TRUCK LOADS AND FLOWS
TASK A - SUMMARY REPORT

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16. ABSTRACT

This study describes the analysis of truck volume data collected by the Washington State Department of Transportation (WSDOT) over four and one half years, from 1988 through 1993. The primary objectives of this research were to: investigate the patterns in truck volumes at various locations in Washington State; determine whether seasonal factors can be developed and applied to short-duration truck volume measurements to better estimate average annual conditions; develop procedures for routinely calculating and applying these values in Washington; develop an easy procedure that other states can use to create their own seasonal factoring process, and produce a guidebook that explains this process and lists the necessary steps clearly and concisely.

This report summarizes all but the last of these objectives. This last objective is met in another summary report.

The project analyses show that it is very difficult to develop and apply truck seasonal adjustment factors that accurately predict annual truck volumes from a single short duration truck volume count. As a result, the project team recommends that, wherever possible and financially appropriate, each state should collect multiple, site specific vehicle classification counts in order to accurately estimate annual truck volumes whenever pavement design projects are to be performed.

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Research Project T9233, Task 16
Truck Flows and Loads for Pavement Management

TRUCK LOADS AND FLOWS

TASK A—SUMMARY REPORT

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This study describes the analysis of truck volume data collected by the Washington State Department of Transportation (WSDOT) over four and one half years, from 1988 through 1993. The primary objectives of this research were to: investigate the patterns in truck volumes at various locations in Washington State; determine whether seasonal factors can be developed and applied to short-duration truck volume measurements to better estimate average annual conditions; develop procedures for routinely calculating and applying these values in Washington; develop an easy procedure that other states can use to create their own seasonal factoring process, and produce a guidebook that explains this process and lists the necessary steps clearly and concisely.

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FINDINGS

Establish Truck Volume Patterns

Comparison Among Vehicle Classes

The project findings reveal that the four vehicle classes (defined in the Glossary) collected by the permanent length classifying equipment have very different seasonal patterns, regardless of the volume or functional classification of the roadway or the geographic location of the site. In general, the longer truck categories show less seasonal variation (i.e., month-to-month changes in daily traffic volumes) than the short truck and automobile classifications. In addition, traffic volumes of Bin 2 vehicles (mostly larger, single unit trucks and RVs) tend to vary the most by season. This variance appears to be attributable to the recreational vehicles in this category. Figures 1 and 2 illustrate the differences in seasonal truck volume patterns among vehicle classes.

