Evaluation of Different Methods to Calculate Heavy-Truck VMT

Final Report—December 2004

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16. Abstract

Reliable estimates of heavy-truck volumes are important in a number of transportation applications. Estimates of truck volumes are necessary for pavement design and pavement management. Truck volumes are important in traffic safety. The number of trucks on the road also influences roadway capacity and traffic operations. Additionally, heavy vehicles pollute at higher rates than passenger vehicles. Consequently, reliable estimates of heavy-truck vehicle miles traveled (VMT) are important in creating accurate inventories of on-road emissions.

This research evaluated three different methods to calculate heavy-truck annual average daily traffic (AADT) which can subsequently be used to estimate vehicle miles traveled (VMT). Traffic data from continuous count stations provided by the Iowa DOT were used to estimate AADT for two different truck groups (single-unit and multi-unit) using the three methods. The first method developed monthly and daily expansion factors for each truck group. The second and third methods created general expansion factors for all vehicles.

Accuracy of the three methods was compared using *n*-fold cross-validation. In *n*-fold cross-validation, data are split into *n* partitions, and data from the *n*th partition are used to validate the remaining data. A comparison of the accuracy of the three methods was made using the estimates of prediction error obtained from cross-validation. The prediction error was determined by averaging the squared error between the estimated AADT and the actual AADT.

Overall, the prediction error was the lowest for the method that developed expansion factors separately for the different truck groups for both single- and multi-unit trucks. This indicates that use of expansion factors specific to heavy trucks results in better estimates of AADT, and, subsequently, VMT, than using aggregate expansion factors and applying a percentage of trucks. Monthly, daily, and weekly traffic patterns were also evaluated. Significant variation exists in the temporal and seasonal patterns of heavy trucks as compared to passenger vehicles. This suggests that the use of aggregate expansion factors fails to adequately describe truck travel patterns.

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EVALUATION OF DIFFERENT METHODS TO CALCULATE HEAVY-TRUCK VMT

MTC Project 2002-02

Final Report
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EXECUTIVE SUMMARY

Reliable estimates of heavy-truck volumes are important in a number of transportation applications. Estimates of truck volumes are necessary for pavement design and pavement management. They also affect bridge performance. Truck volumes are important in traffic safety. The number of trucks on the road also influences roadway capacity. Heavy trucks have more difficulty accelerating and maneuvering than passenger cars and have a lower deceleration in response to braking compared to passenger cars. They are particularly affected by grade. As a result, the number of heavy trucks present in the traffic stream influences traffic operations. Additionally, heavy vehicles pollute at higher rates than passenger vehicles. Consequently, reliable estimates of heavy-truck vehicle miles traveled (VMT) are important in creating accurate inventories of on-road emissions.

Most states use a traffic-count-based method for estimating truck VMT. One method used to estimate truck VMT involves developing separate expansion factors for specific classes of heavy vehicles. Annual average daily traffic (AADT) from shorter term classification counts for a class of heavy vehicles is factored up using the expansion factors. Truck VMT for a highway segment is obtained by multiplying truck AADT by the length (centerline mileage) of a roadway section. This method however is resource-intensive, and, therefore, most DOTs use a more aggregate method to derive truck VMT. In this aggregate method, generic expansion factors are developed that apply to all vehicle classes. A limited number of vehicle classification counts are used to calculate truck percentages. For short-term counts, the expansion factors are applied and AADT for all vehicle types is estimated. VMT is calculated by multiplying AADT by the section length. Truck VMT is calculated by multiplying total VMT by the average truck percentages (by truck types) obtained from limited classification counts. Truck percentage may also be determined from short-term counts.

Several studies have indicated problems with the use of generic expansion factors for estimating truck VMT or volumes. Although truck volumes, like passenger car volumes, vary over time and space, the pattern of temporal variability in truck volumes differs significantly from passenger vehicles. Trucks experience more variability between weekdays and weekends than passenger vehicles, and expansion factors derived from aggregate count data may fail to adequately explain temporal variations in truck traffic.

This research evaluated three different methods to calculate heavy-truck AADT which can subsequently be used to estimate VMT. Traffic data from continuous count stations provided by the Iowa DOT were used to estimate AADT for two different truck groups (single-unit and multi-unit) using the three methods. The first method developed monthly and daily expansion factors for each truck group. Truck AADT was calculated by applying truck expansion factors to short-term counts. The second and third methods created general expansion factors for all vehicles. Truck AADT was calculated by multiplying short-term counts by generic expansion factors and truck percentages. Truck percentages for the second method were based on the annual percentage of trucks for each group from continuous count stations. The third method used daily truck percentages from short-term counts.

Accuracy of the three methods was compared using *n*-fold cross-validation. In *n*-fold cross-validation, data are split into *n* partitions, and data from the *n*th partition are used to validate the

remaining data. Accordingly, data from continuous count stations were divided into four groups, and each group was reserved for one partition as the validation dataset. Short-term counts were extracted from the validation dataset and then AADT was estimated using each of the three methods. Actual AADT by truck group for each count station was compared to the estimated AADT by truck group for each method.

Data were analyzed for rural primary and interstate roadways. Data from continuous count stations for the 2001 counting year were used. Although 2002 data were available, the DOT felt that there had been significant problems with the data and suggested use of the 2001 data. Data were analyzed for two truck categories: single-unit (SU) trucks and multi-unit (MU) trucks. The single-unit truck category included FHWA vehicle classes 4 to 7, and the multi-unit truck category included FHWA vehicle classes 8 to 13.

A comparison of the accuracy of the three methods was made using the estimates of prediction error obtained from cross-validation. The prediction error was determined by averaging the squared error between the estimated AADT and the actual AADT. Overall, the prediction error was the lowest for the method that developed expansion factors separately for the different truck groups for both single- and multi-unit trucks. This indicates that use of expansion factors specific to heavy trucks results in better estimates of AADT, and, subsequently, VMT, than using aggregate expansion factors and applying a percentage of trucks.

Monthly, daily, and weekly traffic patterns were also evaluated. Significant variation exists in the temporal and seasonal patterns of heavy trucks as compared to passenger vehicles. This suggests that the use of aggregate expansion factors fails to adequately describe truck travel patterns.

1. BACKGROUND

1.1 Heavy-Truck VMT

Information about truck volumes is necessary to meet federal reporting requirements and to assist state and local agencies in assessing system performance and needs. Estimates of vehicle miles traveled (VMT) are used for a variety of transportation-related planning and policy analysis purposes. VMT is a measure of the amount of travel along a roadway section for a specified time period. VMT is a function of the number of trips made as well as the lengths of those trips.

VMT estimates are used extensively in transportation planning to estimate vehicle emissions, compute energy consumption, assess traffic impact, allocate highway funds, and estimate pavement performance (Kumapley et al. 1996). Estimates of VMT by vehicle class are required to derive accident rates by vehicle class, compare accident rates across classes, and to allocate highway costs across vehicle classes (Weinblatt 1996). For VMT-related revenue, estimates of VMT by vehicle class are required for producing estimates of revenue forecasts for proposed new taxes, tax payments by vehicle class (for equity analyses), and revenue that should be collected. The U.S. economy thrives significantly on freight transportation, which takes place mostly by truck (Mohamedshah et al. 1993). Estimates of truck VMT are therefore necessary to understand the importance of trucks to the nation's economy and to evaluate the costs and benefits of potential changes in truck regulation (Weinblatt 1996). Estimates of truck volumes are also an essential input in geometric and structural design of roadways and bridges.

Trucks have characteristics that differ from passenger vehicles. Typically, trucks are larger in size and much heavier than passenger vehicles, thus influencing roadway capacity and pavement performance. Trucks are also characterized by less effective acceleration and maneuvering capabilities and have a lower deceleration in response to braking than passenger cars (Mohamedshah et al. 1993). These characteristics need to be accommodated in geometric and pavement design of roadways to facilitate smooth traffic operations. Estimates of truck VMT therefore serve as vital input in geometric and pavement design of roadways. Truck VMT is also a key factor in traffic safety. VMT estimates by vehicle class are required to derive accident rates by vehicle class and compare accident rates across vehicle classes. According to the 2003 Traffic Safety Facts published by the National Highway Traffic Safety Administration (NHTSA), 12% of all the traffic fatalities reported in 2003 resulted from collisions involving large trucks (gross vehicle weight rating greater than 10,000 pounds), yet trucks accounted for only 8% of the total VMT. A better understanding of where trucks are located on the highway system may assist in evaluating the causes of truck-related crashes and consequently minimize fatalities and injuries resulting from such crashes. These important applications of heavy-truck VMT warrant its accurate estimation. Previous research has, however, revealed that current methods used in the estimation of heavy-truck VMT are often less accurate than those used for passenger vehicles. There is, therefore, the need to improve current heavy-truck VMT estimation methods by reducing or possibly eliminating inherent biases.

Each state maintains a traffic count program to collect volume data continuously at permanent count stations sites. Classification counts may also be collected at a limited number of permanent count stations. Daily and monthly expansion factors are calculated from permanent counts. Factors are typically generated for each day of the week by month for separate road types. Portable or short-term counts are collected at other locations to estimate site specific volumes. Short-term counts are usually collected for periods up to 48 hours. Since short-term counts do not represent an average annual daily count, the short-term count data is multiplied by expansion factors to estimate annual average daily traffic (AADT) and VMT. To account for temporal variations in short-duration traffic counts, data from sites that are counted continuously are used to develop expansion factors for factoring short-duration counts to estimates of AADT. Vehicle classification data are used to estimate AADT and VMT by vehicle class. VMT is the product of volume and section length and is usually reported as the total amount of travel in a day (daily vehicle miles traveled) or in a year (annual vehicle miles traveled).

About 70% of state DOTs, including the Iowa DOT, use a traffic-count-based method for estimating truck VMT (Benekohal and Girianna 2002). One method to estimate truck VMT is to develop separate expansion factors for specific classes of heavy vehicles. AADT from short-term classification counts for a class of heavy vehicles is factored up using the expansion factors. Truck VMT for a highway segment is obtained by multiplying truck AADT by the length (centerline mileage) of a roadway section. This method however is resource-intensive, and most DOTs use a more aggregate method to derive truck VMT. In this method, generic expansion factors are developed that apply to all vehicle classes. A limited number of vehicle classification counts are used to calculate truck percentages. For short-term counts, the expansion factors are applied and AADT for all vehicle types is estimated. VMT is calculated by multiplying AADT by the section length. Truck VMT is calculated by multiplying total VMT by the average truck percentages (by truck types) obtained from limited classification counts. Truck percentage may also be determined from short-term counts.

Several studies have indicated problems with the use of generic expansion factors for estimating truck VMT or volumes. Although truck volumes, like passenger car volumes, vary over time and space, the pattern of temporal variability in truck volumes differs significantly from that in passenger vehicles. Trucks experience more variability between weekdays and weekends than passenger vehicles. As such, adjustment factors derived from aggregate count data (total volume) may fail to adequately explain temporal variations in truck traffic culminating in biased estimates of annual average daily truck traffic (AADTT). Hu et al. (1998) evaluated extrapolated data from permanent count stations and reported that more precise estimates resulted for passenger vehicles than for heavy trucks and that estimates were more precise when volumes were high. Stamatiadis and Allen (1997) reported that trucks experience more seasonal variability than passenger vehicles. They also observed more variability between weekdays and weekends for heavy trucks than for passenger vehicles. Both factors are difficult to capture with current extrapolation methods. Hallenbeck (1993) also observed that trucks do not exhibit the same seasonal patterns as passenger vehicles. As a result, seasonal estimates based on aggregate count data may fail to adequately explain seasonal variations in truck flow.

Weinblatt (1996) also indicated that, although extrapolated traffic counts can be quite accurate in estimating VMT for systems of roads, less sophisticated methods are often used to estimate VMT by vehicle class resulting in less satisfactory results. Researchers recommended using seasonal and day-of-week factors developed for several groups of vehicle classes to better reflect heavy-truck patterns and to reduce errors in heavy-truck AADT estimates. Additionally, extrapolation methods, such as the Highway Performance Monitoring System (HPMS) method, were designed for federal-aid roads but are not as applicable to local roads (Kumapley and Fricker 1996).

1.2 Problem Statement and Scope of Work

VMT and vehicle classification are vital inputs in the design and operation of an efficient transportation infrastructure system. In particular, heavy-truck VMT is important as the number of heavy vehicles on a road affects traffic operations, safety, and pavement performance. Research has revealed, however, that current methods used in the estimation of heavy-truck VMT are often less accurate than those used for passenger vehicles. Consequently, the goal of this research was to evaluate existing methods used by state DOTs, identify deficiencies, and make recommendations on reducing uncertainties in heavy-truck VMT estimates.

Current heavy-truck AADT estimation methods were evaluated and compared. Traffic data from permanent counting stations provided by the Iowa DOT were used to develop a statistical model to compare different traffic count–based methods. Although VMT is often the metric of interest, AADT was evaluated for this study since VMT is dependent on AADT estimates and can easily be derived once AADT is estimated. Recommendations on reducing uncertainties in heavy-truck AADT were made.

This research focuses on heavy-truck AADT and VMT. Heavy trucks are defined as the aggregation of all vehicles belonging to classes 4 to 13 of the FHWA 13-class vehicle classification scheme. The FHWA vehicle classification scheme with the definitions of the various classes of vehicles is presented in Appendix A. In this report, the term “truck” is used interchangeably with the term “heavy truck.”

2. INTRODUCTION

2.1 Methods of Estimating VMT

AADT and VMT estimation methods can be classified into two broad divisions. The two methods are non–traffic count based and traffic count based. Each is discussed in the following sections.

2.1.1 Non-Traffic-Count-Based Method

The non-traffic-count-based method for estimating AADT and VMT uses non-traffic data such as socio-economic data, including fuel sales, trip-making behavior, household size, household income, population, number of licensed drivers, and employment.

Travel Demand Forecasting Models

Travel demand models project regional traffic and forecast link volumes through the four-step process. Base year estimates are typically calibrated against ground counts, and then volume projections are made for future scenarios. VMT estimates are obtained from the product of the forecasted link volumes and the respective centerline mileage of the link.

Output from travel demand forecasting models is also used to estimate heavy-truck and passenger-vehicle VMT. One of the main problems with travel demand forecasting models is that they often lack the data to model heavy trucks as well as they model passenger vehicles. The accuracy of the output volumes also depends on the trip generation and trip distribution components of the model and the representativeness of the network to the actual street system. Local roads, for instance, are usually not modeled in travel demand models. Several studies report different methods to improve heavy-truck VMT estimates using travel demand forecasting methods. Drishnan and Hancock (1998) used statewide freight flow data from the Commodity Flow Survey (CFS) with travel demand forecasting in a GIS to estimate truck flows. Ross et al. (1998) recorded trip diaries for heavy trucks to locate origins, destinations, and routes.

Fuel Sales

This method estimates VMT from fuel sales. Total fuel sales for retail gasoline and diesel are divided by the unit price per gallon of fuel to obtain the total amount of fuel purchased in an area. Estimates of fuel fleet efficiency are used to determine miles traveled per gallon of fuel purchased, and VMT is then calculated using the following equation:

$$\text{VMT} = (Ret_{sales} \times MPG)/PPG \qquad (2\text{-}1)$$

where

Ret_{sales} = total sales of fuel for study area in dollars
PPG = average unit price per gallon of fuel in dollars
MPG = fleet fuel efficiency in miles per gallon

Errors associated with this method result from the inaccurate estimates of retail fuel sales and prices. Additionally, wide variations exist in the fuel efficiency of individual vehicles. Consequently, estimates of fleet fuel efficiency are gross estimates at best. Additionally, it is difficult to distribute VMT between residents and non-residents (Kumapley and Fricker 1996).

