TRAFFIC MONITORING GUIDE

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TRAFFIC MONITORING GUIDE
EXECUTIVE SUMMARY

This document summarizes the recommendations in the Traffic Monitoring Guide (TMG). The complete guide should be referenced as needed to understand the technical analysis behind these recommendations.

Actual implementation will vary from agency to agency. Each State or local highway agency has its own traffic counting needs, priorities, budgets, geographic, and organizational constraints. These differences cause agencies to select different equipment for data collection, use different collection plans for obtaining traffic data, and emphasize different data reporting outputs. However, all highway agencies collect the same basic types of data, and each can benefit from using a similar basic data collection framework.

Traffic monitoring has a long tradition and each agency has an established legacy program. The TMG offers suggestions to help improve and advance current programs with a view towards the future of traffic monitoring. A basic program structure for traffic monitoring is presented. The guide provides specific examples of how statewide data collection programs should be structured, describes the analytical logic behind that structure, and provides the information highway agencies need to optimize the framework for their particular organizational, financial, and political structures.

DATA COLLECTION FRAMEWORK

The basic recommended program design consists of:

- portable short duration counts, and
- permanent continuous counts.

The short duration counts ensure geographic diversity and coverage. The continuous counts help the agency understand the time-of-day, day-of-week, and seasonal travel patterns and allow development of the mechanism needed to convert short duration counts into accurate estimates of annual conditions. Adjustments to short duration count data are normally required to remove temporal bias from data used for annual average daily traffic (AADT) computation.

The TMG recommends that the short count data collection consist of a periodic comprehensive coverage program over the entire system on a 6-year cycle. The coverage plan includes counting the Highway Performance Monitoring System (HPMS) sample and universe sections on a shorter 3-year cycle to meet the national HPMS requirement.

The coverage program is supplemented with a “special needs” element where additional counts are performed as needed to meet other more specific data needs. The "special needs" program represents many different operations and may include the following:

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

The specific requirements (what is collected, when and where it must be collected) for these and other "special needs" studies change from agency to agency. The ways in which agencies balance these all-encompassing needs against their limited traffic counting budgets lead to the very different data collection programs that exist around the country.

The TMG recommends a coverage program structure for both volume and vehicle classification programs. Substantial amounts of classification data are needed to better understand truck travel on highways. Highway agencies should collect classification data (which also supply total volume information) in place of simple volume counts whenever possible. The TMG recommends that State highway agencies initially aim to take 25 to 30 percent of their short duration coverage counts with classification counting equipment. Agencies that can exceed this figure are encouraged to do so. The ability to meet or exceed this goal depends on agency perspective and is a function of the equipment available and the nature of the road system. Classification data are difficult to collect in many urban settings because of safety or equipment limitations. Therefore, a city may decide to collect considerably less than 30 percent of its counts as classification counts.

Access to data collected from continuous counters is necessary for all highway agencies. Considerable benefit can be obtained by sharing these data collection resources. Agencies should work together to reduce duplication in the number and location of permanent, continuous data collection devices. Agencies should share the data they collect (e.g., a State DOT should use seasonal and day-of-week information collected at permanent sites operated by a county or city as part of developing adjustment factors for a specific urban area). A single count location can supply information for many purposes (e.g., permanent, continuous weigh-in-motion scales supply weight, classification, and volume data). Opportunities to share data exist not only among agencies but within agencies. Ensuring that planning, operations, maintenance, and construction groups share the data they collect can substantially increase the availability of traffic monitoring data while reducing the overall cost of data collection.

A key source for urban traffic data will be the traffic surveillance systems used for traffic management and control. These systems, currently being installed, expanded, and improved as part of the Intelligent Transportation System (ITS) program offer highway agencies the ability to collect continuous traffic monitoring data at high volume locations. Access to these data requires proactive efforts by the traffic monitoring groups, as archiving and analysis of surveillance data are traditionally less important to the operations groups that build, operate, and maintain these ITS systems. Without proactive efforts by the traffic monitoring groups, the benefits of ITS data can be lost because operations groups spend their scarce resources on operational improvements rather than on the archiving and analysis software needed to convert surveillance data into useful traffic statistics.

The TMG recommends that each agency improve the quality of reported traffic data by establishing quality control processes for traffic data collection and processing. Subjective editing procedures for identifying and imputing missing or invalid data are discouraged, since the effects of such data adjustments are unknown and frequently bias the results. Each highway agency should have formal rules and procedures for their quality control efforts.

VOLUME COUNTS

The measurement of traffic volumes is one of the most basic functions of highway planning and management. Traffic volume counts are the most common measure of roadway use, and they are needed as input to most traffic engineering analyses. While several traffic volume statistics are used in traffic analyses, two are of primary interest for the design of statewide traffic monitoring programs: annual average daily traffic (AADT) and average daily vehicle distance traveled (DVDT). Because DVDT is computed by multiplying the roadway segment AADT by the length of that segment, the primary goal of most traffic monitoring programs is to develop accurate AADT estimates, which can then be expanded to estimates of travel. To achieve this goal, the recommended traffic monitoring program consists of two basic components, a continuous count program and a short duration count program.

Continuous Count Program

All highway agencies should have access to data collected from continuous counters. These data are needed to understand temporal (day-of-week, month) changes in traffic volume. However, not all agencies need to operate these devices. Agencies should work together to ensure that enough data are collected and shared to allow calculation of accurate seasonal adjustment factors needed to convert short duration traffic counts into estimates of AADT. The TMG provides considerable guidance on how to structure continuous count programs, how to determine the appropriate number of counters for adjustment factor development, and how to apply those factors.

Short Duration Counts

The short count program is designed to provide roadway segment-specific traffic count information on a cyclical basis. The TMG recommends the collection of 48-hour periods with counters that record hourly data. To compute AADT, the volume data from the short counts must be adjusted to annual conditions. The adjustments include:

- axle correction (for counts taken with single axle sensors)
- day-of-week (for counts taken for less than one week)
- month (to account for volume changes from month to month).

Since AADT is desired for the current year, growth factors need to be computed and applied to counts not taken during the current year. Also, counts of less that 24-hour duration, usually taken as a last resort and not recommended in the TMG, must be adjusted to represent a full 24-hour period.

Short Count Program Design

Highway agencies perform short duration counts for a variety of purposes, including meeting federal reporting needs (HPMS), supplying information for individual projects (pavement design, planning studies, etc.), and providing broad knowledge of roadway use. The short duration counting program can be most efficient if these various data collection efforts are coordinated so that one count session meets multiple needs. To produce that efficiency, the TMG recommends the following steps to program design:

- Divide the road system into homogeneous traffic volume segments, determine the count locations needed to cover the system over a maximum cycle of six years.
- Determine the count locations required to meet the HPMS needs.
- Determine the count locations and data collection needs of specific projects that will require data in the next year or two. This entails working with the offices that will request these data to determine their data needs.
- Overlay the counts[1] on maps of the highway system including the location of functioning continuous counters.
- Determine how counts can be combined to make best use of available counting resources.
- Schedule the counts to efficiently use the available data collection crews and equipment.

This program design is intended to reduce count duplication and increase the efficiency of the data collection staff.

HPMS Counts

Of particular importance to all highway agencies is the collection of the HPMS sample and universe section traffic data. Volume data from the HPMS are used to apportion Federal-Aid funds. Significant portions of these funds are allocated by each State highway agency to lower jurisdictions, highway districts, or local agencies.

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[1] Included in this effort should be all vehicle classification and WIM counts, since these counts should also provide total volume data.

Consequently, each highway agency has a direct financial interest in the validity of data submitted to the FHWA under the HPMS.

In addition, the outcome of many studies based on the HPMS data affect highway agencies. The HPMS data are used in a number of key analytical tools, including the HPMS Analytical Package, the Surface Transportation Efficiency Analysis System (STEAM), the Highway Economic Requirements System (HERS), and the ITS Deployment Analysis System (IDAS), as well as a host of State-specific planning and performance modeling systems.

The HPMS traffic data collection requirement was initially designed as a statistical sample of highway sections to meet federal data needs. The HPMS data collection system evolved into a combination of a universal count program for the National Highway System and other principal arterials (that is, every HPMS roadway section must be counted) and a statistical sample for the remaining highway systems.

Each State highway agency is responsible for reporting traffic data to the HPMS as specified in the HPMS Manual. To support the HPMS reporting requirement, each NHS, principal arterial, and sample section must be counted at least once every three years. Note that the HPMS covers roads on and off the State highway systems.

In addition, each State should maintain cyclic count coverage data on all arterial and collector roadways covered by the HPMS sample so that those sections can be accurately assigned to HPMS volume strata. This is necessary to expand the HPMS sample counts into accurate estimates of statewide VDT.

State highway agencies may not need to physically count all HPMS sample or universe locations. In some cases, States rely on local governments to collect and report these data. In other cases, procedures such as "ramp balancing" can be used to estimate traffic volumes on roads where portable counts cannot be safely performed. Regardless of how these data are collected, the State highway agency is responsible for the quality, completeness, and accuracy of all submitted HPMS traffic data.

VEHICLE CLASSIFICATION COUNTS

This edition of the TMG significantly departs from the vehicle classification recommendations in previous editions. The new recommendation follows the same basic design as the volume count program previously described. It consists of a coverage count element supported by a continuous count program.

One reason for this change is that the statistical sample previously collected met only a single objective efficiently, the estimation of the average percentage of travel by truck type by functional class of roadway. It did not meet the data collection needs of many other users and did not supply sufficiently accurate data on the percentage of trucks operating on HPMS sample sections.

This change in data collection methodology has other implications. The new approach acknowledges that many uses other than statewide travel estimates must be met. To meet these needs it is necessary to be able to estimate annual average truck travel. Therefore, the TMG recommends a strong continuous classification count program. The continuous classification count program is specifically aimed at providing users with a better understanding of time-of-day, day-of-week, and seasonal variation in truck volumes.

To apply the knowledge of truck volume variation, the TMG recommends new procedures to create and apply factors from the continuous classification count program to the short duration classification counts being collected. The TMG recommends that seasonal and day-of-week adjustment factors be developed for three or four broad vehicle classifications. These factors are similar to those currently applied to traffic volume counts, but recognize that truck travel patterns are very different from those of passenger vehicles. The factors are needed to create accurate estimates of annual truck traffic.

Short Duration Classification Counts

The objective of the short duration classification count program is to ensure that highway agencies have valid truck volume information for all highways under their jurisdiction. This means that agencies need to count truck volumes on all arterial and major collector roads. A specific emphasis is placed on the collection of classification data on the HPMS sample segments, since these data are used in many nationally significant analyses. At the same time, structuring the coverage program on the HPMS sample provides a geographically diverse set of roadway locations to address most other needs. Additional needs would be covered under the "special needs" criteria.

The basic data collection recommendations follow:

- Highway agencies should collect classification counts rather than volume counts whenever equipment and staffing limitations allow. As a rule of thumb, 25 to 30 percent of the volume counts should be classified.
- Each agency should perform at least one vehicle classification count on each route each year.
- For roads that change character and/or sustain significant truck volume changes over their length, one count should be taken on each segment of that roadway each year.[2]
- Where practical, these counts should be performed at existing HPMS standard sample sections.

The classification counts should cover a 48-hour monitoring period and, if possible, should use the standard FHWA 13 vehicle categories. In some locations, equipment limitations prevent the collection of the 13 FHWA categories. This usually

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[2] This and the previous bullet are intended to ensure that sufficient measurements of truck volumes are taken on each important route with a bare minimum of a single count

occurs in high volume, multi-lane situations where vehicle speeds are highly variable, such as congested urban areas, or where traffic signal systems cause vehicles to accelerate or decelerate while being counted. At these locations, highway agencies are encouraged to use any truck classification equipment that can accurately classify trucks, even if that means using a different (usually simplified) classification scheme. If unable to classify under the 13-class scheme due to equipment limitations or safety issues, the TMG recommends the use of four (or three) classes based on total vehicle length.

To meet these guidelines, many State highway agencies will need to increase the number of classification counts they conduct. As old traffic counting equipment is replaced, the new equipment should be capable of classifying as well as counting. For statewide monitoring purposes, highway agencies should attempt to collect classification data whenever possible, given equipment limitations and the need for efficient staff and equipment utilization. The goal for every highway agency should be to collect enough data to provide a valid estimate of truck volume on each route. These estimates should be based on actual traffic counts conducted on the roadways in question.

Permanent, Continuous Classification Counts

The continuous classification count program has one major goal, the creation of factors needed to estimate annual average daily truck volume from short duration classification counts. To accomplish this goal it is necessary to measure day-of-week and seasonal variation in truck traffic and to apply the knowledge to short duration counts. Truck volumes vary significantly by time of day and day of week as illustrated by Figures 1 and 2.

Sufficient continuous counters are needed to measure each of the different truck volume patterns found in a State or region. This means that continuous counters should be placed on different functional classes of roads and in different geographic locations. It is especially important to be able to measure the differences in truck volume patterns between roads that carry primarily local truck traffic and those that serve through-traffic.

A good rule of thumb is that the continuous classification count program should be roughly the same size as the traditional continuous volume count program (the ATR program). In fact, the design of the continuous count program is very similar to the design of the ATR program. While the recommended continuous count program requires a significant number of count locations, it is important to note that continuous classifiers also serve as ATRs. Thus it is possible to use the classification counters in place of ATRs at the same time they are used to supply continuous classification data. Such a step significantly reduces the number of continuous counters an agency needs and reduces unnecessary duplication.

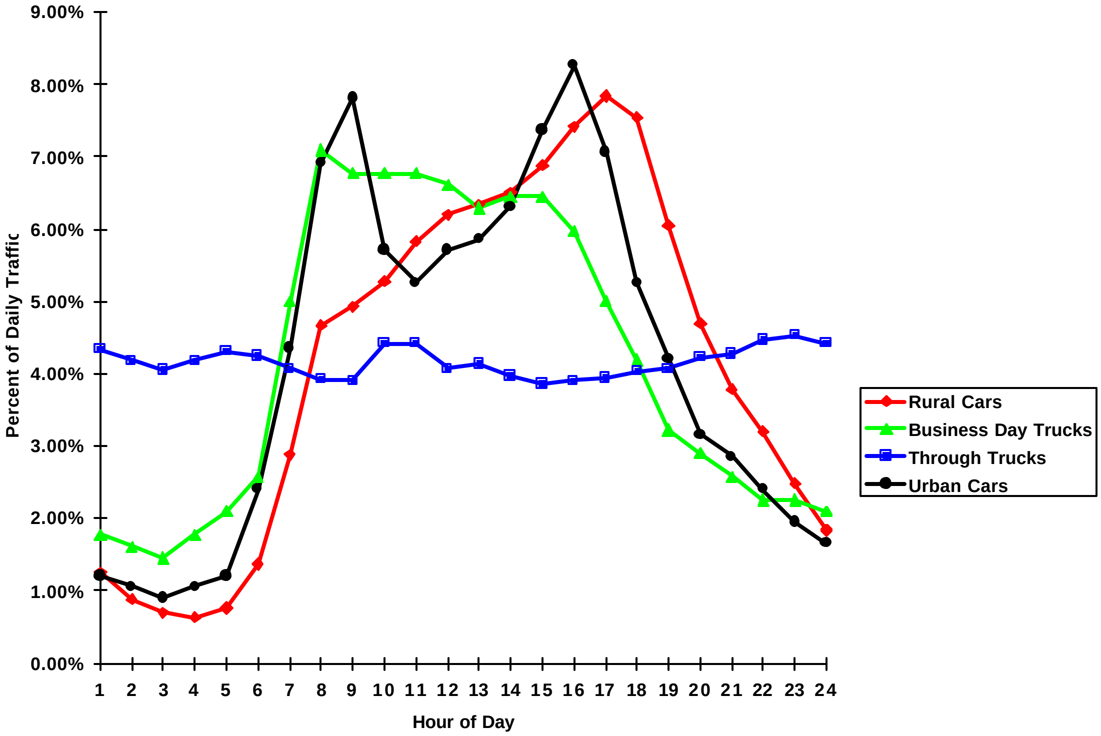

Figure 1: Basic Time of Day Patterns

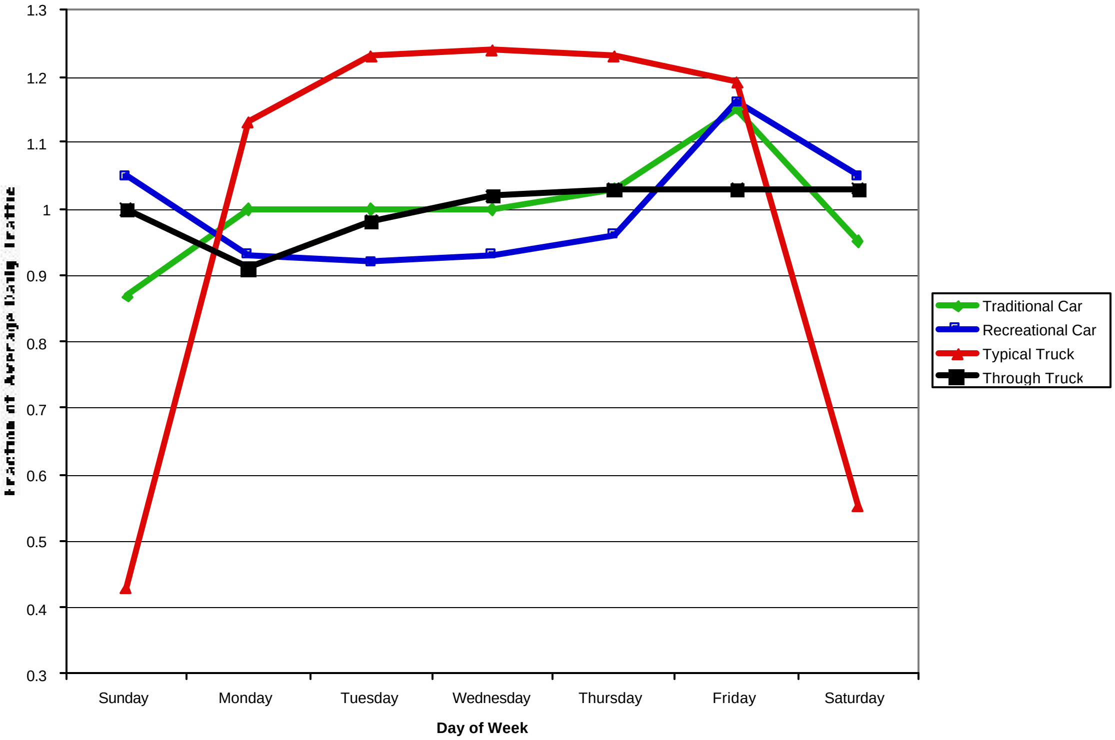

Figure 2: Typical Day of Week Travel Pattern

Factoring of Short Duration Classification Counts

For many years highway agencies have developed and applied adjustment factors to short duration volume counts in order to estimate annual average volumes. Annual average estimates of truck volumes are key inputs to pavement design analyses, trend analyses, revenue studies, accident analyses, and a variety of other studies of high importance and visibility to highway agencies. Therefore, highway agencies must develop adjustment procedures that allow accurate estimation of annual average truck volumes from short duration counts. The definition of trucks in this analysis applies to the longer wheelbase mostly cargo vehicles not to pickup trucks or vans.

Research has shown that truck volumes, like car volumes, vary by time of day, day of week, and season, but truck volumes follow patterns that are significantly different than those of passenger vehicles. Therefore, applying the adjustment factors already computed for volume induces bias in the computation of annual truck volume estimates. What each highway agency needs are adjustment factors specifically designed to convert short duration truck volume counts into estimates of annual average daily truck traffic (AADTT).

These factors and factoring procedures need to be developed by each State highway agency. The development of truck factor procedures is a new endeavor and as such it will take time to mature. The TMG suggests a factoring approach that uses the nature of the road’s freight traffic and, if needed, geography to categorize roads into factor groups. The recommended roadway characterization includes identifying whether the truck traffic on that road is predominantly “locally” oriented or that road carries large “through” truck movements. Roads with mostly local truck traffic tend to have travel patterns that are heavily oriented toward business day travel (that is, few trucks at night and on weekends.) Roads that carry heavy through-movements have higher weekend and nighttime truck volumes.

Geographic stratification for the truck factor groups is suggested for States in which economic activity changes significantly from one part to another. For example, if the southern half is heavily agricultural, while the northern half is heavily oriented toward manufacturing, these two geographic areas are likely to have different seasonal trucking patterns.

Table 1 presents a suggested grouping scheme for the creation of truck factor groups. A key recommendation on the development of truck factors is to create factors for only three or four broad categories of vehicles. The suggested classes for factoring are:

- passenger vehicles
- single-unit trucks
- single combination trucks (trucks and tractors with a single trailer)
- multi-trailer trucks.

States that have few multi-trailer trucks should reduce further to three categories by consolidating the single combination and multi-trailer truck categories.

Table 1: Example Truck Factor Groups [3]

Rural	Urban
Interstates and arterial major through-truck routes	Interstate and arterial major truck routes
Other roads (e.g., regional agricultural roads) with little through-traffic	Interstates and other freeways serving primarily local truck traffic
Other non-restricted truck routes	Other non-restricted truck routes
Other rural roads (e.g., mining area)	Other roads (non-truck routes)
Special roads (e.g., recreational, ports)	

The use of urban or rural breaks may be necessary due to the differences in patterns and volumes at these locations. In many States, such a break may not be considered appropriate.

The aggregated classification scheme for factoring short duration classification counts is recommended for several reasons. In many States, the volumes in many of the FHWA 13 vehicle categories are very low and highly variable. When volumes within a vehicle class are low, the factors computed for those vehicle categories become very unstable and inaccurate. The factors and estimates can change drastically based on a few vehicles. Aggregating vehicle classes allows the factoring process to keep the majority of truck volumes (by class) high enough to provide stability to the factors produced.[4] The aggregation also reduces the computational process to create and apply the factors, since computing factors for 13 classes would become a very cumbersome process.

Other Recommendations

Calibration and Quality Control

A key component of the vehicle classification program is the establishment of quality control procedures including the calibration and testing of equipment used to

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[3] These are strictly examples. Each State highway agency should select the appropriate number and definition of truck groups based on its economic and trucking characteristics.

[4] It is also possible to account for seasonal variation by counting multiple times during the year at a single location and this is appropriate for sites where a high degree of accuracy is needed or where truck adjustment factors are not considered highly reliable.

collect truck volume data. Each State must periodically calibrate, test, and validate the performance of its classification equipment to ensure that the equipment is operating as intended. This includes testing new classifiers received from the manufacturer. The quality control program should include a short field test whenever a classifier is placed in traffic to ensure that the counter is working correctly.

Use of Multiple Classification Schemes

The classification schemes that can be collected are a function of the data collection equipment used and of road conditions. Many States use different classification equipment in different operating conditions and are confronted with the task of dealing with different classification schemes at different points in their roadway network. Each State highway agency must understand the different classification schemes they use and develop conversion rules. For example, if the State uses the FHWA 13 classes but also utilizes length categories from inductance loops on urban freeways, it must develop appropriate length-based classification rules to make both schemes compatible.

To understand how different classification schemes relate to each other, the highway agency needs to periodically perform specific studies to determine the make-up of the different classification schemes. In the example above, WIM data that contain both axle spacing and overall vehicle length information can be used to determine how vehicles categorized with the FHWA 13-category scheme are placed within the vehicle length categories.

TRUCK WEIGHT DATA

The new TMG recommends changing the focus of the truck weight data collection program from collecting data at a random number of locations to adjusting the number of locations to fit the level of variability in truck weights. This is done in recognition of the major cost and difficulties involved in collecting accurate truck weight data. The objective of the new program recommendations is to ensure that each State collects accurate truck weight data to meet agency needs. This is accomplished by:

- defining truck weight roadway groups (so that each road within a group experiences truck weights per vehicle type that are similar to those of other roads within that group)
- collecting weight data from at least six sites within each group
- collecting data on the day-of-week and seasonal changes in vehicle weights that occur within each group
- paying specific attention to the calibration of the WIM equipment used for that data collection.

While structuring a truck weight program similarly to the volume and classification data programs would be preferable, (i.e., a few continuous count locations supported by a large number of geographically-dispersed short duration counts), the cost of weight data collection and the limitations in available equipment make such a design unrealistic. Instead, the program recommends collecting data at a relatively small number of locations designed to be representative of much larger groups of roads. The truck program design is similar to the continuous count elements for volume and vehicle classification. One major difference for the truck weight data collection program is that most of the weight monitoring sites need not operate continuously. The program is designed to ensure that current operational WIM sites become the base of the program. This base can be modified as needed to form the groups.

Truck Weight Roadway Groups

The TMG recommends that each State define its roadway system into "truck weight roadway groups," so that each road within a group experiences truck loading patterns (in terms of vehicle weights per vehicle, not total tonnage using the roadway) similar to those of other roads within that group. Further, it recommends using the characteristics of the freight moved on the roads to help create the roadway groups. This can be accomplished by understanding the type of commodities carried, the vehicles used, and the freight movement function performed by each road. (For example, does the road serve primarily as a through-truck route? Does it serve as a farm to market road? Does it provide access to specific types of heavy industry or mining areas? Does it serve conventional urban/suburban development patterns?)

Small, reasonably homogenous States (e.g., Rhode Island, Vermont) may only need one or two truck weight groups. For example, they might have roads with a large percentage of through-trucks versus roads that are primarily used for local freight movements. Large, diverse States (e.g., California, Texas) may have several different truck weight groups.

States are encouraged to adopt "truck weight groups" that:

- can be easily applied within the State
- can provide a logical means for discriminating between roads that are likely to have very high load factors and roads that have lower load factors.

The truck weight groups need not be the same groups that are used to create vehicle classification factoring. However, the information developed from the vehicle classification groups will be a great help in the development of the truck weight groups. The truck weight groups should follow the vehicle classification groups as much as possible. However, since the number of WIM sites will be much lower than the number of permanent classifiers, the number of truck weight groups will be lower.

The truck route grouping process should, as much as possible, incorporate knowledge about specific types of heavy trucks, so that roads that carry those heavy trucks are grouped together, and roads that are not likely to carry those trucks are treated separately. For example, roads leading to and from major ports might be treated separately from other roads in that same geographic area because of the high load factor that is common to port facilities. These "specialty roads" should be treated just as "recreational" routes are treated when continuous volume count information is collected (that is, as an important but "special" case).

Recommended Number, Length, and Location of Counts

Vehicle weights within each truck weight group should be measured by a number of WIM sites[5] located within the group. For most truck weight groups, a minimum of six sites should be monitored.

At least one of the WIM sites within each group should operate continuously throughout the year to measure temporal changes in the loads carried by trucks operating on those roads. Where possible, more locations within each group should be monitored continuously to provide a more reliable measure of seasonal change. The proper number of additional continuous sites is primarily a function of the State's ability to supply the resources needed to monitor those sites and the need to monitor differences in seasonal weight characteristics.[6]

The remaining WIM sites should be monitored for no less than 24 consecutive hours to account for time-of-day differences in vehicle weights. Data collection sessions of longer than 24 hours are encouraged whenever practical. In particular, when in-ground weight sensors are being used and the data collection electronics can be safely left to operate without on-site staff, a minimum of one-week counts are recommended at all measurement locations that are not being operated continuously.

Given the recommended data collection design, the size of any State's weight data collection program will be a function of the variability of the truck weights (the number of weight groups created) and the accuracy and precision desired to monitor and report on those weights (the more count locations measured within a weight group, the better the highway agency will understand the weights present on that group of roads.)

For a small State that has only two basic truck weight road groups, the basic recommendation would be for a minimum of about 12 weighing locations and two to four continuously operating weigh-in-motion sites. The number of locations can be further reduced by data-sharing agreements with neighboring States to collect "joint" vehicle weight data.

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[5] The exception would be for a specialized road. Just as "recreational" routes are often monitored with a single permanent counter location for volume factoring, a "specialty truck weight road" like that leading to a port may be monitored with a single WIM site.

[6] If the data collection shows that a group of roads has a very stable seasonal pattern, then relatively few continuous counters are needed to monitor the pattern. However, if the State has little data on seasonal weight patterns or if previous data collection has shown the pattern to be inconsistent within that group of roads, a larger number of continuous counters may be needed.

A large State with diverse trucking characteristics could have 10 or more distinct truck weight groups, and therefore 60 or more WIM sites, with a corresponding increase in the number of continuously operating WIM locations. Most States will have far fewer weight groups, at least as a starting point. The number of weighing locations in a State should fall somewhere between the extremes of 12 and 90 locations.

The truck weight monitoring locations cannot be selected in a random or even semi-random manner due to equipment and site selection considerations. Instead, the TMG recommends that each State start with its existing WIM sites and add sites as needed. A plan should be developed to establish the criteria for site selection.

When data collection at existing sites becomes inappropriate, because of pavement failure surrounding the WIM sensors or failure of the WIM equipment itself, or because weight data is no longer needed at that site, the plan should guide the decision to remove or maintain that site. At sites where data are still desired, the equipment should be reinstalled after any necessary pavement repair/rehabilitation takes place. Where a site is no longer necessary, the WIM equipment should be moved to a different site where either vehicle weights are not known or additional data are needed.

Highway agencies should collect WIM data at a variety of locations. This includes moving at least some data collection activity to new roads or new locations whenever the opportunity presents itself. In this fashion, insight can be continuously gained on the truck weight patterns found throughout the State. However, this desire for better geographic distribution of data collection sites must be balanced against equipment and resource limitations and the need to ensure that each site selected for WIM data collection has the physical attributes (flat, strong pavement in good condition with constant vehicle speeds) that allow for accurate WIM system operation.

Data Aggregation and Reporting

The collection of data without effective processing of the data and reporting of information to users reduces the value of the program. States need to improve the processing and analysis of their collected WIM data either by making use of appropriate software or developing it. The TMG contains specific recommendations for the development of load summary tables from the collected WIM data. The Vehicle Travel Information System (VTRIS) package developed by the FHWA allows easy analysis of current WIM data.

For each of the truck weight groups, State highway agencies should develop estimates of:

- average gross vehicle weights (GVW) by vehicle class
- axle load distributions by type of axle (single, tandem, tridem, etc.).

These summaries should then be made readily accessible to users so that this information gains widespread use. Widespread use will translate into more agency-wide support for the data collection activity and better transportation decisions. Of particular interest to many highway agencies will be the need to produce these types of loading estimates for the new AASHTO Pavement Design Guide currently under development.

Need for Calibration

Heavy emphasis is placed on the calibration of WIM data collection equipment. Quality information is more important than the quantity of data collected. It is far better to collect small amounts of well-calibrated data than to collect large amounts of data from poorly calibrated scales.

All equipment at WIM sites should be carefully calibrated before the actual collection of data. In addition to periodic re-calibration of continuously operating WIM equipment, highway agencies need to perform ongoing quality control functions for the data collected and processed. When questionable data are observed, the performance of that equipment must be investigated, and, if necessary, repairs made and new calibration efforts undertaken.

ACRONYMS

Acronym	**Meaning**
3S2	3-axle tractor with a 2-axle semi-trailer
ADT	Average Daily Traffic
AADT	Annual Average Daily Traffic
AADTT	Annual Average Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADUS	Archived Data User Service
ARTS	Advanced Rural Transportation Systems
ASTM	American Society for Testing and Materials
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
ATR	Automatic Continuous Traffic Recorder
AVC	Automatic Vehicle Classification
BMS	Bridge Management System
CAAA	Clean Air Act Amendments (1990)
CMS	Congestion Management System
CVC	Continuous Vehicle Classifier
CVO	Commercial Vehicle Operations
DVDT	Daily Vehicle Distance Traveled
EAL	Equivalent Axle Loading
EPA	Environmental Protection Agency
ESAL	Equivalent Single Axle Loading
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HPMS	Highway Performance Monitoring System
IRI	International Roughness Index
ISTEA	Intermodal Surface Transportation Efficiency Act (1991)
ITS	Intelligent Transportation Systems
LTPP	Long Term Pavement Performance
MADT	Monthly Average Daily Traffic
MPO	Metropolitan Planning Organization
NHS	National Highway System
OFE	Other Freeways and Expressways
OPA	Other Principal Arterial
PMS	Pavement Management System
PSR	Present Serviceability Rating
PTR	Permanent Traffic Recorder (another name for ATR)
SHRP	Strategic Highway Research Program
TEA21	Transportation Equity Act for the 21st Century
TMG	Traffic Monitoring Guide
TVT	Travel Volume Trends
TWS	Truck Weight Study

VDT	Vehicle Distance Traveled
VMT	Vehicle Miles Traveled
VTRIS	Vehicle Travel Information System
WIM	Weigh-in-Motion

Section 1

Overview Of The Traffic Monitoring Guide

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SECTION 1
OVERVIEW OF THE TRAFFIC MONITORING GUIDE

CHAPTER 1
OVERVIEW

The TMG is intended to be a statement of good practice. It is not to be considered a federal standard. Data collection agencies are encouraged to consider the methods presented here in their administration of traffic data collection programs and to compare the effectiveness of this methodology to the procedures they currently use.

This document provides general guidance on the development of traffic monitoring programs for highway agencies. Its focus is on the collection of traffic volume, vehicle classification, and weight information. The TMG is designed as a reference document. Readers are encouraged to use the Table of Contents to identify sections of interest and to turn directly to those sections. The Executive Summary highlights the most important aspects and recommendations. The main body is organized into six major sections. The contents of sections 2 through 6 are summarized below:

Section 2 introduces the basic parameters that affect the design and operation of traffic counting programs. This section includes a complete description of the variation found in traffic volumes and traffic characteristics, as well as the steps required to account for that variation when summary traffic statistics are developed. Section 2 presents a basic structure for collecting both short-term and continuous traffic data and describes how to use those data to improve the state’s knowledge of traffic flow and performance. This material is expanded upon in sections 3, 4, and 5.

Section 2 also discusses the inter-relationships among different aspects of the traffic monitoring system. It discusses how a State can coordinate all aspects of a statewide traffic monitoring program, as well as how to make use of data collected for purposes outside of the traffic monitoring effort. These integration efforts allow a State highway agency to increase the amount of traffic monitoring data available while reducing the overall cost of collecting those data.

Section 3 discusses traffic volume counting. This section focuses on the development of a complete traffic volume counting program, including provision of statistically valid traffic volume estimates and adjustment factors. These estimates are critical to both the reliability of information on traffic volumes and to the computation of many other variables, such as emission estimates, whose calculation are highly dependent on traffic volume estimates. Included in the section are discussions of the federal HPMS reporting requirements, other count programs required by highway agencies, the design of a continuous count program, and the development and application of the adjustment factors needed to meet the needs of each highway agency.

Section 4 covers vehicle classification counts. This section updates previously published federal guidelines for collecting and reporting statewide samples of volumes by vehicle classification. It describes the FHWA vehicle classification categories, describes when other classification schemes should be used, discusses the need for continuous vehicle classification counters, and provides guidance in selecting the appropriate number and location of these counters. Section 4 also gives directions for creating factor groups (and a factor process) that can be used to improve the accuracy of estimates of annual average volume by classification based on short duration counts.

Section 5 presents truck weight data collection information. It discusses the use of weigh-in-motion equipment and describes the reasons for carefully calibrating and managing this type of equipment. This section also updates the recommended sample design process for providing statewide truck weight information and presents reporting ideas that may help States use their truck weight information more effectively.

Section 6 presents the coordinated record formats for station identification, traffic volume, vehicle classification, and truck weight data.

CHAPTER 2
GUIDE OBJECTIVES

Beginning with statewide highway planning surveys of the 1930s, the collection of information on traffic volumes, vehicle types, and truck weights has become a significant portion of the work of highway planning programs in terms of both cost and personnel. Manuals and guides have been issued describing data collection procedures for each type of activity. In the past, each traffic data collection activity was approached as a unique endeavor. Decisions regarding the degree to which each activity should be pursued—for example, number of monitoring sites, duration of monitoring, time or season of year for data collection—have generally been determined by available funding, perceived need for the data, and the size of previous data gathering efforts rather than by a statistical analysis of what monitoring is necessary.

The FHWA has a history of improving the methodologies for monitoring the use of America's highways. In keeping with that history, this document provides guidance for improving traffic counting, vehicle classification, and truck weighing. Beyond simply providing ideas for updating these activities, the guide also provides statistical procedures that will allow the manager to determine how much monitoring is needed to achieve a desired precision level. The TMG and the traffic monitoring framework it describes can be used by all highway agencies, but its primary audience is State highway agencies.

To provide States, Metropolitan Planning Organizations (MPOs), and local highway agencies with information and guidance on monitoring vehicle travel, the guide has three major objectives.

The first objective is to relate the intensity of the monitoring effort to the quality of the information being reported to meet user defined needs. This relationship is achieved through the development of staged program design procedures. The procedures provided allow agencies to assess the ability to meet defined needs in an effective and efficient manner.

The second objective is to change the perception that traffic counting, vehicle classification, and truck weighing are separate activities. Instead, the guide emphasizes the ways in which these activities form a related set of traffic characteristic monitoring functions.

The third objective is to highlight the fact that a considerable number of traffic measurements are being or will be collected for reasons other than traditional traffic monitoring. In many cases, the groups collecting these data are not those traditionally responsible for traffic monitoring. By obtaining data from these non-traditional data sources, it is often possible both to improve the traffic estimates available to users and to reduce the traditional data collection effort in geographic areas covered by these new data sources.

The concept of the direct relationship among volume counts, vehicle classification counts, and truck weight measurements is a unifying element of the guide.

The TMG provides specific recommendations on the number, extent, and duration of monitoring efforts. The design of the data monitoring is set up in an integrated, interrelated, and hierarchical fashion. Truck weighing sessions are designed to provide vehicle classification and volume information, reducing the need for these counts. Vehicle classification counts, in turn, provide volume information. All of these data collection efforts are coordinated with operations, planning, and research efforts within or even outside the State. This "nesting" and coordination of effort leads to economies of operation, improved data availability, and benefits to all concerned.

CHAPTER 3
DATA USES

Traffic data are collected to describe the use and performance of the roadway system. These data are used in a variety of studies. The guide deals with the collection of three specific types of data—volume, vehicle classification, and truck weights—that describe different aspects of the traffic stream. Table 1-3-1 shows examples of the broad range of studies that depend on these types of data. This is not intended as a comprehensive list of data uses but rather is intended to portray the extensive utility of the data.

A variety of other traffic characteristics such as vehicle speeds and vehicle occupancies can also be monitored. These characteristics are not discussed directly within this report. However, activities associated with collecting these data are often a source of traffic volume information. Furthermore, when these additional types of data are required, they must often be reported in the context of traffic volumes and vehicle mix. Therefore, it is important to consider these additional data collection activities when designing the more "traditional" monitoring activities.

Table 1-3-1
Examples of Studies That Use Traffic Characteristics Data

Highway Activity	**Traffic Counting**	**Vehicle Classification**	**Truck Weighing**
Engineering	Highway Geometry	Pavement Design	Structural Design
Engineering Economy	Benefit of Highway Improvements	Cost of Vehicle Operation	Benefit of Truck Climbing Lane
Finance	Estimates of Road Revenue	Highway Cost Allocation	Weight Distance Taxes
Legislation	Selection of Highway Routes	Speed Limits and Oversize Vehicle Policy	Permit Policy for Overweight Vehicles
Maintenance	Selecting the Timing of Maintenance	Selection of Maintenance Activities	Design of Maintenance Actions
Operations	Signal Timing	Development of Control Strategies	Designation of Truck Routes
Planning	Location and Design of Highway Systems	Forecasts of Travel by Vehicle Type	Resurfacing Forecasts
Environmental Analysis	Air Quality Analysis	Forecasts of Emissions By Type of Vehicle	Noise Studies, NOX Emissions
Safety	Design of Traffic Control Systems and Accident Rates	Safety Conflicts Due to Vehicle Mix and Accident Rates	Posting of Bridges for Load Limits
Statistics	Average Daily Traffic	Travel by Vehicle Type	Weight Distance Traveled
Private Sector	Location of Service Areas	Marketing Keyed to Particular Vehicle Types	Trends in Freight Movement

Section 2

Introduction to Traffic Monitoring

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SECTION 2
INTRODUCTION TO TRAFFIC MONITORING

CHAPTER 1
INTRODUCTION

While a wide variety of measures can be collected to describe traffic, this report concentrates on the collection of traffic volume, vehicle classification, and truck weight data. No specific account is taken of vehicle speed monitoring, vehicle occupancy, accident and incident information, or a variety of other traffic measures that describe the performance of the roadway system.

This report presents a data collection framework that highway agencies can refine in order to implement a complete, cost-effective vehicle volume and weight monitoring program that meets the needs of local, State and federal traffic data users. To provide necessary background, this report describes the characteristics of the traffic stream that must be accounted for when collecting, manipulating, and reporting traffic information. Understanding and accounting for the variations that are present in the traffic stream is necessary if unbiased estimates of travel are to be developed and reported.

Even though the basic traffic stream characteristics are similar throughout the nation, each State's traffic collection and reporting needs are somewhat different. In addition, each State has a different set of political, organizational, and functional constraints. As a result, there is no single "traffic data collection plan" that adequately meets all States' needs. Instead, each State highway agency tends to create plans that fit its own unique circumstances. As a result, traffic monitoring programs differ substantially from State to State.

The TMG is designed to help States improve their traffic monitoring programs and ensure that data is available to meet the needs. Each highway agency should carefully consider the Highway Performance Monitoring System (HPMS) reporting requirements, as these data are used to produce the statewide estimates of total vehicle miles of travel (VMT) used for the apportionment of Federal-Aid funds. The HPMS sample does not cover all roadway sections and the HPMS volume data may be insufficient to meet all the data needs of a highway agency. The highway agency should develop a comprehensive data program to meet defined data collection requirements.

Ensuring a sufficient number of traffic volume counts to cover the system is not the only need. Vehicle classification data are extremely useful for many types of analyses, including pavement design, air quality, and maintenance, and most States are now collecting considerably more classification data than were suggested under previous guidelines. The need for vehicle classification data has outgrown the size of many current programs.

Once the State has defined its basic coverage program including the HPMS and other needs, it is possible to refine the "expanded" effort in order to reduce the total data collection effort required. The data collection sites can be refined in a number of ways, including the following:

- some short duration counts can be eliminated because other short duration counts satisfy the same needs
- some short duration counts can be replaced by permanent counters that are required for other purposes
- some volume counts can be replaced by vehicle classification counts, since vehicle classification counts provide total volume measurements as a by-product of the classification effort
- some classification counts (and consequently some volume counts) can be replaced by truck weight data collection efforts, since truck weight data collection results in both volume and volume by classification estimates
- some data collection locations can be moved slightly to allow a single data collection effort to meet multiple uses.

Examples of these refinements include the following:

- volume counts needed for the HPMS may be provided by a freeway surveillance system, thus eliminating the need to physically count that location with portable data collection equipment
- a count taken for the HPMS may be moved one mile to the south (without changing the basic characteristics of the roadway being monitored) to co-locate that count with a Long Term Pavement Performance (LTPP) test site at which vehicle classification data are collected year round. The HPMS volume count is then provided by the data already collected for LTPP, reducing the number of portable volume counts needed
- a State wishes to place a new permanent vehicle classifier to monitor truck volumes throughout the year. It decides to place that counter at an existing HPMS sample site to meet both the HPMS and permanent counter need.

By adding new count locations to meet user needs, integrating counting programs to reduce the total number of counts taken (while taking advantage of monitoring efforts put in place for a variety of reasons), and enhancing/refining of data collection efforts to ensure that all needs are met; a better traffic monitoring program and reduced data collection costs will result.

To successfully integrate and refine data collection efforts, it is important to understand:

- the variability present in traffic
- the types of data collection efforts needed to measure and account for this variability
- the equipment technology available to collect these data

- the various traffic data collection programs that exist within a State
- the data needs and reporting requirements.

These issues are discussed in the remaining chapters of this section. In addition, an appendix describes data collection for Intelligent Transportation Systems projects and how these data can be integrated within the structure of the statewide traffic monitoring program.

CHAPTER 2
VARIABILITY IN THE TRAFFIC STREAM

Traffic varies over time. This is an obvious statement, but only recently has the availability of modern technology allowed States to collect enough data to begin to understand just how traffic varies over time (Wright et al, 1997). Traffic varies over a number of different time scales, including:

- time of day
- day of week
- season (month) of the year.

Traffic also varies from place to place. Not only do roads carry different volumes of traffic, but the characteristics of the vehicles using those roads change from facility to facility. One road with 5,000 vehicles per day may have hardly any truck traffic, while another road with the same volume of vehicles may have 1,000 trucks per day mixed in with 4,000 cars. Similarly, one road section may be traversed by 1,000 heavily loaded trucks per day while a nearby road is used by 1,000 partially loaded trucks.

