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VEHICLE VOLUME DISTRIBUTIONS BY CLASSIFICATION

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July 1997

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INTRODUCTION AND BACKGROUND MATERIAL

This report documents the findings of a study of variability in traffic volumes by vehicle classification. It is meant to update the report, *Highway Performance Monitoring System, Vehicle Classification Case Study*, by Douglas MacTavish and Donald Neuman (1982). This project studied data from a broader geographic distribution of those sites and included a larger data collection period at each site.

Source of the Study Data

Data for the study came from the Central Traffic Data Base of the Long-Term Pavement Performance (LTPP) project. The dataset contained 99 sites from 19 states. Table 1 shows the distribution of sites by state and functional classification. Figure 1 shows their geographic distribution. Table 2 shows how these sites are distributed among LTPP regions. These tables reveal that relatively few sites were included in the two smallest functional classifications of roads, class 7 and class 16. (See Figure 2 for a definition of the Federal Highway Administration [FHWA] functional classifications of roads.) These are under-represented because these types of roads are relatively scarce within the LTPP experiment, and because states participating in the LTPP experiment have tended to collect data for larger volume, higher functional classification roads.

To be selected for this analysis, an LTPP site needed data for all 7 days of the week, for more than 9 months of the year. For the larger functional classes of roadway (classes 1, 2, and 11), only sites that contained data for all lanes and both directions of traffic were selected. For the other roadways, sites that had data for only one direction of traffic were also accepted, although some analyses looked only at the subset of sites with data for both directions of traffic.

Table 1. Number of Sites per State for Each Functional Class

STATE	FC 1	FC 2	FC 6	FC 7	FC 11	FC 12	FC 14	FC 16	Total
Alabama	3	3	1	0	0	0	0	0	7
Arkansas	1	0	0	0	0	0	0	0	1
California	3	0	0	0	0	0	0	0	3
Florida	0	2	0	0	0	0	0	0	2
Indiana	3	4	4	1	0	0	1	0	13
Iowa	0	1	0	0	0	0	0	0	1
Kansas	0	0	0	0	0	0	1	0	1
Kentucky	0	1	0	0	0	1	0	0	2
Massachusetts	1	1	0	0	0	0	0	0	2
Minnesota	0	0	1	0	2	1	0	0	4
Mississippi	1	0	0	0	1	0	0	0	2
Missouri	0	0	3	1	1	0	0	0	5
Nebraska	6	2	0	0	2	0	1	0	11
New York	0	1	0	0	0	0	1	0	2
Pennsylvania	1	1	0	0	0	0	0	0	2
Texas	0	0	6	2	4	0	2	1	15
Vermont	0	3	0	0	0	0	0	0	3
Virginia	2	3	2	1	2	0	1	0	11
Washington	2	5	0	0	1	1	2	1	12
Total	23	27	17	5	13	3	9	2	99

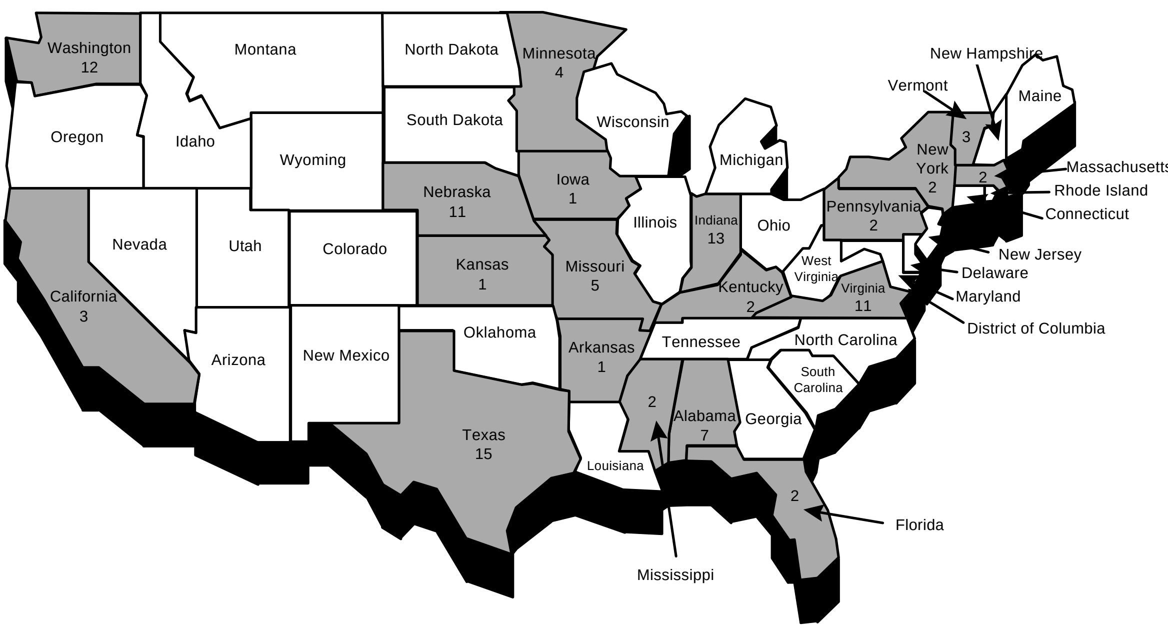

Figure 1. States Represented in the Study (number of sites indicated)

Table 2. Number of Sites per Region for Each Functional Class

REGION	FC 1	FC 2	FC 6	FC 7	FC 11	FC 12	FC 14	FC 16	Total
ATLANTIC	4	9	2	1	2	0	2	0	20
CENTRAL	9	8	8	2	5	2	3	0	37
SOUTH	5	5	7	2	5	0	2	1	27
WEST	5	5	0	0	1	1	2	1	15
Total	23	27	17	5	13	3	9	2	99

Class 1 = Rural Interstate
Class 2 = Rural Principal Arterial
Class 6 = Rural Minor Arterial
Class 7 = Rural Major Collector
Class 8 = Rural Minor Collector

Class 11 = Urban Interstate
Class 12 = Urban Other Freeways and Expressways
Class 14 = Urban Principal Arterial
Class 16 = Urban Minor Arterial
Class 17 = Urban Collector

Figure 2. Functional Classes of Roadways

The data supplied by the states were collected by permanently installed vehicle classification and weigh-in-motion (WIM) equipment placed for the LTPP research tests. Because these sites were not selected to provide information on a specific set of traffic movements (*e.g.*, recreational movements important to a state), they should provide a reasonably unbiased sample of traffic conditions within the U.S. However, the traffic patterns found in the U.S. vary greatly and the number of sites in this study was relatively small in comparison to the range of possible traffic patterns, particularly those found on the lower urban and rural functional road classes. Thus, some care must be taken when using these study results for general application.

The data used in this study had all passed through the LTPP quality assurance[1] process and were further screened as part of this analysis. In addition to removing invalid data, the screening found some questionable traffic volumes for individual days and sites. These data errors were minor in relation to the overall analyses, and tests on the effects of these data showed that their impacts were marginal. However, the presence of these minor perturbations in the data, despite the extensive LTPP quality control and quality assurance tests, showed the need for individual states to adopt and extend these kinds of tests. Data presented in the appendices of this report are based on the "cleanest" possible data within the LTPP dataset.

Applicability of Findings to Other Sites in the Nation

The majority of results presented in this report are for the "average" conditions found in the data. Considerable variation was found in the data reviewed for individual locations. Therefore, readers using these results should be aware that individual sites may vary considerably from these patterns. This is particularly true of the percentage of vehicles by vehicle category, since some vehicle categories are not commonly found in some parts of the country.

Where possible, this report includes measures of data variability to describe the range of values that can be reasonably expected at any given site. However, it is important to realize that local conditions significantly affect the traffic patterns found on any roadway and, therefore, that patterns at any given location can differ greatly from those illustrated in this report.

Vehicle Classification Categories Used

FHWA requests that vehicle classification information be submitted in 13 vehicle categories. These vehicle categories are shown in Figure 3. In some of the tables presented in this report, data are presented for all 13 vehicle categories; however, many of the report's tables and

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1 A brief description of the LTPP quality assurance process can be found in "WIM Data Quality Assurance" in Volume II of the National Traffic Data Acquisition Conference, 1994, pages 251-266.

figures contain an aggregated vehicle classification scheme. This classification scheme uses four broad categories of vehicles:

- Passenger cars.
- Single-unit trucks.
- Combination trucks.
- Multi-trailer trucks.

Class 1 =	Motorcycles
Class 2 =	Passenger cars
Class 3 =	Other 2-axle, 4-tire single-unit vehicles
Class 4 =	Buses
Class 5 =	2-axle, 6-tire single-unit trucks
Class 6 =	3-axle, 6-tire single-unit trucks
Class 7 =	4+ axle single-unit trucks
Class 8 =	4 or less axle combination trucks
Class 9 =	5-axle combination trucks
Class 10 =	6+ axle combination trucks
Class 11 =	5-axle multi-trailer trucks
Class 12 =	6-axle multi-trailer trucks
Class 13 =	7+ axle multi-trailer trucks

Figure 3. 13 FHWA Vehicle Classes

These higher aggregations are used for several reasons.

- At many sites, the daily volumes within some vehicle categories are so small that the factors (or ratios) produced are not stable. These unstable values caused an unrealistically high degree of variability in the mean factors computed for those vehicle classes for various aggregations (*i.e.*, mean day-of-week or monthly factors by functional class of roadway or region of the country).

- In many cases, the traffic patterns for many vehicle classes were very similar, and aggregating the FHWA classes allowed a simplified explanation of the results.
- Modern automated vehicle classification equipment often has difficulty differentiating among specific vehicle types, and the data were more accurately treated at a more aggregated level. (For example, most vehicle classifiers have problems reliably differentiating between some class 2, class 3, and class 5 vehicles, since all of these vehicle categories contain two axles and the wheel bases of some types of vehicles (particularly pickup trucks) fall near the axle spacing borders of these three categories.

Report Organization

This report is separated into the following sections:

- Volumes by day of week.
- Volumes by time of day.
- Urban versus rural volumes.
- Vehicle percentages by functional classification of road.
- Seasonal patterns.
- A summary of key findings.

Each of these sections is subdivided into additional topics, many of which could have been discussed in two or more sections of the report (for example, seasonal patterns by functional classification of road). To reduce the size of this report, individual topics are only covered once, although significant findings are mentioned in multiple sections to ensure that a reader examining only a part of the report sees these findings.

VOLUMES BY DAY-OF-WEEK

The analysis of traffic volumes by day-of-week illustrated both a high degree of consistency in many travel patterns and a high degree of variation in other travel patterns. At times, the functional classes of a road, the region of the country, and the type of vehicle being examined had an impact on whether a specific factor was stable or highly variable, but there are exceptions to all "rules" that are described in this report. In general, the following observations can be made of all sites:

- Sunday traffic volumes are the lowest of the week for truck classes at most sites, but average car volumes on Sundays can be fairly high for many rural sites.
- Mondays have slightly lower truck volumes than other weekdays, although this difference is not significant.
- Tuesday through Thursday volumes are similar for all truck classes.
- Friday is the highest volume day of the week for cars but is similar to other weekdays for truck travel.
- Saturday volumes tend to be very low for trucks but, like Sundays, can be either high or low for cars depending on the location.

Table 3 shows the average day-of-week ratio of daily traffic to annual traffic for each of the four combined vehicle classes.

Table 3. Day-of-Week Patterns for Urban and Rural Roads

Urban Roads	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Cars	0.87%	0.98%	0.98%	1%	1.03%	1.15%	0.99%
Single Unit Trucks	0.42%	1.11%	1.19%	1.20%	1.21%	1.24%	0.63%
Combination Trucks	0.42%	1.13%	1.23%	1.24%	1.23%	1.19%	0.55%
Multi-Trucks Trucks	0.46%	1%	1.21%	1.23%	1.25%	1.23%	0.61%
Rural Roads	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Cars	1.01%	0.95%	0.91%	0.93%	0.98%	1.16%	1.05%
Single Unit Trucks	0.54%	1.07%	1.15%	1.15%	1.18%	1.21%	0.70%
Combination Trucks	0.50%	1.10%	1.20%	1.23%	1.21%	1.15%	0.60%
Multi-Trailer Trucks	0.46%	1.04%	1.19%	1.23%	1.25%	1.17%	0.66%

There are many exceptions to these general findings. The most significant exception is that many sites in the Great Plains (and some Rocky Mountain) states have very different day-of-week patterns (see Geographic Differences below). These differences are caused by large “through”-movements of cars and trucks traveling between the larger midwestern cities and the western states.

