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Task A Report

An Optimal Traffic Data Design for Using Continuous Monitoring Sites

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1.0 Introduction

Information about use of the nation's road system comes from a variety of sources. Traffic is counted periodically for short periods of time (usually 24 or 48 hours) at tens of thousands of locations across the country. The resulting *short counts* are adjusted for seasonal and day-of-week variations in traffic volumes to produce estimates of *annual average daily traffic* (AADT) at each site. The seasonal and day-of-week factors used for these adjustments are derived from hourly, daily, and annual traffic counts collected at a more limited number of locations by *automatic traffic recorders* (ATRs). *Growth factors,* derived from ATR data and possibly from other data, are used to produce annual adjustments to AADT estimates for short-count (or *coverage count*) sites that are not counted every year.

The distribution of total traffic across vehicle classes is estimated from *classification counts* that are obtained using short-term or annual counts from *automatic vehicle classifiers* (AVCs) or from manual classification counts. The most common classification system is the 13-way "Scheme F" used by the Highway Performance Monitoring System[1] (HPMS) of the Federal Highway Administration (FHWA), but several more aggregate classification systems also exist. The Traffic Monitoring System requirements established by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1992 effectively establishes a five-way classification: multiple-trailer combinations; single-trailer combinations; buses; four-tire vehicles; and, as a residual category, other single-unit vehicles (including motorcycles and trucks with more than four tires). Data from classification counts or from coordinated vehicle and axle counts are also used to develop *axle-correction factors* for converting axle counts obtained at many coverage-count sites to vehicle counts.

Various types of permanent or portable *weigh-in-motion* (WIM) equipment are used to measure the dynamic loads of vehicles and individual axles. Axle weights are converted to *18,000 pound* (18 kip) *equivalent single axle loads* (ESALs) to measure the pavement stresses produced by individual vehicles, by classes of vehicles, and by all vehicles.

Estimates of *vehicle-miles traveled* (VMT) on various road systems are developed by dividing each system into sections having reasonably homogenous traffic volumes, multiplying estimated AADT on each section by the section's length, and summing. The AADT estimates used for any section may be developed: from traffic counts on the section; by judgement and interpolation from AADT estimates for adjoining sections ; or, for the lower *functional systems,* by assumption.

For most functional systems, HPMS develops its own estimates of VMT by combining count-based AADT estimates for a random panel sample of sections stratified by functional system and AADT *volume group* with state estimates of the distribution of functional system

[1] Federal Highway Administration, *Highway Performance Monitoring System Field Manual,* December 1987 and draft revisions dated February 1993.

mileage across volume groups. Excluded from this requirement are the *rural local* and *urban local systems* and, effective in 1993, the *rural minor collector system*. Also effective in 1993, the states are required to provide HPMS with AADT estimates for every section of the *Principal Arterial System* (PAS), so that the only systems for which HPMS estimates of VMT will depend on the volume-group stratification will be the *rural* and *urban minor arterial systems* and the *urban collector* and *rural major collector systems*.

The goals of the present study are to review and evaluate the current system for collecting and analyzing data on roadway usage, and to develop and test procedures that can be used for producing improved estimates of road usage. Toward these goals, Task A of this study included:

- a review of documents describing the existing system and procedures used in the collection and analysis of usage data;
- a mail survey of nine states to obtain a general understanding of procedures actually in use; and
- extended interviews with the staff of three of these states (Florida, Ohio, and Washington) to gain a more detailed understanding of the procedures used by these states.

The results of the survey and interviews are presented in Chapter 2 of this report, along with a summary of significant findings. The third chapter presents discussions of several issues relating to the HPMS volume-group stratification and its effect on HPMS estimates of VMT. The fourth chapter describes several proposed Task B analyses of the precision of alternative procedures for estimating AADT, AADT by vehicle class, and ESALs. The final chapter presents several preliminary recommendations that have resulted from our effort so far and that are not related to any of the analyses we propose to perform in Task B.

This report contains four appendices. The first two contain reproductions of the survey instrument used for the mail survey and an interview guide used for the three interviews conducted. Appendix C presents the details of an analysis performed to estimate an apparently small downward bias in the estimates of VMT that result from the use of HPMS' volume-group stratification; the results of this analysis are discussed briefly in Section 3.1 (in Chapter 3). The final appendix summarizes the results of an investigation into alternatives to the volume-group stratification.

2.0 Results of the Survey and Interviews

A mail survey of traffic-monitoring and VMT-estimation procedures used by nine states was conducted in December 1992 and January 1993. The nine states surveyed were Arizona, Florida, Georgia, Iowa, Massachusetts, Ohio, Pennsylvania, Tennessee, and Washington. This survey was supplemented by personal interviews conducted in March 1993 with relevant members of the staff in three of these states: Florida, Ohio, and Washington; and with the Mid-Ohio Regional Planning Commission (which serves the Columbus, Ohio area).

The first section of this chapter presents the most significant findings of the survey and interviews. A more complete summary of the survey responses from the nine states is provided in the second section, a summary of current and planned permanent monitoring sites in those nine states is presented in the following section, and a comparative summary of the information obtained in the course of the personal interviews is presented in the final section of the chapter. The survey instrument used for the mail survey is reproduced as Appendix A, and an agenda used for conducting the personal interviews is reproduced as Appendix B.

2.1 Significant Findings

This section presents those findings of the survey and interviews that appear to have the most significance for this study. These findings are grouped by major topic area.

Short-Term Traffic Counting

Count Duration

Six of the nine states surveyed regularly obtain some or all short-term traffic counts for 24 hour periods. Two states commented on the relatively high rate of failure for tube counters when they are used for more that 24 hours on high-traffic roads and one (Florida) believes 48 hour counts are unnecessary in urban areas because traffic volumes vary little between consecutive weekdays. We plan to analyze this issue further in Task B.

Ohio makes significant use of volume estimates derived from 8, 12, and 24 hour manual, turning-movement counts and Iowa makes at least some use of 8 hour manual counts. Ohio's 8 and 12 hour counts are adjusted to 24 hour counts using separate automobile and truck factors derived from nearby 24 hour counts. These manual counts represent about

60 percent of the volume counts taken on the state highway system and they are a significant influence on the distributions of road miles by volume group reported to HPMS.

Axle-Correction Factors

The axle-correction factors used by most states vary, at least between Interstate and non-Interstate roads and between rural and urban locations. However, Arizona's factors vary only by region.

Information about the sources of data used for axle-correction factors was obtained from Florida and Washington. Both states use 13-class AVC counts; and Washington also uses manual classification counts and simultaneous axle and vehicle counts taken at speed-monitoring sites. It would appear that the most accurate sources of data would be: the complete axle classifications performed at WIM sites; and simultaneous axle and vehicle counts (though the last source could have some difficulty in distinguishing combinations with long drawbars in states where these configurations are used). The errors introduced by the use of 13-class vehicle counts should be quite small, though some guidance on the use of these counts might be desirable — an assumed average of 3.5 axles for Class 8 (three and four axle single-trailer trucks) would appear to be preferable to the value of 4.0 used by Florida. Improved data for deriving axle-correction factors could be obtained from AVCs if their software were modified to produce axle counts as well as vehicle-classification counts.

No questions were asked about several other potentially significant issues relating to the use of axle-correction factors. These are:

- The extent to which axle factors are varied to reflect the effects of local conditions (e.g., a natural-resource based economy) or route-specific conditions (truck routes or load limits). It would appear that Florida's procedure and, to a lesser extent, Arizona's, reflect local conditions.

- The use of separate weekday and weekend axle factors to reflect significant differences in the weekday and weekend traffic mixes.

- The use of seasonally varying axle factors (which may be appropriate in agricultural areas).

- The age of the data used. (We are aware of one state that has not recalculated its axle factors in many years.)

Multi-Lane Roads

Counting procedures for multi-lane roads were not addressed in the written survey and discussed only briefly in the interviews. These roads frequently require special procedures because road tubes are most appropriate for use on roads with no more than two unseparated lanes and they cannot be used when there are more than three unseparated lanes. Accordingly, traffic volumes on freeways with six or more lanes frequently are estimated from a combination of ramp counts and counts obtained at locations where the number of unseparated lanes drops to two. To eliminate these estimation problems as well as the unavoidably high failure rates for road tubes at high volume sites, Washington State has installed permanent loops on the entire Interstate system and Florida is now doing so.

Contractor Counts

At least one state (Florida) uses contractors for some of their traffic counting although the quality of contractor counts is inferior to staff counts and contractors are not less expensive. Contractor counts are reviewed by Highway District staff for consistency with previous counts for counted sections and current counts for adjoining sections, and they are rejected for inconsistencies. Some contracts require the contractor to repeat rejected counts until acceptable counts are delivered. We know of at least one unsurveyed state (Delaware) that also uses contractor counts.

AADT

Seasonal and Day-of-Week Factors

Seasonal and day-of-week adjustments are most commonly made using combined or separate monthly and day-of-week adjustment factors. Massachusetts and Washington use average weekday adjustments instead of day-of-week. Florida uses weekly factors instead of monthly factors, an approach designed to reflect the week-to-week variations in tourist travel. A majority of the states treat holidays as weekdays in developing seasonal and day-of-week factors, resulting in some very noticeable biases in the resulting Monday factors.

At least three different procedures are used for applying day-of-week factors to short counts. Pennsylvania assures a perfect correspondence between the factors and the counts by using midnight-to-midnight periods for all short counts. Florida uses a more common procedure of dividing all counts into portions taken on separate days and applying the appropriate day-of-week factors to the separate portions. Ohio uses a variant of this procedure in which the counts for the first and last day are combined before applying a combined factor. For counts taken for periods ending on Friday, both the Florida and Ohio procedures are likely to overadjust for the increased Friday traffic volumes which are likely to be greatest for P.M. periods that are excluded from the short counts (but included in the day-of-week factors).

Most states derive sets of seasonal and day-of-week factors from data for up to 11 groups of ATRs and associate each short-count site with one of these "factor groups". Florida derives a much larger number of sets of factors (one to four sets for each county), generally using data for a single ATR for each set. (Where multiple sets are used, they distinguish Interstate and other roads, and/or rural and urban location.) One nonsurveyed state (Virginia) uses factors derived from data for individual ATRs that are nearby and believed to be on roads with characteristics that are similar to those of the short-count site, and Washington State does this for certain sites. If performed carefully, this last procedure should produce results that are better than those obtained using grouped data (but these results cannot be evaluated statistically).

At least five of the nine states use historic data for developing seasonal and day-of-week factors. However, Florida and Washington use current-year data, calculating the factors at the end of the year and then applying the factors to all counts taken during the year. This latter procedure should produce more accurate seasonal corrections than use of historic data, particularly in the case of Florida, which uses weekly corrections.

An extensive analysis of the effectiveness of alternative procedures for performing seasonal and day-of-week adjustments is planned for Task B and discussed in Chapter 4 of this report.

Growth Factors

Most states derive annual growth factors from ATR data for the current and preceding year. However, Florida and Massachusetts are experimenting with procedures that use comparisons of all AADT estimates derived from current-year counts to the corresponding preceding-year estimates (most of which are derived using growth factors), and Pennsylvania is also developing such a system. These procedures have two significant advantages over the exclusive use of ATR data and one minor disadvantage. The advantages are:

- ATRs are often located on older roads on which traffic is growing at slower-than-average rates (possibly because volume is approaching capacity). Accordingly, ATR-based growth factors frequently are biased downward.

- The use of all current-year AADT estimates allows the development of growth factors that vary by region, permitting regional variations in growth rates to be better captured.

The main disadvantage of procedures using all current-year AADT estimates is that there will be a tendency for any random errors that occur in the growth factors to be propagated over subsequent years.[1] However, this effect is likely to be smaller than the downward bias that frequently results when only ATR data are used. Accordingly, it appears likely that the Florida and Massachusetts procedures will prove to be preferable to the use of growth factors derived exclusively from ATR data.

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[1] Consider three sets of coverage-count locations, A, B, and C, counted in Years 1, 2, and 3, respectively. Consider also a random error in the growth factors estimated for Year 3 that results in overestimating Year 3 AADT on sections in Sets A and B by one percent. When Set A is counted in Year 4, the *over*estimate of Year 3 AADT on Set A sections will result in *under*estimating Year 4 growth factors, approximately balancing the previous overestimate of AADT on Set B, but producing an underestimate of Year 4 AADT on Set C. This underestimate will persist until Year 6, when new counts on Set C will result in overestimating the Year 6 growth factors and reintroducing an error in the AADT estimates for Sets A and B. This error is likely to differ from the original error because of additional random errors (in either direction) in the Year 4-6 traffic-counting and AADT-estimation process and because the use of ATR data will tend to dampen the errors over time.

Data from Local Agencies

Eight of the nine states use at least some traffic data collected by local highway agencies, though two of these states do not use any of these data for HPMS. All eight states receive raw traffic counts from the local agencies and three also receive at least some estimates of AADT from these agencies. One of the latter states, Washington, uses these AADT estimates for HPMS submission and a second (Iowa) might. Washington State has reviewed the procedures used by the local agencies for estimating AADT and has found them to be "reasonably standardized."

Vehicle Classification

Classification Counting

Most states collect traffic counts by vehicle class at some combination of WIM sites, appropriately equipped ATR sites, and short-term coverage-count sites. Although some states apparently obtain classification counts at only a limited number of coverage-count sites, the three states we interviewed routinely obtain complete or limited classification-count data at a significant portion of the sites at which short-term volume counts are obtained, and Pennsylvania does so at 90 percent of its volume-count sites.

Classification-counting programs vary not only in their extensiveness, but also in the accuracy of vehicle classification. AVCs generally use axle spacing to distinguish a vehicle's class, spacings that can be determined only in the absence of acceleration or deceleration. Accordingly, AVCs cannot be used near intersections or on most city streets. Also, these classifiers frequently have difficulty distinguishing automobiles from four-tire trucks and buses from larger single-unit trucks. Spread tandem axles and small utility trailers also create problems for these classifiers.

The states have adopted various ways of dealing with the limitations of AVCs. For counts with permanent AVCs, Washington State uses 11 vehicle classes instead of FHWA's 13, dropping motorcycles and using a single class for all four-axle vehicles. For counts with presence-detection sensors, Washington goes even further, using only four vehicle classes defined by overall length.

For HPMS reporting, Ohio uses a different approach, adding to FHWA's 13 vehicle classes additional classes for "undefined" and "misclassified" vehicles. Ohio estimates that 8 to 13 percent of all vehicles are categorized as misclassified, with most of these being automobiles. For counts at temporary sites, Ohio uses only four vehicle classes (automobile, other four-tire vehicles, other single-unit vehicles, and combinations) and combines these counts into two classes (four-tire vehicles and others) before releasing them. The counts at temporary sites consist of a mix of manual and machine counts. Ohio is currently investigating the use of a video system to produce more accurate classification counts.

In contrast to Ohio and Washington, Florida uses FHWA's 13 vehicle classes for both permanent and portable classification counts without a separate class for misclassified vehicles. However, we did not discuss the accuracy of the resulting classification counts.

The limitations of existing AVCs suggest that meaningful estimates of average daily bus traffic (required by the proposed ISTEA Traffic Monitoring System) could be difficult to develop without the use of a video system. These limitations also raise questions about the accuracy with which automobiles can be distinguished from four-tire trucks and the desirability of the current HPMS requirement that such a distinction be made. There is also some possibility that AVC misclassification frequency could be reduced by developing improved classification algorithms using state-specific data about vehicle configurations actually operated in the state.

Time-of-Day Factors

Ohio collects a large number of manual eight-hour classification counts, and Arizona Pennsylvania and Washington collect a more limited number of eight or twelve-hour counts at locations that can only be counted manually. For these locations, Washington estimates 24-hour traffic volume by vehicle class using factors derived from total 24-hour traffic at nearby locations, while Ohio does so using separate factors for four-tire vehicles and for other vehicles. Pennsylvania uses separate factors for total traffic and truck traffic by direction using statewide ATR data for ten factor groups. Arizona uses its classification counts, without adjustment, to distribute volume counts across vehicle classes — a procedure that produces the same results as adjusting classification counts to 24-hour values using the same factors for all classes.

Because combination trucks usually constitute a larger portion of nighttime traffic than of daytime traffic, the adjustment procedures used by all four states (and the Arizona and Washington procedures, in particular) are likely to underestimate the percentage of combination trucks at manual-count locations. Better time-of-day adjustments to classification counts could be achieved if separate factors were used for (at least) three types of vehicles: four-tire vehicles; other single-unit vehicles; and combinations.

Also, when adjustment factors are derived using 24-hour classification counts from nearby locations, it frequently may be possible to make meaningful distinctions between the factors to be used for the two directions of travel, capturing variations in the degree of A.M./P.M. directionality to a reasonable extent. However, the development of statewide time-of-day factors that reflect degree of directionality is much more complicated and does not appear to be warranted.

VMT

Procedures Commonly Used by the States

For any road system, the best estimates of VMT are developed using AADT estimates derived from traffic counts on every section of road in the system. Iowa currently obtains such estimates for all nonlocal functional systems, and Florida does so for the entire State Highway System. Several states estimate VMT for the Interstate system using AADT estimates for each section of the system, though, as discussed previously, it is not always practical to obtain separate traffic counts for individual sections that have more than two lanes in each direction. The new *HPMS Field Manual* requires separate AADT estimates for every section of the Principal Arterial System (PAS) and other sections of the National

Highway System (NHS), so VMT estimates derived from these separate AADT estimates will soon be available for the entire PAS/NHS.