2.1.2 Traffic-count-based methods

The traffic-count-based method uses actual counts of traffic volumes. VMT is calculated by multiplying AADT on a section of road by the length of the section. To annualize this value, it is multiplied by the number of days in a year. In estimating VMT using traffic counts, it is customary to assume that a vehicle counted on a section of road travels the entire length of the section. Under this method, some vehicles traveling only a portion of the section will be counted while others will not, depending on whether they cross the counting location (Roess et al. 1998). This method of estimating VMT is presently the most preferred by state DOTs as it utilizes actual data of vehicle movement on a road segment (Kumapley and Fricker 1996). About 70% of state DOTs, including the Iowa DOT, use a traffic-count-based method (Benekohal and Girianna 2002).

Highway Performance Monitoring System (HPMS) Method

The HPMS is a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the nation’s road infrastructure. It was originally developed in 1978 by the Federal Highway Administration (FHWA) to monitor the nation’s highway infrastructure and has been continuously modified over the years (most recently in 1998) to reflect changes in highway systems, legislation, and national priorities, as well as to streamline reporting requirements. The HPMS data are the source of a large portion of information published in the annual Highway Statistics Series and other FHWA publications. They also form the basis of the analyses that support the biennial Condition and Performance Reports to Congress. In addition, data from the HPMS are used to produce statewide estimates of total VMT used for the apportionment of Federal-Aid funds under TEA-21.

The HPMS method of estimating VMT involves the use of continuous count stations to develop expansion factors which reflect daily and monthly traffic patterns. Sample sections on other roadways are identified through a systematic stratified random sampling process. After the sections are identified, 24-hour traffic counts are taken. The short-term counts are extrapolated to reflect annual daily volumes using the expansion factors developed with continuous count data. The sample section VMT is estimated as the product of the centerline mileage and AADT of the section. Sample section VMT is used to approximate area wide VMT. The HPMS method usually covers only roadway sections under state jurisdiction. Local and county roads, which usually form a major percentage of the road network in a state, are not considered in the HPMS submittal (FHWA 2001).

2.2 Calculation of Annual Average Daily Traffic

VMT usually is the product of the roadway section length in miles (centerline mileage) and AADT. In order to obtain reliable VMT estimates, accurate estimates of AADT must be developed from traffic monitoring programs. The Federal Highway Administration's (FHWA) Traffic Monitoring Guide (FHWA 2001) provides guidance for improved traffic counting, vehicle classification, and truck weighing. Statistical procedures are provided that allow State Highway Agencies (SHAs) to determine the amount of monitoring required to achieve a desired precision level for their traffic counting needs. The Traffic Monitoring Guide (TMG) recommends two types of counts to be conducted in order to estimate AADT:

- Long-term or permanent continuous counts (year-round)
- Portable short-term counts

Additional Counts are performed as a supplement to the coverage program to address "special needs" and may include the following:

- Pavement design counts performed to provide data for pavement design
- Maintenance, repair, rehabilitation, and reconstruction
- Traffic operations counts performed to provide inputs to traffic control studies (e.g., the creation of new signal timing plans)
- Traffic counts for other special purpose studies (FHWA 2001)

2.2.1 Permanent Continuous Counts

Continuous counts are performed using permanent counters, frequently called Automatic Traffic Recorders (ATRs), which collect traffic data continuously for 24 hours a day, 365 days a year. The primary goal of the continuous count program is to assist agencies in understanding the time-of-day, day-of-week, and seasonal travel patterns and to facilitate the development of seasonal expansion factors required to convert short-term counts to accurate estimates of AADT. Continuous ATR count data is also reported on a monthly basis to the FHWA for the preparation of the Traffic Volume Trends Report.

Since the ATRs monitor traffic every day of the year, an Annual Average Daily Traffic (AADT) is obtained by adding all volumes collected by an ATR for an entire year and dividing by the number of days in a year. Permanent counters record volume variation by day of the week and month of the year. Expansion factors are created by permanent count data to allow adjusting short-term count data to account for daily and monthly variation facility type (Roess 1998). The adjustment factor is then obtained from the ratio of the AADT to the Monthly Average Daily Traffic (MADT) of the same ATR group for each road type. Multiplying the short-term count by the appropriate factor expands the short-term counts.

2.2.2 Short-Term Counts

The installation, operation, and maintenance of permanent counters are expensive. Consequently, short-term coverage counts are conducted on roadways throughout a state to provide the geographic coverage needed to understand the traffic characteristics of the state roadway system.

The TMG recommends a short-term count program comprised of periodic comprehensive coverage of all roads on all systems over a 6-year cycle and counting on HPMS sample and universe sections on a 3-year maximum cycle to meet the national HPMS requirements. Short-term count data used for AADT computation must be adjusted to remove temporal bias from the data. Seasonal adjustment factors derived from the permanent continuous counts are used to adjust the short-term counts to arrive at AADT estimates (FHWA 2000).

2.3 Truck VMT Estimation

About 70% of state DOTs, including the Iowa DOT, use a traffic-count-based method for estimating truck VMT (Benekohal & Girianna 2003). Currently, two different traffic-count-based methods are used to calculate truck VMT. In the first method, truck VMT is estimated on a highway segment basis by multiplying truck AADT by the length (centerline mileage) of a roadway section. The second method is the HPMS method described above. It estimates truck VMT by multiplying total VMT by an average truck percentage.

The best possible VMT estimates would be those obtained using the traffic-count-based method if all road sections of interest are monitored continuously throughout the year to produce AADT (Kumapley and Fricker 1996). Resource constraints, however, make it impractical for the collection of traffic count data on all sections of interest. Hence, data are collected continuously at a limited number of count locations, while other locations are counted only at infrequent intervals, such as once every 3 years, for relatively short durations—usually 24 or 48 hours (Weinblatt 1996). To account for the temporal variations in short-duration traffic counts, data from sites that are counted continuously are used to develop expansion factors for factoring short-duration counts to estimates of annual average daily traffic (AADT). Although truck volumes, like passenger car volumes, vary over time and space, the pattern of temporal variability in truck volumes differs significantly from that in passenger vehicles (Roess et al. 1998). Trucks experience more variability between weekdays and weekends than passenger vehicles. As such, adjustment factors derived from aggregate count data (total volume) may fail to adequately explain temporal variations in truck traffic, culminating in biased estimates of annual average daily truck traffic (AADTT). In order to obtain accurate estimates of annual average truck volumes and, consequently, truck VMT, truck adjustment factors must be developed specifically to convert short-duration truck volume counts into estimates of AADTT.

3. VMT ESTIMATION METHODOLOGIES USED BY STATE DOTS

The DOTs for ten states were contacted to determine the methodology used in their Traffic Monitoring Program to estimate truck AADT and VMT. When possible, information was obtained from DOTs websites. DOTs were contacted for additional information and clarification when necessary. Responses received from the DOTs are provided in Appendix B.

All the state DOTs contacted use the traffic-count-based method to estimate VMT. The traffic-monitoring programs adopted by the state DOTs contacted were similar and all conform to the recommended procedures outlined in the FHWA's Traffic Monitoring Guide (FHWA 2001). A summary of the methodologies used by the different DOTs to estimate VMT, as well as methods to estimate truck VMT, are provided in the following sections. A summary of the truck VMT estimation methods by the states contacted is presented in Table 3.1 below. In general, two methods are used by these DOTs to estimate truck VMT. In the first method (method 1), truck VMT is estimated on a highway segment basis by multiplying the segment truck AADT by the length of the segment. The second method (method 2), also referred to as the HPMS method, involves multiplying total aggregate traffic VMT (by functional class) by average truck percentages (by truck types).

Of the ten state DOTs contacted, six (California, Illinois, Iowa, Minnesota, Nebraska, and Florida) use method 1 for the estimation of truck VMT. Kansas, Missouri, South Dakota, and Wisconsin DOTs use method 2. A more in-depth explanation of the different methods used by the various states to estimate truck VMT is provided in the following sections.

Table 3.1. Methodologies to estimate truck VMT by state surveyed

State	Methodology	Truck Adjustment Factor
California	Method 1	Yes
Illinois	Method 1	Yes
Iowa	Method 1	No
Kansas	Method 2	No
Minnesota	Method 1	No
Missouri	Method 2	No
Nebraska	Method 1	Yes
South Dakota	Method 2	No
Wisconsin	Method 2	No
Florida	Method 1	No
**Method 1 (highway segment basis): truck AADT by length of a roadway section. **Method 2(HPMS): total VMT by average truck percentages		

3.1 Wisconsin

3.1.1 Data Collection

On the state trunk network, sites are selected to be representative of traffic on a segment bounded by roadways functionally classified as collector or above. Permanent sites were semi-randomly selected to provide a statistically valid sample for each factor group. A total of 27,000 counting sites (permanent and short duration) are located throughout the state of Wisconsin.

Peek 241 and ADR counters are used to collect volume, class, and speed, while Peek ADR and PAT DAW200 are used for Weigh-in-Motion (WIM). The equipment is tested annually to verify their operational integrity. Equipment is bench tested and observed in the field to determine if it is working when installed/inspected.

Wisconsin Department of Transportation (WisDOT) collects both volume counts with loops and axle counts. Axle counts are adjusted using an axle adjustment factor. At the short-term count locations, counting is conducted at 15- to 60-minute intervals for 48 hours every three years. The interval is determined by the population density in the area of the count.

3.1.2 Truck VMT Estimation

WisDOT at this time does not develop separate truck adjustment factors but is moving in that direction. VMT estimates for all vehicles are made. The average percentage of vehicles for each vehicle type by highway functional classification is calculated. VMT for a particular category of heavy trucks for a particular functional class is determined by multiplying VMT for that specific functional class by the percentage of heavy trucks. These are then summed to a statewide total VMT for heavy trucks. Consequently, heavy truck VMT is not disaggregated below the statewide highway functional level (Stein 2003).

3.2 Nebraska

3.2.1 Data Collection

Most of the permanent count sites used by the Nebraska Department of Roads (NDOR) were established years ago. While the exact reasoning behind the selection was not recorded, it is believed that they were selected to give information that was representative of long segments of the natural traffic corridors in the state. In addition, some stations were established to give information on a greater saturation of the most important corridor (I80), while others were established to give information on typical urban routes or county roads. NDOR collects and processes continuous traffic data at 65 locations. Short-duration counts are located to give information that is representative of much shorter sections of road, short enough to be used to update NDOR's computerized traffic log with site-specific information.

"Diamond" brand traffic counters are used for both permanent and short-duration counts. Vehicle classification information is collected at most of the permanent-count stations. At the short-duration stations, volume only is generally collected; although, occasionally, classification information is collected. Nearly all short-duration counts are performed using a pneumatic hose as a detection device. The notable exception to this is the urban interstate and other high-volume urban roads where radar detectors are used.
NDOR has not made an attempt to quantify the level of accuracy it achieves in its counting program. When posting counts, however, a comparison of the final results with historical results is made to give an indication of the reliability of the results of the count.

When factoring short-duration portable counts, a monthly adjustment factor, a day-of-week adjustment factor, and an axle correction factor (if a hose type counter) are used. The adjustment for short-term manual classification counts is based upon the road group category, month, day-of-week, hours-of-count, and the individual vehicle type.

3.2.2 Truck VMT Estimation

Truck VMT is calculated on a biennial basis by NDOR during the years when traffic counts are performed on its state highway system. Expansion factors are developed separately for trucks from the data collected at ATR locations where detailed vehicle classification information is collected. On the highway system, truck VMT is calculated by a simple accrual of what is on the Nebraska DOT's traffic log files. Off the highway system, sample manual counting data is used to estimate truck VMT. NDOR has documentation of its Traffic Monitoring Program that specifies much more detailed information, instructions, and techniques, available for in-house use only (Ernstmeyer 2003).

3.3 Missouri

The Missouri DOT currently does not develop separate expansion factors for trucks. Instead, it determines the average percentage of trucks for each of the ten functional classes, using approximately 60 continuous Automatic Vehicle Classifiers (AVC) statewide. Truck VMT is then estimated by applying this percentage to the total VMT for each functional class of roadway. However, the Missouri DOT is in the process of refining their process and has approximately 550 AVCs to update all Traffic Monitoring Sites (TMS) segments with a similar process as is currently used to update uncounted AADT segments. This process will provide a method for calculating actual Truck VMTs (Grither 2003).

3.4 Illinois

3.4.1 Data Collection

Illinois DOT's (IDOT) permanent count sites were selected in the early 80's using functional class and average daily traffic (ADT) volumes to gain a good representation of roads within Illinois. Additional sites were added in the late 90's using the same criteria along with a geographical distribution. The short-term counts that are done each year are at locations between significant traffic generators. Counts are done in cycles with the marked routes every two years. The rest of the county counts on a five-year cycle. IDOT maintains 88 permanent sites throughout the state of Illinois. 20,000 short-term counts are taken each year. During a five-year period, approximately 85,000 different locations are counted.

The permanent sites use single loops or dual loops with a piezo classifier. A variety of recorders (Peek 241, Peek ADR3000, and ITC TRS recorders) are used. For short-term counts on marked routes, the NuMetric Hi-Star magnetic lane counter is used. This counter is used because it gives volume, vehicle length, and speed (vehicles are counted, not axles). For lower class roads in the counties, road tubes with Mitron counters (axle counts are collected) are used.

When searching for new equipment and new traffic technologies, in-house testing is performed. IDOT will look at manual counts vs. the new equipment, compare different types of equipment, and conduct studies to determine consistency and reliability of the equipment. To evaluate the accuracy of counting devices at the permanent locations, IDOT has someone on staff who downloads the data daily and reviews the data for consistency, looking for loops not reporting or not providing reasonable data. Using this long-term experience with the permanent locations gives a good indication of the reliability of the permanent equipment.

Most short-term counts are 24-hour counts (counted on a Monday, Tuesday, Wednesday, or Thursday). HPMS counts required for FHWA are 48-hour counts.

3.4.2 Truck VMT Estimation

The data (over a four-year period) from the permanent locations is used to derive monthly factors. These monthly factors convert 24-hour short-term counts into annual average daily traffic (AADT). Along with the factoring, the AADT numbers are rounded to the nearest 100, 50, or 25, depending on the volume range. IDOT uses separate adjustment factors for trucks in the estimation of annual average daily truck traffic. The truck factors currently used were developed from an extensive manual count program maintained by IDOT in the past. This extensive manual count program was, however, eliminated many years ago. IDOT is in the process of updating its truck factors based on the permanent locations. Truck expansion factors from the manual count program are used to convert 24-hour short-term truck counts into the truck annual average daily traffic. After factoring, truck AADT is rounded to the nearest 100, 50, 25, or 10, depending on the volume range. The truck ADT for a segment of road is multiplied by the length of that segment to calculate the truck VMT for the individual segment. The total truck VMT is obtained by adding all segments together. For roads where truck counts are not required (lower functional class roads), default values for the trucks are used in the truck VMT calculation.

IDOT has made significant changes in its Traffic Monitoring program during the last few years. It has changed equipment to the NuMetric Hi-Stars for its Marked Routes. Also, the cycles of counts have been revised to better distribute the work between the years. IDOT has an Illinois Traffic Monitoring Guide (ITMG); however, it represents the old way in which IDOT executed the program. It is envisaged that a completely revised version of the ITMG would be available soon (Robinson 2003).

3.5 Minnesota

3.5.1 Data Collection

For AADT segments on Minnesota trunk highways, every traffic segment is counted every two years. A traffic segment is defined by a section of road where traffic is expected to vary longitudinally (up and down the segment) within specified limits. The limits are defined by a curvilinear relationship between permitted percentage difference and the AADT of the segment. Higher AADT segments have a smaller percentage deviation allowance than lower AADT segments. When traffic changes along a segment, special counts can be made to confirm the change of traffic segment definition before a formal change to the segment is made. Changes to segments include simple lengthening and shortening, as well as adding new segments and deleting segments based upon actual traffic measurements and the sliding scale described above.