Through-traffic also appeared to play a major role in much of the variation seen in the LTPP data. For example, both urban and rural truck travel tends to decrease significantly on the weekends. However, many of the sites whose location indicated the potential for large through-truck movements had more modest declines in weekend truck travel than sites that appear to carry much lower through-travel volumes. This could easily be explained by the fact that through-trucks are much more likely to travel over the weekend to arrive at their destination during the weekday than trucks with a local itinerary.

A second common difference appeared to be caused by the effect of recreational travel on automobile volumes. All urban sites in the LTPP dataset have lower Sunday volumes than other days of the week. Some rural sites have this same pattern. However, many rural sites have very high Sunday volumes, which can be divided into two distinct patterns:

- At one set of sites, the highest automobile volumes are on Friday and Sunday, with a small drop in volume (but still greater than average) on Saturday.
- At the other set of sites, the highest automobile volumes are on Saturday, with slightly lower volumes on Friday and Sunday.

One possible explanation for the first of these patterns is that it represents sites with recreational roads that attract weekend traffic, with most travelers arriving early and leaving late in the weekend. (Perhaps the count location was near the location of recreational activity that normally takes the entire weekend.) The other pattern appears to be more closely related to the travel pattern expected of a day trip, with more activity on Saturday (when more individuals engage in recreational activity), and slightly lower activity levels on Friday (when many people are still working) and Sunday (when many people attend church). Another possible explanation for this second travel pattern is that it includes those sites near (possibly within) recreational destinations and that it measures internal traffic within the destination. Attempting to assign one or another of these patterns to a specific site would be impossible without some site-specific information.

Recreational movements affect only cars; these movements do not appear to have an impact on any truck travel patterns. With the exception of the Great Plains states (and some Rocky Mountain states), few locations have high truck volumes on Sundays. Instead, Sundays have by far the lowest truck volumes (with exceptions at various sites). Thus, to accurately estimate annual average conditions, a state must adjust short duration, weekday, classification counts to account for lower weekend traffic volumes. If an adjustment is not made, classification counts taken only on weekdays will tend to significantly over-estimate annual truck volumes. One way to do this would be to create adjustment factors that convert weekday counts to average annual estimates.

Creation of Factor Groups

One goal of this research was to see if factors could be developed to adjust raw data so that it better represented average annual conditions. Part of this effort was an attempt to define specific “factor groups” that could be associated with commonly available site information, such as the functional class of road, the state or region in which that site was located, or the total volume of the road.

It was not possible to create precise day-of-week factor groups from the data available in the LTPP database. (“Factors” used in this analysis were computed as the ratio of average day-of-week volume by class divided by average annual volume by class. Thus a “Sunday Truck Factor” of 0.70 would mean that this site experiences only 70 percent of average daily truck traffic on Sundays.) The variation in the day-of-week factors at the available sites was too great to create consistent factor groups, and the cause of that variation could not be extracted from the available independent variables (functional class, state ID, *etc*.) However, the following observations can be made about the data.

- Few discontinuities in the day-of-week patterns were found at different sites. Day-of-week patterns at different sites followed a smooth continuum from sites with very low weekend volumes to those with fairly flat day-of-week patterns. This continuum is illustrated in Figure 4.
- Within this continuum, there are no obvious regional- or state-specific tendencies other than the frequent presence of high weekend truck travel in the Great Plains states and some Rocky Mountain states.

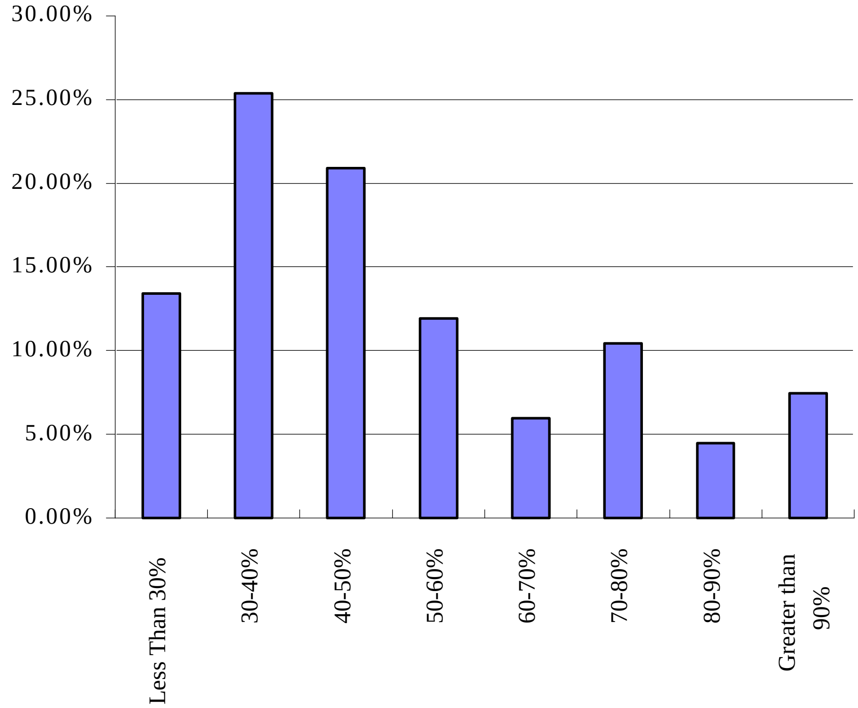

Figure 4. Percentage of Sites with Sunday Day-of-Week Factors for Combination Trucks within a Specified Range

- Automobile and truck day-of-week patterns are essentially unrelated. Knowing the day-of-week pattern for cars does not improve the ability to determine the day-of-week pattern for trucks.

  Consequently, factor groupings that would work for cars are likely to be inappropriate for trucks (*e.g.*, just because sites A, B, and C should be treated as a factor group for automobiles does not mean that those same three sites should be treated as a factor group for trucks).

This research does not conclude that factor groups cannot be constructed. Rather, there is insufficient data in the LTPP database at this time to support the creation of these groups. In addition, the creation of factor groups for trucks may require an additional roadway classification scheme that specifically accounts for truck usage. (Note that studies performed in both Washington[2] and Virginia[3] have shown that it is possible to create seasonal factor groups for adjusting short-duration truck counts to more accurately estimate annual truck volumes.) It is particularly important to have a surrogate value that indicates whether a specific road carries large volumes of lon- distance through-truck travel.

Similar problems arose with automobile factors and total volume factors. Many states have more than one rural factor group (for adjusting total volume counts) to account for regional differences, and many also maintain specific recreational travel patterns to account for the traffic conditions near large recreational areas. The LTPP database does not contain variables that describe the local geographic information needed to account for these variations in automobile and total traffic volume.

Although the LTPP database is large in terms of the number of sites included in the analysis, the wide distribution of these sites across the nation, the limited number of sites for which seasonal truck volume information has been submitted, the relatively large number of different traffic patterns, and the large number of both geographically distinct regions and functionally different roads make accurately identifying, codifying, and applying truck volume trends and patterns difficult at the national level.

Geographic Differences

An excellent example of the effects of specific local conditions can be found in the data for the Great Plains states. Data in the LTPP database (particularly from Nebraska and Wyoming) illustrate the effects of large through-travel movements on day-of-week travel. (This phenomenon also appears to occur in some Rocky Mountain states, but the LTPP data set has

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[2] *Final Technical Report for Task A: Truck Loads and Flows*, by Mark Hallenbeck and Soon-Gwam Kim, November 1993, WSDOT Report #WA-RD 320.3, written for the FHWA.

relatively few Rocky Mountain sites, making it hard to determine the true geographic extent of this pattern.) On many (but by no means all) roads in these states, through-traffic predominates over local traffic. Much of this traffic is generated by or destined for locations more than one day's drive away. Thus, goods that leave their origin on a weekday (*e.g.*, Friday) during business hours pass over these roads during non-standard business hours on other days (*e.g.*, Saturday). Similarly, because only minor amounts of freight leave from or arrive at these origins or destinations on Saturdays and Sundays, the traffic lull that occurs on those days reaches or precedes the Great Plains states one or more days later or sooner.

The result is that the low volume days for combination and multi-trailer trucks for a number of Nebraska roads in the LTPP database are Monday and Tuesday, rather than Saturday and Sunday (see Figure 5). (Wednesday is also a lower volume day for multi-trailer trucks, but not for combination trucks.) For many vehicle types, the same 5-day/2-day traffic pattern found in most other sites also exists at these locations. The difference is that the lower volume days are not the weekends. Note also that not all truck classes at these sites follow this higher weekend pattern, nor do they fall neatly into the 5-day/2-day pattern. At many of these higher volume weekend sites, weekend travel by smaller trucks (*e.g.*, single-unit trucks) is still lower than the weekly average. (These trucks are less likely to be used in long haul, inter-urban freight movements and are therefore less likely to be part of the "through"-truck movement.)

This higher volume weekend truck travel pattern is also found in some states outside the Great Plains, although they are infrequent outside of the Great Plains and Rocky Mountains. The pattern is apparent on roads that carry higher percentages of through-truck traffic and that are located a day or two from the sites that generate the traffic. It is also important to note that this through-travel pattern is normally directional. That is, the lower volume days in the westbound direction may be different from the lower volume days in the eastbound direction.

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[3] *Factoring of Short-Duration Classification Counts*, presented at The National Traffic Data Acquisition Conference, by Herb Weinblatt, Cambridge Systematics, May 5-9, 1996.

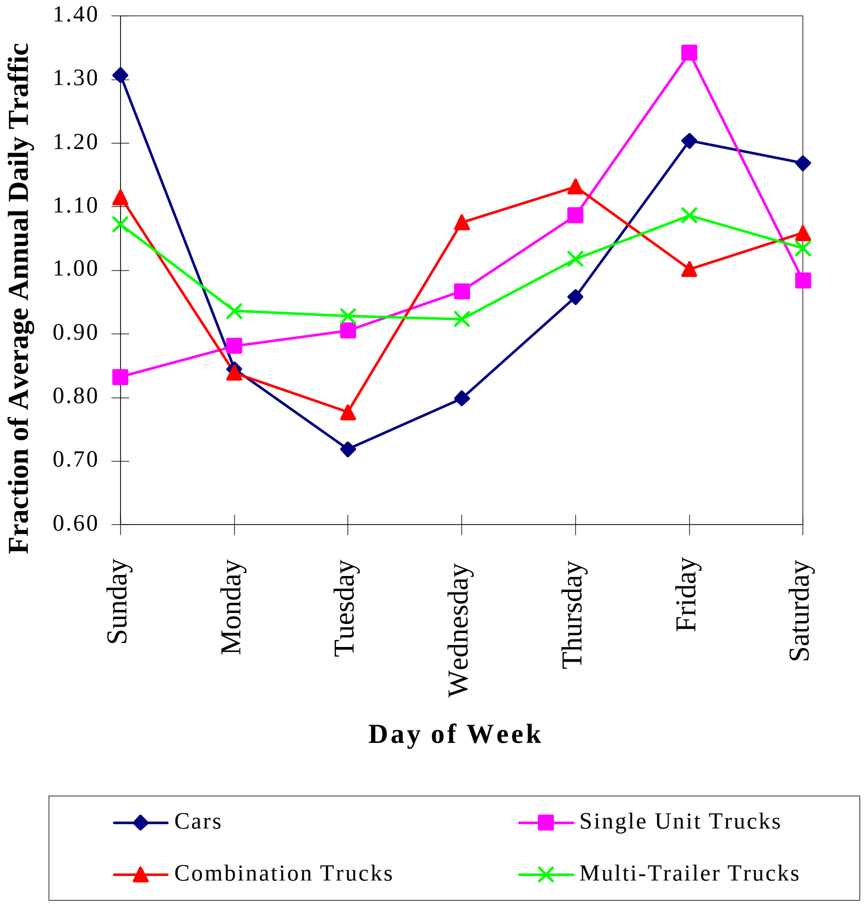

Figure 5. Day-of-Week Patterns at Nebraska Site 3023

As with other day-of-week and time-of-day patterns discussed in this report, local knowledge (obtained by either understanding the traffic using the site or by collecting enough data on the traffic patterns to understand their variation) is needed to accurately assign and apply day-of-week patterns to specific road segments. This requirement causes difficulties with FHWA's desire to have a factoring process that can be applied when states do not submit data correctly adjusted to represent average annual conditions.

