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# Use of Data from Continuous Monitoring Sites

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# Executive Summary

This report presents the results of a study of the use of traffic data from continuous monitoring sites performed under contract to the Federal Highway Administration (FHWA). In the course of this study, we reviewed current procedures for collecting traffic data and for using these data to estimate *annual average daily traffic* (AADT), *vehicle-miles of travel* (VMT), AADT and VMT by vehicle class, and *18,000 pound* (18 kip) *equivalent single axle loads* (ESALs).

As part of this effort, we employed a written survey to learn about procedures being used by nine States, we conducted personal interviews with key staff in three of these States (Florida, Ohio, and Washington), and we performed an extensive analysis of data from continuous *automatic traffic recorders* (ATRs) in four states (including one of the States that was surveyed and interviewed). In addition, we reviewed the traffic data required by FHWA's Highway Performance Monitoring System[1] (HPMS) and by the Traffic Monitoring System for Highways (TMS/H) of the Intermodal Surface Transportation Efficiency Act (ISTEA);[2] and we also

[1] Federal Highway Administration, *Highway Performance Monitoring System Field Manual*, Washington, D.C., August 1993.

[2] (U.S.) Department of Transportation, "Management and Monitoring Systems; Interim Final Rule," *Federal Register*, December 1, 1993, pp. 63441-63485.

reviewed the data collection and analysis procedures required or recommended in FHWA's *Traffic Monitoring Guide*[3] (TMG) and the *AASHTO Guidelines for Traffic Data Programs*[4] (the AASHTO Guidelines) issued by the American Association of State Highway and Transportation Officials.

Volume I of this Final Report presents a number of recommendations relating to the collection and analysis of traffic data that are based on the work we have performed and, in particular, on our analysis of ATR data. These recommendations take a variety of forms. Some are restatements of recommendations in the TMG or the AASHTO Guidelines; others are unhedged recommendations that go beyond those in the TMG or the AASHTO Guidelines and may, in some cases, differ from the previously published recommendations; and still others are suggestions for procedures that can be used to improve the quality of traffic estimates but which require some judgement as to the way in which they can be used most effectively. The new recommendations presented here are those of Cambridge Systematics and are not necessarily accepted by FHWA.

Complete documentation of all analyses performed is contained in Volume II.

## Short-Duration Counts

### Count Duration

We have several observations and recommendations relating to the duration of short-duration counts:

- ***All short-duration volume counts on HPMS sample sections should be taken for periods that are multiples of 24 hours.***
- Although FHWA prefers that short-duration counts be taken for a minimum of 48 hours, the differences in quality between 24 and 48-hour weekday counts is small. Some advantages of 48-hour counts are that data for two 24-hour

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[3] Federal Highway Administration, *Traffic Monitoring Guide*, Washington, D.C., October 1992.

[4] AASHTO Highway Subcommittee on Traffic Engineering, *AASHTO Guidelines for Traffic Data Programs*, American Association of State Highway and Transportation Officials, Washington, D.C., 1992.

periods can be used to check the consistency of results, and hourly data from one of these periods can be used to replace missing hourly data from the other period. ***If unusual events (inclement weather or incidents) affect travel volume during any 24-hour period, data for the affected period should not be used and, if necessary, the counters should be left in place for an extra 24 hours.***

- ***There is no need to take counts on a midnight-to-midnight basis.***

## Some Recommendations for Improving the Quality of Counts

***All short-duration volume counts should be checked for reasonable consistency with previous counts obtained for the same section and with current counts obtained for nearby sections of the same road.*** We recommend that all questionable counts be retaken.

***We recommend avoiding the use of contractors for the routine collection of volume and vehicle-classification counts.*** Permanent highway-agency personnel usually are able to obtain these counts more efficiently and more reliably. If contractors are used, they should be required to use counters that record hourly data, their counts should be subjected to consistency checks by highway-agency personnel, and their contracts should require that rejected counts be repeated until acceptable counts are produced.

## Axle-Correction Factors

With the possible exception of counts taken on rural minor collectors and functionally local roads, ***every count taken with a single road tube should be adjusted using an axle-correction factor. Road-specific factors are recommended for any mainline axle counts obtained using road tubes on the IS and on other NHS roads. For use on other roads, we recommend the development of axle-correction factors that vary by functional system and perhaps by region.*** These systemwide axle-correction factors should be recalculated at least once every three years.

# Use of Continuous ATR Data

We define an ATR *station* as consisting of one or more ATRs used for collecting continuous traffic data at a two-way site or at a pair of one-way sites. For road sections on which continuous ATR stations are located, ***AADT should be derived from traffic counts that are collected for every day of the year.*** If reliable counts are not available for a small number of days, traffic counts for these days may be imputed implicitly using the AASHTO procedure for obtaining AADT.

For sections that do not contain an ATR, AADT must be estimated from short-duration counts (short counts) taken for some multiple of 24 hours by applying factors that adjust for seasonal and day-of-week variation in traffic volume. Good factoring procedures can produce AADT estimates that are substantially better than those produced by using unfactored counts; while poor procedures can produce little or no improvement in the estimates, and they can also introduce biases that adversely affect aggregate results derived from AADT estimates for different sites. Our most important recommendations relating to the use of data from ATR stations are:

- *All AADT estimates submitted to HPMS should be derived using factors developed only from actual or imputed "current-year" data*; i.e., from data for a continuous 12-month (or 52-week) period that includes the dates of the counts to be factored. Exhibit S.1 compares the quality of AADT estimates derived using "current-year" factors with those derived using "historic" factors.

- *Nonfunctioning or malfunctioning ATRs should be restored to service as quickly as possible;*

- *All ATR data should be subjected to a systematic review to eliminate unreliable or misleading data;*

- *The quality of AADT estimates can be improved by increasing the number and homogeneity of factor groups;*

- *Although factor groups should reflect at least some functional-system distinctions, geographical distinctions usually are more valuable;*

- *The use of separate "urban Interstate" and "urban other" factor groups is unnecessary; and*

- *There appears to be little value in using more than five to eight ATR stations per factor group.*

## Exhibit S.1 Effect of "Historic" and "Current-Year" Factors on AADT Estimates for Two States

| | Mean Absolute Error | Average Error | P (Error > 20%) |
|---|---|---|---|
| Unfactored | 10.1 % | +0.5 % | 11.4 % |
| Current-Year Factors | 6.8 | -0.2 | 4.1 |
| Historic Factors | 8.2 | +3.5 | 5.8 |

Based on application of "Combined Month and Day-of-Week Procedure" to 48-hour short counts.

## Growth Factors

***We recommend that, in each year, all states that have a need for region-specific growth factors:***

- ***Obtain growth rates for each ATR station and also for each short-count site counted routinely in that year for which a reasonably reliable preceding-year AADT estimate also exists; and***
- ***Develop growth factors for each region by taking a simple average of growth rates obtained for the ATR stations and short-count sites in the region.***

States with NAAQS nonattainment areas that contain urbanized areas should develop separate growth factors for each VMT Tracking Area. All states may develop region-specific growth factors for other substate regions that are of particular interest or that are believed to have atypical VMT growth rates.

## VMT

***We recommend that the estimates of road miles by functional system and volume group submitted to FHWA reflect AADT estimates for*** all ***sections for which such estimates exist,*** including AADT estimates derived from special counts collected for project-related purposes and counts collected by local governments.

***We recommend that factoring for growth should be performed annually (and such factoring should be required, at least, for all VMT Tracking Areas corresponding to EPA air-quality non-attainment areas). Also, we recommend that current-year seasonal and day-of-week factors be applied to all newly collected counts as soon as the procedures discussed in Chapter 3 are implemented.*** We recommend the use of computerized procedures for performing all factoring and for assigning sections or miles of road to volume groups.

# Vehicle Classification

## Classification Recorders

We prefer that ATRs used for classification be programmable. Programmability provides State personnel with direct control over the classification algorithm used and permits fine-tuning of this algorithm to reflect changes in the axle spacing and axle weights of individual classes of vehicles operating in the State.

## Ambiguous Vehicles

***We recommend that all vehicles be assigned to one of the standard classes*** even when there is some ambiguity as to which is the correct class. Ambiguities usually are between two relatively similar classes (e.g., automobiles and four-tire trucks). By assigning an ambiguous vehicle only to an "undefined" or "unclassifiable" class, valuable information (whether the vehicle is light or heavy) is lost. However, ambiguous vehicles may be assigned to a nonstandard class *in addition to* a standard class; such nonstandard classes may be used as a diagnostic tool in identifying weaknesses in the classification algorithm.

***We also recommend that the classification algorithm used by each State be tested periodically and modified if appropriate.*** Modifications may be required to handle new vehicle configurations (e.g., articulated buses). Also, if tests indicate that the algorithm is overestimating the number of four-tire trucks and underestimating the number of six-tire trucks, the weight or axle-spacing threshold used for distinguishing four-tire trucks from six-tire trucks should be reduced slightly.

## Count Duration

***Short-duration classification counts obtained with automatic vehicle classifiers (AVCs) should be collected over periods that are a multiple of 24 hours and are* at least *48 hours long. Seven-day counts are preferable,*** since they eliminate the need for day-of-week factoring, and they reduce the effects of random fluctuations on the counts obtained for buses and other relatively small classes of vehicles.

## Manual Classification Counts

***If partial-day classification counts are to be used*** to derive estimates of daily traffic volume by vehicle class, ***time-of-day factors must be used.*** Because time-of-day usage patterns differ significantly by vehicle class, we recommend the development and use of separate sets of factors for:

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

## Estimating AADT by Vehicle Class

For road sections on which a permanent AVC is located, AADT by vehicle class (AADTVC) should be obtained directly from annual data produced by that AVC. For nearby sections on the same road, AADTVC should be obtained by counting total traffic on the section for a short period of time, using factors to produce estimated total AADT, and using data from the nearby AVC to distribute total AADT across vehicle classes. Options for estimating AADTVC on other sections are:

- Collect several seven-day classification counts over the course of a year and average the results;
- Obtain classification counts for a single period of at least 48 hours and use annual data from one or more AVCs on other roads to factor these counts; or
- Obtain classification counts for one or two periods of at least 48 hours and use these counts to distribute estimated AADT across vehicle classes.

*If this last option is used, counting either should be performed for a seven-day period or it should be performed on both weekdays and weekends with the counts adjusted to represent a seven-day period.* Failure to include weekend data will result in appreciable overestimates of volume for most truck classes.

### Estimating VMT by Vehicle Class

*Estimates of VMT by vehicle class should be developed* only *from classification data that reflect both weekday and weekend conditions.* They may be based on AADTVC estimates that were developed from annual AVC data, from short-duration classification counts taken on both weekdays and weekends, or from weekday classification counts factored using annual classification data. Alternatively, they may be based on unfactored short-duration classification counts taken throughout the year on both weekdays and weekends. *The use of unfactored weekday classification counts taken throughout the year produces significant overestimates of VMT for most truck classes.*

## Weigh-in-Motion Data

### Distribution of WIM Sites

We recommend that, *instead of distributing weigh-in-motion (WIM) sites across functional systems and volume groups, the sites should be distributed across* regions. Regional differences in the economic base are likely to have a greater influence on truck weight characteristics than are functional systems and AADT, particularly on roads with significant amounts of locally generated traffic. For this reason, we consider regional distribution to be more valuable, particularly for non-IS sites. Also, *states with significant systems of roads with different weight limits should consider distributing WIM sites both across regions and across systems of roads with different weight limits.*

### WIM Installations and Interpretation of WIM Data

Users of WIM data should be aware that these data are likely to produce higher estimates of average ESALs than would weighing of the same vehicles on stationary scales. The degree of this variation is affected by the quality of the road surface, the suspension characteristics of passing trucks, the loads carried by those trucks, and, to a limited extent, the sensor design and sensor configuration of the WIM device. To reduce this effect, ***we recommend that pavement in the vicinity of permanent WIM installations be maintained to higher standards than those used for other pavement, that portable WIM equipment only be used at locations where pavement is in good condition, and that, when piezo-electric sensors are used, at least two be used in each lane.*** By weighing each axle more than once and averaging the results, axle weights can be obtained that are closer to those that would be obtained by stationary scales. Also, ***we do not recommend the use of site-specific WIM data for project-design purposes.***

### Estimating ESALs from WIM Data

***We recommend that ESALs estimates be developed only from WIM data collected over time periods during which the calibration of WIM equipment can be maintained with a high degree of accuracy.*** In areas where maintenance of calibration is difficult, the time periods for which WIM data is collected probably should be no more than one week long.

## Documentation

All procedures used for estimating AADT, AADTVC, and VMT by vehicle class and for developing data on vehicle weights and ESALs should be documented in writing.

# 1.0 Introduction

This report presents the results of a study of the use of traffic data from continuous monitoring sites performed under contract to the Federal Highway Administration (FHWA). In the course of this study, we have reviewed current procedures for collecting traffic data and for using these data to estimates *annual average daily traffic* (AADT), *vehicle-miles of travel* (VMT), AADT and VMT by vehicle class, and *18,000 pound* (18 kip) *equivalent single axle loads* (ESALs).

As part of this effort, we employed a written survey to learn about procedures being used by nine States, we conducted personal interviews with key staff in three of these States (Florida, Ohio, and Washington), and we performed an extensive analysis of data from continuous *automatic traffic recorders* (ATRs) in four states (including one of the States that was surveyed and interviewed). In addition, we reviewed the traffic data required by FHWA's Highway Performance Monitoring System[5] (HPMS) and by the Traffic Monitoring System for Highways (TMS/H) of the Intermodal Surface Transportation Efficiency Act (ISTEA);[6] and we also

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5 Federal Highway Administration, *Highway Performance Monitoring System Field Manual*, Washington, D.C., August 1993.

6 (U.S.) Department of Transportation, "Management and Monitoring Systems; Interim Final Rule," *Federal Register*, December 1, 1993, pp. 63441-63485.

reviewed the data-collection and analysis procedures required or recommended in FHWA's *Traffic Monitoring Guide*[7] (TMG) and the *AASHTO Guidelines for Traffic Data Programs*[8] (the AASHTO Guidelines) issued by the American Association of State Highway and Transportation Officials. Our work on this study also benefitted from a parallel effort to produce an improved Traffic Monitoring System for the Virginia Department of Transportation.[9]

Volume I of this Final Report presents a number of recommendations relating to the collection and analysis of traffic data that are based on the work we have performed and, in particular, on our analysis of ATR data. All recommendations were reviewed for reasonable and practicality by staff in the three interview states (Florida, Ohio, and Washington). We wish to thank the staff in these states for their review of an earlier draft of this volume as well as for their helpful comments during the initial round of interviews.

Our recommendations take a variety of forms. Some are restatements of recommendations in the TMG or the AASHTO Guidelines; others are unhedged recommendations that go beyond those in the TMG or the AASHTO Guidelines and may, in some cases, differ from the previously published recommendations; and still others are suggestions for procedures that can be used to improve the quality of traffic estimates but which require some judgement as to the way in which they can be used most effectively. The new recommendations presented here are those of Cambridge Systematics and are not necessarily accepted by FHWA.

Complete documentation of all analyses performed is contained in Volume II, along with the summary of the information obtained from the survey and interviews that we conducted.

Volume I contains seven chapters and two appendices. Chapter 2 is a brief chapter presenting several recommendations relating to the collection and use of short-duration traffic counts. Chapter 3 is a much longer chapter discussing several topics relating to the use of data from

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7 Federal Highway Administration, *Traffic Monitoring Guide*, Washington, D.C., October 1992.

8 AASHTO Highway Subcommittee on Traffic Engineering, *AASHTO Guidelines for Traffic Data Programs*, American Association of State Highway and Transportation Officials, Washington, D.C., 1992.

9 Cambridge Systematics, Inc., Gorove/Slade Associates, Inc., and Information Systems and Services, Inc., *Traffic Monitoring Systems Development Study*, Task 2: Review and Evaluation of the Current TMS and Recommendations for an Improved TMS, prepared for the Virginia Department of Transportation, May 1994.

continuously operated ATRs. The recommendations presented in this chapter are based primarily on the results of our analysis of continuous ATR data from four States (Colorado, Illinois, Nebraska, and Washington). The fourth chapter contains a discussion of the use of growth factors and recommendations for the documentation of data used for developing AADT estimates; and the fifth chapter contains a brief discussion of the use of AADT estimates to produce estimates of VMT.