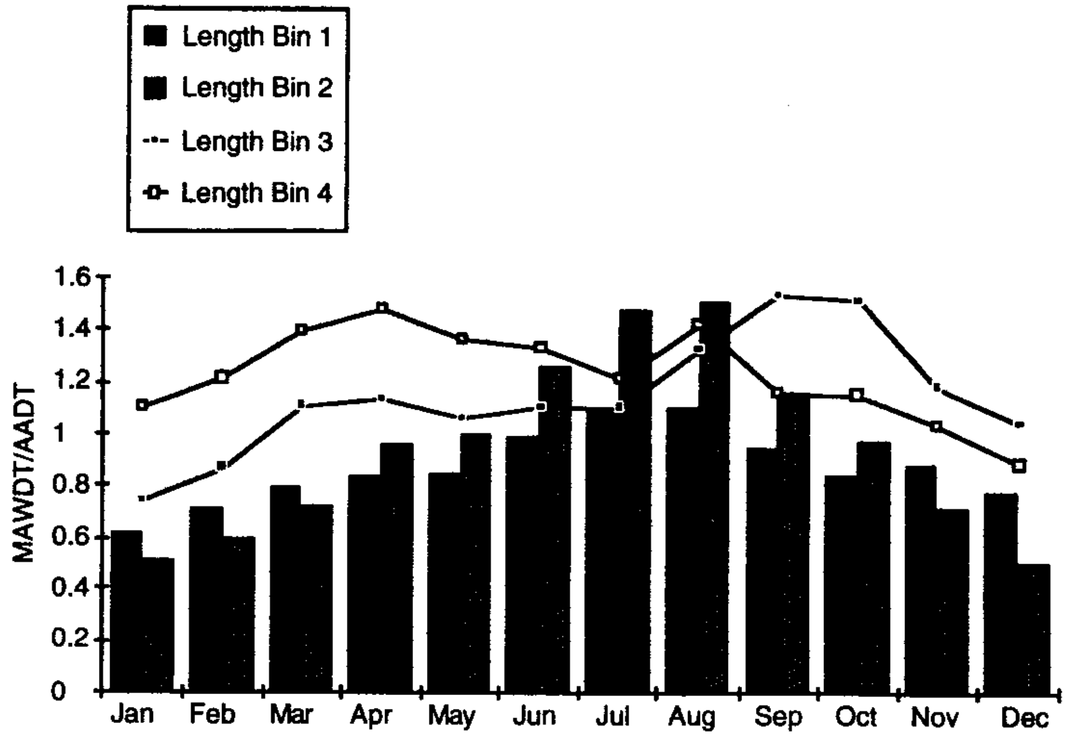

Figure 1. MAWDT/AADT Ratio for Site 61 in 1991

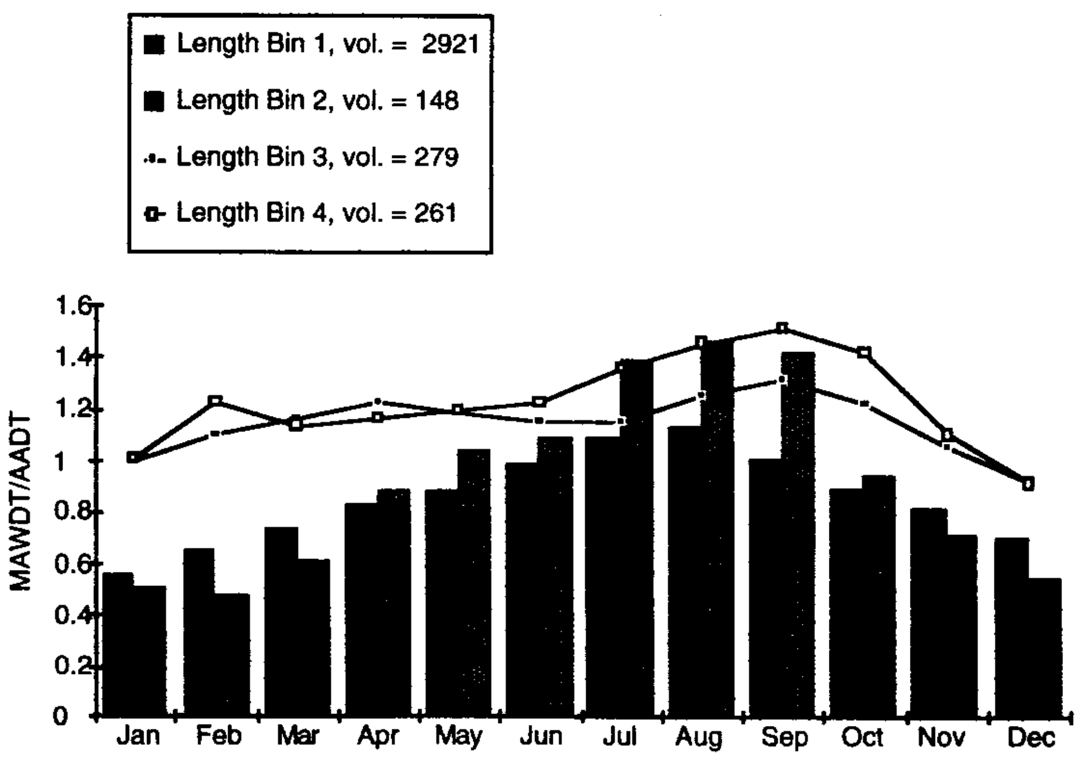

Figure 2. Average Monthly Weekday Volume / AADT, Site 41 - 1991

Geographic and Functional Roadway Distributions

As expected, the functional classification of the road and the location of each data collection site significantly influences the traffic patterns observed at that site. In general, the higher is the functional classification of the road, the higher are the traffic volumes in all vehicle classes. The higher are the traffic volumes, the more stable are the traffic volumes from month to month and from year to year. Conversely, the lower is the road's functional classification, the lower is the traffic volume (particularly in the longer truck categories), and the more unstable is the traffic volume pattern, both from month to month and from year to year. While some low volume roads show reasonable stability in their traffic volume patterns, higher variation is present on these facilities.

The impact of geographic location can also be seen in the traffic volume patterns observed in the data. In addition, the geographic influences change from one vehicle class to the next. For example, the recreational routes show increased automobile volumes (i.e., Bin 1) in the peak recreational periods; however, these increases are not as dramatic (in percentage terms) as those experienced by vehicles in Bin 2, which contains most of the recreational vehicles. Similarly, the two longer truck classes (Bins 3 and 4) are only minimally affected by the recreational peaks. In agricultural areas, the longer truck categories show traffic volume peaks that are not present (or at least not as noticeable) in other portions of the state. Figures 1 and 2 (presented earlier) show examples of these differences at two sites with fairly extreme seasonal variability.

When a site has a low traffic volume level like the site in Figure 3 (AADT for Bin 4 is 14 vehicles per day), relatively small changes in volume significantly affect the computed seasonal factors. Consequently, low volume sites often have highly variable seasonal factors even though the absolute volume changes from year to year are small. This high variability complicates the search for groups of roadway sections that have similar traffic volume patterns and reduces the accuracy of AADT estimates produced with short-duration counts and seasonal adjustment factors. This problem is accentuated