It is necessary to understand and be able to monitor all of these differences in travel to make correct decisions about the design, operation, and maintenance of roadways. This chapter discusses the variation present in the traffic stream. The next chapter discusses the data collection necessary to monitor and account for the variation.

INTRODUCTION

One of the most significant differences between this version of the Traffic Monitoring Guide and previous versions is the attempt to directly account for differences in traffic variation by type of vehicle. Research has shown that truck volumes vary over time and space differently than car volumes (Hallenbeck et al 1997). In fact, these variations can be quite different from one type of truck to another. In addition, the characteristics of specific truck types, especially vehicle weights, can change dramatically from time period to time period and location to location, even within a given truck classification. It is therefore important that each State develop mechanisms within their statewide traffic monitoring program that measure these variations, so that they can be accounted for within the data reporting and analysis process.

TIME-OF-DAY VARIATION

Since the early development of roads, it has been known that the use of a road changes during the course of the day. In most locations, traffic volumes increase during the day and decrease at night. A 1997 study for the Federal Highway Administration (Hallenbeck et al 1997) calculated general time of data distributions by vehicle type, based on traffic data collected for the Long Term Pavement Performance study. This study found the following facts:

Most truck travel falls into one of two basic time-of-day patterns. Most passenger car travel also falls into one of two time-of-day patterns, but these patterns are different than those of trucks. These four patterns are illustrated in Figure 2-2-1.

Cars tend to follow either the traditional two-humped urban commute pattern or the single-hump pattern commonly seen in rural areas, where traffic volumes continue to grow throughout the day until they begin to taper off in the evening. Trucks also have a single-hump pattern. However, the truck pattern differs from the rural car pattern in that it peaks in the early morning (many trucks are used to make deliveries early in the morning to help prepare businesses for the coming work day) and tapers off gradually, until early afternoon, when it declines quickly. In addition, some types of trucks follow a very different time-of-day pattern. These trucks, usually involved in hauling freight long distances, travel constantly throughout the day.

The traffic at any given site comprises some combination of these types of movements. In addition, at any specific location, time-of-day patterns differ significantly as a result of local trip generation patterns that differ from the "norm. " For example, Las Vegas, Nevada, generates an "abnormal" amount of traffic during the night, because that city is very active late at night. Local patterns also have a significant effect on the directional time-of-day pattern for any given road.

Because the volumes of cars and trucks often are very different, the effect of these different time-of-day patterns on summary statistics such as "percent trucks" and "total volume" can be unexpected. Often, in daylight hours car volumes are so high in comparison to truck volumes that the car travel pattern dominates, and the percentage of trucks is very low. However, at night on that same roadway, car volumes may decrease significantly while through-truck movements continue, so that the truck percentage increases considerably, and total volume declines less that the car pattern would predict. Figure 2-2-2 shows how typical values of truck percentages change during the day for urban and rural settings on both weekdays and weekends.

Because these changes can be so significant, it is important to account for them in the design and execution of the traffic monitoring program, as well as in the computation and reporting of summary statistics.

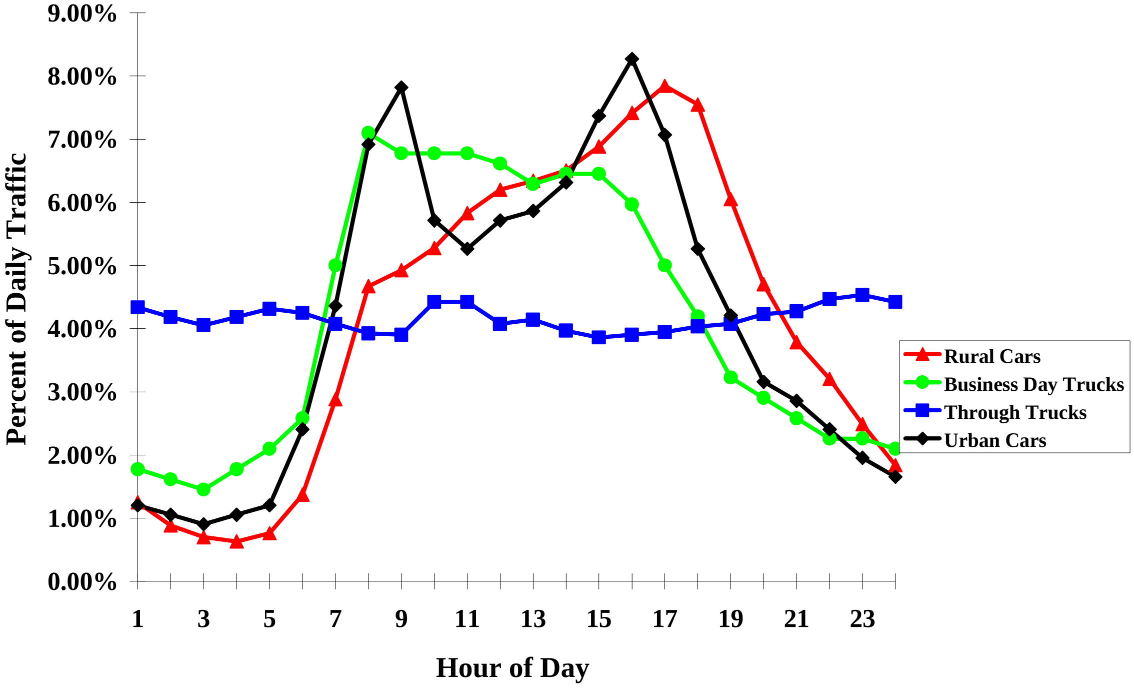

Figure 2-2-1
Basic Time of Day Patterns

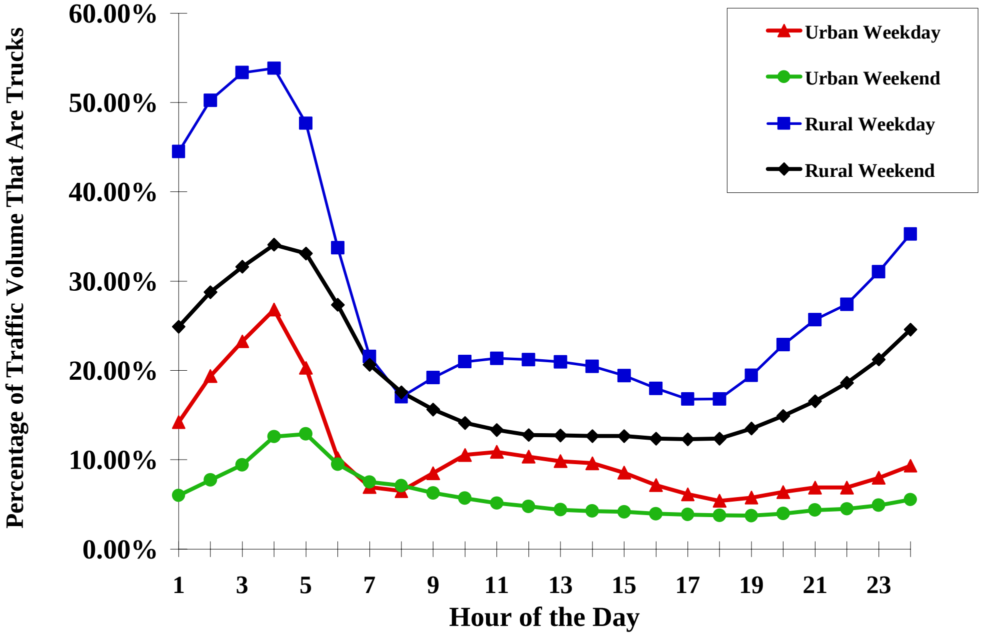

Figure 2-2-2
Weekday/Weekend Truck Percentages

DAY-OF-WEEK VARIATION

Time-of-day patterns are not the only way in which car and truck patterns differ. Day-of-week patterns also differ, in large part because of the use of cars for a variety of non-business related traffic, whereas, for the most part, trucks travel only when business needs require it.

As with time-of-day patterns, day-of-week patterns for cars fall into one of two basic patterns as shown in Figure 2-2-3. In the first pattern (traditional urban), volumes are fairly constant during weekdays and then decline slightly on the weekends, with Sunday volumes usually being lower than Saturday volumes. This pattern also exists on many rural roads. The other pattern, usually found in rural areas that contain recreational travel, shows constant weekday volumes followed by an increase in traffic on the weekends.

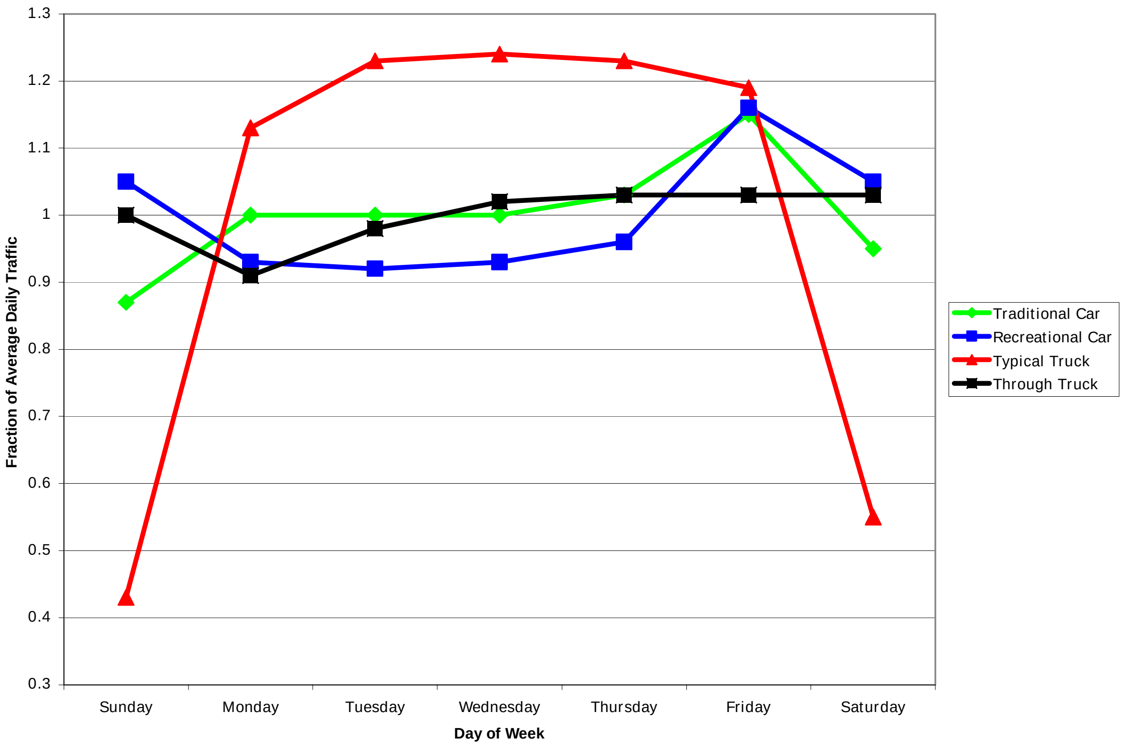

Figure 2-2-3
Typical Day-of-Week Traffic Patterns

Trucks also have two patterns, both driven by the needs of businesses. Most trucks follow an exaggerated version of the "traditional urban" car pattern. That is, weekday truck volumes are fairly constant, but on weekends, truck volumes decline considerably more than car volumes (unlike cars, the decline in truck travel caused by lower weekend business activity is usually not balanced by an increase in truck travel for other purposes). However, as with the time-of-day pattern, long-haul "through" trucks often show a very different day-of-week pattern. Since long-haul trucks are not concerned with the "business day" (they travel as often as driver schedules allow), they travel equally on all seven days of the week. Thus, roads with high percentages of through-truck traffic often maintain high truck volumes during the weekends, even though the local truck traffic declines.[1] This pattern is "visible" in truck volume counts only when through-truck traffic is a high percentage of total truck volume. More commonly what happens is that weekend truck volumes do not drop as precipitously as they do at sites where little through-truck traffic exists.

These significant changes in traffic volumes during the course of the week have several effects on the traffic monitoring program. Most importantly, the monitoring program needs to collect data that allow a State to describe these variations. Second, the monitoring program must allow this knowledge to be shared with the users of the traffic data and applied to individual locations.

Without these two steps, many of the analyses performed with traffic monitoring data will be inaccurate. Pavement designers need to account for reductions in truck traffic on the weekends if they are to accurately predict annual loading rates. Likewise, accident rate comparisons for different vehicle classifications are not realistic unless these differences are accounted for in estimates of vehicle-miles-travel by class.

SEASONAL VARIATION

Further complicating the analysis of temporal variation in traffic patterns is the fact that both car and truck traffic change over the course of the year. Seasonal changes in total volume have been tracked for many years with permanent counters, traditionally called Automatic Traffic Recorders (ATRs). Total volume patterns from these devices show a variety of patterns, including common patterns such as the "flat urban" and "rural summer peak" shown in Figure 2-2-4. The figure is abstracted from the report "Vehicle Volume Distributions by Classification" included in the refereces.

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[1] Note that through-truck traffic is still normally generated during "normal business hours." Thus, through-traffic generated from any one geographic location has the same "5-day on, 2-day off" pattern seen in the "local truck" pattern. Where a road carries through-truck traffic from a single dominant area, the two-day lag in truck volumes is often apparent. However, the lag appears at some other time in the week.

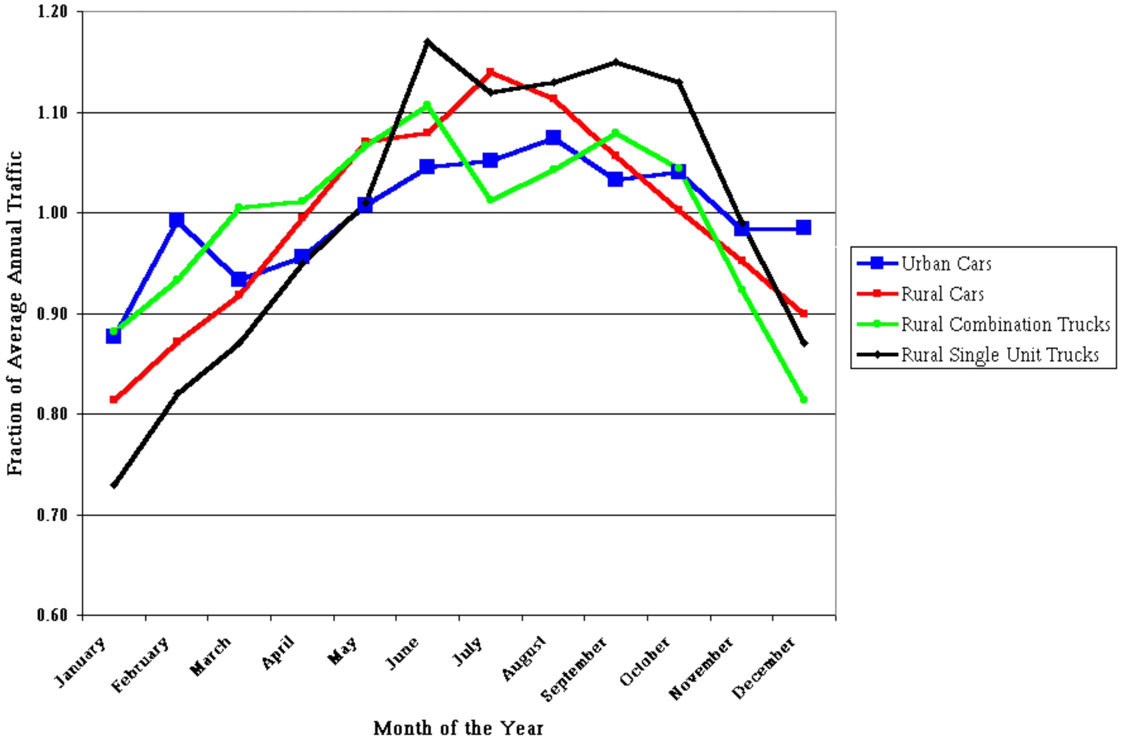

Figure 2-2-4
Typical Monthly Volume Patterns

Most States track four or more seasonal patterns, and they base the patterns being followed on some combination of functional classification of roadway and geographic location. Geography and functional classification are used as readily available surrogate measures that describe roads that follow that basic pattern. Geographic stratification is particularly important when different parts of a State experience very different travel behavior. For example, travel in areas that experience heavy recreational movements follow different travel patterns than those in areas without such movements. Even in urban areas where travel is more constant year round, cities with heavy recreational activity have different patterns than cities in the same State without heavy recreational movements.

Not surprisingly, truck traffic has seasonal patterns that are different than automobile patterns. Some truck movements (often defined by specific types of trucks operating in specific corridors or regions) are stable throughout the year. Other truck movements are highly seasonal, for example in agricultural areas. It has even been shown that the weights carried by some trucks vary by season. This is particularly true in States where seasonal load restrictions are placed on roads and where weight limits are increased during some winter months.

As with day-of-week patterns, tracking of seasonal changes in volumes is necessary to calculate adjustments needed for various analyses. If annual statistics are needed for an analysis, it is necessary to adjust a short duration traffic volume count taken in mid-August to account for the fact that August traffic differs from the average annual condition. Exceptions exist such as Phoenix, where the influx of winter visitors causes August to be a lower volume month relative to the average condition.

Recent research has shown that seasonal monitoring and adjustment must be done separately for trucks and cars (Hallenbeck et al 1997). Truck volume patterns can vary considerably from car volume patterns. Roads that carry significant volumes of through-trucks tend to have very different seasonal patterns than roads that carry predominately local freight traffic. Roads that carry large volumes of recreational traffic often do not experience similarly large increases in truck traffic, but do often experience major increases in the number of recreational vehicles which share many characteristics with trucks.

Thus, it is highly recommended that States monitor and account for seasonal variation in truck traffic directly, and that these procedures be independent of the procedures used to account for variations in car volume.

DIRECTIONAL VARIATION

Not all variation is temporal. Most roads exhibit differences in flow by direction. The traditional urban commute involves a heavy inbound movement in the morning and an outbound movement in the afternoon. On many suburban roads, this directional behavior has disappeared, replaced by heavy peak movements in both directions in both peak periods. When these directional movements are combined, the time-of-day pattern shown in Figure 2-2-1 still holds, but when looked at separately, new time-of-day patterns become apparent.

In areas with high recreational traffic flows, directional movements change the day-of-week traffic patterns as much as the time-of-day patterns. Travelers often arrive in the area starting late Thursday night and depart on Sunday.

Truck volumes and characteristics can also change by direction. One “classic” example of directional differences in trucks is the movement of loaded trucks in one direction along a road, with a return movement of empty trucks. This is often the case in regions where mineral resources are extracted. Volumes by vehicle classification can also change from one direction to another, for example when loaded logging trucks (classified as 5-axle tractor semi-trailers) move in one direction, and unloaded logging trucks (which carry the trailer dollies on the tractor and are classified as 3-axle single units) move in the other.

Tracking these directional movements as part of the statewide monitoring program is important not only for planning, design, and operation of existing roadways, but as an important supplement to the knowledge base needed to estimate the impacts that new development will generate in previously undeveloped, rural lands.

GEOGRAPHIC VARIATION

The last type of variation discussed in this chapter is that caused by locational differences in roadways. This type of differentiation is taken for granted for traffic volumes. Some roads simply carry more vehicles than others. This concept is readily expanded to encompass the notion discussed above, that many of the basic traffic volume patterns are geographically affected (California ski areas have different travel patterns than California beach highways). It is important to extend these concepts even further to recognize that truck travel also varies from route to route and region to region. It is just as important to realize that differences in truck travel can occur irrespective of differences in automobile traffic.

One of the growing areas of interest in traffic monitoring is the creation of truck flow maps and/or tonnage maps. These maps, analogous to traffic flow maps, show where truck and freight movements are heaviest. This is important for:

- prioritizing maintenance and roadway improvement funding
- instituting of geometric and pavement design and maintenance guidelines that account for expected traffic
- studying the effects of regulatory changes in freight and good movements (such as the abandonment of existing freight rail lines).

When these truck flow maps are developed, they often reveal that truck routes exist, irrespective of the traffic flow and/or the functional classification of the roads involved. Trucks use specific routes because those roads lead from the trucks' origin to their destination, and the route has (one hopes) sufficient geometric capacity to accommodate those trucks. Truck drivers do not select routes because they are designated as a "rural principal arterials." They select them because they are convenient for their trip.

In fact, functional classification is a very poor predictor of truck volume or percentage. As an example, Interstates that serve major through movements (even in urban areas) tend to have high truck volumes, but Interstates that do not service major freight movements tend to have very low truck volumes.

Because truck flows (both truck volumes and weights) play such an important (and growing) role in highway engineering functions, it is vital that States collect truck volume data that describe the geographic changes that exist. Which roads carry large freight movements? Which roads carry large truck volumes, even if those volumes are a small percentage of total traffic volume? And which roads restrict or carry light volumes of freight?

CHAPTER 3
DATA COLLECTION DESIGN ACCOUNTING FOR VARIABILITY

The variability described above must be measured and accounted for in the data collection and reporting program a State designs and implements. The data collection program must also identify changes in these traffic patterns as they occur over time. In some cases, observed changes will indicate that the State needs to refine its data monitoring process to better estimate traffic conditions on its roads. (For example, a State may discover that it needs to refine its continuous count and factoring programs in order to account for traffic patterns that it had not previously known about.)

In general, to monitor traffic at the statewide level the recommended data collection plan consists of:

- a modest number of permanent, continuously operating, data collection sites, and
- a large number of short duration data collection efforts.

The permanent data collection sites provide knowledge of seasonal and day-of-week trends. The summarization of the continuously collected data allows the development of adjustment factors needed to convert short count data (data collected for one or two days) into estimates of “annual average” or “design” conditions. Continuous count summaries also provide very precise measurements of changes in travel volumes and characteristics at a limited number of locations.

The short duration counts provide the geographic coverage needed to understand traffic characteristics on individual roadways, as well as on specific segments of those roadways. Traffic volumes tend to vary dramatically from one location to another. Because permanent counters are expensive to install, operate, and maintain, short duration counts are needed on roads throughout the State to provide accurate measurements of traffic conditions on individual roadway sections. These short duration counts are then adjusted to represent annual or design conditions given the patterns measured at the continuous count locations.

Determining where to place continuous counters and how to use the available continuous count data to create reliable short count adjustments are two of the hardest tasks in creating an effective statewide traffic monitoring program. General guidelines for developing and/or modifying this process are included later in this chapter. Specific examples are presented in chapters 3, 4, and 5.

INTEGRATION OF DATA COLLECTION EFFORTS

A well-designed data collection program takes advantage of the fact that sophisticated traffic monitoring equipment can often provide more than one type of data at a time. For example, permanently installed sensors and electronics at a WIM site can be used for continuous vehicle classification and volume data collection even when weight data are not collected. Thus, a continuously operating WIM scale can serve three purposes, reducing the need to place and operate additional data collection devices. This ability to simultaneously collect all three types of traditional traffic monitoring data is called “nesting” traffic counts.

Table 2-3-1

Types of Data Provided By Different Types of Data Collection Devices

Type of Data Provided	WIM Scale	Vehicle Classifier	Volume Counter
Axle and/or Gross Vehicle Weight	X		
Volumes By Type of Vehicle	X	X	
Volume of Vehicles	X	X	X

When used appropriately, this ability to “nest” data collection activities allows a State to either reduce the number of continuous data collection sites it operates or increase the number of data available for monitoring traffic patterns. However, “nesting” is not restricted to traditional classification and weight data collection. A variety of traffic monitoring activities, including vehicle speed monitoring, traffic management activities, toll collection devices, and incident detection sensors, can provide traffic volume information.

A well-designed, efficient traffic monitoring program also takes advantage of traffic data collected by other agencies within the State. For example, truck weights and volumes may be monitored at the State’s borders by the agency in charge of collecting or enforcing the collection of truck fuel taxes. Within the State highway agency, the research office may collect truck weight data as part of specific research projects, while the planning section may collect vehicle weights to meet truck size and weight data needs.

By obtaining, summarizing, and distributing these data, it is possible to increase the availability of traffic monitoring information while decreasing the total cost of monitoring traffic. For example, the weight data collected from the research and enforcement sources mentioned above may be able to supplement or replace truck weight data collected by the planning agency. However, it is important to realize that data collected for specific purposes must be obtained and used with care, as that purpose may bias the data in some fashion. For example, a truck scale placed just upstream of a weight enforcement scale (in order to improve the efficiency of weight enforcement officers) may not produce vehicle weights that are representative of the weights found on other roads in the State. The data at this location may be biased if illegally loaded trucks are able to by-pass the enforcement scale. However, even if they are slightly biased, the enforcement scale data do give an excellent measure of the vehicle weights on the road leading to that scale (useful for any pavement rehabilitation project on that roadway section), as well as an excellent measure of the seasonal changes in volumes and weights associated with roads affected by that enforcement site.

Another example of how integration can assist a statewide traffic monitoring effort is that many local jurisdictions (counties and cities) are installing and operating permanent traffic counters (both volume-only counters and vehicle classification counters). Data from these devices can be used to supplement the permanent counters operated by the State highway agency. They provide additional information on seasonal travel patterns in areas where monitoring those patterns is important.

Often, different groups within a State highway agency monitor traffic for their own purposes. These data collection efforts can include everything from counts for specific project purposes (data collected for pavement or geometric design), to special studies that respond to legislative requirements or policy concerns (the tracking of HOV lane usage), to fully staffed traffic surveillance centers created to help manage traffic on road sections of major importance (mountain passes, major tunnels and bridges).

In many cases, obtaining these data (or summaries) from others' data collection efforts can significantly reduce the data collection burden and/or inexpensively provide data to users who would not otherwise have them. The Intelligent Transportation Systems (ITS) efforts under way in many States offer a potential bonanza in traffic monitoring data. It is up to the highway agency personnel to make sure that these data are captured and put to use. Appendix A describes the steps needed to make this happen.

CONTINUOUS COUNTS

Most States have established continuous count programs. The original intent of most continuous monitoring efforts was to understand seasonal, day-of-week, and time-of-day traffic volume patterns to help improve the accuracy of traffic estimates used in a variety of analyses. As data collection equipment has improved and traffic data needs have changed over time, continuous traffic data collection programs have evolved. Many continuous collection efforts now produce data that are not routinely used for these traditional purposes. Instead, for example, continuous data can be used as input for traffic management systems and other operational purposes. In many cases, continuously collected data are not even saved but are used in real time and then discarded. **A State that recognizes that these data collection efforts exist and is able to cost-effectively capture, summarize, and use these data can significantly improve the quality of its traffic monitoring information at relatively low marginal cost.**

The most common continuous traffic monitoring data collection programs in use today include the following:

- automatic traffic recorders (ATRs)
- automatic, continuous vehicle classifiers used to supplement the ATR program (often abbreviated AVC or CVC)
- continuously operating weigh-in-motion (WIM) scales placed to monitor statewide trends in vehicle weights
- continuous vehicle classifiers or WIM scales used to provide load information to the Long Term Pavement Performance (LTPP) study of the Strategic Highway Research Program (SHRP)
- continuously operating WIM scales used to identify trucks that need to be weighed statically at an enforcement scale
- volume and speed monitoring stations that provide facility performance data to traffic management systems.

The subsections below describe the basic intent and functioning of each of the above programs and how data from each program can fit into a statewide traffic monitoring program. Additional continuous count programs exist in some States. Each of these programs is designed to meet other needs and can produce data useful to a statewide traffic monitoring program.

Automatic Traffic Recorders

When most traffic data collection professionals think about "continuous data collection," they think of automatic traffic recorders (ATR). These devices (most incorporating inductance loop detectors) have been used for many years to monitor traffic at specific locations and to produce the factors applied to short duration traffic volume counts in order to estimate annual average traffic volume conditions.

ATR data are commonly stored on site as hourly volumes by lane and are downloaded periodically (daily, weekly, or monthly) to a central location. At the central location, the data are checked for quality, summarized, and stored for later use. The summary and raw values are then made available to data users within the Department. Among the summary volume statistics that are routinely reported are the following:

- annual average daily traffic at the site (AADT)
- annual average weekday traffic at the site (AAWDT)
- seasonal adjustment factors
- day-of-week adjustment factors
- 30th highest annual hourly volume as a fraction of AADT
- 100th highest annual hourly volume as a fraction of AADT
- lane distribution factors
- growth trends at that location.

Data from multiple ATRs are usually averaged to compute "representative" factors, which are then used to adjust short-term count data from a variety of locations in order to convert those short duration counts into estimates of “annual,” “design,” or “average” conditions. The grouping process is described in Chapter 4.

ATRs are placed at locations throughout the State for a variety of reasons. In many cases, ATR locations are selected to measure specific trends. This is often the case where it is important to monitor a given traffic movement with a high degree of accuracy (for example, on a road of particular importance), or where a specific location provides an accurate measure of traffic activity for a larger, well defined group of roads (e.g., the one road leading into a major recreational area).

Some ATR sites exist because the State has historically monitored trends at specific locations. The reasons those locations were initially selected may or may not be currently known. In addition, the reasons some of those sites were initially selected may no longer be true or applicable, but the fact that a long history of data exist at these locations provides a reason for the continuing efforts to collect data at those locations. (That is, the long-term trend information is valuable in its own right, regardless of the other purposes that site may no longer serve.)

Many other ATR locations are selected semi-randomly, as part of an effort to monitor general travel trends within specific categories of roads. For example, there may be interest in monitoring traffic trends on rural Interstates that travel east/west across the State. Consequently, a specific location from the road sections that fit within that criterion may be selected randomly. A second example might use much less restrictive criteria, such as some combination of the functional classification of the road, the geographic location of the roadway (e.g., the northeast part of the State), or the availability of power and/or telecommunications access to locate the counter so that sufficient numbers of sites are within a given factor group.

<u>Statewide Continuous Vehicle Classification Sites</u>

Many States have begun to expand their continuous count programs to include continuous vehicle classifiers as a result of the development of affordable equipment that can perform this task and from a growing understanding of the importance of truck volume and load information. The results of many traffic analyses are more dependent on truck volumes than they are on total traffic volumes. For example, the depth of a pavement design is primarily affected by the number and weight of heavy vehicles (and particularly their axle weights) using that road section (given soil and weather conditions) and is virtually unaffected by the total number of vehicles crossing that section.

Given the importance of truck information, the need for continuous vehicle classifiers becomes clear with the realization that truck traffic often follows different seasonal and day-of-week trends than do total volumes, which tend to be dominated by automobile traffic. If truck movement patterns are to be understood and accounted for in the traffic monitoring and data analysis efforts, then monitoring volumes by vehicle classification becomes necessary.

Continuously operating vehicle classifiers allow the monitoring of changes in truck volumes and changes in vehicle fleet mix (the percentage of travel by specific vehicle types) to be tracked over time. Other important analyses supported by continuous classification equipment include the following:

- the size of seasonal commodity movements (e.g., how many truck trips are generated on roads in agricultural areas during the harvest season)
- the seasonal fluctuations in truck travel on roads not significantly affected by well defined seasonal commodity movements
- trends in annual truck volumes on specific roadways (nationally, truck travel has grown faster than car travel)
- day-of-week traffic patterns for trucks as opposed to cars
- the lane distribution patterns of trucks.

Continuously operating vehicle classifiers use a variety of technologies. The two most common are axle classifiers and length classifiers. Axle classifiers use a combination of sensors[2] to record the number of vehicles in various categories. The vehicle classification categories are defined by the number and location of axles for each vehicle. Length classifiers usually use dual inductance loops to measure the total length of passing vehicles, which is then used to classify each passing vehicle.

The FHWA standard classification scheme requires the use of axle-based classifiers to categorize vehicles into 13 classes. However, to be useful within the context of a statewide traffic monitoring program, not all continuous classifiers need to be capable of reporting vehicle volumes in these categories. For some analyses three or four vehicle categories are sufficient. In some locations the use of 13 vehicle categories makes volumes within particular vehicle categories so low that the volume estimates become statistically unreliable. It is appropriate in both of these cases to aggregate vehicle categories in order to produce reliable, useful volume estimates by vehicle class. (See Section 4 for an explanation of alternative vehicle classification schemes, their relation to the FHWA 13-category classification scheme, and the application of these alternative schemes and data collection devices within a statewide traffic monitoring program.)

A State may operate different types of vehicle classifiers in different locations. For example, in urban freeway environments, dual loop detectors are used to monitor vehicle speeds as part of freeway management systems. These detectors can provide measurements of total truck volumes by vehicle length category. At the same time, the State may operate a series of axle-sensor-based vehicle classifiers in rural areas to track changes in commodity movements. Both of these data sets add considerably to the knowledge of the movement of freight and goods on State roadways. However, care and skill are required when data from both of these sources are combined.

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[2] Among the more common vehicle classifier configurations are two inductance loops in series (providing measures of vehicle length), two axle sensors in series (providing axle count and spacing information), two axle sensors with an inductance loop (providing an improved measure of axle counts and spacing), and video image processing.

As with ATRs, the location (and initial purpose) of the continuously operating classifiers can be chosen for one of several reasons. The location of some classifiers is based on the need for truck data on specific roads or for specific commodity movements. Other continuous classifier locations are based on the need to collect data for specific pavement sections (see LTPP Sites below), while others are selected to meet statewide monitoring needs, such as the creation of truck factor groups. Finally, in some cases, such as the urban freeway example sited above, truck volume information is a serendipitous extra that results from data collection performed for very different purposes.

In all of these cases, the continuous classification data can and should be used by the State to meet a variety of needs. However, not all of these data are of the same quality, and the fact that some of these sites exist for purposes other than "traditional" statewide monitoring means that some caution must be used when the data from these sites are used for "statewide" analyses. For example, if, because of a freeway management system, 20 locations in one urban area provide truck data and only five other urban locations in the state have continuous truck counts, averaging seasonal patterns from the available data to produce a "statewide urban adjustment factor" will result in an estimate that is heavily biased toward the traffic patterns in that one urban area.

It is important to note that vehicle classifiers also provide the same data as ATRs. That is, by simply combining all vehicle categories, a continuous classifier provides continuous total volume estimates. Thus, a classifier can replace a conventional ATR location while providing more beneficial data. Consequently, when States periodically replace or update existing ATRs, they should consider upgrading them to continuous vehicle classifiers. In addition, where classifiers are placed independently from the ATR system, the State should look to supplement its existing ATR system with data obtained from the continuous vehicle classifiers. That is, volume data from the classifiers may be used to add information to the computation of volume factors estimated with ATR data.

LTPP Sites

One specific set of continuous WIM and/or AVC site locations was created to meet the data needs of the Long Term Pavement Performance project. LTPP is a national research project studying the causes of pavement deterioration and the effects of different pavement and maintenance designs. As part of this research project, States were requested to collect continuous vehicle classification and WIM data at specific LTPP test sites. This data collection effort was intended to accurately measure the traffic loads that are being applied to particular pavement sections. It is very important to LTPP that the changes in loading patterns occurring over the course of a year be measured and included in the loading estimates used in the LTPP analyses.

As a result of this program, many States are now operating permanent vehicle classifiers and/or WIM scales at a number of LTPP test sites. The problem with data collected for LTPP is that States have little flexibility in choosing the location of the sites at which LTPP vehicle classification data are collected. Many of these data collection sites are not where the State would prefer to collect vehicle classification or WIM data as part of a statewide traffic monitoring effort. However, when properly installed, calibrated, and maintained, these sites can contribute valuable data. Because relatively little is known about the variation in truck loads over time on different types of roads in different parts of most States, data from the LTPP sites can add significantly to the understanding of how truck loads change over time. They are particularly useful in helping to assess the types of variation that occur in truck weights during the year and across different roads within the State.

Most States are only beginning to understand the movement of trucks on highways during different times of the year. Data obtained from LTPP sites add considerably to that understanding, even when those sites are not located at "traditional" ATR sites. Weight data are necessary for converting truck volumes into the axle load estimates needed as an input to pavement design and maintenance procedures. In addition to truck and axle weight information, continuously operating WIM scales are also capable of providing the same data as continuous vehicle classifiers and ATRs. That is, a WIM scale counts as well as weighs all of the vehicles crossing the scale. Thus, it can serve as one more site for monitoring volume trends for both cars and trucks.

Coordinating the LTPP data with the statewide monitoring effort is often made more difficult by the fact that in a number of States, LTPP equipment is operated by "research office" personnel rather than "statewide traffic monitoring" personnel. As a result, the LTPP data are often not included in the statewide traffic database. Because these are "research sites," the data are simply collected and shipped to LTPP. They are not summarized and added to the traffic database commonly available to all users. This prevents their being used in a vast number of analyses, including helping define new factor groups specifically aimed at truck volumes.

WIM Scales at Enforcement Sites

Other sources of continuous WIM data are 24-hour port-of-entry operations and other WIM scales that operate continuously upstream of static enforcement scales. At these sites, all trucks are weighed, paperwork may be inspected, and safety checks may be conducted. Many enforcement sites now use WIM scales to sort potentially overweight trucks from trucks carrying loads that are lower than the legal limit. This sorting function speeds up the enforcement process by reducing the number of trucks that must be statically weighed. These same data, if stored, can be used for many other purposes. However, because they are collected in conjunction with enforcement activity, the State must be careful to ensure that these data are not biased measures of actual truck weights. (That is, because truckers are aware that enforcement is taking place, many trucks that are illegally loaded will avoid these scales. Because illegally loaded trucks avoid enforcement scales when possible, the data collected are often not representative of the "complete" trucking population. The data may underestimate the number of very heavily loaded vehicles.) Enforcement site evasion is not a problem for all sites. For example, in many western States, there are few or no by-pass routes around port of entry scales.

Thus, the scale collects a true measure of the truck and axle weights passing through. States should be aware of both the potential for bias and the potential knowledge that can be gained from WIM scales at enforcement sites before such data are either discarded or routinely used.

Statewide Weigh-in-Motion Sites

Many States operate WIM scales that are related to neither LTPP nor enforcement as part of their statewide monitoring program. These sites are selected semi-randomly to be representative of specific parts of the State's highway network. (WIM sites cannot be selected in a purely random fashion because WIM equipment only works accurately[3] on level ground, with good pavement, and with little or no roadway curvature. This eliminates many potential roadway segments from consideration for truck weight data collection locations.) In addition, because WIM equipment is fairly expensive to purchase, install, maintain, and operate, many States cannot afford a large number of these sites. Thus, the "semi-random" locations tend to be heavily oriented toward strategic locations that provide data of high value to the States rather than completely random selections aimed at ensuring statistical purity. These sites can be particularly useful in describing the variability of the "most important" truck routes in the State.

Where no better data exist, these "important" sites, along with unbiased data from LTPP and enforcement locations, must serve as the basis for understanding the weights of an area's truck population. Even when these data collection efforts are imperfect, highway agency personnel must understand that the availability of data and an understanding of their limitations allow much more informed decision-making than a total lack of information.

Traffic Operations Data

Many States have installed sensors to collect real-time surveillance data for traffic management purposes. Much of this equipment can be classified as part of the ITS deployment.

Because many new sensors are being marketed as a result of ITS, and because each ITS traffic management system tends to incorporate slightly different traffic performance inputs, it is difficult to generalize the types of traffic data that can be available from ITS traffic management systems. However, most traffic management systems provide estimates of vehicle volumes and speeds, and some provide simplified vehicle classification information. ITS management systems tend to operate year-round, and thus, many traffic management systems can be viewed as equivalent to ATRs or continuous vehicle classifiers.

Unfortunately, traffic management system data have traditionally not been used effectively for general traffic monitoring purposes. In some cases, the data are collected

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[3] That is, accurately predicts static axle weights.

in "real time" (e.g., 20-second intervals) and then discarded. In other cases the data are stored but are not reported or made available in a useable form to other data users. Often the data are collected by an operations group within the State highway agency but not reported to the traffic monitoring office.

As traffic congestion grows and States turn to increasingly sophisticated traffic management systems to ease the effects of that congestion, the availability of traffic surveillance data from these systems will expand. Collecting and using traffic surveillance data provides a considerable resource that can be used to describe the traffic volume, the nature of the traffic, and in many cases the performance of that traffic (the frequency of congestion, peak periods, the effect of incidents, etc.).

These same data allow the highway agency to produce traditional engineering statistics traditionally obtained from ATRs such as seasonal factors, day-of-week adjustment factors, peak hour factors, and AADT. In fact, these systems can replace the need for "stand alone" ATRs in urban areas that contain traffic management systems. The keys to using these data are in the development of data storage, retrieval, and aggregation software and hardware systems that make the data available to users outside of the operations community.

SITE SELECTION FOR CONTINUOUS COUNTERS

Most States (and some local jurisdictions) have already placed many continuous counters. Because these counters are expensive to move, the primary issue for continuous counters is not where to locate them but how best to use the data that come from these counters to develop short count adjustment factors. This use of permanent counters for factor development is discussed in Chapter 4.

The recommended procedure for designing the continuous count portion of the statewide monitoring program is given below.[4] The procedure is designed to meet as many needs as possible, given limited data collection resources. It recognizes that funding and data requirements tend to come from two different sources: statewide monitoring sources and project specific sources. Statewide monitoring funding is intended to meet general data collection needs. Project specific funding is intended to meet the needs of individual projects that value certain data items highly enough to fund their collection.

The objective of the proposed procedure is to use, whenever possible, project specific funds to meet both project specific and statewide monitoring needs. Under the proposed plan, data from project counts should be used wherever possible to meet the general statewide data collection needs. Statewide needs that are not met by the special project data collection should then be met with statewide funding dollars.

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[4] This same basic framework can also be used by local jurisdictions, although the funding sources and primary program requirements are likely to be different at the local level.

A summary of the recommended steps for selecting continuous count locations is presented below:

- Determine the "statewide" objectives for the continuous count program (including the number and distribution of count locations to develop seasonal and day-of-week factors, statewide trend reports, preparation of reports that use permanent recorder data, etc.).
- Determine what continuous data collection is needed for specific projects (LTPP, other special studies) and what continuous data collection exists or is planned for operational purposes (traffic management, weight enforcement).
- Determine the available funding (including both "traditional" funds and funds from outside divisions that support continuous counter operation that can serve statewide purposes).
- Prioritize the "specific" project locations.
- Place counters at the "specific" project locations for which funding exists. (Note that the funding available for this step may only be a small fraction of the available funding for continuous counters, or it may be the vast majority of funding available.)
- Determine how those data collection efforts can help meet "statewide" needs. (For example, can those count locations be used for factor creation?)
- Determine the number of additional continuous count locations needed to meet statewide needs (using the existing and desired "specific" count locations as much as possible).
- Prioritize these remaining "statewide needs" locations.
- Allocate counters to these "statewide needs" locations on the basis of their priority and the available funding.
- If funding remains after statewide needs have been met, place additional continuous counters at the "specific" project sites for which counters are currently not allocated.

This process allows a State to prioritize its expenditure of resources for permanent counters. It also ensures the ability to use individual count locations for as many purposes as possible. While this process will not solve problems that occur because insufficient funds are available to locate and operate permanent data recorders, it will help to define the size of the budget shortfall and provide a basis for estimating the impact of a "partial" continuous count program.

SHORT DURATION COUNTS[5]

The short duration count program, like the continuous count program, consists of a number of inter-related data collection efforts. The basic purpose of the short duration

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[5] Where "short duration counts" are those generally taken with portable equipment.

count program is to provide up-to-date traffic data for a wide geographic coverage of roadway segments. These data define how specific roadway segments are being used, which in turn determines how highway agencies design, maintain, and manage those segments.

This section describes the basic process a State should use to construct its short count program. More details on this subject, organized by type of data collected (volume, classification, or weight) are included in Sections 3, 4 and 5.

Unlike permanent counts that normally occur in the same location year after year, a State's short count program is largely revised each year. Some locations are counted frequently (every year or every two or three years), and others are only counted occasionally. Roadway sections that are of major interest (locations of pavement design projects, corridors for major investment studies, etc.) are counted often, while other roadway sections with little activity may be uncounted for many years.

Short duration data collection counts that provide geographic coverage can be part of a general statewide monitoring effort or can come from focused, site specific studies or "project counts." General statewide monitoring programs collect data that are intended to meet a wide range of potential uses. These programs are pro-active data collection efforts. That is, they are intended to provide the "average user" with data when that user needs it. This means that the highway agency maintains a database of information (updated with the short count data) that defines in general terms how each roadway section is being used. Because States cannot afford to collect all needed data on all roadway segments, this "pro-active" approach is normally limited to collecting sufficient data to meet routine data needs. Where more extensive data needs exist, special count efforts, designed to collect exactly the data required, are undertaken.