The second best type of VMT estimates consists of those developed using AADT estimates derived from traffic counts on individual sections where available and developed for other sections from those for the counted sections using interpolation and informed judgment. Apparently, many states, including Ohio and Washington, develop such estimates for their entire state highway system (SHS). The quality of these estimates depends upon the percentage of road sections on which actual traffic counts are obtained and the care that is used in developing AADT estimates for sections that are not counted.

HPMS Estimates

HPMS develops VMT estimates for all road systems except for the local functional systems and, starting in 1993, except for the rural minor collector system. The HPMS estimates are developed from data submitted by the states for a random sample of sections, stratified by functional system and volume group. The new Field Manual requires that a 100 percent sample be used for the entire PAS/NHS, thus guaranteeing the consistency of the HPMS estimates for these systems with those produced by the states.

For systems other than the PAS/NHS, HPMS requires AADT and section-length data for a more moderate sample of sections along with universe mileage by system and volume group. For state highway systems, accurate provision of universe mileage by volume group enables HPMS to approximate the state VMT estimates very closely. Florida, Ohio, and apparently Georgia, provide such accurate information, but with the probable exception of Iowa, most or all of the other states surveyed apparently do not. The quality of the HPMS estimates of VMT for non-PAS/NHS roads depends upon both the quality of each state's estimates of SHS VMT and the extent to which these estimates are adequately represented by the universe mileages by volume group submitted to HPMS.

For non-SHS roads, Iowa is probably the only surveyed states that has information that can be used to provide accurate estimates of universe mileage by volume group, though the judgmental procedure used by Ohio makes good use of the limited information it has available. The quality of HPMS estimates of VMT on non-SHS roads is limited by the lack of information on the mileage of these roads in each volume group.

The effect of HPMS' volume-group stratification on HPMS' VMT estimates is discussed in more detail in Section 3.1.

Empty HPMS Volume-Group Strata

Selection of new sample sections is a relatively expensive process for some states. Accordingly, at least four surveyed states are relatively slow to select new sample sections for strata when the HPMS rules indicate that additional samples are required, and at least one state (Ohio) has allowed nonempty volume-group strata that contain no sample sections to exist for several years. Current procedures used for reporting traffic volumes on sections in such strata result in small, but easily avoided, errors in HPMS' estimates of VMT. This situation and a simple procedure for estimating traffic volume on such sections are discussed in Section 3.3.

2.2 Summary of Survey Responses

This section summarizes the responses to the written survey provided by the nine surveyed states (Arizona, Florida, Georgia, Iowa, Massachusetts, Ohio, Pennsylvania, Tennessee, and Washington) and supplementary information obtained from limited telephone follow-up with these states. The responses from Florida, Ohio, and Washington are also supplemented, where appropriate, with information obtained from the interviews with these three states. Information obtained from these interviews is presented in more detail in Section 2.4.

A copy of the survey instrument is reproduced in Appendix A.

I. Permanent Monitoring Stations

1,2. Most states provided updated lists of their ATR and weight-monitoring sites. Some also provided lists of SHRP sites and seasonal ATR sites. A summary of permanent monitoring sites by states is presented in Section 2.3.

3. Five states have at least some equipment that is capable of recording 15 minute counts. Two states sometimes save the 15 minute counts, but the other states do not.

II. Collection of Short-Term Data

1. a) All states obtain 24 and/or 48 hour volume counts. Iowa and Ohio also obtain counts for shorter intervals, and Georgia and Washington also obtain counts for longer intervals. Arizona and Massachusetts are the only states that obtain only 48 hour counts.

   b) All states obtain 24 and/or 48 hour classification counts. Georgia and Washington also obtain counts for longer intervals. Arizona, Pennsylvania, and Washington obtain shorter counts on sections that can only be counted manually and Ohio obtains an extensive number of eight-hour manual counts.

   c) Most states perform weight monitoring for periods of between 24 and 168 consecutive hours. Ohio uses a bridge WIM system for 16 to 20 noncontinuous hours over a two to three day period. Iowa does not have a regular short-term weighing program but did collect weight data for periods of 15 to 23 hours as part of a 1991 truck weight study; they also have four WIM sites. Washington currently performs weighing only at permanent WIM sites; they currently have about 26 two-way WIM sites in operation.

2. a) In most states, the total number of short counts exceeds the number of short counts on HPMS sample sections by a factor of two to seven.

   b) Most states obtain short-term classification counts at 100 to 400 sites. Iowa uses about 1,150 sites, and Pennsylvania about 2,250. For all short counts, Washington now uses counter/classifiers that are capable of producing four-bin classification based on length only. New Florida guidelines will greatly increase the number of classification counts they obtain.

   c) Iowa and Washington are the only states that obtain weight data only at continuously operated WIM sites. The other states indicated that they operate between 14 and 30 short-term sites, though the responses to Question III.7 suggest that at least four of these states operate short-term sites for nonstatistical purposes only.

3. States that schedule counting for periods of 48 hours or more use counts for shorter intervals that result from equipment malfunction, etc. Florida and Georgia volunteered that they require a minimum of 24 hours of data and Iowa that they require a minimum of 12 hours.

4. None of the nine states surveyed said that they have summer-only short-term counting programs, though most cut back or eliminate counting during winter months (and we have been told that local roads are counted by Iowa only during the summer).

5. Six of the nine states collect at least some short-term counts during holiday weeks, though five do not count on the holiday and Iowa does not count on days that are adjacent to the holiday. The sixth state that counts on holiday weeks, Georgia, did not indicate the days on which it counts.

6. Six of the nine states use classification counts or weight data that are collected over a period of less than 24 hours. One of these states, Arizona, uses the resulting classification counts as indicative of the *distribution* of vehicles across classes without any time-of-day adjustment. The remaining states make time-of-day adjustments to the classification counts, but Ohio does not adjust weight data.

7. a) Three states obtain some short-term counts (up to 50 percent) using cumulative counters.

   b and c) This question was an inadvertent repeat of I.3, but there were some inconsistencies in the answers to the two questions.

8. All short-term counting is done by district personnel in Florida, and some of it is done by district personnel in Iowa, Pennsylvania, and Washington. The remaining states say they use only headquarters personnel.

9. For counters with electronic storage units, the number of short-term sites handled per person per week ranges from 12 to 65, with the highest figures reported by the states that do the most counting. These states also appear to obtain the highest numbers of sites counted per counter (see Question 11).

10. All states obtain small numbers of seven-day and/or weekend counts for special purposes.

11. No two states follow the same practice for days of week used for setting up counters and collecting them. Pennsylvania uses only midnight-to-midnight counts collected on Tuesdays and Thursdays. The regime used by Arizona and Washington allows counters to be used at only one site per week, with most Washington counts being for periods of 48 or 72 hours, usually ending at midnight Friday morning. All states, except for Pennsylvania and Washington, evidently begin and end their counting in the middle of the day. Four states follow routines that apparently allow them to use at least some counters at three or four sites per week. Iowa includes Sunday evening traffic in some of their counts.

12. a) Georgia is the only state that does not use any counts collected by metropolitan planning organizations or local jurisdictions, though Ohio and Tennessee do not use such counts for HPMS. Two-thirds of all of Washington's HPMS counts are supplied by county or local agencies.

    b) All states using traffic counts collected by other organizations obtain raw counts from these organizations. However, Iowa, Tennessee, and Washington also obtain AADT estimates from these sources. At least one of these states (Washington) uses the AADT estimates when supplied, apparently without any individual review of the estimates.

    c) All states using traffic counts collected by other organizations now provide these organizations with written standards for obtaining traffic counts. All states obtaining AADT estimates from these sources (and two that do not) also provide written standards for estimating AADT.

III. Traffic Adjustment Factors

1. a and b) Five states use separate monthly and day-of-week or week-day/weekend adjustment factors, and three use combined factors. Florida has used only a weekly correction factor in the past, but some Florida districts are now incorporating day-of-week factors.

    c) All states use axle-adjustment factors.

d) Two states count all sections annually, two states will begin using growth factors in 1993, and the other five are already using growth factors.

e) Pennsylvania uses a separate set of day-of-week by month factors for adjusting truck counts and also two sets of hourly factors for adjusting total traffic and truck traffic when less than 24 hours of data is obtained. Iowa and Ohio also use volume counts obtained for less than 24 hours. Ohio adjusts these counts using automobile and truck counts from a nearby 24-hour manual count; Iowa did not indicate that they adjust these counts.

2. a and b) Most states use four to eleven strata reflecting rural/urban and functional system and/or regional differences in traffic patterns. All states except Iowa and Ohio have some type of regional distinctions and/or a separate recreational stratum. Florida stratifies by county, with some counties having an Interstate/other distinction; Florida eventually hopes to use an Interstate/other distinction in all counties and a rural/urban distinction in urbanized counties.

c) Three states stratify axle correction factors by functional system and four use the same stratification used for seasonal corrections. Tennessee calculates separate factors for each of 485 classification-count sites and selects factors to be used for coverage-count sites by matching characteristics with the classification-count sites. Florida has been using three different procedures, varying by district; their new system will stratify by county and Interstate/other (but not rural/urban).

d) Georgia and Pennsylvania adjust classification counts using the same stratification as they use for volume counts, and Washington is currently developing an adjustment procedure. The other six states apparently do not apply seasonal or day-of-week adjustments to classification counts.

e) Three states adjust ESAL estimates using the same stratification as they use for volume counts, two use other stratifications, two apparently use only annual data, and one apparently uses an informal procedure.

3. a) Seven states recalculate adjustment factors annually, Iowa recalculates monthly, and Ohio biennially.

b) Two states use five years of data when calculating adjustment factors, one uses three years, three use one year, and three did not specify. Two of the three states using one year of data (Florida and Washington) use data for the year for which adjustments are being made, while the third state (Pennsylvania) uses prior-year data.

Tennessee introduces newly revised factors when they become available (i.e., in the middle of the year) but does not apply these factors to earlier counts that have already been adjusted using the old factors.

4. Of the eight states that use day-of-week or weekday/weekend adjustment factors, only three exclude holiday data in calculating these factors.

5. Four states estimate growth factors using only ATR data. Tennessee (which has annual data from both ATR and short-count sites), and Florida and Massachusetts (which do not) use data from both types of sites. (Tennessee uses growth factors only for design projects for locations that are not counted annually.) Pennsylvania currently uses only ATR data but is developing a more sophisticated system that will combine ATR data with counts for HPMS sample sections. One state gave an ambiguous response, and one (Georgia) counts all sites annually and does not use growth factors.

6. a) Question 6 requested information about seasonal and day-of-week adjustments to short-term vehicle classification counts but failed to ask about the number of vehicle groupings for which separate adjustments are made. Washington uses separate sets of adjustments for automobiles, single-unit trucks, single-trailer trucks, and multi-trailer trucks (but they normally do not perform day-of-week or weekday/weekend adjustments). Pennsylvania adjusts all truck counts as a single group. The response from Georgia suggests they adjust truck counts separately, though the specific vehicle categories adjusted are not specified. At least three of the remaining states adjust total volume but not the counts for individual vehicle classes.

   b) Georgia, Pennsylvania, and Washington use data from automatic vehicle classifiers to derive the adjustment factors. Georgia also uses data from periodic counts made at weigh stations, and Washington uses data from special counts "for suspected Friday and Sunday conditions."

7. Five states obtain annual average truck weight estimates from WIM data only, one (Ohio) by adjusting short-term data using judgement, and one (Iowa) by adjusting short-term data using a procedure similar to that used for adjusting AADT. Procedures of this last type are also being developed by Georgia and Washington. Massachusetts provided no indication of how annual truck weight estimates are obtained.

8. At least seven of the nine states develop VMT estimates other than those developed for HPMS. These VMT estimates are usually for the SHS. They usually incorporate counts from appreciably more locations than those counted for HPMS. In some states, all sections of the SHS are counted periodically; in others, AADT on sections not counted is estimated using a combination of interpolation and judgment. The resulting estimates of SHS VMT should be identical to the HPMS estimates for those functional systems

for which HPMS requires a 100 percent sample and they are of higher quality than the HPMS estimates for other functional systems.

IV. Use of HPMS' Volume-Group Stratification

Iowa did not answer the questions in Section IV because it does not use HPMS sampling methods. Responses from the other eight states are summarized below.

1. a) All eight states move HPMS sample sections from one volume-group stratum to another when their AADT changes.

   b) Three states do the same for other sections, three normally do not, and two did not answer the question. At least one of the states that said it does not move nonsample *sections* between volume-group strata (Ohio) does move nonsample *mileage* between strata, an action that has the same desirable effect.

2. In response to this question, Georgia, Massachusetts, and Ohio provided useful data that are reported and analyzed in Appendix C and discussed briefly in Section 3.1.

3 Washington is currently completely revising the assignment of sections to volume groups, apparently for the first time. Five other states have never done so, and the two remaining states misunderstood the question (and probably have never completely revised these assignments).

4. Seven of the eight states have added sample sections to volume group strata, but Massachusetts does so only when the staff has time and Ohio has only recently begun selecting new sample sections. Ohio is now adding sections in one or two urbanized areas per year. In the meantime, when they have an empty sample for any stratum, they move all mileage in the stratum into an adjoining volume group.

   The eighth state, Arizona, apparently does not currently maintain the data needed to select new sample sections, though they are in the process of rectifying this. In the meantime, when they have an empty sample for any stratum, they apparently "borrow" a sample section from another stratum for the purpose of developing data for the stratum.

5. Pennsylvania and Washington are the only states that have dropped sample sections from strata that have excessive numbers of sample sections.

6. It appears that, in all states, there are no special rules for adding sections of newly built roads to the sample, but that such roads have a small probability of being randomly selected if they are in a stratum whose sample requires expansion.

2.3 Permanent Monitoring Sites

Exhibit 2.1 summarizes the approximate numbers of permanent monitoring sites in the nine surveyed states, including sites that are expected to be in operation in the next few years. These sites have (or will have) permanently installed sensors, though they are not all used continuously.

For WIM sites, Exhibit 2.1 distinguishes between sites that have sensors in all lanes and those that have sensors only in selected lanes. The latter sites are Strategic Highway Research Program (SHRP) sites at which the state has chosen to install sensors only in the lanes(s) for which SHRP requires data. The former sites include six in Florida and one in Pennsylvania that either are monitored only in one direction or have AVCs in all lanes but WIM detectors only in some lanes.

The data in Exhibit 2.1 for other AVC sites is only for sites capable of distinguishing axle spacing for use with FHWA's 13 vehicle-class (VC) categorization. Permanent four-class classifiers used by Washington State at 20 sites are excluded from the table. Many of the AVC sites included in the table are not yet in operation, and Tennessee is only in the early stages of planning for the installation of AVC equipment.

The third category of data in Exhibit 2.1 indicates the number of counting sites that have permanently installed sensors but that are not capable of 13 VC categorization. Most of these sites are ATRs, though some are used only for coverage counts.

The final category of monitoring sites in Exhibit 2.1 consists of speed-monitoring sites that are not capable of 13 VC categorization and are not used for traffic counting. These sites generally contain inductive-loop vehicle sensors but no axle sensors.

2.4 Summary of Interview Responses

This section summarizes the responses obtained from interviews conducted with Florida, Ohio, and Washington personnel. A copy of the interview agenda used is reproduced in Appendix B.

Short-Term Traffic Counting

All three states have several different short-term counting programs with procedures that vary among the states and with the programs.

Florida

Florida's Transportation Statistics Office counts traffic on every section of state highway once every three years and on all HPMS sample sections that are not on the SHS once

Exhibit 2.1 Existing and Planned Permanent Monitoring Sites

	Arizona	Florida	Georgia	Iowa	Massachusetts	Ohio	Pennsylvania	Tennessee	Washington
Weigh-in-Motion									
All Lanes	5	13*	90	25	5	20	6*	—	37
Selected Lanes	23	—	16	7	—	—	—	15	—
Other AVC Sites (13 class capable)	4	62	75	30	—	21	16	50	8
Other Counting									
ATRs	38	75	25	122	80	56	60	33	90
Coverage					37	147			
Other Speed Sites	40	—	—	—	30	30	29	4	—

* Includes some sites that are monitored in only one direction or with AVC in all lanes but WIM in only some lanes.

every three or four years. Until recently, state highway sections were counted annually, but the accuracy of the AADT estimates derived from the counts does not warrant such frequent counting. However, sections that are likely to exhibit atypical growth are counted in every year in which such growth is likely. Counts for sites at which traffic is known to be permanently unbalanced between directions are maintained as separate counts. Counts for sites at which temporary directional imbalances exist (e.g., as a result of tourist travel) are combined, but the imbalance is reflected in the directional factor (D-factor) computed for the site.

All counts are for 24 hour periods in urban areas and 48 hour periods in rural areas. The shorter period is used in urban areas primarily because traffic on consecutive days does not change significantly in these areas, though problems with counting equipment at high-volume locations may also be an influence. When counters at rural locations fail before 48 hours of data are collected, they recount.

Counting is performed by about 14 full-time people located in seven district offices and by contractors. The quality of contractor counts is low and the cost high (about $350 per 24-hour count if counts must be retaken until they are acceptable, about $150 per 24-hour count otherwise). Districts that review contractor counts have been rejecting up to 40 percent.