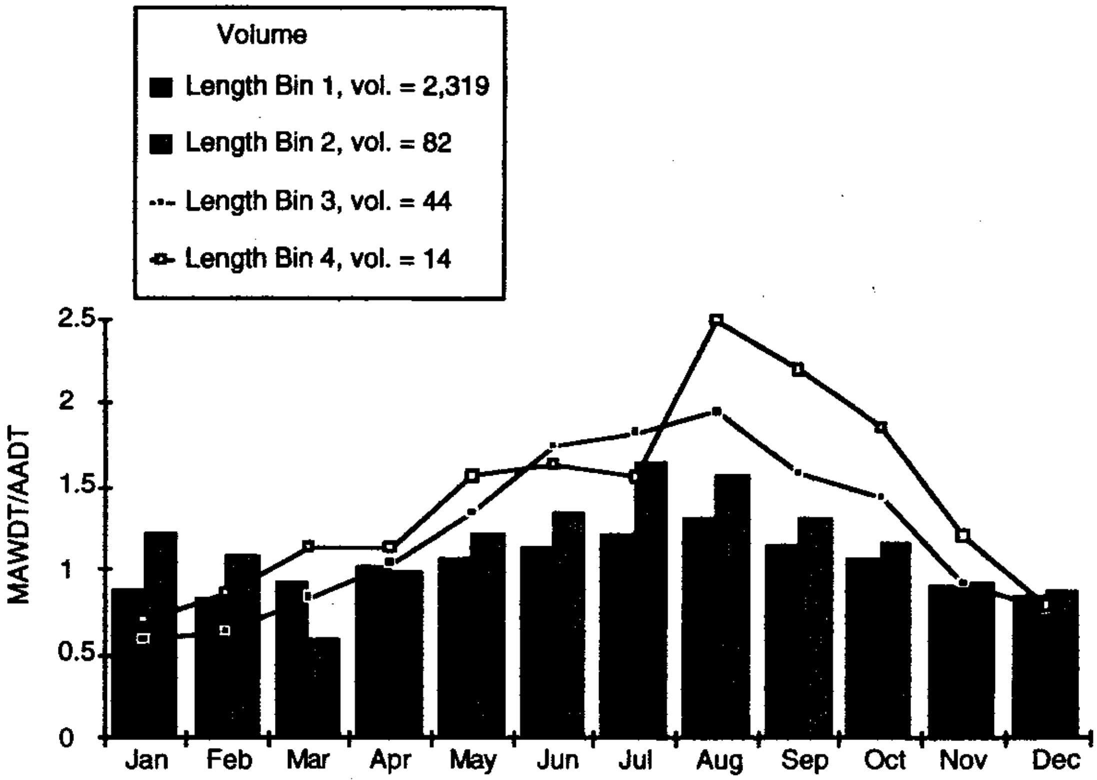

Figure 3. Average Monthly Weekday Volume / AADT, Site 820 - 1990

by more disaggregated classification schemes. That is, the FHWA 13-category classification scheme will produce a greater number of highly variable vehicle class seasonal factors than the four-length bin categories used in Washington. This increase occurs because the more disaggregated vehicle classification scheme causes more vehicle categories to have low volumes, which are, in turn, more unstable than the more aggregated vehicle categories.

13-Bin Versus 4-Bin Classification Schemes

When these disparate vehicle class patterns are combined into fewer categories (for example, the four Washington length classes), the individual peak traffic movements are "dampened." That is, the monthly volume patterns change less from month to month. The primary drawback to this dampening effect is that it masks the actual vehicle patterns that are occurring on the road. However, the dampening effect can prove advantageous. One of its advantages is that the seasonal factors for the larger vehicle categories tend to be more stable. Thus seasonal factors for more aggregated vehicle categories are more capable of predicting total traffic volume. These factors simply do not reflect the changes occurring in the vehicle mix within that volume with a high level of precision.

Stability Of Factors Over Time

The analysis of monthly to average annual traffic ratios over time showed that, in general, the greater the traffic volume is on a road (or within a classification), the more stable is the monthly ratio of weekday traffic to annual average condition. That is, on interstate and heavily traveled, principal arterials, the monthly traffic volume patterns are reasonably stable over time (from year to year). Traffic patterns on lower volume roads are often (but not always) unstable from one year to the next. While some low volume sites have stable monthly factors, others have factors that vary considerably from year to year.

While the actual monthly factors computed for low volume roads may change significantly from one year to another, the general volume patterns remain reasonably constant even for low-volume roads.

Stability Of Factors Over Distance on A Route

In general, the data reviewed in this analysis show that individual long through routes (e.g., interstates) could be classified as a "factor group" for all four vehicle length classes, although some of these classes are on the boundaries of what is acceptable for within-group factor variation. While the interstate sites appear to provide factor groups that are (for the most part) reasonably consistent across the state, it is doubtful that this consistency would be true for smaller roads or for roads that carried less through traffic. However, it is possible that interstate traffic in other states could exhibit similar patterns within the confines of their borders.

Weekday Versus Weekend Traffic

The results of our analyses showed that in most cases Saturday and Sunday traffic volumes differ significantly from weekday traffic volumes. In the majority of cases, weekday traffic volumes are higher than weekend volumes. This is especially true for the longer truck classes, in which large, commercial vehicles dominate. However, for classes with a high percentage of recreational vehicles, weekend volumes are consistently higher than weekday volumes.

The project team concluded that in some locations and/or in some months, volumes on either Monday or Friday were similar to volumes on Tuesday through Thursday. However, in other locations and/or months, traffic volumes on these days are statistically different from those of Tuesday through Thursday. For the sake of consistency, researchers who performed analyses for this paper assumed that weekdays are only Tuesday through Thursday. While this may be a conservative assumption, the decision greatly simplified the performance of the analyses.

Axle Correction Factor Analysis

This analysis found that axle correction factors are highly variable from site to site, as well as from month to month. Weekday and weekend axle correction factors also differ significantly.

In general, at all sites, the axle correction factor measured for weekdays is higher than that measured on weekends. In addition, the difference in axle correction factors among sites is more significant than the difference between axle correction factors from one month to the next. However, the difference in axle correction factors between weekdays and weekends is often as large the difference among sites.

A single-axle correction factor for all seven days predicts too many trucks operating during the weekends and not enough during the weekdays. This prediction results in the underestimation of vehicles on the weekend and the overestimation of vehicles on the weekdays. To avoid these problems, the states should use axle correction factors that are consistent with the axle counts being factored. For example, only data from weekdays from a permanent vehicle classification counter should be used to compute axle correction factors that will be applied to weekday counts.