Chapter 6 covers several topics relating to the collection and use of classification counts. Of particular interest is Section 6.2, which discusses several alternative procedures for estimating AADT by vehicle class that are capable of producing better estimates of truck volumes than the procedures that are in common use. Also, Section 6.3 recommends alternatives for estimating VMT by vehicle class that are likely to reduce or to eliminate the overestimates of truck VMT produced by current procedures.

The final chapter contains several recommendations relating to the collection and use of weigh-in-motion data.

This volume also contains two appendices. Appendix A describes some of the factoring procedures evaluated in Chapter 3; and Appendix B discusses some procedures that may be useful in developing improved factor groups.

# 2.0 Short-Duration Counts

This chapter contains several recommendations relating to the collection and interpretation of short-duration counts (short counts) of total traffic volume.

## 2.1 Count Duration

We have several observations and recommendations relating to the duration of short counts:

- Although FHWA prefers that short-duration counts be taken for a minimum of 48 hours, the differences in quality between 24 and 48-hour weekday counts is small. On a statewide basis, the mean absolute errors in individual estimates of AADT derived from 24-hour weekday counts are only 0.1 to 0.8 percentage points greater than the errors derived from 48-hour weekday counts, with the differences in percentage error magnitudes varying inversely with volume. Some advantages of 48-hour counts are that data for two 24-hour periods can be used to check the consistency of results, and hourly data from one of these periods can be used to replace missing hourly data from the other period. ***If unusual events (inclement weather or incidents)***

***affect travel volume during any 24-hour period, data for the affected period should not be used and, if necessary, the counters should be left in place for an extra 24 hours.***

- ***All short-duration volume counts on HPMS sample sections should be taken for periods that are multiples of 24 hours.*** The factoring of short counts of total volume to represent 24-hour counts introduces an unnecessary source of error and should be used only with great caution.

- ***There is no need to take counts on a midnight-to-midnight basis.*** The factoring procedures presented in Chapter 3 and Appendix A work at least as well using counts started in the middle of the day as they do on counts taken from midnight to midnight.

## 2.2 Some Recommendations for Improving the Quality of Count

***All short-duration volume counts should be checked for reasonable consistency with previous counts obtained for the same section and with current counts obtained for nearby sections of the same road.*** These checks may be conducted using either raw counts or AADT estimates, but AADT estimates are preferred when comparing counts taken at different times of the year. Also, the screening procedures discussed in Section 3.3 should be applied to all counters that record hourly data. We recommend that all questionable counts be retaken.

***We recommend avoiding the use of contractors for the routine collection of volume and vehicle-classification counts.*** Permanent highway-agency personnel usually are able to obtain these counts more efficiently and more reliably. If contractors are used, they should be required to use counters that record hourly data, their counts should be subjected to consistency checks by highway-agency personnel, and their contracts should require that rejected counts be repeated until acceptable counts are produced. Also, all counts should be furnished to highway agencies in electronically readable formats that can be converted easily to the formats specified in the TMG.

## 2.3 Axle-Correction Factors

With the possible exception of counts taken on rural minor collectors and functionally local roads, ***every count taken with a single road tube should be adjusted using an axle-correction factor.*** These may be *road-specific factors* or *system factors.*

***Road-specific factors are recommended for any mainline axle counts obtained using road tubes on the IS and on other NHS roads.*** These factors can be developed in the course of performing classification counting on these roads (as required under ISTEA). We recommend that axle factors be obtained routinely whenever equipment that can both classify vehicles and count axles is used to perform short-duration classification counting on these roads. Axle factors obtained by dividing the resulting vehicle count by the resulting axle count should be used for factoring axle counts obtained at nearby sites *on* the same road (but not at entry and exit ramps). To the extent feasible, the axle factors and the axle counts to be factored should be obtained concurrently or within a few weeks of each other. We recommend that road-specific axle-correction factors be expressed with two or three decimal places of accuracy (e.g., in the form 2.xx or 2.xxx).

***For use on other roads, we recommend the development of axle-correction factors that vary by functional system and perhaps by region.*** Factors generally will decline as one moves from higher functional systems to lower functional systems, and those in recreational areas generally will be appreciably lower than those in rural natural-resource producing areas. For each functional system and region to be distinguished, we recommend that a single "system" factor be developed as an unweighted average of axle/vehicle ratios obtained for several sites in the system. These ratios may be obtained from[10]:

1. Annual counts of axles and vehicles obtained from Strategic Highway Research Program (SHRP) weigh-in-motion (WIM) sites and from other continuously operated automatic vehicle classification (AVC) sites capable of producing both axle and vehicle counts; and

[10] Ideally, if the factors are to be applied to weekday axle counts, the ratios should be derived from annual *weekday* counts (when the ratios come from the first type of source) or from annual average *weekday* traffic (AAWDT) by vehicle class (when the ratios come from the second type of source). The procedures presented in Chapter 6 can be modified to produce estimates of AAWDT by vehicle class for this application. However, the extra effort that would be required may not be warranted.

2. Estimates of AADT by vehicle class developed from short-duration classification counts using procedures presented in Chapter 6.

The development of axle/vehicle ratios from the second type of source requires information on the average number of axles per vehicle for each vehicle class. For vehicle classes for which this number is not uniquely determined, it can be set by judgement (e.g., an average of 3.5 axles per vehicle for three and four-axle single-trailer combinations); however, slightly improved estimates of average axles per vehicle for these vehicle classes can be derived using data from similar WIM and AVC sites (distinguishing, at least, urban and rural sites). For rural minor collectors and functionally local roads, an axle/vehicle ratio of 2.0 may be assumed.

We recommend that systemwide axle-correction factors be expressed with two decimal places of accuracy (e.g., in the form of 2.xx). When they are expressed as vehicle/axle ratios (i.e., using 0.5 to represent two-axle vehicles), a third decimal place may be desirable (i.e., in the form 0.4xx). ***Systemwide axle-correction factors should be recalculated at least once every three years.***

# 3.0 Use of Continuous ATR Data

For road sections on which continuous ATRs are located, ***AADT should be derived from traffic counts that are collected for every day of the year.*** If reliable counts are not available for a small number of days, traffic counts for these days may be imputed implicitly using the AASHTO procedure for obtaining AADT (presented in Section 3.1).

Unfortunately, it is not practical to operate ATRs on more than a handful of road sections. For sections that do not contain an ATR, AADT must be estimated from short-duration counts (short counts) taken for some multiple of 24 hours by applying factors that adjust for seasonal and day-of-week variation in traffic volume. These factors are derived from data collected by continuous ATRs. For brevity, we shall refer to the factoring procedures that are used to adjust for both seasonal and day-of-week variations in traffic volume as *seasonal factoring procedures.*

We define an *ATR station* as consisting of one or more ATRs used for collecting continuous traffic data at a two-way site or at a pair of one-way sites. ***One-way data normally should not be used for developing factors that are used on any roads other than the road on which the ATR is located.*** However, if one of a pair of ATRs is temporarily out of service and *it is known* that daily counts taken by the two ATRs rarely differ by more than 1 or 2 percent, then it is better to infer a two-way count by doubling the count obtained from the in-service ATR than to discard this data altogether.

Good factoring procedures can produce AADT estimates that are substantially better than those produced by using unfactored counts; while poor procedures can produce little or no improvement in the estimates, and they can also introduce biases that adversely affect aggregate results derived from AADT estimates for different sites. Our most important recommendations relating to the use of data from ATR stations are:

- ***All AADT estimates submitted to HPMS should be derived using factors developed only from actual or imputed "current-year" data; i.e., from data for a continuous 12-month (or 52-week) period that includes the dates of the counts to be factored;***

- ***Nonfunctioning or malfunctioning ATRs should be restored to service as quickly as possible;***

- ***All ATR data should be subjected to a systematic review to eliminate unreliable or misleading data;***

- ***The quality of AADT estimates can be improved by increasing the number and homogeneity of factor groups;***

- ***Although factor groups should reflect at least some functional-system distinctions, geographical distinctions usually are more valuable;***

- ***The use of separate "urban Interstate" and "urban other" factor groups is unnecessary; and***

- ***There appears to be little value in using more than five to eight ATR stations per factor group.***

These and other recommendations are discussed below.

## 3.1 Averaging ATR Data and the Use of Imputed Data

The *AASHTO Guidelines* (page 52) presents the following procedure for deriving estimates of AADT and *monthly average daily traffic* (MADT) from daily traffic volumes obtained from an ATR station:

1. For each month of the year, develop seven *monthly average days of the week* (MADW) values by averaging available volumes obtained in that month for each of the seven days of the week;

2. Obtain seven *average annual days of the week* (AADW) values by averaging the twelve corresponding MADW values;

3. Obtain AADT as the average of the seven AADW values; and

4. For each month, obtain MADT as the average of the seven MADW values for that month.

This relatively complex averaging procedure has two interesting properties:

1. The influence of each day of the week on MADT for a given month is independent of whether the day occurs four or five times in a given month. This property can be of some value when factors derived using data for one year are applied to traffic counts obtained in a subsequent year.

2. MADT can be estimated even when counts for some days of the month are missing. Indeed, all that is required is a minimum of one count for each day of the week.

The second property is a significant one. For any ATR station, reliable counts may be unavailable for a variety of reasons, including battery failure, equipment malfunction, or the loss of a magnetic loop detector. When reliable counts are unavailable for, say, one or more Wednesdays in a given month, the AASHTO procedure estimates MADW and AADW by, in effect, assuming that traffic volumes on the missing Wednesdays are the same as the average of the traffic volumes on the remaining Wednesdays of the month. This is a simple way of handling the missing data problem. The AASHTO procedure implicitly *imputes* the traffic volume for the missing Wednesdays by using an unadjusted average of the volumes for the remaining Wednesdays.

Although the AASHTO implicit imputation procedure is simple, it is not as reliable as it might be. During the Spring and Fall, daily traffic volumes on many roads tend to increase or decrease appreciably in the course of a month. Accordingly, if a day is missing during the first or last week of a month, a moderate error in the implicitly imputed value is likely. Indeed, our test of this procedure indicates that there is a 50 percent probability that the error in the implicitly imputed volume for a single missing day will exceed 3.5 percent and a 20 percent probability that it will exceed 8.5 percent.

We were unsuccessful in our attempt to develop a reasonably simple explicit imputation procedure that would produce better results. However, a simple explicit procedure that is quite similar to the AASHTO implicit procedure (but which we did not test) involves imputing a value for a given day by averaging the values for the same day in the preceding week and the same day in the following week.[1] This imputation procedure is likely to produce results that are similar to those produced by the AASHTO procedure and it can be used with factoring procedures that require explicit imputation.

Although the AASHTO implicit imputation procedure appears to be the best procedure for handling data for missing *days*, when data is unreliable or missing for only *a few hours*, use of the AASHTO procedure introduces more error than is necessary. ***When only a few hours of data are unreliable or missing, we recommend that data for those hours be imputed explicitly.*** The imputation procedure described in the preceding paragraph is an appropriately simple procedure for imputing missing hourly counts. Although this procedure can be expected to produce some small errors in the hourly counts, the overall error for the entire day's count can be expected to be smaller than if the AASHTO implicit imputation procedure is used. We recommend that hourly counts be imputed whenever reliable counts exist for at least twelve hours in a day.

***The above results underscore the importance of restoring nonfunctioning and malfunctioning ATRs to service as quickly as practical.*** One state has a goal of restoring service within five days. Also, ***all imputation procedures used,*** including the AASHTO implicit procedure, ***should be documented and all imputed ATR data should be identified as such.***

## 3.2 Seasonal Factoring Procedures

In order to evaluate the effectiveness of alternative factoring procedures, we used actual and imputed[2] 1992 traffic counts from 183 ATR stations in four states (Colorado, Illinois, Nebraska, and Washington) to simulate approximately 15,000 48-hour weekday counts. Each of these counts was used as an unfactored estimate of AADT and compared to actual AADT at the ATR station. Also, for each ATR station, data from all other ATR stations in the factor group were used to factor the individual counts using several different factoring procedures, and the resulting AADT estimates were compared to actual AADT at the site. This process provided extensive statistical information on the reliability of AADT estimates produced using the various factoring procedures with the factor groups currently in use in these four states. The process used is described in more detail in Volume II of this report.

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[1] Possible improvements to this procedure include not using data for holidays (or holiday weekends) when imputing values for non-holidays.

[2] To the extent feasible, daily 1992 traffic counts that were missing were replaced by counts that were imputed from 1991 and 1990 data.

We present below some of the most significant results of our analyses along with recommendations that are based on these results. Additional results and a more complete description of our analyses are contained in Volume II.

## "Current-Year" Factors

Exhibit 3.1 compares the results of applying two alternative factoring procedures to simulated 48-hour counts for 1992 with the results of using no factors. The first procedure uses a version of "current-year" factoring, in which factors are derived entirely from actual and imputed 1992 ATR data; while the second procedure uses a corresponding version of "historic" factoring, in which factors are derived entirely from actual and imputed 1990 ATR data. The second procedure is a variant on one, used by most states, in which all factors are derived from a recent three or five-year period prior to the current year. The analysis used data from only two states, Illinois and Nebraska, because we did not have complete 1990 data for the other two states.

The Exhibit 3.1 results show that current-year factoring produces substantially better AADT estimates than are obtained when unfactored 48-hour counts are used. The first column of the exhibit shows the percentage mean absolute error (MAE) — the average of the absolute value of the errors in each of the individual estimates of AADT expressed as a percentage of AADT. Current-year factors produce an MAE of 6.8 percent, appreciably better than the 10.1 percent MAE resulting when no factoring is used. Similarly, the last column shows that the percentage of all errors that exceed 20 percent (i.e., the probability that an individual AADT estimate is off by more than 20 percent) declines from 11.4 to 4.1 percent.

The middle column of Exhibit 3.1 shows that, in the first two cases, the *average* error is a small percentage of AADT: +0.5 percent without factoring and -0.2 percent with current-year factoring — suggesting that positive and negative errors tend to balance. The average error is an indicator of positive or negative bias that will exist in VMT estimates derived from a large sample of AADT estimates.

Exhibit 3.1 also shows that historic factors do not work as well as current-year factors. MAE declines only to 8.2 percent and the percentage of AADT estimates with errors exceeding 20 percent declines only to 5.8 percent. More significantly, the average error *increases* to 3.5 percent, implying that the tested procedure tends to produce VMT estimates with a relatively significant upward bias. This result indicates that, between 1990 and 1992, weekday traffic grew appreciably faster than weekend traffic. The uneven growth rates between weekday and weekend traffic

## Exhibit 3.1 Effect of "Historic" and "Current-Year" Factors on AADT Estimates for Two States

| | Mean Absolute Error | Average Error | P (Error > 20%) |
|---|---|---|---|
| Unfactored | 10.1 % | +0.5 % | 11.4% |
| Current-Year Factors | 6.8 | -0.2 | 4.1 |
| Historic Factors | 8.2 | +3.5 | 5.8 |

Based on application of "Combined Month and Day-of-Week Procedure" to 48-hour short counts.

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were probably also the principal reason why the historic factors did not improve the other error statistics as much as the current-year factors.

On the basis of the above discussion we conclude:

***Current-year factors produce appreciably better estimates of AADT than historic factors.***

Also, we recommend that ***final AADT estimates for any year submitted to HPMS should be produced using current-year factors.***

Current-year factors for any calendar year cannot be developed until after the calendar year is over. For internal planning and design purposes, many states will not want to wait for current calendar-year factors to be available. Accordingly, most states will want to produce preliminary estimates of AADT. For this purpose, we suggest either of two alternatives:

1. Use current-year factors developed from actual and imputed data for any twelve-month period that includes the dates on which the count to be factored was taken; or

2. Use historic factors developed from actual and imputed data for the preceding calendar year.

The second alternative, use of "preceding-year" factors, is likely to produce AADT estimates with errors that are in between those produced by current-year factors and the two-year-old historic factors evaluated in Exhibit 3.1. As such, they would appear to be reasonable for use on an interim basis.