State counting personnel spend 4 to 4.5 days in the field each week, returning to the office on Friday. They obtain 40 to 50 counts per person per week.

Many of the portable counters used for coverage counts obtain counts by vehicle class. Florida has three procedures for converting axle counts (obtained from nonclassifying counters) to vehicle counts, with the procedures varying by district. These were not discussed, but the survey response indicates the primary procedure uses two or three factors for each county (rural, urban, and sometimes "major highway"). The other procedures are said to be "by count station" and "by highway section;" presumably these are judgmental adjustments. The factors used are derived from 13-bin classification data obtained at AVC sites, with all buses assumed to have two axles and Vehicle Class 8 (three and four axle single-trailer trucks) treated as having four axles.

Permanent loops are being installed on freeways to allow direct counts of through traffic volumes to be obtained.

Additional counting is performed by the traffic operations, construction, and development offices, but the procedures used by these offices were not discussed. Railroad grade crossings are also counted regularly, presumably by the Transportation Statistics Office.

Washington

The Travel Data Collection Branch (TDCB) of the Washington State Department of Transportation (WSDOT) divides the entire SHS into sections with uniform traffic volume. Traffic on each such section is counted at least once every four years or estimated from counts taken on adjoining sections. All SHS sections that correspond to HPMS sample sections are counted once every three years.

HPMS sample sections that are not on the SHS (about two-thirds of the total) are counted by the cities and counties using procedures that were reviewed by the state three or four years ago and that are considered to be reasonably standardized. Concern was expressed about the ability of the cities and counties to provide counts for all sections of the NHS under local control as will be required in 1993 and subsequent years.

The two most urban highway districts in the state do their own counting, while SHS counts in the other four districts are collected by main office staff based in Olympia. In general, Olympia-based counting personnel spend Monday morning and Friday afternoon travelling, Monday afternoon and Tuesday setting up counters, and Friday collecting counters. Wednesday and Thursday are spent doing other useful things, including setting up for special purpose weekend counts (normally taken from noon Friday to noon Monday). Counts usually are obtained for a 48 or 72 hour period ending at midnight Friday morning, but counts for other 48 hour weekday periods may be substituted when 48 hour counts ending at midnight Friday are not available. The Olympia-based counting staff consists of six persons working nine months per year and another four persons working parts of the year. They obtain 12 to 16 weekday counts per person per week.

All WSDOT counting is performed using GK counter/classifiers attached to a pair of road tubes. They have two data modules per classifier so that one can be brought back to the office for reading while the other is counting traffic. These classifiers are used to divide traffic into four classes based on overall axle spacing, corresponding roughly to automobiles, small trucks (predominantly single units), medium trucks (including semis), and large trucks. Permanent counters are installed on freeway mainlines and on some ramps, so they do not require road tubes at high-volume sites. About three percent of sites at which road tubes are used require recounts.

Counting procedures used by local agencies were not discussed. However, it appears that use of axle counters (rather than counter/classifiers) is common. A WSDOT publication (*Short Count Factoring Guide*, November 1991) provides local agencies with a set of axle correction factors by functional system derived from statewide data along with advice that locally derived factors be used if available. However, WSDOT encourages the use of axle factors obtained from nearby sites with similar vehicle mixes. Such axle factors may be derived from 13-class AVC counts, simultaneous axle and vehicle counts taken at speed-monitoring sites, or manual classification counts. Of these three alternatives, the second would appear to be the most accurate, though it appears that the first is used more frequently.

About 30 to 40 percent of all WSDOT TDCB counts are obtained in response to special requests by other offices.

Ohio

The Technical Services office of the Ohio Department of Transportation (ODOT) has several counting programs:

- HPMS;
- SHRP;
- their "Traffic Survey Report";

- special projects;
- Metropolitan Planning Organization (MPO) coverage counts; and
- railroad crossing counts.

HPMS sample sections are counted for 48 hours once every four years using time-period recording counter/classifiers. These counter/classifiers are also used for special-project counts and, most likely, for SHRP counts.

The Traffic Survey Report counts are manual turning-movement counts obtained once every four years. About 12,000 major SHS[2] intersections are counted on a four-year cycle for 8, 12, or 24 hour periods to provide traffic volume data that, along with the HPMS counts, interpolation, judgement, and some research, are used to estimate AADT throughout the SHS. All 8 and 12 hour counts are adjusted to 24 hours on the basis of 24 hour counts obtained at nearby intersections, with separate adjustments used for two to four tire vehicles and for vehicles with six or more tires. These "Traffic Survey Report" counts have been taken manually for many years and provide both SHS traffic volumes and turning-movement data. Since Ohio traffic engineers make only limited use of the turning counts, machine counts (away from the intersections) would be much more efficient. They are now looking into the Autoscope (video) system as an alternative to manual counting, but they are not currently considering conventional machine counting.

ODOT uses cumulative counters to take about 1500 "MPO counts" each year at sites selected by the states' 16 MPOs. Cumulative counters are also used for taking 24 hour counts at railroad crossings and for evaluating alternative intersections at which the "Traffic Survey Report" counts can be taken. All axle counts obtained with these counters are converted to vehicle counts using statewide factors developed by functional system from Monday-to-Friday data for the preceding year.

All ODOT machine counting is handled by three two-person crews that are based in Columbus. Counting is performed in all weeks that do not have a midweek holiday. Usually, Monday morning is spent travelling, and counters are set up Monday afternoon and Tuesday morning. The crews then start checking the Monday counters and resetting them if they have failed. A few additional counters may be set on Tuesday afternoon and Wednesday morning as time permits. If a counter fails, the counting period is restarted; but if they only have 24 hours worth of data at the end of the week, they will use it; ODOT's survey response indicates that this occurs about 20 percent of the time. Counters are retrieved between Wednesday afternoon and Friday morning. In addition to the six persons that handle machine counts, they have ten to twelve full-time employees that conduct manual counts.

For HPMS counting, they handle about 20 sites per person (40 per crew) per week. When they use cumulative counters (for MPO counts, etc.), they handle about 90 sites per person

[2] All Ohio data for the SHS refers to the SHS as it appears on state highway maps, not as identified by local signs (which may differ in some municipalities). The difference between state maps and local signs could have some effect on traffic volumes and functional system assignments.

per week. They estimate that switching HPMS counts from 48 hours to 24 hours would reduce costs by about 30 percent.

They use road tubes on all highway systems in cool weather and tape switches in the summer. They also use paste-down loops in urban areas for volume counts only. On the Interstate system (IS), road tubes have a 25 to 30 percent failure rate, frequently forcing them to use 24 hour counts or one-way counts. For tape switches, the failure rate on the IS is only about 10 to 15 percent.

Annual Average Daily Traffic

Seasonal and Day-of-Week Factors

The three states interviewed use three essentially different systems for applying seasonal and day-of-week factors to short-term counts to produce estimates of AADT.

Washington State uses average-weekday/monthly factors to derive AADT from weekday counts. Factors for each month are derived by dividing AADT from ATRs by average Tuesday-Thursday traffic (excluding any holidays) in the month. A separate set of full-week/monthly factors is also available for adjusting seven-day counts. Separate sets of these seasonal factors are developed for eight factor groups (distinguishing urban/rural location, Interstate/other, three rural regions, and, for one of these regions, east-west vs. north-south travel). Local agencies are advised to use seasonal factors that are derived for their own area, if available, or else to use the appropriate factors produced by the state. However, only four counties adjust their own counts (generally using procedures with which WSDOT was not familiar). All other local agencies evidently provide WSDOT with raw counts that are adjusted by WSDOT.

Florida performs seasonal corrections using weekly factors. These are considered to be superior to monthly factors because of the relatively high week-to-week variation in vacation travel. Separate weekly factors are developed for each county, generally differentiating urban/rural location and Interstate/other highway system; in some cases, further distinctions are made between tourist and non-tourist roads (with a possible in-between category).

Florida is also in the process of introducing a separate set of day-of-week factors. For 24 (or 48) hour counts, taken over a two (or three) day period, each count will be divided into components taken on the two (or three) separate days, multiplied by the appropriate day-of-week factor, and then the separately adjusted components will be added to produce a single overall count.

Ohio uses combined day-of-week/monthly factors for seasonal corrections, with separate factors developed for each functional system. Separate full-week/monthly and Monday-Thursday/monthly factors have also been developed, though their use is unclear. Ohio applies factors in a fashion that is similar to that being used by Florida for day-of-week factors, except that, instead of factoring the counts for the first and last day (of a three-day period) separately, Ohio combines these two counts and applies an average factor for the two days. The Ohio procedure is slightly more complex than the Florida procedure and it could be slightly less accurate, but the difference in results is likely to be small. A more significant weakness of the Ohio factoring procedure is the inclusion of holiday data as normal weekday data in the development of the seasonal factors — this process has a very obvious effect on the Monday factors developed for May and September and the Wednesday, Thursday, and Friday factors developed for November.

The seasonal factors used by Florida for any year are developed at the end of the year using data for that year and then applied to the raw counts. This desirable way of developing seasonal factors is particularly desirable when using weekly factors, because it guarantees appropriate adjustments for Easter week and for the effects of any major storms. Washington uses the same procedure for sections counted by WSDOT, but it is likely that local agencies use factors from an earlier year. (1989 factors are published in WSDOT's *Short Count Factoring Guide.*) Ohio uses five years' worth of data in developing factors, and applies the resulting factors to raw counts obtained for the following year. The use of "same year" seasonal factors, as is done by Florida and WSDOT, is less important for states such as Washington and Ohio, where monthly (rather than weekly) factors are used.

Growth Factors

All three states count traffic on a three or four year cycle. Accordingly, for any given year, estimates of AADT for most sections are obtained by applying growth factors to the preceding year's estimates.

Ohio's growth factors are obtained, by functional system, by comparing current-year ATR data to preceding-year ATR data, without any consideration to regional influences on growth. A similar procedure using WSDOT's eight factor groups is most likely used for SHS counts in Washington State, though we did not verify this. The 1988-1989 growth rates by factor group are published by WSDOT in the *Short Count Factoring Guide* and are probably used by many local agencies for non-SHS counts, though the guide encourages the use of local data. It is interesting to note that these growth rates vary more by highway type than by region!

A different procedure is used by Florida (and, we understand, also by Massachusetts). Florida derives growth factors by comparing current-year AADT for all sites counted in any given year (including ATR sites) with actual or estimated preceding-year AADT for these sites. Separate growth factors presumably are developed for all the systems for which separate seasonal corrections are developed (by county for urban/rural location, Interstate/other highway system, and, in some cases, tourist/non-tourist roads).

Vehicle Classification

Washington

All WSDOT coverage counts are obtained using counter/classifiers that are set to count four vehicle classes distinguished by overall axle spacing. These classes are described as: automobiles, small trucks, medium trucks (including semis), and large trucks. Three of these classes correspond roughly to three of the classes specified in the proposed Traffic

Monitoring System Rules (*Federal Register*, March 2, 1993, pp. 12123-12125): four-tire vehicles, single-trailer combination trucks, and multiple trailer combination trucks. However, since WSDOT does not distinguish tire or trailer configurations, the correspondence is imprecise.

The same seasonal factors are currently applied to traffic counts for all four vehicle classes. However, WSDOT plans to begin using four separate sets of factors in the near future. They currently have classifiers at about 23 permanent counting sites. They plan to increase this number to about 70 (out of a total of about 140 permanent counting sites). About 50 of the permanent classifiers will be capable of distinguishing the 13 FHWA vehicle classes and will be used for developing the distribution of VMT across vehicle classes required by HPMS. (According to WSDOT's January 1992 "Procedures Manual," they currently distinguish only 11 vehicle classes — ignoring motorcycles and using only a single category for four-tire vehicles). All 70 permanent classifiers will be used for developing the seasonal factors.

Vehicle classification capabilities and procedures used by local agencies (for non-SHS roads) were not discussed. However, the "Procedures Manual" states that classification counts in the Seattle urbanized area are 12-hour manual counts that are adjusted using machine counts of total traffic.

Florida

Many of Florida's portable counters are classifiers. These are used to obtain classification counts using the 13 FHWA vehicle classes. The implication was that, in the future, a significant number of such classification counts will be obtained each year, though the survey response indicates that, of 5,500 short-term volume counts, in the past, only about 400 have been classification counts.

Counts for each of the 13 vehicle classes are adjusted separately using weekly factors by functional system (presumably Interstate and others) obtained from approximately 62 permanent AVCs. It does not appear that any evaluation has been performed of the adequacy of the data used for adjusting counts for the less common vehicle classes.

Ohio

Ohio obtains vehicle classification data at 21 permanent AVC sites using the 13 FHWA vehicle classes plus additional classes for "undefined" and "misclassified." Their current algorithm assigns 8 to 13 percent of all vehicles to the "misclassified" category. (Few, if any, are assigned to the "undefined" class.) The majority of "misclassified" vehicles are said to be Chrysler passenger cars. Vehicles with spread tandem axles are also entered into the misclassified category by the AVCs, but not by their WIM equipment.

Ohio also obtains more limited classification data at all HPMS and turning-movement coverage-count sites. Separate counts are said to be collected for four vehicle categories: passenger (P), other four-tire (A), other single-unit (C), and combinations (B). Separate AADT estimates for the entire SHS are published in Ohio's Traffic Survey Report for two more aggregate categories: four-tire vehicles (P and A) and other vehicles (B and C); however, corresponding estimates for the four separate categories do not appear to be available. The seasonal and day-of-week factors used for converting 24 and 48 hour classification counts to estimates of AADT by vehicle class are the same for all vehicle classes; however, they intend to use pavement WIM data for developing separate factors by vehicle class in the future.

Weight Data

Florida and Washington collect weight data by vehicle class at permanent WIM sites.

Ohio currently obtains weight data from portable bridge WIM systems used on a temporary basis at preselected sites. Weight data collected by these systems are used without adjustment for seasonal variation. Ohio also has installed permanent pavement WIM systems; they currently are calibrating these systems and preparing programs for using the WIM data.

HPMS

Ohio

Ohio used its Road Inventory File (RIF) as the sampling frame for the initial selection of HPMS sample sections. SHS sections were assigned to volume groups on the basis of Ohio's estimates of AADT on each section (based on a combination of traffic counts, interpolation, and judgement). Other sections were assigned to volume groups on the basis of judgement and relatively limited traffic count information.

Random samples were then drawn from each volume group. As would be expected, when traffic was counted on these sections, it was found that a few SHS sections and a larger number of non-SHS sections had been assigned to the wrong volume group. These sections were then reassigned to the correct volume group, and, if necessary, additional sections were drawn for any undersampled volume groups. There was no need to collect traffic counts on the many non-SHS sections that were not selected as sample sections, and so the appropriateness of the volume-group assignments for these sections was never verified.

Annual HPMS submissions incorporate AADT estimates developed using counting and factoring procedures described earlier in this section. All HPMS sections are counted by ODOT on a four-year rotating basis.

Each year, Ohio also re-estimates total road miles in each volume group using their most current estimates of AADT for all SHS sections and the best available AADT information for non-SHS sections. The updated distribution of road miles across volume groups is used in the derivation of sample-section expansion factors. This procedure guarantees that, for functional systems consisting entirely of SHS roads, VMT estimates developed by HPMS will closely approximate Ohio's VMT estimates. For functional systems for which 100 percent samples are not used, small differences will exist between the two sets of estimates because HPMS does not have available Ohio's AADT estimates for nonsample sections.

ODOT finds the process of choosing new sample sections for undersampled strata laborious (primarily because milepost information is not included in the RIF). For this reason, there apparently was a period of several years during which they did not add new sample sections. As a result, they have several urbanized-area strata for which they have no sample sections. They usually treat all mileage in each such stratum as belonging to the next higher or lower volume group, though, when sample sections belonging to both the next higher and next lower volume group exist, they may divide the mileage in the unrepresented stratum between the two adjoining volume groups. Such movement of mileage to alternate volume groups introduces some error in the corresponding HPMS estimates of VMT.

ODOT is now redressing the above problem by selecting new sample sections for all strata for which they have no sample sections or for which they have expansion factors that exceed 100. They are picking new sections for one or two metropolitan planning organizations per year. They have found that about 95 percent of the new sample sections are in the expected volume groups, indicating that their volume-group estimates are reasonably good.

Washington

Washington originally assigned all nonlocal mileage to functional systems and volume groups using the best available data, and they selected the initial HPMS sample from this universe using a process that probably was similar to that used by Ohio. However, they have made no effort to change the distribution of road miles across volume groups to reflect subsequent changes in traffic volumes. All changes in road miles by functional system are incorporated by simply scaling the mileage in each of the functional system's volume groups. Sample sections *are* moved to new volume groups when traffic counts indicate that they should be (but it is not clear whether or not the corresponding volume-group mileages are adjusted accordingly).

Because of a lack of resources, WSDOT has not added sample sections to undersampled strata for several years. However, they have never had a stratum without any sample sections.

Annual HPMS submissions incorporate AADT estimates developed by WSDOT for sample sections on the SHS and by the counties and cities for other sample sections. The counting and factoring procedures used by WSDOT and the local jurisdictions were described earlier in this section. Of the sample sections, approximately one-third are on the SHS, one-third are on county roads, and one-third are on city streets.