Developing Alternative Factor Groups

While a number of grouping techniques were tried, none of them worked as well as desired. The accuracy of using factors to adjust short duration truck counts is discussed in the following section of this summary. The research team believes that this was not a limitation in any of the grouping techniques but, rather, a result of the high degree of variability associated with truck volumes. The variation in the truck volumes prevented the groupings from being as "tight" as those traditionally expected from total traffic volume factoring.

The project team tested three different methodologies. The first method employed a subjective, pictorial approach. This methodology included graphing the daily and average monthly traffic volumes and trying to visually match graphic volume patterns from different sites. Means, standard deviations, and expected errors were then calculated for each of the factor groups. Finally, the groups of sites were examined to determine the characteristics they had in common. These characteristics would then be used to assign sites for which year-round data were not available to those groups.

The second method employed a cluster methodology that used a combination of objective and subjective criteria as inputs. For this procedure, objective criteria obtained for each count location (functional class of roadway, traffic volume) and subjective criteria (whether the road was subject to recreational travel or agricultural harvest movements) were used to classify roads into factor groups. For example, one factor group consisted of interstate and principal arterials in rural areas that were subject to harvest hauls, but not subject to substantial recreational travel. This "subjective clustering" approach provided a methodology that allowed the creation of factor groups that were more intuitively attractive to the users of the traffic data.

The third approach to developing factor groups started with the modified cluster analysis described above to which the project team made two major modifications. The first modification was that instead of using monthly factors for each year to compute the factor groups, the project team developed monthly factors based on long-term trends, and used these factors to compute factor groups. A simple, time series-based approach called decomposition was used to calculate a single set of monthly adjustment factors at each permanent counter site on the basis of the monthly adjustment factors for multiple years of data at that site. The second modification the project team made to the cluster approach was to switch from employing a simple cluster approach (i.e., computing a simple average factor for sites that had similar patterns) to using multiple linear regression. The multiple linear regression approach used the same input criteria developed for the modified cluster analysis. However, it computed a different seasonal factor for each site, rather than a single factor for each site within a factor group.

Transferring The Study Results

One of the important findings of this effort was that the groups that were detected in Washington did not necessarily exist in the Idaho dataset examined. Therefore, it is likely that the truck travel patterns apparent in other states will also differ substantially from those presented in this paper. This was not a surprising finding, given the nature of truck traffic (i.e., truck traffic varies considerably from site to site and is influenced both by the characteristics of the land use around each site and by the nature of the through travel).

The differences in the Idaho travel patterns highlighted the concern that the results presented in this report were based on a limited geographic sample of data points. Although the travel patterns found are representative of the sites included in the study; they may not be representative of all of Washington's traffic. Additional, important truck travel patterns may exist in Washington (for example, a different agricultural haul) that were not measured simply because of the location of the permanent counter sites available for this project.

Impacts and Accuracy of Factoring Counts

The use of seasonal factors (MAWDT/AADT) to convert short counts to AADT estimates was tested for each site. In the "best" alternative, a monthly factor was computed for each site and then used to convert short counts *from that same site* to AADT estimates. Different count durations were tested, including individual weekdays (T, W, Th) and combinations of weekdays (T-Th, T-W, W-Th). The calculations produced reasonable AADT estimates, but they also showed the error inherent in factoring attributable to the day-to-day variations in traffic volumes.

Tables 1 through 4 show the expected error associated with factoring for all counter locations available for this study . For Length Bin 1, the average error in the estimate of annual volume ranged from 6 percent to 9 percent, depending on whether the count that was adjusted (factored) was 1 or 3 days long. 95 percent of all estimates were within 18 percent (the mean error plus 2 standard deviations around that error) of the actual annual volume.

Length Bins 3 and 4 had the highest level of volume variation, and consequently, the highest error in the estimates of annual volumes. Mean errors ranged from 9 percent to 23 percent, again depending on the length of the count. 95 percent of all the estimates were within 17 percent to 60 percent of the actual annual volume. (If only 2- and 3-day counts were used, the mean error ranged from 9 percent to 15 percent, with a 95 percent level of confidence of between 17 percent and 36 percent.)

The fact that a 3-day count provided the basis for a more accurate estimate of annual average volumes than a single day estimate was expected. This was true for all four vehicle classifications. However, an interesting finding was that Thursday traffic was more closely related to the MAWDT/AADT ratio than either Tuesdays or Wednesdays. This was true for all four vehicle classes. This finding was also evident in the fact that annual estimates based on counts performed on Wednesday and Thursday were more accurate than estimates based on made on Tuesday and Wednesday.

Another surprising finding was that the annual estimate based on the 3-day count (Tuesday through Thursday) was only marginally better than the estimates based on the 2-day, Wednesday through Thursday, value. If travel was entirely random, the third day of traffic data should have provided an improvement in the AADT estimate. (This held true when the Tuesday - Thursday estimates were compared to the Tuesday - Wednesday estimates.) This result was caused by the "goodness of fit" of the Thursday data (see the previous paragraph). After thoroughly analyzing the data, the project team was not able to explain why Thursday provided better estimates of annual travel than the other weekdays.