These "project counts" often entail multiple counts within a fairly short stretch of roadway (providing much more information than is needed for "routine" tasks) and often include more detail (vehicle class and/or turning movements versus a simple volume count) than the statewide program provides. For example, the statewide counting program may provide a user with a volume count at milepost 167. A pavement design project for that road between mileposts 159 and 169 might require five vehicle classification counts within that 10-mile section to allow more accurate calculation of pavement depth for each of the soil conditions within those 10 miles of road.

An efficient statewide traffic monitoring program stores and makes use of these project counts. In the above case, the volume data needed for the general statewide program can be obtained from the vehicle classification counts performed for the project. Thus, coordination of these two types of short duration counting programs results in a net reduction in traffic counting efforts, without a decrease in the quantity or quality of data available to the data user.

The difficulty with short duration traffic counts is that they only describe the traffic conditions present when the data were collected. Depending on when data collection takes place, the data may or may not represent "average," "normal," or "design" conditions for that road section. This is when factors (obtained from the permanent count data) are used. Factors allow adjustment of "raw" traffic data to represent the desired traffic condition, usually AADT, AAWDT, or some other design value.

In addition to factors for day-of-week and seasonal adjustment, many short duration counts require other types of adjustments. For example, many short duration counters measure the number of axles that pass by, not the volume of vehicles. To estimate vehicle volume, an axle correction factor (the average number of axles per vehicle) for that road must be applied to that measurement.

The steps needed to adjust short duration counts to obtain AADT and other statistics are discussed in the next chapter.

Short Count Program Design

The basic design process recommended for short count programs involves defining and overlaying the different short duration counting requirements and programs. In this manner, it is possible to see where data are needed and which data collection needs overlap. Where overlap occurs, a single data collection effort can often be used to meet numerous needs. Where separate counts are still needed, a reduction in staff and travel time costs can be achieved by combining the data collection activities for these distinct needs. (That is, when the data collection staff sets "project" counts, they can also set "general coverage" counts in that same vicinity, thus having to travel to that general location only once.)

When two or more data collection requirements exist for a given location, collecting the data for the most precise need usually satisfies all other data collection needs. For example, one program requires volume data while another requires volume by classification at the same location. Collecting the classification data can meet both needs. In other cases, data from one or more locations can often be substituted for data from a nearby location. This type of coordination increases the efficiency of the traffic monitoring program.

In general, the highway agency will address the following data collection needs within the short duration count program:

- counts taken to provide system coverage
- counts taken to meet the HPMS needs
- counts for special needs studies.

Statistical sample locations should be selected prior to the special study needs because the statistical sample can suffer from bias, with a consequent loss of accuracy, when data collection locations are not randomly selected.

Coverage Count Programs

Coverage counts are needed to ensure that adequate geographic coverage exists for all roads under the jurisdiction of the State highway authority. In simple terms, “coverage counts” are data collection efforts that are undertaken to ensure that “at least some” data exist for all roads maintained by the agency. How much data should be collected to provide “adequate geographic coverage” is a function of each agency’s policy perspective. Some State highway agencies consider “adequate” a week-long count every seven years with data recorded for every hour of each day. Others consider “adequate” a 24-hour count every year, with no hourly records.

Similarly, the spacing between counts along a roadway is also subject to agency discretion. The primary objective is to count frequently enough so that the traffic volume estimate available for a given highway segment accurately portrays the traffic on that segment of roadway. Generally, roadway “segments” are treated homogenously with respect to traffic (that is, traffic volumes are the same for the entire roadway segment.) For a limited access highway, this is true between interchanges. However, it is also true for all practical engineering purposes for a rural road where access and egress along a 10-mile segment is limited to a few driveways and low volume, local access roads.

The TMG recommends, as a general rule, that each roadway segment be counted at least once every six years. This ensures that reasonable traffic volume data are available, and that roadways are accurately classified within the proper HPMS volume groups when State highway agencies compute statewide VDT as part of their required federal reporting. Careful definition of roadway segments can significantly reduce the number of counts needed to cover all highways within an agency’s jurisdiction, while still providing the accurate volume data required for planning and engineering purposes. Similarly, careful coordination within and between agencies can greatly reduce the number of counts that must be taken.

Finally, not all count locations should be counted on a six-year basis. Some count locations need to be counted more often. Other roads have such stable traffic volumes, that counts can be performed even less frequently. Without knowing how data will be used (and the sensitivity of specific analyses to variability and error in the traffic data inputs), it is not possible to define “adequate geographic coverage”, other than for the HPMS (which meets specified national objectives). Therefore, each agency must make this determination itself, given available funding for data collection, the extent of the State controlled highway system, and the uses for which the data are intended.

In general, roadway sections that experience high rates of growth require more frequent data collection than those that do not experience growth. Therefore, roads near growing urban centers and expanding recreational sites tend to need more frequent counting than roads in predominately rural areas where volumes have changed little in the last ten years. Counting roads frequently in volatile areas allows the highway agency to respond with confidence to questions from the public about road use (a common concern in high growth areas), while also ensuring that up-to-date statistics are available for the roadway design, maintenance, and repair work that is common in high growth areas. These frequent data collection efforts also limit the use of average growth factors in areas where volatile change occurs.

High growth areas (if not necessarily roads with high volume growth) can usually be selected on the basis of knowledge of the highway system and available information on the construction of new travel generators, new highway construction projects, requirements for highway maintenance, applications for building permits, and changes in population statistics. This information can best be gathered by communicating frequently with agency staff familiar with the economic activity of each region within a State.

The HPMS Sample

The basic statewide traffic data collection coverage program includes the collection of volume and classification data for the HPMS. The HPMS is a combination of complete coverage (universe) for the NHS and other principal arterials, and a structured sample of roadway sections for the remaining functional systems excluding the rural minor collectors and local. The HPMS has specific requirements on the collection of traffic data covering all systems. A primary goal of the HPMS traffic data collection effort is to provide a statistically valid estimate of total annual vehicle distance traveled (VDT). The traffic volume data reported to the HPMS are used for a number of important analyses, including the apportionment of Federal-Aid funds to the States.

The HPMS submittal includes both volume and classification information. The HPMS sample selection process (completed many years ago by the States) indicates the location of the HPMS samples. The sample locations are adjusted periodically to account for changes in the road systems. Detailed information on the HPMS requirements can be found in the latest version of the HPMS Field Manual.

Other Statistical Samples

In addition to the HPMS, many States (and local highway agencies) develop and collect traffic volume data as part of statistical studies. These studies produce specific summary statistics within a given range of reliability. Examples include:

- VDT estimates for roads within specific State boundaries (for example at the county level)
- VDT estimates needed to meet data collection requirements for specific State laws (such as growth management or air pollution control efforts)
- VDT in different jurisdictions within a State (used to distribute State highway funds)
- the effectiveness of new traffic management plans and actions
- the changes in traffic conditions that result from new construction or changes in roadway operation.

Count locations and data collection requirements (volume, class, weight, length of count) for these studies are determined as part of the traffic program plan. As a result, limited flexibility is usually available in determining when and where these counts will take place. Therefore, determining these count requirements (including the location, timing, and type of counts to be taken) should occur early in the planning process.

Where these sample counts are required for the same roadway sections covered by the HPMS sample, a reduction in counting is possible. In almost all cases, one count can be used to meet all needs. Note that there usually is flexibility in exactly where and when counts are taken for the HPMS and other studies. Agencies responsible for traffic monitoring should try to take advantage of this flexibility to combine count efforts whenever possible.

Other Special Needs Counts

Statistical samples are the most efficient ways to estimate population means and totals. However, many traffic data uses require statistics other than population means and totals. Random sampling is often an inefficient mechanism for meeting highly specific traffic data needs.

One problem with random sampling is that data may be needed on road sections that are not part of the sample. For example, uncounted roadway sections outside the sample are not a concern for the HPMS because the sample expansion process expands the sample in the statewide VDT computation. However, if a pavement design will be developed for an uncounted roadway section, a statewide average or VDT total is not a good substitute for a traffic count specific to that road segment.

Consequently, States collect data at locations that are not part of the HPMS or any other existing State-specific sampling study. The key to making a program more effective is to limit the number of these “extra” counts to a minimum to save resources for other tasks. This can be done by ensuring that data collected are used for as many purposes as possible, so that new data are not collected whenever an existing count can provide that same information.

Additional “extra” counts generally are required to meet project-specific studies and other hard to anticipate needs. Project counts are undertaken to meet the needs of a given study (for example a pavement rehabilitation design or a specific research project). They cover a range of data collection subjects and are usually paid for by project funds.[6]

Project counts must often be performed at very specific locations. They have traditionally been performed on relatively short notice and often collect data at a greater level of detail than typically is required for the HPMS and coverage counts. Project

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[6] This can actually be a problem in that collection of count data requires time (to schedule the data collection staff efficiently, collect and analyze the data, and report them). The lead time required to supply the data often exceeds the availability of the project funding. This lack of funding must be resolved within the State highway agency to achieve any potential efficiency from coordination.

counts are done on short notice because funding for data collection for major projects is often not available until after a project has been selected for construction, and insufficient time exists by that date to schedule the project counts within the regular counting program. However, where it is possible to include project counts within the regular count program's schedule, significant improvements in staff utilization can be achieved.

Scheduling of project counts is difficult because funding for many project count efforts is not available early enough in the design cycle to meet the scheduling needs of the data collection group. However, many project count locations can be anticipated by examining the highway agency's priority project list. These lists tend to detail and prioritize road projects that need to be funded soon. They normally include sections with poor pavement that require repair or rehabilitation, locations with high accident rates, sections that experience heavy congestion, and roadways with other significant deficiencies. While priority lists are rarely equivalent to the final project selection list, high priority projects are commonly selected (if not this year then next year), analyzed, and examined (for alternative designs, to develop cost estimates, and to properly prioritize the project). Making sure that up-to-date, accurate traffic data are available for these analyses helps make the traffic database useful and relevant to the State's data users and increases the support for maintenance and improvements to that database.

CHAPTER 4
FACTORING TRAFFIC COUNTS

Short duration traffic counts only measure the traffic conditions when the counts are taken. To use these data to estimate "average" conditions or to develop traditional engineering inputs, adjustments must be made to account for variability in the traffic stream. In most cases, these adjustments (factors) are developed from data collected at continuously operated data collection sites. This chapter discusses the basic procedures for creating and applying these factors.

As discussed earlier in this section, common necessary adjustments include the following:

- time-of-day adjustments for counts that consist of less than 24 consecutive hours (the TMG recommends 48-hour counting periods)
- day-of-week adjustments for counts that do not measure traffic conditions for all days of the week
- seasonal adjustments for counts that do not cover periods long enough to account for variation from month to month or season to season
- axle correction adjustments for axle counts (such as counts taken with a single road tube sensor) that do not directly convert the number of axle pulses into vehicle counts by vehicle classification.

Many papers have been written on this subject, including the reports referenced earlier and additional reports referenced here (Weinblatt 1995; Wright et al 1997; Ferlis et al 1980; Cambridge Systematics 1994; Cohen and Margiotta 1992). Many efforts have described the need to adjust short duration counts. All of these reports conclude that seasonal adjustment is needed to reduce the significant temporal bias introduced by short duration traffic counts.

Not all experts agree on the best method for calculating and applying adjustment factors. However, work by Wright and Hu has shown that many of the most common methods for volume count adjusting produce comparable results. Consequently, flexibility is needed because the definition of "best" is often a function of issues such as the number of continuous counters a State can afford to operate and the extent of the roadway system for which factors must be developed and applied. The following recommendations are offered:

- **factors must be applied to short counts**
- **factors should be developed to best utilize available data collection resources**
- **factors should be developed separately for total volume and for estimates of volume for individual truck classifications.**

The last of these recommendations stems from recent analysis of continuous vehicle classification count data, which showed that truck volume patterns tend to be considerably different from automobile travel. These pattern differences include all major temporal variables: time of day, day of week, and season of the year.

THE CREATION OF FACTOR GROUPS

Before creating factor groups, it is important to understand what factors are and how they are applied. Short duration counts normally do not adequately represent "average" traffic conditions. Unfortunately, the data, needed to convert each short duration count into an "average" with accuracy and precision, require a continuous counter. There are insufficient continuous counters to describe how traffic behaves at every location. However, assuming that temporal characteristics affect all roads and since continuous temporal data exist at several points (the continuous counter sites) to describe the temporal variation, it is possible to transfer knowledge by developing factoring mechanisms. Factor groups are used to create temporal variation factors to statistically convert short counts to annual averages.

The factoring process defines a set of roads as a "group." All roads within that group are assumed to behave similarly. Then a sample of locations on roads from within that group is taken and data are collected. The mean condition for that sample is computed and that mean value is used as the "best" measure of how all roads in the group behave. If the sample of data collection sites is randomly selected and moderately large, the distribution of that measure about the mean is a good measure of how well that mean applies to road sections in the group.

This whole process involves a number of assumptions. Limitations in the reliability of those assumptions are the source of many of the errors in "annual" and "design" traffic estimates. Different techniques used to create and apply traffic correction factors allow the user to control or limit the errors associated with any given one of these steps. Unfortunately, none of the available techniques can control for all of the limitations. Thus, selection of the "best" technique is usually a function of the availability of data and knowledge of the roadway system more than the application of a theoretically pure analysis process.

Each of the basic steps required in the factoring process is listed below, along with the primary type of error that is associated with the assumptions that are required to perform each step.

1. It is difficult to define groups of roads that "are similar with respect to traffic variation," and the more "mathematically alike" the factoring groups created from the data, the more difficult it is to define the attributes that determine which roads belong to a given group.

It is easy to define groups of roads with a high level of precision based simply on variability. However, the groups that can be easily defined based on variability usually do not have clear characteristics to identify the group. For example, the category of roads rural Interstate highways is very easy to define. The problem is that all rural Interstates often do not have the same travel pattern. Interstates that pass near major recreational areas have different travel characteristics than Interstates that do not.

Trying to subdivide the category into rural Interstate highway segments that are affected by recreational areas and those that are not places the analyst in the difficult position of trying to guess at just what point on the Interstate highway system the influence of the recreational area disappears. However, if the "group" is not divided, then it includes all the roads despite the difference in temporal patterns. This makes the factor associated with this combined group less "precise." Although the computed factor may be the perfect mean value for the group, it is not a good factor for any one specific location on the rural Interstate highway system.

Therefore, the creation of factor groups usually involves balancing the need to easily define a group of roads against the desire to ensure that all roads within a given group have similar travel patterns.

This same trade-off occurs in the type and magnitude of errors in the factoring process. For groups that are easy to define but include wider ranges of travel patterns within the group, errors occur because the mean factor computed for the group may not be a good estimate of the "correct" factor for a specific road segment. For groups that have very "tight" factors but for which it is difficult to define the roads that fit, the error occurs in defining which factor group a specific road segment belongs to.

2. The grouping process is made more difficult and error prone because the appropriate definition of a "group" changes depending on the characteristic being measured. The best example of this is the computation of factors for total volume versus the computation of factors for individual types of truck classes. Trucks have different travel patterns (time of day, day of week, and season of the year) than cars. Consequently, factor groups that work extremely well for computing and applying total volume adjustments (dominated by car volume patterns) often do not work well for truck volume adjustments.

The variation in truck traffic (and truck percentages) from road to road even for roads of the same basic functional classification and geographic location can also make common "volume factor groups" based on geography and functional classification very poor "groups" for the computation and application of axle correction factors. Factor groups for computing axle correction factors are driven primarily by the presence of common vehicle mixes. But vehicle mix is not a value that would be considered in forming a factor group intended to seasonally adjust total volume counts.

In general, the "best factor groups" are those that can be readily defined and at the same time contain similar traffic patterns. However, it is extremely difficult to find road groups in most States that are both readily defined and that have very similar traffic patterns. In addition, the "best" factoring process usually means having at least two sets of factor groups, one for total volume and one for truck volumes.

3. The next source for error in the factor computation process is that it is very difficult to select a representative sample of roads from which to collect data for calculating the mean values used as factors. The best alternative for selecting these sites is to first define the factor group and then perform a random selection of data collection sites. Normally, neither of these events takes place. Consequently, the "mean" value computed is often not the "true" mean value for the group.

Data collection points are usually not "perfect" for two reasons. The first is that permanent data collection site locations are often selected for a number of reasons, only one of which is factor computation. These reasons include:

- the need for data from a specific site (for example, an LTPP site)
- the desire to track trends over time at sites that have been historically monitored
- the need for specific physical conditions (the availability of power or communications lines, the need for smooth, flat pavement)
- the wish to meet a number of needs with a single data collection station.

Second, because factor groups are often determined on the basis of data from existing data collection sites, the actual site locations often exist before the grouping process, and cost considerations tend to prevent their being moved. Thus, the data drive the grouping process, rather than the grouping process driving the selection of data collection points.

Both of these factors increase the chance that the data sites do not truly represent the road segments included in a given group. When combined with the limited budget available for permanent data collection sites and the fairly high cost of permanent data collection sites, this limitation usually results in a "less than random" sample of sites within a factor group.

This problem is exacerbated by the small number of stations that normally exist within a given group. The cost of installing, maintaining, and operating permanent data collection sites tends to limit the amount of data available for computing "mean" factors. Thus the presence of one "unusual" location within a group of counters can have an overly large effect on the factors computed and applied to individual road segments.

4. The last source of error discussed in this section occurs in the computation of factors because the datasets used to compute those factors are not complete. No data collection device is perfect. Within any given State, a number of permanently operating data collection devices will fail each year, and those failures will last for anywhere from a few hours to several months. The holes produced in the "continuous" data sets for these sites must be accounted for to compute factors. In some cases, so few data are available that the site may not be included in the factor computation at all.

A number of procedures, most notably the AASHTO process for computing AADT (AASHTO 1992), have been designed to limit the effects of missing data. However, because of the holes in the data, errors are introduced into the factors being computed. In general, the more data that are missing, the more error that may be associated with the mean factors applied to any given location. The best way to decrease the chance of these errors occurring is to monitor and repair permanent data collection equipment as quickly as possible. It is also helpful to maintain more than the minimum number of counters within any given factor group, so that if one counter experiences a long data outage, the data from that counter can be removed from the computation process without adversely affecting the factor computation.

HOW TO CREATE FACTOR GROUPS

Three alternative techniques for computing factor groups are discussed below. Each of these techniques has strengths and weaknesses. In most States, some combination of these techniques is used to compute and apply traffic adjustment factors. In many cases, this combination of approaches is probably better than following any one technique exclusively.

The three techniques discussed briefly below are

- cluster analysis
- geographic/functional assignment of roads to groups
- same road factor application.

In addition to this discussion, the cluster analysis technique is illustrated in Appendix B. This technique is more complex than the other two, and the example should help clarify the process for staff unfamiliar with it.

Each of these techniques starts from existing permanent counter data.[7] Therefore, for each of the three basic techniques, the first step is to compute the adjustment factors that will be used in the group selection process (and that would be applied to short counts if just that one counter's data were to be used) for each site for which data are available.

As part of this first step, the analyst should learn about the quality of the data produced by each counting device. This includes understanding when each counter malfunctioned, how the malfunction was detected, and how the data for that counter was edited to account for the malfunction. The implementation of truth-in-data concepts, as recommended by the 1992 AASHTO guidelines, will greatly enhance the ease with which this task is undertaken, as well as help improve the analytical results and establish objective data patterns.

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[7] Data from ATRs with extremely low volumes may be left out of the factor grouping and computation analysis, since very low volumes tend to produce unstable factors.

Cluster Analysis

In the cluster analysis process, a statistical program applied to the computed factors determines which stations are "most similar." The statistical analysis program uses a least-squares minimum distance algorithm to determine which sets[8] of factors are most similar. The stations that are most similar are then grouped together, and the process is repeated to find the next closest group.

The output of the cluster program normally includes a sequential list that indicates which counters have traffic adjustment patterns that are most similar, and in what order each group is formed. For example, cluster analysis software normally provides an output that indicates that in the first step, the stations are broken into two groups. In the second step, the stations are broken into three groups. In the third step, the stations are broken into four groups. This continues until there are as many groups as stations. An example cluster program output is shown in Appendix B.

The analyst's major function is to determine at what point to stop the analysis and apply the groups formed. As described above, the cluster analysis program works in a "step-wise" fashion. That is, in the first step, the closest two groups are formed. In each succeeding step, an additional group is added. At the end of the clustering process, each station is in a single group. It is left to the analyst to make the call as to how many groups are sufficient and how to implement the groups.

Deciding where to stop the groupings is commonly determined in one of two ways. The first way is to look at the mathematical distance between the clusters formed. A number of different mathematical tests can be used to produce these measures of "distance" or goodness of fit. It is sometimes possible to find major changes in the distance between two consecutive group formations. These breaks indicate that although this is the next best fit, the group being formed is not very homogenous. Thus, large changes in the distances between groups indicate that this might be a logical stopping point for the cluster process. Cluster programs usually provide a summary of the explanatory value of the groups formed, which allows a determination of how much explanatory value additional groups add.

The second common approach to ending the cluster process is to choose a predetermined number of groups to be formed. For example, an analyst might want to create no more than five factor groups. The question then is, "what is the best grouping of locations that will give me five groups?"

The next issue for the analyst is the need to define the group of roads a given cluster of continuous counters actually represents. That is, how should the group of continuous counters grouped together be defined spatially? Which roads are included in a factor group that is represented by a specific set of count locations? This "spatial definition" is necessary to assign arbitrary roadway segments to the newly created factor

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[8] The word "set" is used because factor groups are applied for all factors, not just for a single factor. Thus, for monthly factors, the minimum distance is computed for all 12 monthly factors combined, not for a single month's factor.

groups, since the analysts must understand the rules for assigning short counts to the factor groups.

In some cases, the underlying pattern (and the assignment rules) behind a factor group may be obvious. For example, roads with heavy recreational movements are usually outliers in the cluster process. They are included in groups because their traffic patterns are extreme and usually quite different than other roads in the State. As a result, they are often defined as separate "groups." Other groups, such as urban counters, also tend to be distinguished fairly easily because urban areas tend to have much flatter variation patterns than rural roads.

However, in some cases the definition of what roads fit within a cluster group can be difficult to determine. If the definition of "factor groups" is hard to determine, try plotting the locations to see whether a geographic pattern emerges. The difficulty in assigning definable characteristics to the resulting clusters of continuous counters is one reason the cluster process is often modified by the use of secondary procedures to develop the final factor groups.

The cluster process is used to objectively determine the pure variation patterns that exist in the continuous counter database. The information gained is then used by the analyst to define appropriate factor groups. The major difficulty in developing factors groups lies not in the assignment of the continuous counters to the groups, but rather in the specification of definable characteristics to allow the objective assignment of short counts to the seasonal factor groups. The final factor group definition is often a combination of statistical analysis and analyst knowledge and expertise.

<u>Geographic/Functional Classification of Roads Factor Groups</u>

Whereas the cluster analysis is driven by mathematics, the analytical procedure described here is driven by professional knowledge. In this process, the analyst allocates roads into alternative factor groups on the basis of available knowledge about those traffic patterns. Available knowledge is usually obtained from a combination of existing data summaries and professional experience with traffic patterns. Prospective groupings initially based on the expectations of the analysts are compared with available continuous counter data. The initial groupings are modified on the basis of the results of the analysis and the groups finalized.

The initial factor groups selected by the State highway agency will differ from State to State, but they tend to be based on a combination of functional roadway classification and geographic location. Some States have found that the non-Interstate rural functional classes 2, 6, 7, and 8 have similar travel patterns, and others have found that rural principal and sometimes minor arterials have different patterns than the lower rural functional classes of roads. The characterization of roadways using functional class makes it easy to assign individual road sections to factor groups and also allows the creation of factor groups that are intuitively logical. For example, initial factor groups might include:

- urban Interstates and expressways
- other urban roads
- rural Interstates
- other rural roads in the eastern portion of the state
- other rural roads in the western portion of the state
- recreation routes.

In this example, it is assumed that urban and rural roads experience different travel patterns (normally the case). It also assumes that Interstate highways behave differently than non-Interstates. This is often the case because Interstate highways tend to carry considerably more through traffic than non-Interstates. This example also assumes that there is a difference in traffic patterns in the eastern and western portions of the State.

Sub-State differences often occur when two (or more) parts of the State have different traffic characteristics resulting from different levels and types of economic activity (the data-driven cluster analysis would have identified these differences). Finally, the example shows one (or more} recreational patterns. These are roads with particular, unusual traffic patterns. These patterns may or may not be strictly recreational. Any road or geographic area with a known, unusual traffic pattern may require separation from the standard factor groups.

Once the initial factor groups have been identified, continuous counter data are examined for each group.[9] For each factor and each factor group, the mean factor for the group and the standard deviation of that factor are computed. The standard deviation tells the analyst the size of the expected error of the average group factor. It is assumed that the continuous counters for which data are available are representative of a random sample of roads from within that defined group. Given the assumption, the errors should be roughly normally distributed about the factor group mean.

If the standard deviation is too high (i.e., the error associated with factors computed for that group of roads is too large), the definition of roads that fit within that group may have to be changed. This can mean the creation of new factor groups (for example, splitting “eastern other rural roads” into principal arterials and lower functional classes of roads in the eastern part of the State), or the redefinition of those groups (for example, a county that was believed to fall within the eastern group may be more closely associated with the western group). Changing factor group definitions effectively moves continuous counters from one factor group to another and allows the variation within a given group to be decreased.

When the standard deviation of the various factors for a group is examined, it should be remembered that not all factors are of equal importance. For example, in many States, the majority of traffic counting takes place from the middle of Spring to the middle of Fall. Therefore, the factor group variation in January and December is less

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[9] Data from ATRs with extremely low volumes may be left out of this analysis, since very low volumes tend to produce unstable factors.

important (because these factors may never be used) than the variation in the key May through September time period, when most short duration traffic counts are taken. Likewise, if the May to September factors for two defined groups are almost identical, then combining the groups should be considered since the effect on short counts is the same.

Plotting the factors for each continuous counter within a group is also very useful. This allows the analyst to determine specific outliers (continuous counters that don't really fit within the basic pattern that is assumed to exist). Plotting the continuous counter data is also a good first step for redefining the factor groups and for moving a specific counter (and the road segments it represents) from one factor group to another. For example, if a counter does not fit within a factor group, having a plot of that counter's data will allow the analyst to determine whether the data for that site contain potential errors that could affect the grouping process, indicate the need to create a recreational factor group, or provide the insight to place the stations in another group.

The development and application of factor groups is not a perfect process. It combines both data driven analysis, statistical expertise, and knowledge of traffic conditions. The result should be a fairly simple, easy to apply process that reduces the periodic bias in short counts to produce reasonable annualized estimates of traffic. The main objective is neither statistical purity nor complete subjectivity, but rather an effective process that meets the needs of the users of traffic information and is understood by both users and data providers.

Same Road Application of Factors

An alternative to either of the group factoring approaches described above has been commonly used by many States for sites that are near or on the same road as a continuous counter. This process assigns the factor from a single continuous counter to all road segments within the influence of that counter site. The boundary of that influence zone is defined as a road junction that causes the nature of the traffic volume to change significantly. This approach avoids two of the common errors of the group factoring approaches, the application of a mean value that does not accurately describe traffic variation on that given road section, and the problem of associating a specific road section with a vaguely defined factor group.

For this approach, the association of a factor to a given count is quite easy. The short count in question must be taken on the same road as the continuous counter. The factor from the continuous counter is then applied to that count. The likelihood that the traffic variation at the continuous counter is similar to that of the short count is very high. The error associated with the computation and application of that count tends to be small in comparison to that associated with the computation and application of a group factor (Cambridge Systematics 1994 and 1995).

Difficulties in the application of this technique only occur when the short duration count is not near the continuous counter. In such a case, traffic patterns at the count location may be different than those found at the continuous counter.

This approach requires a dense network of continuous counters and/or a very small number of roads against which these "single use" factors are applied. Without these two conditions, there are many roads that will not be associated with any continuous counter and for which no factor can be computed.

Applying factors from a single continuous counter to arbitrary counts on "nearby" but different roads is not advised. Application of factors from individual locations in this fashion creates considerable potential for bias in the factoring process. Without the availability of multiple counters to balance the variability from a single location, unusual traffic (e.g., the diversion effects of nearby construction activity) can have a ripple effect. These unusual patterns are then reflected in the adjustments made to roads that are not affected by the unusual events.

Combining Techniques

As noted at the beginning of this subsection, most States develop and apply factors by using some combination of the above techniques. For example, on road sections where continuous counters exist nearby, factors from specific counters can be applied to short duration counts on those roads. For all other road sections, group factors can be computed and applied. Factor groups can be initially identified by starting with the cluster analysis process followed by the use of common sense and professional judgment. In this way minor adjustments can be made to the cluster results in order to define the final factor groups in such a way that they can be easily identified for factor application. Groups can also be initially defined judgmentally and then confirmed and/or modified by using cluster analysis.

ALTERNATIVES TO FACTORING

An alternative to factoring exists. This technique is not commonly used, but it is appropriate where factor groups are not readily known and the annual traffic estimate must be very accurate. Work done showed that for volume counts by vehicle classification, it was possible to achieve accurate annual estimates by conducting four week-long counts per year at the same location (Hallenbeck and O'Brien 1994).

This approach may seem like data collection overkill, but it provides sufficient data to overcome the primary sources of variation in the data collection process. Taking week-long counts removes the day-of-week variation. Counting at the same location four times at equally spaced intervals removes the majority of seasonal bias.

Similarly, the use of control counting procedures or taking short counts at the same site on different times of the year are commonly used by States to address the special needs of recreational sites or high growth areas.

TYPES OF FACTORS

Different States have adopted different procedures for developing and applying factors. Work by Weinblatt and Margiotta (Cambridge Systematics and Science Applications International 1994) showed that a number of different factoring techniques can result in reasonably similar levels of accuracy when short duration counts are converted into estimates of average annual conditions. The key is that each successful factoring technique must account for all types of variation present in the data.[10]

The Weinblatt and Margiotta work tested seven factoring strategies for adjusting short duration count data (see Table 2-4-1). They found relatively similar results in terms of the reduction in bias and the expected errors remaining.

As can be seen in Table 2-4-1, the primary difference among successful factoring techniques is the level of aggregation that exists in each factor and the definition of “seasonal.” In some techniques, day-of-week and seasonal adjustments are combined in a single factor. In other techniques, these two components are treated as separate factors, although both factors must be applied to a short duration count as part of the factoring process.

For seasonal adjustments, some techniques use monthly factors, whereas others use weekly factors. Both of these techniques can be successful. Seasonality does not necessarily vary smoothly from month to month. Consequently, some States find that weekly factors work better than monthly adjustment factors. However, others find that the monthly factors provide equally good annual adjustments and require considerably less effort to compute and apply. However, if “weekly” factors will be applied, it is very important to use “same year” factors because the characteristics that affect week-to-week travel (such as which week Easter falls on) change from year to year.

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[10] This discussion assumes that each count being factored represents a daily vehicle volume, and therefore, that axle correction and time of day corrections are not needed. These adjustments must be applied if the initial “raw count” data contain less than 24 hours of data and/or are simple axle counts.

Table 2-4-1
Effects of Alternative Current Year Factoring Procedures on AADT Estimates

	Mean Absolute Percentage of Error	Average Percentage of Error	Percent of Observations with Error > 20%	Number of Weekday Counts Required	Number of Weekday and Weekend Counts Required
Unfactored	12.4%	-0.6%	18.2%		
Separate Month and Day-of-Week	7.5%	-0.5%	6.2%	17	19
Combined Month and Average Weekday	7.6%	0.4%	5.9%	12	24
Separate Week and Day-of-Week	7.5%	-0.9%	6.0%	57	59
Combined Month and Day-of-Week	7.4%	-0.2%	5.8%	60	84
Combined Week and Average Weekday	7.3%	0.5%	5.1%	52	104
Specific Day	7.1%	0.2%	5.1%	261	365
Specific Day with Noon-to-Noon Factors	7.0%	0.3%	4.8%	261	365

For day-of-week factors, some States use day-of-week adjustments for each day. Others combine some weekdays (traditionally Tuesday to Thursday or Monday to Thursday). Both techniques can produce acceptable results if they are applied appropriately. Whether a factor that relies on the average of all weekdays is appropriate is a function of the traffic patterns. For example, in some prairie States, weekday travel on Interstates is not constant, particularly for trucks. This is because these roads are heavily influenced by through-traffic, and that traffic can be generated several days' drive away. Consequently, volumes on some weekdays fall in travel patterns that look more like weekend volumes than weekday volumes. For a State with this type of traffic pattern, individual day-of-week factors (i.e., a Monday factor, a Tuesday factor, etc.) will be much more accurate than a single "weekday" factor. In cases where through-travel is less sizable, or in urban areas where traffic is much more constant, a single "weekday" adjustment is simpler to maintain while being equally as accurate.

Finally, it is important to once again stress that these analyses need to be performed separately for total volume factors and for factors that are applied to volumes by vehicle classification. There is no question that on many roads, trucks have very different day-of-week and seasonal patterns than cars, and many types of trucks have different patterns than other types of trucks. States need to be aware of these differences and to treat their factoring procedures accordingly.

COMPUTATION OF FACTORS[11]

Once a State has selected the types of factors it plans to use, it must select the mathematics for computing those factors. There are two basic steps in computing the factors to be used: computing the numerator and the denominator. The numerator is assumed to be AADT. The denominator[12] is dependent on the factoring approach taken.

Computing AADT

Wright, Hu, et al (1997), provide an excellent discussion of alternative algorithms for calculating AADT for continuous count locations. There are two basic procedures. These two procedures are:

- a simple average of all days
- an average of averages (the AASHTO method).

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[11] This discussion concerns primarily the computation of monthly factors. It assumes that the computational task starts with daily traffic volumes from ATRs. The same basic procedures can be used to compute monthly factors by vehicle, as well as weekly factors. The factors computed can be for a given day of the week, or for all weekdays combined.

[12] This assumes that the factor being computed is a multiplicative factor computed as the ratio of AADT to MADT. If the state uses the inverse of this, then simply change the term "denominator" to "numerator" in the discussion.

In the first of these techniques, annual average daily traffic (AADT) is computed as the simple average of all 365 days in a given year. When days of data are missing, the denominator is simply reduced by the number of missing days.

This approach has the advantage of being simple and easy to program. Its drawbacks come from the fact that missing data can cause biases (and thus inaccuracy) in the AADT value produced. In particular, blocks of missing days of data (for example, data from June 15th to July 15th) can bias the annual values by removing data that have specific characteristics. On a heavy summer recreational route, missing data from June 15th through July 15th would likely result in an underestimation of the true annual average daily traffic for that road.

When the simple average is used to compute average monthly traffic, the missing data can bias the results when an unequal number of weekday or weekend days are removed from the dataset. Because most ATRs have some equipment "down time" during a year, and some miss considerable numbers of days, AASHTO adopted a different approach for calculating AADT. The AASHTO approach first computes average monthly days of the week. These 84 values (12 months by 7 days) are then averaged to yield the seven average annual days of the week. These seven values are then averaged to yield the AADT. This method explicitly accounts for missing data by weighting each day of the week the same, and each month the same[13], regardless of how many days are actually present within that category.

The resulting two versions of AADT are very close to each other. The study by Wright, Hu, et al., indicates that the differences are so small as to be unimportant. The "simple average" method is certainly easier to compute. However, where data are likely to be missing, the AASHTO method will provide a more reliable and accurate value.

The AASHTO method for computing AADT is recommended. This is the case because it allows factors to be computed accurately even when a considerable number of data are missing from a year at a site, and because it works accurately under a variety of data conditions (both with and without missing data). On the other hand, the simple average works accurately only when the data set is complete, or when little bias is present in the missing data. Because a common method should be used for all AADT computations, the AASHTO method is preferred.

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[13] For example, if only two Saturdays and two Sundays are present for June, but there are three days of data for all five weekdays, in the "simple average" technique, the weekdays would be over-represented in the "average June day" computation. In the AASHTO procedure, the first computation of the seven average days of the week allows the two Saturdays to be used to estimate the "average June Saturday" while three Mondays are used to compute the "average June Monday." When these seven values are then averaged to compute the "average June day" the proper balance between weekdays and weekend days can be maintained.

Computing the Denominator[14] for Monthly Factors

The numerator is AADT. The denominator depends on the procedure used. For example, suppose a State chooses to compute and use an adjustment factor that converts any weekday ADT for a given month into AADT. This would convert monthly average weekday traffic to annual average daily traffic. The first step is to define what a weekday is. This can be done by determining the days on which data will be collected. If data will be collected on the 5 days of the week (Monday to Friday), then the denominator is the sum of all weekdays (Monday to Friday) divided by the number of days of data present.

If no short count data will be collected on Fridays, then the denominator should be the sum of all Mondays to Thursdays, divided by the number of days of data present. The key is that the only days that should be included in the computation of the denominator are the days that will actually be included in the data collection effort. Using only those days for which data will be collected (and then used in the estimation of AADT) means that the factor computed applies directly to the count against which it is being applied.

Following this same logic means that holiday traffic could be excluded from the calculation of the denominator and thus the adjustment factor, if no traffic volume data is collected on holidays. Few States collect short duration count data on holidays, other than as part of an effort to measure special holiday flows.

The definition of a “holiday” (only for the purpose of computing adjustment factors) should thus be driven by whether short count data is collected on those days. For example, if no traffic data will be collected on the Friday following the fourth of July (because the traffic is so unusual), then this Friday should be excluded from the denominator calculation. Note: holidays are included in the computation of AADT that is used in the factor calculation. The definition of holiday periods can be difficult and changes from year to year. Influence days are the days before and after a holiday where traffic is greatly influenced by the holiday.

The next step in the computation of the denominator is to determine whether simple averages will be used, or the “average of an average” approach recommended by AASHTO for AADT computation. For monthly averages (e.g., monthly average weekday traffic), both techniques are reasonable. The same advantages and disadvantages apply at this level, although for monthly averages, bias caused by missing days of data is more easily introduced because the number of days used in the calculation is smaller than when AADT is computed. In other words, the effect of each missing day is accentuated. This is particularly true if an unequal number of weekdays and weekend days are missing. In general, whichever technique is used for AADT computation should be used for MAWDT.

If the State chooses to compute an average monthly day-of-week factor (i.e., combining the monthly variation and the individual day-of-week variation), then the

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[14] This assumes the factor being computed is equal to AADT / some value (for example, monthly average daily traffic).

denominator is the simple average of available daily volumes for that day of the week for that month.

Computing the Denominator for Weekly Factors

If the State decides to use a weekly factor, the denominator is simply the average of the seven days for the appropriate week. (One of the difficulties with this technique is how to handle missing data without biasing the weekly adjustment.) Holidays in the weekly process are either included or excluded, depending on how data to be used for AADT estimation will be collected.

FREQUENTLY ASKED QUESTIONS—FACTORING

When I compute a "weekday" factor, should I include Mondays in the weekday? Should I include Fridays?

> There is no definite answer. The decision must be made by each organization. Traffic patterns vary from site to site. In most urban cases, Monday traffic volumes are fairly similar to Tuesdays, Wednesday, and Thursdays. Fridays, however, tend to have lower morning volumes and slightly higher afternoon volumes than the other weekdays. In rural recreational areas, Mondays, like Fridays, can have substantially different volumes than the other weekdays. In other rural areas, Monday volumes tend to be similar to Tuesday through Thursday volumes. The procedures recommended in the TMG produce adequate estimates of AADT regardless of whether these days are included or excluded.

Should I compute factors for days that run from midnight-to-midnight or from noon-to-noon?

> The answer to this question depends on the data against which analysts will be factoring. If counts are routinely taken from noon to noon, then computation of the factors using noon-to-noon "days" is appropriate. If the "days" from short duration counts are always based on midnight start times (that is, the earliest hours of the data collection period are essentially discarded), then the "days" used in the factor computation should be based on calendar days. Analysis has shown that the use of either alternative has little impact on the AADT estimates.

Should I use data from this year, last year, or a combination of several years to compute factors for short counts taken this year?

The best factoring results are obtained if the factors being applied are for the same year as the short duration counts being factored. That is, a short count taken in 2000 should be factored with ATR data from 2000. This is done because significant events affecting the ratio of a short duration count to annual travel this year (e.g., a big snow storm) are accounted for in this year's ATR data. They were not present in last year's ATR data.

The drawback to using current year data for the factors is that computation must wait until the end of the year. States often wish to use AADT estimates from short counts taken during the current year before the end of the current year. One alternative is to create and use a "temporary" factor until the calendar year is complete. This factor is computed with the data from the previous 12 months. The "temporary" factor would be used until the "final" factors are computed. This "final" value would then be maintained as the annual estimate.

Another is to use more than one year of data to compute seasonal factors. However, this technique does not account for annual conditions that affect traffic when it is applied to short duration counts that are from a different year.

Perhaps, the simplest solution is to use the available AADT figure until a new one based on the current year factors is computed. **Factors based on "current year" data are recommended**.

How do I assign short counts taken in "rural" areas that are affected by urban traffic? Are they "urban" counts or "rural" counts?

There is no simple solution to this problem. These locations tend to have unique day-of-week patterns that reflect typical urban patterns on the weekdays, but rural patterns on weekends. Similarly, seasonal variation tends to be partway between the flat pattern found in most urban settings and the more varied "peak" patterns often found in rural areas. This occurs with commuter routes where the urban pattern extends outside the urban boundary. In most cases, analyst judgment is the answer.

One alternative is to take longer short duration counts. A week-long count will provide the data needed to account for the day-of-week variation without factors. The factor application then only has to adjust for the seasonal component. Another solution may be to install an ATR for that route. Another may be to apply the appropriate factors outside the group boundaries as a special case.

How many ATRs should be in a factor group?

There is no single answer to this question. Statistics and the desire to have factors that yield annual AADT estimates with ±10 percent accuracy with 95 percent confidence tend to require a factor group size of between 5 to 8 counters. A bare minimum of two counters is required to compute a standard deviation of the average factors that become the group factors. The standard deviation is used to estimate the reliability of the group factors. Recreational or special groups often have only a single continuous counter. Many States prefer to have additional counters to compensate for downtime and missing data problems.

CHAPTER 5
COORDINATING COUNT PROGRAMS

In the fiscal climate in which most State highway agencies operate, it can be very difficult to collect enough data to meet the needs of all its primary data users. One of the best mechanisms available for stretching the available data collection budget is to get all groups interested in traffic monitoring information to coordinate their data collection efforts and share their resulting databases.

WHY COORDINATE PROGRAMS

By coordinating traffic monitoring efforts between divisions within a State highway agency and with other roadway agencies, the following advantages can be obtained:

- More data are available to users at relatively little increase in cost (i.e., at only the cost of the coordination effort itself), since additional data are not being collected. The data already being collected are simply made more accessible.
- Duplication in the collection of traffic counts can be reduced or eliminated, thus either reducing the total cost of data collection or expanding the number of locations for which data are available for the existing budget.
- Resources can be more efficiently distributed to take advantage of each agency's capabilities and interests.
- Independent measures of traffic can be collected, allowing more effective quality control. This improves the quality of the traffic estimates provided to users.
- Expertise in traffic monitoring skills (equipment placement and repair, data processing, data reporting, etc.) can be identified, so that these human resources can be accessed quickly and efficiently when they are needed, resulting in better trained staff in all agencies, quicker problem resolution, and better, more reliable traffic counting programs for all cooperating agencies.

WHO TO COORDINATE WITH AND WHAT DATA CAN BE OBTAINED

Coordination of data collection activities and sharing of data resources often need to take place within the State highway agency as well as outside. It is quite common for multiple groups or divisions within a State highway agency to collect traffic data. Yet, in many cases, many of these data do not become available to other users within the agency.

For example, there are cases where the research program collects traffic data (volumes, classification and weights) that are not included in the agency's main traffic database and are therefore not available to other users. Another common example occurs when traffic control systems collect and store traffic volume and performance data, but those data are not made available as part of the central traffic database for the highway agency. Similarly, short duration data collection efforts are often taken to meet specific project needs, including pavement design inputs, traffic operations and control system improvements, or planning and programming efforts. Often these counts are used for their special project purposes and then discarded. Simply making sure these data are incorporated into the highway agency's primary traffic database may prevent a second data user from having to recount these same roadways.

