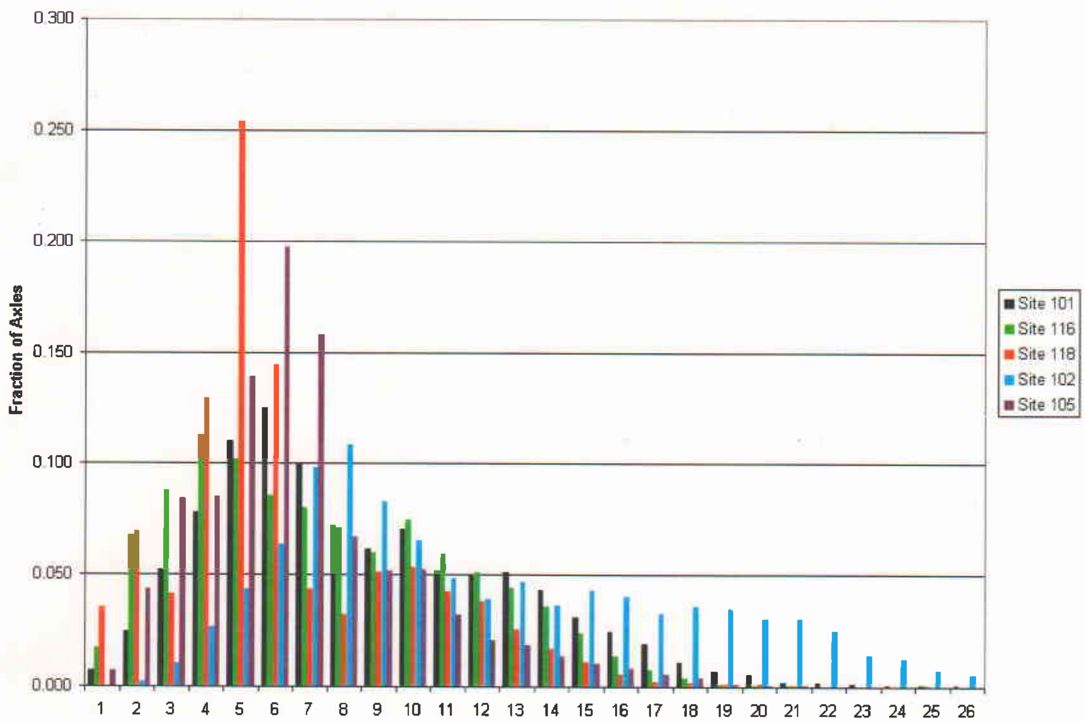

Figure 14: Average Annual Tandem Axle Load Distribution for Class 6 Trucks, Bimodal Truck Weight Road Group