Table 1. Error Due To Factoring
Bin 1—No Site Association Error

Day	Mean Error	Std. Dev. of Error (among sites)	Std. Dev. of Error (Mean w/in years)
Tues-Thurs	0.059	0.037	0.019
Tues-Wed	0.067	0.041	0.019
Wed-Thurs	0.061	0.041	0.017
Tues	0.091	0.044	0.040
Wed	0.074	0.050	0.022
Thurs	0.060	0.035	0.022

Table 2. Error Due To Factoring
Bin 2—No Site Association Error

Day	Mean Error	Std. Dev. of Error (among sites)	Std. Dev. of Error (Mean w/in years)
Tues-Thurs	0.90	0.031	0.024
Tues-Wed	0.107	0.038	0.030
Wed-Thurs	0.091	0.030	0.019
Tues	0.146	0.053	0.051
Wed	0.120	0.044	0.037
Thurs	0.112	0.044	0.039

Table 3. Error Due To Factoring
Bin 3—No Site Association Error

Day	Mean Error	Std. Dev. of Error (among sites)	Std. Dev. of Error (Mean w/in years)
Tues-Thurs	0.088	0.039	0.027
Tues-Wed	0.108	0.045	0.034
Wed-Thurs	0.087	0.046	0.021
Tues	0.159	0.083	0.064
Wed	0.120	0.067	0.046
Thurs	0.110	0.069	0.047

Table 4. Error Due To Factoring
Bin 4—No Site Association Error

Day	Mean Error	Std. Dev. of Error (among sites)	Std. Dev. of Error (Mean w/in years)
Tues-Thurs	0.116	0.086	0.025
Tues-Wed	0.145	0.106	0.035
Wed-Thurs	0.116	0.105	0.027
Tues	0.231	0.173	0.083
Wed	0.182	0.211	0.055
Thurs	0.162	0.184	0.071

While the errors associated with these annual estimates may seem large, especially for the larger truck classifications, the errors were much lower than if the factoring had not been performed. The following tables indicate the size of the errors that could be expected in annual average volume estimates that were based on unfactored, short-duration counts used directly as a measure of annual average conditions.

Table 5. Error If No Seasonal Factors Were Applied—Bin 1

Day	Mean Error	Std. Dev. of Error (among sites)	Std. Dev. of Error (Mean w/in years)
Tues-Thurs	0.149	0.091	0.022
Tues-Wed	0.156	0.10	0.025
Wed-Thurs	0.145	0.079	0.023
Tues	0.149	0.102	0.035
Wed	0.138	0.088	0.021
Thurs	0.132	0.075	0.028

Table 6. Error If No Seasonal Factors Were Applied—Bin 2

Day	Mean Error	Std. Dev. of Error (among sites)	Std. Dev. of Error (Mean w/in years)
Tues-Thurs	0.271	0.089	0.063
Tues-Wed	0.287	0.099	0.062
Wed-Thurs	0.260	0.084	0.066
Tues	0.291	0.123	0.076
Wed	0.248	0.099	0.064
Thurs	0.241	0.097	0.065

Table 7. Error If No Seasonal Factors Were Applied—Bin 3

Day	Mean Error	Std. among. of Error (between sites)	Std. Dev. of Error (Mean w/in years)
Tues-Thurs	0.259	0.083	0.068
Tues-Wed	0.264	0.098	0.072
Wed-Thurs	0.273	0.062	0.062
Tues	0.274	0.129	0.076
Wed	0.265	0.112	0.067
Thurs	0.271	0.093	0.059

Table 8. Error If No Seasonal Factors Were Applied—Bin 4

Day	Mean Error	Std. Dev. of Error (among sites)	Std. Dev. of Error (Mean w/in years)
Tues-Thurs	0.323	0.159	0.064
Tues-Wed	0.321	0.179	0.075
Wed-Thurs	0.369	0.167	0.073
Tues	0.332	0.219	0.076
Wed	0.260	0.221	0.068
Thurs	0.401	0.302	0.119

A comparison of Tables 1-4 and Tables 5-8, shows that the errors present if the short counts were not factored would be considerably larger than the errors if factors are applied. For Length Bin 1 the errors after factoring would be roughly half those if factors were not used. This relationship holds true (with some minor variation in the size of the error differential) for all vehicle classes and count durations.

Another important fact the project team discovered was that increased count duration had no effect on the predicted error if no factors were applied. (In the study sample, the error actually decreased with a shorter count duration in several instances, although this decrease was not statistically significant.) That is, using 3 consecutive days of counting to estimate annual conditions would be only marginally better than using one day of counting, if seasonal adjustment factors were not applied. This finding was not surprising, as the majority of the error associated with unfactored counts was seasonal bias, rather than random variation. Counting for multiple consecutive days did not reduce the bias portion of the error.

To provide a measure of the effect "grouping" had on the accuracy of factors being applied to specific sites, the project team used the output from the regression approach to factoring and computed multiple AADT estimates by class for the tests sites. These AADT estimates were then compared to the actual AADT value by class, and the differences determined.

Table 9 shows the results of this analysis.

Table 9. Error Due To Factoring With The Regression Technique

	Bin 1	Bin 2	Bin 3	Bin 4
Average Error (fraction of AADT)	0.078	0.126	0.113	0.177
Standard Deviation	0.034	0.058	0.073	0.079
Maximum Error	0.130	0.204	0.254	0.305
Minimum Error	0.045	0.043	0.042	0.063

A comparison of these errors to the errors in Tables 1 through 4, which describe the impact of factoring on annual estimates, shows that the regression process only added an additional 3 percent to 5 percent to the error in the annual estimate. However, the standard deviation of that error also increased by roughly 3 percent for vehicle Length Bins 2 and 3. This combination of moderately high average error and moderately high standard deviation will cause relatively large errors to occur occasionally for some estimates of annual conditions.