Another excellent source of traffic monitoring information comes from the other jurisdictions that operate roadways in the state. Local jurisdictions (cities, counties, townships, etc.) almost always perform some level of traffic monitoring on roads they control. These data can provide two specific advantages to the State highway agency. First, they provide coverage on roads that are not already covered by the SHA data collection effort. Many of these counts are needed for the HPMS submittal. In addition, access to these data can often serve a variety of purposes. Larger jurisdictions often maintain sophisticated traffic monitoring programs. These can include permanent counters and vehicle classification counts. These data can be used to expand a State highway agency's knowledge of seasonal and time of day variation in vehicle movements.

In many cases, agencies that collect traffic monitoring data do not realize that they are collecting data that have value to other agencies. This is particularly true when the data are used for purposes other than traditional highway monitoring. Common examples of this are the following:

- commercial vehicle regulatory agencies that collect truck volume and weight statistics (how many trucks are passing an enforcement site, what those trucks weigh)
- environmental agencies that collect their own traffic counts as part of air quality and/or pollutant emission studies
- toll authorities that collect volume and vehicle classification data as part of their revenue collection process.

In each of these cases, these data collection efforts can supply data of significant value to the State highway agency. Data from the commercial vehicle regulatory agency can serve as excellent input for pavement design and rehabilitation efforts on the road on which they are collected. For example, if the data are collected extensively (e.g., they are collected throughout the year), these data can also be used to describe seasonal and day-of-week patterns in trucking movements, even though the presence of the enforcement activity will cause some bias in the data being collected.[15]

How to Make Coordination Happen

The difficulty with sharing data across agency divisions, as well as between different agencies, is that it requires a conscious effort to work outside of normal institutional communication channels. Thus, a specific communications effort that crosses these boundaries must be undertaken to learn about what data are being collected, determine how (and if) those data can be of use, and the best mechanism for obtaining those data.

This communications mechanism may start out as a specific, one-time effort (for example, a consultant contract). However, it needs to become an ongoing process. It does not need to be a large, ongoing activity. It can be a small part of an existing communications effort. For example, in many States "traffic management groups" consisting of traffic engineers from neighboring jurisdictions meet periodically to discuss all of the jurisdictional issues that affect the operation of road networks that cross jurisdictional boundaries. Some of these meetings include planned roadway improvements, coordination of traffic control systems, coordination of incident and emergency response actions. Data sharing opportunities can simply become one more item on the agenda of these existing groups. The availability of data that result from coordination and cooperation can then be broadcast to potential data users through the same mechanisms used to describe other cooperative jurisdictional efforts: newsletters, Web sites, announcements in meetings, etc.

Taking advantage of existing multi-agency groups can significantly improve the success of these data sharing efforts. For example, rural and metropolitan planning organizations (RTPOs and MPOs) are required by federal law to assist in the planning and programming of transportation projects that affect multiple jurisdictions. In many cases, these agencies already collect data from multiple agencies to support their planning function. In some areas, MPOs directly perform data collection under contract to individual agencies. In others, they simply use the data collected by their member jurisdictions. In either case, they are a logical agency to undertake the task of helping coordinate traffic data collection activities and to help ensure that data from these efforts become available to all potential users. Working with these agencies to achieve effective, efficient data sharing can help ensure the success of these efforts.

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[15] Weight data collected at an enforcement scale are often biased in comparison to "normal" truck weights, in that the data are likely to contain fewer overloaded trucks than normally exist. This is because drivers who know that their trucks are overloaded will avoid the enforcement site when it is open. However, the basic time-of-day, day-of-week, and seasonal volume patterns are likely to be representative of the patterns experienced by other similar roads, and the "biased" load data may provide accurate measures of the loads that specific road is experiencing.

Issues to Remember

While coordination and sharing of traffic data have great potential to benefit traffic monitoring, several key issues must be kept in mind if the coordination efforts are to produce the anticipated benefits. These issues include the following:

- Coordination is not free and does not happen automatically. It requires a continuing effort and commitment from the parties.
- Continuing communication between the data collection groups is necessary for the success of the on-going coordination effort.
- Efficient data transfer mechanisms need to be adopted.
- Shared traffic data must be carefully described to users so that they can be used correctly.

One of the primary reasons that traffic data are not shared between the groups that collect them (usually for a specific purpose) and the groups that could productively use them (for some purpose other than what they were originally collected for) is that the group that collects the data has no incentive to take the extra step(s) needed to make those data available to other users. Providing the necessary incentive must become the job of the group in charge of statewide or regional traffic monitoring.

In effect, the sharing of data between agencies or groups must be a win/win situation. Each agency must see some benefit in making the extra effort needed to share their data. In some cases, this means that one agency must provide external incentives (for example, funding, equipment, or staff time) to obtain data from another agency or group. Supplementary funding may be also appropriate to enhance an existing system so that it stores, summarizes, and reports data for later use that are already being collected but not saved. This typically occurs with older traffic control systems that collect but do not store data from surveillance systems.

In some cases, no incentives are needed to support data sharing. All that is needed is open communication to discuss common objectives and define data needs. For example, a county may operate a permanent traffic recorder. The State highway agency is probably not interested in the raw data from that device. Instead they are interested in simple summaries of data including AADT and AWDT values, and seasonal and day-of-week adjustment factors.

Open lines of communication allow cooperating agencies to learn:

- what data are available
- what needs to be done to obtain those data
- in what formats those data can be readily supplied
- where cooperative efforts can be most beneficial
- what improvements can be made to the data sharing process.

One common problem that must be surmounted is the need for a mechanism that allows easy transfer of both data and the location information that indicates where the data were collected. Geographic information systems (GIS) being adopted by many agencies allow for easier sharing of data. While not all GIS are directly compatible, it is usually possible to write conversion software that allows simple file transfers from one system to another. Sharing of traffic data via GIS also encourages different agencies to work toward making sure that their GIS are reasonably compatible, which improves the sharing of other vital transportation system related data.

As data sharing takes place, it is imperative that the new data made available to users be adequately described so that they can be appropriately used. For example, if the data being collected from a local agency are simple ADT values that have not been adjusted to represent AADT, these estimates must be described as ADTs, not AADTs. The agency leading the data sharing effort should work with all groups that collect data to determine the appropriate adjustment factors needed to compute and report AADT, AWDT, and other summary statistics of interest to users.

The issue of ADT values versus AADT estimates is a good example of the last communication issue that needs to be addressed in this report. When sharing data, it is necessary to ensure that each user understands what the data they are about to use represent. A key to this task is adopting a common set of terminology and procedures. In some States, a specific guideline is adopted on how traffic data should be collected, manipulated, and reported. In other States, jurisdictions have more freedom in how they collect data, but “meta-data” must accompany each data item reported, so that users have an accurate understanding of what the data they have obtained represent. The users are then responsible for ensuring that they use those data items correctly.

Efforts to create more standardization result in better data for the end user. The report “AASHTO Guidelines for Traffic Data Programs” (1992) provides an excellent reference for ensuring both the use of proper terminology and the correct manipulation of collected traffic data.

APPENDIX 2-A

ITS AND TRAFFIC MONITORING

One of the major emphases of the FHWA is the implementation of Intelligent Transportation Systems (ITS). Described simply, ITS involve the application of modern electronic and communication technologies to the business of moving people and goods. Most ITS applications involve the collection, analysis, and use of data obtained from sensors in the field to make better operational decisions. For roadway operations, this means the collection of volume, speed, lane occupancy, travel time, and other facility performance data to revise facility control strategies (changing traffic signal timing, detecting and responding to incidents) and improve the overall productivity of the facility.

From a traffic monitoring standpoint, ITS have the potential to be a substantial data resource. Because ITS tend to require current facility performance information to carry out their operational tasks, many ITS include the installation and operation of extensive surveillance systems. Luckily, the same data collected to make operational decisions can be used for a large number of other tasks within the transportation field, including (but certainly not limited to):

- operations planning
- maintenance planning
- safety analysis
- facility performance monitoring
- policy analyses
- congestion monitoring
- systems planning
- environmental analysis.

The Archived Data User Service (ADUS) is the part of ITS that focuses on re-use of ITS-generated data in other transportation activities. The National ITS Architecture includes this user service in the form of an Archived Data Management System (ADMS). This is a relatively new part of ITS which is in various stages of development in different States and regions. What ITS-generated data are archived and what form they are available depend on the stage of ADUS implementation. While ITS is oriented toward operations, ADUS provides an opportunity for those in traffic monitoring to benefit as well.

This Appendix briefly describes what ITS data can do for a traffic monitoring program and the steps necessary to access the data. The following material highlights the types of data that can be obtained from ITS, and the functions needed to obtain and make those data usable for a number of important purposes.

The most important aspect of gaining access to ITS data is for planners and other data users to be proactive in obtaining, interpreting, and archiving data collected by ITS. This means becoming involved as early as possible in the ITS system design process so that the data needs of these users can be understood and incorporated (at least as far as funding allows). Because ITS systems are heavily oriented toward the operation of facilities, the “secondary” uses of data developed by the systems are often unintentionally ignored. Data users must be proactive to alert system designers of the potential uses of these data and to ensure that data user needs are adequately expressed during the design and development process.

WHAT CAN ITS DATA DO FOR YOU?

From a purely practical standpoint, data from ITS can often fill significant holes in the traffic monitoring efforts of many State highway agencies. ITS, particularly the advanced traffic management systems (ATMS) that are designed to optimize the operation of heavily used facilities, can often supply a wealth of information in just those areas that are:

- the most important or that have the highest travel
- the hardest to count with traditional methods (because volumes are too high to place traditional portable counters and costs are too high to place permanent counters strictly for monitoring purposes).

` In addition, ITS often provide a wealth of traffic performance information beyond simple traffic volume measurements. Depending on the traffic surveillance technologies that are used, ATMS can provide the following:

- vehicle volumes
- vehicle volumes by various classifications
- vehicle and average speeds
- travel time measurements
- origin / destination patterns
- incident location, severity, type and duration
- a variety of more specialized data items.

These data items can be used alone or be combined with other data to measure the performance of important roadways (Hallenbeck and Ishimaru 2000), determine the usage of those facilities, and determine the long and short term effects of various transportation systems and travel demand management actions.

Another advantage is that most ITS operate continuously. Thus, at a minimum, many ATMS surveillance sites can serve as additional permanent traffic counting stations. This allows the ITS data to produce “traditional” computed quantities such as:

- day of week factors
- seasonal adjustment factors

- lane distribution values
- peak hour and peak period percentages
- design values for crowded urban facilities.

Consequently, ATMS (which often have surveillance locations at 1/2- to 1-mile spacings) can help reduce the need for both short duration and continuous counts in urban areas while providing accurate traffic measurements on important facilities. This can free data collection resources while providing excellent data for a variety of important analyses. It is worthwhile for agencies to examine the benefits that may accrue by storing ITS data, as well as by creating access to the stored data.

Consideration of data from ITS that deal with public transportation services and commercial vehicle operations suggests how broad the analyses are that ITS data can make possible. In addition to urban ATMS, other ITS, particularly advanced traveler information systems (ATIS), commercial vehicle operation systems (CVO), and advanced public transportation systems (APTS), can provide extremely useful traffic monitoring information. State highway agency personnel in charge of traffic monitoring activities need to be aware of all of the ITS being considered and/or constructed in their States to determine whether these systems can provide useful monitoring information.

CURRENT ITS CONDITIONS

There are no “mature” ATMS in the United States. Most if not all ATMS efforts are still in the design, development, and implementation stages. Many of these systems have been designed with little input or consideration toward the storage and use of data that are being routinely collected to make operational decisions. However, because the systems are still under construction and testing, data storage and access can be incorporated into the design and development of many. Modern computer technology even makes it possible to “add on” data storage and data access to older systems, without changing the basic operational software, by “eavesdropping” on data being transmitted from the field to an operations computer and then sending a copy of the data obtained to a computer specifically designed to provide data storage and access.

While only one of many possible system designs, this "add on" design fits well within the ITS National Systems Architecture and has the advantage of ensuring an extra layer of physical security between the computer providing data to outside users and the machine performing operational tasks. In addition, with this design, changes can be made to the data storage and access system without the operations computer being "touched." This may be important given the sensitivity of operations personnel to the security of their hardware and software systems. This design also allows upgrades to the data storage system to be made more easily if usage of the data becomes so high that a larger, more powerful computer is needed to hold and transmit the data.

AN APPROACH TO CREATING ITS DATA STORAGE SYSTEMS

There are three basic stages to constructing the systems necessary to gain access to ITS data. These stages are as follows:

1. acknowledging that the ITS data have value and that value can be obtained with only marginal expenditures of funds
2. initially designing the data storage and access system to meet user and data provider needs
3. repeating the system design, implementation, and refinement process to allow the data storage and access system to grow to accommodate new users and uses over time.

Creation of the Data Mine[16]

The first step necessary to make use of ITS data is to acknowledge that the ITS system primarily collects data for operational purposes and that the storage of those data once they have been initially collected is only a small additional cost that may produce very large benefits. That is, if the primary reason for collecting data was to create a database, the system would not be built because the cost of sensor installation and operation would be too high to warrant the system. However, these sensors and systems are being installed and operated because of the operational benefits that they provide. Once the sensor and communications systems have been built, the marginal cost of adding data storage and access functions (a “data mine”) is relatively small, and the worth of that “mine” far exceeds the cost of the database function.

Once it has been acknowledged that the “mine” (the data) is of value and that its value exceeds the cost of creating the “mine,” it is possible to determine the design and operation of the data mine.

Technical and Institutional Issues for the Data Mine

Once the decision has been made to build a data storage and access facility, the following issues must be resolved:

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[16] The phrase “data mine” (common in computer science and electrical engineering circles) can be used to describe the resulting ITS database systems. The concept is to store the ITS data in a way that the data itself can be viewed as “unrefined ore.” Processing of that “ore” can result in a variety of useful products, and different groups may process that “ore” very differently. Of course, an advantage of a data mine versus a conventional mine is that the data are not used up when the ore is processed and can in fact be used for multiple and different purposes. As a result, in many cases, the “database” application that stores the information generated by the ITS sensors is less important than the facts that the data are placed in an accessible location and that software is provided to users that allows them to access the data.

- What data will be stored in the mine?
- What quality control functions will take place to ensure that the data from the mine are accurate?
- How will the following communication tasks take place?
    - Telling possible users what data are available for use.
    - Describing to users what the data are and what they represent.
    - Describing to users how to physically get the data (i.e., providing a set of protocols and physical links).
- Determining the costs to develop and operate the mine and how the resources necessary for those operations will be made available.
- Determining who will do what with respect to the mine. (ITS often require cooperation, coordination, and integration across jurisdictional and institutional boundaries. Operation of the data mine may also cross those boundaries.)

Note that each of these issues has both technical and institutional aspects to it.

<u>Data to Be Stored</u>

The first task to is to determine what data will be stored in the data mine. From a technology perspective this means analyzing which data are being physically collected by the ITS surveillance systems, the frequency of data collection, the storage required to maintain the data, and the need for other data sources to make the collected data usable. For example, GIS base files allow location codes to be correlated with other data items. From an institutional perspective this means assessing the benefits that can be potentially produced by providing access to certain data items versus the potential for misuse of the data, along with the sensitivity of some data items.

The institutional issues of whether some collected data should be stored at all, and if they are stored, what access should be allowed to the data (who and by what mechanism) are often far more difficult to resolve and more important for the successful operation of the mine than the technical issues of what data can be physically collected and stored. Many ITS data items raise privacy and public policy concerns, requiring careful consideration of their potential uses before they are stored.

Storing some collected data (for example, probe vehicle information from cars that use toll tags) can present significant privacy problems. Agencies often refuse to store records that contain vehicle ID information. Because of laws that allow public access to public records, agencies that record toll tag IDs might be required to provide them to requesters creating a burden for the agency. Allowing outside access may also discourage vehicle owners from using the tags in the first place, reducing their effectiveness for their primary task, in this case high speed toll collection.

Unfortunately, omitting some data can reduce the effectiveness of the data mine. For example, removing the toll tag ID from a tag observation record prevents those records from being used to calculate travel times and information on vehicle O/D patterns, as well as a variety of other facility performance measures.

There are two major alternatives for cases in which privacy concerns limit the data that can be stored: the computation and storage of secondary statistics (travel times, O/D patterns) before the tag ID information is discarded; and the creation of a new record ID value that cannot be tracked to a specific ID tag but that serves the same purposes within the data mine.

The first alternative works well when the uses for the original data are well known. It is also helpful to include the computation of new statistics from the available raw data before the ID information is discarded. However, it is not possible to use historical data to compute these new statistics because the required ID data have already been discarded.

The second alternative is more complicated and requires more data storage, but it allows more creative use of the raw data. In this technique, a table is created (each day or another given time period) that matches a "real" ID with an "artificial" ID that will be stored in the data mine. This allows all records for a real ID for a given time period to be stored as an "artificial" ID. Once the conversion table has been destroyed (at the end of the given period), the "real" vehicle IDs cannot be traced from the "artificial" IDs stored in the database. It also becomes impossible to track a tag from one period to another. (That is, if the artificial IDs are reset every day, a given vehicle cannot be tracked from one day to the next.) However, a given "artificial" tag can be tracked throughout a given period within the data mine. This alternative allows the vast majority of statistics desired from the database to be computed while maintaining complete vehicle privacy.

Another issue that causes data to be omitted from a database is agency sensitivity to the data. One example of this type of data is video surveillance data. In many areas, accident scenes are not recorded with traffic surveillance cameras. This is not because surveillance cameras can't make such recordings but because the legal implications of having these recordings (dealing with subpoenas, the possibility of the recording being used against the agency in a liability case) outweigh the advantages of storing those images.

In other cases, agencies might not want to store items that might be useful for performance indicators (such as when incident responders are notified of an incident, and when they report reaching the scene) because of either their potential for misuse or because an agency does not want the performance of a specific item monitored. (For example, while the above incident response variables present the opportunity to monitor response time, their use could encourage responders to drive recklessly to an incident scene because they know that their jobs will be reviewed in part on this criterion. Those same data may also not accurately represent the true incident response time, in that many responders do not report when they arrive at the scene until after they have inspected the scene.)

The creation of the mine is further complicated by the fact that ITS data may need to be obtained from, or stored in, more than one computer. In many cases, more than one data mine can be created, each with a different set of useful traffic monitoring variables. These mines may be operated by different public agencies (often State highway agencies, but sometimes cities and counties, transit authorities, or even regional governments and metropolitan planning organizations). When multiple data collection/surveillance systems exist, and/or when these systems involve multiple agencies, a variety of both technical and institutional issues appear. These issues include the following:

- Will the data be stored by the agency that initially collects them, or will they be stored at a single location?
- Can the two sets of data be combined (either within the data mine or outside of the mine)? This usually implies the need for compatible location referencing systems.
- Who is in control of access to those data, the agency that initially collects the data or the agency that operates the data mine (if they aren't the same agency)?

In general, the data collected should be stored in the lowest level of aggregation that can be affordably maintained. This allows the data to be used for the widest possible number of analyses. It also allows the data to be reviewed for quality assurance purposes. The benefits of saving data at these low levels of aggregation must be balanced against the storage requirements for those data, the cost of accessing and maintaining those disaggregated values, and the abilities of users to work with the disaggregated data. (One possible compromise between saving disaggregated data and more highly aggregated data is to store the most disaggregated data only on a sample basis, whereas more highly aggregated levels of data are stored continuously.)

Most users do not need to see the data at their lowest levels of aggregation, and therefore summarized data also need to be provided in the data mine. This means that the mine must contain a data aggregation process and in many cases one or more levels of aggregated data. (Holding aggregated data speeds access to those data in comparison to calculating aggregated values "on the fly" each time they are requested.)

Including the aggregation process in the data mine is necessary because many potential users of the data will not have the time, knowledge, or tools necessary to correctly compute aggregated statistics from disaggregated data.[17] (For example, it is not possible to correctly aggregate data unless the user understands how to treat missing data in the aggregation process.)

In the end, because of the many uncertainties and concerns involved in the creation of ITS data mines, some agencies have elected to build the best system that the current technological and institutional constraints allow them to build. At the same time, they acknowledge that the system is still under construction and that changes to that system (in the data kept, the procedures followed, the access provided) can be expected

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[17] Of course, if disaggregated data are kept, users can perform research on improving the aggregation process using different methods for accounting for missing and invalid data. Conversely, if only aggregated data are kept, it is not possible to go back and look at how the aggregated data values were developed.)

over time as users become familiar with the operation and capabilities of the mine and as participating agencies become familiar with the analyses being performed.

Quality Control Functions

Once decisions on what data to store have been made, a process must be designed and implemented to ensure that only valid data are made available for use. This includes:

- creating procedures that determine that specific data are valid
- developing systems that handle the holes left when invalid data are removed
- providing mechanisms that allow users to report "suspicious" data
- having resources available to investigate those "suspicious" data
- being able to periodically revise the quality assurance system.

One of the intentions and advantages of the "data mine" concept is that the data can be made available to a variety of users. This is good in that when the data can fulfill a large number of uses, support is generated for the operation of the system. However, it is bad in that many of the data users will not be familiar with the intricacies of the data (or the data collection process), and therefore these users may not be able to perform their own "sanity" checks and the other quality assurance functions that are often performed by knowledgeable users as part of their analyses.

Consequently, the data mine itself must contain the quality assurance procedures that ensure that the data are accurate. Quality assurance steps may include:

- tests of sensor output
- checks against historical values
- checks against expected ranges of values
- any number of other comparisons.

Included in the quality assurance function are the data aggregation steps mentioned in the previous section. Handling missing and questionable data in the aggregation process is a technically difficult task that can have dramatic effects on the computation of aggregated statistics. Thus, the quality assurance process must look at both the individual data items and any aggregated statistics computed from the base variables.

The quality assurance function also includes steps that prevent users from accidentally misusing data (this is also part of the communications process described in the next section) by correctly labeling data and describing what they represent. It may also mean preventing some users from accessing some data items stored within the mine, either because the data have not been adequately checked for quality control purposes or because those data are not appropriate for specific types of analyses.

An example of "valid" data that should not be used by the "average" user is traffic volume estimates from stop bar detectors at intersections. Volume estimates from these detectors often underestimate the “true” volume because of the physical design of the loops (which tend to be long and thin, rather than square or circular) and the nature of the traffic that crosses them (which tends to be closely spaced, stop and go traffic, with multiple vehicles over the loop at any given time, as opposed to free flow conditions and gaps between vehicles crossing system loops). Yet stop bar volumes can be very useful for some traffic operations analyses, even if they should not be used blindly for something like VMT estimation.

Communicating what a specific variable stored in the mine represents is often a difficult task. However, it is vital to the use of the mine, as are several other communications issues.

Communications

Communication is the key to successful continued operation of the data mine. If users and potential users are aware of the mine, can access the data in the mine, and have the ability to slowly refine the operation of the mine over time to meet their needs, the mine will be heavily used and widely supported. This support is needed to maintain the revenue stream that allows operation of the mine and, consequently, provides access to the ITS data.

If adequate communications do not take place, history indicates that funding for operation of the mine will disappear as departmental budgets become tighter, and the data resource will cease to exist. As noted above, a variety of communications needs must be met for successful operation of the system. These include the following:

- telling possible users that the data exist so that they know that it is available for use
- describing to users what the data (stored variables) are and what they represent
- describing to users how to physically get the data (i.e., providing a set of protocols and physical links).

The first of these tasks is an outreach effort that must take place both within the organization that is building the ITS system and between organizations in the region. The nature of an ITS data mine is that it should be available for use by many groups (the State highway agency planning office, the district engineering office, the regional MPO, researchers at local and national universities, and private participants in the local ITS systems). Those interested in building the data mine must reach out to these groups to alert them of these data and to help them use the data. This process takes time and effort but is necessary to ensure support. It also must be a continuing process, since ITS will change over time. Thus, the outreach effort must keep users informed of changes, particularly with respect to the addition or subtraction of new types of data, new surveillance system locations, and new mechanisms for obtaining data.

Once potential users know that the ITS data resource exists, they have to be taught about the data, including what data exist (as well as what levels of aggregation are available), how those data are collected, what they represent, and suggested ways to use them. The AASHTO standards of "truth in data" (that is, labeling the data for what they are) must be applied, and training materials to help new users get started, as well as support systems to help users when they have problems, must be provided. The support system should also be used to provide feedback on system refinements.

Finally, the data mine must have protocols and physical links that allow users to obtain the data with relative ease. These may include building and giving away software that allows users to access the data mine, or creating summary files (on CD-ROM or other media) that contain data summaries that are useful to potential users. As technology changes and as users provide feedback, these links (physical and logical) will likely change over time. The communications protocols selected must be capable of handling these changes, and the outreach mechanism used must be capable of communicating them to data mine users.

Costs

Three issues must be addressed in examining the cost of the data mine:

- the cost of constructing the mine
- the cost of operating the mine
- the distribution of those costs among users.

Construction of the mine is the simplest issue, if only because it is primarily a series of technical questions. To develop such a cost, the available ITS data that will be included in the system must be determined. Then the potential users of the system should be gathered, and they and ITS data mine developers should look at the possibilities for the mine itself. Answering the basic questions discussed briefly above (What data will be collected? What types of data do they need? What type of access do they need? What type of communications already exist within the ITS functions of the region?) will allow a basic design to be developed and costs estimated.

Operations costs are more difficult to deal with because many of these costs are bound up in the operational ITS systems that are the basis for the data mines. The data mine, as any database system, will require staff and resources for routine operations and upkeep. Depending on the system design, this may or may not be a significant cost. Similarly, depending on how access to the mine is provided (CD-ROM versus on-line, Internet style access), the communications costs for physically accessing the data could range anywhere from fairly small to fairly large.

Operations costs for bringing data into the system are likely to be higher than the costs for providing access to the data once they are in the mine, since on average, more data are expected to flow into the mine than out of the mine. (The summary statistics that are pulled out will be much smaller than the raw data that are put in.) However, as with the data access costs, these costs will vary considerably, depending on the design of the system. Very little communications cost is associated with a system that requires only a wire from the operations computer to a data server sitting next to it. A system that requires a fast Internet connection to obtain large quantities of operations data from multiple, remote, operations computers will have much higher costs.

Allocating these costs among users can be a difficult political question. Costs can be absorbed by those who operate the ITS systems supplying the data (since one of the major users of the stored data should be the operators of those facilities being monitored), or they can be split among the agencies that desire access to those data sources. Finally, in some regions (where State and local laws allow it) groups can be charged for accessing the data, and those fees can be used to help offset the cost of operating the data mine. These decisions will need to be made on a case by case basis, taking into account the political and fiscal realities of the region in question.

Agency Responsibilities

Allocating agency responsibilities, like allocating costs, must be done at the local level. Which agencies are willing and/or able to perform the various tasks that must be accomplished to build, operate, and maintain the data mine is a function of the structure of the ITS system that supplies the data, as well as the political/organizational structure of the agencies in the region.

In some areas of the country, the State highway agency will take on the primary functions, either using its own staff or hiring contractors to perform those tasks. In other parts of the country, the regional MPO will take on these tasks as part of its regional coordination responsibilities.

The primary requirements are that all participating agencies understand their responsibilities, that they agree and commit to performing those responsibilities, and that all of the important functions of the data mine are accounted for within those responsibilities. It is not important to specify whether public agency or contract staff perform these tasks, only that specific functions take place, take place correctly, and take place in a timely fashion.

It is also important that a structure be designed (usually as part of the communications process discussed above) to allow problems to be identified and solutions to those problems to be developed and implemented. This may mean a formal committee structure (with participating agencies), or a less formal structure, such as including the subject of the data mine in ongoing, regional meetings on other traffic issues, or including a “problem submittal” capability in the communications medium participants used to access the data mine.

Iterative Development Process

One of the confounding problems with ITS is that the systems are so new and different that as they come on-line, system users and operators need to change the ITS operation, both to take advantage of previously unavailable opportunities and to remove functions that prove to be ineffective. Thus, ITS project implementations often require several iterative loops, as feedback from early system development and deployment is used to refine system design and operations.

In the same manner, the design, development, and use of an ITS data mine will be iterative. As more people become aware of the possibilities of ITS data, changes in access, data storage methods, and calculated quantities will likely be necessary to more effectively deal with these user needs. Similarly, changes in technology may cause new mechanisms to become appropriate for obtaining and/or disseminating information. A good illustration of this process is the growth of the Internet and the resulting changes in how information is delivered and exchanged. Another change is the constantly decreasing cost of computing power and data storage. These changes make the storage and retrieval of data much easier and less costly than in the past, and if this trend continues, that may affect what data can be cost effectively stored in the data mine.

Operation of the data mine may reveal needs to change the preliminary quality control process (either because it is too restrictive or because it allows user access to poor quality data). Organizational sensitivity to data changes over time, both as initially unexpected uses of the data surface and as demand for specific data items becomes apparent. Often, restrictive data access policies are relaxed once sufficient safeguards have been developed or as organizational sensitivities to data change. Having outside entities access data may also change an organization's philosophy of what data can or cannot be stored. All of these issues can result in the need to change the basic structure of the data mine.

In the developmental phase of a data mine, it is important to realize that some of these changes will probably take place and to simply plan for these possibilities in the design process. Similarly (and as part of the communications process), it is important for potential data users to participate early in the design process so that their needs will be considered.

At an absolute minimum, the mine must be allowed to grow over time. The surveillance systems used by most ATMS systems are expected to grow geographically and sometimes technologically (i.e., by adding new types of surveillance sensors) over time. This growth must be accommodated in the design of the mine. Changes in the scope of the available data must be seamlessly handled and passed on to users. This will allow users to take advantage of the growth as it occurs and will allow the benefits of the expanding ITS efforts to be incorporated into the region's traffic monitoring process.

APPENDIX 2-B
SEASONAL GROUP DEVELOPMENT USING CLUSTER ANALYSIS

The computer printout tables included in this appendix were produced by the SAS (Statistical Analysis System) package on a microcomputer. For a description of SAS procedures refer to the SAS User's Guides (SAS Institute, Inc Ref. 1 and 2). The SAS statistical procedures are also available for minicomputers or mainframes. Other statistical packages can also be used to conduct the analysis.

Table 2-B-1 describes the continuous ATR data used in the example. The first column presents the observation number (OBS), followed by station number (STNUM), the monthly average daily traffic from January thorough December (Ml to M12), the functional class (FUNC), the AADT, and the coefficient of variation of the monthly values as a percentage (MCV). In the table, the monthly traffic peaks are underlined.

Table 2-B-2 presents the monthly factors (F1 to F12) computed as the ratio of MADT to AADT in the same format as Table 2-B-1, followed by the functional class (FUNC), the average of the factors (MFAC), and the coefficient of variation (CV). The cluster analysis is carried out using the monthly factors, because using the monthly traffic values allows the large volume differences between the stations to impact the cluster formation and invalidate the analysis. As can be seen by examining the variation coefficients from the two tables, the numbers have changed somewhat (due to the data transformation) but the variation picture does not change.

Table 2-B-3 shows statistical information produced by the cluster program and used to evaluate the cluster formation. An understanding of this page is helpful but not necessary to interpret the results of the clustering. A complete explanation of the statistical terminology and procedures is provided in the SAS User's Guide listed in the references.

Table 2-B-4 presents a dendogram or graph of the cluster formation. An understanding of this graph is necessary to select the clusters and an explanation is provided in the SAS references. The station location numbers (STNUM) are presented at the top. The semi-partial R-squared values gained during cluster formation are shown along the x-axis. The blank columns in the graph indicate the cluster breaks. In this example, the first two clusters (separated by the highest blank column) consist of the first 14 and last 6 stations. The third cluster break separated station 14. The fourth separated stations 20 and 15 from the previous group. The process continues until each station is in an individual group at which point all of the variation is explained.

Table 2-B-1: Cluster Analysis Monthly ADT

Cluster Analysis
Continuous ATR Data
Monthly ADT

OBS	STNUM	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	FUNC	AADT	MCV
1	6	15333	17594	16111	16131	17668	18311	20981	21460	20809	22114	17929	16867	1	18442	12.6
2	9	32804	34095	36175	41362	47371	49410	50445	50431	42124	41530	44345	38398	1	42374	14.7
3	18	25424	26269	28001	30186	33693	37683	45575	46661	38521	36077	31847	30643	1	34215	20.3
4	20	11372	11627	13529	15827	18847	22660	28528	19564	15411	13354	11978	14471	2	16431	31.4
5	15	16480	19060	20797	24846	28779	37099	48206	45510	37253	28074	20789	20824	2	28976	36.8
6	5	3785	3188	4206	3147	4671	4872	4572	4781	4835	4768	4445	3772	6	4254	14.9
7	2	2820	2902	2953	3359	4054	4566	5990	5910	4398	4033	3450	3059	6	3958	27.8
8	14	1570	1778	1013	1070	2650	2668	2768	2742	2590	2545	2180	1975	7	2129	30.2
9	26	43544	45043	45822	46704	47865	49329	51554	45851	47108	43581	46240	49501	11	46845	5.1
10	22	63980	66140	71135	75364	77367	77706	75087	77275	76569	76368	73924	68590	11	73292	6.4
11	60	34276	33817	37513	40193	43226	45610	46000	46528	46499	42912	40973	39138	11	41390	11
12	7	13230	13076	14694	16721	18969	21338	24895	26296	22159	19101	17303	16024	11	18651	23.2
13	8	49576	49554	54095	54992	56945	59423	57404	60159	57560	58489	56035	55045	12	55773	6.1
14	19	37879	37977	40989	41970	41753	45023	43756	45391	44822	46168	43325	41780	12	42569	6.4
15	16	20370	19204	21015	21657	22618	24109	24797	25618	25341	23777	22923	22024	12	22788	8.9
16	1	8067	8259	8846	9165	10183	10155	9466	10026	9851	9745	9413	9374	14	9379	7.4
17	13	7244	7305	7848	8183	8589	8765	8570	8885	9039	8895	7724	8090	14	8261	7.6
18	3	6574	6497	7175	7624	7629	7936	7600	8670	7909	7686	7561	7418	14	7523	7.8
19	4	4494	5390	5531	6061	7021	6157	7739	7728	7653	7995	6619	5528	14	6493	17.6

Table 2-B-2: Monthly Factors

Cluster Analysis
Continuous ATR Data
Monthly Factors

OBS	STNUM	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	FUNC	MFAC	CV
1	6	1.2	1.05	1.14	1.14	1.04	1.01	0.88	0.86	0.89	0.83	1.03	1.09	1	1.01	12.2
2	9	1.29	1.24	1.17	1.02	0.89	0.86	0.84	0.84	1.01	1.02	0.96	1.1	1	1.02	15.2
3	18	1.35	1.3	1.22	1.13	1.02	0.91	0.75	0.73	0.89	0.95	1.07	1.12	1	1.04	19.3
4	20	1.44	1.41	1.21	1.04	0.87	0.73	0.58	0.84	1.07	1.23	1.37	1.14	2	1.08	25.9
5	15	1.76	1.52	1.39	1.17	1.01	0.78	0.6	0.64	0.78	1.03	1.39	1.39	2	1.12	33.5
6	5	1.12	1.33	1.01	1.35	0.91	0.87	0.93	0.89	0.88	0.89	0.96	1.13	6	1.02	16.9
7	2	1.4	1.36	1.34	1.18	0.98	0.87	0.66	0.67	0.9	0.98	1.15	1.29	6	1.07	24.6
8	14	1.36	1.2	2.1	1.99	0.8	0.8	0.77	0.78	0.82	0.84	0.98	1.08	7	1.13	41.7
9	26	1.08	1.04	1.02	1	0.98	0.95	0.91	1.02	0.99	1.07	1.01	0.95	11	1	5.06
10	22	1.15	1.11	1.03	0.97	0.95	0.94	0.98	0.95	0.96	0.96	0.99	1.07	11	1	6.84
11	60	1.21	1.22	1.1	1.03	0.96	0.91	0.9	0.89	0.89	0.96	1.01	1.06	11	1.01	11.6
12	7	1.41	1.43	1.27	1.12	0.98	0.87	0.75	0.71	0.84	0.98	1.08	1.16	11	1.05	22.8
13	8	1.13	1.13	1.03	1.01	0.98	0.94	0.97	0.93	0.97	0.95	1	1.01	12	1	6.44
14	19	1.12	1.12	1.04	1.01	1.02	0.95	0.97	0.94	0.95	0.92	0.98	1.02	12	1	6.63
15	16	1.12	1.19	1.08	1.05	1.01	0.95	0.92	0.89	0.9	0.96	0.99	1.03	12	1.01	9.13
16	1	1.16	1.14	1.06	1.02	0.92	0.92	0.99	0.94	0.95	0.96	1	1	14	1.01	7.86
17	13	1.14	1.13	1.05	1.01	0.96	0.94	0.96	0.93	0.91	0.93	1.07	1.02	14	1.01	7.83
18	3	1.14	1.16	1.05	0.99	0.99	0.95	0.99	0.87	0.95	0.98	1	1.01	14	1.01	8.02
19	4	1.44	1.2	1.17	1.07	0.92	1.05	0.84	0.84	0.85	0.81	0.98	1.17	14	1.03	18.8
20	12	1.19	1.19	1.03	0.98	0.94	0.88	0.98	0.96	0.91	0.94	1.03	1.06	16	1.01	9.81

Table 2-B-3 Ward's Minimum Variance Cluster Analysis

Ward's Minimum Variance Cluster Analysis
Eigenvalues of the Covariance Matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	0.136135	0.072741	0.586741	0.58674
2	0.063393	0.048811	0.273226	0.85997
3	0.014582	0.007335	0.062848	0.92281
4	0.007247	0.003818	0.031234	0.95405
5	0.003429	0.000509	0.014777	0.96883
6	0.00292	0.000804	0.012585	0.98141
7	0.002116	0.001131	0.009119	0.99053
8	0.000985	0.000503	0.004243	0.99477
9	0.000481	0.000078	0.002074	0.99685
10	0.000403	0.000159	0.001736	0.99858
11	0.000244	0.00016	0.001053	0.99964
12	0.000084		0.000364	1

Root-Mean - Square Total – Sample Standard Deviation – 0.13905
Root Mean – Square Distance Between Observations – 0.681202

Number of Clusters	Clusters	Joined	Frequency of New Cluster	Semipartial R-Squared	R-Squared Tie
19	8	19	2	0.000387	0.999613
18	22	1	2	0.001211	0.998402
17	CL19	3	3	0.001369	0.997033
16	CL18	13	3	0.001578	0.995455
15	60	16	2	0.001741	0.993715
14	CL16	CL17	6	0.001778	0.991936
13	CL14	12	7	0.003005	0.988931
12	18	7	2	0.003399	0.985532
11	CL13	CL15	9	0.006515	0.979017

Table 2-B-4: Cluster Analysis Dendogram

CLUSTER ANALYSIS
(Continuous ATR Data)
Ward's Minimum Variance Cluster Analysis

STNUM

```
                            2   2       1        1       1     6   1   1            2    1   1
           6   4   9   5    6   2   1   3    8   9   3   2     0   6   8    7   2   0    5   4

    0.45  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
          |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
          |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXXXXXXXX
    0.40  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXXXXXXXX
S         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXXXXXXXX
e         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXXXXXXXX
m   0.35  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXXXXXXXX
i         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXXXXXXXX
p         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXXXXXXXX
a   0.30  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
r         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
t         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
i   0.25  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
a         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
l         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
    0.20  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
          |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
R         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
-   0.15  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
s         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
q         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
u   0.10  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
a         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
r         |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXX     .
e   0.05  |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXX     XXXX     .
d         |XXXXXXXXXXXXXX   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXX      .   .   .
          |XXXXXXXXXXX   .   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXX     .    .   .
          |XXXXX   .   .    .XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXXXXX     .    .   .
    0.00  |    .   .   .    .XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX   XXXXXXX    XXXXXX     .    .   .   .
```

Cluster analysis is used to determine the natural groupings in the data, in this case reflective of the seasonality from month to month. These groupings are based on the variation in the data. The differences between groups and stations within groups can be very large or hardly detectable depending on the natural variability existing in the stations. The cluster program computes the differences in groups or group membership using fixed mathematical algorithms without seeking an explanation. The process is completely driven by the variability in the data without other considerations. The cluster program will always create groups and assign all the stations to groups without recognizing the size of the differences between and within clusters. Stations will be assigned to a group because the program must make an assignment.

The results of the cluster analysis are not the ultimate groups or group assignment. Modifications are to be expected. Statistical programs are tools used by a trained analyst to understand the variation of data. The development of the final factor groups must account for variability but must also include characteristics that define the groups and allow the assignment of short counts to the groups. Caution and judgment are necessary to interpret the results of the cluster analysis.

The basic intent of the cluster analysis is to identify variation patterns to give the analyst the knowledge and insight to develop grouping criteria to expand short counts to AADT. Since the cluster analysis program groups only on variation, it provides no definable characteristic or criteria upon which to form groups. The establishment of the factor groups requires knowledge of the variation, the determination of relevant criteria (functional class, geography, topography, degree of urbanization, etc.), and the use of analytical judgment to make the necessary trade-offs.

Table 2-B-5 presents the four cluster breaks as extracted from Table 2-B-4. Examining the location of the stations and groups on a map is very helpful in identifying or distinguishing the characteristics of the patterns. In this example, the cluster program has identified the patterns and singled out the extreme variation stations, but no criteria for assignment of short counts to the groups has been defined. This is where the descriptive analysis and the use of functional class, geography, or topography are needed to provide adequate criteria for group formation.

Table 2-B-5: Cluster Analysis Example

Cluster 1	ATR Number	Functional Class
	6, 9	1
	5	6
	4	14
Cluster 2	ATR Number	Functional Class
	22, 26, 60	11
	8, 16, 19	12
	1, 3, 13	14
	12	16
Cluster 3	ATR Number	Functional Class
	18	1
	2	6
	7	11
Cluster 4	ATR Number	Functional Class
	15, 20	2
Cluster 5	ATR Number	Functional Class
	14	7

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Section 3

Traffic Volume Monitoring

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TRAFFIC VOLUME MONITORING

CHAPTER 1
INTRODUCTION

The measurement of traffic volumes is one of the most basic functions of highway planning and management. Traffic volume counts provide the most commonly employed measure of roadway usage and are needed for the majority of traffic engineering analyses. While a number of traffic volume statistics are used in traffic engineering analyses, two are of primary interest for the design of a statewide traffic monitoring program: annual average daily traffic (AADT) and average daily vehicle distance traveled (DVDT).

AADT describes the number of vehicles that traverse a road at a specific point on the road system. DVDT describes the travel usage of an entire segment of roadway. DVDT is computed by multiplying the length of a roadway segment by its AADT. AADT is the primary traffic input to most traffic engineering analyses. DVDT is the primary measure for describing roadway usage for an entire system or network of roads.

The primary objective of this section is to describe how to structure statewide traffic monitoring programs to compute AADT and DVDT estimates.

TRAFFIC VOLUME DATA COLLECTION

For many years, the traditional approach to the development of annual average daily traffic (AADT) had consisted of three different but complementary types of traffic counts: continuous, control, and coverage (Federal Highway Administration 1970).

Continuous counts are taken 365 days a year at a small number of locations. These counts provide a variety of useful information. Because these counts are most consistent and are maintained at permanent locations, the FHWA summarizes the information in a monthly Travel Volume Trends (TVT) report.

Control or seasonal counts are much more difficult to characterize because different State planning organizations perform these counts differently. These counts are usually taken from two to twelve times a year, for periods of time ranging from 24 hours to two weeks. The main purpose of control counts was to help identify traffic patterns on specific roads in order to help place those roads into seasonal adjustment factor groups. Control counts can also be used to compute highly accurate measures of annual average daily traffic at specific locations, and are very effective in high growth or recreational areas. The 1985 version of the TMG did not utilize control counts for the development of grouping procedures or for AADT estimation.

Coverage counts are short duration counts, ranging from six hours to seven days, distributed throughout the system to provide point-specific information and area-wide coverage. Coverage count programs also vary considerably, as the diverse requirements and constraints faced by State highway agencies have translated into divergent programs. Many States have implemented coverage programs that feature relatively long (2 to 7 days) traffic counts, but where only a part of the State is counted every year. Other States have emphasized complete coverage of the highway systems each year, resulting in a large number of short duration (usually 24 or 48-hour) counts.

OBJECTIVES OF THE TRAFFIC VOLUME MONITORING PROGRAM

The traffic monitoring program described in this section was designed to meet the following objectives:

- collect data needed by users as efficiently as possible (including both point estimates and summary variables derived from those point estimates)
- provide a mechanism for collecting data needed on “short notice” (that is, data that cannot be collected as part of a program planned six months or more in advance) as efficiently as possible, and ensure that these data are still made available to all users
- ensure that all reliable traffic data collected within the State highway agency are made available to users.