The first alternative will produce better AADT estimates. It is computational more intensive, but it probably is a practical alternative for any state that has a completely computerized procedure for processing ATR data. This alternative involves computing a new set of factors after each month's ATR data has been reviewed, accepted, and entered into the system. The AADT estimates it produces are actually good estimates of AADT for the 12-month period represented by the factors, and these estimates could be considered acceptable to HPMS. However, in areas where AADT is growing, these estimates will tend to underestimate calendar-year AADT. States with completely computerized procedures probably will find it desirable to recompute each year's new AADT estimates at the beginning of the following year using calendar-year factors in order to increase the consistency of the estimates obtained for various short-count sites and to produce better estimates of calendar-year VMT.

## Alternative Sets of Factors

A second issue in specifying factoring procedures is how to group the days of the year to produce a manageable set of factors. The TMG recommends developing seven day-of-week factors for each month of the year, for a total of 84 factors, a process that we call "Combined Month and Day-of-Week" factoring. However, there are at least two other temporal grouping procedures currently in use.

Exhibit 3.2 presents the results of applying several different temporal grouping procedures with current-year factors to simulated 1992 counts for four states.[3] All the procedures incorporate some form of seasonal and weekday/weekend adjustment. The procedures are listed roughly in order of improving performance and increasing complexity (as measured by the total number of factors required). Procedures 2, 4, and 5 are used currently by one or more states (though usually in combination with some form of historic factors). Procedure 4 is the "Combined Month and Day-of-Week" procedure recommended in the TMG. Procedures 1, 2, and 4 can be used in conjunction with the AASHTO implicit imputation

[3] The results for both the unfactored and (Procedure 4) factored estimates presented in Exhibit 3.2 are slightly poorer than the corresponding results in Exhibit 3.1 because Exhibit 3.2 includes data from two additional states, Colorado and Washington, with relatively high volumes of recreational travel — a type of travel that is inherently difficult to factor.

## Exhibit 3.2. Effects of Alternative "Current-Year" Factoring Procedures on AADT Estimates

| | Mean Absolute Percentage Error | Average Percentage Error | P (E > 20%) | Number of Factors Required for | |
|---|---|---|---|---|---|
| | | | | Weekday Counts | Weekday and Weekend Counts |
| Unfactored | 12.4 % | -0.6 % | 18.2 % | | |
| 1. Separate Month and Day-of-Week | 7.5 | -0.5 | 6.2 | 17 | 19 |
| 2. Combined Month and Average Weekday | 7.6 | +0.4 | 5.9 | 12 | 24 |
| 3. Separate Week and Day-of-Week | 7.5 | -0.9 | 6.0 | 57 | 59 |
| 4. Combined Month and Day-of-Week | 7.4 | -0.2 | 5.8 | 60 | 84 |
| 5. Combined Week and Average Weekday | 7.3 | +0.5 | 5.1 | 52 | 104 |
| 6. Specific Day | 7.1 | +0.2 | 5.1 | 261 | 365 |
| 7. Specific Day with Noon-to-Noon Factors | 7.0 | +0.3 | 4.8 | 261 | 365 |

procedure, while the other procedures require some form of explicit imputation in order to handle missing data.

Our evaluation of the seven temporal grouping procedures leads us to conclude that ***all the tested procedures are appropriate for use, though Procedure 4 appears to provide the best trade-offs between complexity and performance.*** Procedures 5-7 produce better results, but they require the use of an explicit factoring procedure (such as the one described in Section 3.1).

Procedure 4 is described below and the remaining temporal grouping procedures are described in Appendix A.

## Combined Month and Day-of-Week Factoring

Combined Month and Day-of-Week (CMDW) factoring (Procedure 4) requires the development of separate day of the week factors for each month of the year — a total of 60 weekday factors and another 24 factors for Saturdays and Sundays.

The CMDW factor for month *i* and day *j* at ATR station *k*, $MDWF_{ijk}$, is obtained as

$$MDWF_{ijk} = \frac{AADT_k}{MADW_{ijk}} \tag{3.1}$$

where $MADW_{ijk}$, the *monthly average day of the week* traffic for month *i* and day-of-week *j* at ATR *k*, is derived as the average of ATR counts for all "j-days" (e.g., Thursdays) in month *i*.[4] To avoid unnecessary biases in the resulting factors, ***we recommend that weekday holidays (such as Thanksgiving Thursday and Friday) be*** **excluded** ***from the computation of MADW*** (but not from the computation of AADT).

The use of Equation 3.1 to derive estimates for the CMDW factors requires a minimum of one 24-hour count for each day of the week in each month of the year. Thus, even if reliable ATR counts are not available for several consecutive days, this procedure can be used without explicitly imputing counts for the missing days.

If weekend or seven-day counts are collected, there are two alternatives for treatment of data for holiday weekends:

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[4] Equation 3.1 is equivalent to the computation procedure presented on pages 3-2-9 and 3-3-12 of the TMG.

1. Do not develop AADT estimates from short-duration counts taken over these weekends, and exclude ATR data for these weekends and for the day preceding the start of the weekend (usually Friday) from the computation of MADW; or

2. Develop AADT estimates from short counts taken over these weekends and include the corresponding ATR data in the computation of MADW.

Both alternatives avoid biasing the AADT estimates. However, because of the characteristic differences between traffic volumes on holiday weekends and those on other weekends, holiday-weekend AADT estimates produced by the second alternative will be somewhat less precise than those produced by the first alternative. (It may be observed that the first alternative, no short counts and no ATR data in MADW, corresponds to the procedure recommended above for weekday short-duration counts.)

The application of factors produced by Procedure 4 to a 48-hour count that is started in the middle of the day, say a Tuesday, requires that the count be decomposed into three components: a Tuesday component, a Wednesday component, and a Thursday component. Separate Tuesday, Wednesday, and Thursday factors are then applied to these components, the results are added (to produce an estimate of annual average 48-hour traffic), and the sum is divided by two to produce estimated AADT.[5]

Procedure 4 factors can also be applied to counts that are started at midnight. Factoring of counts that are taken on a midnight-to-midnight basis appears to be aesthetically preferable to factoring counts that start in the middle of the day. However, midnight-to-midnight counts require extra equipment resources (because of the periods when counters are in place but their counts are not being used) and they usually require a small increase in personnel resources. More importantly, our simulation tests indicate that they apparently produce slightly *poorer* estimates of AADT.[6] Accordingly, ***we recommend that all short-duration counts be started in the middle of the day, rather than waiting until midnight.***

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[5] A variant of this procedure that sometimes is used involves averaging the Tuesday and Thursday factors and applying the result to the sum of the Tuesday and Thursday counts. This variant should produce results that closely approximate those of the procedure described in the text.

[6] The MAE is about 0.2 percentage points higher and the frequency of errors exceeding 20 percent increase by about 0.7 percentage points.

### Annual Average Weekday Traffic

For some planning purposes, *annual average weekday traffic* (AAWDT) or *annual average school day traffic* (AASDT) may be of more interest than AADT.

AAWDT can be estimated from weekday coverage counts using analogues of the procedures presented above (i.e., by substituting AAWDT for AADT in Equation 3.1). Because estimation of AAWDT does not require consideration of the difference between weekday and weekend traffic volume, AAWDT generally can be estimated with somewhat more precision than AADT. This can be seen by comparing factored and unfactored estimates of AAWDT, which are shown in Exhibit 3.3, to the corresponding estimates of AADT shown in Exhibit 3.2.

Similarly, AASDT can be estimated from school day coverage counts using analogues of the above procedures. We would expect that AASDT can be estimated with somewhat more precision than AAWDT, though we have not tested AASDT.

## 3.3 Screening ATR Data

The quality of AADT estimates produced using factors from one or more ATR stations depends upon the quality of the counts obtained from these stations and the general degree to which these counts replicate traffic-volume patterns at short-count sites in the factor group. To assure that only reliable counts are used, ***all ATR counts should be subjected to a series of computerized screening criteria or "edit checks"***. Counts that fail these checks should be subjected to additional review to determine the reason for their failure.

Counts that are affected by any identifiable form of equipment malfunction should be rejected. Counts that appear to have been affected by unusual local conditions (e.g., incidents, severe weather, etc.) that are unlikely to have a similar effect on counts being collected concurrently at short-count sites should be rejected, or they should be adjusted to minimize the effect of these conditions. For the purpose of developing seasonal factors, it is likely that adjustments that reduce the effect of unusual conditions on a given day's traffic to less than 3.5 percent will work at least as well as ignoring the day's traffic altogether.[7]

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[7] Although such adjustments are desirable for the purpose of estimating seasonal factors (e.g., using Equation 3.1), they may introduce a small but unnecessary error in the value of AADT recorded for the

# Exhibit 3.3 Effects of Factoring on AAWDT Estimates

| | Mean Absolute Error | Average Error | P (Error > 20%) |
|---|---|---|---|
| Unfactored | 11.4% | +0.7% | 17.0% |
| Combined Week and Average Weekday Factors | 6.1 | +0.3 | 3.5 |

***All adjusted or imputed counts should be identified as such and all daily counts incorporating adjusted data should be identified as such. Also, all adjustment and imputation procedures used should be documented in writing.***

Counts that are accepted as reliable without any need for adjustment are referred to as *edit-checked*.

The *AASHTO Guidelines* (pages 38-42) presents several recommended screening criteria, and a report by Baloffet and Associates[8] contains a number of somewhat more stringent criteria that appear to have substantial promise. Two additional criteria that we have found to be useful are to examine the data whenever:

- For any string of consecutive hours without any traffic, the total volume during the two hours preceding the string plus the two hours following the string exceeds 60; and
- For any pair of consecutive hours with nonzero volumes, the ratio of the total volume in one hour to that in the other hour exceeds 15 *and* the difference exceeds 300.

It may be desirable to make the numerical thresholds in these criteria a function of historic AADT or to use different thresholds on high and low-volume roads.

section containing the ATR station. If desired, this error can be avoided by calculating AADT for the section from unadjusted counts (but the resulting value for AADT should *not* be used in Equation 3.1).

[8] Baloffet and Associates, *Traffic Analysis Expert System: Overview*, Denver, Colorado, July 1993, Appendix A.

***We also recommend that the accuracy of all continuous ATRs be checked on a regular basis*** (e.g., annually) ***by comparing their counts to manual counts taken for short periods of time (e.g., 15 minutes) or to counts obtained using portable detectors.***

## 3.4 The Formation of Factor Groups

The use of seasonal factors for factoring short counts requires a procedure for associating short-count sites (or road sections) with ATR stations. This is usually accomplished by grouping the short-count sites on the basis of functional system and/or location, and associating each of the resulting *factor groups* with one or more ATR stations. Most states develop a few relatively large factor groups, and they associate with each group several ATR stations established at sites within the group. A few states develop a much larger number of factor groups and associate with each group a single ATR station, again established at some site in the group. The process of developing these associations frequently is described as *grouping ATR stations* though, more properly, it consists of grouping the short-count sites and *associating ATR stations* with the groups of short-count sites.

To the extent that seasonal and day-of-week traffic-volume patterns for all ATR and short-count sites in a group are similar, good estimates of AADT will be produced; to the extent that these patterns differ, some poor AADT estimates will result. In concept, large groups (especially non-urban groups) are relatively likely to contain a number of short-count sites that have traffic-volume patterns that are moderately different from the "typical" (or average) pattern for the group, and the patterns for some of the sites may be markedly different. On the other hand, while it is possible to increase the homogeneity of the traffic-volume patterns by reducing the size of the group, accomplishing this goal requires a considerable amount of judgement. Also, our procedure for evaluating the quality of AADT estimates can only be applied reliably to factor groups that contain several ATR stations, and it cannot be applied at all to factor groups that contain a single ATR station.

The first subsection below discusses some ideas for increasing the homogeneity of factor groups containing multiple ATR stations; the second subsection discusses the alternative of using seasonal factors only from individual ATR stations; and the third subsection discusses three hybrid approaches. These subsections contain a variety of ideas for developing better factor groups than those that are currently in use. However, they present only three clear recommendations:

- ***The quality of AADT estimates can be improved by increasing the number of factor groups and the homogene-***

***ity of the traffic-volume patterns of the short-count sites contained in each factor group;***

- ***Although factor groups should reflect at least some functional-system distinctions, geographical distinctions usually are more valuable; and***

- ***Using separate factor groups for urban IS sites and for other urban sites is unnecessary.***

The first of the above recommendations deserves particular emphasis. ***The effectiveness of seasonal and day-of-week factoring is dependent on the homogeneity of the traffic-volume patterns of the short-count sites in each factor group.***

## Factor Groups Containing Multiple ATR Stations

The TMG recommends the use of multiple ATR stations for each factor group. The TMG also recommends (pp. 3-2-7 - 3-2-8) that, except for recreational groups, the number of ATR stations selected for any group be sufficient to estimate the factors for the group with 10 percent precision with 95 percent confidence (95-10). It should be emphasized that *this criterion is a statement about how well the factors have been estimated*; i.e., how well they represent the *average* of the seasonal and day-of-week patterns of all ATR and short-count sites in the group. This criterion is *not* a statement about how well the factors work.

If a factor group contains short-count sites with significantly dissimilar patterns of traffic, no matter how well the factors are estimated, there will continue to be an appreciable number of short-count site "outliers" for which the factors will not work well. ***For such a group, rather than increasing the number of ATR stations to produce better estimates of the factors, we recommend attempting to split the group into smaller groups with less dissimilarity. We see little value in using more than five to eight ATR stations per factor group.***

Exhibit 3.4 summarizes, by type of factor group, the quality of AADT estimates produced by Procedure 5 (Combined Week and Average Weekday factors) using the factor groups currently in use in the four states (Colorado, Illinois, Nebraska, and Washington). Three types of factor groups are distinguished: urban, rural and recreational. For all three types of group, factoring usually produces a 30 to 40 percent reduction in MAE and an even greater reduction in the frequency of large errors in AADT. Factoring also substantially reduces or eliminates an

## Exhibit 3.4. Effects of Factoring on AADT Estimates by Factor Group

| | Mean Absolute Error | Average Error | P (Error >10%) | P (Error >20%) |
|---|---|---|---|---|
| Urban Groups[1] | | | | |
| Unfactored | 7 - 9 % | +0.8 - +6.5 % | 24 - 44 % | 1 - 4 % |
| Factored | 4 - 7 | +0.2 - +0.9 | 3 - 24 | 0.1 - 2 |
| Rural Groups[2] | | | | |
| Unfactored | 8 - 19 | -13 - +1.4 | 32 - 71 | 6 - 39 |
| Factored | 5 - 10 | -1.5 - +2.1 | 6 - 43 | 0.7 - 12 |
| Recreational Groups | | | | |
| Unfactored | 13 - 36 | -15 - -5 | 53 - 90 | 20 - 77 |
| Factored | 9 - 20 | -3.0 - -0.5 | 38 - 69 | 7 - 38 |
| Overall Average | | | | |
| Unfactored | 12.4 | - 0.6 | 48 | 18.2 |
| Factored Using Current Groups | 7.6 | + 0.5 | 24 | 5.9 |
| Factored Using Functional Systems | 8.4 | + 0.5 | 29 | 8.3 |

All factoring performed with current-year "Combined Week and Average Weekday" procedure and, except as noted, the factor groups currently in use in the four states.

[1] Excludes one "Urban Interstate" group for which data was available from only three ATRs.

[2] Excludes Nebraska's "Low Volume Roads" group.

upward bias in the unfactored AADT estimates for urban groups and downward biases in the estimates for rural and recreational groups.

Exhibit 3.4 indicates that the best results (both with and without factoring) are obtained for the urban groups and that the poorest results are obtained for the recreational groups. ***Of the 25 factor groups used by these states, only two groups (both of which are urban) produce AADT estimates with 10 percent precision with 95 percent confidence.*** Slight improvements in the Exhibit 3.4 results are obtainable by using Factoring Procedures 6 or 7 or by improving upon the imputation procedure used. However, the Exhibit 3.4 results come close to being the best results obtainable with the current factor groups.