This was confirmed by the presence of several large errors in the tests performed for this analysis, as shown in Table 9. Still, while a 30 percent error is quite large, it is considerably smaller than many of the errors that would be present if unfactored truck counts were used as annual traffic estimates or if seasonal adjustments were made on the basis of seasonal patterns for total volume.

An Alternative To Factoring

The difficulties experienced by the project team in developing and applying traditional factoring approaches to truck volumes led to the exploration of other rational methods for estimating annual traffic volumes based on short-duration counts. The most basic method for estimating traffic volumes is counting vehicles at multiple times during the year at the same location and then averaging the counts.

The advantage of this method is that counts from different times of the year reflect the various volume patterns that occur during the year and result in a balanced estimate of high and low volume periods. Secondary benefits include the removal of the need to

- determine factor groups;
- allocate individual roadway segments to specific factor groups; and
- develop, maintain, and apply seasonal factors by truck category.

The initial test of the multiple count technique was to collect data four times during the year for 1 week during each counting session. Approximately 3 months were left between counts. Traffic counts collected during weeks that contained holidays were not used in the analysis. Annual average volumes by class were developed by computing simple averages from the 28 days of data present in each sample site.

A summary of the results of these tests is shown below.

Table 10. Average Error of Annual Traffic Estimates Based on Four, Week Long, Vehicle Class Counts

	Bin 1	Bin 2	Bin 3	Bin 4
Mean Error	0.029	0.038	0.045	0.042
Standard Deviation	0.023	0.026	0.038	0.035
Maximum Error	0.077	0.084	0.157	0.118

These results were better than the results obtained by computing annual volumes using seasonal factors developed from a specific site and applied only to that site (see Tables 1 through 4). More importantly, the above table shows that this system provided estimates of annual traffic for each of the four length bins within 10 percent almost 90 percent of the time. (The mean plus two standard deviations was 7.4 percent for Bin 1, 9.0 percent for Bin 2, 12.1 percent for Bin 3, and 11.1 percent for Bin 4. The mean would drop to 6 percent for Bin 1, 8 percent for Bin 2, 7 percent for Bin 3, and 9 percent for Bin 4 if the sites with the largest variations were dropped from the calculations.)

The errors associated with the multiple count approach were roughly 1.4 to 2 times better than the errors associated with the calculation and application of site-specific seasonal factors. Furthermore, the error associated with factoring short counts was underestimated because no error associated with computing group factors, or assigning a site to a group was included.

Limitations To This Alternative

There were three primary drawbacks to this methodology for calculating annual average truck volumes based on multiple counts. The first was the difficulty in obtaining the staffing resources necessary for collecting 7 consecutive days of vehicle classification data four times per year per roadway section of interest. The second drawback is the need to collect classification data for all 7 days of the week. The problem was that the potential for the portable axle sensors, used by the classifiers, to come loose before the end of the scheduled count increased dramatically as the duration of the count increased. The final drawback was the cost of collecting the required number of counts.

A test to reduce the count program to two week-long counts per year, spaced 6 months apart, produced mixed results. Roughly three quarters of the sites tested experienced a decrease in the accuracy of the annual estimates when the number of counts included in the annual estimate calculation was reduced from four to two. However, a quarter of the sites actually provided better annual estimates when based on 2 weeks of data than on 4 weeks of data. This heightened accuracy occurred when the 2-week periods were more representative of the full year's traffic patterns than the 4-week periods.

A test with a cycle of 3 counts per year was also conducted. For this test, three week-long counts were conducted 4 months apart. The results mirrored those of the two-count period experiment, described above. In each of these cases, a full week of data still had to be collected to account for the differences in traffic between weekdays and weekends.

Another alternative counting approach would be to reduce the duration of the traffic counts used. This counting approach would reduce the likelihood that axle sensors would fail during the count and lowers the cost of data collection.. Traffic counts would be shortened if counts were taken during the weekdays only (as most traffic counts currently are). The axle sensors would then only be on the ground for 3 to 4 days, greatly reducing the chance that a sensor would be dislodged.

This approach was tested by counting 3 consecutive weekdays, four times each year. Each of the weekday estimates was then factored to represent the average annual condition; the 12 counts were then averaged. The results of this test were quite respectable. In most cases, mean errors for the annual estimates ranged from 1 percent to 5 percent, with standard deviations near 5 percent. Thus, under this "best case" scenario, this counting approach provided annual estimates that were as accurate as those provided by using 4-week long counts. Whether this technique was actually accurate depends on how "tight" the factor group was, and how well a specific site was assigned to its factor group.

Table 11. Average Error of Annual Traffic Estimates Based on Four, 3-Day Long, Factored, Vehicle Class Counts

	Bin 1	Bin 2	Bin 3	Bin 4
Mean Error	0.013	0.037	0.021	0.049
Standard Deviation	0.035	0.055	0.047	0.047

However, note that much of the accuracy of this method was due to the averaging of the four counts, rather than to the accuracy of the adjustment factors. The error within the individual estimates of annual conditions (prior to their averaging) was often over 20 percent. However, these errors were normally distributed about an error of 0.00. Thus, when points were averaged (12 points were averaged to obtain a single annual estimate), the mean value for each site was often quite good, even though the individual data points used to make that estimate did not accurately replicate the annual conditions.