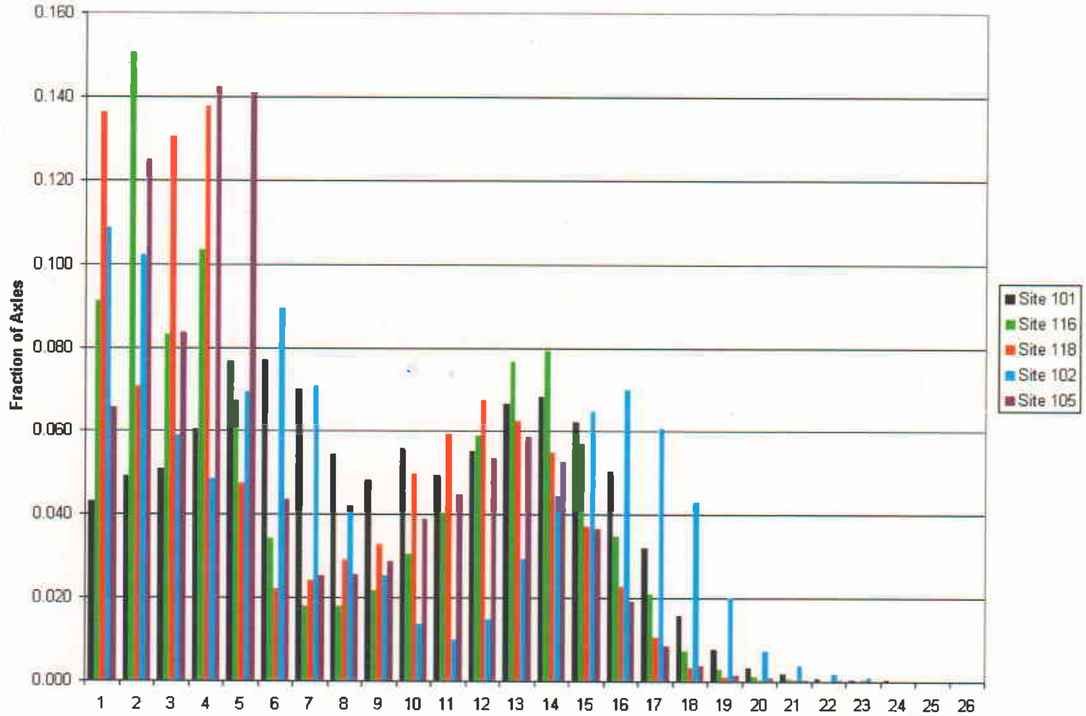

Figure 15: Average Annual Tandem Axle Load Distribution for Class 13 Trucks, Bimodal Truck Weight Road Group

There were very few lightly loaded tandem axles for Class 6 trucks at this site, which might also indicate over-calibration of the scale, but the number of light tandem axles was reasonable for both classes 9 and 13, which suggests a problem with overloaded trucks at the site.

To look for further insight into the status of Site 102's scale calibration, a review of the 12 monthly single axle load distributions for Class 9 trucks is shown in Figure 16. For a consistently calibrated site, this distribution should be fairly stable throughout the year. Figure 16 indicates that the scale calibration for this site may not have been stable throughout much of the year. Without local knowledge of expected changes in the commodities being carried at this site to contradict this conclusion, the recommendation is to remove this site from the group average. If additional analysis shows that a significant overload condition exists at Site 102, that site may need to be treated as a "unique" traffic loading pattern.