ORGANIZATION OF THIS SECTION

The section consists of four chapters. Chapter 2 discusses the needs of users and the steps highway agencies should undertake in order to meet those needs. Chapter 3 presents a framework for collecting the traffic volume data needed to meet user requirements. It also discusses the data processing steps necessary to translate data into information. Chapter 4 presents a ramp counting technique that can be used to estimate traffic volumes on high volume freeway sections where portable traffic counters cannot be placed. Finally, an appendix answers frequently asked question about the design of traffic counting programs and/or the handling of traffic volume data.

CHAPTER 2
USER NEEDS

The measurement of traffic volumes is one of the most basic functions of highway planning and management. Traffic volume counts are the most common measure of roadway usage, and they are needed as an input to the majority of traffic engineering analyses. A key to making the traffic monitoring process valuable to the highway agency's decision makers (a requirement for adequate funding for traffic monitoring) is the ability of the traffic monitoring program to supply users with the data they need. The ease of access to and the quality of the data provided directly affect the level of support users provide to the data collection activity. At the same time, the adage "you get what you pay for" is often true of traffic monitoring information. However, even with limited data collection budgets, good communication between data users and data collectors can result in data summaries that meet the needs, if not always the desires, of the data users.

This chapter discusses very briefly some of the uses that State agency personnel have for traffic data. It is intended to start the communication process by helping data collectors begin to understand how data may be used and, thus, what summary statistics are needed. Data collection personnel are encouraged to expand on this beginning by actively investigating the data needs of their agency and then working creatively to meet those needs.

USES FOR TRAFFIC VOLUME DATA

A number of traffic volume statistics are used in traffic engineering analyses. The statewide traffic monitoring program concentrates on the estimation of annual average daily traffic (AADT) and then the computation of average daily vehicle distance traveled (DVDT) from that AADT value. In addition to VDT calculations, AADT is used in a wide variety of analyses such as calculating:

- exposure rates as part of safety analyses,
- vehicle loadings as part of pavement design,
- vehicle use as part of revenue forecasts
- statistics used by the private sector for placement of businesses and services.

AADT is not the only useful traffic volume statistic. Users commonly request a wide variety of other traffic volume statistics, and a good traffic monitoring program should collect, store, and report those additional statistics in order to meet those needs. In particular, whenever possible, **traffic monitoring programs should collect (at a minimum) hourly volumes by direction (and lane)** since these statistics are commonly used by analysts who must look at operational characteristics of the roadway at different times of the day. Examples of the uses of these lower aggregation volume statistics include:

- traffic signal timing
- air quality analysis
- noise analysis
- planning studies
- planning of the timing of maintenance activities.

To meet user needs, the highway agency should report, at a minimum, the following statistics:

- AADT,
- AAWDT, annual average weekday daily traffic (for roads where weekday traffic is more important than weekend traffic)
- peak hour volumes
- peak period volumes (where the highway agency must also define the duration and timing of the peak period)
- truck volumes and/or percentages (see Section 4)

Data users should also be able to easily obtain adjustment factors that apply to traffic counts taken at each location. These include:

- day-of-week factors
- seasonal adjustment factors
- axle correction factors, and
- growth factors.

All of these statistics can be measured or estimated using the data collection framework discussed in this section.

MEETING USER NEEDS

Collection of data is only useful if those data are processed and the resulting summary statistics are made readily available to users. Users require access to these traffic data in a variety of forms, including both the summary statistics discussed above and the raw data collected from the field. Meeting user needs is further complicated by the fact that many data users are not familiar with the available data resources. Developing a mechanism that users can access to learn what data are available, and how those data can be obtained, is a key component for getting users to take advantage of data already collected by the highway agency.

These “data discovery” mechanisms are becoming more “user friendly” as computer technology and power continues to increase. Each State highway agency should use a fully computerized system to maintain its traffic monitoring data. This system should download data from the field, perform the necessary quality assurance checks to ensure that the data are valid, allow the data to be edited as necessary to remove invalid data, summarize the raw data as appropriate, store the data, report the summary statistics, and allow retrieval of both summary and raw data as needed.

Many highway agencies link their traffic databases to other agency databases through geographic information systems (GIS) and other relational tools. GIS systems are particularly effective means for helping users identify and obtain available traffic information. New Internet technologies that allow remote access to GIS based traffic databases offer even wider distribution of collected traffic data, and can significantly increase the use and utility of traffic data collected by the highway agency. These tools allow users to determine the availability of traffic statistics and then access those data via simple interfaces. In addition, some States have developed CD-ROM based data distribution systems (Florida DOT) that allow users to obtain traffic statistics without having to have web access.

Routine reporting systems (and reports) should be part of this computerized process. Three key reporting capabilities are needed to meet FHWA traffic data requirements. These include the annual reporting of HPMS traffic statistics, the monthly transmittal of hourly ATR records (used to produce the monthly Traffic Volume Trends report), and the annual reporting of WIM data. The standard formats used to perform the ATR and WIM data transmittals are shown in Section 6. The HPMS Field Manual presents information on how to submit HPMS data.

Transmission of the HPMS sample data is particularly important since it is used for a variety of important national and State level analyses. HPMS is unique in that:

- all States collect the HPMS data,
- the HPMS sample design process is the same for all States maintaining national consistency,
- the HPMS database is reasonably comprehensive, and
- there are a number of significant analytical tools available for using the HPMS data.

The HPMS mileage and travel estimates are used in the apportionment of Federal-Aid funds. However, the HPMS data are also used in a number of key analytical tools. These include the HPMS analytical package, the Highway Economic Requirements System (HERS), and the ITS Deployment Analysis System (IDAS), as well as a host of State-specific planning and performance modeling systems.

Finally, all highway agencies require flexible output reporting capabilities in order to meet the wide variety of project level data needs. Traffic data are required to meet the specific analytical tasks associated with all manner of transportation engineering functions (planning, design, operations, maintenance.) In many cases, these analyses require only general statistics (AADT) collected as part of the general data collection program. However, other projects require access to the summary statistics described above, as well as raw data from the field, or special statistics designed to meet specialized project needs.

CHAPTER 3
TRAFFIC VOLUME DATA COLLECTION DESIGN

Previous sections have presented general discussions of the need for a systematic approach to traffic counting in order to reliably account for traffic variability. This systematic approach also improves the statistical reliability of traffic estimates, and it allows integration of multiple traffic counting efforts into a more efficient system. The traffic volume data collection program presented in this section consists of three major elements:

1. a limited continuous count element,
2. an extensive coverage count element, and
3. a flexible special needs element.

This basic framework provides a flexible but comprehensive approach to traffic data collection that allows each highway agency to account for its individual needs and limitations, while providing a very robust data set to meet data user needs.

The procedures presented below are intended to help highway agencies refine their traffic volume data collection efforts to obtain both the system and point estimates they need as efficiently as possible. Although the proposed program does not make use of control or seasonal count programs, these counts can be included in an agency's special needs element, if those counts provide a cost effective means of meeting an agency objective.

In addition, highway agencies are encouraged to look for ways to obtain traffic volume information from a variety of sources to supplement data collected as part of the statewide monitoring program. In many highway agencies, more than one division of the agency collects traffic volume data. In many cases, not all of these data are stored in the central traffic database available to all data users. This often results in duplication of data collection efforts, as one division must collect data at a location where data have already been collected by another division. In many States, agencies other than the State highway agency collect traffic volume information. These groups may include toll authorities, other State regulatory or operating authorities (such as U.S. Customs), as well as local jurisdictions.

Obtaining traffic data already collected by these groups eliminates the cost of having to count those locations, helps foster a stronger working relationship between these diverse groups, and improves a State highway agency's knowledge of the use of its roadway system. As a result, the integration of the data collection efforts performed by different agencies and agency divisions is highly recommended.

SHORT DURATION VOLUME COUNTS

Short duration traffic volume counts are traditionally the primary focus of most statewide traffic monitoring efforts. They provide the majority of the geographic diversity needed to provide traffic volume information on the State roadway system.

The recommended short duration volume counting program is divided into two primary subsets, coverage counts and Special Needs counts. The coverage count subset covers the roadway system on a periodic basis to meet both point-specific and area needs, including the HPMS reporting requirements. The Special Needs subset comprises additional counts necessary to meet the needs of other users. This second category of counts can be further subdivided into counts taken to meet State-specific statistical monitoring goals, to provide increased geographic coverage of the roadway system, and to meet the needs of specific project or data collection efforts.

This chapter also discusses the adjustment factors that must be applied to all short duration counts to develop unbiased estimates of annual average conditions. These adjustments include day-of-week, month, axle correction, and growth (to develop annual estimates for those road segments that are not counted during the current year).

Coverage Count Programs

Coverage counts are needed to ensure that adequate geographic coverage exists for all roads under the jurisdiction of the highway authority. In simple terms, "coverage counts" are data collection efforts that are undertaken to ensure that "at least some" data exist for all roads maintained by the agency. How much data should be collected to provide "adequate geographic coverage" is a function of each agency's policy perspective. Some State highway agencies consider "adequate" a week-long count every seven years with data recorded for every hour of each day. Others consider "adequate" a 24-hour count every year, with no hourly records. Obviously, significant utility can be gained from having at least hourly volume estimates at coverage counts, since that data can be used to obtain a much more accurate understanding of traffic volume peaks during the day.

The spacing between coverage counts in a roadway is also subject to agency discretion. The primary objective is to count enough locations on a roadway so that the traffic volume estimate available for a given highway segment accurately portrays the traffic volume on that segment. Generally, roadway "segments" are treated as homogenous traffic sections (that is, traffic volumes are the same for the entire segment.) For a limited access highway, this is true between interchanges. However, it is also true for all practical engineering purposes for a rural road where access and egress along a ten-mile segment is limited to a few driveways and low volume, local access roads. **Highway agencies are encourage to examine existing traffic volume information to determine how best to segment their roadway systems in order to optimize the number and spacing of coverage counts.** A rule of thumb that has been used in the past to define these traffic count segments is that traffic volume in each roadway segment be plus or minus 10 percent. Breaking the system into very large segments reduces the number of counts needed but also the reliability of the resulting traffic estimates for any given section of that large roadway segment. Use of small segments increases the reliability of a specific count but also the number of traffic counts needed.

The character of the road systems and the volumes carried have a major impact in the definition of segments. For roads where access is controlled (such as the Interstate system), a simple definition of segments between interchanges is appropriate. For lower systems, clear traffic volume breaks are not always apparent and other rules of thumb (such as major intersections) must be applied. Rural and urban characteristics also require different handling. For the lowest volume roads, the 10 percent rule of thumb may be too narrow and a wider definition sought. Careful definition of roadway segments can significantly reduce the number of counts needed to cover all highways within an agency's jurisdiction, while still providing the accurate volume data required for planning and engineering purposes.

Once roadway segments are finalized, **the FHWA recommends, as a general rule, that each roadway segment be counted at least once every six years.** This ensures that reasonable traffic volume data are available for State needs, and that all roadway segments are correctly classified within the proper HPMS volume groups when State highway agencies compute statewide VDT as part of their required federal reporting.

Not all count locations should be counted on a six-year basis. Some count locations need to be counted more often. Other roads can be counted less frequently without loss of volume estimate accuracy. In general, roadway sections that experience high rates of growth require more frequent data collection than those that do not experience growth. Therefore, roads near growing urban centers and expanding recreational sites tend to need to be counted more frequently than roads in areas where activity levels have hardly changed for many years. Counting roads more frequently in volatile areas also allows the highway agency to respond with confidence to questions from the public about road use (a common concern in high growth areas), and ensures that up-to-date statistics are available for the roadway design, maintenance, and repair work that is common in high growth areas.

The coverage count data collection program itself can be structured in many ways. One simplistic approach is to randomly separate all of the roadway segments into unique sets and count one of these sets each year. However, this approach does not always lend itself to efficient use of data collection staff and equipment. Grouping counts geographically leads to more efficient data collection activity, but results in the need to account for the geographic bias in the data collected when computing annual average traffic statistics or looking at trends in traffic growth around the State.

In addition, most highway agencies collect data at some sites on a cycle shorter than six years. For example, more frequent counts (3-year cycle) are requested at HPMS sections, and most States count higher system roads more frequently as well. Still, considerable flexibility is allowed in the structure of each agency's coverage count program.

The HPMS Volume Element

The HPMS sample and universe sections are located within the traffic volume segments defined in the coverage count program. Traffic counts taken to meet the HPMS requirements are taken the same way as other short duration traffic volume counts. The main difference is that the HPMS has specified nationally standardized criteria for the collection and duration of the counts. The coverage count program meets the traffic data needs of the HPMS, but the HPMS has specified a 3-year cycle for the traffic count data. Whenever possible, coverage counts taken within a defined traffic count roadway section should be taken within an HPMS section.

One third of the HPMS universe (NHS/PAS) and sample sections should be included in each current year coverage sample to ensure that at a minimum each of these HPMS universe/sample sections are counted once every three years.

The HPMS traffic data collection system was designed as a statistical sample of locations to meet the HPMS volume stratification criteria to support the estimation of vehicle distance traveled. The HPMS data collection requirement has evolved into a combination of a universal count program for the National Highway System and the Principal Arterial system (that is, a count program in which every segment of the roadway is counted) and a statistical sample. In addition, traffic data is needed on all roadway sections not included in the HPMS data collection sample so that those sections can be accurately assigned to HPMS volume strata. This is necessary to develop expansion factors to expand HPMS sample counts into accurate estimates of statewide VDT, and to meet the many additional identified needs for AADT and VDT. Notice that the HPMS covers all roads in the State regardless of jurisdiction.

The above discussion does not imply that State highway agencies need physically count each HPMS sample location. There may be several HPMS sections within a State traffic count roadway segment. In many cases, State highway agencies rely on local jurisdictions to collect and report these data. In other cases, procedures such as "ramp balancing" can be used to estimate traffic volumes on roads where safety or equipment limitations do not allow portable counting. Permanent counters, classifiers, WIM sites, or ITS installations may also provide the traffic data.

The HPMS locations at which data should be collected have already been selected by each State. The latest Highway Performance Monitoring System Field Manual includes a complete description on how the HPMS sample sections were selected and how to periodically update those sample sections to maintain valid representation as the roadway systems change over time.

The primary HPMS strata are the functional classes of roadway[1] (Table 3-3-1), plus the further designation of rural, small urban, and urbanized areas. In addition, the functional classification strata are further subdivided by traffic volume group.

Table 3-3-1
Functional Classifications of Roadway

Functional Class	Reporting Code
Rural Interstate	1
Rural Other Principal Arterial	2
Rural Minor Arterial	6
Rural Major Collector	7
Urban Interstate	11
Urban Other Freeways and Expressways	12
Urban Other Principal Arterials	14
Urban Minor Arterials	16
Urban Collector	17

Duration of Short Count HPMS Traffic Monitoring Efforts

While short duration traffic counts can be taken for anywhere from just a few hours to more than a week, this Guide **recommends a 48-hour monitoring period for traffic volume and vehicle classification.** The most common data collection time periods for traffic volume counts taken with conventional traffic counting equipment are 24 and 48-hour counts. The 48-hour counts are particularly important for the HPMS because common data collection periods from all States ensure similar levels of accuracy and precision for all volume data in the HPMS database.

In general, the longer the duration of the count, the more accurate the resulting estimate of AADT from the count. At the same time, the longer the count, the higher the cost. This is because fewer counts can be taken with a given number of automatic counters and because the staffing resources needed to place and retrieve counters cannot usually be used as efficiently. Consequently, the selection of a time period for monitoring requires trade-offs. This is a complex decision affected by many other considerations such as quality control procedures for the counts, the cycle (frequency with which counts are taken at the same location) for monitoring, cost of data collection, State characteristics such as size and the percentage of roads controlled by the State highway agency, the volume of roads being monitored, the availability and characteristics of traffic counting equipment, the characteristics of the locations being counted, the rate of traffic growth, and a variety of other data collection constraints.

The recommendations offered are based on research conducted for the FHWA (Hallenbeck and Bowman 1984; Cambridge Systematics and Science Applications International 1994), work done by FHWA staff, reviews of existing State programs, and

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[1] The HPMS sample does not include the lowest functional classes of roadway, rural minor collectors (reporting code 8), and functional system local roads (rural code 9 and urban code 19).

recent work that highlights the importance of quality control in the traffic data collection process. The recommendations assume that automatic monitoring equipment will be used to collect the volume data. In addition, **the use of equipment that record and report hourly volumes is recommended.** The hourly recording allows editing and quality control checks.

The recommendation of a 48-hour monitoring period is a compromise, given various alternatives, and is designed to maximize data validity subject to cost and equipment limitation constraints. Research has clearly shown that the magnitude of daily traffic variation is much larger than the long-term growth trend at most sites (Hallenbeck and Bowman 1984). Figure 3-3-1, from that report, compares cost versus precision for several alternatives ranging from 24-hour annual counts to 72-hour counts on a 5-year cycle. The implicit assumptions of this exhibit are discussed in the reference.

Not all research agrees with these conclusions. More recent work (Cambridge Systematics and Science Applications International 1994) shows that traffic variation at higher volume sites is much lower than estimated earlier. This supports the argument for shorter count duration in urban areas. However, higher levels of daily volume variation have been found in vehicle classification counts, where a combination of more variable traffic generation and the low volume of vehicles within vehicle categories make daily classification volumes much more variable.

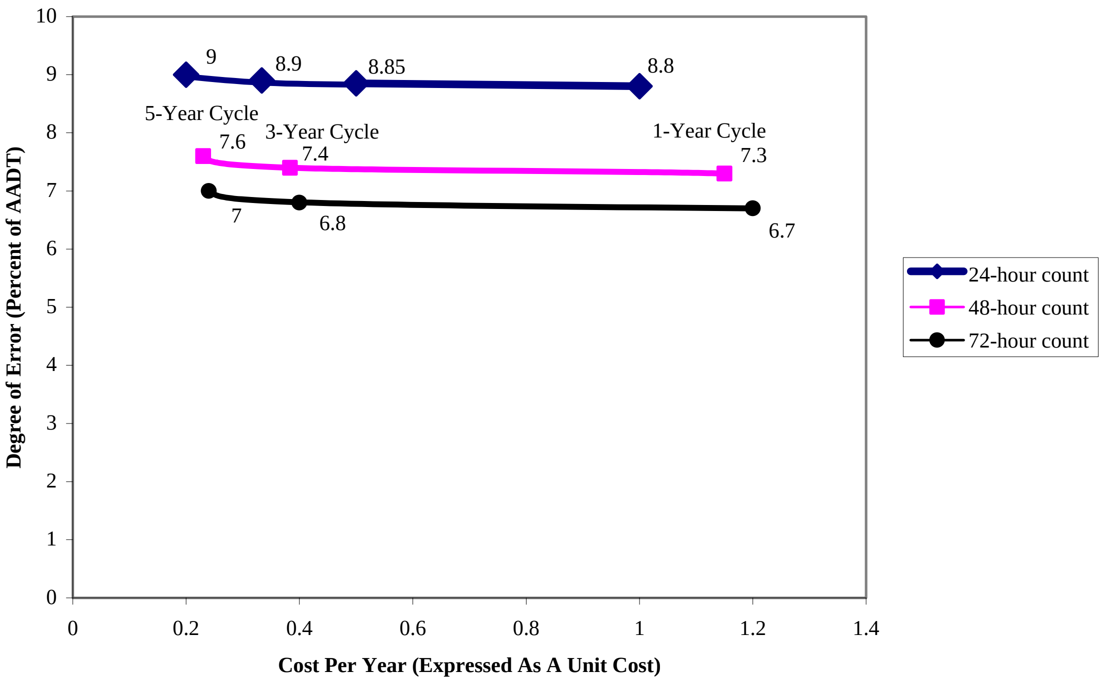

Figure 3-3-1: Relative Cost and Accuracy of Different Count Durations

Location also plays a major role in the level of variability. Urban roads tend to have a much lower level of daily traffic variability than rural roads. Recreational areas have much higher levels of variability than non-recreational areas. Analysis of ATR locations shows standard deviations of 24-hour monitoring periods in the 2 to 25 percent range, depending on the location, volume, and time of year. For sites with higher levels of variability, if estimates of annual average daily traffic volumes are desired with better than 10 percent precision, a minimum of 48 hours must be counted. For sites with little traffic variability, a 24-hour count may be sufficient.

The use of longer periods of time reduces the cost-effectiveness of the program by reducing the number of counts per machine. The equipment being used is also important in that some sensors will not work reliably over long periods of time. For example, pneumatic tubes for collecting volume or classification information may not last longer than 48 hours without being reset on the pavement. Other equipment, such as inductance loop detectors buried in the pavement, to which data collection equipment are attached when desired, are not subject to these constraints.

One last consideration is the fact that longer duration counts allow the comparison of more than one data days. This is particularly valuable when hourly volume measurements for one day can be directly compared to hourly volume measurements for the next day. Comparison of consecutive days of traffic volume considerably improves the quality assurance process because it gives data collection staff confidence that the data collection equipment worked correctly throughout the data collection period. It also allows the identification of "unusual circumstances," such as volume changes caused by accidents or special events that were not anticipated at the time the count was scheduled.

All of these arguments are offered in support of the 48-hour monitoring period recommendation. While this count duration may be slightly more than needed for some locations, it provides reliable data at most locations, regardless of how much is known about a given location's current level of traffic variability. The basic objective of traffic monitoring programs and of the procedures recommended in this chapter is to collect reliable and unbiased information.

Individual State highway agencies may conclude that other traffic counting durations fit their needs more appropriately than the 48-hour recommendation. These agencies are encouraged to collect 48-hour counts for the HPMS sample whenever feasible but may select the count duration that best fits their own constraints for their coverage or special need counts. There may be clear circumstances where the use of shorter or longer periods of monitoring may be more effective. It is important to adequately explore, assess, and document these alternative options to ensure that all avenues have been considered and that the final decision is, indeed, responsive to the specific situation.

Monitoring Cycle Specification

As discussed earlier, the TMG recommends a 3-year cycle for monitoring traffic volume for the HPMS submittal and a 6-year cycle for the coverage program.

Analytical work performed for the FHWA indicated that, in the vast majority of locations, growth is far less of a factor than is daily variation in the measurement and accurate estimation of annual traffic volumes (Hallenbeck and Bowman 1984). The research determined that for many locations, a 48-hour count taken every three years would be a more cost-effective and reliable means of estimating AADT than an annual 24-hour count. The reason is that the daily variability of volume is in the 2 to 25 percent range while annual growth tends to be in the range of 1 to 4 percent.

Highway agencies may decide to collect traffic data more frequently at locations where traffic characteristics are rapidly changing, such as those affected by the opening of a new traffic generator (e.g., a shopping center) or completion of a new road project. Roads in growth areas can easily surpass the normally expected annual growth rates. Short duration counts adjusted to AADT are not very reliable in these situations. More frequent counts, longer periods, or control counting procedures are more effective in high growth or recreational areas.

Another concern is how far to extend the coverage cycle. If a 3-year cycle is better than a 1-year cycle, would a 5-year cycle be better than a 3-year cycle? Solely on a cost basis, a 10-year cycle is more cost effective than a 5-year cycle. However, the law of diminishing returns applies to the collection of traffic volume data. Three-year cycles produce a substantial cost savings, but on average, slightly less reliable estimates than those produced from annual cycles, all else being the same. Five-year cycles would further reduce the cost at an additional reliability penalty. However, errors due to growth tend to expand over time. For a 5-year cycle, the potential error from a compounded 2 to 3 percent average growth rate approach and exceed that from the daily volume variability.

An advantage of using a 3-year cycle instead of an annual cycle for the HPMS is that it reduces the annual counts. For example, establishing the precision levels on a 3-year cycle for the HPMS sections means that only one-third of the universe or sample sections need counting each year, thereby, reducing the annual effort by a factor of 3.

The issue is the selection of a consistent approach that will meet adequate reliability requirements in a reasonable, cost-effective manner. The conclusion reached was to recommend the use of a 48-hour period on a 3-year cycle for traffic volume and vehicle classification for the HPMS. There may be clear circumstances in which the use of different cycles may be appropriate. In those cases, it is important to adequately consider the objectives and constraints, and to document in detail the reasoning process behind the decision.

The TMG recommends that one third of all HPMS volume counts be taken each year of the 3-year cycle. Over the course of the 3-year cycle, all HPMS volume locations should be counted at least once. HPMS standard sample sections not counted during the current year must be reported as part of the HPMS submittal, and their AADT values should be expanded by using the growth factors described later in this chapter. In a perfect world, States should randomly select one third of the HPMS counts each year of the 3-year cycle. Table 3-3-2 provides an example of how the counts required for strata containing three volume groups might be distributed.

The fact that specific count locations are allocated to a given year in the 3-year cycle does not restrict counting during the interim years at those locations. More frequent counting may have been done at any site for specific purposes such as monitoring volumes in a high growth area, for special events, or for projects. The AADT value derived from a current year count may be submitted to the HPMS in place of an earlier year count factored for growth. It should be clear that once a reliable count is taken at the HPMS section within the 3-year cycle, then a second count is not needed (as long as the initial count meets the requirements of the HPMS), but if a more recent count is available then it can be used. The process of integrating the various count programs is intended to identify and as much as possible eliminate duplication and to make use of the best available data for all purposes. Table 3-3-2 presents an example showing how HPMS sections can be subdivided into 3-year counting cycles.

Table 3-3-2
Distribution of HPMS Sample over 3-Year Cycle

Area Type	**Functional Class**	**Volume Group**	**Full Sample**	**Annual Subsets**		
				1	2	3
Rural	Minor Arterial	1	125	42	42	41
Rural	Minor Arterial	2	73	24	24	25
Rural	Minor Arterial	3	15	5	5	5
		Total	213	71	71	71

For the coverage program, the recommendation is to carry it out over a 6-year cycle. The main consideration is to provide a basic count for each section on a periodic basis to cover data needs. State programs vary in their application of system coverage from complete annual coverage each year to several years in between. It is also likely that the coverage cycle will vary depending on the functional system covered and that the longer cycles will be used for the lower systems.

Coverage counts ensure that “at least some” data exist for all roads. The amount of data needed to provide “adequate geographic coverage” is a function of each agency’s policy perspective. Some State highway agencies consider “adequate” to be a 7-day count every seven years, with data recorded for every hour of each day. Others consider “adequate” to be a 24-hour count every year, with no hourly records. Each agency must determine adequate coverage itself, given available funding for data collection, the extent of the highway system, and the uses for which the data are intended.

For the higher systems, a shorter cycle of 3 years, or even an annual cycle may be more appropriate given the data needs. Since these systems are covered fully by the

HPMS universe, the 3-year cycle described earlier for the HPMS applies. Likewise, in cases where ITS systems provide the data or where continuous counts and short ramp counts are used, annual cycles are common.

For the lower functional systems, longer cycles may be applicable, particularly in areas that change very little over time. However, areas do change and very old counts are always questionable resulting in more frequent recounting. The general 6-year cycle recommendation is designed to maintain a reliable data and information source throughout the system. States have to consider their highway systems, the traffic characteristics, the traffic data programs, the resources available, and the needs before making an appropriate judgment. The decision should also include a consideration of the special needs program since more reliable and frequent coverage counting will reduce the need for special counts.

Timing of the HPMS Counts

If HPMS counts were only used to estimate annual average daily vehicle distance traveled, it would be possible to randomly schedule each year's HPMS data collection effort and eliminate the day-of-week, month, and growth adjustments discussed later in this chapter. Unfortunately, two constraints prevent the use of a true temporal random sample approach to HPMS count scheduling.

The first constraint is that HPMS data are used for a wide variety of analyses in addition to statewide VDT estimation. AADT is the basic traffic characteristic required by the HPMS. For many analyses, it is vital that each HPMS section include an unbiased estimate of annual traffic volume.

The second concern is that a truly random sample of data collection times and locations results in a very inefficient use of data collection personnel. In many cases, it is not possible to collect short duration counts simply because of weather and many other conditions.

While a random sample of data collection times for each of the HPMS counts has merit, it is not recommended. Instead, **this Guide recommends that the HPMS short duration counts be fully integrated with the agency's coverage count program.** This means using the same personnel, procedure, equipment, and counting schedule used for coverage and other traffic counts.

This recommendation is likely to cause the data collection effort to be skewed both temporally and geographically. In order to use staff and equipment efficiently, most highway agencies collect data by region, county, or area. For example, all counts that need to be taken in the Southwestern part of the State may be collected in May. In addition, most highway agencies do not collect short count data on weekends except for special studies. Concentrating counts geographically and temporally reduces the travel time and distance between counts, resulting in more efficient use of staff and equipment. Counting only on weekdays results in a better working environment for data collection staff.

Unfortunately, the problem with concentrating counts in this manner is that geographic and temporal biases are easily inserted into the data set. That is, if all counts in the southwestern part of a State are taken in May and bad weather occurs in May (reducing traffic levels there, but not in other places), then the traffic volume statistics will be biased downward. Similarly, if counts are never taken on weekends, the differences between weekend and weekday travel are never accounted for by the short counts.

As a result, the temporal/geographic biases that are created by concentrating the counts must be completely counteracted by the adjustment factors. Theoretically, the statewide adjustment process accounts for both seasonal and temporal biases, but it is not likely to cover smaller regional or temporal effects. Highway agencies should be aware of the potential for geographic and temporal bias when scheduling counts, and counteract it by devising strategies to distribute counts as much as feasible.

Special Needs Counts

The HPMS standard sample meets the need for computation of a statistically reliable measure of statewide travel. The data collected also cover many highway agency needs. However, there remain traffic data needs that cannot be met by the coverage count program. This is where an effective coverage program supplemented by special counts can substantially fill the gap.

Non-HPMS data needs vary dramatically from State to State and from agency to agency. Some State highway agencies are responsible for almost all road mileage in their State. Other State highway agencies control, operate, and maintain only the largest, most inter-regional facilities. Some States must meet strict reporting requirements (by jurisdiction) adopted by their legislatures. Others have relatively few mandatory reporting requirements and, instead, focus on collecting data that meet particular, changing agency priorities. In some extreme cases, agencies are prohibited by law from expending resources outside of their areas of responsibility.

A consequence of this variety of traffic data needs is that no single traffic monitoring program design fits all cases. Therefore, **the philosophy of the Special Needs element is to provide highway agencies wide flexibility to design this portion of their monitoring program in accordance with their own self-defined needs and priorities.** The guidance in this report is intended to provide highway agencies with a framework within which they can ensure that they collect the data they need.

The Special Needs portion of a data collection program can be divided into two basic portions:

- statistical samples for developing system wide summary measures, and
- point-specific estimates intended to meet project requirements and other studies defined by the highway agency.

Statistical Samples in the Special Needs Program

Statistical samples such as the HPMS are the most efficient ways to estimate population means and totals. Most statistical samples involve the collection of data at randomly selected locations to compute unbiased estimates of population means and totals. Random sampling is a very efficient mechanism for computing these totals.

A variety of texts are available on the design of samples. “Sampling Techniques” (Cochran 1977) is one such standard text. The HPMS Field Manual provides a description of how the HPMS sample was developed and implemented. These documents are useful in helping design a sampling program to meet objective needs. The keys to successfully designing a statistical sampling plan are defining the objectives, understanding the variability of the data being sampled, having a clear understanding of what statistics should be computed, and establishing the accuracy and precision of the estimates. Any statistical samples developed should, as much as possible, make use of the available data from the coverage element to minimize the duplication of effort. One possible use of statistical samples is to estimate VDT for the local functional systems, where extensive mileage makes the collection of traffic data very costly.

Point Specific Estimates in the Special Needs Program

Unfortunately, the random selection of count locations required by most statistical samples is an inefficient mechanism for meeting many site-specific traffic data needs. For example, an “uncounted” roadway section is not a major concern for HPMS because the sample expansion process represents all road sections in the statewide VDT estimation. However, if pavement needs to be designed for that section of roadway, a statewide average or total is not a substitute for one or many traffic counts specific to that road section.

Consequently, data needs require agencies to collect data at locations that are not part of the coverage program. However, by maximizing the use of available data, it is possible to keep the number of these “special” counts to a minimum and to save resources for other data collection and analysis tasks. No additional data should be collected if existing data meet the desired need.

Special counts are generally required for specific project needs. Project counts are undertaken to meet the needs of a given study (for example, a pavement rehabilitation design or a specific research project). They cover a range of data collection subjects and are usually paid for by project funds. Project counts are traditionally taken on relatively short notice, and they often collect data at a greater level of detail than for the coverage or the HPMS parts of the program. Often, the need is not realized until after a project has been selected for construction, and insufficient time exists by that date to schedule the project counts within the regular counting program. However, where it is possible to include project counts within the regular count program’s schedule, significant improvements in staff utilization and decreases in overall costs can be achieved.

There are many different types of counts that can fall within the special needs element. Counts are taken by many public and private organizations for many purposes including intersection studies, signal warrants, turning movements, safety analysis, and environmental studies. As much as possible, these activities should be coordinated within the program umbrella.

In general, roadway sections that experience high rates of growth and recreational areas require more frequent counting than those that do not experience growth. Counting roads frequently in volatile areas allows the highway agency to respond with confidence to questions from the public about road use (a common concern in high growth areas), while also ensuring that up-to-date statistics are available for the roadway design, maintenance, and repair work that is common in high growth areas. Many agencies prefer the use of several counts a year to better understand the traffic variability inherent in high growth. Likewise, recreational roads usually experience major traffic peaking at specific times necessitating frequent information.

High growth areas (if not necessarily roads with high volume growth) can usually be selected on the basis of knowledge of the highway system and available information on the construction of new travel generators, highway construction projects, requirements for highway maintenance, applications for building permits, and changes in population. Recreational areas are also well known to experienced transportation professionals.

Coordinating the Coverage and Special Needs Counts

Cost efficiency in the traffic monitoring program is best achieved by carefully coordinating the different aspects within the program. This includes both permanent and short duration counts. It also includes the coverage, HPMS, and special needs counts.

In theory, the highway agency would start each year with a clear understanding of all of the counts that need to be performed. The list could then be examined to determine whether one count could be used for more than one purpose. For example, a classification count at one Interstate milepost might easily provide the data required for both that count and a volume count required at the next milepost, since no major interchanges exist between those mileposts. By careful analysis of traffic count segments, location, and data requirements; it is often possible to significantly reduce the total number of counts required to meet user needs.

The next step is to compare the reduced list of count locations with locations covered by permanent counters (volume, classification, weight, and ITS). Permanent counter locations can be removed from this list, and the remaining sites are the locations that require short duration counts. These locations should then be scheduled to make best use of available staffing and resources.

To make this scenario work, it is necessary to understand not just where data must be collected, but the kinds of data that need to be collected. This can be difficult to do because some requirements, such as those for project counts, are not identified until after the count schedule has been developed. Many project count locations and project count needs can be anticipated by examining the highway agency’s priority project list and from knowledge of previous requests for data. Project lists detail and prioritize road projects that need to be funded in the near future, normally including road sections with poor pavement that require repair or rehabilitation, locations with high accident rates, sections that experience heavy congestion, and roadways with other significant deficiencies. While priority lists are rarely equivalent to the final project selection list, high priority projects are commonly selected, analyzed, and otherwise examined. Making sure that up-to-date, accurate traffic data are available for these analyses helps make the traffic database useful and relevant to the data users and increases the support for maintenance and improvements to that database.

Adjustments to Short Duration Volume Counts

Short duration volume counts usually require a number of adjustments in order to convert a daily traffic volume "raw" count into an estimate of AADT. The specific set of adjustments needed is a function of the equipment used to collect the count and the duration of the count itself. **Almost all short duration counts require adjustments to reduce the effects of temporal bias, if those short duration counts will be used to estimate AADT.** In general, a 24-hour, axle count, is converted to AADT with the following formula:

$$AADT_{hi} = VOL_{hi} * M_h * D_h * A_i * G_h \qquad (3\text{-}1)$$

where

$AADT_{hi}$ = the annual average daily travel at location i of factor group h
VOl_{hi} = the 24-hour axle volume at location i of factor group h
M_h = the applicable seasonal (monthly) factor for factor group h
D_h = the applicable day-of-week factor for factor group h (if needed)
A_i = the applicable axle-correction factor for location i (if needed)
G_h = the applicable growth factor for factor group h (if needed).

This formula is then modified as necessary to account for the traffic count's specific characteristics. For example, if the short duration count is taken with an inductance loop detector instead of a conventional pneumatic axle sensor, the axle correction factor (A_h) is removed from the formula. Similarly, if the count is taken for seven consecutive days, the seven daily volumes can be averaged, substituted for the term VOl_{hi}, and the day-of-week factor (D_h) removed from the equation. Lastly, growth factors are only needed if the count was taken in a year other than the year for which AADT is being estimated.

Seasonal (Monthly) Factors

Monthly factors are used to correct for seasonal bias in short duration counts. Directions on how to create and apply monthly factors are provided in the previous chapter on Continuous Counts, and in the general discussion of factoring in Chapter 4 of Section 2. Those procedures are recommended for the HPMS reporting. States may choose to select alternative seasonal adjustment procedures if they have performed the analytical work necessary to document the applicability of their chosen procedure.

Day-of-Week Factors

Day-of-week factors are needed to estimate AADT if the period of monitoring for a short duration count does not account for the differences in travel by day of week. These factors can be computed and applied independently from the seasonal adjustment factors, or they can be combined into the seasonal adjustment factors (Wright and Hu 1994).

In either case, data from the continuous ATR program must be used to develop the day-of-week factors. These factors should be developed for the same factor groups used for seasonal analysis, but each State should examine its own data to determine whether these groups are homogeneous with respect to day-of-week travel. If day-of-week factors are integral to the seasonal adjustment, this examination will be carried out as part of the factor group creation process. If significant differences are detected, either new seasonal factor groups should be developed, or a separate "grouping process" will be needed specifically for the application of day-of-week adjustments.

Considerable flexibility is given in the creation of day-of-week factors. The report by Cambridge Systematics and Science Applications International (1994) showed that any one of several common approaches to day-of-week factoring yields roughly equivalent results in terms of the expected accuracy of the AADT estimate. Factors may be computed on an individual basis (seven daily factors) or as combined weekday (Monday, Tuesday, Wednesday, and Thursday) and weekend (Friday, Saturday and Sunday) factors. These factors can be combined with the monthly seasonal adjustment, or treated as separate adjustments. Finally, separate day-of-week adjustments can be computed for each month (i.e., 84 factors computed for the year), or a single set of factors can be applied throughout the year.

State highway agencies should select among these varied alternatives on the basis of how these procedures best fit their specific roadway usage conditions. (For example, a mid-western State with Interstate highways heavily influenced by through-traffic might choose to adopt seven day-of-week factors for each month. This is because through-traffic is unlikely to follow the traditional weekday/weekend pattern of an urban area, and that pattern might change as economic conditions change elsewhere in the country. A northeastern State that is primarily urban/suburban might choose to incorporate the day-of-week adjustment into its seasonal factor and treat it as a simple weekday/weekend adjustment. This is because its traffic is heavily dominated by urban/suburban traffic patterns, which tend to be consistent from weekday to weekday.)

Adequate documentation should be maintained to support the decisions made and to allow future reexamination of those decisions as experience is gained with the factoring process.

Axle Correction Factors

The application of axle correction factors is dependent on the type of equipment in use. Equipment that detects vehicles directly (such as inductance loops or vehicle classification counters), do not require axle adjustment. However, the preponderance of data collection equipment dependent on pneumatic tubes actually counts axles rather than vehicles. To represent vehicles, counts taken by axle counting equipment require adjustment by axle correction factors. In general, the higher the percentage of multi-axle vehicles on a road, the more significant the need for axle correction factors.

Axle correction factors can be applied at either the point or system level. That is, axle correction factors can be developed either from specific vehicle classification counts at specific locations, or from a combination of vehicle classification counts averaged together to represent an entire system of roads.

Because truck percentages (and consequently axle correction factors) change dramatically from road to road, even within functional classes and HPMS strata, **this Guide recommends that axle correction factors be developed for specific roads, from vehicle classification counts taken on that road whenever possible.** Where possible, the axle correction factor applied to an axle count should come from a classification count performed nearby, on that same road, and from a vehicle classification count that was taken during the same approximate period as the volume count. For roads where these adjustment factors are not available, a "system wide" factor is recommended. The "system wide" factor should be computed by averaging all of the axle correction factors computed in the vehicle classification count sample within a functional classification of roads. Where State highway agencies have developed a "truck route" classification system, this classification system may be substituted for the functional class strata.

A methodology for computing axle correction factors is given in Chapter 4 of Section 4.

Growth Factors

Available research does not reach a definitive conclusion about the "best" mechanism for computing growth factors for application to AADT estimates from previous years (Cambridge Systematics, Volume I, 1994).

Growth factors at a particular point can be best estimated when a continuous ATR is available, assuming that the ATR data is reliable and that the differences found from year to year can be attributed to growth. However, it is well known that volumes at a single point can be affected by a variety of extraneous factors, and thus growth factors computed from the limited number of ATRs operated by a State highway agency can be easily biased.

Growth factors can also be developed from the short duration counts. The individual estimates of AADT at these locations are not nearly as accurate as those available at an ATR. However, because of the large number of volume counts, and the wide geographic distribution of those counts, the potential for bias from the use of ATRs is significantly reduced. In addition, if the same count locations are used continually over time to compute growth, errors at any one given location due to the inaccuracy of the AADT estimate are self-correcting. That is, if this year's AADT count is too high, making this year's growth estimate too high, next year's "correct" AADT value will cause a much lower growth estimate to be computed, resulting in a more reliable growth estimate over time.

The use of the AADT at HPMS sample locations also allows the computation of region-specific growth factors. Many States have VDT growth rates that differ dramatically from one region to another. The large number of HPMS sample locations means that in most cases, a large sample of data sites will exist within each region. Thus, region-specific growth factors can be developed.

The point of the above discussion is to emphasize that there is not a best procedure that is applicable in all cases. Instead of concentrating on a specific procedure, a better approach is to use all the tools available to examine the growth issue from several perspectives. Rather than develop a single estimate, the different programs may be used to provide a number of alternatives from which appropriate growth estimates can be derived.

Annual Vehicle Distance Traveled (AVDT) Estimation

The HPMS procedures for developing daily vehicle distance traveled (DVDT) rely on the standard HPMS sample expansion. The first step is to compute an AADT estimate for each HPMS section. Next, the section AADT is multiplied by the section length to compute section-specific DVDT. These are then summed for an entire stratum and multiplied by the HPMS stratum expansion factor to compute DVDT. Aggregate estimates at any stratification level (volume group, functional class, area type, statewide, or other combinations of these) can be derived by summing the DVDT of the appropriate strata. For example, to obtain estimates of Interstate Rural DVDT, sum the expanded DVDT estimates for each volume group strata within the Interstate Rural system.

Annual vehicle distance traveled (AVDT) is computed by multiplying any resulting DVDT estimate by 365. Estimates of DVDT or AVDT for specific HPMS vehicle classes can be derived by multiplying DVDT strata figures by the appropriate percentages derived from the vehicle classification counts and aggregating to the strata totals as done for volume.

An estimate of the standard error of a stratum DVDT estimate is given by the following equation:

$$s_h = \sqrt{\frac{N_h(N_h - n_h)}{n_h(n_h - 1)}\left[\sum D_{hi}^2 + \left(\frac{\Sigma D_{hi}}{\Sigma L_{hi}}\right)^2 \left(\sum L_{hi}^2\right) - 2\left(\frac{\sum D_{hi}}{\sum L_{hi}}\right)\sum D_{hi} L_{hi}\right]} \qquad (3\text{-}2)$$

where s_h = standard error of DVDT estimate in stratum h
N_h = number of universe sections in stratum h
n_h = number of sample sections in stratum h
D_{hi} = DVDT of section i in stratum h
L_{hi} = length of section i in stratum h.

This equation is presented on page 155 of “Sampling Techniques” (Cochran 1977). A complete discussion of ratio estimation procedures is included in the reference. The estimates produced by this process are conservative since the errors introduced by using the factors to develop AADT estimates have been ignored. The assumption is that these errors are normally distributed and therefore will cancel out when aggregated. The equation shows that estimates of the standard error of aggregate VDT estimates for HPMS strata are derived by summing the squared standard errors of the appropriate strata and taking the square root of the total. Coefficients of variation and confidence intervals can be derived by standard statistical procedures.

As a rule of thumb, the precision of statewide DVDT estimates (excluding local functional class) are expected to approximate ±5 percent with 95 percent confidence, although the analysis assumed that the AADT values reported were exact. Because of this assumption, precision estimates are conservative. Computation of annual DVDT estimates with the complete HPMS standard sample by expanding the AADT from each HPMS standard sample would be expected to approximate the stated precision.