Another alternative method to account for differences in weekday/weekend travel without counting for 7 days at a time would be to count the weekend and only one weekday. That weekday could be either before or after the weekend. The 1 weekday counted (either Thursday or Tuesday) would then be used as a surrogate for the missing 2 weekdays. Removing 2 weekdays from the count (i.e., counting Thursday through Monday, or Friday through Tuesday), decreased its accuracy. This decrease ranged from

1 percent or 2 percent at sites with stable vehicle classification volumes, and from 6 percent to 10 percent at sites with unstable vehicle classification volumes.

Counts Needed For A Statewide Pavement Management System (PMS)

The project team examined written material describing nine states' pavement management systems. These states included

- Arizona,
- Arkansas,
- California,
- Florida,
- Idaho,
- Minnesota,
- Nevada,
- Ohio, and
- Washington.

In all of these states, some measure of traffic was used in the pavement management system. However, in none of these systems did truck volumes or an estimate of actual equivalent single axle loads (ESAL) play a leading role in the determination of expected pavement deterioration rates or pavement section rehabilitation prioritization.

In almost all cases, the need for pavement maintenance or rehabilitation was determined by the current pavement condition and the expected remaining life of that pavement. The expected life was predicted in years, not ESALs, and was usually a predetermined function based on standard deterioration curves adjusted (in some cases) to reflect actual pavement performance. In none of the examined PMS were the deterioration rates based directly on ESAL estimates measured on individual road segments.

The use of cumulative years and current pavement condition to determine expected pavement life within the structure of PMSs, rather than the use of cumulative ESALs, was in part due to the lack of valid truck data available at the time these systems were designed and implemented. Deterioration rates were used to predict remaining pavement life, rather than actual loading rates. Deterioration rates were used partly because the PMSs lacked accurate loading data and partly because the use of actual deterioration rates allowed the PMS to account for a variety of causes of pavement deterioration (e.g., poor quality construction, unexpected environmentally caused distress, poor mix performance), in addition to differences between the expected and predicted loading rates.

IMPLEMENTATION

Implications Of The Factoring Analyses

None of the factoring approaches selected and tested within this effort consistently produced annual traffic estimates within the accuracy desired by FHWA. The limitations in the techniques tested appear to be due primarily to the variable nature of truck traffic and the relatively low volume of truck traffic (within some vehicle classes) on many highways rather than to problems inherent with the techniques tested. Unless a new technique can be developed that can more accurately account for the variability inherent in truck traffic volumes, it is unlikely that a factored, short duration truck count on a moderate to lower volume road will be within 25 percent of the actual value, 95 percent of the time.

According to the analyses performed for this project, the best method of accounting for seasonal and day-of-week variation in truck traffic volumes is to count traffic at a site multiple times during a year, and then to average those counts. The preferred methodology is to collect data four times during the year. Each count should be 1-week long and the four counts should be spaced equally throughout the year (i.e., at roughly 3-month intervals). This method of data collection and analysis provides estimates of annual truck volumes within 7.5 percent to 12.2 percent of the true value 95 percent of the time.

Because this data collection methodology is expensive, it is probably not a practical approach for producing all truck volume estimates. However, this method should be used whenever new pavement will be applied to a highway; because the potential benefits from accurate data are very large, given the cost of any pavement project (usually over $1 million in direct costs) and the relatively low cost of vehicle classification data collection activities using portable, automatic classifiers.

For most other truck volume data needs, the benefit obtained from the increased accuracy of multiple counts is not outweighed by the cost of collecting the data. In most states, two sources of traffic counting funding are available, funding for specific projects (charged to that project budget) and funding for general purpose traffic counts. Given the limited availability of these "general purpose" funds, the project team recommends the development of a short count factoring procedure for use in improving the annual truck volume estimates available to other data users who do not have access to additional data collection funding.

Because low volumes appear to cause a significant portion of the variation inherent in the truck traffic estimates, the project team recommends that this factoring procedure be based on an aggregated vehicle classification scheme, rather than FHWA's 13-category scheme. While this research did not attempt to identify the appropriate number of classification categories, a general rule of thumb the project team devised on the basis of its use of Washington data is that the number of vehicle classes should range between four and six. These vehicle classes should be aggregates of classes routinely collected by a state as part of its ongoing data collection effort. (That is, the vehicle classifications could be either length-based, or an aggregation of axle-based vehicle classes.) The development of these vehicle classes should be state specific and should entail a review of the travel patterns of different vehicle types, the availability of seasonal pattern information from permanent counting devices, and the types of vehicle classification equipment used by the state.

The "best" factoring technique investigated in this project was the regression approach using monthly seasonal factors aggregated over several years as dependent variables. The modified cluster procedure is also an acceptable method for developing factor groups. Both of these methods could be improved upon, and additional research should be pursued to develop better techniques.

Implications For Pavement Management Systems

The findings of a literature search suggest that the improved accuracy of truck volume estimates possible through the factoring techniques discussed in this report will have a relatively limited, direct impact on existing pavement management systems. (By pavement management system, this discussion includes that part of the PMS that predicts the need for rehabilitation and/or maintenance work and estimates the anticipated design or cost of that work.)

This is not to say that significant advantages will not be obtained from improvements in the truck loading estimates used to design pavements. Improvements to pavement management will occur as a result of the design of new pavement sections and the selection and design of maintenance and rehabilitation treatments at sites identified by the PMS. These pavement designs will perform better than their predecessors because the load estimates used in the designs will be more accurate as a result of improved truck volume and load forecasts based on permanent counter site data.