Impacts of Local Conditions

Local conditions can easily affect the day-of-week pattern of specific vehicle classes. An important part of these conditions is recreational travel by cars, but freight movements (either local or through-movements) can also create unusual day-of-week conditions. Local conditions (such as harvest movements in farm areas) can affect entire regions or individual roads (for example, freight movements caused by factory production schedules). In many respects, large through-movements of long-haul freight can be considered “local conditions”, even though the cause for those traffic patterns is located far away from the road section in question.

The effect that local conditions (including through-truck movements) have on day-of-week vehicle patterns is a function of total volume and the relative influence of other traffic patterns. Much of the variation in the percentage of truck travel that occurs on weekends at individual sites may be caused by through-traffic at these sites. On roads that appear to have a lot of long-haul, through-truck traffic, weekend truck volumes tend to be high. On roads whose percentages of long-haul, through-traffic appear to be moderate in comparison to local traffic, weekend truck travel percentages tend to be moderate. On roads with little long-haul, through-truck traffic, weekend truck travel volumes tend to be low.

It was not possible to correlate these different truck travel patterns with different functional classes of roads or with particular states. As noted above, the Great Plains states consistently demonstrated higher weekend truck volumes, but these higher weekend volumes were apparent in other states as well.

From a functional classification perspective, two broad conclusions were reached:

- Urban roads are less likely to have higher weekend truck volume percentages than rural roads.

- Lower functional class roads (classes 6, 7, 8, 14, and 16) are less likely to have higher weekend truck percentages than higher functional class roads (classes 1, 2, 11, and 12).

However, within each functional classification of road, there was a large degree of variation. For example, Virginia site 1023, a rural interstate, carries 77 percent of average daily combination truck traffic on Sundays, whereas Virginia site 1464, also a rural interstate, carries only 38 percent of average daily combination truck traffic on Sundays. These differences can be explained by understanding the trucking patterns on these two roads. Site 1023 is on I-95, and carries large volumes of through-truck traffic. Site 1464 is on I-64, near Norfolk, and its truck traffic predominately carries freight bound to or from that city.

The LTPP data set also contains lower functional class roads in urban areas that have high weekend truck traffic. The research team was unable to identify commonly available surrogate variables (such as functional class) that could be used to accurately predict when these variations in truck volume patterns would occur.

VOLUMES BY TIME-OF-DAY

As illustrated in Figure 6, the analysis revealed four basic time-of-day patterns. These patterns are as follows:

- Rural automobile.
- Urban automobile (two humps).
- Business day trucking.
- Through-trucks.

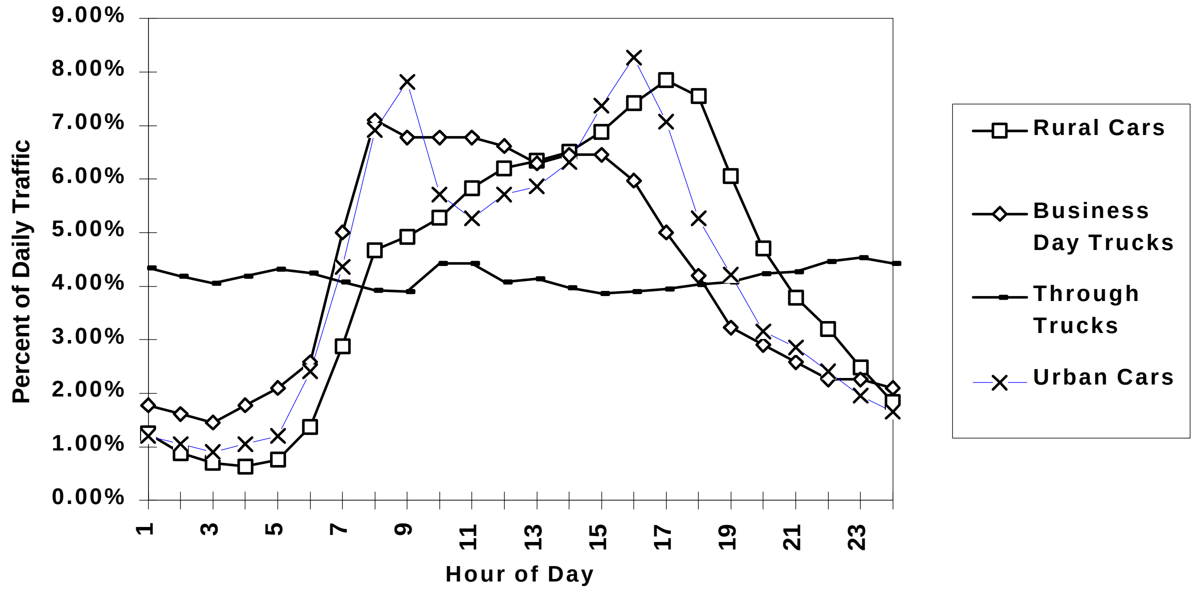

Figure 6. Basic Time-of-Day Patterns

The presence of any one of these patterns is determined by geographic location and roadway function, which are not necessarily equivalent to roadway functional classification. The specific height of the curves for percentage of traffic by time-of-day and the exact location of the peak travel periods vary somewhat from location to location, depending on the volume of traffic on a road (particularly in relation to roadway capacity) and the proximity and nature of traffic generators. (As with all generalities, there were significant exceptions to these patterns. For example, I-15 between Los Angeles and Las Vegas experiences a large night-time travel movement, particularly on Friday nights, because of the vehicles going from Los Angeles to Las Vegas for the weekend. These types of site-specific peaks can be expected near major, unique traffic generators.)

The rural automobile pattern consists of a single peaked distribution, with the peak normally occurring in the afternoon. It is commonly found on rural roads that are not affected by nearby urban areas, and it is also found on weekends in both urban and rural areas. Traffic volumes generally begin increasing between 5:00 and 6:00 a.m. and continue increasing until sometime in the afternoon. The exact time of the afternoon peak is determined by site-specific conditions.

The urban travel pattern consists of the classic two peaks associated with commuter trips. This pattern is present on most urban roads during weekdays, on many roads with rural functional classes where commuters live in rural areas on the outskirts of urban areas, and on some rural roads that are affected by intercity traffic generated by nearby urban areas. (For example, I-5 midway between Seattle, Washington, and Portland, Oregon, exhibits an urban travel pattern even though it lies 90 miles from either city because the two cities generate a considerable amount of business day travel between them.) This double peak travel pattern is often directional. That is, the morning peak occurs only in one direction, and the afternoon peak occurs in the opposite direction. The peaks are still obvious when volumes for both directions are combined, but the height of the curve (when expressed as a percentage of daily traffic) is usually lower when expressed as a fraction of bi-directional volume.

The third pattern is the business trucking pattern. The “business trucking pattern” fits most truck classifications (when aggregated nationally, only truck classes 11 and 12 did not exhibit this pattern; see Figure 7). The vast majority of trucking movements in the nation start and end during the normal, extended business day (that is, between 6:00 a.m. and 6:00 p.m.). Consequently, most truck traffic occurs during these times. The exact timing of the business day travel varies from site to site, as well as by vehicle class and direction within each site. The truck travel pattern differs from the rural automobile pattern in two major respects. The truck pattern usually peaks earlier in the day (although both patterns show significant increases in traffic volume by 6:00 a.m.), and the truck pattern usually drops earlier in the day than the rural automobile pattern.

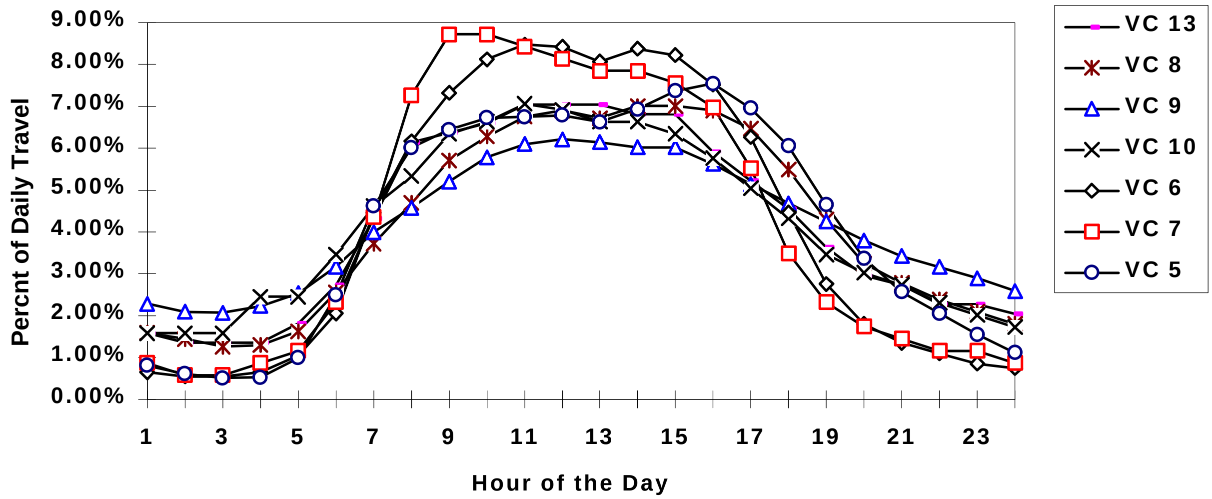

Figure 7. Business Day Trucking Pattern

Note that, although the "classic" business trucking pattern has only one "hump", the actual pattern on a given roadway may be directionally oriented, with trucking movements in one direction on a road during some parts of the day and in the opposite direction during other parts of the day. This type of pattern is typical for distribution services, where specific styles of trucks leave a warehouse in the morning and return in the late afternoon. Figure 8 illustrates how, at one individual site, the very different directional patterns combine to equal the "typical" business day pattern.

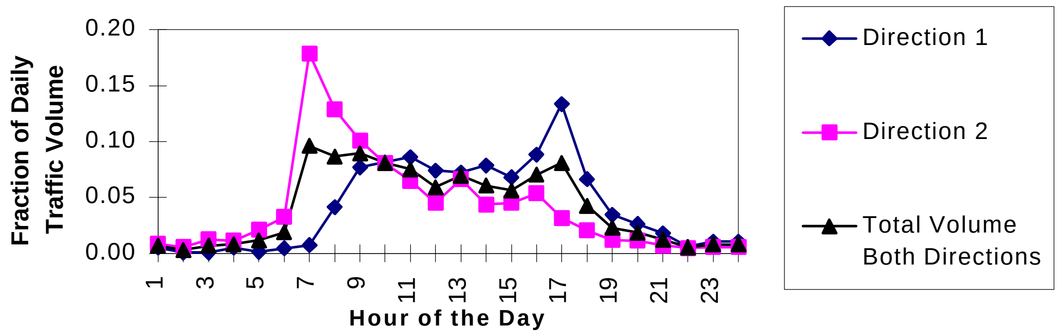

Figure 8. Directional Time-of-Day Distribution for Multi-Trailer Trucks at Site 5009

The final pattern is the through-truck pattern. This pattern reflects the fact that long distance trucks are not constrained to the normal business day. Many travel at night to avoid traffic congestion. In addition, because many long distance drivers are paid by the mile rather than by the hour, there is incentive to drive whenever possible. Consequently, the percentage of daily travel at night by these vehicles is much higher than for other vehicle classes. This pattern has a fairly flat volume pattern with individual site characteristics controlling whether volumes increase or decrease slightly at night.

The smaller truck classifications (classes 5 through 8) usually follow the business day trucking pattern. Classes 11 and 12 often follow the through-truck pattern. The remaining truck classes (9, 10, and 13) switch from one pattern to the other, depending on the nature of truck traffic on each road. class 9 trucks, in particular, are commonly used for both long distance and short haul trucking duties in the United States. Consequently, at some sites, class 9 vehicles fall into the business day pattern, at other sites they follow the through-truck pattern, and at still other sites, they create a combination pattern. The effects of being used in these multiple roles is apparent in Figure 7, where the class 9 truck pattern has higher late night travel percentages than the other trucking classes shown.