The sliding scale represents a minimum coverage strategy for Minnesota DOT (MnDOT) traffic monitoring program. Additional locations are sampled routinely, even if they are within the allowable limits, to increase sensitivity to traffic volume differences between segments in some areas and along certain roadways. The same segmenting procedure is used for county and municipal highways when determining AADT. Local highways are counted on a two or four-year cycle, depending upon how many changes the local jurisdictions believe will happen in the near future. Quickly growing jurisdictions typically desire a two-year count cycle, while relatively slow growing jurisdictions are content with a four-year cycle.

Short-duration vehicle classification count studies are usually conducted on segments between the intersection of one trunk highway and the intersection of another trunk highway. Some trunk highway to trunk highway segments have more than one vehicle classification count site since the shorter segments were found to be serving different commercial traffic.

Permanent sites were initially selected decades ago to represent traffic in many different areas of the state and on different highways where a variety of traffic patterns and volumes exist. The initial selection process had more to do with differences in traffic patterns and volumes than with which functional class systems the highways belong to.

MnDOT reduced the number of ATRs from 144 to 78 in an effort to remove relatively redundant sites. The active ATRs were retained because of their importance to the department in the following areas:

- Location of the monitors provides the traffic pattern data that, when clustered statistically, provide the basis for determining adjustment factors (day of the week and month of the year). These factors are used to expand short counts (48-hour ADT counts) to annual average daily traffic.
- Values from a number of stations closely follow the measured statewide VMT growth rate during the past ten years. The data from these ATRs are used to constrain the annual statewide VMT every year as counted and uncounted road system AADTs are determined through counts and through annual growth factoring.
- Traffic volumes and traffic patterns (Design Hour Volume among other things) on interstate highways in the Minneapolis/Saint Paul metropolitan area are necessary for a number of applications.
- Traffic volumes and traffic patterns (Design Hour Volume among other things) on interstate highways in the rest of the state are necessary.
- Traffic volumes and traffic patterns for state identified "interregional corridor" highways were desired.
- Speed monitoring capability is present.
- Continuous vehicle classification using traffic volumes and patterns is becoming a stronger emphasis in MnDOT’s traffic monitoring program.

Approximately 32,000 locations are counted for AADT. About 4700 of those 32,000 locations are on the trunk highway system, and many of these counts are taken directionally. MnDOT has 78 ATRs (for continuous volume counting), 14 of which are classification capable. Data from the department's traffic management center loop detectors are used in place of tube counts or intermittently sampled loop sites for the freeway system in the Minneapolis/Saint Paul area. There are approximately 1000 routinely sampled short-duration classification count locations in the state that are sampled on a two- or six-year cycle. Additional classification counts are conducted to satisfy special requests and additional research needs.

ATRs are equipped with either piezo-loop-piezo detectors, dual-loop detectors, or single-loop detectors with PEEK ADR controllers. Short-duration ADT tube counts are taken with equipment from TimeMark and Golden River. Short-duration vehicle classification tube counts are taken with TimeMark equipment by people assisted by a personal computer touch-screen based application. For short-count equipment, the tubes are checked for holes and the counters’ switches are checked for accuracy each year. Inevitably, some data are suspect, and recounts are usually taken at the same location to verify an unexpected value or determine whether there was a faulty count taken the first time. Accuracies within 5% for classification and 2% for axle hits and for vehicle detection at the ATRs are normally expected.

At the permanent sites data are checked within one month following the date of collection to determine if there are failing electronics or detectors. It is believed that such failures can be detected when the daily and hourly directional data are compared to historically typical data at the same sites. If a consistent bias seems to be "creeping" into the data, a field test is requested, and the results allow salvaging the data for the time period in question if it is warranted. This type of data screening and editing only happens for ADT data and not for vehicle classification data. A system is currently being developed to screen the continuous classification data.

For short-duration ADT counts, raw data are screened using a system that compares the factored raw counts to previously determined past AADT and to previously adjusted raw counts from the same count cycle and from the past count cycle. Direction distribution is compared where possible and a report is run for machine numbers where the machines have been involved in a high proportion of "suspect data" instances. Those machines are identified and pulled from the active stock during the counting program to be bench tested. For locations with counts that are deemed "suspect" according to a permitted percentage change function, recounts are requested during the same year or count cycle. Short-duration classification counts are compared to previous counts at the same location. Axle correction factors are determined at each of the routine and special count classification sites (approximately 1400 statewide). Segments adjoining and beyond the classification sites also have axle correction factors. The factors, however, are determined using an algorithm based on "change in AADT" vs. "change in vehicle mix" relationship relative to the vehicle classification sample site and the roadway segments associated with the vehicle classification site.

Usually sample 48-hour counts are taken at all of the short count sites where counting equipment is used. Past federally sponsored "best practices" research indicated that 48 hours is better than 24 hours but only marginally worse than 72 or more hours. Also, more tube anchorage failures have been experienced in counts longer than 48 hours. For each manually counted vehicle classification site, two periods of 8 hours at a time are monitored between 8 AM and 10 PM. MnDOT does not count over the weekend and tries to conduct counts between noon on Monday and noon on Friday during weeks that do not include holidays or local festivals or events. In towns and cities, counting is done during the school year.

3.5.2 Truck VMT Estimation

MnDOT currently does not develop separate adjustment factors for trucks but is now investigating how it might in the near future. Since MnDOT has a census-based estimating system for the trunk highway system, Heavy Commercial Annual Daily Traffic (HCADT) by segment is used to estimate Truck VMT on a highway segment basis. The segment Truck VMT is then summed to produce a statewide total for trunk highways. For county, municipal (and other types of roadways) default values are used to estimate truck VMT to complete truck VMT statewide calculations (Flinner 2003).

3.6 California

3.6.1 Data Collection

The following is taken into account when selecting sites for permanent and short-term counts:

- Beginning of Route
- End of Route
- Break in Route
- Significant change in traffic (approximately 10% change)

A breakdown of the count sites (permanent and short-term) located throughout the state of California is given as follows:

- 650 permanent count sites where data is collected 365 days a year
- 1800 quarterly sites which are counted for a one-week period 4 times a year every 3 years
- Over 5000 profile sites which are sites on conventional highways counted between one and seven days every 3rd year
- Over 14,000 Freeway on and off ramps counted between one and seven days every 3rd year

The California Department of Transportation (CalTrans) uses the same equipment for both permanent and short-term counts. The number of lanes and type of detector used will determine how many detectors the counter will have. The equipment must meet the following accuracy standards:

- ***Accuracy of Traffic Volume counts*:** The unit must have an accuracy of plus or minus 5% with a 95% confidence level when using pneumatic tubes and plus or minus 3% when using inductive loops.
- ***Accuracy of Vehicle Classification*:** Vehicle classifiers must classify to accuracy standards as follows:
  - ***Permanent Classifiers:*** The accuracy of permanent classifiers using inductive loops and piezoelectric axle sensors must be such that, if good lane discipline is maintained, the recorded axle spacing must consistently be within plus or minus four inches of the actual measured spacing.
  - ***Portable Classifiers:*** The accuracy of portable classifiers using dual pneumatic tubes must be such that, if good lane discipline is maintained, the recorded axle spacing must consistently be within plus or minus six inches of the actual measured spacing. Of the 650 continuous and 1800 quarterly count sites, total volume is collected at all of them. At 200 of them, vehicle class is collected. Only total volume is collected at all other count sites. If resources are available, truck counts are collected at a limited number of sites.

3.6.2 Truck VMT Estimation

From continuous and quarterly count sites, daily and seasonal factors are developed to extrapolate one-day counts. CalTrans develops separate adjustment factors for trucks from continuous truck count sites. If resources are available, short-term truck counts are collected at a limited number of sites. The short-term counts are converted to Annual Average Daily Truck Traffic (AADTT) using the truck factors obtained from the continuous truck sites.

3.7 Kansas

3.7.1 Data Collection

Permanent count sites were selected for coverage of the major highways. Portable count sites were selected for coverage of HPMS sections, for spatial coverage between permanent sites, and for special needs studies. Portable classification sites were selected for stratified coverage as specified in the TMG and for special needs studies. Permanent classification/weight sites were chosen for proximity to long-term pavement performance (LTPP) test sections. The permanent count sites maintained by the Kansas DOT (KSDOT) are made up of 103 volume-count sites, 3 vehicle classification sites, and 12 weigh sites. The short-term count sites are made up of over 30,000 volume-count sites, over 1,000 vehicle classification sites, and 73 portable weigh sites.

3.7.2 Truck VMT Estimation

The Kansas DOT at this time does not develop adjustment factors separately for trucks. Average truck percentages are determined from continuous vehicle classification sites for each functional class of roadway. Truck VMT is then estimated by applying this truck percentage to the total VMT for each functional class (Spicer 2003).

3.8 South Dakota

3.8.1 Data Collection

There are 51 ATR locations around the state of South Dakota. The breakdown by functional classification is given as follows:

Classification	Urban	Rural
Interstate	3	9
Principal Arterial	4	17
Minor Arterial	3	6
Collector	4	5

ATRs collect traffic data continuously 24 hours a day, 365 days a year. The data collected are used for the development of seasonal factors to expand the short-term counts to AADT. ATRs also provide peak hour, 30th highest hour, or design hour and are used to track volume trends on the state highway system. The PEEK Inc. ADR traffic counters are used for the collection of data at all the 51 ATR stations.

Short-term traffic volume counts provide the majority of the geographic diversity needed to provide traffic volume information on the state roadway system. There are approximately 6,660 short-term count locations throughout the state. These are located on all functional classifications of highways—from the interstate system to the local roads system. Short-term interstate counts are taken 2 times a year for 48 hours each time. All other short-term counts are taken once a year for 24hours. A sampling plan is developed each year for short-term counting and is based on the following monitoring cycle:

- All trunk locations—every other year
- Non-state trunk locations with ADT<75—every eight years
- Non-state trunk locations with ADT>75—every four years
- Urbanized areas—every four years
- Small cities and towns—every six years
- HPMS sample segments (non-interstate)—every year
- HPMS sample segments (interstate)—every three years
- Special site-specific counts as requested
- Sites are chosen each year for specific data needs for future construction projects and for requirements of HPMS

3.8.2 Truck VMT Estimation

Short-term volume count results are posted in the station description file spreadsheet, where the appropriate seasonal and axle correction factors are applied to calculate the AADT for that location. Comparison of the AADT with the historical count record at that location is made, and any count that does not compare reasonably to the historical pattern is flagged and marked to be reset and counted again during the current count season. Counts that pass this check are used in the year-end reporting process.

At the end of the year, all counts in the station description file are entered into the roadway environment subsystem (RES) spreadsheet at their proper locations along a highway based on mileage reference marker (MRM). The counts are averaged with the previous year's counts and the result is reviewed to ensure realistic flow in comparison with surrounding sites. All counts passing this check are then entered into the RES traffic file located on the mainframe computer. The program calculates growth factors and applies them to locations where counts were not taken for the current year. Current year traffic is calculated from the previous year's traffic on these sections using the calculated growth factors. Twenty-year projected traffic counts are also calculated for each section of highway. A final count edit check program is run comparing the new count information with the previous years. A percentage of increase or decrease from the previous years is calculated. Any percentage outside the range set for the volume group the count falls in is flagged and manually analyzed. The South Dakota DOT uses only the HPMS method for Truck VMT estimation. Expansion factors are not developed separately for trucks.

3.9 Florida

3.9.1 Data Collection

The Florida Department of Transportation (FDOT) maintains more than 300 Telemetered Traffic Monitoring Sites (TTMSs) across the state of Florida. All these sites count traffic volumes, 49 of them record speed as well, 194 record vehicle classification, as well as volume and speed, and 37 measure vehicle weights in motion. Data are collected continuously at the TTMSs and are downloaded over phone lines each night. The seasonal variations in data at the TTMSs are used to apply seasonal corrections to the spot counts at the Portable Traffic Monitoring Sites (PTMSs) to make them representative of year-round averages.

There are over 6,100 PTMSs across the state of Florida. Data are collected over a 24- or 48-hour period each year. Vehicle classification data are collected at nearly 2,000 sites, and weigh-in-motion data are collected by portable equipment at 24 sites for FDOT's Strategic Highway Research Program.

3.9.2 Truck VMT Estimation

Truck VMT is calculated by multiplying segment AADT by percentage of trucks and segment length and then summing all the segments on the highway system. Counts are taken each year on all of the state highways for which FDOT is responsible to obtain the AADT of each segment of its highway network. Florida state highway system consists of about 1,100 sections, each of which can be broken into smaller segments. Traffic data is collected on about 7,000 of those smaller segments. Of those segments, all are counted, and about 2,500 are classified. FDOT's procedures call for a minimum of one class survey on each of the 1,100 sections of road. For the segments not classified, percentage of trucks is assigned based upon the axle factor categories assigned to all stations. The great majority of FDOT's count stations have highway-specific axle factor categories assigned to them. For the segments of road without either actual class stations or axle factor categories, percentage of trucks is assigned by either region or statewide functional class defaults.

4. IOWA DOT METHODOLOGY

The Iowa Department of Transportation uses the traffic-count-based method to estimate VMT. To achieve the desired precision required for national reporting requirements for AADT estimates, the Iowa DOT bases their methodology on the procedures outlined in the Federal Highway Administration's (FHWA) Traffic Monitoring Guide (TMG) for its Traffic Monitoring Program.

In compliance with TMG procedures, Iowa DOT's Traffic Monitoring Program consists of a short-term count program and a permanent continuous count program. The short-term counts are usually conducted for a 24- or 48-hour period to ensure that adequate geographic coverage exists for all roads under the jurisdiction of Iowa DOT. The permanent continuous counts conducted continuously throughout the year facilitate the computation of seasonal adjustment factors utilized in the conversion of the short-term counts to AADT.

4.1 Permanent Continuous Count Program

A total of 139 permanent continuous count stations are located throughout the state of Iowa. Data collected at the permanent count sites include volume, classification (3-class and 13-class), speed, and axle weight. A breakdown of the type of data collected at these stations is presented in Table 4.1. A number of sites have been in place since 1950, when the Iowa DOT began its Traffic Monitoring Program. Additional new sites are selected on the basis of regionality, population, and functional class.

Table 4.1. Data collected at permanent stations

Data Type	Number of the Count Stations Capable of the Indicated Function
Volume	139
Speed	93
3-Class	67
13-Class	38
Automatic Traffic Recorder	128
Weigh in Motion	22
LTPP/SHRP	15

*ATR-Automatic Traffic Recorder, WIM-Weigh-in-Motion, LTPP-Long Term Pavement Performance, SHRP-Strategic Highway Research Program.

The Iowa DOT uses PEEK ADR 2000 and the Trafficomp (TC) 3 control units, which are attached to piezo-electric sensors (Brass Linguini (BL) Axle Sensors) or induction loops, which are permanently embedded in the road surface for continuous data collection. The use of piezo-electric sensors enables the collection of the same information as that obtained using a portable counter unit but with a slightly higher level of accuracy and precision. The use of induction loops facilitates vehicle classification by overall length instead of axle spacing but results in less precision. On the other hand, the accuracy of volume data obtained using induction loops is increased since the true presence of vehicles is detected.

4.2 Short-Term Count Program

For the purpose of short-duration counts, the state was divided into four quarters, as shown in Figure 4.1. One quarter of the state is counted each year; thus, the entire state is covered in a four-year cycle. During the four-year cycle, the complete road network in some counties within a quadrant is covered, whereas only major routes are covered in the remaining counties. Counties scheduled for complete counting in the current schedule are shown hatched in Figure 4.1. The reverse is true in the alternate cycle. This ensures that the entire road network within a quadrant is covered in an eight-year cycle and enables Iowa DOT to concentrate its effort in providing more detailed information while utilizing its resources efficiently.