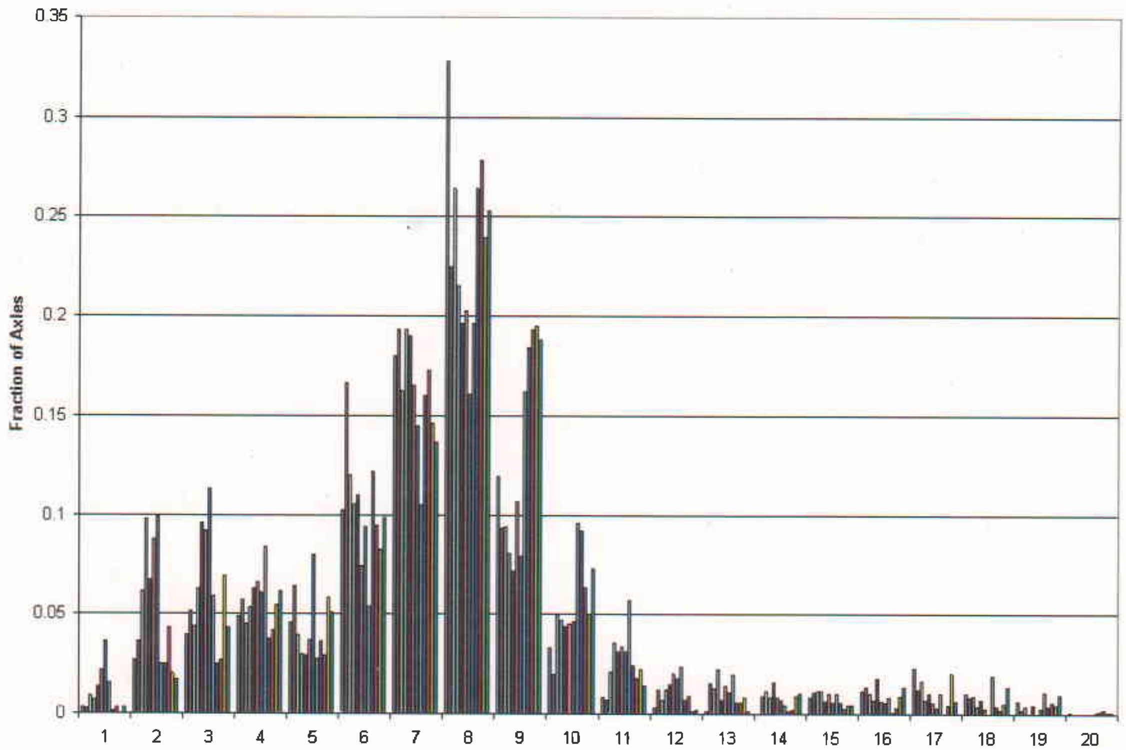

Figure 16: Monthly Single Axle Load Distribution for Class 9 Trucks, at Site 102

Lightly Loaded Condition

The fourth truck weight road group represents road segments where unloaded trucks dominated the truck loading pattern. Figure 17 illustrates the tandem axles load distribution pattern common to these sites. A significant peak exists for very lightly loaded tandem axles, with little or no peak in the loaded axle weight ranges.

This pattern is relatively common in the national LTPP database, but only two sites in the Montana data supplied for this effort illustrated this trend. One of those sites, 109, was on a low truck volume road (S 273, near Galen). It averaged less than five

Class 9 trucks per day during the year and essentially no multi-trailer trucks. The other site in this group (115) was on U.S. 87 near Fort Benton. It carried fairly substantial truck traffic (over 75 combination trucks per day).

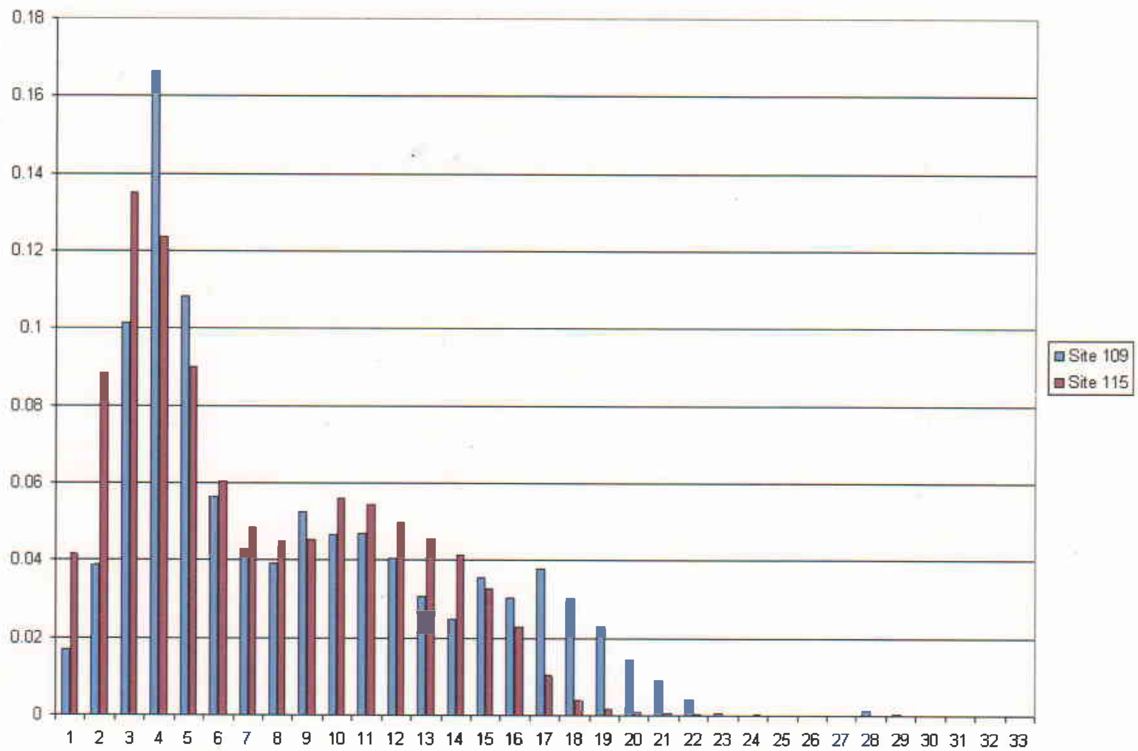

Figure 17: Average Annual Tandem Axle Load Distribution for Class 9 Trucks, Lightly Loaded Truck Weight Road Group