The bottom of Exhibit 3.4 compares the effectiveness of factoring using the factor groups currently being used in the four states with factoring using factor groups based more purely on functional system. The latter results are appreciably worse. Errors increase in each of the three states that currently use some geographically defined factor groups (and especially in Colorado, which uses three different recreational groups). In the fourth state, Nebraska, which does not distinguish factor groups geographically, an increase in the number of functional-system-based factor groups from five to seven had only mixed effects on the quality of the AADT estimates produced. We conclude that generally ***it is more useful to distinguish factor groups on the basis of geographic variables than on the basis of functional system.***

If AADT estimates for individual short-count sites that are more reliable than those discussed above are desired, it will be necessary to increase the homogeneity of the factor groups. *For those that are interested in achieving this goal*, the remainder of this subsection presents some general guidelines and Appendix B presents some quantitative tools that might be helpful. We observe that increasing the homogeneity of factor groups involves a substantial amount of judgement and may require an increase in the number of ATR stations operated. The TMG suggests that there normally should be five to eight ATR stations per factor group. This suggestion appears appropriate for all factor groups that contain significant numbers of short-count sites (though, as discussed subsequently, fewer ATR stations may be appropriate for factor groups that contain relatively small numbers of homogenous short-count sites).

We start by making the following observations about how patterns of traffic tend to vary across different types of section:

1. Urban sections tend to have relatively similar patterns and these usually are different than those of rural sections.

2. Rural sections with low percentages of local traffic (e.g., rural Interstates) tend to have relatively similar seasonal

patterns, though their day-of-week patterns may vary with the percentage of truck traffic they carry.

3. Rural sections with higher percentages of local traffic (e.g., minor arterials) have patterns that differ from those of rural Interstates and that also may vary geographically across the state.

4. Sections with high volumes of recreational traffic have patterns that are very different from other sections. The timing of the seasonal peaks on these sections may vary geographically (especially between summer and winter recreational areas) and the peaks vary in intensity with the percentage of traffic carried that is recreational.

These observations lead us to conclude that, when forming factor groups, there should be:

1. An urban factor group;
2. One (or possibly more than one) factor group for rural sections with low percentages of local traffic;
3. In most states, at least one recreational factor group; and
4. One or more other rural factor groups.

To the extent that this last category contains more than one factor group, geographical distinctions are likely to be more useful than functional-system distinctions. However, a distinction between functional systems that carry moderate volumes of nonlocal traffic (other principal arterials and, perhaps, minor arterials) and systems that carry lower volumes of such traffic could prove useful.

The appropriate number of recreational factor groups depends upon the degree to which recreational seasons in different parts of the state vary. We recommend creating separate groups for each set of recreational areas with distinct seasonal patterns. Also, consideration should be given to the creation of separate "recreational" groups (consisting of roads that primarily serve recreational areas and exhibit strong peaking patterns ) and "semi-recreational" groups (consisting of roads that carry a mix of traffic and exhibiting more modest recreational peaks). In states where it appears appropriate to distinguish more than two or three recreational groups, consideration may be given to using data from only a single ATR station for developing factors to be applied to small groups. This last possibility is addressed further under "Hybrid Procedures," below.

We *do not recommend* creating separate factor groups for urban Interstates and other urban roads (in contrast to the TMG recommendation). The seasonal and day-of-week patterns of *most* urban arterials and collectors are sufficiently similar for a single factor group to work relatively well. Indeed, we have found that combining the urban Interstate (IS) and other urban ATR stations into a single factor group usually produces a very slight *improvement* in the AADT estimates for individual urban IS sections. (This improvement probably is due to the increase in the number of ATR stations used to provide the data from which the factors are derived.)

***We recommend combining most or all urban sections into a single factor group and reducing somewhat the number of ATR stations located on these sections.*** Reducing the number of ATR stations by one-third to one-half is likely to have no more than a minimally adverse effect on the generally high quality of the AADT estimates developed for urban sections while freeing resources for developing improved AADT estimates for other parts of the highway system. The most effective use of these resources is likely to be in improving data for the rural and recreational groups. However, it is possible to use these resources to distinguish some minor groups of urban sections that have patterns of traffic that differ somewhat from most urban sections. Two such groups are:

- *Quasi-urban IS sections* with rush-hour peaking patterns that are more muted than the more typical urban IS sections. These sections are likely to be located in small urban places and some of the smaller urbanized areas, but they may also include some radial and beltway segments (such as I-255 East of St. Louis) on the periphery of larger urbanized areas.

- *Suburban retail-oriented sections* which have weekend (and, in particular, Saturday) traffic volumes that rival or exceed their weekday volumes. These sections are invariable non-IS sections with distinctive time-of-day patterns that make them readily identified from short counts. Typically, they have relatively high traffic volumes from late morning until early evening with a lower peak occurring during the normal morning rush-hour.

Separating one or both of these minor groups from the main group of urban sections should produce better AADT estimates for sections in these groups. Furthermore, if these groups contain any ATR stations that currently are providing data used in developing factors to be applied to the main IS or non-IS groups of urban sections, then removal of these ATR stations from the main groups will improve both the quality of both the factors estimated for the resulting main urban group and the resulting AADT estimates.

Finally, we turn to the handling of rural sections with low percentages of local traffic. The TMG recommends using a single factor group, "rural IS," for these sections, and excluding from this group any non-IS sections.

If trucks account for similar percentages of total traffic on all rural Interstates in a state, a single "rural IS" group will work well. However, if these percentages vary significantly, a single group may work less well. Truck traffic frequently declines on weekends while automobile traffic tends to increase. Accordingly, the ratio of AADT to typical weekday traffic counts tends to vary inversely with the percentage of total traffic accounted for by trucks. Hence, on roads with high truck percentages, AADT is likely to be overestimated; while on roads with low truck percentages, it is likely to be underestimated.

In order to achieve the stated TMG goal of attempting to produce particularly good AADT estimates for IS sections, we recommend that states give some consideration to dividing the rural IS system into two or three factor groups, differentiated by the percentage of total traffic accounted for by trucks. Each of these groups may be of a size that warrants the use of several ATR stations for factoring, or there might be one large group and one or two smaller groups. In the latter case, judgement may be used in determining the appropriate number of ATR stations for the smaller groups. A "high-truck IS" group consisting of a single route may be factored very well using a single ATR station on that route; and separating the route from the main IS group is likely to improve the AADT estimates for all IS sections. Low-truck IS routes may be handled similarly, or they may be effectively combined with other National Highway System (NHS) sections with similar truck percentages.

## Using Factors from Individual ATR Stations

For any short-count site, there usually are one or two ATR stations that will produce factors that will work better than those produced by any group of stations. These ATR stations are at sites that have seasonal and day-of-week traffic-volume patterns that resemble the pattern at the short-count site, and frequently they resemble that pattern quite closely. A factoring procedure that is capable of associating such an ATR station with every short-count site would work extremely well. Unfortunately, for many short-count sites, identification of the "best" ATR station may be quite difficult.

One approach that is sometimes used for associating individual ATR stations with short-count sites is to divide an entire state into small areas, such as counties or groups of counties, and to operate two to four ATR stations in each of these areas; e.g., one in an urban location, one on a rural Interstate, and one on another rural road. All short-count sites in each area are then associated with the appropriate ATR station on the basis of functional system. If the seasonal influences on traffic volume are reasonably constant across the area, such a procedure should work reasonably well. However, effective use of such an approach requires both the division of the state into areas with reasonably homogeneous seasonal influences on traffic, and the selection of ATR stations that have volume patterns that really are typical of the patterns at the associated short-count sites. ***We recommend a minimum of three ATR stations for each small area, corresponding to the urban system, rural Interstates, and other rural roads.***

A major limitation of using individual ATR stations is that these stations do not produce data that can be used to evaluate how well the factoring is performed. When a factor group contains multiple ATR stations, seasonal and day-of-week patterns at the different stations can be compared to provide an indication of the homogeneity of the entire group of short-count sites. Without such data to evaluate the quality of the ATR assignments, ***extreme care is needed in dividing the state into homogeneous areas and in selecting ATR stations for each of these areas.*** In particular, selection of an ATR station with an unusually high (or low) ratio of weekend/weekday traffic will result in consistent over (or under) estimation of AADT at all short-count sites associated with the ATR station and in relatively significant over (or under) estimation of VMT for the area.

## Hybrid Procedures

The preceding subsections discussed the use of relatively large groups of short-count sites with several ATR stations per group and the use of smaller groups with a single ATR station per group. We discuss below three alternatives for combining these two types of approach.

### 1. Individual ATR Stations for Special Cases

In developing reasonably homogeneous factor groups, it is quite likely that some relatively small factor groups will be identified. Such factor groups may be too small to justify the operation of several ATR stations for each one, but combining these groups with each other or with any of the larger groups may result in relatively poor AADT estimates for the short-count sites in the small groups and some deterioration in the estimates for short-count sites in any larger groups with which the small groups are combined. ***When such small factor groups are identified, we recommend that they be maintained as separate factor groups with one or two ATR stations for each factor group.***

One example of such small factor groups occurs when there is a recreational area with different seasonal peaks than the other recreational areas of the state. For such an area, only factors derived from local ATR stations will be able to capture the area's seasonal patterns. Furthermore, the seasonal patterns may be relatively strong on those roads in the area that carry relatively little non-recreational traffic, and weaker on other roads that carry a wider mix of traffic. The creation of one or two separate factor groups consisting of the road sections in this area would appear to be appropriate, but the cost of operating several ATR stations for each of these groups may not be justified. Use of only one or two ATR stations for each of these factor groups may not produce highly reliable AADT estimates for all short-count sites in these groups; however, the AADT estimates are likely to be better than those that would be produced using factors from ATR stations with seasonal patterns that differ from those in the area in question.

A rather different example occurs when one rural Interstate has a traffic-volume pattern that is distinctly different than the patterns on other rural Interstates. In the absence of interchanges with other Interstates, such a distinct pattern is likely to remain relatively constant over an extended stretch of this IS. Factors derived from data from a single ATR station that is located anywhere on this stretch of road are likely to produce relatively good estimates of AADT when applied to short counts obtained anywhere on this stretch, and these AADT estimates are likely to be better than those produced using factors derived from a larger group of "rural IS" ATR stations. Also, excluding an ATR station located on such a stretch of atypical road from the "rural IS" group is likely to result in some improvement in the AADT estimates obtained for short-count sites in the larger group.

### 2. Individual ATR Stations for Extended Segments of the IS

The second hybrid procedure may be viewed as a generalized version of the second application of the first procedure.

Except at major interchanges, seasonal and day-of-week traffic-volume patterns on the IS change relatively slowly over the length of an Interstate highway. Accordingly, the IS can be divided at major interchanges into a series of "extended segments"[9] each of which has a relatively uniform traffic volume pattern. If an ATR station is located on any extended segment, factors derived from data for that station alone are likely to produce AADT estimates for short-count sites on this segment that are better than the AADT estimates produced using factors derived from data for that station along with data for other more distant stations. There are two alternatives for taking advantage of this observation:

1. For all short counts obtained at sites on any extended segment of the IS containing an ATR station, use factors obtained from that station alone, and for short counts

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[9] Our definition of "extended segment" differs slightly from the ISTEA definition of "major system segment." "Major system segments" are broken at all interchanges (and intersections) with other NHS highways. "Extended segments" are broken only at "major" interchanges at which a significant change in the character of traffic is considered likely.

obtained at any other IS site, use factors obtained from the appropriate group of ATR stations; or

2. Increase the number of ATR stations so that there is one on every extended segment of the IS (or just the rural IS), and factor all short counts obtained at sites on each extended segment using factors obtained from the ATR station on the segment.

In both cases, there are likely to be some extended segments that are classified as being partly urban and partly rural. If any of these segments contains an ATR station, the rural/urban distinction should be ignored when applying factors from that station to short counts obtained on the segment; i.e., in this case, it is entirely appropriate to apply factors obtained from a rural ATR station to short counts obtained at nearby urban sites, and vice versa.

The above alternatives also can be extended to cover some non-IS short-count sites:

- Non-IS short counts obtained at sites that are relatively close to an ATR station belonging to the factor group that normally would be used for factoring may be factored instead of using factors obtained from that ATR station alone; and
- If desired, Alternative 2 can be extended to cover additional roads belonging to the National Highway System (NHS) and/or the Principal Arterial System (PAS).

This last extension could be an attractive option for producing relatively high quality estimates of total AADT for the NHS (and, as discussed in Section 6.2, estimates of AADT by vehicle class as well). However, since traffic-volume patterns on non-IS portions of the NHS tend to change somewhat faster than those on the IS, the appropriate length for extended segments of the non-IS portion of the NHS is shorter than it is for the IS, so that a relatively high density of ATR stations may be required.

### 3. Weighted Averages

A variant of the preceding procedure associates nearly every short-count site on the IS, and, optionally, on some additional NHS or PAS roads, with a pair of ATR stations — one in either direction from the short-count site. Counts obtained at any short-count site are factored using a weighted average of the factors obtained at the two associated ATR stations. For any short-count site, the weights assigned to the two ATR stations would reflect the perceptions about the relative similarity of the short-count site to the two ATR sites, taking into account relative distances and the numbers and importance of intervening interchanges and intersections.

Use of weighted averages should permit the use of somewhat fewer ATR stations and/or some modest improvement in the AADT estimates, with the greatest benefits occurring off the IS. However, effective use of weighted averages requires a substantial amount of judgement in developing a pair of weights for each short-count site to which the procedure is to be applied.

## 3.5 Location of ATR Stations

When factors derived using data from a single ATR station are to be used for factoring counts from any group of short-count sites, the ATR should be located at a site that is likely to have a traffic-volume pattern that, to the extent practical, typifies the patterns at the remaining sites in the group.

When factors derived using data from multiple ATR stations are to be used for factoring counts from a group of short-count sites, some diversity in the ATR locations is desirable. However, ***sites that are likely to have atypical traffic-volume patterns should not be used as ATR sites.*** Examples of such sites are those near a fairgrounds or a major sports complex. Such sites are likely to exhibit idiosyncratic seasonal and day-of-week traffic-volume patterns that will tend to produce factors that are relatively inappropriate for application to data for other roads in the group.

Sites with low values of AADT (say, less than 400) are also relatively undesirable sites for ATRs. Traffic-volume patterns at these sites are subject to greater random variation (e.g., as a result of a large party) than patterns at higher volume sites.

***Except as noted above, the sites of ATR stations used for factoring counts from a group of short-count sites should be chosen to be broadly representative of the range of short-count sites in the group.***

# 4.0 Other Topics Relating to AADT

This chapter contains recommendations relating to the use of growth factors to adjust previous-year AADT estimates for growth in traffic volume, and for documentation of the information used in estimating AADT.

## 4.1 Growth Factors

The TMG requires that traffic be counted on all HPMS sample sections a minimum of once every three years. For any such site, in years that traffic is counted, AADT is estimated by applying seasonal and day-of-week factors to the volume counts obtained at the site. In other years, AADT is estimated by applying a *growth factor* to the preceding year's estimate.

Growth factors can be developed from AADT estimates[1] for any set of sites for which both current year and preceding-year AADT estimates exist. The quality of an AADT estimate developed with the use of a

[1] Growth factors should *not* be developed from unfactored counts. Such counts are too unreliable to provide meaningful estimates of growth in traffic.

growth factor depends upon both: the quality of the AADT estimates used in the derivation of the growth factor; and the extent to which traffic growth at the site in question resembles traffic growth at the sites that provide the AADT estimates used in developing the growth factor.

Most commonly, the estimation of growth factors is designed to reflect "typical" or "average" growth in traffic volume. Use of these growth factors produces overestimates of AADT at sites where traffic is growing slowly and underestimates at sites where it is growing rapidly. However, when all AADT estimates are used to estimate VMT, the over and underestimates tend to cancel, producing relatively reliable estimates of VMT.

There are two potential sources of AADT estimates for use in growth factors:

- AADT estimates for ATR stations obtained directly from ATR data for both the current year and the preceding year; and

- Current-year AADT estimates for short-count sites counted in the current year along with preceding-year AADT estimates for the same sites, with the latter estimates usually developed using growth factors.