Mechanical and manual counts are conducted at the short-term count sites to collect volume and classification data. Approximately 11,000 to 12,000 mechanical counts and 800 to 1,000 manual counts are performed in each counting year. The ADR or TraffiComp3 portable automatic counters connected to pneumatic road tubes are used for mechanical counts and the Titan count board (a portable microprocessor) is used for manual counts. Mechanical counts are usually conducted for a 24- or 48-hour period, whereas manual counts are usually done in two time periods of four hours each or three consecutive eight-hour blocks. Counts are conducted in at least 48-hour periods on interstates and primary roads and 24-hour periods on non-primary roads.

Volume data are obtained either by manual counts or by factoring axle strikes from mechanical counts using axle correction factors (obtained from continuous counts and based on the type of road system).

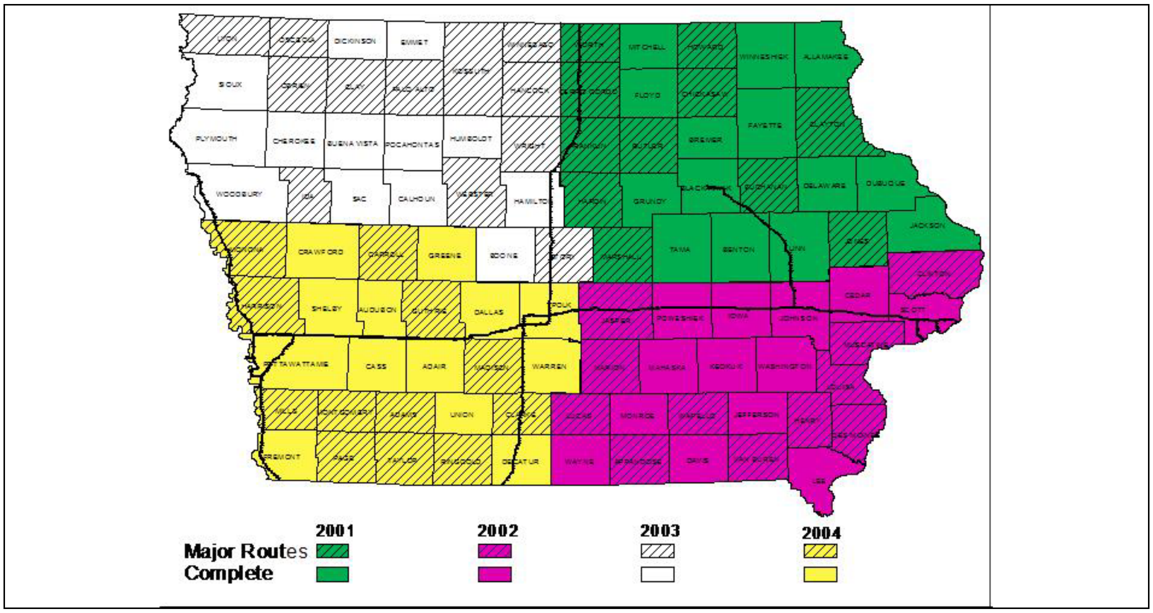


Figure 4.1. Iowa Traffic Count Program (2001-2004). Source: IDOT Traffic Monitoring Manual

4.3 Factoring Process

The conversion of raw data from short-term counts to estimates of AADT requires the application of adjustment factors to account for temporal biases, as well as the type of traffic counting equipment used. The specific set of adjustment factors required is therefore a function of the equipment type and the duration of the count (FHWA 2001). For example, a 24-hour short-term count at a particular location in which axle strikes are collected will require the application of an axle-correction factor, day-of-week, and seasonal factors. In this case, the equation for the estimation of AADT will be the following:

$$AADT = VOL_{24} \times M \times D \times A \tag{4-1}$$

where

AADT=the annual average daily traffic
VOL=the 24-hour axle volume
M=the applicable seasonal (monthly) factor
D=the applicable day-of-week factor
A=the applicable axle-correction factor

4.4 Axle-Correction Factors

Iowa DOT usually collects axle strikes on rural secondary roads and city streets using short-duration portable recorders with one pneumatic hose. Since most vehicles have two axles, axle strikes are divided by two to provide a total volume, assuming all vehicles are cars. The portable counters do this automatically. The volume obtained after dividing the total axle strikes by two is then multiplied by axle correction factors computed for the various road systems using thirteen-class manual count information.

4.5 Seasonal and Day-of-Week Factors

Two different methods are used to create adjustment factors, as described in the following paragraphs.

Specific road approach. With this approach, road specific adjustment factors are developed using data collected from continuous counts. Short-term classification count for a specific road is adjusted using factors from the nearest continuous classification counter on that road. This method, in addition to simplifying the computation and application of adjustment factors, also has an advantage of reducing errors associated with using average adjustment factors to estimate AADT. It is, however, more costly since state DOTs have to maintain a large number of continuous counters (Benekohal and Girianna 2002).

Group factor approach. With this approach, roadway sections with similar travel patterns and roadway functional classification are grouped together. Continuous classification count locations are selected from each grouping of roadway sections and adjustment factors are developed for data collection sites within each group. Adjustment factors for each group are averaged and used to adjust short-term data that are collected at locations within the group.

Iowa DOT utilizes the group factor approach for the development of combined seasonal and day-of-week adjustment factors. Six different factor groups clustered according to road system type and regionality are developed. Roadway types include rural interstate, rural primary, rural secondary, municipal interstate, municipal primary, and city streets. Factor analysis was used to determine if breakdown by road system type and regionality was appropriate. Factors are generated based on the volume data obtained from the permanent continuous count sites. AADT at the permanent count sites is a simple average of volume data for all days. Since traffic is monitored continuously throughout the year at these sites, adding all volumes collected by an ATR for an entire year and dividing by the number of days in a year produces an AADT:

$$\text{AADT} = \frac{\sum_{i=1}^{365} \text{VOL}_{24}}{365} \qquad (4\text{-}2)$$

The ratio of the AADT to the average total traffic of each day of week for a specific month of the same individual ATR produces factors for each day of the week, by month, for each road system type. An average of the factors for all ATRs within a factor group is determined. In the computation of the factors, data for the last three years at each ATR location are utilized. The days when holiday traffic may skew the results are excluded.

Raw data from the 24- or 48-hour mechanical and manual short-duration counts are multiplied by the adjustment factors based on the day-of-week, month, and road type to obtain the estimated AADT.

4.6 Missing Data

Some ATRs may suffer periods of down time due to problems with the equipment, communication, and power failures. This may result in hours or days of missing data that consequently introduces biases in the factor computation, particularly when blocks of data are lost (FHWA 2001). To account for missing data, the Iowa DOT employs historical methods. This involves analyzing data from previous years for the same period in which data are missing in the current year and making projections to fill in the missing data. For instance, if data collected at an ATR station on a Monday in October 2002 are missing data from 1 pm to 3 pm, data for the same period in previous years, such as 1999, 2000, and 2001, are used to extrapolate the missing hours. In a case where an ATR station is missing data over a long period of time, the entire data from that station are excluded from the factor computation. This is sometimes the case when there is an ongoing construction activity along the section of road on which the ATR station is located.

4.7 Estimation of Heavy-Truck AADT

The Iowa DOT specifically conducts short-term truck counts from which truck AADT is obtained. On the primary roads system, truck volumes are obtained primarily from manual turning movement counts and a few portable automatic traffic classifiers. For the secondary road system, truck volumes are obtained from portable automatic traffic classifiers installed at eight locations per county—four on gravel roads and four on paved roads. The Iowa DOT is, however, in the process of revising its traffic count program to ensure an extensive coverage of the secondary road system by installing more traffic counters capable of collecting both volume and vehicle classification data. In the case of city streets where traffic volumes are usually high with relatively small gaps between vehicles, the use of ATRs has been found to produce inaccurate vehicle classification results. Truck volumes on city streets are therefore obtained from eight-hour manual turning movement counts only. These manual counts yield total volume for all vehicles and classification for three vehicle classes: passenger vehicles, single-unit trucks and combination trucks. To expand truck volumes obtained to truck annual average daily traffic, seasonal day-of-week adjustment factors for trucks are developed based on the permanent continuous count locations.

4.8 VMT Estimation

VMT is generally obtained by multiplying the roadway segment AADT (obtained as described above) by the length of that segment. In particular, truck VMT is estimated on roadway segment basis by multiplying the roadway segment truck AADT by the length of that segment. The total truck VMT by road system type is obtained by summing the truck VMT for individual segments belonging to that road system. Multiplying by the number of days in a year annualizes this value. Typically, VMT for municipal roads are adjusted based on the percentage increase or decrease in AADT obtained from the ATR stations (Meraz and Bunting 2003).

5. METHODOLOGY

The purpose of this research was to evaluate and compare several different methods to calculate heavy-truck AADT and, subsequently, VMT. Traffic data from continuous count stations provided by the Iowa DOT were used to estimate AADT for two different truck groups (single-unit and multi-unit) using three different methods. The first method developed monthly and daily expansion factors for each truck group. Truck AADT was calculated by applying truck expansion factors to short-term counts. The second and third methods created general expansion factors for all vehicles. Truck AADT was calculated by multiplying short-term counts by generic expansion factors and truck percentages. Truck percentages for the second method were based on the annual percentage of trucks for each group from continuous count stations. The third method used daily truck percentages from the short-term counts.

Accuracy of the three methods was compared using n-fold cross-validation. In n-fold cross-validation, data are split into *n* partitions and data from the *nth* partition are used to validate the remaining data. Accordingly, data from continuous count stations were divided into four groups, and each group was reserved for one partition as the validation dataset. Short-term counts were extracted from the validation dataset, and then AADT was estimated using each of the three methods. Actual AADT by truck group for each count station was compared to the estimated AADT by truck group for each method. A description of the data and methodology is provided in the following sections.

5.1 ATR Data

Automatic Traffic Recorder (ATR) data for rural primary roadways and rural interstates were obtained from the Office of Transportation Data of the Iowa DOT for the 2001 counting year (January 2001 to December 2001). The study started in 2003, and the 2002 ATR dataset was preferred. However, the DOT indicated that numerous errors were present in the 2002 data and suggested use of the 2001 data instead. Additionally, they felt that the rural interstate and primary road data were the most reliable. Consequently, analysis was made for these two road types.

The rural primary network is made up of all federal and state highways, excluding interstates, outside the limits of any incorporated city or town. Rural interstate network encompasses all interstates outside the limits of any incorporated city or town. Traffic data are collected year round at all ATR sites. Only ATR sites that collect vehicle classification data were considered for the study. At some of the sites, data were collected for 3 classes: passenger vehicle, single-unit (SU) truck, and multi-unit (MU) truck. At other sites, data were collected for all 13 classes of the FHWA vehicle classification scheme.

Some of these sites had a considerable amount of missing data as result of equipment malfunction, communication, and power failures. Data from such sites was discarded. A total of 36 ATR sites remained for the rural primary analysis after eliminating ATR sites which were missing substantial amounts of data. The locations of the 36 ATR sites on the rural primary network are shown in Figure 5.1. A total of 14 rural interstate ATR stations remained for the rural interstate analysis.

5.2 Vehicle Classification Scheme

Ideally, each of the FWHA truck categories would be evaluated separately, and expansion factors would be created for each class. However, many of the FHWA truck classes contain low traffic volumes. Expansion factors based on low volumes can be unreliable since, with low traffic volumes, small changes result in high percentage of changes. In order to develop reliable seasonal and day-of-week truck adjustment factors, an aggregation of the 13 classes of the FHWA classification scheme into three or four vehicle categories is recommended by the traffic monitoring guide (FHWA 2001). Additionally, a number of ATR stations only recorded 3 classes of vehicles. Consequently data were aggregated into 3 vehicle classes. Stations that reported 13 classes were aggregated into the 3 vehicle classes reported by the remaining stations. The 3 vehicle categories consist of passenger vehicle, single-unit truck, and multi-unit truck. Aggregation of the 13 FHWA vehicle classes is shown Table 5.1.

Table 5.1. FHWA vehicle classes in each vehicle category

Vehicle Category	FHWA Class
Passenger Vehicle (PV)	Classes 1 to 3
Single Unit Truck (SU)	Classes 4 to 7
Multi-Unit Truck (MU)	Classes 8 to 13

Truck VMT is estimated by multiplying AADT by section length once AADT has been estimated. Consequently, AADT, not VMT, was the variable used to evaluate the different methods.

5.3 Creation of Expansion Factors

The Iowa DOT uses the group factor approach to develop expansion factors. The factor groups are made up of all the ATR stations in that functional class, as described in Section 4.5. The group factor approach was used to estimate expansion factors for this research as well. AADT was first determined for each station, and then expansion factors were created for each station.

5.3.1 AADT

ATR data were available in the form of a single 24-hour count for each day for each station. A sample is provided in Appendix C. Each file contains counts by hour of the day, and data are presented by vehicle class. Some stations report 3 vehicle classes, and other stations report all 13. Data were aggregated into 3 vehicle classes, as discussed in Section 5.2. All daily data had to be summarized for each station in order to calculate AADT and expansion factors, requiring a significant amount of effort.

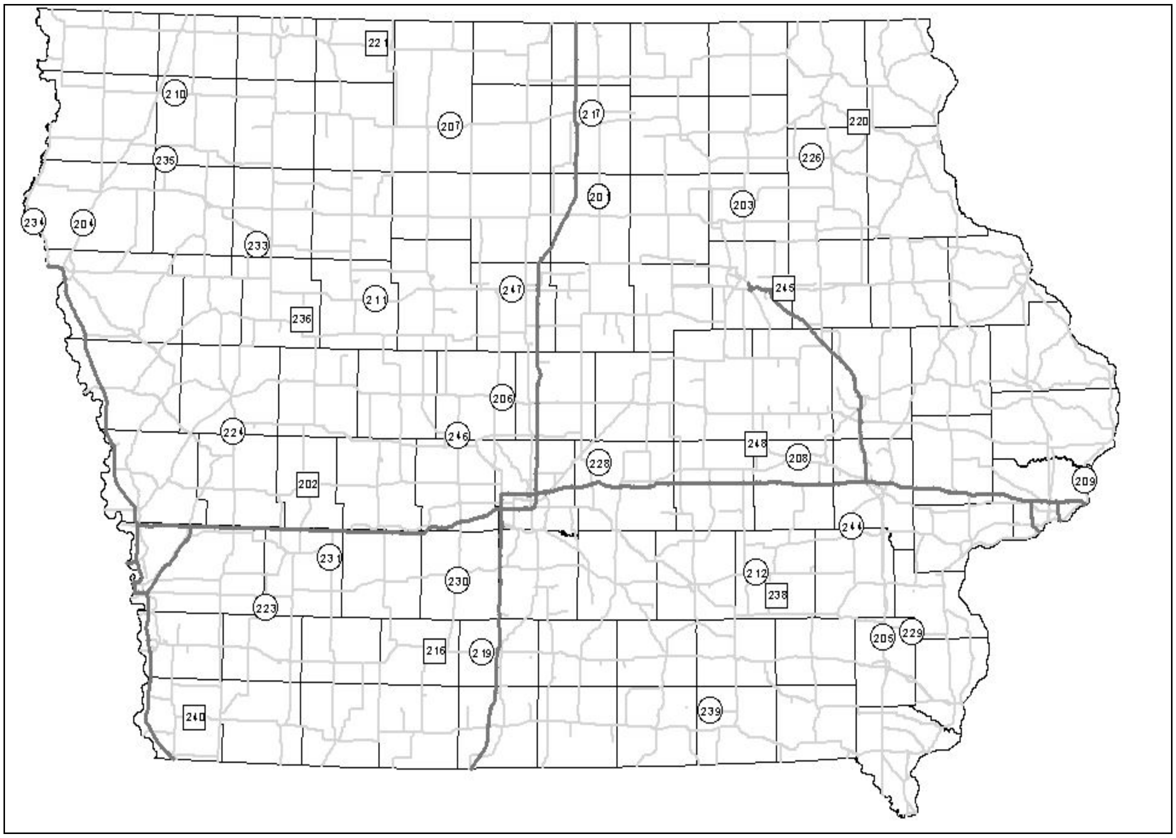


Figure 5.1. Location of rural primary ATR stations

AADT by vehicle category and for total traffic for each ATR station was computed using the American Association of State Highway and Transportation Officials (AASHTO) method—a three-step averaging process. This method was used instead of the simple average of days approach because it has the advantage of effectively removing most biases that result from missing days of data. This advantage is especially important when those missing days are unequally distributed across months or days of the week by weighting each day of the week and each month the same regardless of how many days are actually present within that category (FWHA 2001).