Buses (FHWA vehicle class 4) follow one of the four patterns mentioned above. Generally, within urban areas, transit buses appear to predominate within this class. The data show that these vehicles fall within the general automobile patterns (*i.e.*, the double-peak urban pattern on weekdays and the single-peak rural pattern on weekends). In rural areas, intercity buses predominate (often supplemented by misclassified large recreational vehicles) and tend to follow the rural automobile pattern.

For all four basic time-of-day volume patterns and all vehicle classes, vehicle volumes decrease at night (although, in many cases, reductions in through-truck volumes may be very small). However, car volumes decrease more late at night than truck volumes, thus truck percentages (computed from truck volumes divided by total traffic volume) tend to increase late at night (see Figure 9). This pattern is true for both urban and rural areas, although the percentage of trucks is usually higher in rural areas than urban areas. (The available data sets also contain relatively few small urban roads, where truck percentages are small to begin with and may decrease to near zero late at night.)

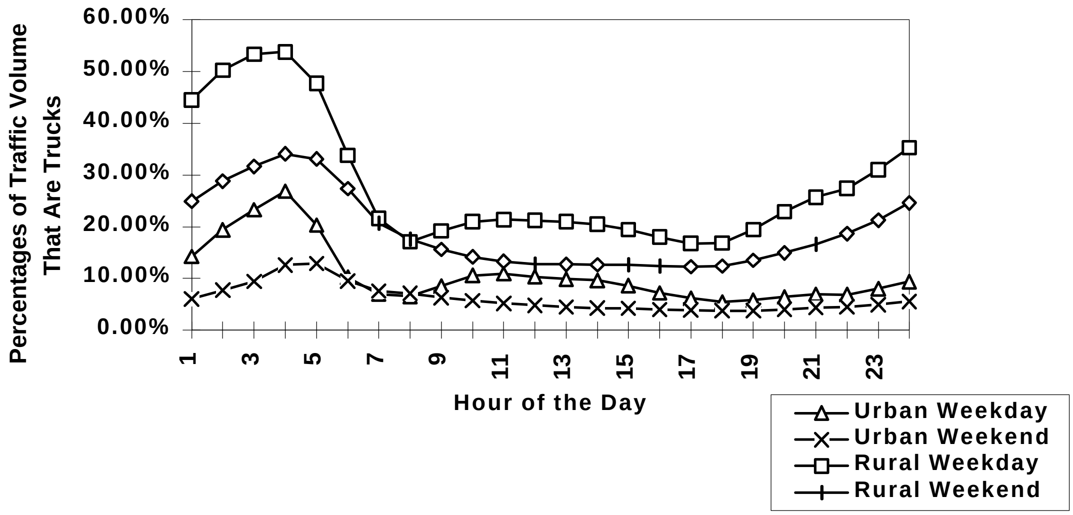

Figure 9. Weekday/Weekend Truck Percentages

What these graphs show is that motorists get the impression that very large truck movements take place at night. The reality is that, in most cases, these late night truck movements are not that big; they just seem large because the percentage of trucks on the road is so high. Note that where long-haul, through-trucks make up the majority of trucks on the road, traffic volumes may decrease very little, if at all, making the night time truck percentage even higher and the perception of high truck volumes even stronger.

Directional Differences

It was difficult to determine nationally applicable statistics for time-of-day travel by direction, since directional characteristics are site-specific. The LTPP database contains numerous sites for both urban and rural functional classes that exhibit either very directional traffic (that is, time-of-day traffic patterns that are substantially different in one direction than they are in the other) or strongly bi-directional. It is necessary to have local knowledge of a site to be able to correctly assign time-of-day factors on a directional basis.

For urban areas, many of the suburb-to-suburb movements that are growing most quickly are multi-directional. Morning commuter traffic moves from City A to City B, and from City B to City A. This creates urban peak movements (a.m. and p.m. peaks in the time-of-day distribution) in both directions on major roads linking these cities. At the same time, many urban roads still demonstrate traditional traffic patterns, with a large inbound peak in the morning and a corresponding outbound peak in the evening.

The available data do not show the flattened peak periods associated with heavy congestion during the peak hours. This is not surprising because the LTPP tests sites (from which the data are collected) were located where pavement tests could be carried out safely and with fairly small disruptions to traffic. Consequently, heavily congested urban roads are not strongly represented in the LTPP database.

Analysis of the LTPP database showed that trucks also have directional splits in urban areas. Directional truck travel appears to be similar to that of cars (*i.e.*, trucks travel in the same peak directions), but these directional differences are often not as large for trucks as they are for cars. However, the LTPP data do show that directional peak-period differences vary considerably by vehicle type, and it is likely that local conditions will make the travel patterns of many urban roadways unique.

One hypothesis for the similarity of directional movements between cars and trucks in urban areas is that, although through-trucks are able to avoid peak traffic periods by stopping outside of the urban area, local truck traffic must operate during the business day to pick up and deliver goods. This places local trucks in some portion of the peak period. In addition, the delivery and pick-up of most goods take place at commercial activity centers, the same locations that generate a large percentage of commute trip automobile traffic.

For rural areas, peak-period directional differences are also apparent at many sites. Some rural sites do exhibit typical “urban” directional travel, even within some of the heavier truck classes (for example, Figure 8 is a rural site), but other sites with great differences in peak period directional travel show a different pattern (see Figure 10). In this second pattern (which is more common in the LTPP database), travel in one direction appears to be offset by approximately 1 hour from travel in the other direction. This produces a substantial difference in the percentage of traffic that occurs during the a.m. or p.m. peak periods (when those periods are defined as a given time period, such as 6:00 to 9:00 a.m.), but it does not represent an extreme difference in travel patterns.

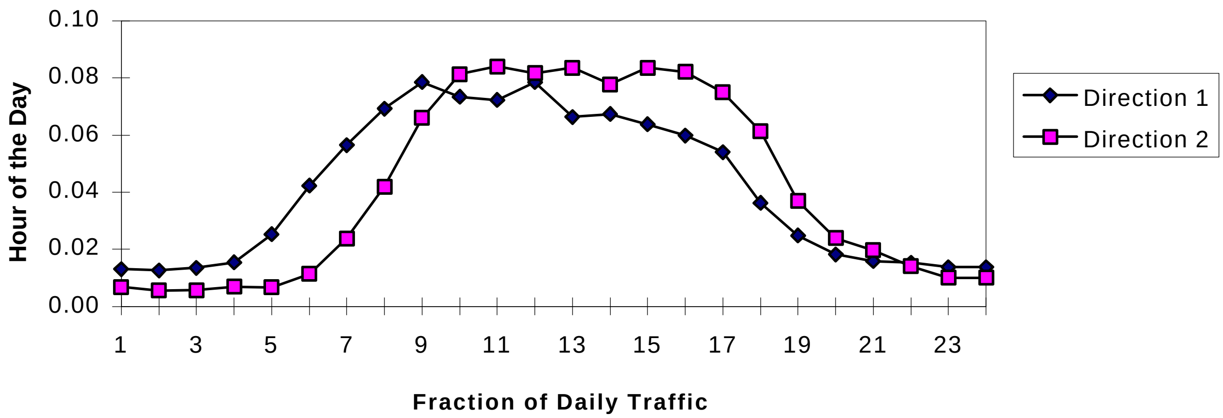

Figure 10. Difference in Combination Truck Travel by Direction

If these same data are used to express truck percentages as a function of the time-of-day, the result is a graphic such as that shown in Figure 11. Figure 11 illustrates that, although truck volumes decrease during the late night hours, the truck percentage rises significantly because car volumes tend to drop even more drastically. Truck percentages are generally higher in rural areas than in urban areas, and larger roads (functional classes 1 and 2 in rural areas, 11 and 12 in urban areas) are more likely to have high truck percentages than smaller functional road classes; however, the correlation between truck percentage and functional classification of road is very poor. Truck percentages are highly route specific. Individual roads, regardless of functional classification and total volume, can have very high or low truck percentages, depending on the nature of the traffic.

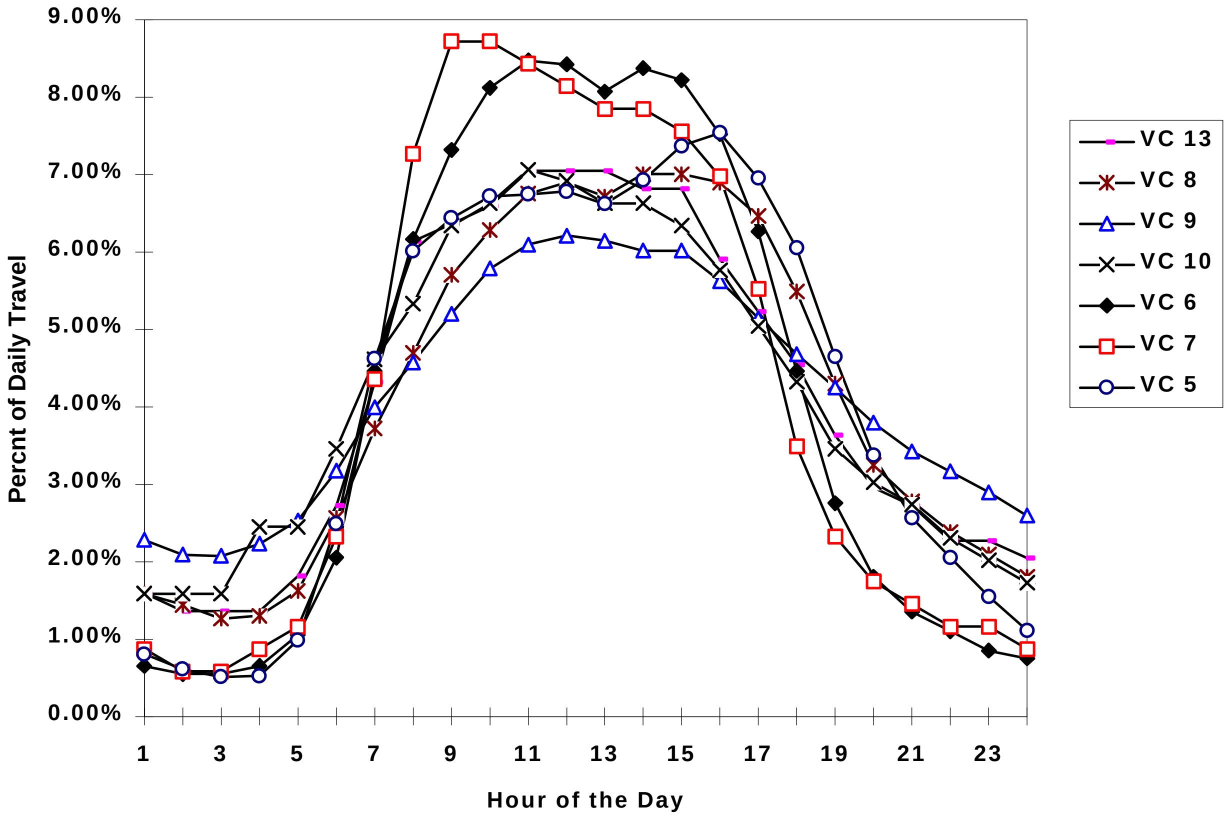

Figure 11. Rural Truck Percentages by Functional Class and Time-of-Day

In summary, as with most other distributions, at any individual site the timing and nature of directional peaking characteristics can vary substantially from national averages and from those common patterns given as examples above. These locational differences depend on the level of recurring congestion, the nature of the traffic using the road, and the location and nature of commercial development and other traffic generators.

Weekday/Weekend Differences

The time-of-day distributions for cars change from weekdays to weekends in urban areas. On weekend days, there is usually no morning peak in the time of day distribution, and the afternoon peak is often a lower percentage of daily traffic than that of weekdays. Consequently, vehicles are more evenly distributed during the middle of the day (see Figure 12). Similar patterns occur on all of the larger functional classes of urban roads.