Florida

Florida Transportation Statistics Office (TSO) personnel were not familiar with the original stratification of highway sections for HPMS, though the procedure used presumably was similar to that used by Ohio and Washington. The Florida TSO changes the volume-group assignments of both sample and nonsample sections whenever new AADT estimates indicate their volume-group has changed. This practice should assure that the correct volume-group stratification is maintained for all SHS sections (which are all counted once every three years). The Florida SHS corresponds roughly to the entire arterial system.

Treatment of non-SHS sections was not explicitly discussed. However, since the only such sections counted by the TSO are HPMS sample sections and grade crossings, it is likely that non-SHS sample sections are moved to higher volume groups when their traffic increases but that off the SHS very few nonsample sections are moved.

Movement of sections between volume groups has resulted in both some volume-group strata becoming empty and the introduction of sections into some formerly empty strata. They have never had a nonempty stratum for which they had no sample sections (suggesting that whenever a nonsample section is moved into a formerly empty stratum, the section is immediately picked as a sample section). Sample sections are dropped from the HPMS sample only if they are abandoned or reclassified as local.

Local VMT

Both Florida and Ohio estimate VMT on functionally local roads and streets by using a single value of AADT for all these sections, deriving this value from railroad-grade crossing traffic counts on functionally local roads and streets. Ohio has found that this procedure tends to overestimate local VMT. However, Florida believes that they have a significant number of grade crossings that are virtually driveways, so that they do not believe that there is an overestimate.

VMT estimation for functionally local roads and streets was not discussed with Washington State.

3.0 The Volume-Group Stratification

For several functional systems, the VMT estimates produced by HPMS are developed from AADT estimates for a random panel sample of highway sections stratified by traffic volume group. Starting in 1993, states will begin developing count-based AADT estimates for all sections on the PAS (including Interstates and other freeways and expressways) plus other roads of national significance designated as being on the NHS. Accordingly, in the future, the volume-group sampling approach will be used primarily for the minor arterial and collector systems, and issues relating to volume-group stratification are important only for these functional systems.

The most significant issue relating to the volume-group stratification is how well it is applied — in particular, how well are nonsample sections distributed across volume groups? Errors in the distribution of the mileage of nonsample sections across volume groups can affect the resulting VMT estimates significantly. Two appreciably less significant issues relate to the estimates of mean AADT used for each volume group, and the estimation of VMT for volume groups that do not contain any sample sections. Each of these issues is discussed below.

3.1 Distribution of Mileage Across Volume Groups

A key issue in the use of a volume-group stratification is: How well can a system of highway sections be distributed across volume groups when the traffic volumes on many of them are unknown? Random errors in the distribution process will tend to cancel out and so will tend not to have any significant effect on the resulting VMT estimates for the highway system. However, systematic errors (such as a consistent tendency to underestimate the volume group of sections for which AADT estimates do not exist) can have a greater effect.

The following subsections discuss how highway sections and mileage were originally distributed across volume groups, how these distributions are maintained, and the effects on HPMS estimates of VMT. Our conclusions are:

- For sections on a state's state highway system (SHS), the original distributions are probably adequate or better.

- For these sections, maintenance of the distributions varies in quality, but poor maintenance frequently may not have any significant effect on the VMT estimates.

- For other sections, the original distributions are likely to have been based on inadequate data, adversely affecting VMT estimates for the lower functional systems.

To avoid the problems of applying a volume-group stratification to non-SHS sections, alternative stratifications were developed and evaluated. These stratifications were not found to be successful. The alternate stratifications and their analyses are discussed briefly in Appendix D.

The Original Distribution

Procedures originally used to distribute sections in each functional class across volume groups undoubtedly vary across states, and many states cannot easily reconstruct the procedure that they used. However, the procedure used by Ohio is probably typical of that used by many states.

For many years, Ohio, like many other states, has maintained AADT estimates for its entire SHS and much more limited AADT information for sections off the SHS. In Ohio's case, the SHS AADT estimates are developed from a combination of traffic counts, interpolation, and informed judgement. Ohio also maintains a Road Inventory File (RIF) that contains information on all roads and streets in the state, divided into reasonably homogenous sections.

For HPMS, Ohio used the RIF as their sampling frame and used all available information to assign RIF sections to volume groups. Random samples were then drawn from each volume group. As would be expected, when traffic was counted on these sections, it was found that a few SHS sections and a larger number of non-SHS sections had been assigned to the wrong volume groups. These sections were then reassigned to the correct volume group, and, if necessary, additional sections were drawn for any undersampled volume groups. There was no need to collect traffic counts on the many non-SHS sections that were not selected as sample sections, and so the appropriateness of the volume-group assignments for these sections was never verified.

The Ohio experience suggests that their assignment of SHS sections to volume groups was reasonably accurate, while their assignment of other sections was less accurate. In Ohio's case, the SHS includes all rural arterials, some rural collectors, most or all urban freeways, most other urban principal arterials, and some urban minor arterials and collectors. Thus, it can be concluded that Ohio developed generally accurate volume-group assignments for sections in the three highest rural and urban functional systems, and less accurate assignments for sections in the lower functional systems. It is likely that the latter assignments resulted in some systematic error in the distribution of mileage across volume groups, but the size and direction of this error is not known.

Many other states have good traffic data for sections on the SHS (and some even obtain traffic counts on all such sections), but little or no data for other sections. Hence, it is likely that in many states, the initial assignments to volume groups were generally accurate for SHS sections and less accurate for non-SHS sections. Excluding the local functional systems, there are now about 635,000 miles of SHS and, in 1980, there were about 610,000 miles. It is likely that most of this mileage was appropriately distributed to volume groups, but that many non-SHS roads were less appropriately distributed. In 1980, there were about 585,000 miles of such roads excluding functionally local roads.

Maintaining the Distribution

Over time, traffic volumes on existing roads change, new roads are built, a few are abandoned, and the functional classifications of some roads are changed. All states modify their estimates of universe miles by functional class and volume group for the effects of new roads, abandonments, and changes in functional class. However, many do not modify these estimates for changes in traffic volumes on nonsample sections. Furthermore, although all states change the volume groups to which sample sections belong to reflect the effects of changes in estimated AADT on these sections, they do not all change their distributions of universe miles across volume groups accordingly.

There are two procedures that can be used for changing the distribution of mileage across volume groups to reflect changes in traffic volume. One, used by Florida and Georgia, involves maintaining information on each universe section's volume group, along with other roadway characteristics, in a roadway inventory. Then, whenever a new AADT estimate indicates that a section's volume group should be changed, the universe mileage in the section's old and new volume group are adjusted accordingly. This procedure's capability for keeping a state's nonsample sections appropriately stratified depends on the extensiveness of the state's program for re-estimating AADT on these sections. In many states (including Florida), this program is largely limited to the SHS, so that much of the traffic growth off the SHS will be missed.

An alternative procedure is used by Ohio. In Ohio, estimates of mileage in each volume group are obtained annually from the state's (computerized) RIF. For the SHS, the distribution is derived from AADT estimates contained in the file; while, for non-SHS mileage, the distribution is developed primarily from judgement, using whatever AADT information is in the file and an assumption that, for a given functional system, traffic volumes off the SHS are about one volume group lower than those on the system. The distribution used for non-SHS mileage is clearly less accurate than the one for SHS mileage. However, it is developed consistently over time; and, assuming traffic volumes grow at the same rate on and off the SHS, the non-SHS distribution appropriately captures traffic growth.

For functional systems consisting entirely of SHS mileage, the volume-group data provided by Ohio enables HPMS to approximate Ohio's own VMT estimates closely. However, since Ohio's VMT estimates are derived using Ohio's AADT estimates for all sections, while HPMS' are derived using volume-group means, some small differences will exist between the Ohio and HPMS VMT estimates. These differences should be insignificant (and, for the PAS, they will disappear when 100 percent sampling is adopted), but it should be observed that the better estimates are those produced by Ohio. (The Ohio estimates are based on the best available AADT estimates for each section, while the HPMS estimates are derived by approximating Ohio's AADT estimates with volume-group means.)

Implications

SHS Mileage

The discussion of the preceding subsections indicates that many states have very good count-based VMT estimates for the entire SHS. Some states, such as Ohio, provide HPMS with information on roadway mileage by volume group that enables HPMS to produce VMT estimates that closely replicate the state's estimates. However, many states (including Washington) do not. The result is that, for the SHS, HPMS estimates of VMT currently are not as good as those produced by the states or those that could be produced by HPMS if all states adopted the Ohio or Georgia procedures for providing HPMS with updated information on roadway mileage by volume group.

The new HPMS requirements for 100 percent sampling of the PAS and NHS (the PAS/NHS) should improve the HPMS VMT estimates for the PAS/NHS (but not for other parts of the various SHSs). In particular, for states such as Florida, which currently counts traffic on every section of the SHS, the new requirements will enable HPMS to use AADT estimates derived from these counts for the entire PAS/NHS.

For Ohio, the effects of the new regulations will depend on the way they are implemented. If Ohio is required to collect 24 or 48-hour machine counts on every Ohio section of the PAS/NHS, the quality of both the Ohio and HPMS estimates of VMT on these sections will improve. If Ohio is only required to collect such counts on "major sections," some improvement in Ohio's estimates of VMT can also be expected (due to the replacement of 8 and 12 hour manual counts by 24 or 48 hour machine counts). The HPMS estimates will also improve; however, if HPMS uses only AADT estimates derived from traffic counts on the major sections without considering Ohio's analysis of how traffic varies on the smaller sections that make up the major sections, HPMS will not be taking full advantage of all of Ohio's information. In this case, the Ohio and HPMS estimates are likely to differ slightly, with the Ohio estimates likely to be the better ones.

The above discussion indicates that, for many states, the HPMS estimates of VMT for those portions of the SHS that are not part of the PAS are not as good as the state's estimates. However, an analysis presented in Appendix C suggests that, for many of these states, the differences are likely to be quite small. That analysis attempts to estimate the downward bias that results in VMT estimates due to the failure of many states to modify the distribution of mileage across volume groups as traffic increases. The Appendix C analysis uses some relatively heroic assumptions to estimate this bias, and so we do not believe that too much should be made of the results of this analysis. However, that analysis does suggest that the bias results in reducing the estimated growth in VMT by no more than one percent and that the effect on the estimates of total VMT is probably no more than one or two hundredths of a percent per year. The latter effect is cumulative, but it still should take many years before a significant effect on VMT results.

As previously observed, it is likely that many states initially assigned SHS sections to HPMS volume groups on the basis of the AADT estimates they then had for these sections. For the SHS in these states, the original HPMS estimates of VMT should have closely replicated the state's estimates. However, over time, some divergence between the two estimates is likely for states that did not modify the HPMS distribution of mileage over volume groups to match the changes they found in AADT by SHS section. Such changes could have resulted because of increasing traffic volumes and/or because of improvements in the state's procedures for counting traffic and estimating AADT. However, the Appendix C results suggest that the effects of increasing traffic volumes on the distribution of mileage over volume groups are quite small. Hence, we conclude that, although, for those portions of the SHS that are not part of the PAS/NHS, the HPMS estimates of VMT are not as good as the state's estimates, the only states for which significant differences are likely are those which do not modify their distribution of mileage over volume groups to reflect changes in their estimates of AADT and which also either did not use SHS AADT estimates in developing their original distribution or have since improved (or otherwise modified) their procedures for estimating AADT.

Non-SHS Mileage

Although most states have well developed programs for estimating VMT on the SHS, most expend no more than limited resources for estimating VMT on other roads and streets. Accordingly, in most states, the distributions of non-SHS sections across volume groups reflect a substantial amount of judgement and relatively little data. Hence, the resulting HPMS estimates of VMT for functional systems dominated by non-SHS mileage are likely to exhibit substantially greater percentage errors than those for higher functional systems.

The errors resulting from improper stratification of mileage in the lower functional systems could potentially be reduced if stratification by volume group were replaced by stratification by one or more readily observed variables. For this purpose, some potentially useful variables are surface type, number of lanes, and (for multi-lane roads) degree of access control. In the course of Task A, several stratifications using these three variables were evaluated. Unfortunately, it was found that, although these stratification variables performed reasonably well for the higher functional systems, they performed very poorly for the lower functional systems (and, in particular, for rural major and minor collectors). A brief summary of the evaluations performed is presented in Appendix D.

3.2 The Volume-Group Means

This section examines issues relating to the estimation of mean AADT for each volume group. A family of alternative procedures for estimating these means in a fashion that reduces traffic-counting requirements is developed, and one procedure in this family is evaluated. The concluding subsection of this section suggests that reducing the amount of traffic-counting required for estimating volume-group means could allow an increase in the amount of traffic-counting on nonsample sections, resulting in improvements in the distribution of mileage across volume groups.

The AADT Distributions

Consider the collection of all sections in any functional system in any state and the distribution of AADT values for these sections. Some typical AADT distributions are shown in Exhibit 3.1. The dotted lines in the exhibit represent the appropriate volume groups for the functional system.

The first of the Exhibit 3.1 distributions represents a situation that is most likely to occur in the case of the lower rural functional systems of some West Central States and other states with road systems that are dense relative to their population. This distribution is highly skewed toward the low end of the AADT range. Most of the sections are in the first volume group, with many, if not most, in the lower half of this volume group. The second and third distributions represent situations with progressively less skewing, with the third coming close to a normal distribution.

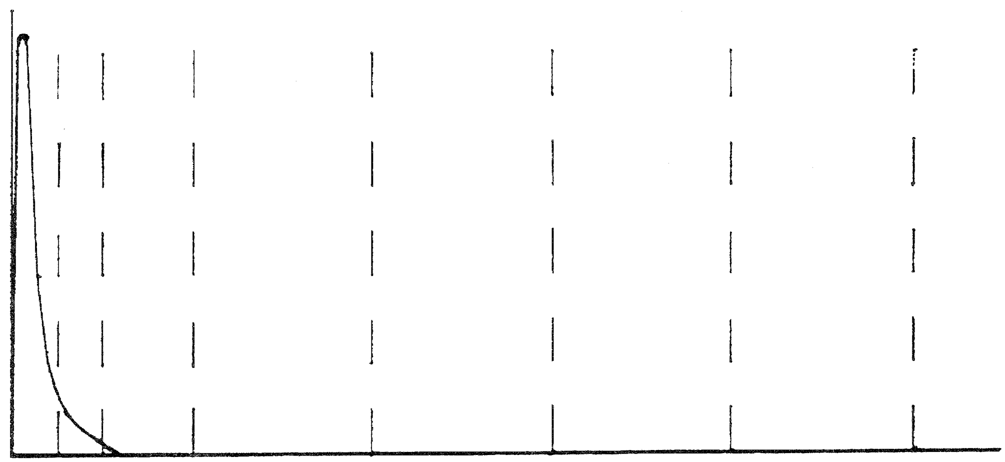
An examination of the three distributions shown in Exhibit 3.1 can provide reasonable qualitative estimates of the approximate means for each of the volume groups. With a few exceptions, it can be seen that most of the volume group means lies reasonably close to the midpoint of the volume group. The most notable exceptions are: the highest nonempty volume group of each distribution (e.g., Volume Group 3 for Distribution (a)), which all have means near the low end of their volume group; and the lowest nonempty volume group of each distribution which, except for Volume Group 1 of Distribution (a), have means near the high end of their volume group.

If all sections in a volume-group are of the same length, total VMT in the volume group is obtained by multiplying the volume-group mean by the total length of these sections. If the sections are of varying length, total VMT can be obtained by multiplying the *length-weighted* volume-group mean ($\Sigma L_i \times AADT_i / \Sigma L_i$) by total length ($\Sigma L_i$). If there is no relationship between a section's length and its AADT, the expected value of the length-weighted mean will equal the expected value of the unweighted mean. Since such a relationship is either extremely weak or nonexistent, the two means usually lie fairly close to each other, and substituting one for the other does not result in any significant bias in an estimate of VMT.

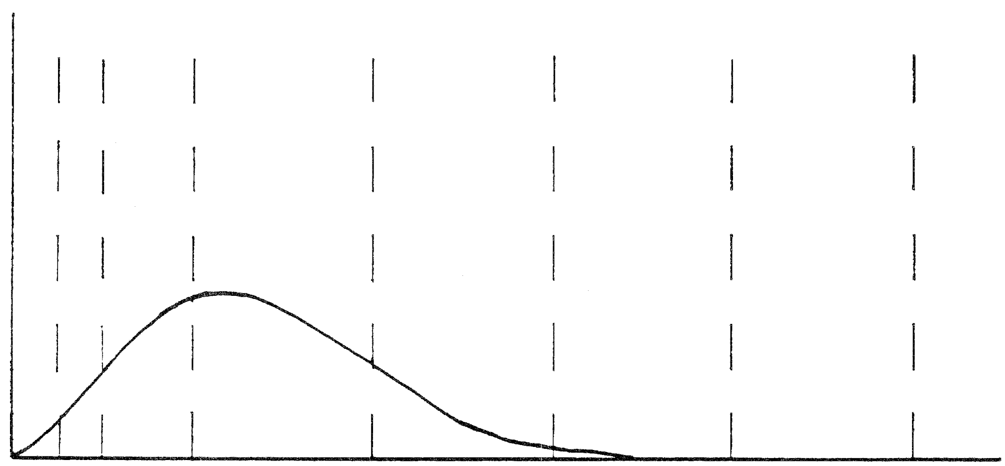
Consider now estimates of VMT derived using the volume-group *midpoint* instead of the length-weighted volume-group mean. The above discussion suggests that usually the midpoint and the mean are reasonably close, so that only modest errors will result in the estimates of VMT — with notable exceptions likely to occur only for the lowest and highest nonempty volume groups. Furthermore, if results for several volume groups are aggregated, the errors will tend to cancel, so that VMT estimates for several volume groups derived using midpoints are likely to be better than similarly derived estimates for a single volume group. (In particular, for AADT distributions similar to those shown in Exhibit 3.1 (b) and (c), VMT underestimates for the lower volume groups will tend to be balanced by overestimates for the higher volume groups.)