In the first step of this process, 7 averages corresponding to the 7 days of the week were obtained for each month of the year for each vehicle category and total traffic. These 84 (12 months by 7 days) monthly average days of the week traffic (MADWT) volumes are then averaged across all 12 months to yield 7 annual average days of the week (AADW). The 7 AADW values are averaged to produce AADT.

The AASHTO approach for computing AADT can be expressed as follows:

$$AADT_c = \frac{1}{7}\sum_{i=1}^{7}\left[\frac{1}{12}\sum_{j=1}^{12}\left(\frac{1}{n}\sum_{k=1}^{n} VOL_{ijk}\right)\right] \tag{5-1}$$

where

$AADT_c$= Annual average daily traffic for vehicle category *c*
VOL = Daily traffic for day *k*, of day-of-week *i*, and month *j*
I = Day of the week
j = Month of the year
k = 1 when the day is the first occurrence of that day of the week in a month and 4 when it is the fourth day of the week
n = The number of days of that day of the week during that month (usually between 1 and 5, depending on the number of missing data)

5.3.2 Expansion Factors

For each ATR station, different expansion factors for each day of the week of a specific month were developed. The combined seasonal and day-of-week expansion factor is given by the ratio of the annual average daily traffic (AADT) to the monthly average day of the week traffic (MADWT), as shown in Equation 5-2:

$$f_{atrgi} = \frac{AADT_c}{MAWDT_c} \qquad (5\text{-}2)$$

where

f_{atrgi}= Combined seasonal and day-of-week factor for vehicle category *c* for station *i*
$ADDT_c$= Annual average daily traffic for vehicle category *c* for station *i*
$MAWDT_c$= Monthly average day-of-week traffic for vehicle category *c* for station *i*

Table 5.2 illustrates data used to calculate AADT for rural interstate Station 119. The dataset includes all vehicles. The daily average was calculated by summing AADT for a specific day of the week over the 12 months and then dividing by 12. Final AADT was calculated by summing the daily average over the 7 days and dividing by 7.

Table 5.2. Volumes by day-of-week AADT for Station 119

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Daily Avg
Mon	19336	21138	22389	24164	25994	27160	28123	28656	26476	24869	23713	19957	24331
Tue	21365	21131	22946	24126	25562	26473	27768	27851	25296	24278	24705	21274	24398
Wed	21927	21155	23950	24975	26292	27948	26620	29120	26255	25223	28055	24798	25527
Thu	22510	21875	24350	26798	27717	29582	30080	30388	28207	26735	24412	25453	26509
Fri	23588	22797	27354	30026	32258	33640	34560	35574	32339	31079	27407	28241	29905
Sat	19681	18727	22464	22780	25609	28266	29026	30396	26539	24706	24637	23581	24701
Sun	17373	18495	22394	23804	24567	27973	30120	30423	26317	26690	26765	19931	24571
AADT													25706

Resulting expansion factors (f_c) are presented in Table 5.3. Data are shown for Station 119. The expansion factors are shown for all vehicles. Expansion factors were calculated using Equation 5-2. The expansion factor for a Monday in January, for instance, was calculated by dividing 25706 by 19336, which equals 1.33.

Table 5.3. Expansion factors for Station 119

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mon	1.33	1.22	1.15	1.06	0.99	0.95	0.91	0.90	0.97	1.03	1.08	1.29
Tue	1.20	1.22	1.12	1.07	1.01	0.97	0.93	0.92	1.02	1.06	1.04	1.21
Wed	1.17	1.22	1.07	1.03	0.98	0.92	0.97	0.88	0.98	1.02	0.92	1.04
Thur	1.14	1.18	1.06	0.96	0.93	0.87	0.85	0.85	0.91	0.96	1.05	1.01
Fri	1.09	1.13	0.94	0.86	0.80	0.76	0.74	0.72	0.79	0.83	0.94	0.91
Sat	1.31	1.37	1.14	1.13	1.00	0.91	0.89	0.85	0.97	1.04	1.04	1.09
Sun	1.48	1.39	1.15	1.08	1.05	0.92	0.85	0.84	0.98	0.96	0.96	1.29

5.4 *N*-Fold Cross-Validation

N-fold cross-validation was used to evaluate the three methods. In *n*-fold cross-validation, data are split into *n* partitions and data from the *n*th partition are used to validate the model created from the remaining data. For example, if four partitions are used, for the first partition, data from partition *n*=1 are removed from the sample and data from partitions *n*=2, *n*=3, and *n*=4 (referred to hereafter as the “model” dataset) are combined to create the model of interest. Data from partition *n*=1 (refereed to hereafter as the “validation” dataset) are used to validate the model. For the second partition, data from partition *n*=2 are removed and data from *n*=1, *n*=3, and *n*=4 are used to create the model. Data from partition *n*=2 are used to validate the model. Partitions 3 and 4 follow the same method.

The 36 rural primary ATR stations were randomly partitioned into four groups of nine stations. The four groups are presented in Table 5.4. The 14 rural interstate ATR stations were divided into four groups, as shown in Table 5.5.

Table 5.4. Division of rural primary ATR stations

	Group 1	Group 2	Group 3	Group 4
ATR Station	201	202	203	204
	205	206	207	208
	209	210	211	212
	220	216	217	219
	224	221	228	223
	230	226	233	229
	235	231	238	234
	240	236	246	239
	244	245	248	247

Table 5.5. Division of rural interstate ATR stations

	Group 1	Group 2	Group 3	Group 4
ATR Station	120	100	119	116
	106	113	104	110
	109	115	118	111
		102		

5.5 Short-term Counts

Short-term counts were used to evaluate the accuracy of each of the three methods. For each partition, stations from the model datasets were used to create expansion factors, and stations from the validation dataset were used to create short-term counts. Expansion factors for each model dataset were computed for the two truck (SU and MU) categories and for total traffic by averaging expansion factors for all ATR stations in a model dataset creating an average factor for the group:

$$F_{cg_{av}} = \frac{\sum_{i=1}^{m} f_{atr_{gi}}}{m} \qquad (5\text{-}3)$$

where

$F_{cg_{av}}$ = Average expansion factor for vehicle category *c* in group *g*

$f_{atr_{gi}}$ = Expansion factor for station *i* in group *g*

c = Vehicle category

g = ATR group

m = Number of ATR stations in group *g*

Consequently, expansion factors were created for both rural interstate and primary roads for each partition *n* for each vehicle type. For each partition, factors were created for total vehicles, single-unit trucks, and multi-unit trucks. An example is shown in Table 5.6 for single-unit vehicles for rural interstates for partition 1.

Table 5.6. SU expansion factors for rural interstate group 1

Group 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mon	1.56	1.16	1.18	1.01	0.99	0.88	0.81	0.86	1.00	1.05	1.24	1.66
Tue	1.29	1.17	1.16	1.02	0.95	0.91	0.83	0.91	1.05	1.09	1.23	1.54
Wed	1.17	1.22	1.10	1.00	0.93	0.84	0.91	0.82	1.03	1.02	1.14	1.34
Thu	1.16	1.15	1.09	0.94	0.87	0.76	0.76	0.77	0.91	0.94	1.21	1.25
Fri	1.15	1.23	1.01	0.86	0.75	0.63	0.62	0.64	0.79	0.86	1.07	1.14
Sat	1.74	1.70	1.47	1.24	1.10	0.81	0.78	0.79	1.03	1.17	1.37	1.70
Sun	2.26	2.11	1.73	1.36	1.31	0.99	0.88	0.86	1.18	1.33	1.56	2.20

Data from stations reserved as validation datasets were used to create short-term count datasets. The Iowa DOT collects short-term counts from June to August. The summer

DOT counting period was also used for analysis. Four days were randomly selected for each of the 3 summer months (June, July, and August), and 24-hour counts were extracted from the validation dataset for weekdays (Monday through Thursday). For each day, a 24-hour classification count was extracted from each station in the validation dataset. For instance, if nine stations were present in the validation dataset, a total of 9 x 3 x 4, or 108 individual 24-hour counts, would have been extracted for each partition. The days used in the analysis were the following:

June 6	July 9	Aug 8
June 11	July 18	Aug 14
June 19	July 26	Aug 23
June 28	July 31	Aug 27

AADT was estimated for each station from each 24-hour count using the expansion factors for each method. The actual AADT for each vehicle category was calculated using Equation 5-1 for each station and was compared to the estimated AADT by vehicle category generated using each method.

5.6 Description of Three Methods

AADT was estimated for each vehicle category for each 24-hour count for each partition for each of the three methods. Each method is described in more detail in the following sections.

5.6.1 Truck Expansion Factor Approach

This approach involved developing separate expansion factors for single-unit (SU) and multi-unit (MU) trucks. Expansion factors were used to estimate annual average daily truck traffic (AADTT) for each truck category using the 24-hour counts. AADTT was calculated using Equation 5-4 for each validation station for each partition. Expansion factors were created, as discussed previously, by averaging expansion factor for the model dataset for each partition.

$$AADTT_c = V_{c_{24}} \times f_c \qquad (5\text{-}4)$$

where

$AADTT_c$ = Annual average daily truck traffic for truck category *c*

$V_{c_{24}}$ = 24-hour short-term truck count for truck category *c*

f_c = Averaged seasonal and day-of-week adjustment factor for truck category *c*

In order to use this approach, short-duration truck counts must be collected as part of the traffic monitoring program.

5.6.2 Yearly Truck Percentage Approach

This approach calculated a single expansion factor for all vehicles for each partition. Truck AADT was calculated for each validation station using Equation 5-5. Truck AADT was calculated by multiplying AADT for all vehicles by a yearly truck percentage. The percentage of single-unit and multi-unit trucks for each partition was calculated by summing the number of trucks in each category for all the stations in the "model" dataset and dividing that by total AADT for the stations, as shown in Equation 5-6.

$$AADTT_c = P_c \times [V_{t_{24}} \times f_t] \tag{5-5}$$

where

P_c = Average yearly truck percentage for truck category *c*

$V_{t_{24}}$ = 24-hour short-term volume count for total traffic for station *i*

f_t = Averaged seasonal and day-of-week adjustment factor for total traffic

$$P_c = \frac{\sum_{j=1}^{12}\left(\sum_{i=1}^{n} truck\,Vol_{mij}\right)}{\sum_{j=1}^{12}\left(\sum_{i=1}^{n} Vol_{ij}\right)} \tag{5-6}$$

where

P_c = Annual truck percentage for truck category m

$truck\,Vol_{mij}$ = Truck volume for truck category *m* for day *i* in month *j*

Vol_{ij} = Total traffic volume for day *i* in month *j*

i = Day of the month

j = Month of the year

Unlike in the first approach, the collection of short-term truck counts is not required. The truck percentages are developed from vehicle classification data and are given by the ratio of truck volume to total traffic volume. Yearly truck percentages for rural interstates for each partition are provided in Table 5.7. Percentages for rural primary roads are shown in Table 5.8 for each partition.

Table 5.7. Average truck percentage by partition for each vehicle category for rural interstate road

Partition	PC	SU	MU
n = 1	75.6%	3.3%	21.1%
n = 2	70.7%	3.2%	26.1%
n = 3	73.6%	3.1%	23.3%
n = 4	75.0%	3.0%	22.0%

Table 5.8. Average truck percentage by partition for each vehicle category for rural primary road

Partition	PC	SU	MU
$n = 1$	86.0%	4.4%	9.6%
$n = 2$	85.6%	4.5%	10.0%
$n = 3$	85.8%	4.6%	9.6%
$n = 4$	85.6%	4.5%	9.9%

5.6.3 Count Specific Truck Percentage Approach

Expansion factors that represented all vehicle categories combined were calculated for each validation station for each partition the same way as for method 2. Total AADT was factored for each validation station from each 24-hour count using expansion factors. Single-unit and multi-unit AADT were calculated by multiplying truck percentages for each category. Truck percentages for this method were based on the 24-hour classification count. Consequently, the percentages of single-unit and multi-unit trucks were calculated separately for each validation station for each 24-hour count according to Equation 5-7.

$$P_c = \frac{T_c}{Vol_{24}} \qquad (5\text{-}7)$$

where

P_c = Percentage of trucks in category c

T_c = 24-hour volume of trucks for category c

Vol_{24} = Total 24-hour volume

5.7 Cross-Validation

N-fold cross-validation was the method used to evaluate the accuracy of AADT computed using the three different estimation methods. As discussed above, one dataset was reserved as the validation dataset, and expansion factors were calculated using the remaining model datasets. Four partitions were used for both the rural interstate and rural primary road categories. Truck AADT was estimated for each station in the validation dataset for each of the 24-hour counts using the three different methods, as described previously.

5.7.1 Comparison of Methods

A 4-fold cross-validation was performed. One partition was reserved for testing, while the other 3 partitions were used for fitting the model. This procedure was repeated until all four partitions were used as a test set. The 4-fold cross-validation was applied to the ATR data using the 3 methods for estimating AADTT, as discussed. A comparison of the accuracy of the 3 methods was made using the estimates of prediction error obtained from cross-validation. The prediction error was determined by averaging the squared error between the estimated AADTT and the actual AADTT, as shown in Equation 5-8.

$$MSEP = \frac{\sum \left(AADTT_{est} - AADTT_{actual} \right)^2}{n} \qquad (5\text{-}8)$$

where

$MSEP$ = Mean squared error of prediction

$AADTT_{est}$ = Estimated annual average daily truck traffic from a particular method

$AADTT_{true}$ = Actual annual average daily truck traffic

n = Number of observations

5.7.2 Results of Cross-Validation

To perform an accuracy assessment of the results obtained from the three AADT estimation methods, the estimates of the mean squared error of prediction (MSEP) for the methods obtained from cross-validation were compared. On average, the smaller the MSEP, the less errors in the predictions and, consequently, the better the method. Observed MSEP values for the three methods are given in Table 5.9 for the rural primary category. Values are averaged over all days and stations. Average MSEP for each station for single-unit trucks is presented in Table 5.10 and for multi-unit trucks in Table 5.11.

The results for single-unit trucks for rural primary roads show that the estimated MSEP for the truck expansion factor method (method 1) is 2,354, the corresponding MSEP for the annual truck percentage method (method 2) is 11,942, and the MSEP for the daily truck percentage method (method 3) is 2,595. Thus, for single-unit trucks, the truck expansion factor method performed the best in terms of minimum expected error. In the case of multi-unit trucks, the results show that the MSEP for method 1 is 12,341, the corresponding MSEP for method 2 is 98,837, and the MSEP for method 3 is 28,773. Again, the best method in terms of minimum prediction error is the truck expansion factor method.