ATR stations clearly provide better estimates of AADT. However, the total number of such stations is small. In most states, ATR stations may be used to produce a reasonably good estimate of average growth for the entire state, but there probably are not enough ATR stations to provide reliable information about how growth rates vary across the state.

Short-count sites produce poorer estimates of AADT. However, in each year, there are large numbers of such sites that can be used in estimating growth factors. The large numbers mean that separate growth factors can be developed for every region of interest, and also that there are likely to be enough sites to allow a degree of cancellation of errors. Furthermore, to the extent that errors occur, they will tend to be self-correcting over time.[2]

Region-specific growth factors are of value in producing improved VMT estimates for regions of particular interest. Such regions include the VMT Tracking Areas corresponding to National Ambient Air Quality Standards (NAAQS) nonattainment areas that contain an urbanized area. Annual

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2 Overestimates of AADT in one year tend to reduce the size of the following year's growth factors, thus reducing the AADT estimates for that year, resulting in a tendency to underestimate AADT in the second year (but to a smaller extent than AADT is overestimated in the first year).

VMT estimates for each such Tracking Area are required by the Environmental Protection Agency. Also, some states require VMT estimates by county or by substate district for use in formulas for distributing state highway funds.

On the basis of the above discussion, ***we recommend that, in each year, all states that have a need for region-specific growth factors:***

- ***Obtain growth rates for each ATR station, and also for each short-count site counted routinely in that year for which a reasonably reliable preceding-year AADT estimate also exists; and***

- ***Develop growth factors for each region by taking a simple average of growth rates obtained for the ATR stations and short-count sites in the region.***

To avoid biasing the growth factors upward, all special counts should be excluded as well as any other extra short counts that may be taken at sites where high growth rates are anticipated.

***States with NAAQS nonattainment areas that contain urbanized areas should develop separate growth factors for each VMT Tracking Area. All states may develop region-specific growth factors for other substate regions that are of particular interest or that are believed to have atypical VMT growth rates.*** Area-specific growth factors need not be distinguished by functional system, especially in the case of small areas; however, for large areas, a three-way distinction between urban, rural IS, and rural non-IS could be useful. We believe that growth factors distinguished by area (and, optionally, by functional-system grouping) will provide better estimates of area-specific variations in VMT growth than growth factors distinguished by seasonal factor group.

We recommend that every growth factor be developed as an unweighted average of the observed AADT growth rates at all appropriate sites in the relevant area.

## 4.2 Documentation

***The procedures used for estimating AADT should be documented in writing.*** We prefer that all factoring be performed by State agencies; however, if some AADT estimates submitted to FHWA are developed by local governments, the factoring procedures used by these governments also should be documented.

Descriptions of all ATR stations should be recorded in the Number 1 record format specified in the TMG (Figure 3-2-1), and hourly data collected at these stations should be recorded in the Number 3 format (TMG Figure 3-2-2). In addition, for each short-count site, the following information should be available:

- Site identification (location and section number);
- Date, day of the week, and hour the count was started;
- Duration of the count;
- Traffic-counter identification number;
- The unfactored count, by hour and lane if available;
- Codes identifying the factor groups or individual ATRs used as sources for the seasonal and day-of-week, growth, and (if required) axle-correction factors used;
- Estimated AADT for the most recent year for which HPMS data has been submitted to FHWA; and
- (Optionally) estimated AADT for one or more earlier years in which the section was counted.

We suggest that most or all of this information be available interactively from a computer system that is used both to store TMS/H data and to perform all the required computations.

# 5.0 VMT

HPMS requires AADT estimates and section length for every section of the Principal Arterial System (PAS) and the National Highway System (NHS). For other arterials, rural major collectors, and urban collectors, HPMS requires AADT estimates and section length for a sample of sections, stratified by functional system and volume group, along with estimates of total road miles in each functional system and volume group. The quality of the estimates of total VMT produced by HPMS for these functional systems depends upon both the AADT estimates (discussed in Chapters 3 and 4) and the estimates of road miles by volume group, discussed below.

For each of the functional systems in question, AADT estimates exist for some or all highway sections (including all HPMS sample sections), though the quality of these estimates varies. Variation in quality results from:

- Whether or not the estimates incorporate seasonal and day-of-week factoring and the quality of the factoring;
- Whether or not they have been factored for growth;
- Whether they are based on counts for the section in question or on counts for nearby sections of the same road; and
- Possible variations in procedures used for collecting counts on different highway systems.

***We recommend that the estimates of road miles by functional system and volume group submitted to FHWA reflect AADT estimates for*** all ***sections for which such estimates exist.*** These estimates should include AADT estimates derived from special counts collected for project-related purposes and from counts collected by local governments, and they also should reflect AADT estimates derived by interpolation from estimates obtained for other sections of the same road. Volume data from local governments may be obtained for individual sections or in aggregated form.

Initially, the AADT estimates used for distributing road miles to volume groups need not incorporate seasonal, day-of-week, or growth factors. However, ***we recommend that factoring for growth should be performed annually after the first year in which AADT estimates are used for distributing road miles across volume groups (and such factoring should be required, at least, for all VMT Tracking Areas corresponding to EPA air quality non-attainment areas). Also, we recommend that current-year seasonal and day-of-week factors be applied to all newly collected counts as soon as the procedures discussed in Chapter 3 are implemented.*** We recommend the use of computerized procedures for performing all factoring and for assigning sections or miles of road to volume groups.

For each functional system in question, all sections for which AADT estimates exist should be assigned to volume groups on the basis of these estimates. (If it is believed that old AADT estimates for some sections are grossly misleading, it may be reasonable to modify the assignments of these sections provided that the modifications and the reasons for the modifications are fully documented.) The result is an estimated distribution of road miles across volume groups for those sections for which AADT estimates exist.

For any other roads and road segments in the functional system, a second distribution of road miles across volume groups should be developed. This distribution should be developed judgmentally from the first distribution taking into account differences between the kinds of roads for which AADT estimates exist and those for which they do not exist. This distribution should be updated annually to reflect the effects of growth in traffic volume. The updating should use changes in the first distribution as a guide; e.g., if AADT estimates for the first set of roads result in moving 5 percent of the miles of these roads to a higher volume group, then 5 percent of the miles of road in the second set also should be moved to a higher volume group.

Typically, AADT estimates may exist for roads in one administrative system (e.g., state highways) and generally be lacking for roads in a lower administrative system. For this case, one way of handling the second set of roads is to derive the second distribution systematically from the first distribution; e.g., by shifting the entire distribution down one volume group and scaling to produce the correct total road miles.[1] Summing the two distributions produces an overall distribution of road miles for the functional system across volume groups.

If there are roads for which no AADT estimates exist, the procedure used for distributing the mileage of these roads across volume groups should be documented.

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[1] As an example, assume there are 1,000 miles of road for which AADT estimates exist and 3,000 miles for which they do not exist, and that the 1,000 miles are distributed across Volume Groups 1-3 with 100 miles in Group 1, 500 in Group 2, and 400 in Group 3. Shifting this distribution down one group and multiplying by 3 indicates that the second distribution consists of 1,800 miles in Group 1 and 1,200 miles in Group 2. Summing the two distributions produces an overall distribution for all 4,000 miles of 1,900, 1,700, and 400 miles in Groups 1, 2, and 3, respectively.

# 6.0 Vehicle Classification

Data on AADT and VMT by vehicle class are required for pavement design and pavement management, for estimating road-capacity requirements, for deriving axle-correction factors, for estimating accident rates by vehicle class, and for analyzing and mitigating road noise. Unfortunately, existing procedures for estimating AADT and VMT by vehicle class tend to overestimate AADT by trucks.

The first section of this chapter contains several recommendations relating to the collection of classification counts. This is followed by a relatively long section discussing several procedures for estimating AADT by vehicle class. The discussion presents alternatives for reducing or eliminating the tendency to overestimate truck AADT. However, we have not developed any specific recommendations as to how best to achieve this goal.

Section 6.3 is a brief section presenting four alternatives for estimating VMT by vehicle class that should produce better estimates of truck VMT than procedures that are currently in use. ***We recommend that all estimates of VMT by vehicle class be developed using one of the procedures presented in Section 6.3.*** We observe that distributing classification counts throughout the year is not sufficient to eliminate the overestimation of truck VMT unless classification counting is performed on weekends as well as on weekdays.

The final section of this chapter presents recommendations for documentation of vehicle-classification procedures and data that are similar to those presented in Section 4.2 for AADT-related procedures and data.

## 6.1 Classification Counts

The 13 standard FHWA vehicle classes are defined in Exhibit 6.1. The following subsections contain several recommendations relating to the collection and interpretation of classification counts.

### Classification Recorders

We prefer that ATRs used for classification be programmable. Programmability provides State personnel with direct control over the classification algorithm used and permits fine-tuning of this algorithm to reflect changes in the axle spacing and axle weights of individual classes of vehicles operating in the State. Programmability also allows the division of some of the standard classes into subclasses of interest to the state (e.g., the division of Class 8 into three-axle combinations and four-axle combinations). However, some care is required when modifying the classification algorithm to make sure that no unintended consequences result.

### Ambiguous Vehicles

*We recommend that all vehicles be assigned to one of the standard classes* even when there is some ambiguity as two which is the correct class. Ambiguities usually are between two relatively similar classes (e.g., automobiles and four-tire trucks). By assigning an ambiguous vehicle only to an "undefined" or "unclassifiable" class, valuable information (whether the vehicle is light or heavy) is lost. However, ambiguous vehicles may be assigned to a nonstandard class *in addition to* a standard class; such nonstandard classes may be used as a diagnostic tool in identifying weaknesses in the classification algorithm.

*We also recommend that the classification algorithm used by each State be tested periodically and modified if appropriate.* Modifications may be required to handle new vehicle configurations (e.g., articulated buses). Also, if tests indicate that the algorithm is overestimating the number of four-tire trucks and underestimating the number of six-tire trucks, the

# Exhibit 6.1 FHWA Vehicle Classes

1. Motorcycles (optional)
2. Passenger Cars
3. Other Two-Axle, Four-Tire Single Unit Vehicles
4. Buses (with Six or More Tires)
5. Two-Axle, Six-Tire, Single Unit Truck
6. Three-Axle, Single Unit Trucks
7. four or More Axle Single Unit Trucks
8. Four or Less Axles Single Trailer Trucks
9. Five Axle Trailer Trucks
10. Six or More Axle Single Trailer Trucks
11. Five or Less Axle Multi-Trailer Trucks
12. Six or Less Axle Multi-Trailer Trucks
13. Seven or More Axle Multi-Trailer Trucks

N.B. Four-tire vehicles pulling light utility trailers are classified as if they are not pulling trailers.

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weight or axle-spacing threshold used for distinguishing four-tire trucks from six-tire trucks should be reduced slightly.

## Count Duration

***Short-duration classification counts obtained with automatic vehicle classifiers (AVCs) should be collected over periods that are a multiple of 24 hours and are* at least *48 hours long.*** Daily counts for individual vehicle classes frequently are quite small and so they can be affected significantly by random fluctuations in traffic volumes. Increasing the duration of counts reduces the significance of these random fluctuations and increases the quality of the resulting estimates of AADT by vehicle class. ***Seven-day counts are preferable,*** since they eliminate the need for day-of-week factoring (discussed subsequently), and they reduce the effects of random fluctuations on the counts obtained for buses and other relatively small classes of vehicles.

### Manual Classification Counts

AVCs require reasonably constant speeds to work well, and they usually cease classifying when speeds drop below some threshold, typically 20 or 25 mph. Accordingly, manual classification counts may be preferred at many sites on urban surface streets. Because of cost and safety considerations, such manual counts usually are collected during only part of the day.

***If partial-day classification counts are to be used*** to derive estimates of daily traffic volume by vehicle class, ***time-of-day factors must be used.*** Because time-of-day usage patterns differ significantly by vehicle class, we recommend the development and use of separate sets of factors for:

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

These time-of-day factors can be developed either from a limited number of manual 24-hour counts or from AVC data collected at carefully selected urban sites.

## 6.2 Estimating AADT by Vehicle Class

Potential approaches for estimating AADT by vehicle class (AADTVC) for a given site include:

1. Collecting classification counts at that site for an entire year;
2. Collecting classification counts at the site for a short period of time (e.g., 48 hours) and using annual data from a nearby permanent AVC on the same road to factor these counts to produce estimated AADTVC;
3. Counting total traffic volume at the site for a short period of time, using factors to produce estimated total AADT for the site, and using data from a nearby permanent AVC on the same road to distribute total AADT across vehicle classes;

4. Collecting classification counts at the site for a short period of time, dividing by the duration of the count (in days), and using these results without further adjustment;

5. Collecting classification counts at the site for a short period of time and using these counts to distribute estimated AADT across vehicle classes;

6. Collecting classification counts at the site for a short period of time and using annual data from one or more AVCs on other roads to factor these counts; and

7. Collecting classification counts at the site for several weekday and weekend periods and averaging the results.

The first approach is clearly capable of producing excellent estimates of AADTVC (limited only by the accuracy of the classification procedure used). The second and third approaches are also capable of producing good estimates of AADTVC, though the quality of these estimates depends on the similarity of traffic at the AVC to the traffic at the site in question. The third approach usually will work best if the seasonal and day-of-week factors used to estimate total AADT are obtained from the nearby AVC.

Unfortunately, the first approach can be used only at a relatively limited number of sites served by permanent AVCs, and the second and third approaches can only be used at sites that are relatively near these AVCs. Also, the last approach is relatively expensive, Approaches 4 - 6 cannot produce estimates of AADTVC that are as good as those produced by the first three approaches, and the versions of Approaches 4 and 5 that frequently are used tend to produce significant overestimates of truck AADT on many roads.

Approach 6 is analogous to the factoring procedures discussed in Chapter 3 for estimating total AADT. However, for several reasons, this approach is likely to perform less well than the procedures used for total AADT:

- Seasonal and day-of-week volume patterns for trucks are different than they are for automobiles;
- Seasonal volume patterns for trucks tend to vary geographically as a result of local factors such as time of harvest;
- Localized influences on seasonal volume patterns vary in strength with the percentage of traffic that is locally generated; and

- Traffic volumes for individual vehicle classes and groups of related classes are smaller than total traffic volume and so they are more subject to random influences.

Volume patterns for single-unit trucks with three or more axles (Classes 6 and 7 in Exhibit 6.1) can be particularly idiosyncratic, varying independently of season as a result of nearby construction projects. The same is also true for Class 10 vehicles in states where double-bottom dump trucks are common. Also, volume patterns of Vehicle Class 4 (buses with six or more tires) can be influenced or even dominated by recreational vehicles (RVs)[1] which have seasonal and day-of-week volume patterns that are very different from those of buses and trucks.

Seasonal and day-of-week volume patterns also may vary by vehicle class. However, to minimize the effect of random variations in daily traffic, AVC data should be combined across vehicle classes before being used to derive factors. The resulting factors will be better suited to producing AADT estimates for groups of vehicle classes than for individual vehicle classes.

The above observations imply that, for sites at which Approaches 1 - 3 cannot be used, the development of good estimates of AADTVC will be costly, difficult or impractical. Nonetheless, estimates of AADTVC frequently are needed for planning and highway projects, and ISTEA requires such estimates for the entire NHS. Options available for the development of such estimates include:

a) Using available data (e.g., for other sites in the same functional system) on the distribution of AADT across vehicle classes as the basis for distributing a site-specific estimate of AADT across vehicle classes;

b) Using site-specific classification data from a short-duration count for this purpose;

c) Extending the site-specific count to seven days (thus eliminating the effect of day-of-week variation) and/or taking multiple counts over the course of a year (thus reducing seasonal effects); or

d) Applying seasonal and day-of-week factors to site-specific short-duration classification counts.

[1] Some states assign RVs with six or more tires to Class 4 (buses), though the TMG specifies that they should be assigned to Classes 5 and above. Following the TMG recommendation shifts the problem discussed in the text to Classes 5 and 6 and reduces its significance.