The above discussion suggests that reasonable estimates of VMT can be derived by using AADT estimates from actual volume counts for samples of sections in the lowest and highest nonempty volume group of each functional system and using volume-group midpoints for all other volume groups.

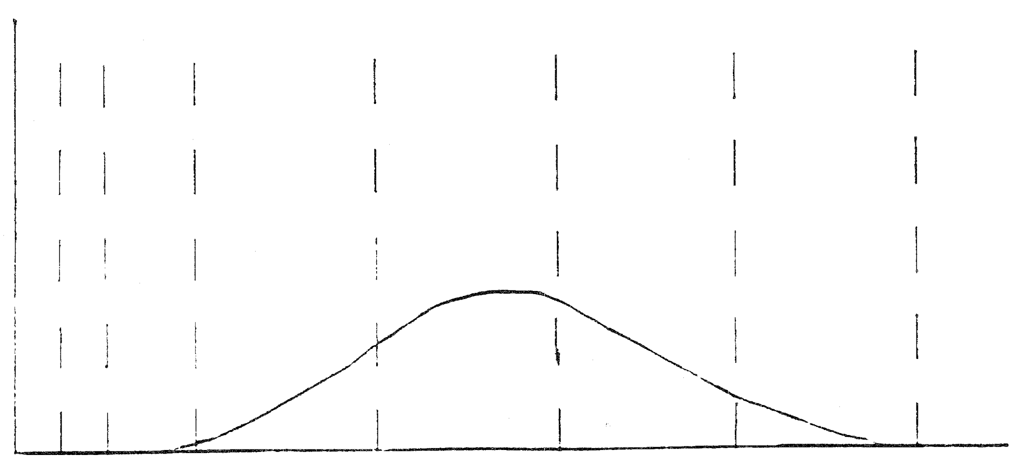
Exhibit 3.1 Typical Distributions of AADT Across Volume Groups



(a)



(b)



(c)

Empirical Results

The quality of VMT estimates derived using volume-group midpoints was evaluated by applying a "midpoint procedure" to HPMS data for 1991 and comparing the results to those produced by the normal HPMS procedure. For this evaluation, the midpoint procedure used was:

1. For Volume Groups 1 and 13, estimate VMT using AADT estimates for all sample sections (as is done by HPMS).

2. For all other volume groups, estimate VMT by assuming that the volume-group midpoints represent the (length-weighted) mean AADT of all sections in the volume group.

Resources did not permit testing of the slightly more sophisticated procedure proposed at the end of the preceding subsection. We would expect that procedure to produce somewhat better VMT estimates than the procedure actually tested. However, we would not expect a significant difference in the quality of the estimates.

When considering the above results, it is important to keep in mind that the VMT estimates derived using the two procedures are *both* estimates. To some extent, the HPMS procedure produces estimates of VMT that differ from those produced by the midpoint procedure because the universe of sections contains a relatively large number of sections with AADTs above (or below) their volume-group midpoints; and to some (probably lesser) extent, it does so because the volume-group means of the HPMS sample differ from the volume-group means of the universe. The differences in the estimates produced by the two procedures are due to some currently unknown combination of the errors produced by the two procedures; they are not due entirely to errors produced by the midpoint procedure.

Exhibit 3.2 compares the estimates of statewide nonlocal VMT produced using midpoints for Volume Groups 2-12 and the AADTs of sample sections for Volume Groups 1 and 13 (in Column 2) with VMT estimates derived entirely from AADTs (in Column 1).[1] The VMT estimates produced by the two procedures are quite close. The estimate of national VMT obtained using midpoints is 1.34 percent smaller than the estimate obtained only

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[1] Before performing this analysis, one adjustment was made to data for South Dakota. The AADT distribution of rural major and minor collectors in South Dakota is very similar to that shown in Exhibit 3.1(a), with a very disproportionate share of sections falling into Volume Group 1 when the standard HPMS volume groups are used. To improve the HPMS estimates of overall VMT, for HPMS submissions, South Dakota has adopted a nonstandard volume-group stratification for sections in these functional, narrowing the range of Volume Group 1 and shifting a number of sections into higher volume groups. For our analysis, all South Dakota sections were restratified using the standard HPMS volume groups.

In the other states, only two sections, both urbanized-area minor arterials in Kentucky, were found not to be in the standard HPMS volume groups. In our analysis, no special adjustments were made for these sections.

Exhibit 3.2 Estimates of Statewide VMT Using Conventional and Alternative Estimation Procedures

State	Traditional VMT	VMT W/Midpt exc Vol. Group=(1,13)	Percent Difference from Traditional VMT
Alabama	34,172	34,192	0.06
Alaska	3,216	3,142	-2.31
Arizona	29,818	29,717	-0.34
Arkansas	20,697	20,886	0.91
California	241,866	238,121	-1.55
Colorado	26,292	26,040	-0.96
Connecticut	23,866	23,612	-1.06
Delaware	5,518	5,371	-2.67
District of Columbia	3,067	3,042	-0.80
Florida	90,301	88,331	-2.18
Georgia	61,726	60,641	-1.76
Hawaii	6,417	6,216	-3.14
Idaho	7,928	8,003	0.95
Illinois	76,167	75,180	-1.29
Indiana	47,345	46,357	-2.09
Iowa	20,890	21,129	1.15
Kansas	19,982	19,885	-0.49
Kentucky	30,903	30,333	-1.85
Louisiana	30,614	29,739	-2.86
Maine	10,538	10,534	-0.03
Maryland	38,167	37,591	-1.51
Massachusetts	40,175	39,652	-1.30
Michigan	74,672	73,861	-1.09
Minnesota	64,266	34,371	0.31
Mississippi	19,295	19,248	-0.25
Missouri	45,100	44,554	-1.21
Montana	7,042	7,019	-0.33
Nebraska	12,187	12,475	2.36
Nevada	9,597	9,468	-1.34
New Hampshire	9,131	9,055	-0.84
New Jersey	47,657	47,030	-1.32
New Mexico	13,545	13,500	-0.33
New York	96,251	94,468	-1.85
North Carolina	54,133	53,229	-1.63
North Dakota	5,195	5,229	0.66
Ohio	77,324	75,335	-2.57
Oklahoma	29,729	29,786	0.19

State	Traditional VMT	VMT W/Midpt exc Vol. Group=(1,13)	Percent Difference from Traditional VMT
Oregon	22,941	22,632	-1.35
Pennsylvania	74,581	73,246	-1.79
Rhode Island	6,255	6,271	0.27
South Carolina	30,753	30,582	-0.56
South Dakota*	6,075	6,103	0.47
Tennessee	41,815	41,249	-1.35
Texas	134,835	132,746	-1.55
Utah	13,222	13,082	-1.07
Vermont	5,016	5,057	0.80
Virginia	51,403	50,583	-1.60
Washington	42,032	41,214	-1.95
West Virginia	15,240	15,056	-1.21
Wisconsin	37,815	37,261	-1.47
Wyoming	5,482	5,502	0.37
Puerto Rico	11,223	10,954	-2.39
U.S. Total	1,903,479	1,877,904	-1.34

* South Dakota data modified. See footnote to accompanying text.

using AADTs. For individual states, the estimates using the "midpoint" procedure range from 3.14 percent lower (in Hawaii) to 2.36 percent higher (in Nebraska).

A further analysis could be undertaken to estimate the relative errors produced by the two procedures. Such an analysis would estimate VMT[2] using AADT estimates for all sections of nonlocal roads from states that count traffic on all such sections (e.g., Iowa or Virginia) and would compare these VMT values to those produced using the volume-group procedure and those derived using only AADT estimates for the HPMS sample. Unfortunately, resources do not permit such an analysis.

[2] Because traffic volumes for individual sections are not uniform for the entire length of the section, and because the AADT values for individual sections are themselves only estimates, it is not possible to obtain a completely accurate estimate of VMT. Accordingly, the standard of comparison used in the footnoted sentence is identified as an estimate rather than an accurate value of VMT.

The Role of AADT Estimates in Estimating VMT

The above discussion and that of Section 3.1 suggest that, for the purpose of using the volume-group approach to estimating VMT, estimates of AADT play two roles:

1. They provide information about the (length-weighted) mean AADT of their volume-group; and

2. They permit individual sections to be assigned to volume groups correctly.

For the purpose of estimating statewide VMT, AADT estimates for sample sections in the lowest and highest nonempty volume groups of each functional system are needed for their first role. However, the results presented in Exhibit 3.2 indicate that, for other sample sections, the first role of AADT estimates is appreciably less important — reasonably good estimates of statewide VMT can be obtained using volume-group medians instead of sample data. For sections in these volume groups, the second role of the AADT estimates may be as important or more important than the first role. Indeed, as suggested in Section 4.1, the lack of AADT information for nonsample sections that are not on the SHS probably results in an appreciable amount of error in the distribution of universe miles across volume groups for the lower functional systems, compromising the VMT estimates for these systems. The above discussion leads to the observation that it may be possible to improve the VMT estimates for the lower functional systems by adopting procedures that focus more on the second role of AADT estimates and less on the first. In particular, a volume-group median procedure for estimating VMT could be adopted in conjunction with:

- reduced counting-frequency requirements for non-PAS/NHS sample sections that are not in the lowest or highest nonempty volume group of their functional system; and

- new requirements for periodically estimating AADT on nonsample sections (from additional volume counts and/or AADT estimates on adjoining sections).

There is some likelihood that such procedures could produce moderately (or even significantly) improved VMT estimates for the lower functional systems at no increase in annual costs (but some initial cost for implementing the procedures). However, an appreciable amount of additional research would be required to develop and to evaluate these procedures further.

3.3 Treatment of Unsampled Volume Groups

The movement of sample sections from one stratum to another (as a result of changes in traffic volume or, less frequently, changes in functional system) can result in some volume-group strata that contain no sample sections but that are believed to contain nonsample sections. Such an occurrence is very rare for states that select new sample sections whenever the sample for any stratum that includes any nonsampled sections falls below three. However, for states that do not maintain a road inventory file with mileposts and AADT for all sections of nonlocal road, the selection of new sections can be a time-consuming process. As a result, some states do not add sample sections to a stratum until *after* the sample has dropped to zero, and some have allowed nonempty strata without sample sections to exist for several years before new sample sections are selected.

Unsampled strata are most likely to occur for individually sampled urbanized areas. For any functional system within an urbanized area, unsampled volume-groups are likely to be among the highest and/or lowest of the nonempty volume groups.

When an unsampled stratum occurs, some states, such as Arizona, borrow sample sections from an adjoining volume group to represent the sections in the stratum, while others, such as Ohio, temporarily move all mileage in the stratum to adjoining strata. Both these alternatives produce representations of the mileage in the unsampled stratum, as required by the HPMS Analytical Process,[3] that are reasonable for most purposes. However, both procedures introduce an unnecessary and easily avoided error in the estimation of VMT: sections that are believed to have AADT in one volume group (e.g., 20,000-29,999) are treated as having AADT in a different volume group (e.g., 10,000-19,999). Clearly, a very simple alternative that would produce better VMT estimates would be to use the midpoint of the appropriate AADT range (25,000) as the estimated average AADT for all sections in the nonsampled stratum. This alternative can be met by requiring that:

1. a sample section be borrowed from an adjoining stratum; and

2. setting the AADT of borrowed sections to the midpoint of the AADT range of the volume group into which they are moved.

The second rule cannot handle strata that have open-ended volume-group ranges (Volume Group 13 for most strata, Volume Group 5 in the case of special donut-area strata). For this special case of an unsampled stratum, we suggest setting the AADT equal to the average value used when the stratum last contained sample sections.

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[3] The HPMS Analytical Process uses detailed data for HPMS sample sections to evaluate the condition and performance of all nonlocal roads. (Federal Highway Administration, *Highway Performance Monitoring System Analytical Process*, Version 2.1, Three Volumes, December 1987.)

4.0 Plans for Task B

This chapter describes several analyses we propose to perform in the course of Task B. These analyses relate to three aspects of the analysis of traffic data:

- Seasonal and day-of-week factors;
- Estimation of AADT by class; and
- Equivalent single axle loads (ESALs) for individual sections.

4.1 Seasonal and Day-of-Week Factors

Issues relating to seasonal and day-of-week factors to be addressed are:

- The time period during which short counts are collected and the relationship between this period and the day-of-week factors;
- Alternative types of seasonal and day-of-week factors; and
- The relative value of factors derived from current-year data vs. factors derived from historic data.

The first subsection below describes the basic analytic procedure to be used for addressing these issues. Three additional subsections then describe the analyses we currently intend to perform relating to each of the above issue areas.

The Analytic Procedure

The analysis will make use of ATR data for selected states. Most of the analysis will use only data for 1992, including imputed values for 1992 derived from data for earlier years using a procedure discussed in the second subsection below.

The Basic Procedure

For each state and each factoring procedure, a separate analysis will be performed using data from each of the seasonal factor groups containing two or more ATRs. For each factor group, the analysis consists of using data from one ATR at a time to simulate coverage counts that could be obtained at the ATR site, and deriving AADT estimates corresponding to each of these counts by applying factors derived from the remaining ATRs in the factor group. For most of the counting and factoring procedures to be evaluated, between 100 and 200 nonoverlapping simulated weekday counts will be obtained per ATR. Error statistics will then be generated by comparing the various AADT estimates derived for each of the ATR sites to the actual AADT[1] at the site (as indicated by the ATR data). These statistics should provide a reasonably accurate representation of the precision of AADT estimates produced using the factoring procedure being evaluated.

The precision of the various factoring procedures will be compared to each other using the root mean square (RMS) error of all the AADT estimates produced (possibly excluding those for recreational factor groups).[2] The mean error of all AADT estimates will also be obtained to identify any procedures that produce biased estimates of AADT. Attractive procedures will be identified on the basis of their precision, lack of bias, ease of use, and other relevant characteristics (e.g., similarity to currently popular procedures). For one or two of the most attractive or most precise procedures, resources permitting, some further evaluation may be performed on the precision of the estimates obtained for individual factor groups (e.g., how the precision tends to vary with functional class, number of ATRs in the factor group, type of grouping used, etc.).

Unfortunately, the above approach is not capable of evaluating factoring procedures that use ungrouped ATR data (e.g., the factoring of each coverage count using data from a nearby ATR believed to have similar characteristics). We currently have no plans for evaluating such procedures. However, we observe that, if properly implemented, such procedures should produce AADT estimates that are at least as accurate as those performed using grouped data.

Imputation of Missing Values

ATRs are intended to provide hourly (or 15-minute) traffic counts for every day of the year. However, for several reasons, data from individual ATRs may be missing for various periods of time. For the purpose of the Task B ATR analyses, we intend to drop any ATR for which an excessive amount (perhaps, more than 90 days) of 1992 data is missing. For other ATRs for which 1992 data is missing, we intend to use a careful procedure for imputing missing values that is intended to have as small an effect on our results as practical.

For ATRs with partial-day data, we intend to use this data to impute counts for the full day if the number of hours of data meets or exceeds some minimum (perhaps, 16 hours).

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[1] Actual AADT will be derived as a true average by dividing total annual traffic by the number of days in the year and not by using the more complex multi-stage averaging procedure suggested on page 52 of *AASHTO Guidelines for Traffic Data Programs.*

[2] The resulting estimates of RMS error may be biased downward: because of the intentional omission of recreational factor groups; because of the lack of data for any single-ATR factor groups; and because factor groups developed using cluster analysis are relatively unlikely to contain extreme outliers among the ATR sites in a cluster and, even after correction for the differences in population sizes, extreme outliers are relatively more likely to exist among the corresponding coverage-count sites. On the other hand, a compensating upward bias in the RMS error estimates may result because, for a factor group of n ATRs, factors used in this analysis are derived using data from only n-1 ATRs instead of the n ATRs used in the procedure being simulated.

these imputations generally will be based on time-of-day data for the same ATR for the same day of the following and/or preceding week with appropriate modifications made for holidays.

Values for other missing 1992 data for any ATR generally will be imputed from 1991 data for the other ATRs in the factor group. Our current inclination is generally to impute values for each individual day using year-earlier data for the same day of the week from 52, 53 or 55 weeks earlier (adjusting the week used to maintain appropriate relationships to Monday holidays, Thanksgiving and Easter) and using corresponding day-specific growth factors. Data for 1990 will be substituted in this process when it is available and 1991 data is not.

The imputation procedure will be modified appropriately for handling missing data in the vicinity of the major fixed-date holidays (Christmas, New Years, and the Fourth of July). To minimize the effect of the imputations on our results, we may choose not to simulate any short counts taken in the vicinity of these three holidays (January 1-6, June 27-July 6, and December 19-31).