Table 5.9. Average mean squared error of prediction for rural primary roads

	Average MSEP for All Days and Stations		
	Truck Expansion Factor Method (1)	**Annual Truck Percentage Method (2)**	**Count Specific Truck Percentage Method (3)**
Single-Unit	2,354	11,942	2,595
Multi-Unit	12,341	98,837	28,773

Table 5.10. Average mean squared error of prediction by station for rural interstate roads for single-unit vehicles

Station	Average MSEP for Each Station		
	Truck Expansion Factor Method (1)	Annual Truck Percentage Method (2)	Count Specific Truck Percentage Method (3)
201	4393	126	3933
205	451	15510	1199
209	1356	3613	2667
220	319	98	586
224	2986	36390	1154
230	127	164	159
235	100	19	182
240	103	70	157
244	294	10677	475
202	1934	4634	2017
206	1762	66413	2589
210	1151	300	1419
216	750	1000	864
221	804	58	745
226	1746	64	1969
231	57	33	172
236	405	47	494
245	1675	1675	1675
203	6902	1040	6962
207	1793	1226	2116
211	1042	20	830
217	11215	197932	12018
228	4050	935	4135
233	214	763	336
238	160	68	202
246	17042	45724	18086
248	1928	4099	1814
204	4191	39816	6142
208	1753	1353	2440
212	1176	3226	629
219	13119	8082	14718
223	784	45	981
229	84	87	98
234	771	62	994
239	121	260	108
247	1483	10715	5245

Table 5.11. Average mean squared error of prediction by station for rural interstate roads for multi-unit vehicles

Station	Average MSEP for Each Station		
	Truck Expansion Factor Method (1)	**Annual Truck Percentage Method (2)**	**Count Specific Truck Percentage Method (3)**
201	228557	834	379230
205	21046	652003	155548
209	1188	22094	7121
220	8085	4991	25150
224	3809	48323	5929
230	57	13681	290
235	249	912	976
240	562	3139	1234
244	894	131228	1244
202	752	19664	3154
206	3730	347525	24832
210	1355	2557	8816
216	1708	2505	8058
221	1892	2608	4597
226	5561	2811	19757
231	111	1233	431
236	928	1839	2986
245	12590	1258	66899
203	5452	105929	22129
207	2425	239	6837
211	39814	131449	11001
217	6791	1217586	20400
228	4967	4098	11539
233	432	2955	1254
238	140	1585	207
246	58890	239169	91912
248	1603	1798	321
208	512	70565	1584
212	399	5997	5571
219	1806	4556	8081
223	350	6798	858
229	394	1065	799
234	1696	233	4904
239	52	2863	83
247	17100	494516	257806

Average MSEP for the rural interstate category is presented in Table 5.12. Shown is the average MSEP for all days and all stations. Average MSEP by station for single-unit trucks is presented in Table 5.13 and for multi-unit trucks in Table 5.14. As shown overall, the mean squared error is lowest for the method that developed expansion factors separately for the different truck groups for both the single- and multi-unit truck categories (method 1). For some stations, different methods produce different results, but the average MSEP is lowest overall for that method.

Table 5.12. Average mean squared error of prediction for rural interstate

	Average MSEP for All Days and Stations		
	Truck Expansion Factor Method (1)	**Daily Truck Percentage Method (2)**	**Annual Truck Percentage Method (3)**
Single-Unit	34,028	61,490	161,331`
Multi-Unit	698,851	1,700,949	10,623,191

Table 5.13. Observed mean squared error of prediction for rural interstate for SU vehicles

Station	Average MSEP for Each Station		
	Truck Expansion Factor Method (1)	**Daily Truck Percentage Method (2)**	**Annual Truck Percentage Method (3)**
1000	10,605	12,935	6,446
1020	4357	4570	23979
1040	3,875	13,462	19,083
1060	33,283	10,987	67,835
1090	19,404	40,435	2,656
1100	151,233	128,080	89,939
1110	30,378	71,420	268,078
1130	914	2,955	449
1150	19,013	88,346	16,597
1160	105,470	205,378	73,991
1180	48,028	152,219	1,004,315
1190	8,823	28,564	202,026
1200	6,977	40,020	321,916

Table 5.14. Observed mean squared error of prediction for rural interstate for MU vehicles

Station	Average MSEP for Each Station		
	Truck Expansion Factor Method (1)	**Daily Truck Percentage Method (2)**	**Annual Truck Percentage Method (3)**
1000	7,599	89,369	4,317,140
1020	52,221	239,339	275,992
1040	71,780	503,876	634,217
1060	55,192	307,571	879,533
1090	115,361	551,819	86,126
1100	7,036,514	14,294,839	8,672,671
1110	256,355	1,555,521	4,436,701
1130	32,058	184,502	193,389
1150	302,891	406,634	4,996,260
1160	536,091	475,280	238,742
1180	211,889	976,603	103,888,065
1190	161,179	761,648	880,880
1200	245,936	1,765,337	8,601,773

5.8 Hourly, Weekly, and Monthly Variations

In addition to testing the different methods using *n*-fold cross-validation, the different methods were also graphically compared. Figure 5.1 illustrates the fraction of monthly volume that occurs on a specific month of the year for four rural interstate stations. As shown, passenger vehicle and single-unit truck patterns are more similar than multi-unit truck pattern. Passenger and SU volumes peak in the summer months, while MU volumes are more constant over the year. Figure 5.2 illustrates weekly variation for four rural interstate stations. In general, higher truck volumes occur during the weekdays (Monday through Friday), with much lower volumes on weekends for both truck groups. Passenger vehicles peak on Friday and have higher weekend volumes. Figures 5.3 and 5.4 show volume variations by hour of the day for the same four interstate stations. Figure 5.3 shows data for a typical Monday in July, and Figure 5.4 shows a typical Saturday in July. As shown, passenger vehicle and single-unit truck volumes follow similar hour trends, while multi-unit trucks have a much flatter curve. On Mondays, the multi-unit truck curve peaks later in the day. On Saturdays, the trend is similar but flatter than for the other two vehicle categories.

Figure 5.5 illustrates monthly variation in vehicle volumes for four rural primary stations. Volume trends for multi-unit trucks and passenger vehicles for three of the stations are more similar than for single-unit trucks. Weekly variations for the four rural primary stations are provided in Figure 5.6. As shown, truck volumes peak on Monday through Friday and then drop on Saturday and Sunday, while passenger vehicle volumes peak on Fridays and weekends are similar to weekdays. Figures 5.7 and 5.8 illustrate hourly variation for the same station for a typical Monday and Saturday in July, respectively. As shown, multi-unit truck volumes have significant variations throughout the day, while single-unit and passenger vehicles follow a smoother trend.

As shown, weekly and monthly truck patterns are different from passenger vehicle patterns. The *n*-fold cross-validation confirmed that using truck specific expansion factors resulted in more accurate estimates of truck AADT and, consequently, truck VMT. Graphical comparison indicated the same conclusion.

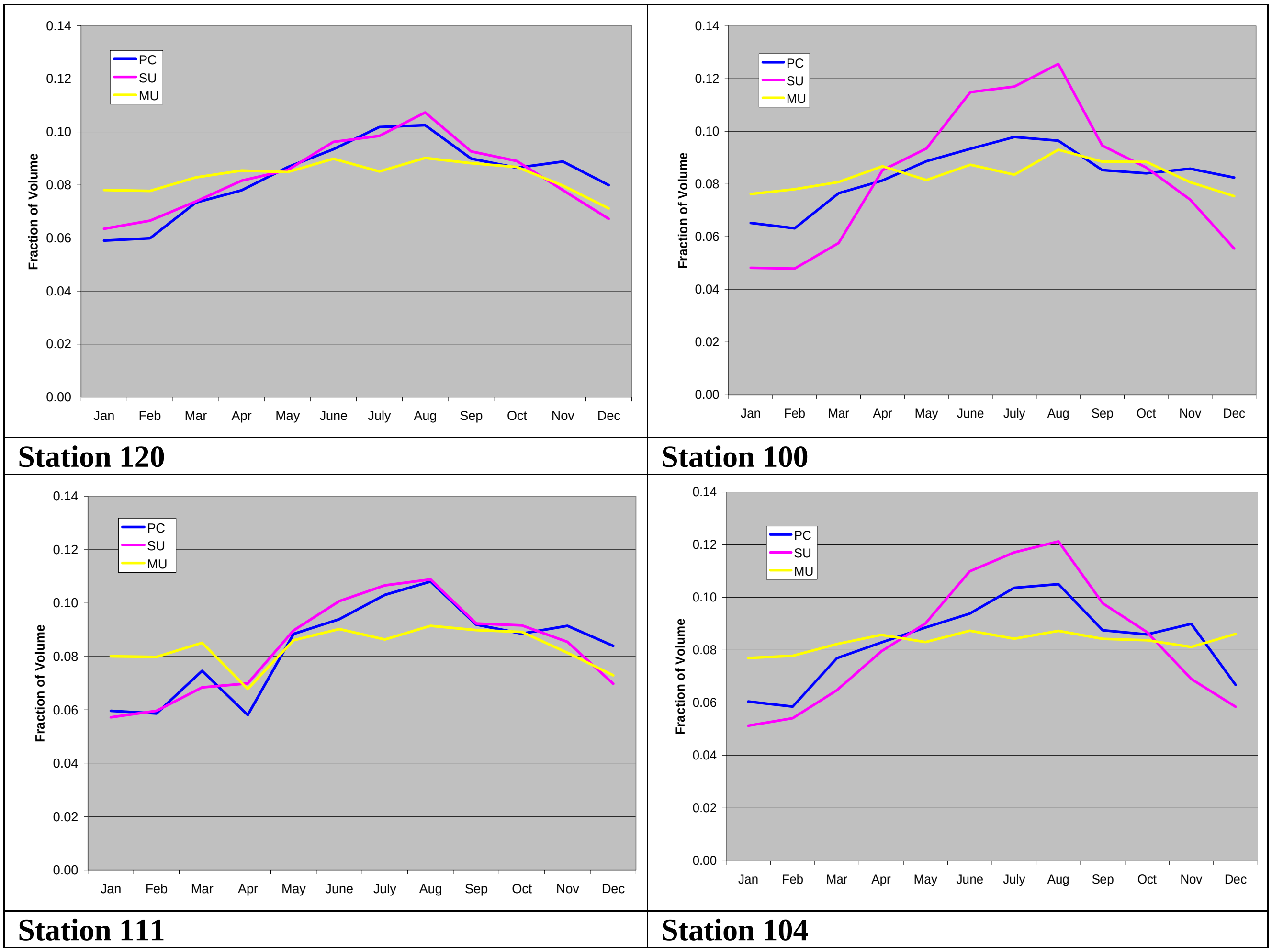
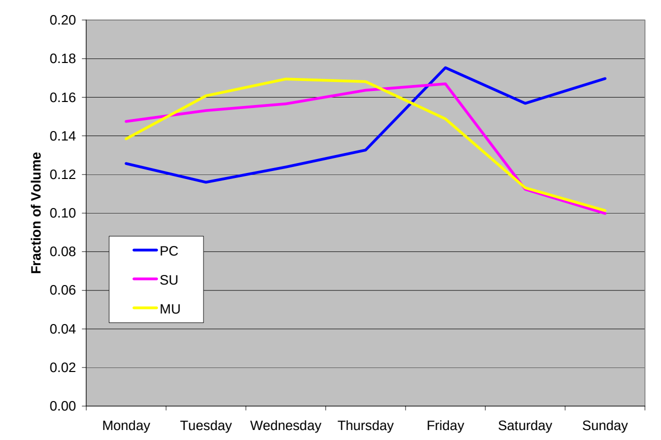
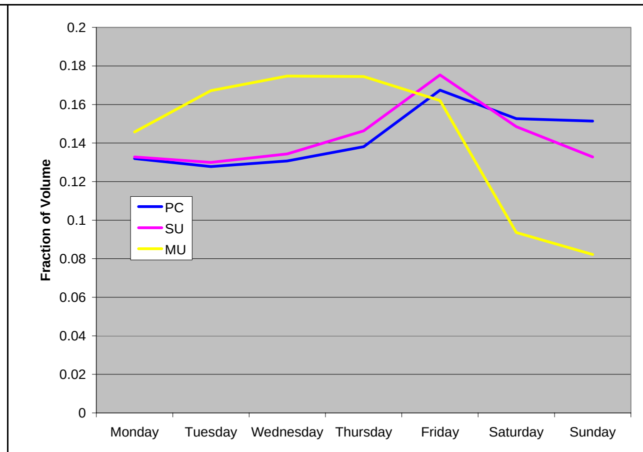


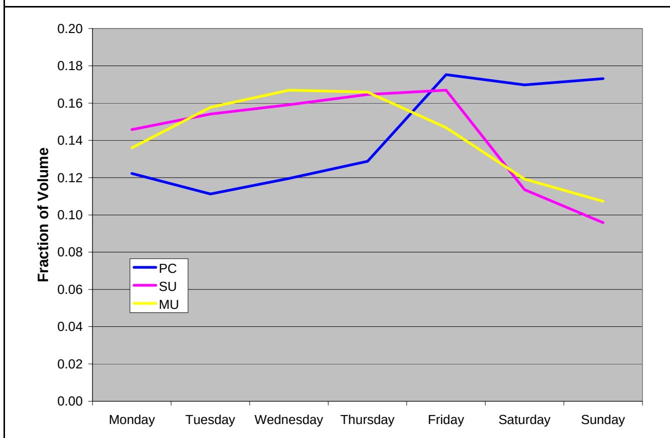
Figure 5.1. Monthly variations for rural interstate stations



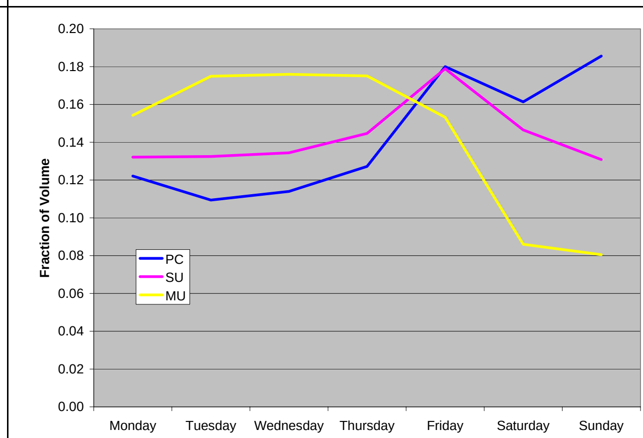
Station 120



Station 100

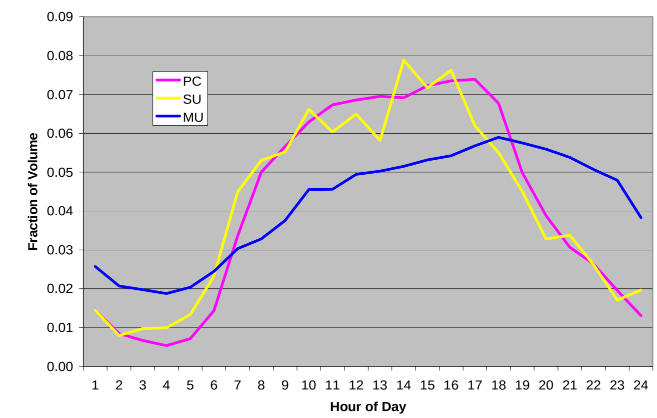


Station 111

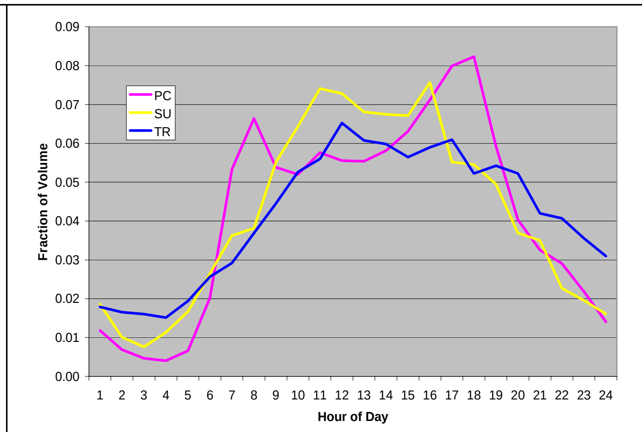


Station 104

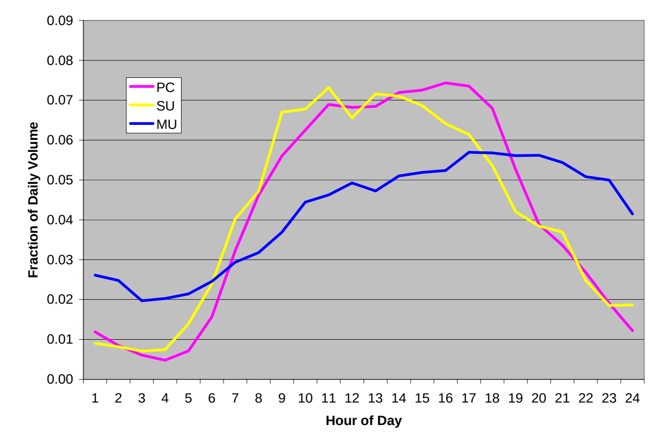
Figure 5.2. Weekday variations for rural interstate stations