The HPMS standard sample sizes were defined in terms of AADT within strata (described in the HPMS Field Manual). To estimate the precision of DVDT estimates, a complex procedure is needed to account for the variation in AADT and also for the variation in section length. The equation to estimate the sampling variability of aggregate DVDT estimates is given on page 164 of “Sampling Techniques” (Cochran 1977). In an early HPMS study, the precision of statewide estimates of Interstate DVDT to approximated ±2 to 3 percent with 95 percent confidence, but these results considered only sampling variability and ignored error introduced by equipment or the factoring process used to estimate sample section AADT.

Other Data Collection and Processing Considerations

Many concerns must be addressed when a traffic monitoring program is established. Only some of the most salient considerations are addressed here. So far, no mention has been made of the detail of data to be collected. Obviously, much depends on equipment capability and the objectives of the program. In general, **hourly breakdowns are recommended for traffic volume and vehicle classification data collection.** This allows examination of other concerns such as peak-hour volume and design-hour factors. **For special analysis, urban location data may be desired in 15-minute intervals.** Although the TMG recommends the use of 48-hour periods for short counts, a break or subtotal for each 24-hour period is recommended for all locations. The daily (24-hour) break is very useful for analysis of daily variation and is required for the factoring procedures. Furthermore, it may be very desirable to standardize the coverage program on an hourly basis (equipment permitting). This allows other related concerns to be addressed, such as peak-hour periods or traffic conditions during specific hours, and provides sufficient records to detect equipment malfunctions or to help edit periods that are missing because of equipment malfunction.

Counts missed because of equipment failures, bad weather, or other reasons should be made up during the year. Partial counts of less than 24 hours should, as a general rule, be retaken. Abnormal situations such as major construction, etc., should be handled according to the judgment of the responsible staff. The typical procedures in use by each State should be consistently applied and fully documented.

Data processing procedures should be designed to allow efficient utilization of computerized data. All procedures for data editing, the calculation of AADT estimates, and the development of factors should be fully computerized. Documentation of the processes, including tables of the factors used, should be maintained for historical purposes and to allow future evaluation. Computerized data management and analysis procedures should allow the use of both mainframes and microcomputers and provide a connection to other relevant databases.

THE CONTINUOUS COUNT ELEMENT

All State highway agencies (and many local highway agencies) operate continuous count programs. These programs tend to have strong historical ties and usually supply much of the basic planning data used by those agencies. Continuous traffic volume counters are so widespread that many States now operate several different continuous count programs, sometimes without realizing it. Not all of these programs currently supply data that are actively used as part of the traffic monitoring program, although many of the data could be used for these purposes.

These ATR counters are most commonly operated by, or in conjunction with, the agency planning office. They are used to collect data that provide the seasonal, day-of-week, and time-of-day adjustments needed to convert short duration traffic volume counts into estimates of AADT. They are also used to accurately monitor traffic trends at a small number of locations in each State.

In addition, State highway agencies need to realize that a number of other permanent, continuously operating data collection devices may also exist that can collect continuous traffic count data and provide these same statistics. These devices are being installed and operated by different groups for entirely different purposes. For example, modern traffic control and management systems require continuous monitoring of traffic volumes and speeds. Automated weight enforcement sites also tend to involve monitoring of traffic volumes continuously throughout the year. These systems are not primarily intended to serve as ATRs, but they collect all of the data required from ATRs and can be used to supplement the existing ATR program.

Because all States already operate ATR programs, and because the existing continuous count equipment is expensive to move and/or significantly expand, the emphasis is to review existing continuous count programs in order to refine their performance for more accurate and cost effective operation.

Refining the continuous count program consists of the following tasks:

- defining the objectives of the continuous count program
- reviewing the existing continuous count program
- developing an inventory of the available continuous count locations and equipment
- determining the traffic patterns that need to be monitored by examining the seasonality in the State's traffic
- establishing seasonal pattern groups
- determining the appropriate number of count locations in each group, and
- selecting specific count locations.

Also discussed below are how to compute seasonal adjustment factors and the need to develop analytical procedures that meet the needs of the agency's data users.

Objectives of the Continuous Count Program

The objectives of continuous ATR programs are many and vary from State to State. ATRs can be used to develop adjustment factors. They can be used to track traffic volume trends on important roadway segments. They can be used to provide inputs to traffic management and traveler information systems.

The number and location of the counters, the type of equipment used, and the analysis procedures used to manipulate data supplied by these counters are functions of these objectives. As a result, it is of the utmost importance for each organization responsible for the implementation of the continuous ATR program to establish, refine, and document the objectives of the program. Only by thoroughly defining the objectives and designing the program to meet those objectives will it be possible to develop an effective and cost-efficient program.

The TMG assumes that **the development of seasonal factors to expand short-term counts to annual average daily traffic (AADT) is the primary objective of the continuous ATR program, and this is the objective that should carry the most weight in establishing the number and location of ATR sites operated by the state highway agency.** Secondary objectives include the following:

- ATRs provide peak hour, 30th highest hour, and directional distribution data used by traffic forecasters and roadway designers.
- ATRs track volume trends on specific roadway sections on the State highway system.
- ATRs are dispersed geographically to understand geographic differences in travel trends.

- ATRs are directly integrated with the HPMS volume sample.
- ATRs collect data on roadway sections where it is not possible, or is prohibitively expensive, to collect data with portable counters.
- The number of ATRs installed and operated by the highway agency is minimized to the extent possible in order to contain the cost of the ATR program.

These additional objectives can be met by refining the preliminary ATR locations. It is obvious that some objectives are better served by increasing the number and diversity of ATR locations. Other objectives are better served by minimizing the number of ATR locations. This conflict between primary objectives requires careful analysis within each State highway agency. Each agency will need to develop its own balance between having larger numbers of ATRs (increasing the accuracy and reliability of the analyses that depend on the data supplied by those counters) and reducing the expenditures required to operate and maintain those counters. The TMG recommendations provide highway agencies sufficient flexibility for each agency to find the appropriate compromise between objectives.

When determining the balance point, the primary objectives of the permanent counter programs should be statewide in nature, and the initial focus of the ATR program should reflect this statewide perspective[2]. As a result, the initial ATR program should be developed to meet the minimum requirements of the State highway agency for factor development. Sub-area and road specific data collection needs should be secondary considerations in the design of the ATR program as desired by the appropriate agency.

Consequently, the TMG recommends that the State highway agency division responsible for factor development operate, at least, the minimum number of ATR locations needed to meet the accuracy and reliability requirements of the factoring program. Expansion of the data available through the ATR program should come from other available count programs. That is, data available through continuous count programs such as advanced traffic management systems and WIM programs, where the funding for the installation and operation of the counters comes from other sources, should be used to supplement and expand the ATR database. This will allow expansion of the database provided by the ATR program while minimizing the cost of the total data collection process.

Note, however, that while the cost of equipment installation and operation of these supplemental ATR programs is the responsibility of those other programs, the statewide monitoring division should be responsible for making these data available to users. Determining how best to obtain, summarize and report these data is an issue that can only be addressed at the State level.

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[2] Local agencies are not affected by this same constraint, although local agencies can substitute “area” for “State” the primary goal of their ATR program is to develop region specific adjustment factors.

Review the Existing Continuous Count Program

The first step in refining the ATR system is to define, analyze, and document the present continuous ATR program. A clear understanding of the present program will increase confidence in later decisions to modify the program. The review should explore the historical design, procedures, equipment, personnel, objectives, and uses of the information.

This review should start with an inventory of the available, continuously operating traffic data collection equipment in the State. It should then progress to determining how the data are being used, who is using it, and how it would be used if tools for using it in new ways were available.

Next, the data should be reviewed to determine what traffic patterns exist in the State and whether previous patterns have changed to establish whether the monitoring process should change.

The next step is to review how the data are being manipulated, and whether those data manipulation steps can be improved or otherwise made more efficient. Of considerable interest in this review is how the quality of the data being collected and reported is maintained. Establishing the quality of the traffic data reported by the ATR system and the outputs of the ATR analysis process is a prerequisite for future improvements. Permanent traffic data are subject to discontinuities due to equipment malfunctions and errors. The way a State identifies and handles errors in the data stream is a key component of the ATR program. Subjective editing procedures for identifying and imputing missing or invalid data are discouraged, since the effects of such data adjustments are unknown and frequently bias the resulting estimates.

Each State highway agency should have formal rules and procedures for these important quality control efforts (ASTM 1991). **The implementation of truth-in-data concepts as recommended by the AASHTO Guidelines for Traffic Data Programs will greatly enhance the analytical results and help in establishing objective data patterns.**

Truth-in-data implies that agencies maintain a record of how data are manipulated, and that each manipulation has a strong basis in statistically rigorous analysis. Data should not be discarded or replaced simply because “they didn’t look right.” Instead, each State should establish systematic procedures that provide the checks and balances needed to identify invalid data, control how those invalid data are handled in the analysis process, and identify when those quality control steps have been performed. Finally, the State highway agency should periodically review whether these procedures themselves are performed as intended or need to be revised. For states that currently do not have formal quality control procedures, the documentation being developed by the Minnesota pooled fund study to examine automated data collection procedures provides an excellent starting place (Intelligent Decision Technologies 1997). In addition, the AASHTO has also provided guidance on how to develop and implement a quality control process for traffic data collection (Guidelines for Traffic Data Programs 1992).

The last portion of the review process should entail the steps for creating summary statistics from the raw data collected by ATRs. These procedures must be consistent and must accurately account for the limitations that are often present in continuous count data. For example, AASHTO has adopted a recommended procedure for computing AADT for data collected at continuous count locations. The procedure computes average day-of-week values by month, and then averages those summary values to create annual average day-of-week volumes, and finally averages those seven values to compute AADT. This procedure allows consistent computation of AADT even when significant portions of a month of data are missing, without losing the effects of seasonal or day-of-week effects.

Develop an Inventory of the Available Continuous Count Locations and Equipment

Correctly manipulating continuous count data after the data have been collected is vital. The inventory of existing (and planned) ATR sites ensures that the State's traffic monitoring effort obtains all of the continuous count data that are available. As noted earlier, the key to the inventory process is for the agency to identify not just the traditional ATR sites but also other data collection devices that can supply continuous volume data. These secondary sites include, but are not limited to:

- continuous classification counters
- continuous weigh-in-motion sites
- traffic management systems
- regulatory monitoring sites (such as international border crossings and toll plazas).

Data collection devices operated by the same group that operates the ATRs are the easiest to obtain volume data from, but a surprising number of State highway agencies do not make use of these data as part of their ATR process.

Posing more challenge are devices operated by other divisions within the State highway agency. Obtaining these data can be more difficult, particularly where internal cooperation within the agency is limited. However, the current emphasis on improved cost-efficiency in government means that in most States there is strong upper management support for "making the most use" of data resources, wherever they exist. The key to taking advantage of this support is to make the transfer of the data as automated as possible, so that little or no staff time has to be expended outside of the ATR data collection group to obtain the data.

Lastly, the State highway agency should look for data outside of its own agency. While it may not be possible to obtain these data at the level provided by standard ATR devices (i.e., hourly records by lane for all days of the year), it is often possible to obtain useful summary statistics such as AADT and seasonal volume patterns from these locations. These summary data can, at a minimum, be used to supplement the State's data at those locations and geographic areas. The availability of data from supplemental locations reduces the cost of collecting and increases access to useful data.

To obtain these data, the State highway agency may have to pay for the development of software that automatically collects and reports these data. The intent, once again, is to reduce the operating agency's staff time needed to collect and transmit the data. The easier this task is for the agency collecting the data, the more likely it is that these data can be obtained by the highway agency.

A second part is to inventory data uses and users. This step involves determining how the ATR data are currently being used, who the customers are for those data, and which data products (raw data? summary statistics? factors?) are being produced.

Many organizations seem to collect data for the sake of collecting data, that is, data is not being used as it should be. Data need to be collected for a purpose, and the users and uses of those data should be given priority in the data collection process. By themselves, data have no value. Data only have value in that they answer important questions. Thus, by understanding who uses the data and how those data are being used, it is possible to develop a clear understanding of what value the data collection effort has to the organization. Understanding this value, and being able to describe it, is crucial to defending the data collection budget when budget decisions are made.

At the same time, this inventory process may uncover the fact that some data and/or summary statistics are not being used. If that is the case, then these data and statistics can often be eliminated in favor of the collection of data or production of statistics that will be used. This results in better use of available resources, makes the data collection system more focused on products actively desired by agency users, and results in more support for the data collection program from others in the agency.

Determine the Traffic Patterns to Be Monitored

One of the tasks central to the existence of the continuous counter program is the monitoring of traffic volume trends. Foremost among these trends are the monitoring of AADT at specific highway locations over time, and the tracking of seasonal and day-of-week patterns around the state. The inventory process should document how the ATR program is being used to create and apply adjustment factors to short duration traffic counts in order to estimate AADT, as well as which highway locations require continuous counters simply because of the importance of tracking volume with a high degree of confidence.

Monitoring AADT with continuous traffic counters is not a primary issue that significantly determines the design of the ATR program. Instead it is a secondary consideration normally dealt with when siting the ATRs. The collection of continuous data to determine AADT should only be necessary at a limited number of locations.

Monitoring seasonal and day-of-week patterns is of much greater concern in the refinement of the continuous count program, since the effectiveness of the seasonal factoring process (and consequently the accuracy of most AADT counts) is a function of the seasonal patterns observed around the State. Understanding what patterns exist, how those patterns are distributed, and how they can be cost-effectively monitored is a major portion of the factor review process.

The review of seasonal patterns can be undertaken with a number of analytical tools. Two of the most useful are cluster analysis, which can be performed using any one of several major statistical software packages such as SAS or SPSS, and the graphic examination of seasonal pattern data from individual sites.

The intent of the seasonal pattern review is to assess the degree of seasonal (monthly) variation that exists in the State as measured by the existing ATR data. Also, to examine the validity of the existing factor grouping procedures that produce the seasonal factors. The review consists of examining the monthly variation (attributed to seasonality) in traffic volume at the existing ATR locations, followed by a review of how roads are grouped into common patterns of variation. The goal of this review is to determine whether the State's procedures successfully group roads with similar seasonal patterns, and whether individual road segments can be correctly assigned to those groups.

The review process begins by computing the monthly average daily traffic (MADT) and the monthly factors at each ATR location. The monthly factors are then used as input to a computerized cluster analysis procedure. The patterns for individual sites can also be plotted on paper or electronically, so that patterns from different sites can be overlaid to visually test for similarities and/or differences.

If the groups of roads reported by the cluster analysis are very similar to the groups of roads already in use, or if the visual patterns of all ATRs in each factor group are similar, then it can be concluded that the factor groups are reasonably homogeneous; that is, that the ATRs that make up the factor group all have the same basic seasonal pattern.

It is not necessary for the factor groups to be identical to the cluster analysis output. This is for two reasons. For any given year, the cluster output is likely to be slightly different, as minor variations in traffic patterns are likely to be reflected in minor changes in the cluster analysis output. In addition, the cluster analysis output will require adjustment in order to create identifiable groups of roads.

The remaining review step is to make sure that the groups are defined by an easily identifiable characteristic that allows easy assignment of short counts to the group. The definition of each group must be complete enough to allow analysts to correctly select the appropriate factor for every applicable roadway section.

Establish the Seasonal Pattern Groups

If the factor groups are not reasonably homogeneous, the definition of the groups is not clear, or new traffic patterns are emerging; it may be necessary to re-form the seasonal factor groups. The TMG recommends that the seasonal analysis be carried out monthly because studies have shown that patterns based on weekly or daily variation reduce the reliability of the resulting seasonal factors (Hallenbeck and Bowman 1984).[3]

The basic statistic used to create factor groups can be either the ratio of AADT to MADT, or the ratio of AADT to MAWDT. A general description of alternative methods for creating factor groups is presented in Section 2.

In most cases, the patterns of variation that stand out from the grouping process are those of rural roads, urban roads, and recreational areas. However, in some States there are significant geographic differences in travel that need to be accounted for in the seasonal factoring process. For example, rural roads in the northern half of the State may have very different travel patterns than rural roads in the southern half of the State. In addition, in some States clear patterns have failed to emerge.

The cluster procedure is illustrated by an example in Appendix A of Section 2, where the monthly factors (ratio of AADT to MADT) at the ATR stations are used as the basic input to the statistical procedures. An understanding of the computer programs used or of statistical clustering procedures is helpful but not required to adequately interpret the program results.

The cluster analysis procedures have two major weaknesses. One is the lack of theoretical guidelines for establishing the optimal number of groups. It is often difficult to determine how many "groups" should be formed. The cluster analysis process starts with all ATRs in a single group, and proceeds until each ATR is in an individual group. The difficult task is to determine at what point to stop this sequential clustering process. Unfortunately, the "optimal" number of groups cannot be described mathematically.

The second weakness in the cluster analysis approach is that the groups that are formed often cannot be adequately defined, since the cluster procedure considers only variability at the ATRs not applicability to the short counts. Plotting on a map the sites that fall within a specific cluster group is sometimes helpful when attempting to define a given group output by the cluster process, but in some cases, the purely mathematical nature of the cluster process simply does not lend itself to easily identifiable groups.

Two advantages of cluster analysis are that it allows for independent determination of "similarity" between groups, thus making the groups less subject to bias, and that it can identify travel patterns that may not be intuitively obvious to the analyst.

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[3] Some States prefer to use weekly factors, since there is no direct correlation between traffic patterns and months, while there is a strong relationship between specific weeks and traffic patterns. For example, the week containing the Fourth of July always has a different traffic pattern than the remaining weeks of July. However, weekly factors are less stable than monthly factors and have accuracy drawbacks. Monthly factors are recommended, but States have the option of choosing the factoring process that best meets their traffic patterns and needs.

Thus, it helps agency staff investigate road groupings they might not otherwise examine, which in turn can lead to more efficient and accurate factor groups, as well as providing new insights into the State's travel patterns.

The more subjective traditional approach to grouping roads and identifying like patterns is based on a general knowledge of the road system combined with visual interpretation of the monthly graphs. An example of the traditional approach to creating vehicle classification factor groups is presented in Appendix 4-B.

The advantage of the "traditional" approach is that it allows the creation of groups that are easier for agency staff to identify and explain to users. This happens because the grouping process starts by defining road groups that are expected to "act alike." The hypothesis is then tested by examining the variation of the seasonal patterns that occur within these "expected" groups.

The initial groups of roads that "act alike" could consist of roads of the same functional classification, or a combination of functional classifications. The groups should be further modified by the State highway agency to account for the specific characteristics of the State. Expected revisions include the creation of specific groups of roads that have travel patterns driven by large recreational activities, or that exhibit strong regional differences.

The decision on the appropriate number of factor groups should be based on the actual data analysis results and the analyst's knowledge of specific, relevant conditions. As a general guideline, a minimum of three to six groups is usually needed. More groups may be appropriate if a number of recreational patterns need to be monitored, or if significant regional differences exist.

Because of the importance and unique inter-regional nature of travel on the Interstate system, it is also recommended that States consider maintaining separate volume factor groups for the Interstate functional categories. The Interstate system, because of its national emphasis and high usage levels, will always be subject to higher data constraints. Most States maintain many ATRs on the Interstate system. As a result, it is usually easy to create separate Interstate groups.

The TMG recommends the following groups as a minimum:

Recommended Group	**HPMS Functional Code**
Interstate Rural	1
Other Rural	2, 6, 7, 8
Interstate Urban	11
Other Urban	12, 14, 16, 17
Recreational	Any

The first four groups are self-defining. The recreational group or groups requires the use of subjective judgment and knowledge of the travel characteristics of the State. Usually, recreational patterns are identifiable from an examination of the continuous

ATR data. The existence of a recreational pattern should be verified by knowledge of the specific locations and the presence of a recreational travel generator.

Distinct recreational patterns cannot be defined simply on the basis of functional class or area boundaries. Recreational patterns are very obvious for roads at some locations but non-existent for other, almost adjacent, road locations. The boundaries of the recreational groups must be defined on the basis of subjective knowledge. The existence of different patterns, say summer vs. winter, further complicates the situation. Therefore, the recommendation is to use a strategic approach, that is, to subjectively determine the routes or general areas where a given recreational pattern is clearly identifiable, establish a set of locations, and subjectively allocate factors to short counts on the basis of the judgment and knowledge of the analyst. The road segments where these recreational patterns have been assigned must be carefully documented so that these recreational factors can be accurately applied and periodically reviewed.

While this may appear to be a capitulation to ad hoc procedures, it is actually a realistic admission that statistical procedures are not directly applicable in all cases. However, recreational areas or patterns are usually confined to limited areas of the State and, in terms of total VDT, are small in most cases. The direct statistical approach will suffice for the large majority of cases.

The procedure for recreational areas is then to define the areas or routes based on available data (as shown by the analysis of continuous and control data) and knowledge of the highway systems and to subjectively determine which short counts will be factored by which continuous ATR (recreational) location. The remaining short counts should be assigned on the basis of the groups defined by the State.

The minimum group specification can be expanded as desired by each State to account for regional variation or other concerns. However, more groups result in the need for more ATR stations, with the corresponding increase in program cost and complexity. Each State highway agency will have to carefully examine the trade-offs between the need for more factor groups and the cost of operating additional ATRs.

The above definition of these seasonal patterns based on functional class provides a consistent national framework for comparisons among States and, more important, provides a simple procedure for allocating coverage counts to the factor groups for estimating annual average daily traffic (AADT). It also provides a direct mechanism for computing the statistical precision of the factors being applied.

The precision of the seasonal factors can be computed by calculating the mean, standard deviation, and coefficient of variation of each adjustment factor for all ATR locations within a group. The mean value for the group is the adjustment factor that should be applied to any short count taken on a road section in the group. The standard deviation and coefficient of variation of the factor describe its reliability. The error boundaries can be expressed in percentage terms using the coefficient of variation, where the error boundaries for 95 percent of all locations are roughly twice the coefficient of variation.

Typical monthly variation patterns for urban areas have a coefficient of variation under 10 percent, while those of rural areas range between 10 and 25 percent. Values higher than 25 percent are indicative of highly variable travel patterns, which reflect "recreational" patterns but which may be due to reasons other than recreational travel.

Determine the Appropriate Number of Continuous ATR Locations

Having analyzed the data, established the appropriate seasonal groups, and allocated the existing ATR locations to those groups, the next step is to determine the total number of ATR locations needed in each factor group to achieve the desired precision level for the composite group factors. To carry out this task, statistical sampling procedures are used. Since the continuous ATR locations in existing programs have not been randomly selected, assumptions must be made. The basic assumption made in the procedure is that the existing locations are equivalent to a simple random sample selection. Once this assumption is made, the normal distribution theory provides the appropriate methodology. The standard equation for estimating the confidence intervals for a simple random sample is:

$$B = \bar{X} \pm T_{1-d/2,\, n-1} \frac{s}{\sqrt{n}} \tag{3-3}$$

where

B = upper and lower boundaries of the confidence interval

$\bar{X}$ = mean factor

T = value of Student's T distribution with $1-d/2$ level of confidence and $n-1$ degrees of freedom

n = number of locations

d = significance level

s = standard deviation of the factors.

The precision interval is

$$D = T_{1-d/2,\, n-1} \frac{s}{\sqrt{n}} \tag{3-4}$$

where

D = absolute precision interval

S = standard deviation of the factors.

Since the coefficient of variation is the ratio of the standard deviation to the mean, the equation can be simplified to express the interval as a proportion or a percentage of the estimate. The equation becomes

$$D = T_{1-d/2,\, n-1} \frac{C}{\sqrt{n}} \tag{3-5}$$

where

D = precision interval as a proportion or percentage of the mean
C = coefficient of variation of the factors.

Note that a percentage is equal to a proportion times 100, i.e., 10 percent is equivalent to a proportion of 1/10.

Using this last formula, it is now possible to estimate the sample size needed to achieve any desired precision intervals or confidence levels. Specifying the level of precision desired can be a difficult undertaking. Very tight precision requires large sample sizes, which translate to expensive programs. Very loose precision reduces the usefulness of the data for decision-making purposes. Traditionally, traffic estimates of this nature have been thought of as having a precision of ± 10 percent. A precision of 10 percent can be established with a high confidence level or a low confidence level. The higher the confidence level desired the higher the sample size required. Furthermore the precision requirement could be applied individually to each seasonal group or to an aggregate statewide estimate based on more complex, stratified random sampling procedures.

The reliability levels recommended are 10 percent precision with 95 percent confidence, 95-10, for each individual seasonal group, excluding recreational groups where no precision requirement is specified.

When these reliability levels are applied, the number of ATR locations needed is usually five to eight per seasonal group, although cases where more locations are needed exist. The actual number of locations needed is a function of the variability of traffic patterns within that group and the precision desired. Thus, the required sample size may change from group to group.

Recreational factor groups usually are monitored with a smaller number of ATRs, simply because recreational patterns tend to cover a small number of roads, and it is not economically justifiable to maintain five to eight ATRs to track a small number of roads. The number of stations assigned to the recreational groups depends on the importance assigned by the planning agency to the monitoring of recreational travel, the importance of recreational travel in the State, and the different recreational patterns identified.

Select Specific Count Locations

Once the number of groups and the number of ATRs needed for each group have been established, the existing ATR locations can be modified if revision is necessary. The first step is to examine how many ATRs are located within each of the defined groups. This number is then compared to the number of locations necessary for that group to meet the required levels of factor reliability.

If the examination reveals a shortage of current ATR locations, the agency will need to select new locations to place ATRs within that defined group. Since the number of additional locations will probably be small, the recommendation is to select and include them as soon as possible. Issues to be considered when selecting locations to expand the sample size are discussed below.

If there is a surplus of ATRs within a group, then redundant locations are candidates for discontinuation. If the surplus is large, the reduction should be planned in stages and after adequate analysis to ensure that the cuts do not affect reliability in unexpected ways. For example, if twelve locations are available and six are needed, then the reduction could be carried out by discontinuing two locations annually over a period of three years. The sample size analysis should be recomputed each of the three years before the annual discontinuation to ensure that the desired precision has been maintained. Location reductions should be carefully thought out. Maintaining a few additional surplus locations may help supplement the groups and compensate for equipment downtime or missing data problems.

Because of the small number of locations under consideration, extensive criteria for discontinuation or selection of additional sites will not be presented. Several important considerations are as follows:

1. **Other uses of existing information or other reasons the sites are important—** As mentioned before, seasonality is not the only objective for use of continuous ATR data. Each State should ensure that these other criteria are met before discontinuation. It should also be clear that additional locations increase the reliability of the data.

2. **Quality of the traffic data—** Permanent counter data are subject to many discontinuities due to equipment downtime, which results in missing data, and to the vagaries of data editing and imputation.

3. **Existing locations—** Available locations from control or other programs may be candidates for upgrading to continuous status.

4. **Location on or near HPMS sites—** Because of the direct linkage to the HPMS standard sample sections, these locations should be given priority.

5. **Tie-in to the classification, speed, or weight programs—** Coordination with other programs is essential.

6. **Distribution over geographical areas of the state**

7. **Distribution by functional class system**

8. **Random selection to reduce bias**— New locations should be randomly selected, if possible, from HPMS standard sample sections.

9. **Quality of ATR equipment of sites**— Older or malfunctioning equipment should be given higher priority for discontinuation.

Compute Monthly Factors

The procedures for developing and using monthly factors to adjust short volume counts to produce AADT estimates follow directly from the structure of the program. **The individual monthly factors for each ATR station are the ratio of the AADT to MADT.** Alternatively, the State can combine the day-of-week adjustment and monthly adjustment into a single factor, for example the ratio of annual average daily traffic to monthly average weekday traffic (AADT / MAWDT). This term, or a similar seasonal adjustment, can be substituted directly for the ratio of AADT / MADT in the factor grouping and application process if desired.

For an ATR site that operates 365 days per year without failure, the AADT can be computed by adding all of the daily volumes and dividing by 365. Similarly, the MADT can be computed by adding the daily volumes during any given month and dividing by the number of days in the month.

The problems with this approach are that few ATRs operate totally reliably during any given year. Most suffer at least small amounts of down time because of power failures, communications failures, and other equipment or data handling problems. These missing hours or days of data can cause biases and other errors in the calculations, particularly when moderate amounts of data are lost in a block. As a result, AASHTO adopted a modified formula for computing these types of statistics that directly accounts for missing data.

The AASHTO formulation for AADT is as follows:

$$AADT = \frac{1}{7}\sum_{i=1}^{7}\left[\frac{1}{12}\sum_{j=1}^{12}\left(\frac{1}{n}\sum_{k=1}^{n}VOL_{ijk}\right)\right] \tag{3-6}$$

where: VOL = daily traffic for day k, of day-of-week i, and month j

i = day of the week
j = month of the year
k = 1 when the day is the first occurrence of that day of the week in a month, 4 when it is the fourth day of the week.
n = the number of days of that day of the week during that month (usually between 1 and 5, depending on the number of missing data).

This formula computes an average day of week for each month, and then computes an annual average value from those monthly averages, before finally computing a single annual average daily value. This process effectively removes most biases that result from missing days of data, especially when those missing days are unequally distributed across months or days of the week.

The AASHTO calculation of MADT is similar to that of AADT. An average day-of-week is first computed for a given month, and then these seven values are averaged. MAWDT is similarly computed. However each State can define the specific days present in the MAWDT calculation. For example, some States do not count Fridays for routine short duration traffic counts and, therefore, choose not to include Fridays in the computation of MAWDT.

Monthly factors for each ATR are computed by the ratio of AADT to MADT or AADT to MAWDT. Group monthly factors are computed as the average of the factors for all ATR locations within the group. Both the individual ATR and the group factors should be made available to users in tabular and computer accessible form.

Seasonal factors are most accurately developed and applied on a year by year basis. That is, a short count taken in 1999 should be adjusted with factors developed exclusively from ATR data collected in 1999. This allows the adjustment process to account for economic and environmental conditions that occurred in the same year the short count was taken.

This last recommendation creates problems for the timing of factor computation and application. That is, if a short count is taken in the summer of this year, the “true” adjustment factor for this year cannot be computed until January of next year at the earliest, which may not be timely enough for many users. The recommendation is to compute “temporary” adjustment factors for estimating AADT before the end of the year, and then to revise that preliminary estimate once the year’s “true” adjustment factors can be computed in January. “Temporary factors” can be developed in one of three ways:

- applying last year’s factors
- computing an average of the three previous year’s factors
- computing a monthly rolling average (for example, the temporary July 1999 factor would be computed as the factor for the 12 consecutive months from August 1998 through July 1999).

The first of these approaches is the easiest but also the least accurate, because the effects of this year’s and last year’s economic/environmental conditions are likely to be different. The second approach reduces the biases that occur from using a single year's factors. The last approach produces the most accurate adjustment factor but also requires the most labor-intensive data handling and processing effort.

SUMMARY OF VOLUME DATA COLLECTION REQUIREMENTS

The recommended traffic monitoring program consists of two basic components, a continuous count program and a short duration count program.

Continuous Count Program

All highway agencies should have access to data collected from continuous counters. These data are needed to understand temporal (day-of-week, seasonal) changes in traffic volume. However, not all agencies need to operate these devices. Agencies should work together to ensure that enough data are collected to allow calculation of accurate day-of-week and seasonal adjustment factors needed to convert short duration traffic counts into estimates of AADT. Roughly six ATRs are needed[4] for each "factor group" in order to develop stable, representative factors.

Short Duration Counts

The short count program is designed to provide roadway segment-specific traffic count information on all covered roads. To compute AADT, the data collected during the short counts must be adjusted to annual conditions. These adjustments include

- axle correction (for counts made with single axle sensors)
- day-of-week (for counts taken for less than one week)
- seasonal (to account for changes in volume that occur from one time of year to another)
- time-of-day (for counts taken for less than 24 hours).

In addition, since AADT is usually desired for the current year, growth factors may also be computed and applied to earlier year counts. Finally, it is recommended that traffic volume data be collected for 48-hour periods with counters that record data at hourly intervals. Periods longer than 24 hours eliminate the need for time-of-day adjustments, provide data on peak travel times and the percentage of traffic volume occurring in those periods. The recommended 48-hour period provides sufficient hourly data to verify the quality and reliability of the collected data.

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[4] The major exception to this rule of thumb is for recreational routes and other "unusual" roads which experience unique travel patterns. In these cases, a single ATR may be all that is necessary to monitor each unique pattern.

Short Count Program Design

The short duration counting program can be most efficient if the data collection efforts of different groups are coordinated so that one count session meets multiple needs. To produce that efficiency, the TMG recommends the following program design:

- Establish a coverage count program that covers the complete system on a 6- year cycle.
- Determine the count locations required to meet HPMS reporting needs. The HPMS universe/sample sections should be counted once every 3 years.
- Determine the count locations and data collection needs of special projects (such as pavement design or traffic operation improvement studies) that will require data in the near future.
- Overlay these counts[5] on a map of the highway system, along with the location of functioning continuous counters.
- Determine how these counts can be combined to make best use of available counting resources
- Schedule the counts to most efficiently use the available data collection crews and equipment.

This program design is intended to reduce count duplication and increase the efficiency of the data collection staff.

HPMS Counts

Of particular importance to all highway agencies is the collection of the HPMS data. Volume data on HPMS universe/sample sections are used to apportion Federal-Aid funds to the States. Significant portions of these funds are then allocated by each State highway agency to lower jurisdictions. Consequently, each highway agency has a direct financial interest in the validity of data submitted to FHWA under the HPMS.

Each State highway agency is responsible for reporting data for each HPMS section on the National Highway System (NHS) and other principal arterials (PAS). In addition, the State highway agency is required to report traffic volume information on a sample of other arterials and major collector roads in the State. To support this reporting requirement, each roadway section for which an HPMS volume count is required must be counted at least once every three years. In addition, each State must maintain periodic count data on all roadway sections not included in the HPMS sample so that those sections can be accurately assigned to HPMS volume strata. This is necessary to expand the HPMS sample counts into accurate estimates of statewide VDT. To accomplish this,

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[5] Included in this effort should be all vehicle classification and WIM counts, since these counts should also provide total volume data.

the HPMS recommends that all road segments in the coverage program be counted on a six-year cycle.[6]

State highway agencies may not physically count all HPMS sample locations. In many cases, State highway agencies will rely on local jurisdictions to collect and report these data. Many sites are instrumented with permanent volume, classification, WIM, or ITS equipment. In other cases, procedures such as "ramp balancing" can be used to estimate traffic volumes on roads where portable counts cannot be safely performed.

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[6] This is a general recommendation. Roads in high growth areas should be counted more frequently, whereas roads in low growth portions of a State could conceivably go much longer between counts without a discernable loss in accuracy.

CHAPTER 4
FREEWAY-EXPRESSWAY RAMP COUNTING PROCEDURES

The importance of the Interstate system necessitates that AADT based on actual traffic counts be estimated and reported to the HPMS for all Interstate highway sections. Unfortunately, the installation and use of portable traffic counting equipment on high volume freeways present great difficulties. Ensuring the safety of traffic counting crews and the motoring public is costly and requires extensive traffic control. In addition, the traffic volumes on multilane facilities are often higher than can be accurately counted by conventional, widely available, portable axle detectors. Therefore, in many cases, portable counters cannot be used to collect mainline counts on freeways and expressways.

This chapter describes the use of special study ramp counts to estimate freeway and expressway mainline traffic volumes. Although this technique can be used to estimate any basic volume statistic on these sections of roadway, the discussion emphasizes the ability to compute the AADT estimates needed for submittal as part of the HPMS process. These count procedures are applicable to any controlled access facility. They are especially applicable to the Interstate system.

There are two alternatives for collecting these data. The first involves the installation of permanent traffic sensors covering roadway sections. The second relies on counts taken at entrance and exit ramps between known mainline volume counts. The mainline counts are then adjusted for the changes in volume that occur at each ramp.

The installation of permanent sensors is the most effective way to meet the need for data on these facilities. Permanent sensors can be operated continuously, often as part of a traffic management system, or periodically, as part of a data collection/performance reporting system. Continuously operating sensors are more common on high volume urban roadways, where the collected data are often needed by traffic management systems. When sensors are operated periodically, the State highway agency connects portable sets of data collection electronics to permanently installed sensors to collect data when needed. This allows staff to collect data without having to physically place vehicle or axle detectors on the road. This practice is becoming more widely used on high volume, high speed roadways.

The installation of permanent sensors is expensive, particularly if all sections of an urban facility must be covered. Funding for extensive freeway data collection is normally beyond the budget of most data collection groups. These detectors are most commonly installed as part of area-wide advanced traffic management systems that require facility performance data to help optimize roadway usage. The increasing installation and operation of traffic management systems is expected to increase the availability of basic traffic volume data from these permanently operating sensors.

However, State highway agencies must be aware of the large efforts needed to make the data collected by these systems available to other data users.

Where continuous data are not available from traffic management systems, ramp counting is the mechanism most commonly used to estimate volumes on freeways and expressways. The ramp counting process can be performed quickly with existing technology and staff.

THE RAMP COUNTING PROCESS

Ramp counting is the process of counting traffic volumes on all entrance/exit ramps between two established mainline counters, such as permanent ATRs or other installations, and then reconciling the count data to estimate mainline AADT.

The process is designed to estimate **mainline** AADT. Annual mainline estimates of AADT are a reporting requirement of the HPMS system. The HPMS definition of Interstate mainline AADT excludes volume from frontage roads, collector-distributor roadways within interchanges, and the ramps themselves.

The following sections describe the methodology for developing a ramp counting program and reconciling the counts to mainline estimates of AADT. An example, consisting of one figure and three tables, illustrates the process. Figure 3-4-1 presents a diagram of the example study section. Table 3-4-1 shows the estimation of adjusted daily volumes for mainline sections. Table 3-4-2 shows the estimation of AADT for those mainline sections. Table 3-4-3 shows the reconcilement of the mainline AADT between ramps into AADT for the HPMS reporting sections. (These figures are presented in the text as they are discussed in the paragraphs below.)

The ramp counting process is similar to a traffic flow problem in which mainline volumes are known at two points and all input/outputs are measured between those two points. The two boundary points are normally ATRs or other instrumented mainline locations that provide a highly accurate measurement of annual traffic volumes. These points are used to control the counting and adjustment process and are referred to as "anchor points."

Another requirement of the ramp counting process is the availability of detailed maps or computerized inventories showing the locations of the anchor points and the ramps for each direction of travel. These inventories should also provide the detail needed to map the freeway segments to the HPMS sample sections. This is particularly important where an HPMS section includes more than one interchange, and thus more than one "computed volume section." In this case, computation of HPMS section volumes must account for the travel on each of the "computed volume sections" that make up that HPMS section.

One of the limitations of the ramp counting approach to mainline volume estimation is that travel-lane volumes cannot be estimated because traffic entering the road cannot be allocated to lanes. This limitation is not a problem for data collected to meet the specifications of the HPMS, but it may have implications for other programs that depend on lane-specific traffic volume information.

ESTABLISHING THE ANCHOR POINTS

The first step in ramp counting is to select the two anchor points (continuous counters or other loop installations) that will be used to control the estimation process. The use of permanent counters as anchor points provides the highest accuracy and is preferable. However, the number of existing permanent ATRs available for this purpose is often not sufficient and the cost of a large number of continuous counter installations may make this option infeasible. Therefore, any available instrumented site may be used as an anchor point. However, they should only be sites where mainline volumes can be accurately obtained. The installation of additional permanent detectors (counting either continuously or periodically) to provide accurate anchor points is strongly recommended whenever sufficient budget exists for this activity.

When determining the number of anchor points to be used for any given facility, the State highway agency must trade off accuracy and cost. Generally, the closer together the anchor points (in terms of the number of ramp interchanges between them) the more reliable will be the estimates for roadway sections between those points. On the other hand, the farther apart the anchor points are placed, the lower the number of anchor points needed to estimate volumes on the complete facility. The “correct” number of anchor points depends on the specific location and traffic characteristics under consideration. The number and placement of anchor points is really a function of the available budget; the importance of interchanges and major route connections (junctions); and the availability and location of existing mainline count locations, including ATRs, control counters, permanent loops, toll booths, traffic control points, and other instrumented sites. **Each State will have to make its own determination regarding the appropriate number of anchor points. As a general rule-of-thumb, the recommended number of interchanges between anchor points is five.**

TAKING COUNTS BETWEEN TWO ANCHOR POINTS

Many studies have shown that traffic patterns tend to vary considerably during the day. Therefore, **the minimum period recommended for collecting ramp volume data is 24 hours.** Ideally, **all ramps between two anchor points should be counted for the same 24-hour period.** Multi-day counts are preferable to 24-hour counts, especially where these counts can extend over both weekdays and weekend days, and assuming that the vehicle detectors will continue to function accurately for more than 24 hours. Traffic patterns change from day to day, especially from weekday to weekend day. Ramp volumes (and thus mainline section volumes) are often particularly affected by day-of-week volume changes, as some activity centers have dramatically different weekday/weekend usage patterns. Directly accounting for these changes in the ramp count data will help improve the accuracy of the mainline volume estimation process.

Ramp counts collected with conventional axle counting devices must be converted to estimates of vehicle volume before use in this process. Selection of appropriate axle correction factors is discussed under Axle Correction for Ramp Counts, presented later in this chapter.

Collecting all ramp data between two anchor points on the same day(s) eliminates the need to adjust the counts before reconcilement[7]. When ramp counts cannot be taken during comparable periods, they may have to be adjusted to AADT before reconcilement. If all ramps can be counted on the same day, conversion to AADT should be done after reconcilement. If some ramp counts are missed because of equipment problems, errors, or staffing limitations, recounts should be taken as soon as possible during the same days of the week as the original count and, preferably, during the same month to limit the potential for errors caused by variation in the traffic and by limitations in the adjustment process used to estimate annual conditions from short duration counts.

Where volumes on an entire Interstate freeway are estimated in this fashion, the schedule of counts can be organized systematically over the counting season to minimize the staff needed and to allow recounting as needed.

So far this discussion has assumed that all ramps can be counted with portable detectors such as road tubes, mats, switches, magnetic sensors or portable loops. However, some ramps will be impossible to count with these methods. In those situations, the use of shorter visual or video counts may become necessary. In these cases, an appropriate adjustment process will have to be developed to expand these short duration counts to estimates of 24-hour traffic. For example, an 8-hour count could be converted to a daily estimate with data from the anchor points. This estimate could then be treated as if it were a 24-hour count. However, such an adjustment will add considerably to the error associated with the ramp counting approach.

MAINLINE DAILY VOLUME ESTIMATION BASED ON RAMP COUNTS

The reconcilement of ramp counts to anchor points begins by establishing the daily volume at the two anchor points for the 24-hour period during which the ramps were counted. Then one of the two anchor points is selected as the starting point. Because the access and egress points will vary by direction of travel, **it is recommended that the reconcilement be carried out independently by direction of travel and that the computation proceed in the direction of traffic flow.** This will provide AADT estimates for each direction of travel. The two directions are added to provide total AADT. The computation by direction of travel simplifies the identification of on and

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[7] Reconcilement is the process by which ramp counts and data from anchor points are converted into mainline AADT estimates.

off-ramps. It also simplifies the computation of AADT for facilities that incorporate reversible travel lanes. However, it does require twice as many computational steps as doing both directions simultaneously. Several States have indicated that in many cases combining both directions of travel produces almost the exact results but reduces the effort required. Where interchange design allows both directions of travel to be treated simultaneously, States may choose to use this option.

The process of addition or subtraction is carried out until a daily directional volume has been calculated for each mainline section between each ramp between the two anchor points. In theory, assuming no equipment error and exact vehicle counts at each ramp, the addition/subtraction process should produce a mainline volume estimate for the section ending at the end anchor point that is equivalent to the volume computed from data collected at that anchor point.

In practice, because of equipment error and other factors, a difference will always exist at the end of the process. The difference should not be large. A large difference is an indication of problems, usually related to equipment accuracy. **It is recommended that the difference be proportionally allocated to each section between the two anchor points, but only if the difference is greater than 1 percent and less than 5 percent ($1 < d < 5$) of the directional volume at the ending anchor point.** Differences under 1 percent can be considered negligible and ignored. If the process is computerized, then the adjustment should be carried out to ensure an exact volume match. In most cases, differences greater than 5 percent may require, at a minimum, a check and verification of the ramp counts and anchor point data. At worst, it may necessitate a complete recount of all the ramps between the anchor points.

The allocation of the volume difference to the ramps (and subsequently to the mainline volume estimates) is carried out by proportionally distributing the volume difference remaining at the ending control point to each of the ramps. The adjustment to each ramp is computed as the ratio of the difference in volume (remaining at the end of the reconcilement) to the sum of the ramp volumes. This process is described in the example.