"Specific-Day" Factors

The first set of analyses to be performed will use factors that are developed for a specific day of the year. Such "specific-day" factors would be developed separately for every day on which short-term traffic counting is performed.

Although specific-day factors are not currently in use, they have some characteristics that make them helpful to our analysis. In particular, consider the application of these factors to short counts collected on a midnight-to-midnight basis (as is done in Pennsylvania). Each 24-hour count would be factored to an AADT estimate on the basis of ATR traffic volumes that were recorded for precisely the same time period as was used for collecting the short count. The resulting adjustment will reflect imprecision due to the use of data from ATR sites that are different from the short-count site. However, it will not reflect any additional imprecision due to imperfect matching of time periods.

The initial analyses to be performed will include application of specific-day factors to:

1. Midnight-to-midnight short counts;
2. 24-hour noon-to-noon short counts; and
3. 48-hour noon-to-noon short counts.

The last two analyses will represent reasonable approximations to the counting practices in most states, in which most or all short counts are obtained for 24 or 48-hour periods that begin and end in the late morning or early afternoon. It is expected that these two analyses will produce slightly greater errors than the first analysis because of the imperfect correspondence between the periods used in developing the specific-day factors (two or three 24-hour periods) and the short-count periods (a pair of 12-hour periods or a pair of 12-hour periods preceding and following a 24-hour period). Indeed, for short-count periods ending on Friday, we would expect a tendency for AADT to be underestimated because the Friday factors reflect the full effect of increased Friday traffic volumes, which tend to be concentrated in the latter part of the day, while the short counts reflect only the slightly elevated morning traffic volumes.

Evaluations will be conducted of the overall precision of each of the three alternatives and separate evaluations will be made (at least for Alternatives 2 and 3) of the precision for urban and rural systems (testing the hypothesis that 48-hour counting is more valuable in rural areas than in urban areas). If resources permit, we will perform Analysis 2 two different ways: one using separate factors for each of the three days over which the 48-hour period is spread; and one using Ohio's procedure of combining the factors for the first and third day before applying them. Otherwise, we will analyze only the first of these variants. Our expectation is that the two variants will produce very similar results with the first one producing marginally better precision levels.

Finally, we plan to perform a fourth analysis using a factoring procedure that provides a better match than Analyses 2 and 3 between the time period represented by the factors and the short-count time periods without requiring any change to the most commonly used counting procedures. In particular, we propose to use factors derived from noon-to-noon ATR data and to apply them to "typical" 24 (or 48) hour short-count periods, most likely represented as a mix of short counts that start at 10 a.m. and 2 p.m. (representing relatively typical offsets in both directions from the noon-to-noon ATR factors).

More Aggregate Factors

The second set of analyses will compare the use of specific-day factors to several of the more aggregate types of seasonal and day-of-week factors currently used. We currently plan to analyze five of these more aggregate types of factors:

a) Combined month and day-of-week factors;
b) Combined month and day-of-week factors treating holidays as if they are weekdays;
c) Separate month[3] and day-of-week factors;
d) Combined month and average weekday (Monday-Thursday) factors; and
e) Separate week and day-of-week factors.

The "specific-day" factors that will be used as the basis for these comparisons can also be thought of as combined week and day-of-week factors and can be added to the above list as Alternative (f).

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3 The monthly factors used in Alternative (c) will be derived using the two-step procedure for deriving average monthly traffic presented on page 57 of *AASHTO Guidelines for Traffic Data Programs*. The first step of this procedure is the derivation of seven *Monthly Average Days of Week* (MADW) values for each month. The average traffic for the month is then obtained as an average of the seven values of MADW. This procedure provides equal weight to the contributions of all days of the week to the monthly averages, regardless of the amount of data available for the various days of the week. (Data availability varies because of ATR down time and because months contain four and a fraction weeks).

This second set of analyses will start by selecting one of the more attractive short-count time periods addressed in the first set of analyses. The overall precision produced using this version of specific-day factors will then be compared with the precision produced using corresponding versions of each of the five more aggregate types of factors listed above. For those aggregate factoring approaches that are found to be attractive (considering precision, ease of use, and current popularity), a limited number of additional evaluations will be performed to determine the precision obtained when these approaches are combined with other attractive short-count time-period options.

Use of Historic Data

In order to evaluate the imprecision resulting from the use of historic data instead of current-year data, two or three of the most attractive combinations of factoring approach and short-count time period will be tested using factors derived exclusively from historic (1991 and, if available, 1990) data and compared to the results obtained using factors derived from current year (1992) data. It is expected that seasonal factors derived from historic data will produce less precise estimates of AADT than similar factors derived from current year data, and that the difference in precision will be greater for precise-day and weekly/day-of-week factors than for any version of monthly factors.

Data to Be Used

The above analyses of seasonal and day-of-week factoring procedures will be conducted using ATR data for 1990-1992 submitted by the states to FHWA. FHWA has received complete data for all three years from six states, including one state surveyed in Task A (Pennsylvania),[4] and complete 1991 and 1992 data from 31 additional states, including four surveyed states (Georgia, Iowa, Ohio, and Washington). As of April 14, one additional surveyed state (Massachusetts) had submitted data for all months of 1991 and 1992 (except for December 1992) and may have submitted complete data by now.

The number of states whose data should be analyzed is not immediately clear. Our planned imputation procedure is relatively labor intensive, and its costs will rise with the number of ATRs to be analyzed (and so, with the number of states used). The costs of most aspects of the proposed analyses, however, are relatively independent of the number of states used — we plan to focus on the overall precision of the alternative procedures with some separate breakouts for urban and rural areas and, perhaps, for states with high volumes of tourism. Labor costs of producing these results will be relatively independent of the number of states used (but processing costs will not be). However, if resources permit us to perform some analysis of how precision varies across factor groups and/or across states for one or two attractive factoring procedures, the costs of *these* analyses *will* increase with the number of states used.

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[4]The other states are California, Illinois, Kentucky, Nebraska, and Oregon.

The quality of our results will increase with the number of states analyzed, though with diminishing returns. To conserve study resources, we are inclined to start off using data for only three states, increasing the number of states to six or eight if resources permit.

It will be marginally easier to use states that have been surveyed, since we already have information on their factor groups. However, at least one of the states analyzed should be a state with a significant amount of seasonal vacation travel; Colorado, Utah and Vermont would be appropriate. Also, there could be some advantage in using states for which three complete years of data are available; and, of these states, California (and perhaps Illinois) could be interesting in its own right. Finally, we observe that variations among states in ATR downtime will affect the quality of data and the amount of imputation required, and data from states that do not group ATRs will not be usable for the analysis of seasonal and day-of-week factors.

The preceding discussion suggests that the states from which we are most likely to use data are:

Georgia	Arizona	Colorado	California
Iowa	Florida	Utah	Illinois
Massachusetts (?)		Vermont	Kentucky
Ohio			Nebraska
Pennsylvania			Oregon
Washington			

If we limit ourselves to three states for the initial analyses, they are most likely to be Pennsylvania, Washington, and one of the three recreational states in the third column. Both Pennsylvania and Washington have factor groupings that reflect both regional and functional-system considerations.

4.2 Vehicle Classification

A copy of the draft report "Truck Flows and Loads for Pavement Management" by the Washington State Transportation Center (TRAC) was received on June 1. Our current recommendation for analysis of vehicle-classification procedures during Task B of our study are based on a brief review of that report:

- Traffic volumes for Vehicle Class 7 (single-unit trucks with three or more axles) are dominated by construction trucks, whose volumes are extremely variable and not readily forecasted from historic site-specific data. We are currently inclined to investigate procedures for estimating current and future volumes of these vehicles using percentages of AADT (or possibly of AADT for four-tire vehicles) obtained from groups of similar roads. This investigation probably would use classification data from WIM sites in selected states.

- Aside from the special case of Vehicle Class 7, the procedures recommended by TRAC appear to be appropriate. They will be reviewed and evaluated further in Task B. However, we do not believe any further quantitative analysis of these procedures is warranted during Task B of our study.

A brief memorandum discussing these preliminary recommendations in slightly more detail accompanies this Task A Report.

4.3 Site-Specific Estimates of Equivalent Single Axle Loads

Two alternative approaches exist for developing estimates of average daily 18,000 pound (18 kip) equivalent single axle loads (ESALs) for individual sites (other than permanent WIM locations). These approaches are:

1. a) Estimate average daily traffic volumes at the site for 11 to 13 vehicle classes;
   b) For each of these vehicle classes, estimate average ESALs per vehicle using data from similar sites monitored with permanent WIM equipment; and
   c) Combine the results of (a) and (b).

Or:

2. a) Use portable WIM equipment to monitor the site for a short period of time (one to seven days);
   b) For this time period, obtain average ESALs per vehicle by vehicle class for four to thirteen vehicle classes;
   c) Use data from permanent WIM sites to adjust these results to reflect annual average ESALs per vehicle for each vehicle class; and
   d) Apply these estimates to estimates of average daily traffic at the site for each of the four to thirteen vehicle classes.

The second approach is somewhat more complicated, it requires more resources (the use of portable WIM equipment), and, as described above, it is less well defined. However, Florida DOT is currently evaluating alternative versions of this approach, so more precise descriptions of the more attractive versions of the approach may be available in the near future.

The precision of procedures using both approaches depends in part on the precision of estimates of average traffic by vehicle class.[5] The precision of the procedure using the first approach also depends upon the similarity of the ESALs per vehicle by vehicle class at a specific site and the corresponding values at "similar" WIM sites. On the other hand, the precision of the procedures using the second approach depends on the similarity of the seasonal and day-of-week distributions of ESALs per vehicle by vehicle class at a specific site and at "similar" WIM sites. For roads with low truck volumes, the precision of

[5] Throughout this paragraph, we use "vehicle class" as shorthand for "those vehicle classes that contribute significant shares of total ESALs at the site."

procedures using the second approach also depends upon collecting WIM data for sufficient numbers of trucks in each class to produce reasonably precise estimates of ESALs per vehicle.

A variant of the Section 4.1 evaluation procedure can be applied to data from permanent WIM sites to evaluate the precision of commonly used procedures using the first approach and alternative procedures using the second approach. However, since WIM sites usually have moderate-to-high truck volumes, a good evaluation of the precision of applying the various procedures to roads with low truck volumes may not be possible at the present time.

One possibility for evaluating precision at low truck-volume sites would be to simulate several such sites by selecting random or systematic samples of WIM records for higher volume sites. However, such a simulation is not likely to capture the idiosyncratic distributions of truck weights that may exist at sites where truck traffic is dominated by trucks serving a single shipper.

Another alternative would be to limit the initial analysis to sites with medium and high truck volumes. *If* the results of this analysis identify ESAL-estimating procedures using the second approach that are effective for sites with medium truck volumes, then a new program could be developed to obtain WIM data at sites with lower truck volumes. These data could then be used to evaluate the precision obtainable when procedures using the second approach are applied to sites with low truck volumes. Since we think it likely that such procedures will not be suitable for roads with low truck volumes, we are not concerned about the relatively long period of time that would be required to evaluate them for this use. Accordingly, the Task B analyses will not attempt to simulate data for sites with low truck volumes.

The ESAL-estimating procedures to be analyzed in Task B will be selected after reviewing the results of a study currently being performed by the Florida DOT.

5.0 Preliminary Recommendations

We present below preliminary recommendations resulting from our Task A review and analysis of current state procedures for estimating highway usage and related literature. We exclude from this list recommendations that will receive detailed evaluation in the Task B analyses described in the preceding chapter. However, we include some recommendations that may warrant some less quantitative evaluation in the course of Task B. The recommendations are grouped by subject area.

5.1 Traffic Volume and AADT

Axle-Correction Factors

Site-to-Site Variations

The Washington State Transportation Center (TRAC) has found substantial site-to-site variation in axle-to-vehicle (AV) ratios. The TRAC results indicate that use of a single axle-correction factor for each seasonal factor group can result in appreciable errors in the resulting estimates of AADT — up to ten percent for some sites in the lower functional systems.

The TRAC results suggest that additional review of the determination of axle-correction factors for individual sites is warranted. Some possible alternatives are:

- Require the use of vehicle counters for all volume counts - probably the most expensive alternative.
- Assign axle-correction factors to individual sites on a more site-specific basis.
- In the absence of AADTC estimates for individual sites, continue to use average AV ratios for each of several factor groups. The best groupings probably would be those produced by the regression analysis proposed by TRAC. If good estimates of the true averages of these ratios can be developed, this alternative would produce accurate estimates of systemwide AADT for each factor group.

Although the AADT estimates for individual sites produced by this last alternative would be less accurate, they would not really be less meaningful. In particular, consider two sites with the same actual values for AADT but different AV ratios. The site with the higher AV ratio would have a higher axle count, so applying the same axle-correction factor to both axle counts results in a higher AADT estimate for this site. Although the number of *vehicles* at both sites is identical, the percentage of trucks at the site in question is higher. Since trucks take up more road space (and cause more pavement wear), in a *qualitative* sense, *traffic* at this site *is* higher than at the second site. Hence, in the absence of good AADTC estimates for individual sites, AADT estimates derived using average AV ratios would appear to be quite reasonable.

Seasonal and Day-of-Week Variation

The TRAC study found an appreciable difference between weekday and weekend AV ratios and also some seasonal variation. The former result indicates that axle-correction factors to be applied to weekday axle counts should be derived from weekday data only, with separate Saturday and Sunday factors developed for application to Saturday and Sunday axle counts. The latter result indicates that axle-correction factors probably should vary seasonally, at least in areas with significant volumes of seasonally varying natural-resources or recreational traffic.

One possibility would be to combine axle correction with conventional seasonal and day-of-week factoring; i.e., to develop a set of factors that, in a single step, converts axle counts to traffic volumes and adjusts these volumes to AADT estimates. Such an approach could be evaluated by applying the Section 4.1 evaluation procedure to annual classification counts (e.g., from WIM sites) or to ATR data that records both axle and vehicle counts. Because of the high site-to-site variation in axle factors and the fact that existing factor groups were not developed for use in developing axle-correction factors, the precision results produced by such an evaluation likely would appear to be appreciably poorer than those obtained when axle-correction issues are ignored.

Data Quality

Ideally, axle-correction factors should be derived from pairs of axle and vehicle counts obtained at one or more sites. Such pairs of counts can be obtained from Truck Weight Study data for all WIM sites, and some states record both axle and vehicle counts at some other monitoring sites. However, at most monitoring sites, only one of these types of counts is recorded, even of both are obtained. Accordingly, 13-class AVC data are commonly used as the basis for axle-correction factors.

The differences between axle-correction factors derived from 13-class AVC counts and those derived from pairs of axle and vehicle counts are very small and can readily be ignored. However, it also appears to be fairly easy to reduce these differences further or to eliminate them entirely. In particular, these differences could be eliminated if 13-class AVCs recorded total axle counts in addition to the vehicle counts that they already produce. It is likely that many AVCs would require no more than a simple software modification to produce total axle counts.

In the absence of such a software modification, two steps can be taken to reduce the small errors that are produced by AVC data used for axle-correction factors:

- For vehicle classes which include configurations with different numbers of axles (e.g., three or four axle combinations), use an average number of axles per vehicle derived from Truck Weight Study data; and

- Eliminate the use of any catchall categories of unclassified vehicles (though use of narrowly defined classes, such as "ambiguous two-axle vehicles" and "nonstandard five-axle configurations," could be used if desired).

One other data-quality issue relates to the frequency with which axle-correction factors are updated. Changes in vehicle mix and evolving truck size and weight regulations have resulted in AV ratios that tend to grow slowly over time. Software to recalculate these factors should be reasonably straightforward to develop and probably should be used for annual recalculation of axle-correction factors. In the absence of such software, a minimum recalculation frequency of every three or six years probably should be adopted.

Growth Factors

Florida and Massachusetts are currently testing a procedure for estimating growth factors using AADT estimates for all locations counted in the most recent year (instead of those for ATR sites only). This procedure appears to have two advantages relative to the conventional procedure:

- It eliminates a (usually downward) bias that may exist in growth factors due to the siting of ATRs; and

- It allows region-specific growth factors to be developed and used where appropriate — a capability of particular value for air-quality nonattainment areas (AQNAs).

State experience with this procedure should be monitored for three or four years. Assuming that its statistical quirks (described in Section 2.1) are not found to be significant, general adoption of the procedure should be encouraged.

AADT Estimates Produced by Local Governments

In many states, all traffic-counting off the SHS is performed by county and local governments; and in some of these states, these governments derive AADT estimates from the raw counts. It would be appropriate for FHWA to require that states provide a summary of the counting and factoring procedures used in the development of all data used by the state highway department for functional systems of national interest, regardless of the source of these data.

5.2 Vehicle Classification

"Scheme F"

The use of FHWA's 13 "Scheme F" vehicle classifications warrants some review. Our thoughts are presented below.

Automobiles and Four-Tire Trucks

Automobiles and four-tire trucks cannot be accurately distinguished by most AVCs now in use. Furthermore, since a majority of four-tire trucks (and nearly all small four-tire trucks) are personal-use vehicles, the value of distinguishing these two vehicle types may not be worth the effort and the resulting statistical inaccuracies. Alternatives that warrant consideration are use of a single vehicle class (four-tire vehicles) or use of two vehicle classes explicitly distinguished by wheelbase. The latter alternative would result in one class consisting of personal-use vehicles (automobiles, minivans, and small pickups) and a second consisting primarily of four-tire commercial vehicles (full-sized vans and pickups, limousines, and minibuses) plus a few misclassified small six-tire vehicles.