A review of figures 17 and 18 suggests that Site 109 was over-calibrated relative to Site 115. Site 109 had a large percentage of heavy tandem axle weights for both Class 9 and Class 6 trucks relative to what was measured at Site 115. These axles were also fairly heavy in comparison to most other tandem axles measured at other sites in the Montana data set. Finally, the loaded peak for Class 9 trucks was located in load category 17, which corresponds to 36,000 to 38,000 pounds, a value that exceeds the legal limits. However, given the small number of trucks included in the Site 109 data set and without on-site calibration, it is not certain whether this site had an overload or scale calibration problem. Site-specific calibration checks are needed to answer this question.

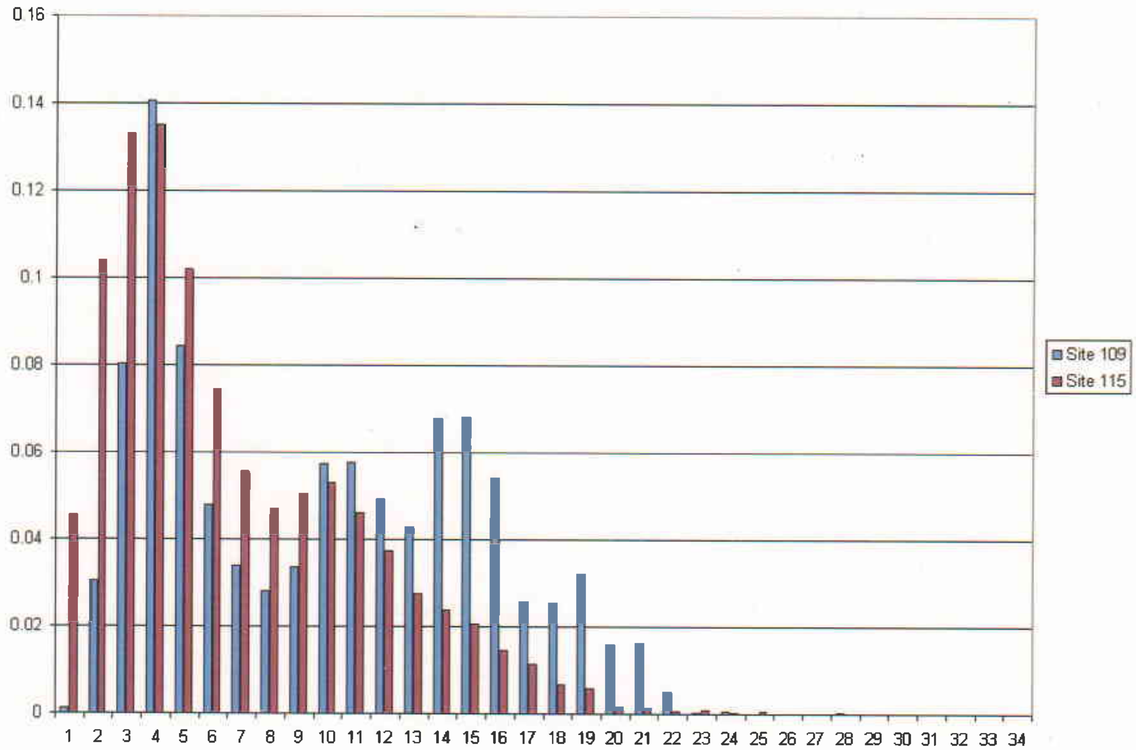

Figure 18: Average Annual Tandem Axle Load Distribution for Class 6 Trucks, Lightly Loaded Truck Weight Road Group

The initial assumption for the development of traffic load inputs for Montana's new pavement design guide is that Site 109 is somewhat over-calibrated. As a result, it is suggested that the "Lightly Loaded" truck weight road group use only the weights from Site 115 until the calibration of Site 109 can be confirmed.