This last option corresponds to Approach 6 on our earlier list, and Options (b) and (c) correspond to Approaches 5 and 7, respectively. Option (d) can be expected to produce better estimates of AADTVC than Options (a) or (b), and it is less expensive than Option (c). However, Approaches 1-3, presented earlier, clearly should be used whenever practical. Also, although Option (d) can be expected to produce better results than Options (a) or (b), the circumstances when the improvement is sufficient to warrant the extra complexity are not clear.

The following subsections provide brief descriptions of Approach 1, a procedure based on Approach 3, Approaches 4 and 5, some suggestions for implementing Approach 6 (also referred to above as Option (d)), and Approach 7. A procedure based on Approach 2 is presented in Appendix F of Volume II.

## Approach 1 — Direct Observation

For any section of road that contains a permanent AVC, data collected by that permanent AVC throughout the year should be used to provide values of AADTVC. The accuracy of these estimates will be limited only by the accuracy of the AVC's classification algorithm and the possible loss of some data should the AVC be temporarily out of service. To minimize the effect of missing data, we recommend that, for each vehicle class, AADTVC be derived by applying the AASHTO three-step averaging procedure (presented in Section 3.1) to daily counts for that vehicle class.

## Approach 3 — Distributing AADT Across Vehicle Classes

Approach 3 yields a relatively simple procedure for estimating AADTVC that is appropriate for sites that are on the same road as a permanent AVC and relatively "near" the AVC (as discussed below). This procedure consists of:

1. Obtaining a short-duration count of total traffic volume for the site;

2. Factoring this count to produce an estimate of total AADT (using one of the procedures discussed in Chapter 3); and

3. Distributing total AADT across vehicle classes in proportion to the annual distribution observed at the AVC.

This procedure presumes that, on an annual basis, the distribution of vehicles across vehicle classes at the site in question is very similar to the distribution at the AVC. The quality of the estimates will deteriorate as this similarity declines. Good estimates are likely if there is no major change in the "character" of the traffic between the AVC and the site in question. Such a change in "character" may be presumed if there is:

- a major change in traffic volume;
- a major change in the annual average volume of any class of trucks (as will occur at an interchange or intersection that generates significantly higher volumes of trucks in one direction than in the other); or
- a staging area at which multiple-trailer truck configurations are assembled and disassembled.

This procedure is recommended for use at any site that is on a road with a permanent AVC and sufficiently near the AVC so that there is no major change in the character of the traffic between the two locations. The procedure may also be used when the two locations are more widely separated, but the estimates produced are likely to be of somewhat poorer quality.

Procedures based on Approach 2 are appropriate for use as an alternative to the above procedure. However, procedures based on Approach 2 are more complicated and more expensive than the above procedure, and the simpler ones are likely to perform less well. A sophisticated procedure based on Approach 2 is presented in Appendix F of Volume II.

## Sites That Are Not Near a Permanent AVC on the Same Road

Approaches 1-3 cannot be used for short-duration classification-count sites that are not near a permanent AVC on the same road. For these sites, Approaches 4, 5, 6, or 7 must be used.

Approach 6 is likely to produce better estimates of AADTVC than Approaches 4 or 5. However, we have only developed a set of suggestions for implementing this approach rather than a fully specified procedure, and we have no information on the quality of the estimates that it is capable of producing. Even if fully specified, this approach is relatively complicated and it requires more computer resources than the other approaches.

Of the remaining approaches, Approach 4 (which uses no factoring) is simpler, especially if estimates are only required for truck and bus classes; while Approach 5 is aesthetically more pleasing, because it produces a complete set of AADTVC estimates that are consistent with AADT estimates for the site (but are not necessarily more accurate than those produced by Approach 4).

Approach 7 may be warranted for pavement-design purposes for some high-cost projects. For other purposes, we are inclined to recommend that states with sufficient resources to develop and test Approach 6 do so, and that other states use Approaches 4 or 5.

## Approach 4 — Using Unfactored Short-Duration Classification Counts

For sites that are not near a permanent AVC on the same road, the development of meaningful estimates of AADTVC requires the collection of a short-duration classification count at or near the site in question.

The simplest use of short-duration classification counts is to use them in unfactored form to provide estimates of AADTVC (e.g., by dividing values obtained from a 48-hour count by two). In general, such unfactored counts do not provide very good estimates of AADTVC:

- Truck usage generally is appreciably higher on weekdays than on weekends, so unfactored weekday truck counts normally tend to overestimate AADT by trucks.

- Truck usage is subject to seasonal fluctuations that vary by road in their timing (as a result of harvests, nearby construction projects, etc.) and in their magnitude (due to the mix of local and through traffic).

These seasonal and day-of-week influences usually are stronger for trucks than they are for total traffic. Accordingly, unfactored short-duration classification counts generally will not provide good estimates of AADTVC for individual sites. However, on at least some roads, appropriately timed unfactored counts may be capable of producing adequate estimates of AADTVC for truck classes.

The roads on which unfactored 48-hour counts are likely to work best are those with a known seasonal peak in truck traffic and relatively constant truck usage the remainder of the year. On such roads, we recommend that classification counts be collected on weekdays during the off-season, thus avoiding the relatively high counts that would be obtained in season and the relatively low ones that would be obtained on weekends. If the extra in-season traffic provides an appropriate balance to the reduced traffic on weekends, the resulting counts will produce reasonable estimates of AADTVC for truck classes. However, strong seasonal peaks will tend to produce underestimates of AADTVC, while weak seasonal peaks will tend to have the opposite effect.

Another alternative is to use seven-day classification counts or a pair of weekday and weekend classification counts. (A pair of 48-hour weekend and weekday counts, or a single 96-hour weekday/weekend count, can be adjusted to approximate a single seven-day count as discussed under Approach 7.) Unfactored seven-day counts will not have any weekday/weekend bias, but they are likely to have some seasonal bias.

AADTVC estimates obtained from unfactored counts normally will not be consistent with AADT estimates for the same site, since the latter estimates incorporate seasonal and day-of-week factors. Accordingly, unfactored counts should be used only for the bus and truck classes (Classes 4-13). If separate counts for the other classes are desired, they can be obtained by subtracting the counts for Classes 4-13 from AADT and scaling the counts for the remaining classes to be consistent with this result.

## Approach 5 — Using Short-Duration Classification Counts to Distribute AADT Across Vehicle Classes

Approach 5 is similar to Approach 3, but it can be applied to sites that are not near a permanent AVC on the same road. The Approach 5 procedure consists of:

1. Obtaining a set of short-duration classification counts at the site in question;

2. Estimating total AADT at this site (using one of the Chapter 3 procedures); and

3. Distributing total AADT across vehicle classes in proportion to the distribution observed during the period when the classification counts were obtained.

Most commonly, the Step 2 estimate of total AADT is derived from a total volume count obtained for the same period as used for the classification count. When this is the case, this procedure is equivalent to applying the seasonal and day-of-week factors used for total volume to the classification counts as well – a procedure that is now being used by several states.

Two factors reduce the quality of Approach 5 estimates of AADTVC:

- Truck volumes usually constitute an appreciably higher percentage of total traffic on weekdays (when the counts usually are taken) than on weekends; and

- Seasonal volume patterns for trucks usually are different than they are for automobiles.

The second problem tends to cause both overestimates in the values obtained for truck AADT when classification counts are obtained during a period of high truck travel and more moderate automobile travel, and underestimates when the reverse is the case. However, the first problem produces a consistent tendency toward overestimates of truck AADT. Possible ways of eliminating this bias are the use of seven-day classification counts or the introduction of day-of-week factors (as discussed under Approach 6). The bias can also be reduced or partially reversed by performing 48-hour weekday counts during the off-season, as discussed under Approach 4. ***We recommend that Approach 5 not be used unless steps are taken to limit this bias.***

## Approach 6 — Factoring With Data From AVCs on Other Roads

Approach 6 consists of collecting short-duration classification counts at individual sites and multiplying these counts by seasonal and day-of-week factors derived for groups of vehicle classes using current-year data from AVCs on other roads. We have not developed a fully specified procedure for implementing this approach. However, recommendations and suggestions for implementing it are presented below.

As in the case of total volume counts, we recommend that all factoring of classification counts be performed using "current year" factors; i.e., the factors applied to any short-duration count should be derived from AVC data for a 12-month or 52-week period that *includes* the period when the count was being collected. In order to perform such factoring on a timely basis, it will be necessary to have automated procedures for recomputing all classification-count factors weekly or monthly as new data becomes available. Although the alternative of using factors derived from historic data is computational less demanding, our limited analysis of the use of historic factors for estimating total AADT indicates that historic factors are less effective than current-year factors. We do not know how well Approach 6 will work if historic factors are used.

For any group of vehicle classes, the average number of vehicles counted during any period of time will be much smaller than for counts of total traffic volume, and so classification counts will be more readily affected by random variation in traffic volume. For this reason, the factoring procedures that make use of relatively aggregate temporal groupings (e.g., Combined Month and Average Weekday factoring) may work as well as the more desegregate procedures.

The vehicle-class factors may represent seasonal and day-of-week patterns at a single AVC or they may be an unweighted or weighted average of factors for a group of AVCs. One simple alternative would be to develop separate sets of factors for all AVCs in the state, take an unweighted average of all sets of factors, and apply the resulting set of average factors to all short-duration classification counts. Another simple alternative would be to combine AVC data from all AVCs and to use the combined data to produce a single statewide set of factors. The latter alternative produces factors that are strongly influenced by characteristics of the highest volume AVC sites and may not be particularly appropriate for application at medium-volume sites. On the other hand, the former alternative may produce factors that do not adequately discount data from low-volume AVCs that are unduly influenced by random events.

Better results probably can be attained if, for each short-duration count site, factors from a single AVC (or a small set of AVCs) are selected for use. The selected AVC(s) should have seasonality characteristics (e.g., harvest seasons) that are similar to those of the short-count site and a reasonably similar mix of locally generated and through traffic. If multiple AVC sites are believed to have characteristics that make data from these AVCs appropriate for factoring short-duration counts from a given site, an average of the factors from the AVCs would be appropriate for use. Such an average may be unweighted or it may be weighted on the basis of perceived similarity of the AVC sites to the short-duration classification-count site.

There is some likelihood of imperfect matches between the seasonal peaks (and valleys) at AVC and short-count sites. Accordingly, we suspect that AADTVC estimates derived from short-duration counts taken during seasonal peaks (or valleys) at either the short-count site or the AVCs used for factoring will be somewhat less reliable than estimates derived from counts taken when truck volumes are more normal. For this reason, we suggest that, to the extent practical, short-duration classification counts not be collected during peak periods or during periods when truck volume is unusually depressed.

The remainder of this subsection addresses the question of how vehicle classes should be grouped for the purpose of deriving factors.

We recommend that one group contain Class 9 vehicles (five-axle single-trailer combinations) and probably all other classes of combinations (Classes 8-13). The volumes of the other classes of combinations usually will not support the development of a separate factor group, and combining them with Class 9 appears to be a fairly reasonable way of handling them.

Treatment of the remaining classes of vehicles is less clear. Buses (Class 4) have relatively unique usage patterns, but their volumes may not be sufficient to support a separate set of detailed factors. One option would be to combine all AVC data for buses and to derive a single set of factors from the combined data. If the combined data does not appear adequate to support a complete set of factors for buses, a more limited set might be appropriate (perhaps just weekday/weekend factors, or a combination of weekday/weekend factors with three-month seasonal factors). Another possibility is to treat Class 4 in the same way as Classes 1-3, as discussed subsequently.

Classes 6 and 7 present a somewhat different problem. In some areas, use of these vehicles to haul mine products produces seasonal patterns that are relatively consistent across a substantial number of roads. However, elsewhere, use of these vehicles is dominated by the localized and relatively temporary requirements of nearby construction projects, making "seasonal" factoring very difficult. Our inclination would be to develop both day-of-week (or weekday/weekend) and seasonal factors from local AVC data for use in the former areas and just day-of-week (or weekday/weekend) factors for use in the latter areas. The estimates produced for the latter areas will be free of any weekday/weekend bias, but they will *not* provide reliable estimates of actual Class 6 and 7 AADT at a site.

The remaining class of commercial vehicles, Class 5 (two-axle, six-tire vehicles other than buses), does not clearly warrant a group by itself, but there appear to be no satisfactory classes with which to combine it. One option would be to treat it separately and to develop factors for this class using combined data from all rural AVCs and separately combined data from all urban AVCs. The combined data should support the development of rural and urban day-of-week weekday/weekend factors and perhaps seasonal factors as well.

AADT estimates for the remaining vehicle classes, 1 - 3 (and possibly 4), probably should be derived as a residual; i.e., by subtracting the estimates for the other classes from the estimate for total AADT and allocating this result across vehicle classes 1 - 3 (or 1 - 4) in proportion to any available count data for these three (or four) classes.

## Approach 7 — Using Multiple Short-Duration Classification Counts

The final approach consists of collecting several short-duration classification counts at a particular site over the course of a year and averaging these counts (without factoring) to produce estimates of AADTVC. This is a relatively expensive procedure, but it may be warranted for pavement-design purposes for some high-volume sites. Because of the time period required for data collection, use of this approach for pavement-design purposes requires that a decision to use the approach be made a year or more before a project is begun.

Each short-duration count should be collected over a period of four to seven days and *should include* a weekend. The simplest procedure is to use a full seven-day period for each count. A slightly less expensive alternative is to use a four or five-day period that includes both Saturday and Sunday and to approximate the counts that would be obtained over a seven-day period by assuming that hourly counts for the uncounted weekdays are the same as the average of the corresponding hourly counts for the counted weekdays (perhaps excluding Monday AM and Friday PM). A minimum of four short-duration counts should be collected, spaced reasonably uniformly over a one-year period (e.g., four counts at approximately three-month intervals). To the extent feasible, these counts should not be obtained for periods with unusually high or low truck volumes (such as Christmas week).

## 6.3 Estimating VMT by Vehicle Class

For each functional system, the percentage of VMT contributed by each vehicle class is estimated by obtaining the ratios of AADTVC/AADT at all classification sites in the system for each vehicle class and taking an *unweighted* average of these ratios across all the sites. For each functional system, VMT by vehicle class (VMTVC) is then estimated by applying these percentages to estimates of total VMT for the system.

To minimize the likelihood of biasing the estimates of VMTVC in either direction, the TMG recommends that classification counts be distributed throughout the year. This recommendation is intended to result in a mix of observations taken at times of relatively high and low truck usage that will tend to balance each other, producing relatively unbiased estimates of VMTVC, though it is likely that periods of very low truck usage (e.g., Christmas week) will continue to be under represented. Furthermore, in states that perform all classification counting on weekdays, this recommendation does not address the effect of systematic differences between the weekday and weekend distributions of traffic across vehicle classes. ***For these states, appreciable overestimates of truck VMT are likely to result.*** Options for reducing or eliminating this bias are:

1. Perform all short-duration classification counting for a period of seven days.

2. Use a mix of weekday and weekend classification counting so that underestimates of truck AADT from weekend counting will balance the overestimates due to weekday counting. (If this option is used, we recommend that approximately three out of seven short-duration counts be collected for periods that run from midday Friday to midday Monday, and that the remaining short counts be collected on weekdays.)

3. Avoid collecting short-duration weekday counts during seasonal peaks in truck traffic (e.g., during harvest season)

so as to minimize the upward bias (as discussed in Section 6.2 under "Approach 4").

4. Use only estimates of AADTVC that are derived from annual data or factored (using "Approach 6" of Section 6.2) to avoid weekday/weekend biases.

***We recommend that all states adopt one of the above options for reducing or eliminating upward biases in estimates of truck VMT.*** For many states, the second option is likely to be the most cost-effective. ***We do not recommend the use of the TMG procedure by itself.***

## 6.4 Documentation

***Procedures used for estimating AADTVC and VMTVC should be documented in writing.*** For each section for which AADTVC is estimated, in addition to the AADT-related information discussed in Section 4.2, the following information should be available, using codes where appropriate:

- The procedure used for estimating AADTVC; and
- Identification of the AVC groups and/or sites used for data for distributing AADT across vehicle classes, or of the AVC groups and/or sites used as sources for seasonal and day-of-week factors applied to short-duration classification counts obtained on the section.