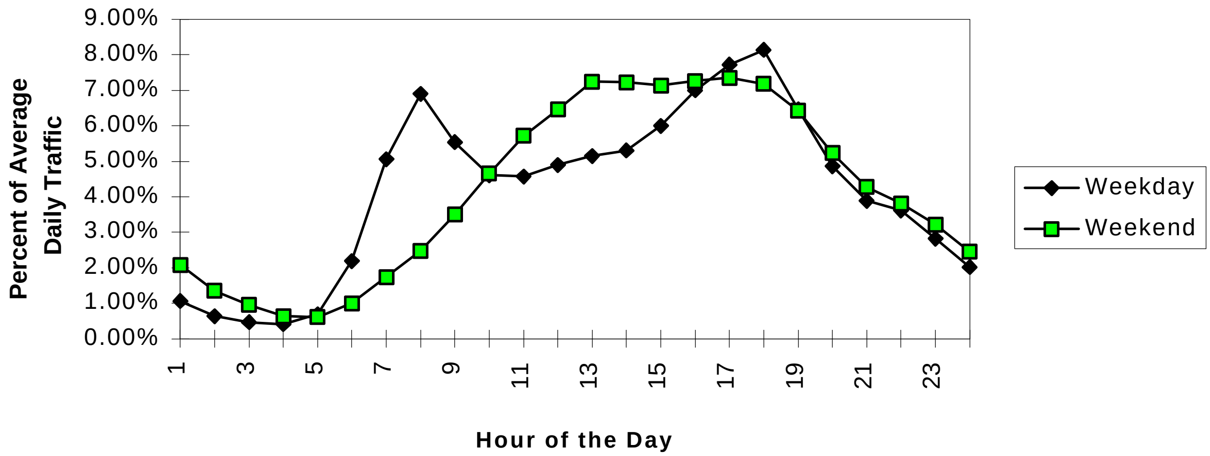

Figure 12. Weekday versus Weekend Automobile Patterns

Weekday/weekend changes are not as apparent for urban truck travel except for individual roads that show marked weekday peaking in specific truck classes. Although truck volumes drop considerably in urban areas on weekends, the time-of-day distribution of trucks tends to not change appreciably. (Roads with unique trucking patterns experience unique changes based on the nature of the local truck trip generator.)

Similar changes for both cars and trucks occur on rural roads, except that recreational roads usually experience significant increases in automobile traffic on weekends (often including Fridays). The timing of these increases is a function of the nature of the recreational activity and the distance that road section is from major population centers. That is, rural roads that exhibit urban travel characteristics tend to lose the morning peak in the time-of-day distribution, whereas rural roads that do not experience significant commuter traffic tend to have relatively similar weekday and weekend travel patterns.

URBAN VERSUS RURAL VOLUMES

One of the major findings from the LTPP data is that many roads exhibit total volume traffic patterns that are not characteristic of their functional classification coding, that is, a large number of "rural" roads act like urban roads, and vice versa. As noted in the time-of-day section above, many "rural" roads are located close enough to urban areas to exhibit urban time-of-day travel characteristics. Similarly, some "urban" roads are located in areas with relatively little urban development and appear to have characteristics that are more rural, since the volume of through-traffic is much larger than the locally generated "urban" traffic. In most cases, automobile volumes cause a "rural" road to exhibit "urban" traffic patterns, since rural and urban truck patterns are similar.

The primary differences between urban and rural travel patterns involve the patterns of car usage and the through-truck traffic. In urban areas car travel fits the standard weekday commute pattern (with the commute period peak in either one or two directions), with lower weekend volumes. Rural roads generally fit into one of two patterns, one oriented toward recreational travel and one without significant recreational attributes. Both of these patterns tend to have a single time-of-day peak in the afternoon. In the rural recreation car pattern, weekend traffic volumes are higher than the average day, whereas in the non-recreational pattern, weekend automobile volumes decrease like those normally found on urban roads.

For trucks, the classic "business day" time-of-day pattern occurs on both urban and rural roads. However, on some rural roads, the percentage of long-haul, through-trucks is high enough that the time of day pattern for total trucks is quite flat. On most urban roads and on many rural roads, though, truck traffic drops substantially late at night.

Truck percentages on significant rural roads are commonly higher than those on comparable urban roads (for example, compare the interstate classes of 1 and 11, or the principal arterial classes 2 and 14 in Table 4.) Within the LTPP database, over 40 percent of the rural interstate sites have truck percentages of over 20, whereas no urban site in the LTPP database has a truck percentage that reaches 20 percent. On the other hand, rural interstates can also have very low truck percentages. One quarter of the rural interstate sites have truck percentages below 10 percent, with the low falling under 2 percent. There are also several urban freeways in the LTPP database that have very low truck percentages.

Table 4. National Average Truck Percentages by Functional Classification of Roadway

Functional Class of Roadway[4]	Cars	Single-Unit Trucks[5]	Combination Trucks	Multi-Trailer Trucks
1	75.5%	3.5%	19.0%	2.0%
2	88.3%	3.7%	7.4%	0.6%
6	91.5%	3.3%	5.2%	0.1%
7	92.7%	4.8%	2.5%	0.1%
11	91.5%	2.6%	5.2%	0.7%
12	88.9%	3.7%	5.9%	1.5%
14	90.5%	3.2%	5.8%	0.6%
16	94.4%	2.4%	2.9%	0.3%

Similarly, the larger roads tend to have higher truck percentages than the smaller roads typically found within functional classes 6, 7, 8, and 16. However, just as a number of freeways and expressways have relatively small truck percentages, some rural minor arterials in the LTPP database have truck percentages of just under 10, which is higher than 20 percent of the rural and urban interstate sites.

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4 Note that functional class 12 is not present in this table because of the very small number of sites present in the test data set that fell within this classification of road.

5 Includes buses and FHWA class 5 (2-axle, 6-tire) trucks.

Consequently, although it is easy to conclude that freeways tend to have larger truck percentages, local conditions can make these “national” conclusions incorrect. Local knowledge or data are needed to accurately describe the patterns found at any one site.

VEHICLE PERCENTAGES BY FUNCTIONAL CLASS

Table 5 provides information on the average fraction of vehicles by FHWA classification on each functional class of roadway. These numbers were the basis for the summary discussion of vehicle percentages for rural and urban roads in the previous section. Before relying extensively on these numbers, an analyst should be aware that the lower functional classes include relatively few data collection sites (see Table 6); this makes the statistical certainty fairly small that these values represent the “true” mean values for these roads in the United States. This statistical uncertainty is further increased by the fact that truck characteristics vary among regions of the country and, in many cases, from state to state because of the variations in state truck regulations. Therefore, the states from which these data were taken do not equally represent the regions of the country for all functional classifications of roadway.

Be aware, for example, that specific vehicle types, such as class 12 and class 13 vehicles, are relatively common on many roads in the western United States but are fairly uncommon throughout most of the eastern United States. Other vehicle types, such as class 7, are uncommon in most states but can represent a large proportion of vehicle loads on some roads in some states (for example, heavy dump trucks or large Kentucky coal trucks are often 4-axle single-unit trucks).

Table 5. Vehicle Percentage Chart for Each Functional Class

Functional Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
1	0.2%	63.1%	12.3%	0.3%	2.3%	0.8%	0.1%
2	0.2%	72.1%	16.0%	0.3%	2.5%	0.8%	0.1%
6	0.1%	72.3%	19.1%	0.3%	2.2%	0.7%	0.1%
7	0.0%	74.5%	18.2%	0.4%	3.7%	0.6%	0.0%
11	0.2%	75.7%	15.7%	0.2%	1.6%	0.8%	0.0%
12	0.2%	71.3%	17.4%	0.2%	2.5%	0.6%	0.3%
14	0.1%	74.2%	16.2%	0.4%	2.0%	0.7%	0.1%
16	0.0%	74.5%	19.9%	0.1%	1.9%	0.4%	0.0%
Functional Class	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**	
1	1.8%	16.8%	0.3%	1.5%	0.2%	0.3%	
2	1.5%	5.6%	0.4%	0.2%	0.1%	0.2%	
6	1.6%	3.5%	0.1%	0.1%	0.0%	0.0%	
7	0.9%	1.5%	0.0%	0.0%	0.0%	0.0%	
11	1.1%	3.9%	0.2%	0.2%	0.1%	0.6%	
12	1.4%	3.9%	0.6%	0.3%	0.4%	0.8%	
14	1.1%	4.5%	0.2%	0.3%	0.1%	0.2%	
16	1.2%	1.3%	0.3%	0.0%	0.1%	0.2%	

Table 6. Number of Sites per LTPP Region for Each Functional Class

REGION	FC 1	FC 2	FC 6	FC 7	FC 11	FC 12	FC 14	FC 16	Total
ATLANTIC	4	9	2	1	2	0	2	0	20
CENTRAL	9	8	8	2	5	2	3	0	37
SOUTH	5	5	7	2	5	0	2	1	27
WEST	5	5	0	0	1	1	2	1	15
Total	23	27	17	5	13	3	9	2	99

A second observation about Table 5 is that many of the vehicle types make up a fairly small percentage of the traffic stream, regardless of the functional classification of roadway. On a high-volume interstate, a very low percentage (less than 0.25 percent) can still represent a fairly large volume of vehicles, but on a moderate volume rural road (e.g., 10,000 Average Daily Traffic [ADT]), 0.25 percent would equal only 20 vehicles per day in the traffic stream.

When volumes within a class drop to levels this low, it becomes difficult to accurately compute adjustment factors to account for time-of-day, day-of-week, or month-of-year variation, since the factors themselves become unstable with small absolute changes in traffic volumes. This problem caused considerable difficulty in the computation of national averages.

The research team recommends, therefore, that factors be developed and statistics be reported for a much smaller number of vehicle classes than the 13 classes FHWA currently uses. Our recommendation is that most factors be produced for:

- Passenger cars and light trucks (plus motorcycles where collected).
- Single-unit trucks.
- Combination trucks.
- Multi-trailer vehicles.

In urban areas where buses are an important part of the fleet mix, buses can be treated as a fifth vehicle classification. In rural areas, where monitoring bus travel is less important, buses can either be counted separately, or they can be treated as part of the single-unit truck classification.

This classification scheme is a simple aggregation of the 13 existing FHWA classes:

- Classes 1-3 are passenger vehicles.
- Classes 4-7 are single-unit trucks and buses.
- Classes 8-10 are combination trucks.

- Classes 11-13 are multi-trailer trucks.

It is also possible to include class 5 trucks (2-axle, 6-tired trucks) as part of the passenger vehicle category, since it can be difficult to separate vehicle class 5 from class 3 when only axle spacing information is used. (Class 5 has been placed with the single-unit trucks because the FHWA's definition of the class indicates that it is primarily intended to contain small urban delivery trucks, rather than extra large passenger vehicles.)

Although these aggregated classes suffer from the problem of each class containing a variety of vehicles with different characteristics (gross vehicle weight [GVW], load/axle, types of movements), the 13 FHWA classes also suffer from these problems, but to a lesser extent.

SEASONAL PATTERNS

General Findings

At the national level, both rural and urban sites exhibit a general pattern of lower volumes in the winter months and higher volumes in the late spring through early fall. These basic patterns are true for all four aggregated vehicle categories. However, although the national average monthly traffic patterns are similar for all four aggregated vehicle classes, the monthly patterns of the four vehicle classes at individual sites tend to be different. Very few sites have monthly automobile travel patterns that are similar to the monthly patterns for the truck classifications. At the national level, however, the averaging necessary to compute mean statistics smoothes out a great deal of this variation, leaving only the most basic trends visible (see Figure 13 and Table 7).

The basic trend visible in Figure 13 and Table 7 supports the generally held assumption that people travel less in the winter and more in the summer. This assumption seems to hold true for truck travel as well, although the timing of the travel peaks during the middle of the year is somewhat different for the four vehicle categories. In particular, several of the urban truck patterns peak in early fall. Because cars make up a large percentage of the total traffic volume for most roads (and most sites with available data), the monthly pattern for total volume tends to be similar to that for cars.