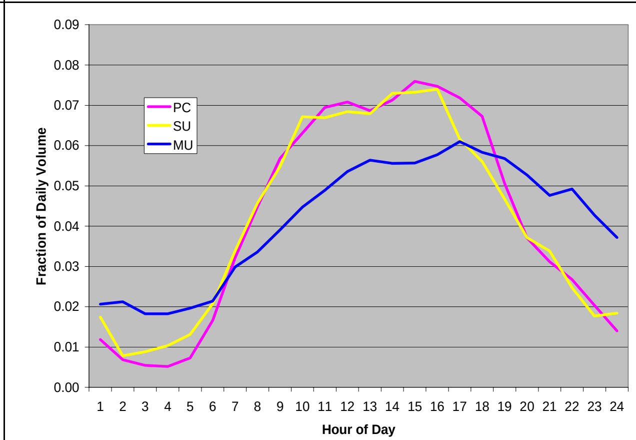
Station 120



Station 100

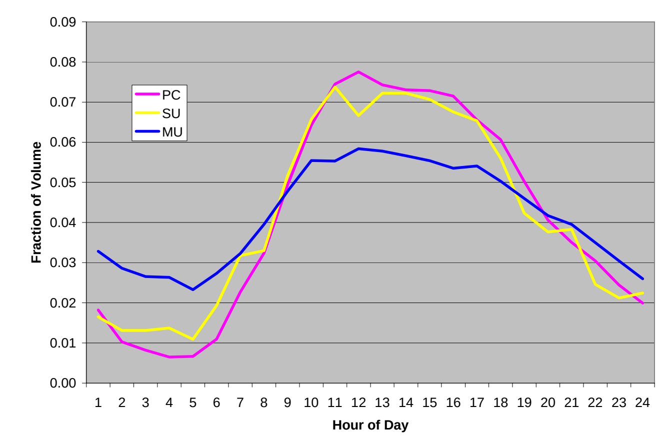


Station 111

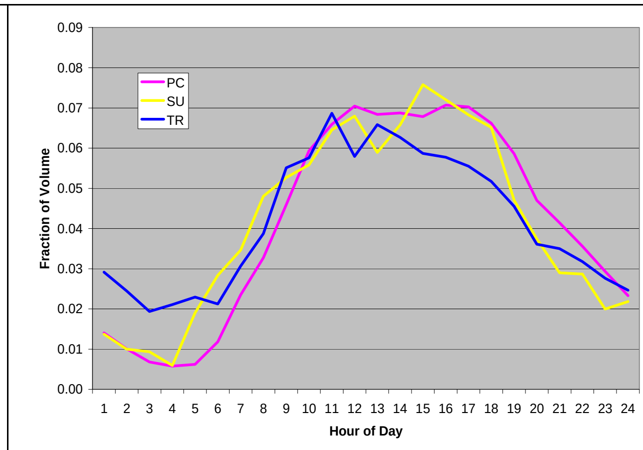


Station 104

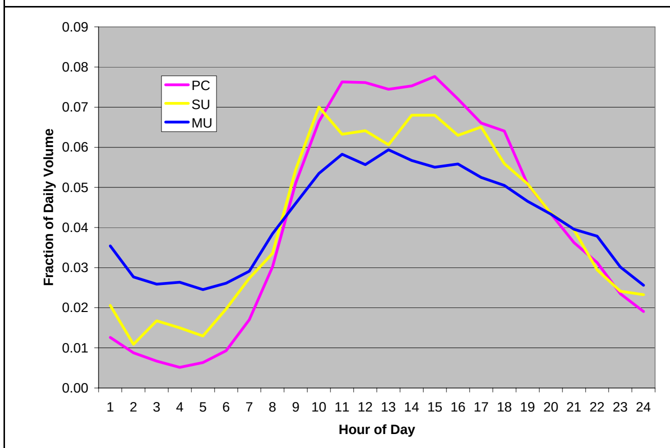
Figure 5.3. Weekday variations for rural interstate stations (Monday in July)



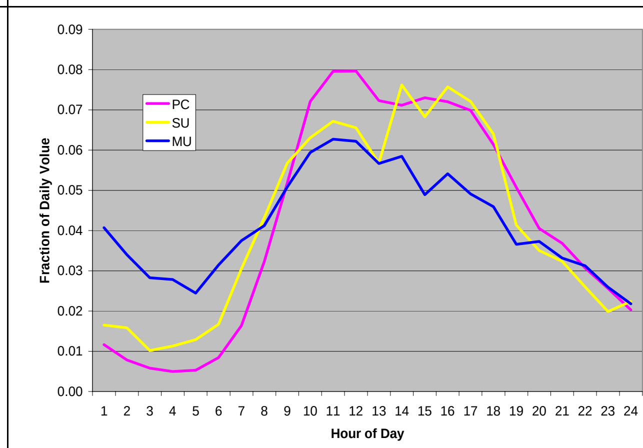
Station 120



Station 100



Station 111



Station 104

Figure 5.4. Weekday variations for rural interstate stations (Saturday in July)

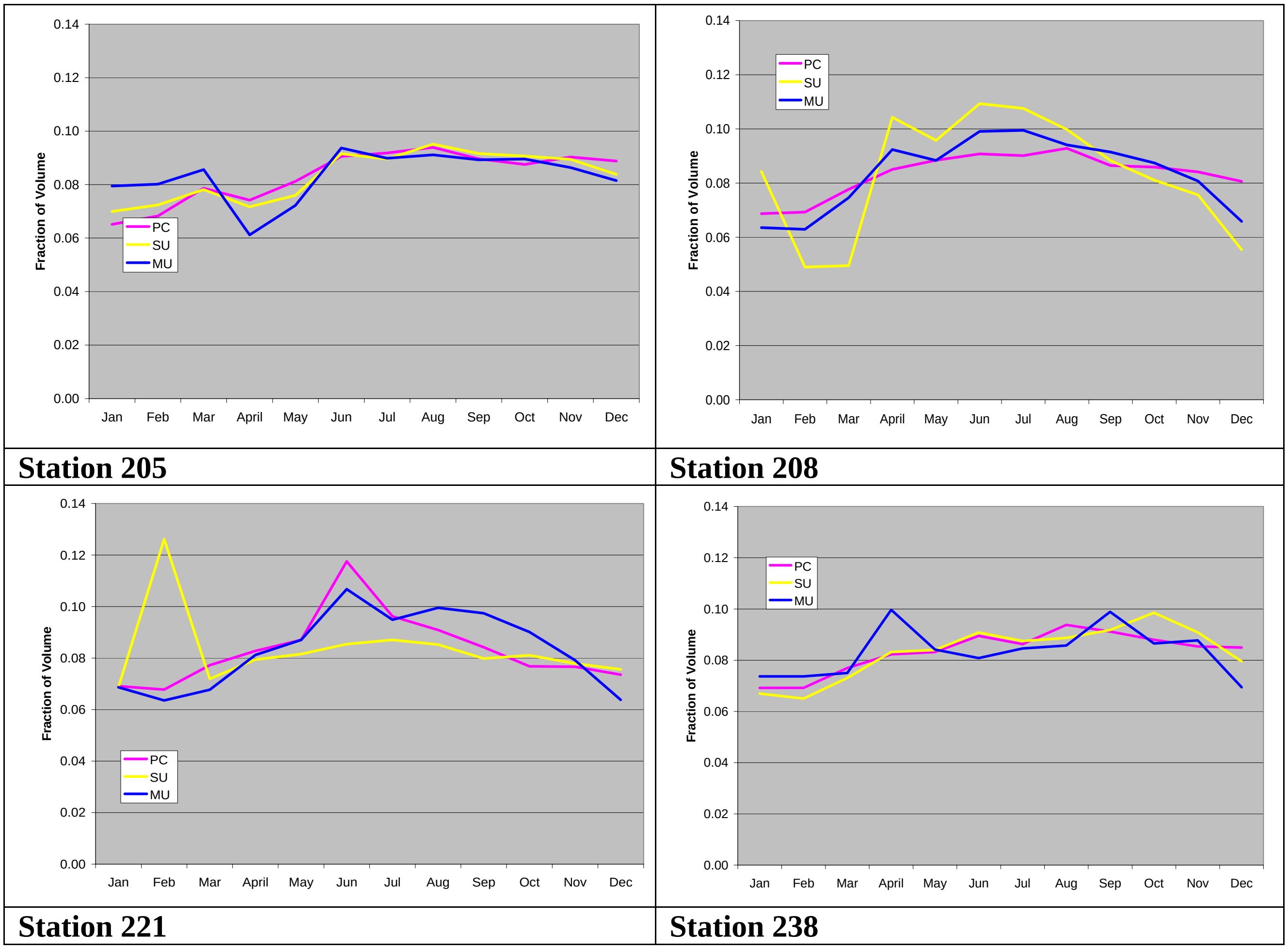


Figure 5.5. Monthly variations for rural primary stations

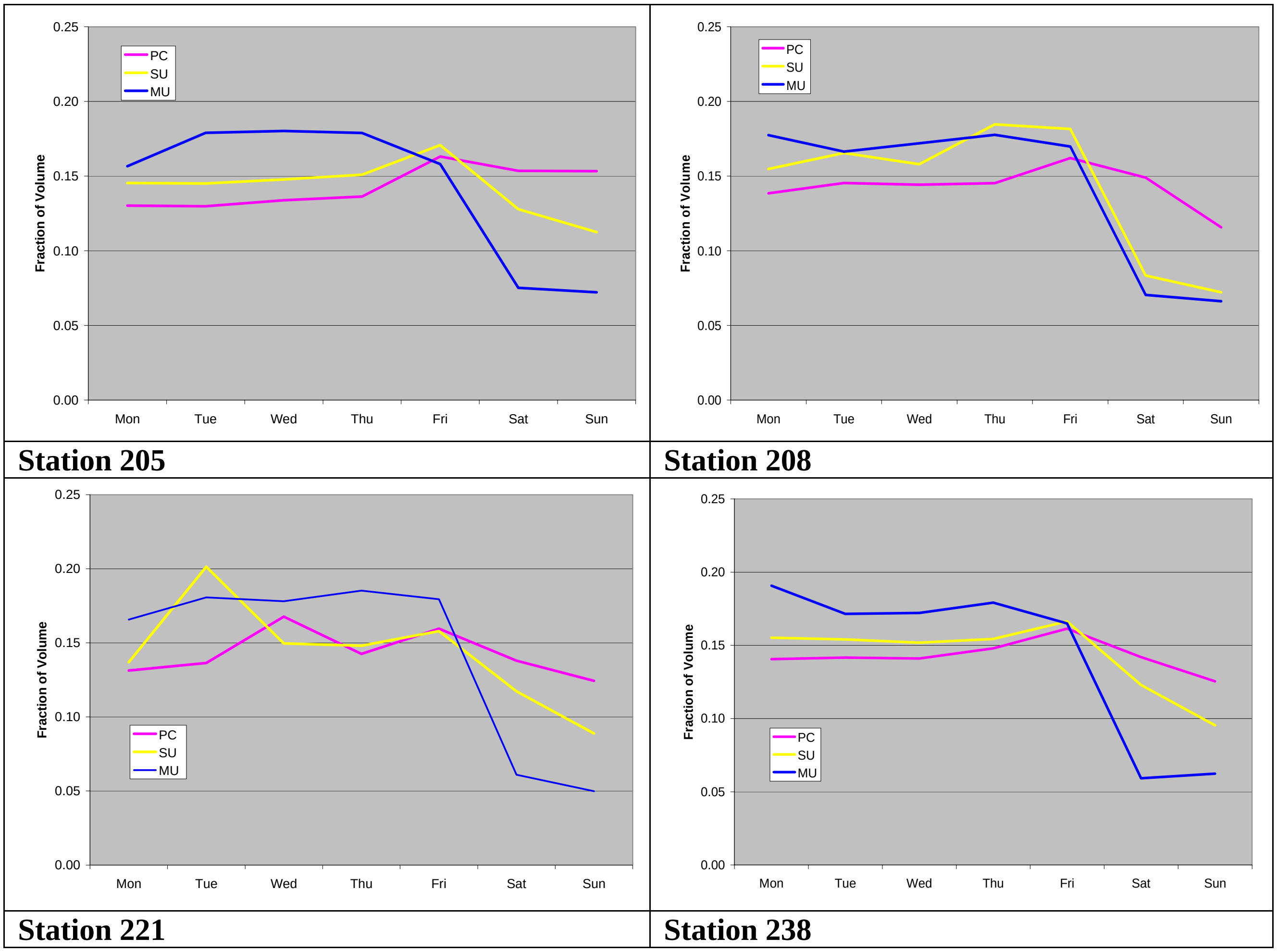
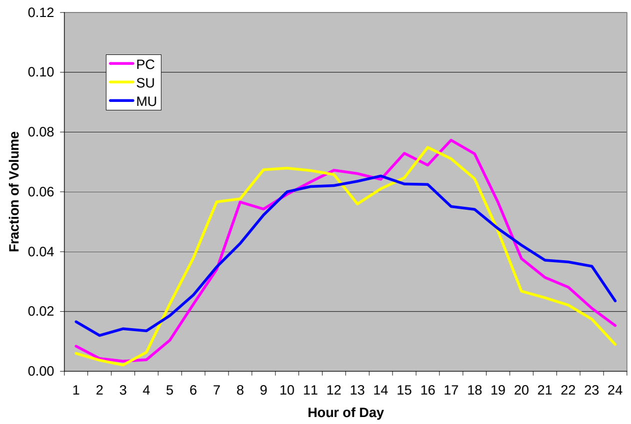
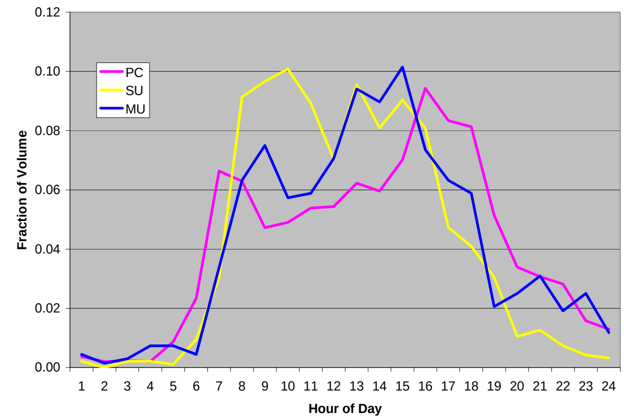