Multi-Trailer Combinations

At the other end of the spectrum, Scheme F lumps into a single class, Class 13, three vehicle configurations for which separate data would be very valuable: triples; double-trailer configurations with nine or more axles; and double-trailer configurations with seven or eight axles. Better data on the use of these three types of configurations would be helpful for analyzing the economic and safety implications of potential changes in size and weight regulations.

Another possible change in classification requirements would be combining Classes 11 and 12 (five and six-axle multi-trailer configurations). These two classes consist primarily of twin 28-foot trailer configurations operating with a two or three axle tractor. Although Classes 11 and 12 are readily distinguished by AVCs, the distinction between these two classes appears to be of relatively limited value to users of classification data.

AVC Algorithms

The algorithms used by AVCs to classify vehicles probably warrant some review and perhaps some fine-tuning. In particular, factors for adjusting for some inevitable misclassifications (e.g., short wheelbase six-tire trucks as four-tire trucks) probably should by implemented if they are not already in use (and may need updating if they already exist).

Buses

Under ISTEA, there is increased interest in data on bus traffic. However, vehicle classification based on axle spacing cannot distinguish mid-sized buses accurately (and four-tire minibuses are not even classified as buses). In urban areas, at least, estimates of bus volumes and bus VMT might be best developed using information from bus operators rather than that from vehicle classifiers.

"Unclassifiable" Vehicles

Certain vehicles cannot be assigned unambiguously to one of the 13 Scheme F classes on the basis of axle-spacing information alone. Current state practice with regard to these vehicles varies:

- some states use software that hazards a best guess for all such vehicles; while
- others assign some or all such vehicles to an "unclassified" or "undefined" category.

The former alternative would appear to be preferable. It guarantees classification results that provide a good representation of the distribution of vehicles across size categories without any significant undercounting of vehicles in any particular size category (as can result, for example, if the difficulty in distinguishing four-tire trucks from automobiles results in the nonclassification of significant numbers of four-tire vehicles). Another alternative would be to require that otherwise "unclassifiable" vehicles be classified purely on the basis of number of axles (with approximately six additional vehicle classes created for this purpose).

Both the elimination of "unclassifiable" classes and the creation of new unclassified classes based on numbers of axles would improve the quality of data available for use in deriving axle-correction factors. However, the latter of these two alternatives might have the undesirable effect of encouraging increased use of the unclassifiable classes, reducing the number of vehicles that are fully classified.

Time-of-Day Factors

Because AVCs can be used only at locations where speeds are reasonably constant, they are of limited value in urban areas. Accordingly, many states classify urban traffic manually, usually using six, eight, or twelve-hour counting periods. We believe that this is an appropriate practice that should not be discouraged. However, such partial-day classification counts will be misleading unless they are adjusted to 24-hour values using separate factors for major vehicle classes with different time-of-day usage patterns. Pending further review, three sets of factors should be used:

- four-tire vehicles and buses;
- other single-unit trucks;
- combination vehicles.

Such time-of-day factors for classification counts can be developed either from a limited number of manual 24-hour counts or from AVC data collected at carefully selected urban sites (such as certain freeway ramps).

Partial-day classification counts usually are collected over time periods that include periods of peak congestion. This practice makes it possible to use these counts for any congestion analyses of interest without introducing any imprecision due to factoring. This practice should be encouraged.

Adjustment Factors by Direction

Currently, one surveyed state develops separate time-of-day factors by direction. The procedure used does not produce valid estimates of directional differences in daily traffic and it does not appear that any real use is made of information about these directional differences. Accordingly, this use of adjustment factors by direction should be discouraged.

Time-of-day factors by direction *may* be needed for unpaired one-way facilities and for certain other locations. When needed, such factors probably should be developed from 24-hour counts at nearby sites believed to have the same time-of-day traffic characteristics.

5.3 VMT

Stratification by Volume Group

The quality of HPMS estimates of VMT is compromised by the failure of many states to use all available AADT information in distributing functional system mileage across volume groups. This failing only affects VMT estimates for systems for which AADT estimates are submitted to HPMS for only a sample of sections. The new HPMS Field Manual limits this problem to the minor arterial and collection systems.

To improve HPMS estimates of VMT, all states should be required to revise their distributions of minor arterial and collector mileage across functional systems annually, using the best available AADT estimates for these revisions. These revisions can be made by reviewing the volume-group assignments of all sections (including all *nonsample* sections) or by developing aggregate data on functional system mileage by volume group. The latter alternative (currently used by Ohio) appears to be easier and is described below.

Most states develop AADT estimates for every section of the SHS at least once every three or four years. These estimates should be used to distribute SHS mileage across functional systems and volume groups.

The remaining mileage in each functional system probably should then be distributed across volume groups judgementally, using available AADT estimates for non-SHS sections in these functional systems, comparisons between these estimates and corresponding estimates for the SHS, and the distribution obtained for SHS mileage. An appropriate assumption used by Ohio for this last step is that, except as otherwise indicated by AADT information, the distribution of non-SHS mileage for each functional system can be derived by shifting the corresponding SHS distribution down one volume group (e.g., if 50 percent of SHS urban collector mileage is in Volume Group 4 than 50 percent of non-SHS urban collector mileage is assigned to be in Volume Group 3). Consideration should be given to adopting the one volume-group shift as a recommended procedure for estimating VMT on non-SHS portions of the minor arterial, urban collector, and rural major collector systems, and requiring justification for the use of any procedure that produces higher VMT estimates.

The above procedure will produce improved distributions of functional system mileage across volume groups and improved HPMS estimates of VMT. However, for states that do not apply growth factors to all AADT estimates derived from previous-year volume counts, the procedure will tend to underestimate VMT slightly. This small and consistent downward bias can be ignored. Alternatively, growth factors can be incorporated into the computer program used for distributing SHS mileage across volume groups or appropriate adjustments can be made to the HPMS estimates of VMT. The best alternative probably is to encourage the states to incorporate growth factors into their computer programs.

The above procedure produces improved volume-group distributions and VMT estimates by using *all* available AADT estimates, not just those for HPMS sample sections. The use of an expanded number of AADT estimates, however, raises questions about the appropriate quality standards to be applied to AADT estimates for nonsample sections. Some FHWA review of the procedures used for developing these AADT estimates would be desirable. This review should make sure that the procedures used are appropriate and do not bias the AADT estimates. However, we believe it would be undesirable for FHWA to institute volume-counting and AADT-estimating standards for nonsample sections that would produce any significant increase in costs to the states.

Unsampled Volume Groups

As discussed in Section 3.3, procedures currently used by the states for handling nonempty volume groups that are not represented by any sample sections produce small but unnecessary errors in the HPMS estimates of VMT. A simple set of rules for handling this situation without introducing any unnecessary error is:

1. Whenever a nonempty stratum occurs that is not represented by any sample sections, represent the stratum by a fictitious section that is identical to a sample section in an adjoining stratum in all respects except for AADT.

2. a) Set the AADT of the fictitious section to the midpoint of the stratum's volume group; or
   b) if the volume-group is open-ended (and so has no midpoint), set the AADT to the average value used when the stratum last contained sample sections.

3. To prevent this situation from recurring, pick three sample sections to represent the stratum next year (or, if the stratum contains fewer than three sections, pick all sections in the stratum).

5.4 VMT Forecasting and Tracking

The Clean Air Act Amendments of 1990 require the development of VMT forecasts for certain carbon monoxide and ozone AQNAs and comparisons of these forecasts to subsequent estimates of actual VMT. Some improvements in procedures for estimating AADT and VMT may have nontrivial effects on VMT estimates. If any such improvements are adopted, it will be necessary to estimate their effect on VMT estimates for all AQNAs for which VMT forecasts are required and to adjust the VMT forecasts accordingly. The effect on VMT estimates of any change in procedures can be estimated (as a percentage of VMT estimates obtained using the original procedures) by comparing estimates produced by the new and old procedures after the new procedures are implemented fully.

Appendix A The Survey Instrument

1992 STATUS OF TRAFFIC MONITORING PROCEDURES

Cambridge Systematics
1140 Connecticut Ave. N.W.
Washington, DC 20036

If any information on the following questions is contained in existing documents, you may respond by supplying the document and noting the appropriate pages for specific questions.

I. PERMANENT MONITORING STATIONS

Appended to this questionnaire is a list of permanent traffic-monitoring stations in your state used in the production of FHWA's traffic-volume trends report and also a list of permanent truck-weight sites.

1. Could you identify any additional *permanent* monitoring installations that you operate for any purpose (such as LTPP/SHRP). Please include any permanent installations that are only used intermittently (such as permanent sensors used for obtaining short counts on high-volume highway sections and those to which receiving units are only attached intermittently).

2. What uses are made of the data collected from these additional stations?

3. a) Does your monitoring equipment record traffic counts by 15-minute interval or one-hour interval?

   b) If your equipment records data by 15-minute interval, do you save the 15-minute counts or do you aggregate them to hourly counts?

II. COLLECTION OF SHORT-TERM DATA

The following questions relate to all counting that is performed on a noncontinuous basis. Manual counts are included.

1. Over how long a period of time is short-term counting performed for:

   a) Traffic volumes?

   b) Vehicle classification?

   c) Weight monitoring?

2. Approximately how many sites are used per year for short-term counting of:

   a) Traffic volumes?

   How many of these are on HPMS sample sections?

   b) Vehicle classification?

   c) Weight monitoring?

3. If short-term traffic counting is performed for periods of 48 or more hours, do you ever use data for less than the full period?

   How frequently?

   For what reasons?

4. Is short-term counting performed throughout the year?

   If not, over what months is it performed?

5. Are short-term counts collected during weeks with holidays?

   For which days of the week?

6. Do you use for statistical purposes any vehicle classification or weight data that are collected over a period of less than 24 hours?

   If so, do you adjust these data for the time of day when it was collected?

7. a) About what percentage of short-term traffic-volume counts are performed using devices that record counts by time interval (as opposed to devices that record only a single count for the entire period being monitored)?

   b) Are the time intervals 15 minutes or one hour?

   c) If the time intervals are 15 minutes, do you save the 15-minute counts or do you aggregate them to hourly counts?

8. Is short-term counting performed by headquarters personnel or by district offices?

9. About how many short-term sites are handled per person in a typical week?

   In a typical week, about how many hours does this person spend in the field performing duties connected with short-term monitoring?

10. Approximately what (if any) percentages of short counts are obtained for

    a) periods of seven or more days?

    b) weekends?

11. On what days of the week is short-term traffic-counting equipment normally set up?

    On what days is the equipment normally picked up and read?

12. a) Does the State use traffic counts collected by metropolitan planning organizations or local jurisdictions

    for HPMS?

    for other purposes?

    b) If so, do the MPOs and local jurisdictions provide you with estimates of AADT or do they submit raw traffic counts from which you estimate AADT?

    c) Are there written standards for these organizations to use

    in obtaining traffic counts?

    in estimating AADT?

III. TRAFFIC CORRECTION FACTORS

1. In estimating AADT, which of the following types of correction factor do you use:

    a) Monthly?

    b) Day-of-week or weekday/weekend?

    c) Axle-correction factors?

    d) Growth factors?

    e) Other (please specify)?

2. In developing seasonal and day-of-week correction factors, separate factors are usually developed for rural Interstate highways, other rural roads, urban Interstate highways, and other urban roads and streets. These factors may be further distinguished (e.g., by region of the State), and separate sets of factors may be developed for several other specific categories of roads or areas (e.g., recreational areas, etc.). What distinct sets of correction or distribution factors do you use for:

   a) Seasonal corrections?

   b) Day-of-week or weekday/weekend corrections?

   c) Axle corrections?

   d) Estimating VMT by vehicle class?

   e) Estimating ESALs per vehicle?

3. Are seasonal and day-of-week (or weekday/weekend) correction factors recalculated every year? If not, how frequently do you recalculate them? How many years of data are used in their calculation?

4. In calculating day-of-week (or weekday/weekend) correction factors, are data for holidays excluded?

5. Do you estimate growth factors using data from ATR sites only, or do you also use data from short-term counting sites?

6. a) Do you adjust short-term vehicle classification counts

    For day-of-week or weekday/weekend variations?

    For seasonal variations?

   b) Are these adjustments made using data from

    Permanent automatic vehicle classifiers?

    Periodic 24-hour or 168-hour classification counts made at weigh stations (or other selected sites)?

    Other (please describe briefly)?

7. How do you obtain annual average truck weight estimates:

    Directly from annual WIM data only?

    By adjusting short-term weight data using a procedure similar to that used for estimating AADT?

    By adjusting short-term data using judgement?

    Other (please explain briefly)?

8. Do you develop VMT estimates for various highway systems other than the VMT estimates developed for HPMS? If so, could you briefly describe how the development of these estimates differs from those developed for HPMS? If traffic counts are used from sites that are not on HPMS sample sections, are these sites selected at random?

IV. USE OF HPMS' VOLUME-GROUP STRATIFICATION

1. a) Under what circumstances do you move an HPMS sample section from one volume-group stratum to another?

   b) A non-HPMS sample section?

2. About how many sections are moved from one volume group stratum per year?

   _____ out of ______ total HPMS sample sections

   _____ out of ______ total other sections

   Of the sections that are moved from one volume-group stratum to another, approximately what percentage are moved to a higher volume stratum?

3. Do you ever completely revised the assignment of sections into volume-group strata?

   a) About how frequently?

   b) When this was last done, what effect, if any, did it have on your estimates of VMT by functional system?

4. Do you ever add sample sections to volume group strata that have lost sample sections because of changes in traffic volume? What rules do you use for this purpose?

5. Do you ever drop sample sections from volume-group strata that are being oversampled? What rules do you use?

6. What additional rules, if any, do you have for adding sections of newly built roads to the sample?

Please provide the name, title and telephone number of the person responsible for responding to Sections I-III of this questionnaire and (if different) of the person responsible for responding to Section IV.

Appendix B. The Interview Guide

1992 Status of Traffic Monitoring Procedures — Agenda for State Visits

Questions for Data Users

What traffic volume and truck weight data do you use?

How do you use it? What procedures do you apply?

To what extent is this data collected especially for your office (on special request) and to what extent is this data collected routinely?

Are there any ways in which this data could be made more useful to you? What additional traffic volume and truck weight data would be useful? Why?

Questions for Data Collectors

A. *Procedures and Costs*

Please describe how short-term traffic-counting is handled:

About how many people are involved in laying down and picking up traffic counters?
How do they spend a typical week?
How many weeks per year do they spend doing this?
What equipment is used? How much does it cost? Are maintenance-related costs significant?
Are they based at headquarters or at district offices?
What percentages of traffic counts are provided to you by MPOs or other local jurisdictions—for HPMS? for other purposes?

Please describe how short-term classification counting is handled.

If you perform any short-term weight monitoring for statistical purposes, please describe how it is handled.

Are your weight-enforcement and statistical weight-monitoring programs operated separately or jointly? How?

Please describe how you handle traffic counting on freeways.

How do you identify the design hour on ATR sections? On other sections?

To what extent are equipment problems (tube failures, etc.) a problem? Under what circumstances are these problems most likely?

When equipment fails at a site, under what circumstances do you salvage the data collected? What special adjustments are made to the data?

What is the annual budget for your data-collection program and approximately how is it distributed across program elements (ATR operation, WIM operation, collection of short-term volume counts, collection of short-term classification counts, data processing and editing, etc.)?

How would the costs of short-term counting be affected if you switched your counting period to 24 hours (or from 24 hours to 48 hours)?

B. *Adjustments*

What kind of adjustments do you apply to raw volume counts:
- Monthly and/or day-of-week or weekday/weekend?
- Axle corrections?
- Growth factors?
- Time-of-day?

Which of the above are applied to raw classification counts?

When adjusting classification counts, how do you group vehicle types?

If you perform any short-term weight monitoring for statistical purposes, what adjustments are made to these data?

What is the most recent data used in developing the adjustment factors that have been or will be applied to 1992 traffic counts?

Are any adjustment factors developed separately for the two directions of travel?

If you use weekday/weekend adjustment factors, how do you define the weekend?

In developing your day-of-week or weekday/weekend adjustments, how are Monday holidays handled? Other holidays? Do you collect short counts on holidays?

If you use data collected by counties, MPOs or local jurisdictions, in what form do you use it: raw counts or AADT? If the latter, what checks do you run on the data?

Does your procedure for estimating VMT for non-HPMS purposes differ from that used by HPMS? If so, please describe. What stratification do you use, if any?

C. *Uses*

What uses do state and local agencies make of the traffic volume and truck weight data you develop?

About how many requests do you get annually for special volume counts? For special classification counts? For special collection of truck weight data?

What agencies submit these requests?

How are requests handled?

How do the annual resource requirements for these special requests compare to those for HPMS and SHRP/LTPP data collection?

D. *HPMS*

Are you familiar with the original effort to stratify your road system by volume group? If so, could you describe how the stratification was developed?

What procedures do you use for revising the volume-group stratification over time?

Have you ever been left with a volume-group stratum that contains nonsample sections but no sample sections? How frequently? What do you use as the mean AADT for this stratum?