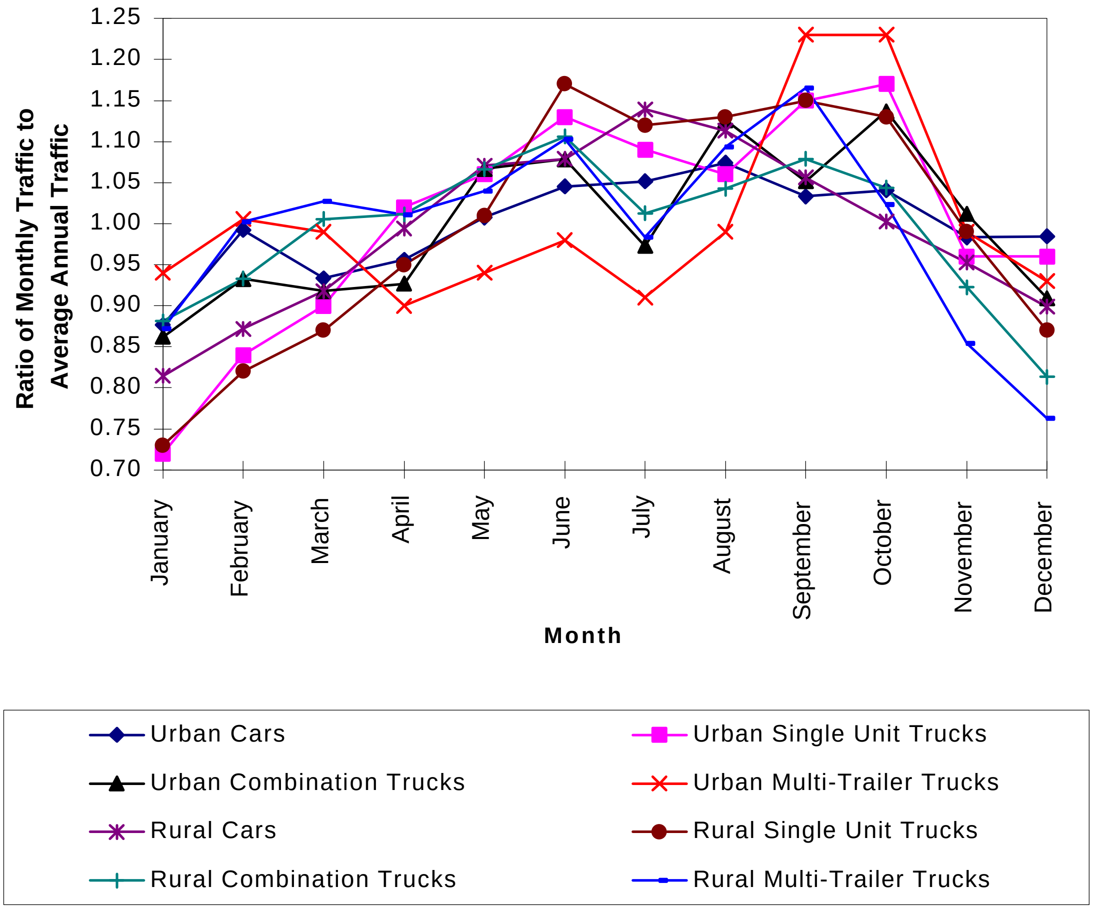

Figure 13. Seasonal Factors by Aggregated Vehicle Class

Table 7. Seasonal Factors for Aggregated Vehicle Classes by Urban/Rural Designation for All Roadway Classes Combined

Urban Roads	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Urban Cars	0.88	0.99	0.93	0.96	1.01	1.05	1.05	1.07	1.03	1.04	0.98	0.98
Urban Single Unit Trucks	0.72	0.84	0.9	1.02	1.06	1.13	1.09	1.06	1.15	1.17	0.96	0.96
Urban Combination Trucks	0.86	0.93	0.92	0.93	1.07	1.08	0.97	1.13	1.05	1.14	1.01	0.91
Urban Multi-Trailer Trucks	0.94	1.01	0.99	0.9	0.94	0.098	0.91	0.99	1.23	1.23	0.99	0.93
Rural Roads	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Rural Cars	0.81	0.87	0.92	0.99	1.07	1.08	1.14	1.11	1.09	1	0.95	0.9
Rural Single Unit Trucks	0.73	0.82	0.87	0.95	1.01	1.17	1.12	1.13	1.15	1.13	0.99	0.87
Rural Combination Trucks	0.88	0.93	1.01	1.01	1.07	1.11	1.01	1.04	1.08	1.04	0.92	0.81

If the monthly traffic patterns are examined for individual sites and individual vehicle classes, the following additional conclusions can be drawn.

- Cars and combination trucks have much lower levels of seasonal (monthly) variation than that of single unit trucks and multi-trailer trucks. This is true for both month-to-month variation at a site, and variation from one site to another.
- Consequently, seasonal adjustments to short-duration car and combination vehicle estimates will be much more precise than those associated with single-unit trucks or multi-trailer vehicles.
- Much of the high variability (instability) in single-unit and multi-trailer truck volumes can be traced to the fairly low daily volumes at many sites of these vehicles.
- It is suspected (although no proof is available within the LTPP database) that some of the month-to-month variation is caused by equipment errors and limitations.

Even relatively small numbers of errors in classifying vehicle categories with low volumes can have a large impact on the adjustment factors computed for those classes.

- Attempting to calculate monthly adjustment factors for all 13 FHWA vehicle classes will cause seasonal adjustment values to become even more variable (unstable) and inaccurate, primarily because of the mathematical problems caused by low traffic volumes for many of the categories.
- Extremely low- or high-volume traffic months can occur during any month at a given site.

These points are discussed in more detail below.

Seasonal Variation by Vehicle Classification

For the sites at which LTPP data are available, automobiles tend to follow fairly traditional patterns. This “classic” automobile volume pattern shows a fairly continuous rise in traffic volumes from January to a peak in the summer, followed by a decrease throughout the rest of the year. However, in most cases, car volumes vary only moderately from month-to-month from the average annual condition during the year.

For example, almost 60 percent of the months of data examined at all sites had average daily car volumes within 10 percent of the average annual daily condition (see Table 8) The average monthly car volumes were more than 30 percent different from the average condition only 6 percent of the time (that is, only 6 percent of the time is the ratio of the monthly average daily traffic [MADT]/annual average daily traffic [AADT] greater than 1.3 or less than 0.7). This includes winter months.

This means that, in a large percentage of cases, collecting short-duration counts of car volumes will lead to a reasonably[6] accurate measure of annual conditions, regardless of when those counts are taken. In the remaining cases, adjustments are necessary, but the maximum error caused by monthly variation in car volumes should be around 30 percent at most non-recreational sites.

Table 8. Size of Monthly Tavel Factors by Vehicle Class

	Percent of Months with Factors Different from 1.0 by Less than 5%	Percent of Months with Factors Different from 1.0 by Less than 10%	Percent of Months with Factors Different from 1.0 by Less than 20%	Percent of Months with Factors Different from 1.0 by Less than 30%	Percent of Months with Factors Different from 1.0 by Less than 40%	Percent of Months with Factors Different from 1.0 by Over 40%
Cars	33	58	82	94	97	3
Single Unit Trucks	14	33	60	74	84	16
Combination Trucks	26	49	76	88	96	4
Multi-Trailer Trucks	18	34	57	73	82	18

The data in Table 8 show that combination vehicles are only slightly more variable from month-to-month than cars. In almost 50 percent of months, average day-of-the-month combination truck volumes are within 10 percent of annual average daily conditions, whereas in only 12 percent of the months do average monthly volumes vary more than 30 percent from the average annual daily condition.

In contrast, the other two aggregated truck classes have much higher levels of month-to-month variation. Average daily single-unit truck volumes by month fall within 10 percent of average annual daily conditions in less than 33 percent of the months; for multi-trailer trucks, this figure rises to only 34 percent of the months. Perhaps more importantly, for single-unit trucks in over 16 percent of the months, average day-of-the-month volumes vary more than

6 In this case, "reasonably" is defined based on the pavement life analyses for which the LTPP data was intended. If load was proportional to car volume (which it is not), the error present by not adjusting for seasonality would be considered acceptable for many pavement life analyses.

40+ percent from the annual daily average. For multi-trailer trucks, this condition is true for 18 percent of the months. These compare to less than 4 percent of the months for both cars and combination trucks. (Note that these estimates exclude data from sites that counted fewer than 10 trucks per day within a given vehicle class, since monthly factors computed for these sites tended to be unstable.)

This variation in truck volumes is not a simple matter of low-volume winter months and high-volume summer months. For the single-unit and multi-trailer truck categories, volumes often change dramatically from month to month. Although the basic pattern of low winter and high summer volumes holds true at most sites, this pattern is often not a steady increase and decrease over time but a highly variable "jagged line", with volumes increasing or decreasing radically from one month to the next. Figure 14 shows some examples of single-unit truck volume patterns found in the LTPP data.

It is unclear if this variation is caused by real changes in the truck volumes within these classes (often the truck volumes within even the combined vehicle classes are low enough so that modest increases in truck volumes will cause significant changes in the monthly factor) or by the limitations of the data collection equipment. For example, if there is a road with 10,000 vehicles per day and 60 percent of those vehicles are class 2 (6,000 vehicles) and 2 percent are class 6 (200 vehicles), a 1 percent misclassification rate of class 2 vehicles (assuming they are misclassified as class 6, because of either lane changes over the sensor or ghost axles from the sensor) results in an additional 60 vehicles (a 30 percent increase) in the single-unit truck category. This same type of misclassification error (usually caused by misclassifying closely following vehicles as a multi-trailer truck) may also be responsible for much of the variability in the multi-trailer truck class, particularly in those states where these trucks are rarely found. Another common error that affects the number of trucks counted on a road is the inability to determine the difference between longer 2-axle, 4-tired pick-up trucks (class 3) and short wheel base 2-axle, 6-tire delivery trucks (class 5).

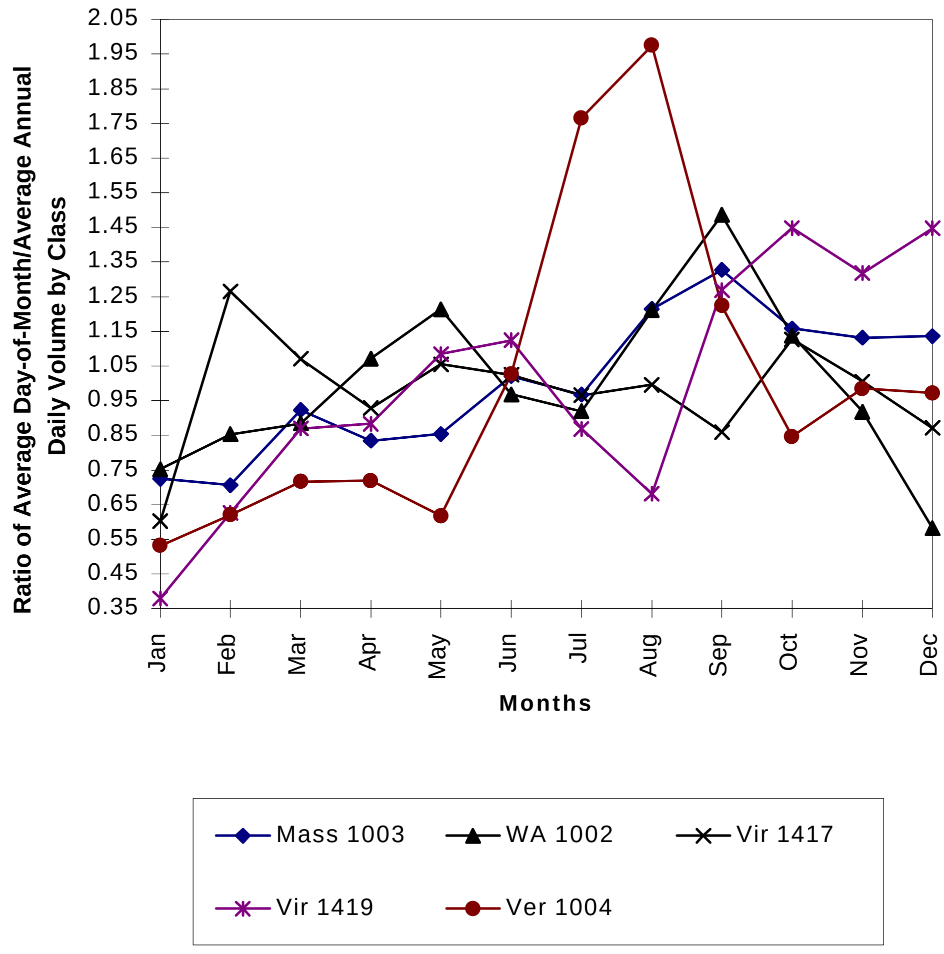

Figure 14. Example of Single-Unit Truck Seasonality

Differences in Factors by Functional Classification of Road

Monthly traffic volume patterns were also examined by functional class of roadway (see Figures 15, 16, 17, and 18). In general, these plots illustrate three basic conclusions:

- The smaller the number of sites in a sample, the more likely that extreme monthly variation will be observed (functional classes 7, 12, and 16).