<u>Flat Distribution</u>

The last tandem axle weight distribution pattern observed was apparent at Site 113. This WIM site had a tandem axle load distribution curve for Class 9 trucks that was essentially flat between axle load category 5 (12,000 to 14,000 lbs) and category 16

(34,000 to 26,000 lbs) (see Figure 19). This was the only site with such an even distribution. The even distribution was a sign that either many trucks at this site carried partial loads or the scale had significant calibration difficulties.

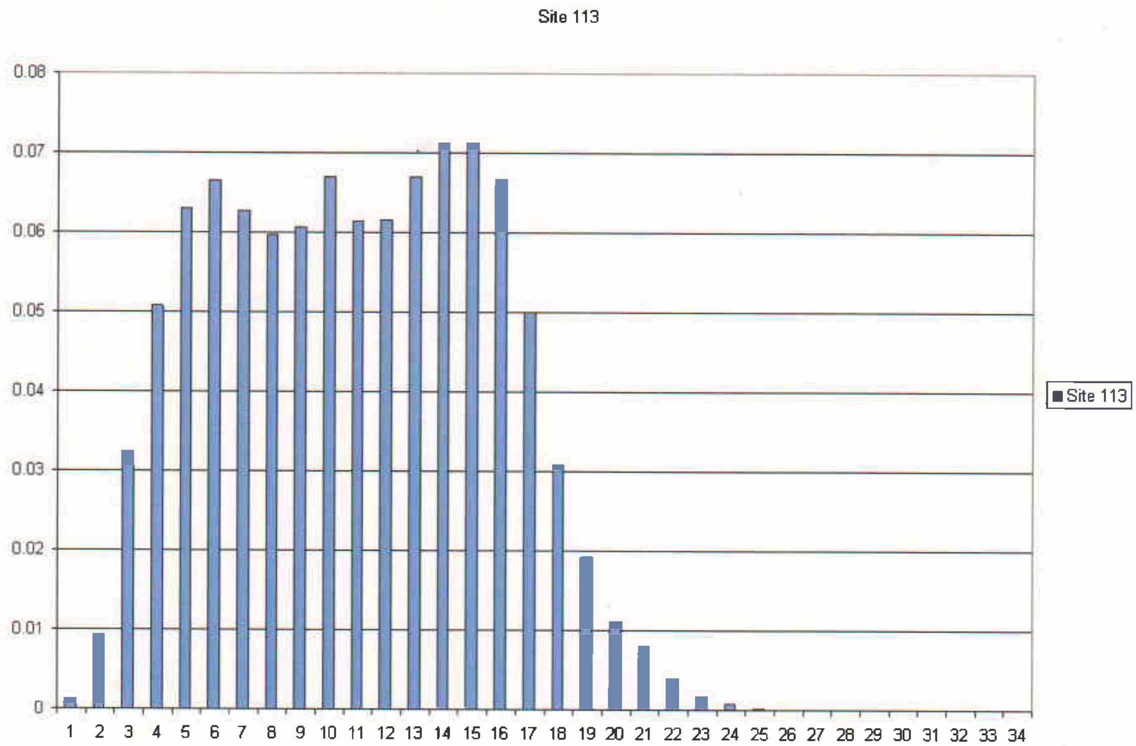

Figure 19: Average Annual Tandem Axle Load Distribution for Class 9 Trucks, Flat Truck Weight Road Group

A review of the graph that depicts the 12 monthly tandem axle load distributions (see Figure 20) and the graph for monthly average distribution of front axle weights for Class 9 trucks (see Figure 21) indicates that this site probably had significant calibration difficulties. The distribution of axle weights changed from one exhibiting very light axles for April through July to one with very heavy axles in November 2000 through

January 2001.[10] When combined these very different patterns yield an "evenly distributed pattern" unlike what is likely being experienced at this site.