The real improvements in pavement performance will come from the design phase for projects identified as needing rehabilitation or maintenance. Once these projects have been identified by the basic PMS, states should arrange for site-specific vehicle classification counts at those sites, following the count duration and factoring guidelines described in this report. The result of these counts will be a very reliable estimate of baseline traffic loading for use in the design process. While error will still exist in the final loading estimate used for the pavement design (primarily as a result of the errors inherent in forecasting traffic conditions), the potential for a pavement design reaching its expected design life (in years) will be greatly enhanced. When safety factors are included in the pavement design to account for the variation inherent in input variables (traffic, soil condition, materials), as recommended in the current AASHTO pavement design procedures, the number of pavement sections meeting or exceeding their expected design life should increase. Over time, this should result in improved pavement performance for the system as a whole.

A second advantage of improved traffic load estimates is that they will allow forensic analysis of failed pavements. Most states undertake forensic reviews of pavements that fail prematurely to determine the cause of their failure. Lessons learned from these forensic studies are then applied to future pavement projects to prevent similar premature failures from occurring.

CONCLUSIONS

The analyses described above indicate that in most cases, an unadjusted, 24-hour vehicle classification count is a poor estimate of average annual conditions. At most sites, an unadjusted, 24-hour weekday count will consistently overestimate the annual average number of larger trucks using that road. Conversely, except during the peak recreational travel periods, unadjusted weekday counts will underestimate the average annual volume of RVs using the roadway. If counts are taken during peak recreational periods, weekday counts will overestimate the average annual RV volumes.

A comparison of the Length Bin 1 patterns (Length Bin 1 is primarily automobiles and pick-ups and contains the vast majority of total vehicle volume) to the other three vehicle length classifications shows that in most cases, the use of traditional seasonal factors to adjust short-duration truck volumes is inappropriate for estimating average annual truck volumes. The analyses conducted in this study show that during most portions of the year, the seasonal adjustments for different vehicle classes are significantly different.

Where the monthly adjustments for both total volume and individual vehicle classes are all above or below 1.0, use of an adjustment factor based on total volume will improve the AADT estimate, although this improvement is rarely as good as that produced by a class specific factor. When one factor (either the factor for total volume, or the factor for the specific vehicle class) is above 1.0 and the other is below 1.0, the adjustment based on total volume will provide an estimate of total truck traffic that is worse than the unfactored volume estimate.

Seasonal adjustment factors for truck volumes can be developed from data routinely collected by permanent vehicle classification counters. Use of these adjustment factors will improve the estimation of annual average truck volumes, but not with the accuracy associated with total volume adjustments currently performed using seasonal factors developed using conventional ATR equipment.

Where funding allows, a more accurate estimate of annual truck volumes (by class) can be obtained by counting several different times during a year at that site. These multiple counts should contain data from an equal number of the seven days of the week and be spread evenly throughout the year. Four, week-long counts are recommended to provide annual estimates within ± 10 percent, 90 percent of the time at specific sites.

Improvements made in the estimation of annual vehicle volumes by vehicle classification will have a positive impact on a state's pavement management system both as a result of improved pavement life due to better design information, and as a result of more accurate forensic analyses for those pavement sections that fail prematurely. While most PMS do not use truck volume estimates directly in their pavement deterioration prediction functions, improvements to the accuracy of truck volume estimates should produce long term improvements in pavement life as a result of improvements in pavement design information.

RECOMMENDATIONS

The project team recommends that wherever possible and financially appropriate, each state should collect multiple, site specific vehicle classification counts whenever pavement design projects are to be performed.

Where it is impractical to collect this much data at a specific site, seasonal adjustments should be applied to individual short duration vehicle classification counts.

These adjustments should be based on permanent vehicle classification counters operating year round, not on seasonal factors based on total volume counts.

In most cases, aggregated vehicle classifications should be used for developing seasonal factors. The 13 FHWA vehicle classifications are too disaggregated to provide stable seasonal adjustment factors for the majority of moderate and low volume rural roads. For these roads, a more stable factor applied to all FHWA vehicle classifications within that aggregated group is preferable. The exception to this recommendation is for high volume interstate and principal arterial routes, where sufficient volume is present to calculate stable adjustment factors for all 13 FHWA classifications.

GLOSSARY

AADT — Annual Average Daily Traffic

ATR — Annual Traffic Recorder. A data collection device that can count vehicles 365 days per year. An ATR usually uses one or two inductance loop detectors as input sensors.

Bin 1 — In Washington, length bin 1 corresponds to those vehicles less than 26 feet in total length, as measured by counters using two inductance loops as vehicle sensors. This vehicle class primarily contains automobiles and light pick-up trucks.

Bin 2 — In Washington, this second length bin includes vehicles ranging from 26 to 39 feet in length. This vehicle class primarily contains single unit commercial vehicles.

Bin 3 — In Washington, this third bin includes vehicles ranging from 39 to 65 feet in length. This vehicle class primarily contains single trailer commercial trucks.

Bin 4 — In Washington, this last bin includes vehicles ranging between 65 and 115 feet in length. This vehicle class primarily contains multi-trailer commercial trucks (double bottom trailers).

ESAL — Equivalent Single Axle Loads. The standard unit for pavement design. One ESAL is equal to the damage done by one pass of an 18,000 pound single axle.

FHWA 13 vehicle classification scheme — This is the standard vehicle classification system used by FHWA for the HPMS, the biennial truck weight survey, and other state submittals and reports. A complete definition of this vehicle classification scheme can be found in FHWA's Traffic Monitoring Guide.

MAWDT — Monthly Average Weekday Traffic

PMS — Pavement Management System