In addition, for each station at which classification counting is performed, descriptions of the station should be recorded in the Number 2 record format specified in the TMG (pp. 5-4-3 to 5-4-5), and hourly data should be recorded in the Number 3 format (TMG pp. 5-4-5 to 5-4-6).

We suggest that this information be available interactively from a computer system that is used both to store all TMS/H data and to perform all the required computations.

# 7.0 Weigh-in-Motion Data

The most important use of weigh-in-motion (WIM) data is in the analysis of expected damage to highways caused by heavy vehicles and in the selection of pavements designed to withstand the stresses imposed by these vehicles. Weight data are also used in fatigue analysis of bridges and as an indicator of the economic value of bridges for use by bridge management systems. WIM systems also may be used for screening vehicles at static scales. WIM data may also provide information on the effectiveness of weight-limit enforcement efforts, and WIM systems can be used to provide information for use in developing improved enforcement strategies. However, to avoid biasing results, WIM data being collected for statistical purposes unrelated to weight enforcement should never be collected in the vicinity of ongoing weight-enforcement operations.

This chapter contains several recommendations relating to the calibration and use of WIM data.

## 7.1 Distribution of WIM Sites

The TMG requires the annual submission of data from ten WIM sites on the IS and from another 20 sites on other roads. States with extensive highway systems are encouraged to establish 30 sites on the IS and 60 on other roads, and to submit data from one-third of the sites each year on a three-year rotation. States with smaller highway systems may establish fewer sites and use data from these sites more than once every three years.

The TMG recommends that the sites be distributed across urban and rural functional systems and, within each functional system, across specified groupings by AADT. The distribution is to be in proportion to the distribution of VMT across these functional systems and volume groups.

We believe that, ***instead of distributing WIM sites across functional systems and volume groups, the sites should be distributed across*** regions. Regional differences in the economic base are likely to have a greater influence on truck weight characteristics than are functional systems and AADT, particularly on roads with significant amounts of locally generated traffic. For this reason, we consider regional distribution to be more valuable, particularly for non-IS sites. Regions to be used for this purpose may be State Highway Agency districts, taken individually or aggregated. Alternatively (and perhaps better) they may be groupings of counties that correspond to different types of dominant economic activity.

Another potentially important influence on vehicle weight in some states is the variation in weight limits across systems of roads. ***States with significant systems of roads with different weight limits should consider distributing WIM sites both across regions and across systems of roads with different weight limits.***

To the extent feasible, the distribution of WIM sites across regions should be in proportion to the distribution of VMT across regions. Non-IS sites in regions with more than one such site should be distributed across functional systems. IS sites in regions with more than one such site probably should be assigned to different IS routes (if multiple routes exist).

States with regionally dispersed WIM sites may wish to consider how average weight and average equivalent single-axle loads (ESALs) per vehicle varies by region (and, possibly, by functional system) when determining the weight and ESALs factors to be used in their Pavement Management Systems. Because of ambiguity about the appropriate ESALs factors to use for individual roads, states also may wish to use portable WIM equipment to obtain road and direction-specific estimates of ESALs prior to resurfacing or reconstructing these roads.

## 7.2 WIM Installations and Interpretation of WIM Data

Users of WIM data should be aware that these data are likely to produce higher estimates of average ESALs than would weighing of the same vehicles on stationary scales. The latter scales measure the weight, or downward force, of each axle when at rest, while WIM sensors measure this force when the vehicle is moving. Because road surfaces impart a degree of up-and-down movement to all axles, the downward force of each axle varies as it travels. The degree of this variation is affected by the quality of the road surface, the suspension characteristics of passing trucks, the loads carried by those trucks, and, to a limited extent, the sensor design and sensor configuration of the WIM device.

To reduce the effect of variations in force (*i.e.*, in measured weight), ***we recommend that pavement in the vicinity of permanent WIM installations be maintained to higher standards than those used for other pavement,***[1] ***and that portable WIM equipment only be used at locations where pavement is in good condition. Also, when piezo-electric sensors are used, at least two should be used in each lane.***[2] By weighing each axle more than once and averaging the results, axle weights can be obtained that are closer to those that would be obtained by stationary scales.

If WIM equipment is properly calibrated, the average of all weights obtained will be close to that obtained using stationary scales. However, for individual axles, there will be some differences between the weights obtained with WIM equipment (even when averaged between multiple readings) and those obtained with stationary scales. Because ESALs rise roughly with the fourth-power of axle weight, the overestimates produced by vehicle dynamics will have a greater effect on average ESALs than will

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[1] The ASTM Standard E 1318 sets standards for the pavement conditions needed for accurate estimation of static loads from WIM equipment. While it may not be possible to maintain pavement containing WIM equipment to this level routinely, it is necessary for accurate replication of static loads.

[2] One recent study has found that even more accurate results can be obtained by using five sensors in each lane (Michael S. Mamlouk and B. Sailendra, "Design of Multiple-Sensor Weigh-in-Motion Device," Arizona State University, presented at the Transportation Research Board Annual Meeting, January 1994). For roads on which normal truck speeds are 50 to 60 mph, this study recommends spacing the sensors about ten feet apart.

the underestimates, so that ***WIM equipment will produce higher estimates of average ESALs than would static weighing of the same vehicles.***[3]

Because the magnitude of this effect on ESALs is influenced by pavement condition, project-related WIM data collected at sites whose pavement is in poor condition will produce ESALs estimates that are not only higher than those that would be produced by static weighing of the same vehicle, but are also higher than the ESALs estimates that would be obtained once the pavement is improved. For this reason, ***we do not recommend the use of site-specific WIM data for project-design purposes.***

## 7.3 Calibration

A significant problem with data from permanent WIM sites is the loss of accuracy resulting from equipment calibration drift. Studies have shown that otherwise correctly functioning WIM scales can suffer from calibration drift as high as 10 percent.[4] Because of the fourth-power relationship between weight and ESALs, a 10 percent overestimate of axle weight can produce as much as a 45 percent overestimate in ESALs.

Calibration drift can be caused by a number of factors, including changes in temperature, changes in pavement roughness and pavement strength, sensitivity of sensors to varying load and tire configurations, aging of electronic components, degradation of sensor installations, and poor hardware/software design by manufacturers. To minimize calibration drift, many WIM equipment vendors attempt to adjust calibration coefficients directly for those factors that tests have shown affect their specific hardware design. For example, many systems measure ambient temperature and adjust calibration factors based on those temperatures.

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[3] It may be noted that WIM data are a better representation of the forces imposed on highway pavement (at least at the WIM site) than are static weight data. However, the AASHTO equations representing the effects of axle weight on pavement are based on static weights. Accordingly, for the purpose of applying the AASHTO equations, it is preferable to derive ESALs from static weights and not from the dynamic weights measured by WIM equipment. It is expected that procedures for analyzing the pavement damage caused by dynamic forces measured by WIM equipment will be developed from data now being collected under the Strategic Highway Research Program Long-Term Pavement Project.

[4] Curtis Dahlin and Mark Novak, Minnesota Department of Transportation, "Comparison of Weight Data Collected at Weigh-in-Motion Systems Located on the Same Route," presented at the Annual Meeting of the Transportation Research Board, Washington, D.C., January 1994.

To account for other factors that are not directly included in the equipment design (such as the temperature example above), many vendors adjust the calibration coefficient based on a rolling average of the front axle weight of loaded 3S2 (five axle, tractor semi-trailer) trucks. This calibration adjustment feature is based on research that indicates that this statistic remains fairly constant over time.

The success of these and other auto-calibration techniques has received mixed reviews. Not enough is known at this time to make a definitive statement on the best methods for calibrating or maintaining the calibration of WIM scales. NCHRP study 3-39(2) was recently funded to look into these issues. Until the completion of the NCHRP study and other efforts underway both nationally and within various states, the only completely reliable method for ensuring the validity of WIM scale calibration factors is periodic on-site testing and adjustment of the scales.

## 7.4 Estimating ESALs from WIM Data

For vehicles with a specific axle configuration (e.g., five-axle combinations), average ESALs per vehicle may vary seasonally as a result of changes in the mix of commodities carried. For more broadly defined classes of vehicles (e.g., single-trailer combinations), average ESALs per vehicle may also vary seasonally and/or by day of week as a result of changes in the mix of axle configurations being operated. Unfortunately, at the present time, only limited information exists about the amount of this variation and the extent to which it is uniform from site to site. On the other hand, the difficulty of calibrating WIM equipment and maintaining accurate calibration of this equipment over extended periods of time is reasonably well known.

For these reasons, we are inclined to believe that, at the present time, procedures for estimating average ESALs per vehicle focus primarily on calibration issues rather than on seasonal and day-of-week variation in ESALs per vehicle. More specifically, ***we recommend that ESALs estimates be developed only from WIM data collected over time periods during which the calibration of WIM equipment can be maintained with a high degree of accuracy. This recommendation applies to all sites being monitored under the Strategic Highway Research Program (SHRP) as well as to all other sites used for collecting data submitted to FHWA.***

We further recommend that, ***if necessary, the number of sites at which WIM data is collected be reduced to a number that can be used without compromising the quality of the WIM calibration.*** In areas where maintenance of calibration is difficult, the time periods over which WIM data is collected probably should be no more than one week long.

Until more information is obtained about the day-of-week variation in ESALs per vehicle by vehicle-class grouping, we recommend that each portable WIM session last at least 96 hours and include a full weekend. For WIM sessions lasting less than seven days, average weekly ESALs per vehicle should be estimated by assuming that the average on the weekdays for which data is collected represents, the average for all weekdays.

We outline below a suggested procedure for collecting and using WIM data. This procedure is consistent with the above principles. However, it has not been subject to a careful review.

1. Distinguish a small number of road types based on the perceived weight characteristics of the heavy trucks using the road, considering at least the percentage of trucks carrying natural resources.

2. For each road type, identify one or more locations at which data is to be collected, and maintain the road surface at these locations at a high standard. (Do *not* compromise pavement or calibration standards in order to increase the number of locations.)

3. At each selected location, collect WIM data for one or more four-to-seven day periods in each year (or every third year). At locations with seasonal natural-resources traffic, collect data for two or more periods — an in-season period and an out-of-season period.

4. For the duration of each WIM session, maintain the calibration of the equipment for the full range of medium and heavy axle loadings. (The *goal* probably should be $\pm 2$ percent, corresponding to ESALs errors of up to 8 percent.)

5. For each session, derive estimates of weekly average ESALs per vehicle (by vehicle-class grouping), adjusting the estimates for under representation of weekday data if data is collected for less than a seven-day period. For each vehicle-class grouping, at least two estimates of average ESALs should be developed: one for flexible pavement, using a structural number (SN) of 5.0; and a second for rigid pavement, using a slab thickness (D) of nine inches.

6. For each site, estimate annual average ESALs per vehicle (by vehicle-class grouping and pavement characteristics) by taking a subjectively weighted average of the values obtained for all WIM sessions at the site. (For a site with one "in-season" session and one "out-of-season" session, for each vehicle-class grouping, the weights should represent

estimates of the total numbers of vehicles in the grouping that traverse the site in season and out of season.)

7. For each road type, estimate annual average ESALs per vehicle (by vehicle-class grouping) by averaging the values obtained for the corresponding WIM sites. These averages normally would be unweighted (but they may be weighted if some sites are considered to be more representative of the road type than others).

# Selected References

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U.S. Environmental Protection Agency, *Section 187 VMT Forecasting and Tracking Guidance*, Washington, D.C, January 1992.

# Appendix A. Alternative Factoring Procedures

Exhibit 3.2 in Chapter 3, presents the results of simulation tests performed on seven temporal grouping procedures for seasonal and day-of-week factors. The procedure that appears to provide the best trade-offs between complexity and performance is Combined Month and Day-of-Week factoring (Procedure 4). This procedure is described in Section 3.2. The other six temporal grouping procedures are described in this appendix. Of these, we believe the procedures of most interest are Combined Week and Average Weekday factoring, described in Section A.4, and Specific-Day factoring, described in Section A.5.

## A.1 Separate Month and Day-of-Week Factoring

Separate Month and Day-of-Week factoring (Procedure 1) requires the development of one set of 12 monthly factors and a second set of seven day-of-week factors.

The *monthly factor* for month $i$ at ATR station $k$, $MF_{ik}$, is obtained as

$$MF_{ik} = \frac{AADT_k}{MADT_{ik}} \tag{A.1}$$

where $AADT_k$ and $MADT_{ik}$ are derived using the procedure presented in Section 3.1;

The *day-of-week factor* for day $j$ at ATR station $k$, $DWF_{jk}$, is obtained as

$$DWF_{jk} = \frac{AADT_k}{AADW_{jk}} \tag{A.2}$$

where $AADW_{jk}$, *annual average days of the week* for day $j$ and ATR station $k$, is derived using the Section 3.1 procedure or a minor variant of it. Factoring of short-duration counts is handled the same way as when Combined Month and Day-of-Week factoring (Procedure 4) is used, except that pairs of separate monthly and day-of-week factors are used instead of combined monthly day-of-week factors.

Of the seven temporal grouping procedures tested, Procedure 1 produces the least precise estimates of AADT (i.e., it has the highest probability of producing relatively large errors in the estimates of AADT). The primary weakness of this procedure is that it is unable to reflect seasonal variation in the *relative* volume of traffic on different days of the week — a particular weakness in areas in which the seasonal variation in weekend traffic is appreciably greater than the seasonal variation in weekday traffic. Procedure 1 requires the computation and use of a significantly smaller number of factors than the similar *Combined* Month and Day-of-Week procedure (Procedure 4). However, we do not believe that this minor advantage justifies the reduced effectiveness of the procedure.

## A.2 Combined Month and Average Weekday Factoring

Combined Month and Average Weekday factoring (Procedure 2) requires the development of an average weekday factor and an average weekend-day factor for every month of the year — 12 weekday factors and another 12 weekend factors.

The *monthly weekday factor* for month $i$ at ATR station $k$, $MWDF_{ik}$, is obtained as

$$MWDF_{ik} = \frac{AADT_k}{MAWDT_{ik}} \quad (A.3)$$

where $MAWDT_{ik}$ is the *monthly average weekday traffic* for month $i$ at ATR station $k$. We recommend that MAWDT be derived from ATR counts for weekday periods that roughly correspond to the periods when weekday coverage counts are being collected (e.g., the periods used in the derivation might run from noon on Monday to noon on Friday).

Similarly, the *monthly weekend factor* for month $i$, at ATR station $k$, $MWEF_{ik}$, is obtained as

$$MWEF_{ik} = \frac{AADT_k}{MADWET_{ik}} \quad (A.4)$$

where $MADWET_{ik}$ is the *monthly average daily weekend traffic* for month $i$ at ATR station $k$. We recommend that $MADWET_{ik}$ be derived from ATR counts for all periods of month $i$ that are not used in the derivation of $MAWDT_{ik}$.

Our tests indicate that, when applied to 48-hour counts, Procedure 2 performs slightly less well than Procedure 4. We did not test the application of Procedure 2 factors to 72-hour counts (to which these factors are commonly applied); however, the increase in short-count duration to 72 hours is likely to produce a small improvement in the quality of the AADT estimates.

## A.3 Separate Week and Day-of-Week Factoring

Separate Week and Day-of-Week factoring (Procedure 3) requires the development of one set of 52 weekly factors and a second set of seven day-of-week factors.

The day-of-week factors used by this procedure are identical to the ones used by Procedure 1, as given in Equation A.2; and the *weekly factor* for week $i$ at ATR station $k$, $WF_{ik}$, is obtained as

$$WF_{ik} = \frac{AADT_k}{WADT_{ik}} \quad (A.5)$$

where $WADT_{ik}$ is *weekly average daily traffic* for week $i$ at ATR station $k$. For the purpose of this factoring procedure, all weeks may be treated as starting on a Sunday, as is the normal convention, or, if more convenient, a different first day of the week may be used. Short-duration counts are factored using pairs of factors in the same way as when Procedure 1 is used.