Actions that can be taken to minimize error include accuracy checks on the counters, proper installation of equipment, adequate control over monitoring periods and the use of vehicle counters rather than axle counters. Ramp counting can be a difficult operation, and staff workloads should be designed to emphasize quality rather than quantity. Regardless of the actions taken, a small reconcilement difference should always be expected.

Figure 3-4-1 illustrates the recommended ramp counting process. Table 3-4-1 presents the computation of the adjusted mainline volumes for a 24-hour period in one direction of travel. Figure 3-4-1 shows an Interstate segment of six kilometers bounded by ATR anchor locations. The eastbound direction of travel consists of four segments separated by three ramps. The segments are identified by capital letters (A, B, C, and D). Ramps 1 and 3 are entrance ramps, and ramp 2 is an exit ramp. The length between the ramp-separated segments is included.

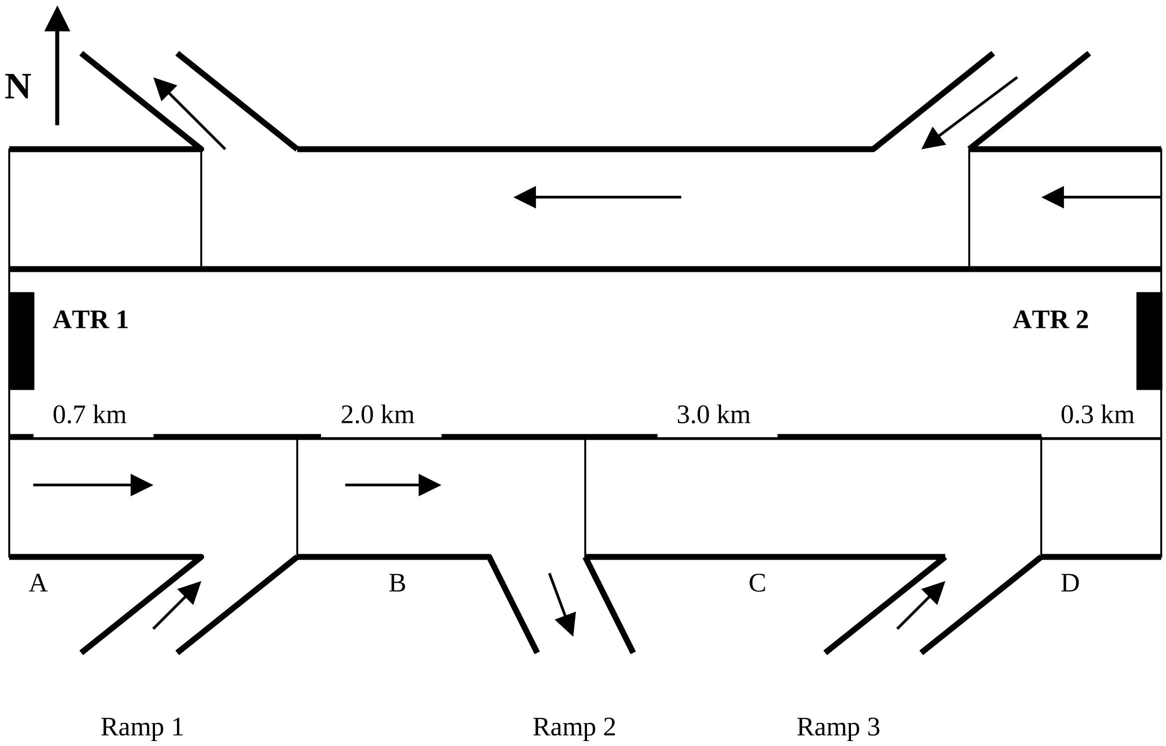

Figure 3-4-1
Ramp Counting Freeway Layout Example

For computing section lengths, roadway sections that end with entrance ramps are, by definition, measured from the point where the ramp first connects to the mainline of the Interstate. Likewise, sections with exit ramps are measured from the last point where the ramp touches the mainline. The level of accuracy of these distance measurements should be governed by the State's existing roadway inventory database.

The volumes in Table 3-4-1 are computed starting with the volume at ATR # 1 and adding or subtracting ramp volumes until ATR # 2 is reached. In the example, a difference of -3 percent resulted at the end. The adjusted ramp figures were computed by proportional allocation of the difference based on ramp volumes [dividing the difference (402) by the total ramp volume (2762) to compute the allocation proportion (.145) and multiplying this factor by the counted ramp volumes].

Table 3-4-1
Computation of Adjusted Mainline Volumes

Ramp count date: May 17
Length of analysis section: 6 kilometers
Direction of travel analyzed: Eastbound

Ramp Counts

	Ramp 1	Ramp 2	Ramp 3	Total
Ramp count volume	923	1,053	786	2,762

Initial Mainline Volume Estimates

	ATR 1	A	B	C	D	ATR 2	Remaining Difference
Initial Volume	11,995	11,995	12,918	11,865	12,651	13,053	402 (-3%)

Adjusted Ramp Volumes

	Ramp 1	Ramp 2	Ramp 3	Total
Ramp adjustment	+134	-153	+115	402
Balanced ramp volume	1,057	900	901	

Adjusted Mainline Volume Estimates

	ATR 1	A	B	C	D	ATR 2	Remaining Difference
Balanced Volume	11,995	11,995	13,052	12,152	13,053	13,053	0

Allocations, whether accompanied by this method or others, can substantially change some of the ramp volumes. This is because differences in mainline volumes (usually caused by equipment error) at the two anchor points may be low in percentage terms (meaning reasonably small equipment error) but quite high in comparison to individual ramp volumes. Thus, whereas the percentage error in the mainline volume estimate may be small, that same absolute error can be a significant fraction of a given ramp volume.

As a result, it is important to recognize the effects of the adjustment process on ramp volumes. An equipment error in any of the initial counts may have caused the problem with the ending difference, and the error is then further aggravated by the adjustment. When calculating adjustments, large differences should be suspect and thoroughly examined by checking the ramp counts and the ATR figures. In general, the effects of these errors will be minimal (in percentage terms) for mainline volumes but can be substantial for ramp volumes.

In examining the validity of ramp counts, the use of historical data, if available, is of great help. Likewise, knowledge of the equipment, the area, and any special events that may have affected the counts may help explain discrepancies and assist in the verification and correction process.

AXLE CORRECTION FOR RAMP COUNTS

As previously shown, ramp counting requires accurate volume measurements to reduce the size of adjustments needed to reconcile the estimates. Daily volumes at anchor points are expected to directly represent vehicles rather than axles converted to vehicles.

Axle correction for ramp counts is a difficult issue because the ramp counts must represent precise figures that are reconciled to known volumes from ATRs. For this reason, **ramp counts should be taken with vehicle counters to eliminate the need for ramp axle correction.**

Unfortunately, accurate vehicle classification may not be possible at many ramps because acceleration and deceleration over the axle/vehicle detectors and the close spacing of many cars on ramps significantly degrade the accuracy of this type of equipment. Vehicle classification equipment must be carefully placed and tested at each ramp location before being trusted. If an axle count must be made due to equipment, **the collected axle counts must be converted to vehicle estimates before reconcilement.**

The use of axle correction at ramps introduces much error and complexity and should be avoided as much as possible. Axle correction factors applied to ramps should be based on the most reliable estimates available and account for temporal and spatial concerns. Temporal comparability means that the classification counts used to develop the axle correction factors for specific ramps should be taken the same day of the week and same month as the ramp counts. At a minimum, counts taken on weekdays should be adjusted with classification counts taken during weekdays. Spatial comparability means that axle correction factors applied to ramps should be based on classification counts representative of the route connecting the ramp to the roadway. At an absolute minimum, the axle correction should be based on the functional classification of the connecting route.

Local knowledge of the ramp traffic is particularly important when estimating axle correction factors for ramps. The volumes and characteristics (numbers of axles per vehicle) of trucks using ramps, particularly in urban areas, can change dramatically from ramp to ramp. The emphasis the TMG places on collecting classification data can result in much more accurate vehicle data and help reduce the problems with axle correction. The development of statistically based axle correction factors for system wide application is covered in the vehicle classification section. However, system-wide factors are not appropriate for adjusting ramp counts and should be used only as a last resort.

ESTIMATION OF MAINLINE AADT

Once the daily volumes for each mainline section between the anchor points and each ramp have been developed, then the volumes are converted to AADT. As with the axle correction factors, system factors are not appropriate for this adjustment process when better site-specific data are available. Consequently, **directional section-specific AADT expansion factors should be computed from the two anchor ATRs and applied to the estimates developed between the anchor points.** For the sections where the permanent ATR counters are located, the AADT from the ATRs should be used.

A directional factor should be computed for each ATR as the ratio of directional ATR AADT to the directional daily volume on the ramp at that date. For example, if a ramp count is taken on May 17, then the adjustment factor is the ratio of AADT at the ATR to the May 17 daily volume at that ATR. If more than 24 hours of data are collected for the ramp count, the daily volume for all days counted should be averaged at the ATR, and the ratio of AADT to that average used as the adjustment factor.

Because there are two ATR anchor points, the directional factors at the starting and ending ATRs are averaged to compute the final daily AADT conversion factor. The directional mainline daily volume estimates are multiplied by this conversion factor to obtain mainline directional AADT estimates.

The use of system-wide factors to adjust the ramp counts will add additional error to the mainline volume calculation process and should only be used in exceptional cases, such as when the anchor points are not ATRs, and no other AADT conversion information exists.

Table 3-4-2 illustrates the process used to develop the mainline AADT estimates and continues the example introduced in Table 3-4-1. The AADT conversion factors are computed for each specific day of ramp data collection. In the table, the factor at ATR #1 for May 17 is 1.16 (the ratio of 13,914 to 11,995). The factor applied is the average of the two ATRs.

Table 3-4-2
Estimation of Mainline AADT

ATR	Volume (May 17)	AADT	AADT Conversion Factor
1	11,995	13,914	1.16
2	13,053	14,574	1.14

		Average	1.15

Section	Daily Volume (5/17)	AADT Factor	AADT Estimate
A	11,995	--	13,914
B	13,052	1.15	15,010
C	12,152	1.15	13,975
D	13,053	--	14,574

Section	AADT Estimate	Final AADT[8]
A	13,914	14,000
B	15,010	15,000
C	13,975	14,000
D	14,574	14,600

ADJUSTMENT OF AADT ESTIMATES TO CURRENT YEAR

AADT estimates based on counts taken during the current year need no current-year adjustment. If no new ramp volume data are collected in a given year, the AADT estimates from the last year data were collected should be adjusted to estimate current year traffic using anchor ATR factors.

The current year factors are developed on the basis of the anchor ATRs. The factor for each ATR is the ratio of current year AADT to previous year AADT. A one-year factor is the ratio of current-year AADT to the previous year's AADT, while a two-year factor is the ratio of current-year AADT to the AADT from two years earlier.

The current year factor for all the mainline estimates between two anchor points is the average of the factors at the two anchor points. The sections where the ATRs are located use the ATR AADT values directly and require no adjustment.

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[8] Note that the accuracy of both the traffic counting equipment and the ramp count adjustment process does not warrant the use of more than three significant digits. Thus, after completion of the ramp counting mainline estimation procedure, mainline AADT volumes should be rounded to three significant digits.

The process becomes more complex where continuous ATRs are not the anchor points. In these cases, the factors must be based on other continuous counters. The list of possible ATRs from which to obtain these data includes locations near the sections in question and on the same route, locations within the same urban area, or system-wide growth factors for the appropriate functional class and/or geographic region. Because many conditions affect the selection of the appropriate base for making this adjustment, each State will have to examine and develop its own special case procedures.

CONVERSION OF MAINLINE ESTIMATES TO HPMS SECTION ESTIMATES

The ramp counting/reconcilement process results in directional AADT estimates between every ramp or between anchor points and ramps. The already defined HPMS standard sample or universe sections may extend over several ramp breaks because of the more detailed definition of lengths between ramps. If the HPMS section exactly coincides with a ramp break in both directions of travel, then no conversion is necessary. Otherwise, ramp estimates are converted to produce the HPMS section AADT by weighing the ramp AADT estimates by the length of the ramp segments within the HPMS section.

Each directional ramp segment AADT is multiplied by its length. The results are summed until the HPMS section is covered. Then the sum is divided by the total HPMS section length. This yields the HPMS section AADT. This process is equivalent to computing the DVDT of each ramp section within the HPMS section, summing those values, and then dividing by the HPMS section length. After the AADT is estimated for each direction of travel, both directions are summed to produce the total HPMS section AADT.

Table 3-4-3 continues the example under the assumption that the HPMS section begins at the first ATR and ends at the second ATR. As mentioned earlier, collector-distributor interchange, frontage road, or ramp volumes are excluded from the HPMS Interstate mainline volume estimate.

HPMS sections on the Interstate or Other Freeway/Expressways must not extend beyond the next interchange, with limited exceptions in low volume States where interchange volumes are very low. Any discrepancies of this nature found during the analysis should be corrected by redefining the HPMS sections.

Table 3-4-3
Estimation of Eastbound HPMS Section AADT

Segment	AADT	Length (km)	AADT × Length (km)[9]
A	13,914	0.7	9,740
B	15,010	2.0	30,020
C	13,975	3.0	41,925
D	14,574	0.3	4,372
		---------	-------------
	Sum	6.0	86,057

HPMS Section Eastbound AADT = 14,300
HPMS Section Westbound AADT = 13,200 (assumed)
HPMS Section AADT = 27,500 (rounded to three significant digits.)

SYSTEM APPLICATION OF RAMP COUNTING

The ramp reconcilement process should produce accurate estimates of AADT for all mainline sections between ramp breaks in the defined area. Likewise, all HPMS universe (and sample) sections should be estimated. Estimates will also be available for each entrance and exit ramp, although these ramp estimates may represent only daily estimates. If annualized estimates are desired at each ramp, then the appropriate adjustment factors must be applied to the ramp count data collected.

The ramp counting and reconcilement process can be applied as needed by the highway agencies. Agencies may decide to apply the process only to areas where mainline counting is not possible, only to urban areas, or to the complete Interstate system. Because of the simplicity of counting ramps in rural areas, many States apply the process statewide to ensure consistency and to provide complete coverage of the Interstate system. Other States use ramp counting because of a need for ramp volume information and as a check on the accuracy of mainline counts.

The intense geographical detail needed to apply the ramp reconcilement process, coupled with the data collection, data manipulation, and data dissemination functions, make it a likely candidate for the use of a microcomputer database, spreadsheet, or geographical information system (GIS). Such an application greatly simplifies entering, storing, computing, maintaining, and reviewing the Interstate traffic figures.

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[9] This example shows more significant digits than the count program warrants. It does so simply to make the math easier to follow. The user needs to remember to limit the number of significant digits when reporting the results.

APPENDIX 3-A
FREQUENTLY ASKED QUESTIONS

Can ATRs be used to accurately track VDT?

ATRs track traffic at a point. Depending on the site, this can be expanded to a section or route. It is rarely practical, to track areawide travel with ATRs. Few agencies have the large number of ATRs required to provide statistical reliability to the areawide travel estimates. In most cases, agencies use a limited number of ATR locations to provide traffic trends at a limited number of sites. Individual road volumes are dramatically affected by local changes in land use and economic activity. The use of a small number of ATR locations can result in highly biased VDT calculations. The FHWA uses the ATR data reported monthly to the Travel Volume Trends (TVT) system combined with the annual HPMS VDT estimates to track changes in monthly travel. A similar approach could be applied statewide for States with sufficient number of ATRs.

How do I define a “Road Segment" for traffic counting?

A road segment for traffic counting is a section of road with homogeneous volume (i.e., the traffic volume does not change throughout the segment). Many State traffic programs divide their systems into traffic segments and physically count each segment to provide complete system coverage. Traffic volume is constantly changing and a perfect segment definition is not possible. For access-controlled systems, a definition between interchanges is the simplest. For non-controlled systems, the TMG recommends keeping a single segment until volume changes of plus or minus 10 percent are identified, at which point a new segment should be created.

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Section 4

Vehicle Classification Monitoring

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SECTION 4
VEHICLE CLASSIFICATION MONITORING

CHAPTER 1
INTRODUCTION

This section addresses the collection, manipulation, and reporting of vehicle classification data to meet the needs for vehicle classification information. It includes examples of how to apply the general data collection principles discussed in Section 2 to the subject of vehicle classification counting.

This chapter summarizes the material presented in Section 2, with specific emphasis on vehicle classification counting. Chapter 2 discusses the basic user requirements that the vehicle classification program needs to meet. Chapter 3 presents the recommended process for selecting the size, frequency, and duration of vehicle classification counts to meet those needs. Chapter 4 discusses the computation of annual summary information and provides ideas on how to present that information effectively. Finally, Chapter 5 discusses the data collection equipment that is currently available and the need for both acceptance testing and field validation tests after the equipment has been installed.

VARIABILITY

Traffic volumes vary over time on all roads. Traffic volumes also vary dramatically from one road to another. These variations in traffic volume are even more apparent when volumes for specific vehicle types (classification) are analyzed. Consequently, the vehicle classification data collection program must gather sufficient data on traffic patterns of important vehicle types to accurately quantify the truck traffic stream to meet the needs of users.

The same sources of variation that are present in traditional traffic volumes apply to vehicle classification estimates. These include:

- time of day
- day of week
- time of year
- direction
- geography.

Complicating the monitoring of these traffic patterns is the fact that not much data has been collected by classification and not much analytical work performed. Thus, many of these patterns are not well understood at the State and individual roadway levels. Further complicating matters is the fact that travel patterns for trucks are usually quite different than those for cars, and the data collection plans currently used tend to be structured around understanding the movements of cars not trucks.

Thus, the structure of the recommended traffic data collection plan has been expanded to understand and account for the movement of trucks.

DATA COLLECTION TO ACCOUNT FOR TRUCK MOVEMENTS

The recommended structure of a good classification counting program parallels that traditionally followed for volume counting. The classification counting program should include both extensive, geographically distributed, short duration counts and a smaller set of permanent, continuous counters.

A fairly large number of short duration classification counts should be performed to monitor and capture truck movements taking place on individual roads. These counts should be collected by equipment capable of providing hourly volume summaries. They should normally include data for all lanes and directions for a given location, since truck traffic varies considerably from lane to lane and often by direction. This data collection effort yields the basic truck traffic statistics needed on any given road including the geographic variability of truck movements, and the time-of-day distribution at a variety of locations.

These data serve as the starting point for other statistics needed including truck VDT (or VMT), freight flows (tonnage) carried by trucks on specific roadways and along specific corridors, and traffic load design statistics (ESAL and axle load distributions).

However, without adjustment, short duration classification counts yield biased estimates. Thus, as with traditional traffic volume counting, classification coverage counts must be supplemented by the use of permanent, continuously operating, vehicle classification counters (CVC). The permanent counters provide an understanding of how truck travel varies by day of the week and season of the year.

As with traditional volume counting, the permanent classifiers should be used to compute adjustment factors that can be applied to short duration classification count data to convert a daily count into an estimate of annual average daily volume for that roadway. The difference between the recommended counting program for vehicle classification information and the traditional volume counting program is that the factor groups used for volume counts do not usually create accurate factors for adjusting vehicle classification data.

Truck volumes patterns are heavily affected by local economic activity. They are also heavily influenced by the presence or absence of large through-freight movements. For example, a high percentage of through trucks on a road tends to result in higher weekend truck traffic and higher nighttime truck traffic than would otherwise be expected. Similarly, the lower the volume of through-traffic, the lower the volume of trucks in the evening, and the more heavily oriented truck travel is to weekdays. Because typical volume factor groups do not differentiate among these types of roads, total volume-based adjustment factors do not accurately account for these factors.

Finally, traditional volume factoring groups are oriented toward functional classification of roadway, which may or may not correlate well with truck travel patterns. Consequently, to better estimate the annual average travel by trucks on the roads, most States will need to develop a classification factoring process specifically to factor short duration classification (truck) counts.

INTEGRATION OF CLASSIFICATION COUNTING PROGRAMS

The vehicle classification counts required should not be considered separate from the volume counts traditionally performed. Instead, they should be integrated with the traditional volume counts. Because classification counts provide both classification and total volume information, they can replace traditional volume counts reducing duplication and error. This is true for both short duration counts and permanent traffic recorders.

Traffic surveillance equipment used as part of advanced traffic management systems (ATMS) or advanced traveler information systems (ATIS) can be used to supply both total volume and vehicle classification information. Intelligent transportation system (ITS) technology and its resulting data are often present at high profile locations as part of safety enhancement systems.[1] These systems can supply useful, continuous traffic monitoring data, while also accomplishing their primary ITS safety/operations objective. Other agencies and even multiple divisions within a State DOT collect classification information that can be routinely incorporated into the statewide traffic counting database. Coordinating these traffic monitoring activities can lead to significant improvements in the amount of data available to users, while at the same time reducing the cost of data collection.

Excellent sources of classification data can often be found at locations associated with freeway operation surveillance systems, long-term pavement performance monitoring, vehicle weight enforcement, and toll facility revenue collection points. Finding these sources and developing the procedures to obtain and make the data available to others, can be significant tasks. However, the benefits of cooperation in the data collection process are substantial and long lasting. The benefits from the effort are well worth the cost.

REQUIRED OUTPUTS FROM THE VEHICLE CLASSIFICATION DATA COLLECTION PROGRAM

It is difficult to describe all of the outputs that can result from the vehicle classification data collection effort. In general, a State DOT should be able to provide users with an estimate of the amount of truck traffic by type of truck by road segment. Truck volume and percentage estimates should be made available for the date when data

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[1] For example, Colorado DOT operates truck rollover and truck speed/braking warning systems that can provide truck use data.

were collected and as annual average estimates corrected for seasonal and day-of-week variation. States should always provide annual average daily truck volumes by truck type, but other average statistics, such as average peak hour truck volume, may also be appropriate.

CLASSIFICATION SCHEMES

Highway agencies use a large number of vehicle classification schemes. For many analyses, simple vehicle classification schemes (passenger vehicles, single unit trucks, combination trucks) are more than sufficient. In other cases, more sophisticated vehicle classification categories are needed. For example, in the early 1990's Canada investigated the creation of a classification scheme that would have included the type of hitch used between tractors and trailers. This would have allowed much more reliable research on the crash history, and consequently the safety benefits, of alternative hitch types. Unfortunately, the available data collection technology could not accurately classify vehicles by hitch type.

As was found in Canada, the classification schemes that can be used are a function of the data collection equipment available. The three types of sensors most frequently used for collecting truck volume information (visual, axle, and presence sensors) each provide a different mechanism for classifying vehicles. Within each of these three broad categories are an array of sensors with different capabilities, levels of accuracy, performance capabilities within different operating environments,[2] and output characteristics. Each type of sensor works well under some conditions and poorly in others.

Further complicating matters is the fact that different manufacturers attach different types of electronics to those sensors and analyze, store, and report sensor outputs differently. Some data collection equipment is capable of maintaining large amounts of data that provide very descriptive classification information. For example, some systems store individual vehicle images (either video images or axle weights and spacing information) and differentiate among a wide variety of vehicle types. Other, less powerful systems can differentiate only a few general classes, based largely on measures of overall vehicle length, and store and report the data only as summary totals for specified time intervals.

The result is an array of options for classifying vehicles, and an even wider array of ways in which the resulting vehicle counts are stored and reported from the field. Many States use a variety of equipment for different conditions and therefore are confronted with the task of dealing with different vehicle classification schemes at different points in the network. This is not necessarily a bad situation. **The key is to understand how the different classification schemes relate to one another**. That is, if

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[2] That is, some work well at high vehicle speeds but not under congested traffic conditions. Some work well in all weather conditions, but only when vehicles remain in their lanes, whereas others are not affected by poor lane discipline but can be affected by weather conditions such as snow or fog.

the State normally uses axle classification schemes (such as the FHWA 13 categories) but relies on inductance loop classifiers on urban freeways, it must determine the appropriate length-based classification boundaries that allow accurate comparison between these two schemes. This can be accomplished by comparing estimates of overall vehicle length stored on individual vehicle weight records obtained from a WIM scale that uses inductance loops for detecting vehicle presence with the FHWA 13-category classification scheme associated with each vehicle. **States should maintain and be able to report the classification algorithm used to define each vehicle category they collect.**

The FHWA 13-Category Classification System

In the 1980's, the FHWA developed the 13-category scheme used for most federal vehicle classification count reporting (Appendix 4-C). The scheme was a compromise among several factors: the manual (vision based) classification schemes used before that time, the need to create a nationally consistent classification scheme, the automated counters being developed at that time, and the need to provide basic information on different truck types as input to a variety of policy issues.

All States currently use this classification scheme or some variation of it for classifying vehicles, although few use it exclusively. Many States separate one or more of the FHWA categories into two or more additional classifications to track vehicles of specific interest to them. They then aggregate the categories back together when reporting to the FHWA. This allows each State to meet both its own needs and the FHWA's needs. In addition, many States use other classification schemes in places where axle sensors do not work effectively (e.g., congested urban conditions) or where non-intrusive sensors are needed.

Since the earliest work done by Maine DOT (Wyman, Braley and Stevens 1985) on classification algorithms[3], it has been apparent that different States have trucking fleets with slightly different axle spacing characteristics. Thus, even when States use the same FHWA classification scheme, the algorithm they use to convert axle-sensor information into vehicle counts by category differs. In most cases, the vehicle classification algorithm provided by each manufacturer needs to be "fine tuned" to accurately convert that State's truck fleet axle spacing characteristics into an accurate measure of truck volumes for the FHWA categories.

Fine-tuning the classification algorithm is needed because the visual basis of the FHWA 13 categories does not translate to an exact set of axle spacings. For example, classes 2 and 3 (passenger car and other two-axle, four-tire, single-unit vehicles) are easily identified visually. However these classes are often inter-mixed by axle-sensor-based classification counters. This is because larger cars often have wheelbases equal to or longer than those of small trucks. Consequently, it is not possible to create an

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[3] The Maine DOT work, led by John Wyman, created the algorithm commonly referred to as "Scheme F," which serves as the basis for most current axle-sensor based classification counter algorithms.

algorithm that uses only axle spacing information to differentiate between these two classes of vehicles.

These types of problems exist in a variety of vehicle classes. Recreational vehicles are particularly hard to classify with axle sensors. In many cases, States can do little about these problems (such as the class 2 and 3 problem mentioned above). Difficult choices are made to fine-tune the classification algorithms to limit the effects these errors have on the data they collect. This usually means ensuring that the algorithms correctly classify "important" truck categories and only have problems classifying types of trucks that are rare and of less importance to the highway community. Highway agencies must educate their users on the limitations in the data collected.

Calibration and Testing of Classifiers

Each State must periodically calibrate, test, and validate the performance of its classification equipment to ensure that the equipment is operating as intended. This includes testing each new shipment of classifiers received from the manufacturer, and a short field test whenever a classifier is placed in traffic to ensure that the counter is working correctly. The quality of the data collected is highly dependent on the quality of the calibration/testing operation.

Alternative Classification Schemes

When the FHWA 13 categories cannot be used (because the data collection equipment can not collect them), or the FHWA classes do not meet State needs, it is recommended that the classes be either a subset of the FHWA classes or a clean disaggregation of the FHWA classes. That is, the State should strive to create classes that consist of either several FHWA classes added together (e.g., a "single-unit truck" category that consists of FHWA classes 5, 6, and 7), or FHWA categories split into two or more classes (e.g., dividing FHWA Class 13 into the two classes, "triple-trailer trucks" and "other seven or more axle multi-trailer vehicles").

The aggregation of the FHWA 13 classes into three or four classes is specifically recommended for the seasonal factoring of truck volumes.

Highway agencies are also encouraged to collect and analyze detailed vehicle characteristic data (i.e., actual axle weight and spacing information) every few years from several WIM locations to examine changes in fleet characteristics over time. Examination of detailed axle spacing information will allow currently emerging vehicle characteristics such as split tandems and changing axle spacing relationships to be tracked. Such changes can result in the need to update vehicle classification algorithms.

The detailed data needed for this type of analysis (number of axles, axle spacings, total vehicle length, and trailer configuration information) can be obtained from individual vehicle records collected by WIM equipment. For some analyses, these data need to be supplemented by a video record with a visible time recording to allow the video record to be matched against the WIM vehicle record.

CHAPTER 2
USER NEEDS

User needs drive the data collection process. **A key to making the data collection process valuable to agency's decision makers (a requirement for adequate funding) is the ability of the traffic monitoring program to supply users with the data they need.** This can be a difficult problem because in many cases data users and collectors do not communicate well with each other.

Data collectors and data users are frustrated by the lack of communication. Data collectors often know little about how the data will be used but are asked to provide data and summary statistics. Many of these statistics require the application of professional judgment, and that judgment is hard to apply when the impact of different assumptions on analytical outcomes are not fully known. Data users often receive data with no explanation. The precision of the estimates is rarely provided. In many cases users settle for the data or summary information provided. Generally, better data and information will result if communication between the data and user groups are improved.

This chapter discusses briefly some of the uses of traffic classification data. It is intended to start the communication process by helping data collectors begin to understand how data may be used and, thus, what summary statistics are needed. Data collection personnel are encouraged to actively investigate the data needs of their agency and then work creatively to meet those needs.

USES FOR CLASSIFICATION DATA

Vehicle classification data are of considerable use to agencies involved in almost all aspects of transportation planning and engineering. The need for information on truck volumes and freight movements is growing with the recognition of the role that freight mobility plays in the economy, and as highway engineers realize the importance of truck volume and operating characteristics on the geometric and structural design of roadways and bridges. Common uses of truck volume information include the following:

- pavement design
- pavement management
- scheduling the resurfacing, reconditioning, and reconstruction of highways based on projected remaining pavement life
- prediction and planning for commodity flows and freight movements
- provision of design inputs relative to the current and predicted capacity of highways
- development of weight enforcement strategies
- vehicle crash record analysis
- environmental impact analysis, including air quality studies
- analysis of alternative highway regulatory and investment policies.

In short, vehicle classification data are extremely important and will become even more important as transportation agencies and legislatures grapple with increasingly older, more congested roadways that need long lasting repair and rehabilitation in order to ensure statewide economic vitality.

SUMMARY VEHICLE CLASSIFICATION STATISTICS

The many uses for classification data require the production of a wide variety of summary statistics. For example, a State wishes to develop the annual average daily traffic by class for each roadway. To comply, several actions are required which the program must be capable of producing. A sufficient base of short duration classification counts must be taken. The short-duration classification counts must be adjusted to account for changing traffic volumes on different days of the week and different months of the year. The adjustment process must be developed and applied, which assumes the availability of continuous classification counter data. The resulting statistics are then capable of meeting defined user needs.

The average classification estimates can also be combined with load data to produce annual average loading conditions useful for monitoring the growth of trucks over time, for determining the loads being placed on pavement and bridges, and for tracking freight movements on the road system.

In addition to annual average conditions, users may want to be able to describe truck traffic by time of day during the average weekday. These estimates can be useful for scheduling road closures and in examining the effects of new development. Weekdays are also a normal design consideration from a traffic operations perspective, and understanding the mix of traffic is an important input to the design of an operational control strategy. Special procedures based on the available data can be developed to produce the desired information

Many statistics can be extracted from the vehicle classification data available from a comprehensive program. Several current revenue distribution formulas require vehicle distance traveled (VDT) information, and given the sensitivity of pavement design procedures to truck volume and load, it is quite possible that at some point, truck VDT could also be used in this fashion. Other common uses of VDT statistics by vehicle class include:

- air quality emission calculations
- crash statistics by type of vehicle
- general trend monitoring.

VDT by classification is a critical input to vehicle safety studies (crash rate and exposure calculations), cost responsibility studies, and vehicle size and weight studies. Many States track the use of specific types of vehicles. For example, Oregon tracks the use of triple-trailer combination trucks. Computing statewide or systemwide VDT by classification allows the State to compare not just total travel trends, but differences between trends for the subject vehicle class and for other similar classes. Oregon can not only measure the growth of triple-trailer truck travel (and changes to the crash exposure of these vehicles) but can also compare the growth of travel in that category of trucks to the increased travel of vehicles in other large truck classifications.

Developing data collection programs and aggregation methodologies that allow the computation of average facility statistics from average daily traffic estimates allows users to target these types of analyses to much lower levels (for example, how much is heavy truck travel growing on Interstate highways?). These statistics in turn facilitate improved geometric design work, more accurate safety analyses, and improvements to other critical engineering tasks.

The user may not always be interested in producing results using all 13 of the FHWA vehicle classes. In many cases three or four simple categories may suffice to meet user needs. Four traditional categories often used are:

- passenger vehicles (cars and light pick-ups)
- single unit trucks
- single combination trucks (tractor- trailer)
- multi-trailer trucks

Each of these categories is an aggregation of existing FHWA classes. Reporting and use of these simpler categories has the advantages of requiring less work (by the data collectors and the user) and of providing more statistically reliable truck volume counts for many analyses. Several of the FHWA categories contain so few vehicles that it is not possible to count and accurately report them. Using a smaller number of vehicle classes increases the confidence in the volume estimates reported.

Where practical, a State highway agency should collect data in the 13 FHWA vehicle classes but perform the majority of its data reporting with a more aggregated classification system, such as the four categories described above. This has the advantage of providing most users with as much information as they can use, while allowing those users who require more detailed information to obtain it. Such an approach is successful as long as users understand that more detailed data are available at some locations but that the quality of the details may be lower.

Axle correction factors are derived from classification data. Conventional volume counting performed with road tubes or other single axle sensors provides axle counts that must be converted into vehicle volume estimates. If all vehicles were passenger cars, dividing the number of axle hits by two would provide a good estimate of the total traffic volume. However, the more multi-axle vehicles that are present, the less accurate an adjustment factor of 2.0 becomes.

Where classification counts exist (particularly those that use the 13 FHWA classes), a much more accurate axle correction factor can be computed by assigning an average number of axles to each of the 13 classes and then calculating the average number of axles per vehicle for each vehicle on that road. This number can then be used to factor conventional axle counts taken on that road near the classification count. Table 4-2-1 provides a sample conversion chart that can help compute axle correction factors from classification counts that use the FHWA 13 vehicle classes.

Table 4-2-1
Conversion Chart

Vehicle Class	Average Number of Axles Per Vehicle
1	2
2	2
3	2
4	2.2
5	2
6	3
7	4
8	4
9	5
10	6
11	5
12	6
13	7

Axle correction factors should be taken from classification counts performed on the same days of the week as the volume count (or at least weekday counts need weekday classification counts) because the difference in vehicle mix from weekday to weekend at many sites can create significant error.

Axle correction factors from multiple counts within a group of roads can also be averaged to provide an estimate of an “expected” axle correction factor for roads within that group. This procedure is useful for computing axle correction factors for roads on which no recent classification count has been computed.

States should look to expand on the classification data they provide to users. Several States publish “truck volume” maps and/or “freight flow” maps. These maps, analogous to traditional traffic flow maps, show truck volumes (or truck freight tonnage) in a graphic form by roadway. They allow visual inspection and comparison of the magnitude of freight movement carried by alternative routes. The information can be used to prioritize alternative road improvement projects, provide public information needed to reach consensus on required transportation alternatives, and provide a resource for engineers and planners who are trying to balance funding constraints with the need to support freight movement.

Lastly, States have traditionally reported a basic “truck percentage” statistic for most roadways. This statistic can be easily computed and reported on the basis of the annual average vehicle classification estimates. Time of day and day of week biases can affect the calculation of truck percentages and can also affect the use of this statistic. For example, the truck percentage calculated from a 24-hour classification count taken on a Wednesday, while being accurate for the period where the data were collected, probably overstates the true annual truck percentage. This percentage is also probably incorrect if it is used to estimate peak period truck traffic. Peak hour and peak period truck percentage statistics should be produced and reported specifically to meet those data needs.

CLASSIFICATION DATA NEEDS FOR PAVEMENT DESIGN

The new pavement design guide currently being developed by the NCHRP[4] requires considerably more traffic data than traditional pavement design procedures. Location-specific truck volume estimates are crucial to the accurate estimation of pavement loads. The annual average daily truck traffic statistics discussed above meet the primary need for current truck volume estimates necessary to compute pavement loadings.

However, the new pavement design guide also requests knowledge about seasonal variation in truck volumes and time of day distributions in those volumes. Seasonal variation will be input to the guide as monthly factors. Seasonality is important to pavement design, because the structural response of most pavements changes with environmental conditions. Thus, the timing of loads is important to the accurate prediction of pavement life.

Time-of-day distributions are used in the draft NCHRP design guide to predict the day and night temperature differentials on the curling and warping of PCC pavements.

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[4] The new pavement design guide, currently in draft form, will be reviewed by AASHTO.

CHAPTER 3
VEHICLE CLASSIFICATION DATA COLLECTION DESIGN

As with traditional traffic volume counts, a vehicle classification counting program should consist of both short duration and continuous counts. The short duration counts provide geographic coverage and the continuous counts provide the information needed to account for day-of-week and seasonal variations when the short duration counts are converted into annual estimates.

Data on volumes by vehicle classification come from a variety of sources. The majority of the spatial data will come from short duration counts. Other sources include WIM sites, urban traffic management centers, toll facilities, and other agencies that collect truck volume information. Obtaining data from these external sources greatly increases the data available for agency use, often at a far lower cost to the highway agency than if it had collected the data directly.

The key to a successful classification data collection program is not the source of the data, but the ability to routinely obtain it, verify its validity, summarize it into useable formats, report it in a manner that is useful to data users, and manage the process efficiently. Major portions of the management function involve understanding the need for both short duration and continuous vehicle classification counts and creating a program that collects the appropriate amount of data within both categories.

SHORT DURATION COUNTS

Short duration vehicle classification counts serve as the primary mechanism for collecting information on truck volumes. They provide the geographic distribution necessary to meet the general agency needs and the needs of its customers, as well as the site-specific knowledge needed for the more detailed technical analyses of users.

Large numbers of transportation analyses are starting to require more and better truck volume information. Truck volume information has become particularly important for pavement design, freight mobility, planning, safety, and project programming decisions.

Earlier versions of the TMG recommended the collection of 300 vehicle classification counts during a three-year data collection cycle. This recommendation stemmed from research performed in the early 1980s, when automated vehicle classifiers were just beginning to be adopted by highway agencies. However, 100 vehicle classification counts per year is not adequate to meet the current truck volume data needs of most State highway agencies, and many currently collect far more classification data than this.

A more comprehensive approach is needed to provide the classification data. The recommendation is based on the following objectives:

- increasing the accuracy and availability of truck volume data
- improving the truck volume data for national studies
- improving the truck volume data used for site-specific studies
- decreasing the cost of collecting the truck volume data by making it a primary focus of the traffic data collection program.

Short duration counts by themselves, however, are only part of the data collection process. Research has shown that truck volumes vary dramatically during the day, often differ significantly between weekdays and weekends, and can change as well from one season to the next season. If adjustments are not made for day-of-week and seasonal variation, the result is likely to be erroneous analytical conclusions. For example, safety research that uses truck crash rates computed only from weekday counts will significantly under-estimate the truck crash rate for most locations because unadjusted weekday volumes tend to over-estimate annual average daily volumes. A base of continuous classification counters is used to support the temporal factoring process.

Classification Coverage Counts

The classification coverage count program should be designed to operate like a traditional volume coverage program to provide a minimum level of truck traffic data on all system roads. The basic coverage program would be supplemented by special counts as needed to meet site-specific data needs.

To develop a classification coverage program, the highway system should be divided into vehicle classification (truck) segments akin to what is currently done for volume and described in Section 3. Vehicle classification segments should, in theory, carry a homogeneous volume of trucks, where trucks are defined as the aggregation of FHWA classes 4 to 13. In practice, development of these section definitions is a judgment call since the definition is usually based on the available classification data combined with specific knowledge of the system. The more classification data and the better knowledge of trucks available, the easier and better the definition will be. The availability of truck or commercial vehicle flow maps during the road segmentation process is very useful.

Most vehicle classification segments are expected to span several traffic volume segments because truck traffic can remain fairly constant despite changes in total traffic volume (that is, changes in car volumes do not necessarily result in changes in truck volume). With time, as more data and information become available, the definition of segments will improve.

As with traffic volume, the classification segments will change over time as roadway and traffic characteristics change and as more classification data helps to better define the segments. Periodic reassessments will be necessary to maintain the classification segment inventory current.

Many caveats apply to the development of the classification coverage count program. Each agency will have to develop a classification inventory system to cover its roads that meets its needs. In some cases, the truck traffic may not change over large expanses of road and a small number of classification segments will cover the road. In the Interstate system, for example, classification segments may extend over several interchanges and be very long. The character of the highway and the traffic it carries will play a major role in the definition of these segments and in the number of classification counts needed. Roads that service truck traffic generating activities will necessitate more classification segments, more classification counts, and more frequent revision than roads through regions that experience little trucking activity.

Lower functional systems, where truck traffic may be sporadic, may require long segments in some areas and shorter segments in others, particularly, where truck traffic generators are found. Judgment will play a large role in the roadway segmentation and the classification count planning in these areas. Additional classification counting may be needed to better identify where significant changes occur and how these affect the definition of segments.

The structure of the road system is superimposed by a system of traffic volume segments that allow the traffic counting program to cover it. Likewise, the traffic volume segments will be covered with a smaller subset of vehicle classification segments that allow the establishment of a vehicle classification program that covers the system and provides comprehensive truck data.

The vehicle classification segment inventory will allow a determination of how much classification counting is needed and how many of the volume counts should be classified. **A general rule of thumb is that 25 to 30 percent of the coverage volume counts should be classified.** This, of course, depends on the actual volume coverage program in operation, the character of the road system covered, and many other considerations. The general rule of thumb applies to the traffic volume program recommendation using a coverage program over a 6-year cycle.

Common sense and judgment are greatly needed to determine how to integrate classification and volume counting. Different agencies will make different decisions depending on many considerations. In some cases, the availability of low cost classification equipment can almost justify the conversion of all counting to classification. The gain in information on trucks combined with the elimination of the error introduced by axle correction may justify the extra cost. Many of the newer counters perform classification and many agencies that have acquired the new equipment classify rather than count.

On the other hand, changes in program direction, the acquisition of newer equipment, and the implementation of program changes do not occur overnight. Many organizations depend on available counters, have long-term data collection contracts, or do not have established classification programs.

Many lower volume roads do not have the volume of classified vehicles (trucks) to justify the full conversion of volume counting to classification. These are the roads where the installation of classifiers based on road tubes is easier and where equipment limitations are not a problem. However, once a classified count is taken, additional repetitive counts may not improve the truck volume estimates. In these cases, a decision to save a little time, effort, and funding could be appropriate.

On higher road systems, repetitive classification may greatly enhance the understanding of truck volume variability and result in better truck volume estimates. However, on these roads the collection of classification data is much more problematic. In the higher volume systems, portable equipment installation may not be safe or effective and the installation of more expensive equipment the only solution.

Such constraints may dictate a slower conversion from the current data collection program to the recommended program that emphasizes classification counting. Still, all highway agencies need to understand the use of their roadways by trucks, and thus counting of trucks is an important task. To help achieve that objective, **another useful rule of thumb is that a minimum of one vehicle classification count should be taken on each road each year** to insure a minimum of data available annually to represent each road. Where practical, these counts should be taken at existing HPMS volume sample sections to insure the quality of classification data reported to the HPMS.

Many caveats apply to this rule of thumb as well. For long roads (such as roads that extend across an entire State), far more than one count must be taken. For roads that change character (e.g., a route may be primarily a farm to market road in one place but become a major freight hauling road in another) several classification counts may be appropriate.

Roads that experience significant changes in truck traffic due to changes in industrial activity and/or junctions that lead to truck generators may need classification counts on either side of the junctions where truck activity levels change. For minor routes, a single classification count may be all that is needed. Finally, some agencies may decide to take additional vehicle classification counts whenever resources permit simply because truck volume data play a major role in defining coverage program segments and to insure quality data are available to meet user needs.

The implementation of a comprehensive classification coverage program requires direct integration into the standard volume counting program activities. The manner of scheduling, equipment, staff, and resources must be adequately considered.

It may not be necessary to perform vehicle classification counts at the same location every year. Any placement within the defined segment should provide adequate representation and any additional counts taken help to verify the annual estimate provided. Likewise, classification counts need not be taken at the same time each year because the conversion to annual estimates accounts for the temporal variability. In fact, counts taken at different times of the year provide independent estimates that will help to verify and/or improve the segment estimate. Careful scheduling of the data collection effort may also be necessary to measure important, seasonal truck movements such as those due to harvesting or other highly seasonal events.