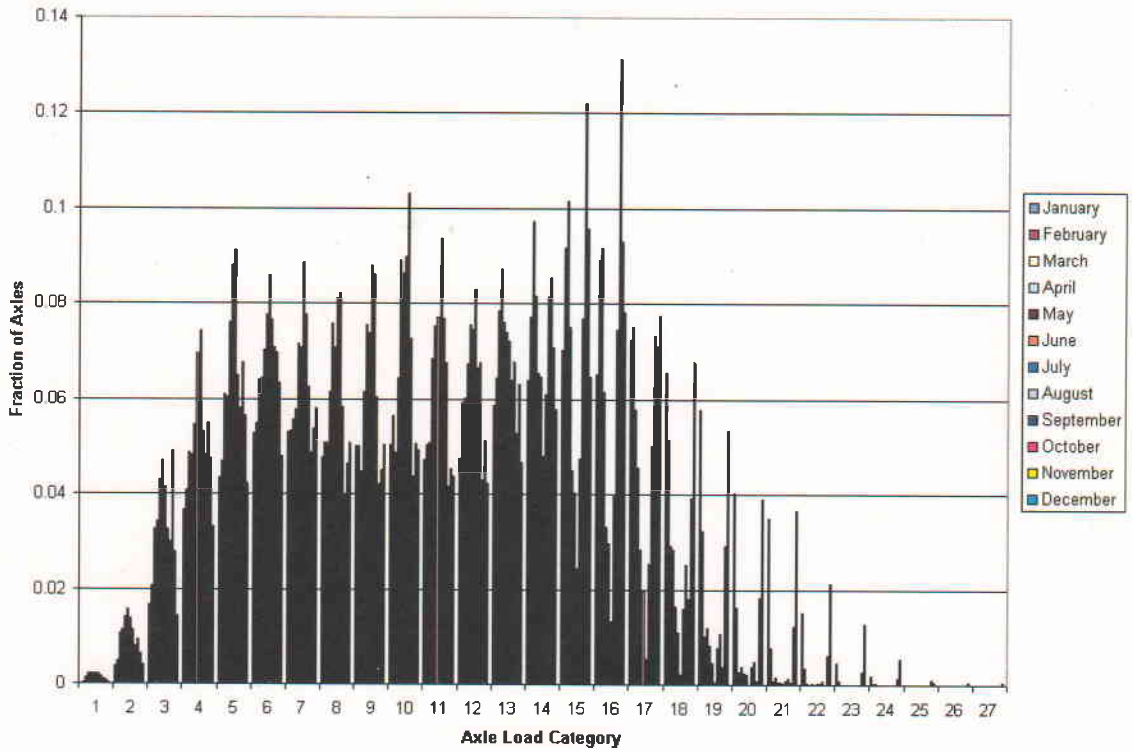

Figure 20: Average Monthly Tandem Axle Load Distribution for Class 9 Trucks, Site 113

Unlike Site 109, which also exhibited signs of significant scale calibration drift, Site 113 had fairly large Class 9 truck volumes (~170 Class 9 trucks per day), so a lack of Class 9 truck volume is unlikely to be the cause of an inability to maintain scale calibration. However, according to the information included on Montana DOT's "Station Records," the scale used a piezo-electric sensor. These sensors are known to periodically experience calibration drift problems associated with an inability to control for changes in the weight sensor's sensitivity to temperature fluctuations.

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[10] Note that the weight data supplied by Montana DOT ran from May 2000 through July 2001, so the axle load distributions shown in these figures for May, June, and July include data from two different time periods. This may disguise some of the possible drift in WIM scale calibration.