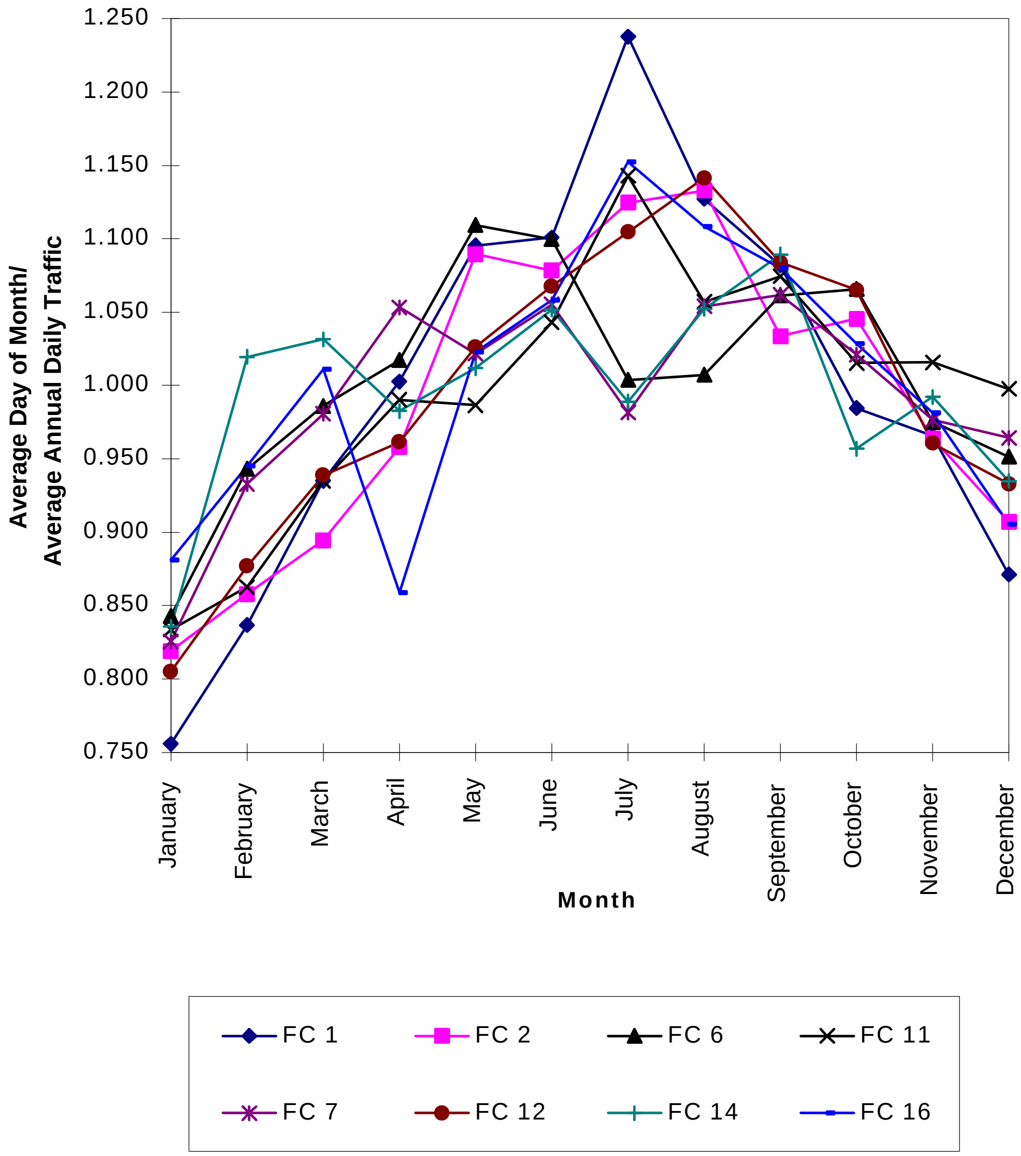

Figure 15. Monthly Passenger Vehicle Volume Patterns by Functional Class

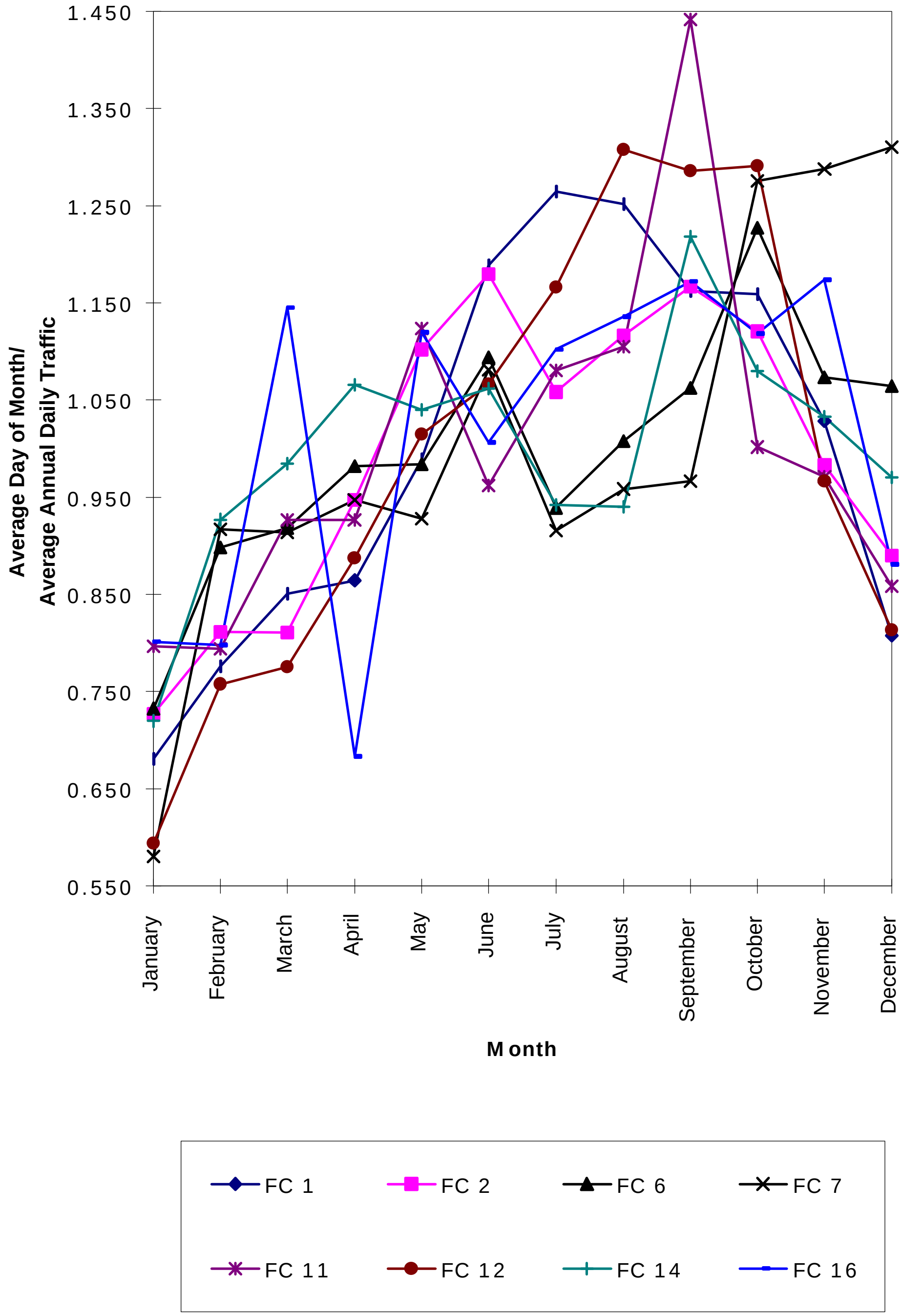

Figure 16. Monthly Single-Unit Truck Volume Patterns by Functional Class

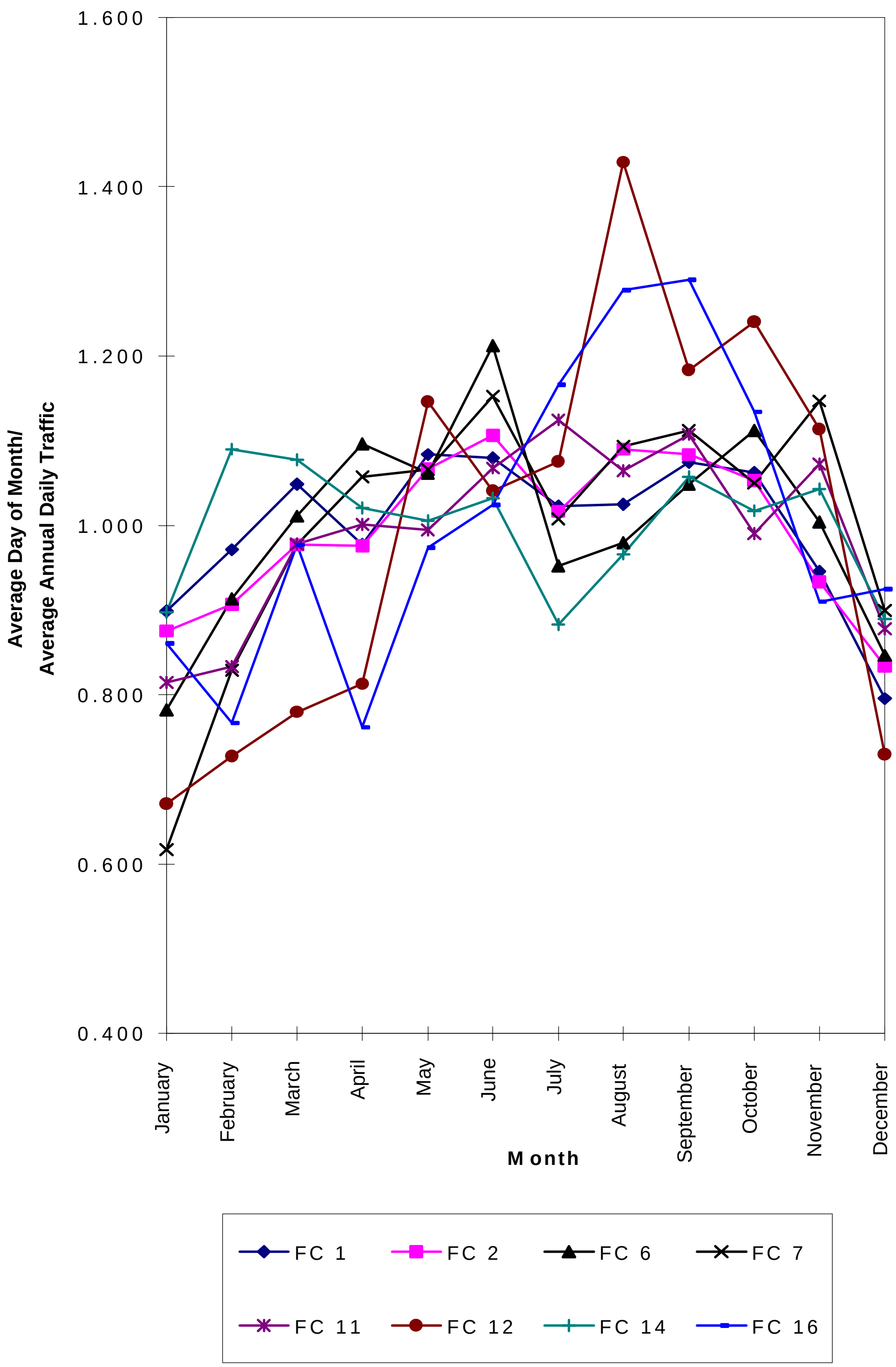

Figure 17. Monthly Combination Truck Volume Patterns by Functional Class

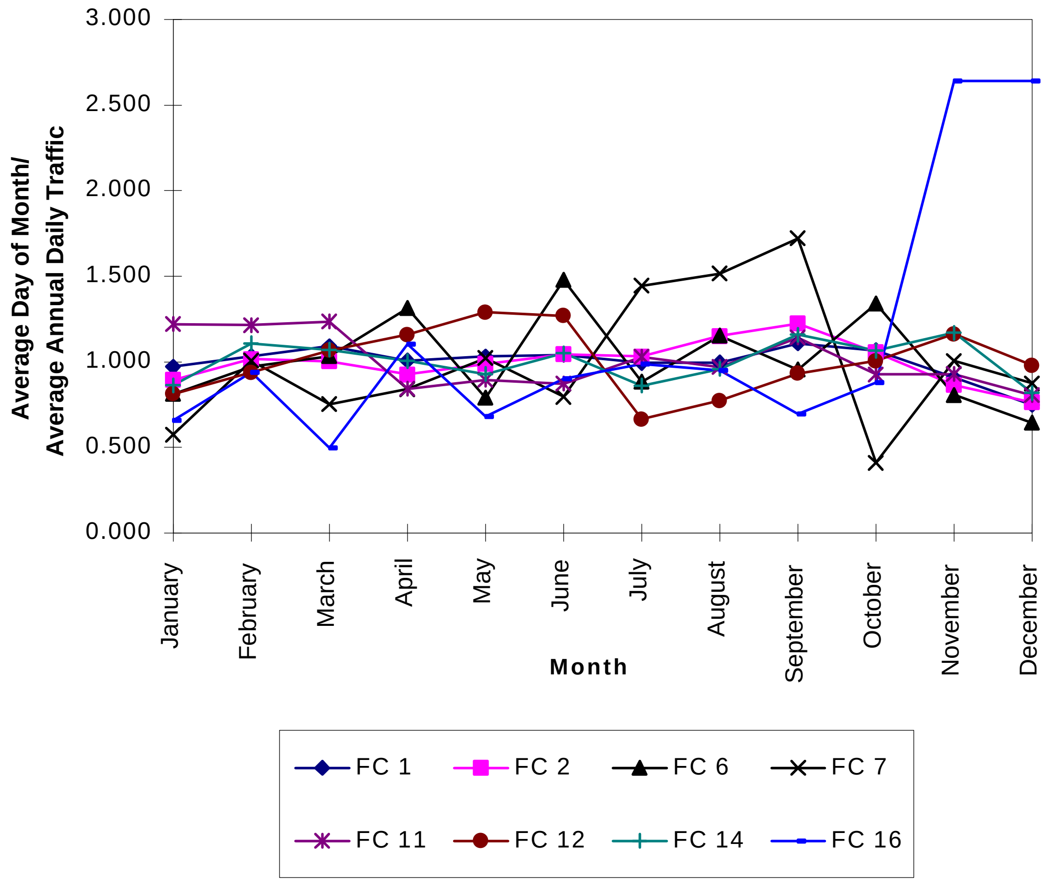

Figure 18. Monthly Multi-Trailer Truck Volume Patterns by Functional Class

- The lower functional classes of roads (functional classes 6, 7, and 16) have more month-to-month variation in traffic volumes than the functional classes that are likely to have larger traffic volumes (functional classes 1, 2, and 11).
- Traffic volumes on urban roads often experience as much seasonal variation as volumes on rural roads.

High levels of variation can be seen in the single-unit and multi-trailer truck categories, regardless of the functional classification of road. In general, the high degree of variability in seasonal factors within functional classes of roads means that, if FHWA decides to adjust truck volumes submitted by the states, these factors should be developed by aggregating data for all classes of roads. This aggregation is necessary because it is not possible at the national level to obtain the information needed to apply a more definitive value with the required level of accuracy. If this grouping is too generic, FHWA should consider using three basic factoring categories—rural interstates, other rural roads, and urban roads—perhaps by broad geographic region of the country.

Although the available LTPP data do not indicate that this stratification would lead to statistically better truck factors, there is a logical basis for assuming that these crude categories of roads could improve the precision of monthly adjustment factors. The logic behind these categories is the following.

- Although the existing functional classification system does not account for the nature of truck traffic using a road, urban traffic patterns can be assumed to be fundamentally different from rural patterns, and rural interstates are likely to carry more long-distance traffic than other rural roads.
- Long-distance travel is likely to be subject to different economic stimuli than local traffic and, therefore, may be somewhat different than locally generated traffic.
- Regional economic (and weather) differences are likely to lead to differences in trucking patterns by geographic location. (This is heavily supported by the significant differences in types of vehicles present in different parts of the country.)

Nevertheless, as noted earlier, the research team was not able to determine statistically significant differences in vehicle volume patterns that could be applied to short-duration counts with confidence.

Effects of Low Volumes

The primary problem with low volumes within individual vehicle classes is that small changes in volume within a vehicle class lead to large changes in percentage of volume. For example, if a vehicle class contains an average of only 10 vehicles per day (many sites in the east contain far fewer multi-trailer trucks than this), the addition of two vehicles per day represents a 20 percent increase in volume within that category.

If car volumes are reasonably high at a site (10,000 vehicles per day if FHWA vehicle classes 2 and 3 are added together), it is easy for a few cars traveling close together to be misidentified by most classification equipment as a multi-trailer truck. Two of these errors in a day would be inconsequential to the car volume estimate (and well within the acceptable tolerance of the classification equipment). However, these same errors would have a significant impact on traffic volumes predicted within the multi-trailer truck category.

In addition to the magnified effects of equipment error, small changes in the local economy can produce small changes in (true) vehicle volumes within these classes. For example, the start or end of a construction project can dramatically change the number of dump trucks (which are commonly found in FHWA vehicle classes 6, 7, and 13, depending on the part of the country) using a road. Although these changes do in fact occur, these patterns do not represent all roads of that type in that geographic area since the dump truck traffic may be confined to a small area and since seasonal adjustment factors that account for these changes are not applicable to many other sites. Similarly, seasonal adjustment factors computed from this site are not even applicable the following year at that same site.

Therefore, it is recommended that low-volume vehicle classes be avoided in computing adjustment factors. This is most easily done by aggregating FHWA's existing vehicle classification scheme, as was done for many of the analyses in this report.

SUMMARY

This review of the temporal distribution of car and truck volumes reached the following basic conclusions. Although the LTPP database is large in terms of the number of sites included in the analysis, the wide distribution of these sites across the nation, the limited number of sites for which seasonal truck volume information has been submitted, the relatively large number of different traffic patterns, and the large number of both geographically distinct regions and functionally different roads make accurately identifying, codifying, and applying truck volume trends and patterns difficult at the national level.

Volumes by Day-of-Week

In general, the following observations can be made from the LTPP database:

- Sunday traffic volumes are the lowest of the week for truck classes at most sites, but average car volumes on Sundays can be fairly high at many rural sites.
- Mondays have slightly lower truck volumes than other weekdays, although this difference is not significant.
- Tuesday through Thursday volumes are similar for all truck classes.
- Friday is the highest volume day of the week for cars but is similar to other weekdays for truck travel.
- Saturday volumes tend to be low for trucks but, like Sundays, can be either high or low for cars, depending on the location.

There are many exceptions to these general findings. The most significant difference is that many sites in the Great Plains and some Rocky Mountain states have different day-of-week patterns. These differences are caused by the large through-movements of both cars and trucks traveling to and from the western states.