Under what circumstances do you add or drop sections from the HPMS sample? What procedures do you use?

Appendix C. Estimating the VMT Bias Created by the HPMS Volume-Group Stratification

The effectiveness of the HPMS volume-group stratification depends, in part, on how well this stratification is maintained for both sample sections and other sections. Some states regularly update their stratification to reflect the latest information on the entire highway system; some modify the mileage in various volume groups to reflect the movement of sample sections from one volume group to another but not the movement of other sections represented by the sample sections; and some do not even revise the distribution to reflect movement of sample sections across volume groups. (One of the last group of states, Washington, scales the mileage in each volume group of a functional system to reflect changes in total miles in the functional system but makes no other adjustments to the volume-group stratification.) Failure to modify the volume-group stratification to reflect movement of sections to new volume groups results in some deterioration of the volume-group stratification and of the quality of the resulting VMT estimates. Moreover, in areas where traffic volumes are growing, a failure to shift mileage to higher volume groups to reflect the effects of this growth will result in a reduction in the resulting estimates of VMT. In such areas, a downward bias in the VMT estimates can be expected.

Section IV, Question 2 of the Task A survey of states was designed to obtain data that would allow the extent of any bias to be estimated. Of the nine states surveyed, three provided responses to this question that allowed the development of rough estimates of the extent of the bias. The analysis presented below suggests that the extent of this bias is quite small (probably representing less than one percent of VMT growth in most states). Special measures to reduce or to eliminate this bias probably are not warranted, though elimination of the bias would be one of the benefits of adopting the revised stratification procedures presented in Section 5.2.

Complete responses to Section IV, Question 2 were received from Massachusetts, Ohio and Georgia. The first seven lines of Exhibit C.1 summarize these responses for these three states and show two percentages derived from these responses.

The last two lines of Exhibit C.1 show the percentages of sample and nonsample sections counted each year in each of the three states (derived from other survey responses). Although all three states count traffic on nonsample sections to some extent, apparently only Georgia and Ohio revise their distributions of all mileage across volume groups systematically. Ohio does so using a procedure (described in Section 2.4) that does not require tracking all sections individually, while Georgia does track sections individually. Exhibit C.1 shows that the percentage of nonsample sections in Georgia moved to new volume groups is approximately the same as the percentage of sample sections moved (3.5 percent). This result implies that, for sections counted in any year, the probability of being moved to a new volume group is greater for nonsample sections than it is for sample sections. This result is reasonable, since the percentage changes in traffic volumes between

Exhibit C.1 Selected Survey Responses from Three States

	Massachusetts	Ohio	Georgia
1. Number of HPMS sample sections	2,401	3,247	2,833
2. Approximate number moved to new volume group each year	349	225	100
3. Percent moved	14.5%	7.0%	3.5%
4. Other sections	28,731	29,000	164,297
5. Approximate number moved to new volume group each year	1	NA*	5,800
6. Percent moved	0.0%	NA*	3.5%
7. Approximate percentage of sections moved to new volume group that are moved to a higher volume group	59.9%	65%	96%
Percent of sections counted each year			
8. Sample sections	33%	25%	33%
9. Other sections	4.5%	23%	12%

* Not applicable to Ohio's procedure — see text.

counts are likely to be greater on sections that are only counted once every six or eight years than on sections that are counted every three years. Although Georgia moves approximately the same percentage of nonsample and sample sections to new volume groups each year, the average lag before sections are moved is greater for nonsample sections than for sample sections. The result is an overall bias that does not grow over time and which is much smaller than for states that never move nonsample sections to new volume groups. However, for the purposes of the central analysis of this appendix, the data submitted by Georgia can be used to estimates the bias that *would* exist *if* nonsample sections were never moved to new volume groups. Similarly, the Ohio data will be used to estimate the bias that would exist if Ohio did not annually revise its distribution of mileage across volume groups.

The data submitted by Georgia is also interesting in another way: the percentage of sample sections moved to new volume groups in Georgia is $^1/_4$ to $^1/_2$ what it is in the other two states, and only four percent of sections that are moved are moved to lower volume groups. These results suggest that an appreciable fraction of sections moved to new volume groups by Massachusetts and Ohio are the result of random fluctuations in the AADT estimates for individual sections (rather than true declines in traffic volumes). We understand that Georgia minimizes the effects of random fluctuations by judgementally discarding counts that appear to be inconsistent with historical data.

Exhibit C.2 Estimating the VMT Bias Created by the HPMS Volume-Group Stratification

	Massachusetts	Ohio	Georgia
1990 VMT (millions)	39,848	70,646	58,523
1991 VMT (millions)	40,177	76,492	61,294
VMT growth 1990-1991 (millions)	329	5,846	2,771
Growth rate, 1990-1991	0.8%	8.3%	4.7%
Total mileage	12,799	34,897	36,692
HPMS sections	2,401	3,247	2,833
HPMS mileage	1,676	2,962	2,241
Average length of HPMS section (miles)	0.70	0.91	0.79
HPMS sections moved up	209	146	96
HPMS sections moved down	140	79	4
Typical stratum width	10,000	10,000	10,000
Effect of shift (vehicles)	691,020	675,000	920,000
Effect of shift (VMT)	482,361	615,753	727,752
Expanded effect of shift (VMT)	3,683,617	7,254,535	11,915,510
Effect lost (VMT)*	3,201,256	6,638,782	11,187,759
Percentage of total estimated VMT lost*	0.0080%	0.0087%	0.0183%
Percentage of growth lost*	0.97%	0.11%	0.40%

* For Georgia and Ohio, estimates are for effects that would be lost if Georgia did not collect traffic counts on nonsample sections and move these sections between volume groups accordingly.

The data shown in Exhibit C.1, along with data from 1991 HPMS submissions by the three states, were used to produce some very rough estimates of the extent to which the procedures used by Massachusetts resulted in underestimating growth in VMT and the extent of the corresponding underestimates that would have resulted in Georgia and Ohio if these states did not routinely revise their volume-group distributions every year. Exhibit C.2 shows the HPMS data used and the intermediate and final results of applying the estimation procedure to the Exhibit C.1 data from all three states. The remainder of this appendix describes the development of these estimates.

The first two lines of Exhibit C.2 show total 1990 and 1991 VMT by state for all functional systems except the local systems; and the next two lines show the indicated VMT growth between these two years and the corresponding growth rate. The next three lines show the total mileage of nonlocal roads in the three states, the number of HPMS sample sections, and the total length of these sections. Line 8 shows the average length of a sample section and is obtained by dividing Line 7 by Line 6. Lines 9 and 10 show the number of sample sections moved, respectively, to a higher or lower volume group, as indicated by the Exhibit C.1 information about number of sections moved and percent moved to a higher volume group.

Line 11 indicates that a "typical" volume-group stratum has an AADT width of 10,000 vehicles, though many have smaller widths (as low as 1,000 vehicles), many have larger widths (as high as 25,000 vehicles), and, for all functional systems, Volume Group 13 is open-ended.

Line 12 is derived using an assumption that is central to this analysis—that, *on average*, every movement of a sample section from one volume group to another represents the result of a 10,000 vehicle increase or decrease in the traffic volumes on sample sections. This assumption actually is derived from three additional assumptions.

The first assumption is that, if one considers each movement of a section from one volume group to a higher one and the pair of midpoints of the corresponding volume groups, then the *average* distance between pairs of midpoints is 10,000 vehicles (using any reasonable definition of the "midpoint" of the highest volume group). It should be noted that a few movements may be to nonadjacent volume groups. The assumed average of 10,000 vehicles appears reasonable, but clearly is not accurate. A second assumption is that, for all movements to lower volume groups, the similarly defined average distance between midpoints is also 10,000 vehicles.

The third assumption is that, on average, every movement of a sample section from one volume group to another "represents" a change in traffic volumes equal to the distance between volume-group midpoints—i.e., a change of 10,000 vehicles, on average. This is the change in traffic volume that must occur on some subset of the sample sections in the two affected volume groups if the movement of the section to a new volume group is not to affect the observed mean traffic volumes in either of the affected volume groups. This is the extent to which increasing (or decreasing) traffic volume on sample sections has no effect on volume-group means and so has no effect on the estimates of traffic and VMT that are developed for nonsample sections using these means.

The above assumptions imply that the 209 sample sections in Massachusetts moving to higher volume groups represent a traffic increase of 2.09 million vehicles on sample sections, and the 140 sections moving to lower volume groups represent a decrease of 1.4 million vehicles. The net effect is an increase of 690,000 vehicles (shown as 691,020 in the Exhibit C.2 spreadsheet where all calculations are done without rounding). This estimate is sensitive both to the assumed average of 10,000 vehicles between volume-group midpoints and the assumption that this average is the same for sections moving to higher volume groups as it is for those moving to lower groups. If the latter sections are more concentrated in the lower functional systems and the lower volume groups of these functional systems, the actual average for these sections may be appreciably lower than it is for sections moving to higher volume groups, and the net increase in vehicles represented by sections moving between volume groups could be greater than 690,000.

The Line 12 estimate of the net increase in traffic on sample sections that is represented by those sample sections that have been moved to another volume group is multiplied by the average section length of sample sections to produce an estimate of the net increase in sample section VMT represented by sample sections that have been moved to another volume group. This result, shown on Line 13, is then multiplied by the ratio of total road miles on nonlocal systems (Line 5) to road miles of HPMS sample sections (Line 7) to produce an estimate of the net increase in VMT on the entire nonlocal system represented by sample sections that have been moved to another volume group. This result is shown on Line 14.

The estimate of increased VMT represented by migrating sample sections shown on Line 14 consists of two components: increased VMT on sample sections and increased VMT on other sections. The movement of sample sections to new volume groups, performed by some states, results in the current VMT-estimating procedure properly capturing this first component. However, the second component is only captured to the extent that nonsample sections are moved to new volume groups. Since only one such section was moved in Massachusetts, virtually all of this component of growth was lost in this state. Subtracting the estimate of the first component (Line 13) from Line 14 produces a rough estimate of the VMT growth in Massachusetts that is not captured by the procedure in current use. This result is shown on Line 15.

The Line 15 entries for Georgia and Ohio show corresponding estimates of VMT growth that *would* be lost *if* these states used procedures that reflect the effects of changes in the distribution across volume groups of sample sections but not those of nonsample sections. For all three states, if procedures were used that do not modify the volume-group distributions to reflect the effects of *any* movement of sections across volume groups, then the entire effect of the shift in the volume-group distributions, shown on Line 14, would be lost.

The significance of the Line 14 and 15 underestimates of VMT growth can be evaluated in two ways. On Line 16, the Line 15 values are expressed as a percentage of each state's estimate of total VMT in 1991 (from Line 2). These values are very small — on the order of 0.01 to 0.02 percent. It should be observed that the errors will tend to accumulate over time. Nonetheless, the analysis suggests that it will take 50 to 100 years until the total error reaches one percent.

The second evaluation of the Line 15 underestimate is obtained by expressing the underestimate as a percentage of each state's estimate of VMT growth (Line 3). This evaluation is shown on Line 17. This evaluation is important because of the new Environmental Protection Agency's Section 182 and 187 requirements for limiting estimated VMT growth. To the extent that failure to monitor VMT on nonsample sections results in underestimating VMT growth, states that do not perform such monitoring will have an advantage in meeting the EPA requirements. The results shown on Line 17, however, indicate that the underestimate approaches one percent of estimated VMT growth only in Massachusetts, and is this high only because of this state's low (0.8 percent) VMT growth rate (shown on Line 4). The small underestimate of VMT growth would appear to be tolerable for EPA's purposes.

Appendix D. Alternative Stratification Procedures

In order to estimate VMT on a functional system, HPMS stratifies all road sections in the system on the basis of each sections' AADT, defining 13 AADT volume groups for each functional system (and five volume groups for the donut-area sections defined in the new HPMS Field Manual). The use of the volume-group stratification has the very desirable effect of producing strata with very low variances for AADT (but not necessarily for other variables in the HPMS database). However, as discussed in Section 3.1, the effectiveness of this stratification is compromised by the lack of information about traffic volumes on many road sections that are not on a SHS and by the failure of some states to use the information they have to maintain the volume-group stratification properly.

One of our Task A objectives was to evaluate possible alternative stratification procedures that would use only road characteristics that are related to traffic volume and that are readily known for all road sections. Characteristics that were evaluated were: number of lanes; degree of access control (for multi-lane roads); and, for two-lane roads, lane width and surface type. We found that these stratification variables worked adequately for the higher functional systems (where number of lanes is an important variable), but quite poorly for rural major and minor collectors (where the stratification was based almost entirely on surface type). This appendix provides a brief summary of the evaluations performed.

The stratification analyses were performed using data for the 118,752 sample sections in the 1991 HPMS database. For each of these sections, this database shows AADT, number of lanes, and lane width; and it distinguishes 15 surface types, three types of access control (none, partial, and full), and four types of median.

All of the analyses stratified sections by number of lanes, usually: 2, 3, 4, 5, 6, 7-8, 10, and 12 or more. Most of the analyses further stratified four- and six-lane roads by type of access control (none, partial, or full) and two-lane roads by surface type. Instead of surface type, one analysis used lane width (to the nearest foot, with expanded strata for six feet or less and for 16 feet or more). The lane-width variable was found to be less effective then surface type, so subsequent analyses focused on surface type.

An initial stratification tested consisted of the above eight numbers of lanes with two-lane roads further stratified by 15 surface types and four- and six-lane roads further stratified by the three types of access control. The results of this test suggested that, for the purpose of estimating AADT, the 15 surface types could be combined into seven groups:

- unimproved;
- graded and drained;
- soil, gravel and stone;
- low-type pavement;
- intermediate-type pavement;

- "simple" high-type pavement (HPMS codes 61, 71-73, and 80); and
- "complex" high-type pavement (HPMS codes 62 and 74-76).

Sections falling into this last category have been repaved at least once since first receiving a high-type pavement and either currently have a rigid pavement or have had such a pavement in the past. For two-lane roads, average AADT for sections with "complex" high-type pavement tends to be somewhat higher than it is for sections with "simple" high-type pavement — a category that includes many sections that have not required repaving since first receiving a high-type pavement.

Other stratifications tested included: collapsing the seven surface-type strata for two-lane roads to two (paved and unpaved) and eliminating the distinction between partial access control and none; and distinguishing only four numbers of lanes (one, two, three, or four).

The various stratifications were tested using 1991 HPMS data for three states: Iowa, Pennsylvania, and Texas. Texas and Pennsylvania are the states with the largest HPMS samples (7,695 and 5,982 sections, respectively). Iowa, one of our survey states, also has a large HPMS sample (3,506 sections) and has the third largest sample of rural non-Interstate sections (a category of particular interest for evaluating the surface-type and lane-width stratifications). Although all stratifications were evaluated on the basis of how well they performed for individual states, the stratifications were also tested using national data.

Exhibit D.1 presents a small portion of the results of the stratification tests. This exhibit summarizes the results obtained for two of the functional systems in Pennsylvania when one of the more interesting stratifications was tested — the use of 12 lane/access-control combinations with seven surface types distinguished for two-lane roads. The results are shown for the Interstate system in urbanized areas and for rural major collectors.

The results for the Interstate stratum show some promise. All sample sections fall into four strata (four, five, six, and seven or eight lanes), with their coefficient of variation (CV — the ratio of the standard deviation to the mean) lying between 0.36 and 0.49. One somewhat unexpected result for these sections is that average AADT for five-lane sections is about 25 percent higher than it is for six-lane sections.

The results for rural major collectors are less satisfactory. All but four of the 169 sample sections fall into three strata — those for two-lane roads with intermediate or high-type pavement. Appreciable differences exist in the average AADT for each of these strata (1,833, 2,628, and 3,727), showing that a definite correlation exists between AADT and these three surface types. However, the CVs for these strata are relatively high, ranging from 0.87 to 1.44. These CVs suggest that the surface-type stratification is of no more than limited value for reducing sample-size requirements below those that would be required in the absence of this stratification. (Indeed, a separate analysis obtained a CV of 1.23 for these two-lane roads when the surface-type stratification was dropped.)

The results for other functional systems in Pennsylvania generally fall into the range of results indicated in Exhibit D.1, with moderate CVs for most multi-lane strata and CVs that frequently exceed 1.00 for two-lane strata. The results for Iowa, a relatively homogeneous

Exhibit D.1 Selected Results Using an Alternative Stratification for Pennsylvania — Seven Surface Types with Number of Lanes

	Urbanized Areas — Interstate			Rural Major Collector		
	Observations	Average AADT	CV	Observations	Average AADT	CV
2 Lanes						
unimproved				1	22	—
graded & drained						
soil/gravel/stone						
paved — low type						
paved — intermediate type				51	1,833	1.44
paved — high type, simple				78	2,628	1.29
paved — high type, complex				36	3,727	0.87
3 Lanes				2	13,495	0.25
4 Lanes				1	4,428	—
no control						
partial control						
full control	470	41,536	0.49			
5 Lanes	34	76,226	0.43			
6 Lanes						
no control						
partial control						
full control	126	61,514	0.49			
7 or 8 Lanes	26	110,074	0.36			
10 Lanes						
12+ Lanes						

state, are generally somewhat better than those for Pennsylvania; while those for Texas, an extremely diverse state, are generally somewhat worse.