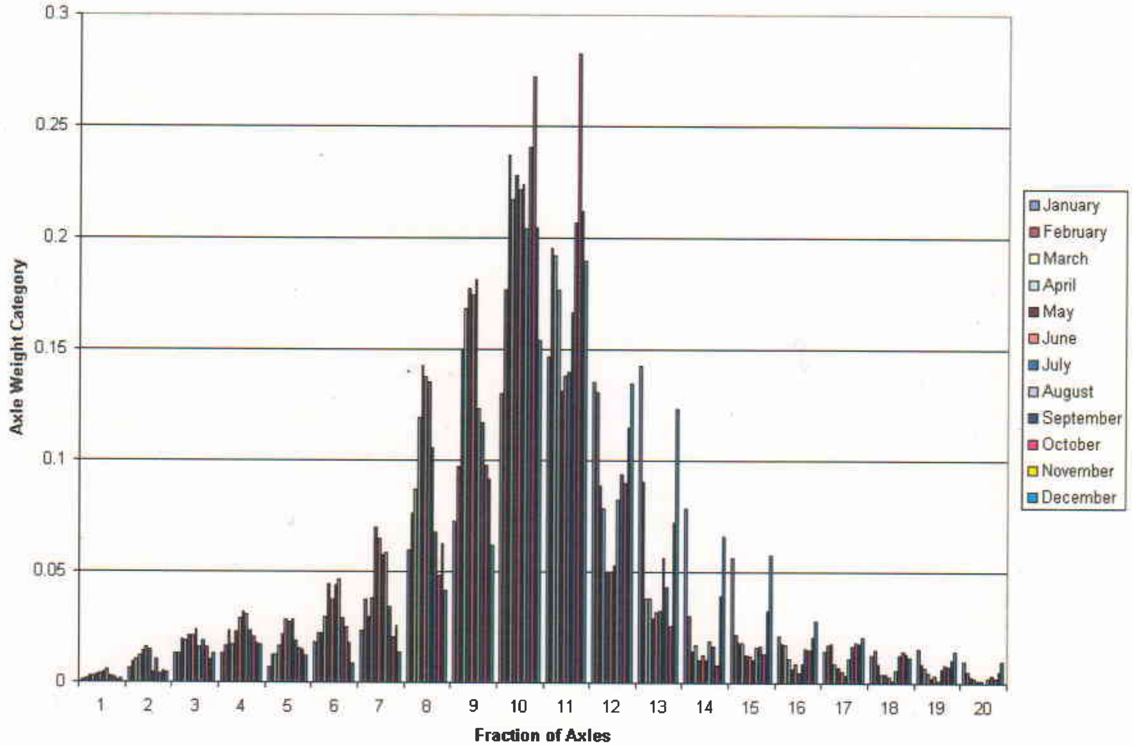

Figure 21: Average Monthly Tandem Axle Load Distribution for Class 9 Trucks, Site 113

A month by month review of the tandem axle load distribution for Class 9 trucks indicates that if calibration were held constant, this site might belong in the Heavy-Bimodal axle distribution truck weight road group. However, without considerably more information on scale calibration at this site or local knowledge about trucking activities on this road, it is not appropriate at this time to assign this site to a specific truck weight road group.

It is recommended that Montana consider not using this particular truck weight group for pavement design until additional work confirms that the data observed accurately describe actual axle loading conditions.

SUMMARY AND CONCLUSIONS

Seasonal Factoring of Vehicle Volumes by Classification

For the initial testing and calibration of the new pavement design guide, it is recommended that Montana develop and apply seasonal adjustment factors for three categories of trucks: single units, combinations, and multi-trailer trucks. When these factors are applied for pavement design, the Department should use either statewide average factors or factors for site-specific, permanent data collection sites that are located on roads for which a pavement design is being developed. To use a site-specific seasonal factor, a major truck trip generator (e.g., a major urban area, a large industrial facility such as a mine, or the intersection of the route in question with another major roadway) should not be located between the continuous data collection site from which the seasonal factors have been developed and the roadway section for which the pavement is being designed.

For all other sites, the statewide average should be used for now. While a minor improvement in the accuracy of truck volume estimates might be gained by using multiple seasonal factor groups instead of a single statewide average, the complexity that such an approach brings to the traffic load estimation process does not appear to be warranted at this time.

However, it is recommended that Montana continue to analyze its growing archive of truck volume data to determine whether a more appropriate factoring group process can be developed. In addition to the mathematical analysis of its data, the Montana DOT should consult experts who understand the economic activity patterns of the state and can help provide explanations of what is occurring in the observed patterns.

This will help determine if use of regional or functional stratifications of Montana's roads would allow a more accurate application of truck volume seasonal factors (and the association of specific road sections to those groups), thus improving the accuracy of truck loading estimates used in pavement design.

Truck Weight Groups

The review of truck axle load distributions showed that the basic shape of the axle load distributions does not appear to change dramatically during the year at any given site. However, individual sites do have different axle load distribution patterns. In addition, the data analyzed for this report indicated that many Montana WIM sites experience seasonal calibration changes that can affect the accuracy of the load estimates used for pavement design.