Like the Combined Week and Average Weekday procedure (Procedure 5), Procedure 3 works best if used in conjunction with an explicit imputation procedure. However, unlike Procedure 5, Procedure 3 produces AADT estimates that are slightly less precise than those produced by Procedure 4 (Combined Month and Day-of-Week factoring). Accordingly, we see little reason for using Procedure 3.

## A.4 Combined Week and Average Weekday Factoring

Combined Week and Average Weekday factoring (Procedure 5) requires the development of an average weekday factor for every week of the year — a total of 52 factors. If counting is also performed on weekends, another 52 factors are required for each of the weekends of the year.

The *weekday factor* for week *i* at ATR station *k*, $WDF_{ik}$, is obtained as

$$WDF_{ik} = \frac{AADT_k}{AWDT_{ik}} \qquad \text{(A.6)}$$

where $AWDT_{ik}$, *average weekday traffic* for week *i* at ATR station *k*, is derived from ATR counts for the period running from noon on the first day of week *i* on which weekday coverage-count counters are laid down until noon on the last day on which they are retrieved. This period usually runs from Monday noon until Friday noon, but it starts on Tuesdays on weeks with a Monday holiday and it ends on Wednesday on Thanksgiving week. ***We recommend that weekday short counts*** not ***be collected during weeks with a midweek (e.g., Wednesday) holiday or that special factoring procedures be developed for these counts.***[1]

During normal weeks, the weekday factors are derived from ATR counts for the period from Monday noon through Friday noon — a period of time that roughly corresponds to the period when weekday coverage

[1] Holiday-period counts may be factored using analogues of the weekend factors discussed subsequently (e.g., Monday-noon to Thursday-noon factors for Monday-to-Thursday counts). However, factors derived for periods that include a holiday should not be applied to counts taken for shorter periods that exclude the holidays.

counts are being taken (Monday morning through Friday afternoon). This is also a period when day-to-day variation in traffic volumes is relatively small — the increase in volume that occurs on Friday is appreciably smaller in the morning than it is later in the day.[2]

If weekend or seven-day short counts are collected, weekend factors will be required. These are defined analogously to the weekday factors; i.e., the *weekend factor* for weekend *i* at ATR station *k*, $WEF_{ik}$, is obtained as

$$WEF_{ik} = \frac{AADT_k}{ADWET_{ik}} \tag{A.7}$$

where $ADWET_{ik}$, *average daily weekend traffic* for weekend *i* at ATR station *k*, is derived from ATR counts for the period from noon of the day preceding weekend *i* (normally a Friday) to noon of the day after weekend *i* (normally a Monday). This period corresponds roughly to the period when weekend counts usually are collected, and so these factors should work well for factoring weekend counts (though we have not tested them).

Seven-day counts can be factored by decomposing each full seven-day count into counts obtained during each of three periods (a weekday period, a weekend, and a second weekday period), using the appropriate factors for each of these three periods, adding the results, and dividing by seven. When decomposing seven-day counts, we recommend that the weekend period run from noon to noon in order to match the period used in deriving the weekend factor that will be used in factoring this portion of the seven-day count.

The use of Equation A.6 to derive weekday factors for an ATR station requires a minimum of one actual or imputed 24-hour count between Monday noon and Friday noon for each week. In concept, Equation A.7 can be used to derive weekend factors for an ATR station if a minimum of one such 24-hour count exists for every weekend period, but the weekend factors will be somewhat unreliable unless data for the entire weekend period is used. Because of these relatively stringent require-

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2 Deriving weekday factors from ATR counts for Monday to Thursday (midnight-to-midnight) produces a slightly lower MAE (7.4 percent) but increases the average error (upward bias) to 1.0 percent. We have rejected this alternative because of the relatively large bias. This bias occurs because traffic volumes are higher on Friday mornings (when short counts are being taken but ATR data is not being used) than on Monday mornings (when very little short count data is being collected but all ATR data is being used).

ments, ***we recommend that Procedure 5 only be used in conjunction with an explicit imputation procedures such as the one described in Section 3.1.***

Exhibit 3.2 indicates that the application of Procedure 5 to weekday counts produces somewhat better estimates of AADT than does the application of Procedure 4 — there is a slight reduction in MAE and a more appreciable reduction in the probability that the error will exceed 20 percent. The primary reason for the better performance is that, for the Monday-noon to Friday-noon period, traffic volumes vary more from week to week than they do from day to day. The advantages of Procedure 5 are greatest in areas, such as recreational areas, where there is significant week-to-week variation in traffic volumes.

Although we have not tested Procedure 5 on weekend counts, we believe it also will handle these counts better than Procedure 4 *provided* that it is applied only to counts taken for the full weekend period (i.e., from the middle of the day preceding the weekend to the middle of the day following the weekend). Because traffic volumes vary appreciably over the course of a weekend, ***the Procedure 5 weekend factors should* not *be applied to counts obtained for only a part of a weekend period.*** This limitation becomes an issue only when incomplete weekend counts are obtained (e.g., when a road tube becomes dislodged). Three options exist for handling this situation:

- Do not use any incomplete weekend counts;
- Use other information about the day-to-day (and hour-to-hour) variation in weekend counts to estimate the full weekend count that would have been obtained if the equipment had not failed); or
- Develop a set of combined month and day-of-week factors for use in this case or for all factoring of weekend counts — these factors may correspond to the ordinary days of the week (Friday, Saturday, Sunday, and Monday), or they may be defined on a noon-to-noon basis in the same way as the normal Procedure 5 weekday and weekend factors are defined.

The choice as to which of these three options should be used will depend upon the uses made of weekend and seven-day counts and the frequency with which incomplete weekend counts occur.

If computer resources permit, states that use Procedure 5 and that recompute current-year factors regularly during the course of a year may choose to recompute these factors weekly or biweekly (rather than monthly, as suggested earlier). For this purpose, we suggest deriving AADT by applying the AASHTO procedure for deriving AADT to 13 four-week "months" of data.

## A.5 Specific-Day Factoring

Specific-Day factoring (Procedure 6) requires the development of separate factors for every day of the year.

The *specific-day factor* for day $i$ at ATR station $k$, $SDF_{ik}$, is obtained as

$$SDF_{ik} = \frac{AADT_k}{C_{ik}} \quad \text{(A.8)}$$

where $C_{ik}$ is the actual or imputed count for day $i$ at ATR station $k$. Factoring with specific-day factors is performed in the same way as factoring with the combined month and day-of-week factors of Procedure 4.

The development of specific-day factors requires the availability of actual or imputed counts for every day of the year. Accordingly, this procedure requires the use of an explicit imputation procedure such as the one described in Section 3.1. However, Specific-Day factoring is otherwise quite straightforward, and it produces AADT estimates that are somewhat more precise than those produced by Procedures 4 or 5. We believe the use of Specific-Day factoring warrants further investigation.

## A.6 Specific-Day Factoring with Noon-to-Noon Factors

The last temporal grouping procedure tested, Specific-Day Factoring with Noon-to-Noon Factors (Procedure 7), requires the development of 365 daily factors. However, instead of being derived using counts for calendar days (as is the case with Procedure 6), the Procedure 7 factors are derived using actual and imputed counts for 24-hour periods *starting at noon* on each day of the year.

Applying Procedure 7 factors to a 24-hour count starting at any time on day $i$ is accomplished by applying a single factor developed using ATR counts for the 24-hour period starting at noon of that day. Similarly, a 48-hour count starting on day $i$ is factored by decomposing the count into two 24-hour counts, applying a pair of factors, and averaging the results; the factors used are those developed using ATR counts for the 24-hour periods starting at noon on days $i$ and $i+1$.

Procedure 7 is somewhat more difficult to describe and to understand than Procedure 6. However, it provides a very good match between the time period used in developing the factors and those that are used in obtaining the short-duration counts to be factored.

The advantage of this temporal match may be best understood if one considers the case of short-duration counts collected for periods ending Friday morning or Friday afternoon. Using Procedure 7, the last 24 hours of any such count is factored using ATR counts for a 24-hour period ending at noon on Friday. This factor will reflect Friday morning traffic volumes (which usually are *slightly* higher than volumes on other weekday mornings) but not Friday evening volumes (which usually are *appreciably* higher than volumes on other weekday evenings). The characteristics of Friday traffic will thus have an effect on the factor that is relatively similar to the effect it has on the short-duration count being factored.

On the other hand, using Procedure 6, the Friday portion of the count is factored using ATR counts for all of Friday. This factor will reflect both the (slightly elevated) Friday morning volumes and the (significantly elevated) Friday evening volumes. The result is a tendency to over adjust the Friday portion of short-duration counts.

The good Procedure 7 temporal match results in AADT estimates that are slightly more precise than those produced by Procedure 6 (and better than those produced by any of the other temporal grouping procedures that were tested).[1] Like Procedure 6, Procedure 7 requires the use of an explicit imputation procedure.

[1] For the purpose of evaluating Procedure 7, all simulated short-duration counts were assumed to start at either 10 AM or 2 PM (representing typical morning and afternoon start times for these counts).

# Appendix B. Evaluation of Factor Groups

This appendix discusses three alternatives for developing data that can provide some insight into splitting factor groups for the purpose of improving the homogeneity of the groups and the quality of the resulting AADT estimates.

## B.1 Cluster Analysis

Cluster analysis is a commonly used tool for providing information for grouping road sections. The TMG (Section 3, Appendix A) presents a procedure for using cluster analysis to identify clusters of ATR stations that are potentially useful for grouping road sections.

The TMG procedure recommends applying cluster analysis to twelve *monthly factors*, computed as the ratio of MADT to AADT. This procedure produces clusters that reflect similarities in seasonal patterns of traffic volume, but they do not take into account similarities and differences in weekday/weekend patterns. In order to incorporate both seasonal and weekday/weekend patterns into the analysis, ***we recommend that cluster analysis be applied to* monthly average weekday *factors, computed as the ration of MAWDT/AADT,*** where MAWDT is *monthly average weekday traffic*. We suggest that MAWDT be computed for each month by considering only Monday through Thursday traffic volumes, excluding all holidays, and applying the AASHTO procedure presented in Section 3.1.[1]

Cluster analysis is somewhat better suited as a tool for grouping observations about which little is known than as a tool for splitting or reorganizing existing groups. For the latter purpose, we suggest that the results of the cluster analysis be viewed as a way of *partitioning* ATR sites. A review should be conducted of ATR sites that currently fall into the same factor group but which the cluster analysis suggests should be partitioned into separate clusters. This review should determine whether there are any readily identifiable and generalizable criteria that can be applied to all short-count sites that will result in distinguishing between the ATR sites in one cluster and those in another. Possible criteria may include:

- *Degree of urbanization.* In addition to urban and rural groups, there may be a role for in-between groups consisting of sites in small urban areas and/or the fringe of urbanized areas. Such short-count sites could exist in both "urban" and "rural" areas and they may be distinguishable on the basis of hourly traffic volumes that indicate relatively muted rush-hour peaks.

- *Seasonality of recreational areas.* Short-count sites in recreational areas should be placed in the same group *only* if they serve areas with similar recreational seasons. AADT estimates for sites in recreational areas can be improved by developing separate groups for recreational areas having major or minor peaks in the summer, winter, hunting-season, foliage season, Spring break, etc.

- *Degree of recreational influence.* Roads that primarily serve recreational traffic exhibit relatively extreme peaking, while arterials that carry a mix of traffic may have similar seasonal patterns but with more muted peaks.

- *Other geographic influences on seasonality*, such as the harshness of winter.

- *Retail orientation.* Small numbers of retail-oriented sections in numerous, predominantly suburban, locations are likely to have relatively unique day-of-week volume patterns (with a relatively high percentage of traffic occurring on Saturdays). These locations may be identifiable from their

[1] A slightly more sophisticated procedure for MAWDT uses 24-hour volumes for periods starting at noon on Monday, Tuesday, Wednesday, and Thursday, excluding all 24-hour periods that begin or end on a holiday.

hourly traffic patterns (high volumes from late morning until early evening with a lower weekday morning rush-hour peak).

## B.2 Comparison of Factors

A second approach to evaluating the homogeneity of a factor group containing several ATR stations is to compare the factors obtained for each of the stations. Dissimilarities are an indication that it may be appropriate to divide the factor group. Some dissimilarities that may be fairly easy to observe are:

a) Consistent differences in the size of weekday factors — indicating that some sites carry a larger share of total traffic on weekdays than other sites;

b) Differences in the *degree* of seasonal variation in the factors; and

c) Differences in the *timing* of seasonal peaks and valleys in the factors. (These peaks and valleys correspond, respectively, to seasonal troughs and peaks in traffic volume.)

Plots of each station's weekday factors (if Combined Week and Average Weekday factors are being used) or Wednesday factors (if Combined Month and Day-of-Week factors are being used) can be helpful in identifying dissimilarities.

Unfortunately, the identification of dissimilarities does not necessarily provide the basis for splitting a factor group. Additional information is needed to determine how to split the road sections that correspond to the ATR stations. Some possibilities are:

a) Consistently high weekday factors may indicate relatively low truck volumes or the existence of nearby weekend traffic generators. The former cause may be handled with some sort of truck-route/non-truck-route identifier, such as functional system; while weekend traffic generators (such as retail complexes) may be identifiable at individual short-count sites by the peculiar weekday hourly traffic-count patterns that they create.

b) The degree of seasonal variation frequently varies geographically (e.g., as a result of differences in: urbanization, the harshness of winter, or the influence of recreational travel).

c) Differences in the timing of seasonal peaks and valleys are most likely to occur as the result differences in seasonal patterns of recreational travel. Such differences are likely to be geographical in nature.

## B.3 A Factoring Test

A third approach to evaluating the homogeneity of a factor group containing several ATR stations is to evaluate how well factors developed from data for some of the stations work when they are applied to simulated short-duration counts obtained for other stations in the group. This approach may be operationalized:

1. Choose one ATR station in the factor group.

2. Using the AASHTO procedure presented in Section 3.1, derive AADT for the station.

3. From ATR data for that station, systematically generate 48-hour weekday counts corresponding to the various Monday-Wednesday, Tuesday-Thursday, and Wednesday-Friday periods used during the year for collecting coverage counts. (The start times for the counts may be assumed always to be noon or they may be assumed to be randomly distributed over the workday.)

4. Develop a set of seasonal factors from data for the remaining ATR stations in the group (or, optionally, from some subset of these stations).

5. Apply these factors to each of the 48-hour counts to produce a set of AADT estimates developed from short counts.

6. Develop statistical measures of how the Step 5 AADT estimates differ from the Step 2 AADT value. We suggest

focusing on the percentage root-mean-square (RMS) error[2] and the mean percentage error.[3]

7. Repeat Steps 1 - 6, choosing, in turn, each of the other ATR stations in the factor group.

At the end of this process, a set of statistics will be generated identifying how well short counts at each ATR station can be factored using data from the other stations in the group. Stations for which relatively large error statistics exist are candidates for being moved into a different factor group. We suggest that RMS errors in the 10 to 20 percent range are borderline and larger errors are a clear indication that a station fits poorly in its current group. Some further information about how the factor group may be redefined can be obtained by examining the mean percentage errors — stations with strongly positive numbers (e.g., greater than 10 percent) probably should be separated from those with strongly negative errors — and also by examining the seasonal patterns of the individual factors. However, as usual, revising the groups requires the ability to identify appropriate indicators for distinguishing groups. As discussed in Section B.1, such indicators may be based on location, roadway system, or hourly count patterns.

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2 For $n$ estimates of AADT, denoted $X_1, X_2, \ldots, X_n$, the percentage RMS error is defined as:

$$100\left[\frac{1}{n}\sum_{i=1}^{n}(X_i - AADT)^2\right]^{\frac{1}{2}} / AADT$$

This error statistic is somewhat less intuitive than MAE (used in the body of this report), but it is a better comparison tool because it weights large errors more heavily than small ones.

3 The mean percentage error provides a measure of how well the factors adjust for differences between weekday and weekend volumes. Positive values indicate the factors are derived from data from ATR stations that have a higher percentage of their traffic on weekends than does the station chosen in Step 1. Negative values indicate the opposite.