A second common difference appears to be caused by recreational travel. All urban sites in the LTPP dataset have lower Sunday automobile volumes than other days of the week. Some rural sites have this same pattern. However, many rural sites have very high Sunday volumes.

The research team concluded that the LTPP database contains insufficient data at this time to support the creation of factor groups that can adequately differentiate between sites with and without high levels of through-traffic and/or recreational traffic. Local knowledge would need to be added to the factor group creation and application process for these groups to be useful. This same type of site identifier would need to be added to other roadway databases to allow these factors to be applied to individual roadway sections. Currently available variables (functional class, state, volume) are not capable of identifying these patterns.

Time-of-Day Patterns

There are four basic time-of-day patterns:

- Rural automobile—a single-mode distribution pattern, commonly found in rural areas that are not affected by urban commute traffic and also found on weekends in urban areas.
- Urban automobile—a bimodal distribution that reflects morning and evening commuter traffic.
- Through-trucks—a flat time-of-day distribution that reflects long-haul truck traffic in areas outside of the cargo's origin or destination.
- Business day trucking—a single-mode distribution that reflects the fact that most truck traffic starts and ends during the normal extended business day.

A large degree of variation is present within each of these patterns. For example, the peak period in any of these distributions is affected by the relative location of a road's section in relation to the nearby activity centers. Similarly, individual traffic generators (*e.g.*, gravel pits) may create site-specific time-of-day patterns that differ dramatically from these generic patterns.

Time-of-day analyses can be (but are not always) affected by directional distributions, *e.g.*, time-of-day traffic patterns at many sites are different in one direction than in the other direction. The size of the directional differential varies from site to site and depends significantly on local conditions rather than on functional class or other routinely stored parameters. Thus, the time-of-day tables presented along with this report, which are not directional, can be used for both directions of traffic unless local knowledge suggests the application of direction-specific factors.

Urban versus Rural Volumes

Many roads exhibit traffic patterns that are not characteristic of their urban/rural functional classification coding (a large number of "rural" roads act like urban roads, and *vice versa*). Roads in areas designated as "rural" but located near urban areas often exhibit traffic patterns with urban characteristics (*e.g.*, highly directional, peak period automobile volumes). Similarly, some "urban" roads are located in areas that, while designated "urban", have yet to be significantly developed, and where externally generated traffic is a predominant portion of the total traffic volume. These roads tend to exhibit traffic patterns more commonly expected in rural areas (lack of commuter peaks, high weekend volumes).

Basic trucking patterns tend to be reasonably similar in both urban and rural areas. The proportion of through-traffic to local traffic, rather the urban or rural designation of a site, appears to be the major factor in determining truck patterns. However, the percentage of through-truck traffic is more often (but by no means always) higher in rural areas than in urban areas.

Vehicle Percentages by Functional Class of Road

The distribution of vehicles among vehicle classes changes dramatically by geography and, to a lesser extent, by functional class of roadway. In particular, the presence or lack of multi-trailer trucks tends to be geographically based. These larger trucks seem to be uncommon in eastern and southern states and much more common in the western states.

Thus, "national average" vehicle distributions are misleading for sites in most states. The data available to this study through the LTPP traffic database are insufficient at this time to provide a list of which states have significant volumes of specific vehicle types and which do not. These data should be available from the LTPP database after all states have completed submitting traffic data for their test sites, particularly if those data are then combined with existing Highway Performance Monitoring System (HPMS) submittals.

Seasonal (Monthly) Patterns

Cars and trucks at most sites follow different seasonal patterns. Applying factors computed for cars or total volume to trucks volumes or individual truck classification categories will create bias in the annual truck volume estimates for a site. However, at the national level, the "average" seasonal trends are reasonably similar for both cars and trucks.

Factors created to seasonally adjust car and truck volumes by vehicle class tend to be unstable when a given vehicle class has low vehicle volumes. This problem is particularly common of the multi-trailer truck and motorcycle classes, but it also applies to FHWA class 7 and occasionally to FHWA class 4 vehicles. Consequently, it is recommended that seasonal adjustment factors be developed and applied for more aggregated vehicle classes. The project team recommends the use of the following four categories:

- Cars (including motorcycles).

- Single unit trucks.
- Combination trucks.
- Multi-trailer trucks.

Buses may be either treated separately (usually appropriate for urban areas) or as part of the single-unit truck category (usually appropriate for rural areas), depending on the needs of the user.

The four categories of vehicles listed above can be approximated fairly easily by simply aggregating data collected in the 13 FHWA vehicle categories.

Other Findings

Large, site-specific differences were found within all of the data stratifications researched for this study. Local conditions appear to have an extremely large impact on the basic time-of-day and day-of-week patterns exhibited by, or the vehicle mix present on, a given roadway, regardless of roadway type or level of traffic volume on that roadway. It is not possible to predict these variations from the average condition without more information than is commonly available in national traffic databases.

Appendix

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