The differences observed in the shape of axle load distributions lead to the recommendation that Montana DOT maintain four different truck weight road groups (TWRG). (TWRG are groups of roads for which a common axle load distribution is maintained.) The four recommended groups are named after the shape of the tandem axle load distribution for Class 9 trucks. The recommended groups are

- primarily loaded roads (including all Interstates)
- bimodal loading condition with more heavy than light trucks
- bimodal loading condition with an even distribution between loaded and unloaded trucks
- lightly loaded condition (primarily empty trucks).

The WIM sites associated with each of these groups are shown in Table 3.

Table 3: Assignment of WIM Sites to Truck Weight Road Groups

Truck Weight Road Group	WIM Sites Belonging to That Group
Primarily Loaded Trucks	103, 104, 108, 112, 119, 202, 203, 301
Bimodal Loading Condition – Heavy Distribution	106, 107, 110, 11, 114
Bimodal Loading Condition – Even Distribution	101, 192, 105, 116, 118
Lightly Loaded Trucks	109, 115
Flat Distribution (do not use for pavement design)	113

Montana DOT should compute average monthly axle load distributions for each classification of trucks at each WIM site. TWRG averages can then be computed by simply averaging the axle load distributions for all of the sites contained in a given TWRG. This analytical process can be performed by using the software developed in NCHRP project 1-39.

There appears to be considerable drift in the weights reported in the 2000–2001 data for a number of the Montana WIM scales. This can result in substantial shifts in estimated pavement damage computed for a given number of trucks. It is unclear whether these reported weights are correct or the data provided to the consultant team had scale calibration problems; in several cases there were strong indications that scale calibration was drifting.

If Montana DOT has not already developed an ongoing calibration process that confirms the accuracy and reliability of axle weight data collected by its WIM scales, such a program should be developed and implemented. At a minimum, seasonal calibration checks of several of WIM stations should be performed to determine whether the observed changes in load spectrum are caused by changes in the performance of the scale, or in fact considerably heavier loads are being carried by trucks at some times of the year (usually winter).

Finally, Montana DOT will need to perform additional work to assign individual roadway segments from around the state to the four recommended TWRGs. This assignment should be based on the relative percentage of Class 9 trucks that are operated fully, or nearly –fully, loaded. If no knowledge of the truck loading distribution is available, and the road in question is not an Interstate highway, it is recommended that Montana DOT assign the road to the "Heavy, Bimodal" distribution. This is because most non-Interstate roads carry a reasonable number of unloaded or lightly loaded trucks, and the "Heavy-Bimodal" axle load distribution is the most conservative load distribution for pavement design purposes.

APPENDIX A

LOAD RANGES USED FOR NCHRP 1-37A LOAD SPECTRA

Table A-1 shows the upper bounds associated with the load range categories used to create the axle load distributions that are inputs to the NCHRP 1-37A pavement design procedures. All weights shown in the table below are given in "kips" (1,000s of pounds). For example, Load Range 1 for Single Axles contains the single axles that weigh less than 3,000 pounds. Load Range 20 for tandem axles contains the axles with weights equal to or greater than 42,000 pounds but less than 44,000 pounds.

Table A-1: Load Ranges Used for Load Spectra
Upper Limit of Load Ranges (kips) by Type of Axle Group

Load Range	Single	Tandem	Tridem	Quad
1	3	6	12	12
2	4	8	15	15
3	5	10	18	18
4	6	12	21	21
5	7	14	24	24
6	8	16	27	27
7	9	18	30	30
8	10	20	33	33
9	11	22	36	36
10	12	24	39	39
11	13	26	42	42
12	14	28	45	45
13	15	30	48	48
14	16	32	51	51
15	17	34	54	54
16	18	36	57	57
17	19	38	60	60
18	20	40	63	63
19	21	42	66	66
20	22	44	69	69
21	23	46	72	72
22	24	48	75	75
23	25	50	78	78
24	26	52	81	81
25	27	54	84	84
26	28	56	87	87
27	29	58	90	90
28	30	60	93	93
29	31	62	96	96
30	32	64	99	99
31	33	66	102	102
32	34	68		
33	35	70		
34	36	72		
35	37	74		
36	38	76		
37	39	78		
38	40	80		
39	41	82		