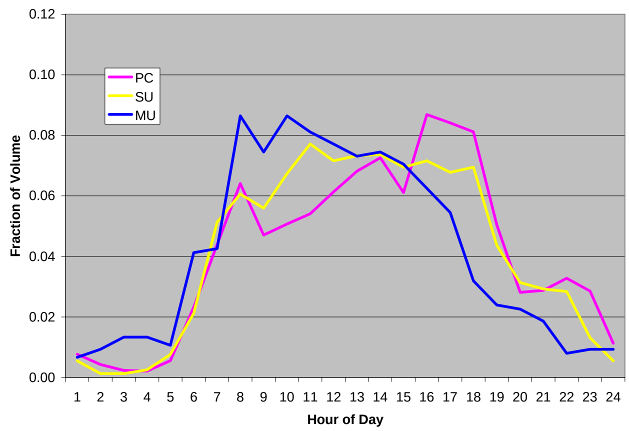
Figure 5.6. Weekly variations for rural primary stations



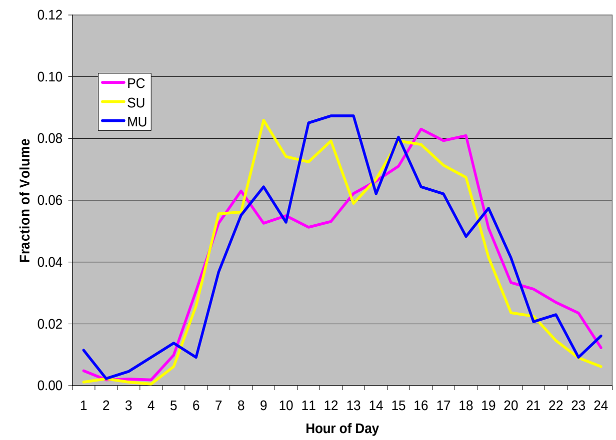
Station 205



Station 208

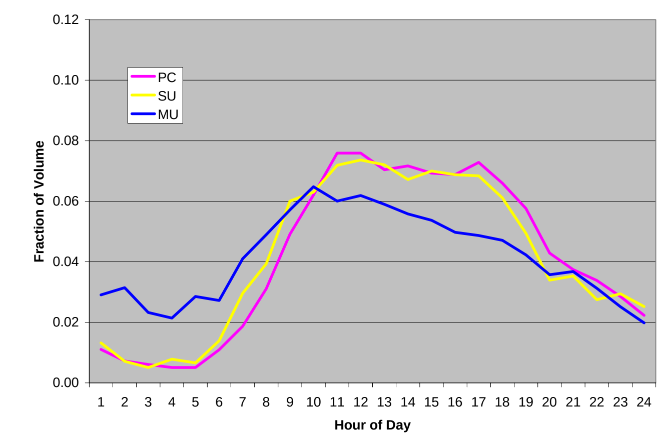


Station 221

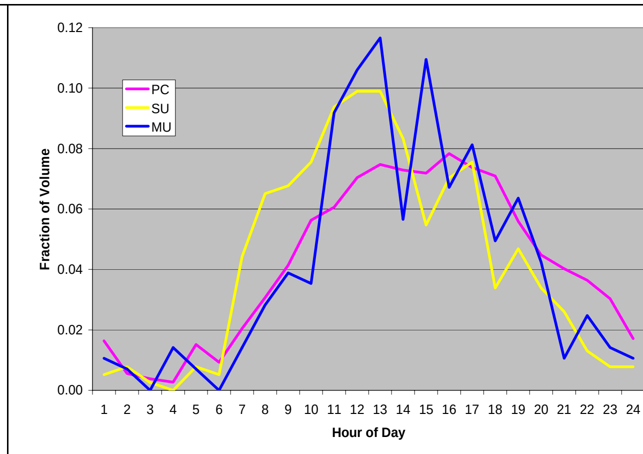


Station 104

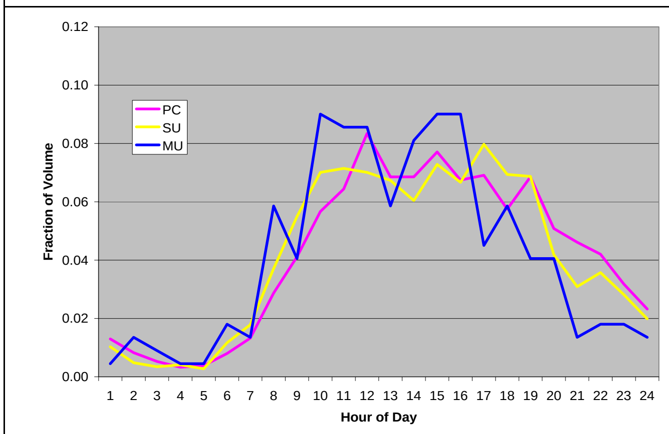
Figure 5.7. Daily variations for rural primary stations (Monday in July)



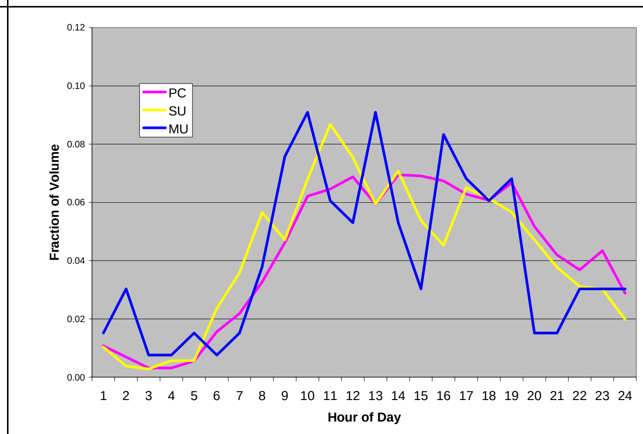
Station 205



Station 208



Station 221



Station 238

Figure 5.8. Daily variations for rural primary stations (Saturday in July)

6. SUMMARY AND CONCLUSIONS

This research evaluated three different methods to calculate heavy-truck AADT and, subsequently, VMT. Traffic data from continuous count stations provided by the Iowa DOT were used to estimate AADT for two different truck groups (single-unit and multi-unit) using the three methods. The first method developed monthly and daily expansion factors for each truck group. Truck AADT was calculated by applying truck expansion factors to short-term counts. The second and third methods created general expansion factors for all vehicles. Truck AADT was calculated by multiplying short-term counts by generic expansion factors and truck percentages. Truck percentages for the second method were based on the annual percentage of trucks for each group from continuous count stations. The third method used daily truck percentages from short-term counts.

Accuracy of the three methods was compared using *n*-fold cross-validation. In *n*-fold cross-validation, data are split into *n* partitions, and data from the *n*th partition is used to validate the remaining data. Accordingly, data from continuous count stations were divided into four groups, and each group was reserved for one partition as the validation dataset. Short-term counts were extracted from the validation dataset, and then AADT was estimated using each of the three methods. Actual AADT by truck group for each count station was compared to the estimated AADT by truck group for each method.

Data were analyzed for rural primary and rural interstate roadways. Data from continuous count stations for the 2001 counting year were used. Although 2002 data were available, the DOT felt that there had been significant problems with data quality and suggested use of the 2001 data. A total of 36 rural primary ATR stations and 14 rural interstate stations were used. Data were analyzed for two truck categories: single unit trucks (SU), which was composed of FHWA vehicle classes 4 to 7, and multi-unit trucks (MU), which included FHWA vehicle classes 8 to 13.

To perform an accuracy assessment of the results obtained from the three methods, the estimates of the mean squared error of prediction (MSEP) obtained from cross-validation were compared. On average, the smaller the MSEP, the less errors in the predictions and, consequently, the better the method.

The results for rural primary roadways for single-unit trucks show that the estimated MSEP for the truck expansion factor method (method 1) was 2,354, the corresponding MSEP for the annual truck percentage method (method 2) was 11,942, and the MSEP for the daily truck percentage method (method 3) was 2,595. Thus, for single-unit trucks, the truck expansion factor method performed the best in terms of minimum expected error. In the case of multi-unit trucks, the results show that the MSEP for method 1 was 12,341, the corresponding MSEP for method 2 was 98,837, and the MSEP for method 3 was 28,773. Again, the best method in terms of minimum prediction error was the truck expansion factor method.

Similar results were found for the rural interstate category. The mean squared error was lowest for the method that developed expansion factors separately for the different truck groups for both the single- and multi-unit truck categories (method 1). For single-unit trucks, the MSEP was 34,028 for method 1, 61,490 for method 2, and 161,331 for method 3. For multi-unit trucks, the MSEP was 698,851 for method 1, 1,700,949 for method 2, and 10,623,191 for method 3. For some stations, different methods produce different results, but the average MSEP was lowest for that method.

Overall, the prediction error was the lowest for the method that developed expansion factors separately for the different truck groups for both single- and multi-unit trucks. This indicates that use of expansion factors specific to heavy trucks results in better estimates of AADT and, subsequently, VMT than using aggregate expansion factors and applying a percentage of trucks.

Monthly, daily, and weekly traffic patterns were also evaluated. Significant variation exists in the temporal and seasonal patterns of heavy trucks as compared to passenger vehicles. This suggests that the use of aggregate expansion factors fails to adequately describe truck travel patterns.

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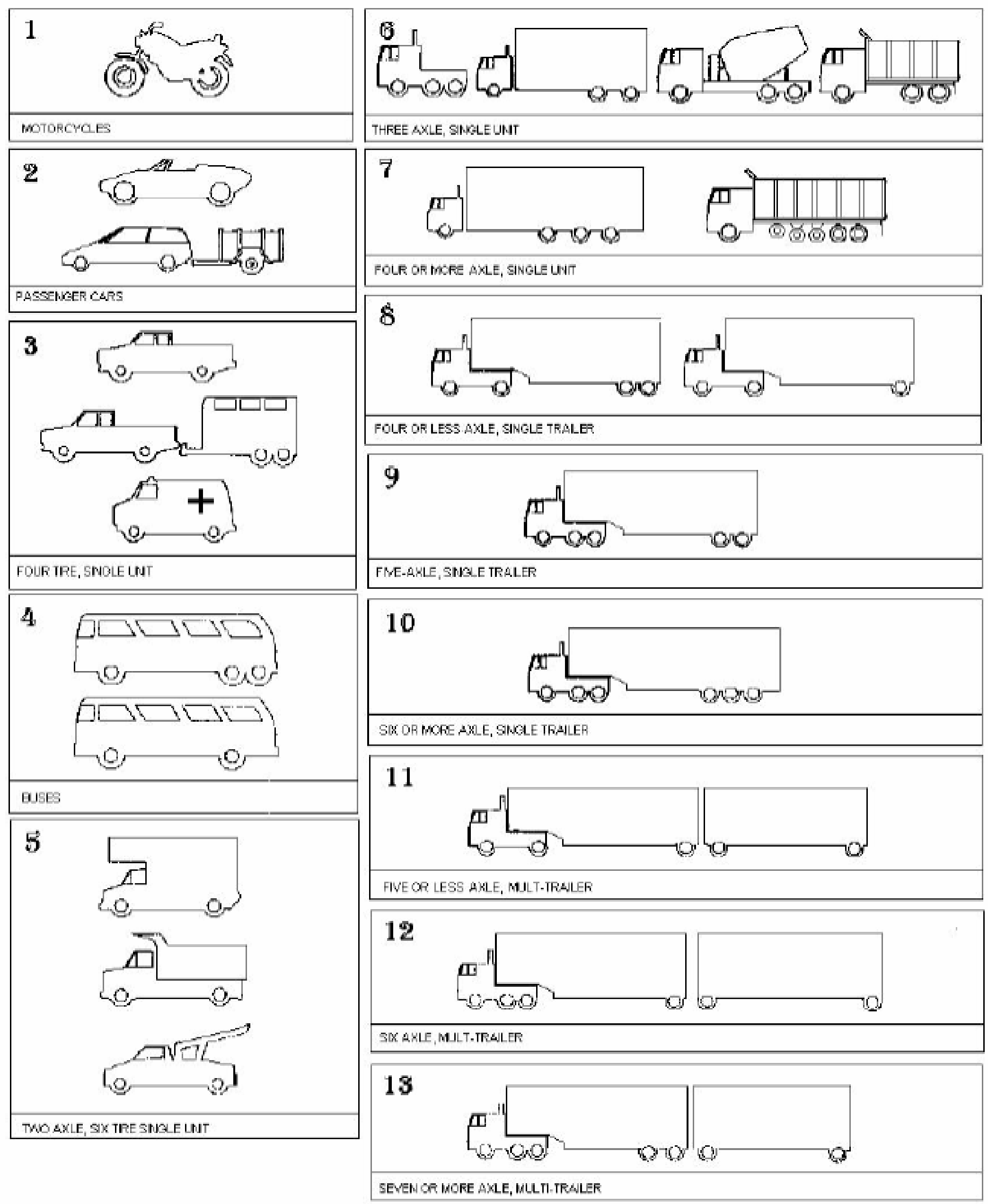
APPENDIX A: FHWA VEHICLE CLASSIFICATION SCHEME (USDOT 2001)

The FHWA Classification scheme is divided into categories based on whether the vehicle carries passengers or commodities. Commodity carriers (Non-passenger vehicles) are further subdivided by number of axles and number of units, including both power and trailer units. Note that the addition of a light trailer to a vehicle does not change the classification of the vehicle. A pictorial representation of the classification scheme is given below:



Vehicle Class Definitions

Class 1- **Motorcycles:** All two- or three-wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handle bars rather than wheels. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheeled motorcycles.

Class 2- **Passenger Cars:** All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.

Class 3- **Other Two-Axle, Four-Tire, Single-Unit Vehicles:** All two-axle, four-tire vehicles other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single unit vehicles pulling recreational or other light trailers are included in this classification.

Class 4- **Buses:** All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. Modified buses should be considered to be trucks and be appropriately classified.

Note: In reporting information on trucks the following criteria should be used:

a. Truck tractor units traveling without a trailer will be considered single-unit trucks.

b. A truck tractor unit pulling other such units in a “saddle mount” configuration will be considered as one single-unit truck and will be defined only by axles on the pulling unit.

c. Vehicles shall be defined by the number of axles in contact with the roadway. Therefore, “floating” axles are counted only when in the down position.

d. The term “trailer” includes both semi- and full trailers.

Class 5- **Two-Axle, Six-Tire, Singl-Unit Trucks:** All vehicles on a single frame, including trucks, camping and recreational vehicles, motor homes, etc., having two axles and dual rear wheels.

Class 6- **Three-axle Single-Unit Trucks:** All vehicles on a single frame, including trucks, camping and recreational vehicles, motor homes, etc., having three axles.

Class 7- **Four- or More Axle Single-Unit Trucks:** All trucks on a single frame with four or more axles.

Class 8- **Four- or Less Axle Single-Trailer Trucks:** All vehicles with four or less axles consisting of two units, one of which is a tractor or straight truck power unit.

Class 9- **Five-Axle Single-Trailer Trucks:** All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.

Class 10- **Six- or More Axle Single-Trailer Trucks:** All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.

Class 11- **Five- or Less Axle Multi-Trailer Trucks:** All vehicles with five or less axles consisting of three or more units, one of which is a tractor or straight truck power unit.

Class 12- **Six-Axle Multi-Trailer Trucks:** All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.

Class 13- **Seven- or More Axle Multi-Trailer Trucks:** All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

APPENDIX B: SUMMARY OF RESPONSE FROM DOTS

State	Response to Questionnaire	Additional Information Received
California	Yes	-
Illinois	Yes	-
Indiana	No	-
Iowa	Yes	Iowa DOT Traffic Monitoring Program Manual
Kansas	Yes	Traffic Counting & Adjustment Procedures Document
Minnesota	Yes	MN DOT Procedure Manual for Forecasting Traffic on Minnesota's Highway Systems
Missouri	Yes	-
Nebraska	Yes	-
South Dakota	Yes	SD DOT Traffic Monitoring Manual
Wisconsin	Yes	-
Florida	Yes	Project Traffic Forecasting Handbook

APPENDIX C: RAW DATA FROM COUNT STATION 201

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