The recommended length of monitoring for vehicle classification data remains 48 hours. The recommended cycle of monitoring for the classification program is also 6 years. The schedule of counts should be developed to insure that coverage of each classification segment occurs at least once within a 6-year cycle.

Whenever possible, vehicle classification counts should be taken within the HPMS volume sample sections. This results in direct estimates for each sample section, thereby allowing the expansion of the truck percent variables in the HPMS to valid system estimates of truck travel.

Other Special Needs Counts

As with traditional volume counting, the vehicle classification count program requires special counts in addition to those collected for coverage to meet needs that the coverage program does not cover. Traditionally, these counts have been primarily project related.

Project Counts

In many States, the majority of classification counts are project related. Most commonly these counts are taken to determine the truck traffic on a road segment that requires a traffic load estimate as an input for a pavement rehabilitation design. Collection of the data specifically for the road segment being rehabilitated ensures that the count data reflect current conditions and that the data used in the geometric and structural design procedures are accurate enough to ensure adequate performance of the new pavement over the design life of the project. Common reasons for project counts include pavement design, operational design (e.g., signal timing or testing the need for truck climbing and/or passing lanes), geometric design, and corridor studies. Each project count can have different requirements for duration, spatial frequency, and types of summary measures that must be produced.

The establishment of a classification coverage program will allow a more complete understanding of truck traffic on the highway systems and hopefully limit the need for additional counting to special cases.

Urban Classification Count Programs

The need for classification data in urban areas is pressing. Unfortunately, these are some of the most difficult places for current data collection equipment to operate. Existing counter technologies have significant difficulty classifying vehicles in conditions where vehicles do not operate at constant speed, where vehicles follow very closely, or where stop and go traffic occurs. This is particularly true for equipment that relies on inductance loops and axle detectors.

However, this does not mean that vehicle classification counts cannot be taken in urban areas. Agencies must simply take special care in selecting both the technologies they use and the locations where they place the equipment to ensure that the data collected are valid. Research efforts to investigate new technologies should continue. Several new technologies, particularly video and various laser-based technologies, can classify accurately in urban conditions when they are correctly placed and calibrated.

Studies can be undertaken to identify the classification segments where classification data needs exist. The first step may be identifying current installations where classification data may already be collected by ITS installations, State permanent counters, tolls, bridges, traffic signals, etc. Retrieving that data reduces the need for the use of portable data collection equipment at many sites. Second, identify the remaining locations where the portable data collection program can collect data using current technology. Subtracting these sites from the set of all needed locations should result in a set of locations where data cannot be collected using current means. The use of visual counts is often a last resort in cases where data cannot be collected by other means. Finally, a determination can be made of the counting/classification program needed to provide system coverage and meet special count needs.

Classification data also offers the additional advantage of providing speed data that are often used in air quality analysis and other urban studies. Likewise, speed studies provide classification data. Thereby offering an opportunity for coordination and reduced data collection.

Integration of the Coverage Count Program with Other Programs

At first glance, the coverage program recommended for classification counts can seem large. It is true that the recommended program is an expansion over previous recommendations. The expansion is due to the maturation of vehicle classification technology and an explosion of the need for truck data. However, many States that already actively collect substantial amounts of classification data to meet their own data needs may find that the current recommendations do not significantly increase the size of the program.

The first level of integration is that classification counts should replace traditional volume counts on road sections where classification counts are taken. Thus, for every classification count taken, one less volume count is needed.[5] Use of classification counters to provide total daily volume estimates also has the advantage of providing direct measurement of daily volume since the need for axle correction is eliminated.

The coverage count program should also be integrated as much as possible with the project count program. Existing project counting activities can eliminate the need for coverage counts. Similarly, existing coverage counts can often supply project information, if the existing coverage count meets the informational needs of the project.

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[5] In most cases, this still requires an increase in data collection resources because it takes more staff time as well as more physical data collection equipment to set classification counters than it does to set traditional volume counters for the same number of lanes of data collection.

Finally, the classification count program should be integrated with other traffic surveillance systems, particularly those involving regulation of the trucking industry (such as mainline sorting scale operations upstream of weight enforcement stations), as well as surveillance systems installed as part of traffic management, safety, and traveler information systems.

Duration of Short Counts

The period of monitoring recommended for vehicle classification counts is 48 consecutive hours. Other count durations can produce reasonable results in some cases, but are not recommended for general use. Equipment that can collect data in hourly traffic "bins" should be used for the general program. In urban areas or for special studies, the use of shorter intervals, such as 15 minutes, may be appropriate. The use of 48-hour periods is recommended because:

- the accuracy of the annual load estimates of 48-hour counts is better than that of 24-hour counts
- significant improvement in quality control capabilities become possible with the comparison of one day's hourly traffic counts against the second day's counts
- axle sensors will normally stay in place for 48 hours if correctly installed.

Counts for less than 24 hours are not recommended unless they are intended to provide project specific information (such as turning movement counts for signal timing plans). This is because truck travel changes significantly during the day, and some sites can experience relatively large truck volumes at times when other traffic volumes are light. Counting throughout the day is important to determine accurate daily truck volumes, particularly in roads that carry substantial numbers of trucks.

Counts of less than 24 hours are usually taken as a last resort when other data collection alternatives are not available. These counts need to be adjusted to daily totals using a daily adjustment factor to convert the shorter period to a 24-hour estimate. This adjustment factor should be obtained from more extensive classification counts on similar roads because the time-of-day distribution of truck volume is not the same as that for total volume. The daily volume must also be converted to an annual estimate by using the appropriate day-of-week and monthly factors.

Vehicle classification counts of longer than 48 hours are useful, particularly when those counts extend over the weekend, since they provide better day-of-week volume information. However, in many locations it is difficult to keep portable axle sensors in place for periods that significantly exceed 48 hours. Many highway agencies have also experienced difficulty in developing cost-effective staff and equipment utilization plans when using 72-hour or longer count durations. Whether a highway agency can conduct longer counts is a function of coverage area size, staff utilization, and other factors.

While a strong case can be made for a number of other count durations, the benefits of 48-hour counts are supported by recent research findings. In particular, a study of truck volume variability and the effect of factoring classification counts showed that an improvement of between 3 and 5 percent in estimation of annual average volumes could be achieved by increasing the duration of the classification count from 24 to 48 hours (Hallenbeck and Kim 1993). A study of total traffic volume counts by Cambridge Systematics found that lower volume roads tend to have much greater day-to-day volume fluctuations (in percentage terms) than higher volume roads. These roads showed the greatest improvement when traffic counts were extended from 24 to 48 hours (Cambridge Systematics et al 1994).

PERMANENT/CONTINUOUS CLASSIFIERS

Research has shown that truck travel does not follow the same time-of-day, day-of-week, and seasonal patterns as total volume (Hallenbeck and Kim 1993, Weinblatt 1996, Hallenbeck et al 1997). Analysis of continuously collected data sets also seems to indicate that truck volumes on many roads (even high volume Interstate) can change dramatically as a result of changes in the national and local economy. Continuously operating classification counters are needed to monitor truck flows so that these patterns can be detected and accounted for in engineering and planning analyses. **Each State highway agency needs to operate a set of continuous classification counters to measure truck travel patterns and provide the factors to convert short classification counts to annual averages.**

All State highway agencies have been operating permanently installed, continuous traffic counters (commonly referred to as ATRs) for many years. It has only been since the mid-1980s that technology allowed the installation and operation of similar counters to collect continuous classification data. A significant increase in the number of these counters has taken place since 1990, as a result of the start of traffic data collection for the Strategic Highway Research Program's (SHRP) Long Term Pavement Performance (LTPP) project. Many States have also converted ATR installations to classification as the old equipment wore out and was replaced.

Data from these continuous classification devices have shown that truck volumes have time-of-day, day-of-week, and seasonal variations that are very different from those of cars. In addition, sources of continuous classification data may be obtained from installations from regulatory, safety, and traffic management systems installed to operate and manage the infrastructure. To obtain these existing data, highway agencies often must create close working relationships with other public agencies. The effort may result in considerable improvement to the available classification data.

Introduction to Continuous Classification Counts and Factors

The objective of seasonal factor procedures is to remove the temporal bias in current estimates of truck volume. There are four primary reasons for installing and operating permanent, continuously operating vehicle classifiers for traffic monitoring purposes. These include the ability to:

- provide a highly accurate measure of truck volumes at a limited number of specific sites around the state
- track the changes in those volumes over time with a high degree of accuracy
- determine the travel patterns of different truck types on different roadways across the State
- create adjustment factors and factor groups that allow application of the factors for converting short duration classification counts into annual average estimates of vehicle volume by vehicle type.

This section discusses ways to establish a continuous vehicle classification count program, and presents two alternative methods for the development of factor groups for classification. The continuous vehicle classification data collection program is related to, but can be distinct from, the traditional ATR program. In addition, factoring of vehicle classification counts (i.e., truck volume counts) may be performed independently from the process used to compute AADT from short duration volume counts.

There is still a significant lack of data in most States concerning the travel patterns of trucks. Much work needs to be done to gain the knowledge needed to refine the vehicle classification factor groups and factor procedures. The first step has been taken to recommend a process that will improve the quality of truck volume data and information. To become effective the process will have to be implemented and given time to mature and fully develop as knowledge is gained and improvements made.

Vehicle Classes Used for Factoring

Regardless of the approach taken for the computation and application of factors, **it is recommended that adjustment factors be computed only for three or four “generalized” vehicle classes.** The groups recommended are:

- passenger vehicles (motorcycles, cars, and light trucks)
- single-unit trucks (including buses)
- single-unit combination trucks (tractor-trailers), and
- multi-trailer combination trucks.

In States with few multi-trailer trucks (often the case East of the Mississippi River), three vehicle classes may be sufficient. In these cases, single-trailer and multi-trailer combination trucks should be combined. Highway agencies may adjust these categories to best reflect their vehicle fleets and travel patterns, as well as the capabilities of the classification equipment in their programs.

Several reasons support the recommendations. The factoring process does not work well with very low traffic volumes. With low volumes, even small changes result in high percentage changes that make the computed factors highly unstable and unreliable. Even on moderately busy roads, many of the 13-category vehicle classes will have mathematically unstable vehicle flows simply because their volumes are low. Aggregating the vehicle classes provides for more stable and reliable factors.

A second reason is that computing factors for 13 vehicle classes, in what is clearly recognized as the pioneering development of classification factoring processes, may introduce too much complexity and may create a computational and application nightmare. There is no gain in separately annualizing extremely variable and rare vehicle classification categories at this relatively primitive stage of the process.

A third reason is that many issues relating to the quality of the classification data available from continuous and portable counters remain unanswered. Adequate editing procedures, resolution of the assignment of vehicles to classification categories, inability of equipment to collect a standard set of vehicle classes in all conditions, and tremendous disparity in equipment already present major challenges to the factor development and application process. Unnecessary complications at this stage of development should be avoided.

Alternative Factor Procedures

Two alternative truck volume factor procedures are presented. Both have advantages and disadvantages. Both are very complementary and can be combined as appropriate. Unlike procedures for total traffic volume that have benefited from many years of trial and error by 50 State highway agencies, the procedures discussed here are in their infancy. Recognizing that fact, flexibility is offered to apply these or any other alternatives that effectively remove temporal bias.

The first procedure involves the use of roadway-specific factors. The second is an extension of the traditional traffic volume factoring process involving the creation of groups and the development of average factors for each of the groups.

Either applying factors to a road or fitting road segments into groups involves making decisions to resolve difficulties. A factor process may result in one set of factors for cars, another set of factors for trucks, and the combination of both to arrive at a total volume. A factor process may also require more than one set of factors for trucks when different truck types are factored separately. Some roads could conceivably fit in one factor group for cars, a second factor group for single unit trucks, and a third factor group for combination trucks. Resolutions have to be made by each State between the need for accuracy, and reductions in unnecessary complexity in the approach to removing temporal bias. The current state-of-the-art has not progressed to the point where detailed guidance can be given on the precise number of factor groups that need to be created or on the resolution of the many issues that will arise.

There are two basic parts to the factoring process, the computation of the factors that will be applied to the short counts, and the development of a process that assigns these factors to specific counts taken on specific roadways. The roadway-specific and the traditional procedures approach these two aspects of the factoring process differently. The result is two very different mechanisms for creating and applying factors, each with its own strengths and weaknesses.

Roadway-Specific Factors

This process was developed by the Virginia Department of Transportation (VDOT) in the late 1990's. The VDOT operates continuous counters on all major roads and the counters are used to develop road-specific factors. A short classification count taken on a specific road is adjusted using factors taken from the nearest continuous classification counter on that road. A factor computed for a specific road is not applicable to any other road.

As a result, a continuous classification counter must be placed on every road for which an adjustment factor is needed. This requires a large number of continuous vehicle classification counters and substantial resources. However, it ensures that a road can be directly identified with an appropriate factor and provides considerable insight into the movement of freight and goods within the State. The rule for assigning factors to short counts is simple and objective.

Identifying a specific road with a specific factor removes a major source of error in the computation of annual traffic volumes by removing the “location” error associated with applying an average factor. Further, it produces factors that are applicable to all trucks using that road. The fact that different truck classes (single-unit versus combination trucks) exhibit different travel patterns is irrelevant, since all patterns are computed for that road.

Having road-specific continuous counters also greatly reduces the number of short duration counts that are needed, since the continuous counters provide classification data for road sections near the count locations. The quality of data from continuous counters is usually superior to that of short counts.

Finally, this approach has the advantage of simplifying the calculation of adjustment factors, the application of those factors, and the maintenance of the program. For example, there is no need to develop groups and the application is done one road at a time. Problems with continuous counters only apply to the affected roads and prioritization of counter problem correction can be based on road priority.

There are also disadvantages with this approach. The most important is cost. It is expensive to install, operate, and maintain large numbers of continuous traffic counters.

The larger the system that must be covered the larger the cost. Even for smaller States, the cost to install a large counter base may be prohibitive. However, this approach may apply effectively to the Interstate, where sufficient continuous counters may be available. It can also be applied to roads where current counters are installed.

A second disadvantage is that many roads are quite long and the character of truck traffic over their length can change drastically. This is why short count coverage programs are needed at all. An adjustment factor taken on a road segment may not be applicable to another segment a few miles down the road, particularly if large truck generation activities take place along that stretch of roadway. Truck patterns change because of economic activity, traffic generators, or road junctions. Not only does this further increase the number of continuous counters required, it also creates difficulty in selecting between the two permanent counters when a short count falls in between.

The next problem is maintenance. Because of the large number of counters required, some counters will always be down. The inability to quickly repair failed continuous counters results in a lack factors for those roads.

One solution may be to develop and use the “traditional” method described below as a “back-up” for places where a specific road factor is not available. That is, specific road factors may be used for the most important truck roads and the traditional factor groups for routes without continuous counters. When continuous counters fail, traditional factoring techniques can then be used to provide adjustment factors on those roads. This combination of the traditional and “roadway specific” factors may be an effective compromise between these two techniques

One final problem with the “roadway specific” technique is that there is no mathematical mechanism that allows computation of the accuracy/precision of the factors as they are applied to a given roadway section. When these factors are applied to count locations that are close to the continuous counter, they can be assumed to be quite accurate. However, as the distance between the short count and the permanent counter grows, and particularly as more opportunity exists for trucking patterns to change, the potential for error in the factor being applied grows, and at an unknown (but potentially substantial) rate.

The Traditional Factor Approach

The traditional factor process involves categorizing roads that have similar truck traffic patterns. A sample of data collection locations is then selected from within each group of roads, and factors are computed and averaged for each of the data collection sites within a group. A definition for each group describes characteristics that “explain” the observed pattern and which is used to allow the objective assignment of short counts to the groups.

For traffic volume, the traditional “characteristics” for grouping roads have been the functional class of the road (including urban or rural designation) and geographic location within the State. These groups are then supplemented with an occasional "recreational" designation for roads that are affected by large recreational traffic generators.

This same technique can be applied to truck traffic patterns. However, the characteristics that need to be accounted for can be very different. Functional class of roadway has been shown to have a very inconsistent relationship to truck travel patterns (Hallenbeck et al 1997). Instead, truck travel patterns appear to be governed by the amount of long distance "through" truck traffic versus the amount of locally oriented truck traffic, the existence of large truck traffic generators along a road, such as agricultural or major industrial activity, and the presence or absence of large populations that require the delivery of freight and goods. Understanding how these and other factors affect truck traffic is the first step toward developing truck volume factors.

Create Initial Factor Groups

States must depend on available classification data and knowledge to begin the development of basic truck traffic patterns. Truck traffic patterns are governed by a combination of local freight movements and through-truck movements. Extensive through-truck movements are likely to result in higher nighttime truck travel and higher weekend truck travel. Through-traffic can "flatten" the seasonal fluctuations present on some roads, while creating seasonal peaks on other roads that have nothing to do with economic activity associated with the land abutting that roadway section. Similarly, a road that primarily serves local freight movements will be highly affected by the timing of those local freight movements. For example, if the factory located along a given road[6] does not operate at night, there will likely be little freight movement on that road at night.

Functional road classification can be used to a limited extent to help differentiate between roads with heavy through-traffic and those with only local traffic. Interstates and principal arterials tend to have higher through-truck traffic volumes than lower functional classes. However, there are Interstates and Principal Arterial highways with little or no through-truck traffic, just as some roads with lower functional classifications can carry considerable through-truck volumes. Thus, functional classification of a road by itself has been shown to be a poor identifier of truck usage patterns. To identify road usage characteristics, additional information must be obtained from either truck volume data collection efforts or the knowledge of staff familiar with the trucking usage of specific roads.

Local truck traffic can be generated by a single facility such as a factory, or by a wider activity such as agriculture or commercial and industrial centers. These "point" or "area" truck trip generators create specific seasonal and day-of-week patterns much like recreational activity creates specific passenger car patterns. Truck trips produced by these generators can be highly seasonal (such as from many agricultural areas) or fairly constant (such as flow patterns produced by many types of major industrial plants). Where these trips predominate on a road, that road has truck travel patterns that match the

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[6] Not subject to significant amounts of through traffic

activity of the geographic point or area that produces those trips. In addition, note that changes in the output of these facilities can have dramatic changes in the level of trucking activity. For example, a labor problem at one West Coast container port may produce dramatic shifts in container truck traffic to other ports. This results in significant changes in truck traffic on major routes serving those ports. Expansion or contraction of factory production at a major automobile plant in the Midwest can cause similar dramatic changes on roads that serve those facilities.

Truck trip generators can also affect the types of trucks found on a road. Specific commodities tend to be carried by specific types of trucks. However, State-specific truck size and weight laws can mean that trucks typical in one State may not be common in others. For example, multi-trailer trucks are common in most western States, while they make up a much smaller percentage of the trucking fleet in many eastern States. Understanding the types of trucks used in a State to carry specific commodities (e.g., coal trucks in Kentucky and Pennsylvania) is critical to understand the trucking patterns that should be expected on a road and how those patterns are likely to change.

There are many other patterns that affect truck travel. For example, construction trucks operate in an area's roads until the construction project is completed and then they move somewhere else. This type of truck movement is difficult to quantify. Roads near truck travel generators, such as quarries or trash dumps, carry consistent truck traffic and the type of truck is well known.

Summarizing the different patterns in a way that allows creation of accurate factor groups is difficult. Obviously, the more knowledge that exists about truck traffic on a road, the easier it is to characterize that roadway.

Geographic stratification and functional classification can be used to create truck volume factor groups that capture the temporal patterns and are reasonably easy to apply. An initial set of factor groups might look something like that shown in Table 4-3-1. Roads might then be moved between these initial starting groups as needed.

Definitions like those presented above group roads with as homogenous truck travel patterns as possible, and also provide easy identification of the groups for application purposes. They present a starting point to begin the identification process necessary to form adequate groups.

Performing a cluster analysis using truck volumes (as done in Section 3 for total volume) will help to identify the natural patterns of variation and to place the continuous counters in variation groups. This will help in identifying which groups may be appropriate and in the determination of how many groups are needed. One of strengths of the cluster analysis is that it identifies groups but only by variation. The weakness is that it does not describe the characteristics of the group that allow application of the resulting factors to other short counts.

The example definition in Table 4-3-1 does exactly the opposite. It clearly establishes group characteristics but cannot indicate whether the temporal variation is worth creating separate groups or not. As is the case for AADT group procedures, a combination of statistical methods and knowledge must be used to establish the appropriate groups.

Table 4-3-1
Example Truck Factor Groups

Rural	Urban
Interstate and arterial major through-truck routes	Interstate and arterial major truck routes
Other roads (e.g., regional agricultural roads) with little through traffic	Interstate and other freeways serving primarily local truck traffic
Other non-restricted truck routes	Other non-restricted truck routes
Other rural roads (e.g., mining areas)	Other roads (non-truck routes)
Special cases (e.g., recreational, ports)	

Determine the Variability of Group Patterns

All roads within the defined factor groups should have similar truck volume patterns. To verify that, the continuous counter data available within the groups must be examined. For each continuous classification counter in a group, compute the temporal adjustment factors of interest (day-of-week, month, or combined) for each of the vehicle types desired and then compute the mean and standard deviation for the group as a whole. Plots of the volumes and the factors over time can also help to determine whether the travel patterns at the continuous sites are reasonably similar.

In most cases only a few roads within each group will have data (continuous counters) needed to estimate travel patterns. The assumptions this analysis makes are similar to those made for AADT factors. The implication is that the continuous counters typify the existing temporal variation. Then the continuous counter variation reflects the variation existing at locations where there are no continuous counters. A combined monthly and weekday factor can be computed as follows[7]:

$$\text{Adjustment Factor}_{C,\ June} = \text{AADTT}_{C} / \text{MAWDTT}_{C,\ June} \qquad (4\text{-}1)$$

where $\text{Adjustment Factor}_{C,\ June}$ = a multiplicative factor for a specific vehicle type used to convert a 24-hour count taken on any weekday in June to an estimate of annual average daily traffic.

AADTT_{C} = annual average daily (truck) traffic volume for a specific vehicle type

$\text{MAWDTT}_{C,\ June}$ = monthly average weekday (truck) traffic volume for the month of June for a specific vehicle type.

Computing the mean (or average) for the June factor for all sites within the factor group yields the group factor for application to all short counts (weekdays in June) taken on road segments within the group. The standard deviation of the factors within the group describes the variability of the group factor. The variability can be used to determine whether a given factor group should be divided into two or more factor groups, to compute the precision of the group factor, and to estimate the number of continuous counter locations needed to compute the group factor within a given level of precision.

The variability of each statistic computed for the factor group will have a different level of precision. For example, the June factor will have different precision than the July factor. The precision will also vary for each of the vehicle types analyzed.

Test the Quality of the Selected Groups

The information on variability must be reviewed to determine whether the roads grouped together actually have similar truck travel patterns. A number of methods can be used to determine whether various sites “belong” together. A statistically rigorous approach to testing the precision of the selected groups requires the use of fairly complex statistics, an examination of all the truck classes used, the comparison of statistical reliability for all the different types of statistics produced with the reliability users need for those statistics.

This is a complex and difficult analysis. The analysis can be simplified by concentrating on the most important vehicle classes and statistics produced. However, even with the simplifications suggested, trade-offs are necessary. No designed group will be optimal for all purposes or apply perfectly to all sites.

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[7] This formulation assumes a multiplicative application, that is, AADTT is equal to the average 24-hour count times the adjustment factor. Many states use the inverse of formula 4-1 and apply the resulting factor by dividing the average 24-hour volume obtained from their short count by the adjustment factor.

For example, in one group of roads, the single tractor-trailer volumes on roads within each group may have similar travel characteristics, but the single-unit truck volume patterns are very different from each other. By changing the road groups, it may be possible to classify roads so that all roads have similar travel patterns for single-unit trucks, but then the single tractor-trailer patterns become highly variable.

At some point, the analyst will need to determine the proper balance between the precision of the group factors developed for these two classes of trucks, or they will have to accept the fact that different factor groups are needed for different vehicle classes. Then each road may end up in multiple factor groups depending on what vehicle classification volume is being factored. Use of multiple groups may result in a more accurate factor process but will certainly result in a more complicated and confusing procedure.

The trade-offs between alternative factor groups can only be compared by understanding the value of the precision of each statistic to the data user. In most cases this is simply a function of determining the relative importance of different statistics. For example, if 95 percent of all trucks are single tractor-trailer trucks, then having road groups that accurately describe tractor-trailer vehicle patterns is more important than having road groups that accurately describe single-unit truck patterns. Similarly, if single-unit trucks carry the predominate amount of freight (this occurs in mineral extraction areas), then the emphasis should be on forming road groups that accurately measure single-unit truck volume patterns.

The quality of a given factor group can be examined in two ways. The first is to graphically examine the traffic patterns present at each site in the group. Figure 4-3-1 gives an example of a set of monthly truck volume patterns for a group of sites in the State of Washington that could be considered a single factor group. Graphs like these give an excellent visual description of whether different data collection sites have similar travel patterns.

The second method is to compute the mean and standard deviation for various factors that the factor group is designed to provide. If these factors have small amounts of deviation, the roads can be considered to have similar characteristics. If the standard deviations are large, the road groupings may need to be revised.

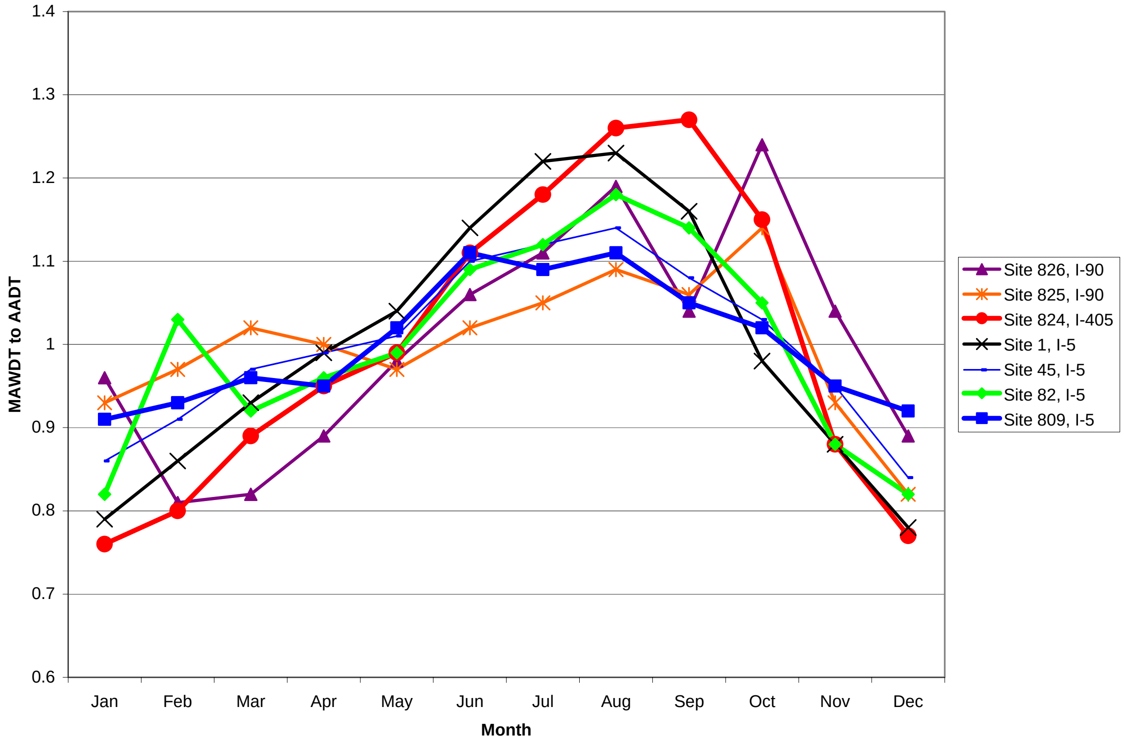

Figure 4-3-1: Ratio of Average Weekday Traffic per Month to Average Annual Daily Traffic for Combination Trucks (FHWA Classes 8 - 10) at Interstate Sites

Determine the Precision of Factors

An estimate of the precision of the group factor can be derived from the standard deviation. For example, the precision of the June adjustment factor computed above can be estimated using the standard deviation of that estimate. The precision of the group factor can be estimated with 95 percent confidence as approximately[8] plus or minus 1.96 times the standard deviation divided by the square root of the number of sites in the group.

Increasing the number of continuous counter locations within a group will improve the precision of the group factor. However, increasing the number of continuous counter locations only marginally improves the precision of the group factor application at specific roadway sections. That is, increasing the sample size makes the group factor itself a better measure of the mean for the group, but the mean value may or may not be a

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[8] This is a relatively crude approximation because it assumes that the standard deviation calculated from the seven sample sites is equal to the actual standard deviation of the population of the group of roads. The value 1.96 should be used only for sample sizes of 30 sites or more. A more statistically correct estimate would use the Student's *t* distribution, which for six degrees of freedom (seven classification sites) is 2.45. The calculation also assumes that the factors are normally distributed, and that sites are randomly selected.

good estimate of the pattern at any given roadway section within that group. The standard deviation of the group factor measures the diversity of the site factors within the group.

There can be cases where the factors will not improve the annual volume estimates, particularly in high variability situations. An alternative is to take multiple site-specific classification counts at different times during the year to directly measure seasonal change. This can be an effective way to accurately estimate annual truck traffic for high profile projects that can afford this additional data collection effort. This alternative can also be used to test the accuracy of the annual estimates derived from the group factors.

Refine the Factor Groups

If the factor groups selected have reasonably homogenous travel patterns (i.e., the variability of the factors is low), then the groups can be used for factor development and application. If the factors for the group are too variable, then the groups may need to be modified.

These modifications can include the creation of new groups (by removing the roads represented by some continuous counters from one group and placing them in a new group), and the realignment of counters within existing groups (by shifting some counters and the roads they represent from one existing factor group to another). This process continues until a judgment is made that the groups are adequate.

Be aware, as noted earlier, that if very precise adjustment factors are desired, it is possible that the factor process will require different factor groups for each vehicle class. That is, traffic patterns for combination trucks may be significantly different (and affected by different factors) than the traffic patterns found for smaller, short-haul trucks. These patterns may in turn be sufficiently different than passenger vehicle patterns that three different factor groupings may need to be developed. In such a case, passenger car volumes may need to be adjusted using the state's existing factor process (since total volume tends to be determined by passenger car volumes in most locations); while single unit trucks are factored with data obtained from different groups of counters and combination trucks are factored with counts obtained from those same counters but aggregated in a different fashion. Then the three independent volume estimates need to be added to produce the total AADT estimate.

Determine the Number of Locations to Monitor

Once groups have been established and the variability of the group factors computed, it is possible to determine the number of count locations needed to create and apply factors for a given level of precision. Note that because each statistic computed for a group has a different level of variability, each statistic computed will have a different level of precision.

The first step in determining the number of sites needed per group is to determine which statistics will guide the decision. In general the key statistics are those that define the objective of the formation of groups, that is, the correction for temporal bias in truck volumes. The combined day-of-week and monthly factor, computed for the truck-trailer combination vehicles during the months when short duration counts are taken, may well be the most appropriate statistic to guide the group size, at least for the Interstate/arterial groups. For other groups, the single-unit truck may be more appropriate.

If counts are routinely taken over a nine-month period, the one month with the most variable monthly adjustment factor (among those nine months) should be used to determine the variability of the adjustment factors and should thus be used to determine the total sample size desired. In that way, factors computed for any other month have higher precision.

For most factor groups, at least six continuous counters should be included within each factor group. This is an initial estimation based on AADT factor groups. If it is assumed that some counters will fail each year because of equipment, communications, or other problems, a margin of safety may be achieved by adding additional counters.

Collect Additional Data and Refine the Established Process

Much needs to be learned about vehicle classification. **States are encouraged to convert as many of their ATR continuous counters to classification as possible and to analyze the available data to better understand truck travel patterns and variation.**

A substantial continuous vehicle classification program allows States to refine the classification count factoring process as needed. The addition of new continuous count locations allows the comparison of newly measured truck travel patterns with previously known patterns. This is true even for the road-specific factoring procedure, since traffic patterns along a road can change dramatically from one section to another. One way of adding new count locations is to move counter locations when equipment or sensors fail and need replacement at an existing continuous site.

If a new data collection site fits well within the expected group pattern, that site can be incorporated into the factor group. However, if a new site shows a truck travel pattern that does not fit within the expected group pattern, a reassessment of the truck volume factoring procedures may be appropriate. Modifications include moving specific roads or road sections from one factor group to another, creating new factor groups, and even revising the entire classification factoring process.

The factoring process should be reviewed periodically to ensure that it is performing as intended. For the first few years after initial development or until the process has matured, these evaluations should be conducted every year. After that, the classification process should be reviewed periodically every 3 years or the same review cycle used for the AADT group factor process.

CHAPTER 4
COMPUTATION AND REPORTING OF ANNUAL, SUMMARY, VEHICLE CLASSIFICATION STATISTICS

This chapter presents basic procedures for computing statistics or estimates derived from the vehicle classification program. Statistics discussed include:

- AADTT (annual average daily truck traffic)
- axle correction factors
- factors for converting daily truck traffic counts into estimates of AADTT (by class)
- factors that allow conversion of AADTT estimates (by class) into average day of week estimates for use in the draft NCHRP 1-37A Pavement Design Guide.

COMPUTATION OF AADTT

Computation of AADTT (by vehicle class) from a short duration count requires the application of one or more factors that account for differences in time-of-day, day-of-week, and seasonal truck traffic patterns. These adjustments are the same as those applied to traditional volume counts, except that they must be applied by individual vehicle classification when working with classification count data.

Estimating Daily Volumes from Less-than-Daily Counts

Classification counts should be taken for 48 consecutive hours. When it is not possible to collect at least 24 hours of data, time-of-day adjustments are needed to expand the short counts to daily estimates. Most classification counts are taken in hourly increments. When these hourly volumes add up to less than 24 hours (usually with visual counts), it is necessary to expand them to 24-hour estimates.

This should be accomplished using adjustments from data collected by permanent vehicle classification counters. Adjustment tables should be created for specific types of roadways (using the factor groups discussed in the previous chapter of this section if a better system is not available) and specific hours of the day. In this manner, the factor applied to adjust a very short count to an estimate of daily traffic volume (by class) will depend not just on how many hours were counted but on which hours were counted, as well as on which class of vehicles is being adjusted. For example, the adjustment for a 6-hour count taken from 8 AM to 2 PM may be very different than the adjustment that should be applied to a 6-hour count taken from 2 PM to 8 PM.

These adjustment tables can be created by simply computing the percentage of daily traffic that occurs during any one hour of the day for each vehicle class for each type of day of the week. These percentages can then be added together as needed to create an adjustment percentage for any series of hours of data collection.

Table 4-4-1
Calculation of Average Travel by Time of Day for Combination Trucks at an Example Continuous Counter Site

Hour	Average Weekday Volumes By Hour	Percentage of Traffic
Midnight - 1 AM	20	1.9%
1 AM - 2 AM	30	2.8%
2 AM - 3 AM	10	0.9%
3 AM - 4 AM	10	0.9%
4 AM - 5 AM	20	1.9%
5 AM - 6 AM	40	3.7%
6 AM - 7 AM	80	7.4%
7 AM - 8 AM	100	9.3%
8 AM - 9 AM	60	5.6%
9 AM - 10 AM	80	7.4%
10 AM - 11 AM	70	6.5%
11 AM - Noon	80	7.4%
Noon - 1 PM	50	4.6%
1 PM - 2 PM	60	5.6%
2 PM - 3 PM	90	8.3%
3 PM - 4 PM	80	7.4%
4 PM - 5 PM	50	4.6%
5 PM - 6 PM	40	3.7%
6 PM - 7 PM	30	2.8%
7 PM - 8 PM	20	1.9%
8 PM - 9 PM	10	0.9%
9 PM - 10 PM	20	1.9%
10 PM - 11 PM	10	0.9%
11 PM - Midnight	20	1.9%
	1080	100%

To compute the daily total traffic volume estimated by the short count, the simple formula below is used:

$$\text{Daily Traffic Volume} = \frac{\text{Short count volume} * 100}{\text{percent of travel during time period counted}} \qquad (4\text{-}2)$$

Thus, if a 6-hour count was taken from 6 AM to noon on a weekday, and 260 combination trucks were counted, then using Table 4-4-1, the total daily combination truck volume would be estimated as 600 trucks (260 * 100 / 43.6 = 596 ≈ 600).

Estimating Annual Average Daily Traffic Volume from a 24-Hour Classification Count

This calculation is equivalent to converting ADT to AADT. It requires the application of two adjustments, a day-of-week adjustment and a seasonal adjustment. These two factors can be applied as one combined factor (usually a ratio of AADT / MAWDT, or annual average daily traffic to average weekday traffic for a given month), or as two separate factors, a seasonal adjustment (usually AADT to monthly average) and a day-of-week adjustment.

Both of these techniques work with roughly the same accuracy, if the factor groups that are used to compute and apply those factors are correctly formed.

Estimating Annual Average Daily Traffic Volumes from More Than 24-Hour Counts

If the data collected cover more than 24 hours, the data should be summarized to represent a single daily count. This can be done in two ways, depending on how the factoring process is performed.

If individual day-of-week factors are used (e.g., a different factor for Tuesdays than for Wednesdays), then each 24-hour count can be converted into an estimate of annual average daily traffic, and the different daily values averaged into a single estimate of AADTT.

If a general day-of-week adjustment (e.g., a single weekday to average day-of-week adjustment), the individual hourly volumes[9] can be averaged. These averages are then totaled to produce a single daily volume, which can then be adjusted for seasonality and day of week.

COMPUTATION OF AXLE CORRECTION FACTORS

Emphasis on the collection of classification data should minimize the need for axle correction. Whenever possible, axle correction factors needed to convert axle counts to vehicles should be developed from vehicle classification counts taken on the specific road. In addition, the classification count should be taken from the same general vicinity and on the same day of week (a weekday classification count is usually sufficient for a weekday volume count) as the axle count it will be used to adjust. Where a classification count has not been taken on the road in question, an “average” axle correction factors can be estimated from the WIM and continuous classification sites.

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[9] Only data for complete hours should be used. Partial hours should be discarded.

The computation is the same whether the data come from a single short duration count or from a continuous WIM scale. Table 4-4-2 illustrates the process.

In the table, vehicle volume is computed by dividing the total number of axles counted by the average number of axles per vehicle. Thus, an axle count of 4,520 axles would be equal to a vehicle volume of 1,949 (4,520 / 2.32 = 1,949).

Multiplicative axle correction factors can be derived as the inverse of the average number of axles per vehicle. In the above example, the factor would be 0.43 (the inverse of 2.32. The number of vehicles (1,949) would then be estimated by multiplying the number of axles (4520) times the factor (.43).

Table 4-4-2[10]
Number of Axles per Vehicle

FHWA Vehicle Class	Daily Vehicle Volume	Average Number of Axles Per Vehicle	Total Number of Axles
1	100	2	200
2	1,400	2	2,800
3	45	2	90
4	15	2	30
5	20	2	40
6	40	3	120
7	5	4	20
8	15	4	60
9	120	5	600
10	5	6	30
11	15	5	75
12	5	6	30
13	10	7	70
Total Volume	1,795	Total Number of Axles	4,165
		Average Number of Axles Per Vehicle	2.32

FACTORS FOR CONVERTING DAILY CLASSIFICATION COUNTS TO AADTT BY CLASS

The calculation of factors for converting average daily traffic (by class) to annual average conditions begins by computing average day-of-week, average-day-of-month,

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[10] This table provides a conservative estimate of the number of axles per vehicle for the 13 FHWA vehicle classes. Appropriate numbers must be computed at each site.

and annual average daily traffic statistics at each continuous count location. The ratios from each continuous count location are then averaged within the factor groups to produce the average factor for the group.

The first step in computing day-of-week adjustment factors is to compute an average day of week for each month. For example, the average Monday is computed by adding the Monday traffic volumes in the month, and then dividing by the number of Mondays in the month.

An average-day-of-month can be computed by simply averaging the seven daily values within each month. This is preferable to calculating a simple average for all days of the month, because then average monthly statistics can be compared from one year to the next without worry that in one year there were more weekend days than in another year.

Annual average daily traffic for each day of the week for each vehicle class can then be computed as the average of the 12 months. The best computational procedure is recommended in the AASHTO Guidelines for Traffic Data Programs and can be shown mathematically as follows:

$$AADTT_c = \frac{1}{7}\sum_{i=1}^{7}\left[\frac{1}{12}\sum_{j=1}^{12}\left(\frac{1}{n}\sum_{k=1}^{n} ADTT_{ijkc}\right)\right] \tag{4-3}$$

where: $ADTT_c$ = daily truck traffic for class c, day k, of day-of-week i, and month j

i = day of the week

j = month of the year

k = 1 when the day is the first occurrence of that day of the week in a month, 4 when it is the fourth day of the week

n = the number of days of that day of the week during that month (usually between 1 and 5, depending on the calendar and the number of missing days).

CHAPTER 5
VEHICLE CLASSIFICATION DATA COLLECTION EQUIPMENT

A variety of equipment can be used to classify the traffic stream. Available technology allows use of axle, vehicle length, and machine vision classifiers. New technologies are rapidly evolving. As a last resort, human observation is used.

For each of the technology solutions (axle, length, or vision) there are generally a number of different sensor technologies. Each sensor has its own advantages and disadvantages regarding cost, reliability, accuracy, life span, ease of set up, and type of information provided.

Each of the basic classification and sensing technologies has strengths and weaknesses that allow some classification techniques to work better than others under specific environmental and traffic conditions. No technology has proven to be the best under all conditions.

The different sensor technologies also require a variety of different vehicle classification schemes because the vehicle characteristic information provided by each sensor differs. The ideal vehicle classifier would be able to measure a wide variety of vehicle characteristics to differentiate trucks on the basis of several different factors and to meet the needs of different users. Unfortunately, such a sensor does not currently exist at an affordable price. Consequently, agencies must select the technologies that provide the data they most need to provide the classification information they require, at the locations where those data are needed, at prices they can afford.

For most engineering tasks the primary issue is separating “heavy” vehicles from “light” vehicles, because heavy vehicles cause more pavement damage and tend to have poorer acceleration and braking characteristics. However, weight is not the only issue, since total vehicle size (length, width, height) has a major impact on the geometric design needed for safe roadway operation. Other desired vehicle classification attributes include the type of connection used on multi-unit vehicles (the connection has major safety implications) and the type of engine that provides the power (since the type of engine affects the amount and type of pollutants emitted). Unfortunately, these last two vehicle characteristics are extremely difficult to obtain from conventional classification equipment, and as a result, these vehicle characteristics are normally collected as part of special studies, not as part of the traffic monitoring effort.

The FHWA 13-category classification system is a direct result of the compromises forced on highway agencies by the limitations in affordable vehicle sensors. The FHWA 13-category classification scheme is a compromise between a classification scheme based on standard axle sensing technology, and a classification scheme based on observation of the traffic stream by human observers. Like all compromises, the FHWA 13-category scheme is not perfect. However, its strengths and weaknesses are viewed differently by different groups, each of which needs a different type of data to perform a particular important analysis. **The FHWA 13-category scheme does provide an**

excellent mechanism for classifying vehicles, given available technology. Its use is recommended as the basic classification scheme for highway agencies. However, agencies may choose to expand on the FHWA scheme to meet their own needs, and they may use other classification systems in locations where non-axle based vehicle sensors are in operation.

The remainder of this chapter introduces the available vehicle sensor technology. However, because this field is changing rapidly, the reader is encouraged to access current research results when exploring vehicle sensors. Good starting points for further research in this field are the Vehicle Detector Clearinghouse operated by the New Mexico State University and the North American Travel Monitoring Exhibition and Conference, held every two years.

The basic strengths and weaknesses of the commonly available technologies are presented below.

MANUAL COUNTS

Historically, truck counts (classification counts) could only be done by visually counting the traffic stream. Visual counts are traditionally called manual counts. Manual classification of the traffic stream has several advantages. Visual identification can classify trucks on the basis of a vehicle’s body style (tank trucks versus dump trucks versus flat bed trucks versus delivery trucks). Looking at trucks can also increase the accuracy with which an individual truck is classified into being either “potentially heavy” or “not likely to be heavy”. That is, a human observer can easily determine the difference between a car pulling a light trailer and a tractor pulling a semi-trailer, when these two vehicles have the same number of axles and possibly even similar axle spacing characteristics. Thus, “classification errors” from human observers are usually small when the data collector is highly motivated. Visual short counts can potentially be taken in all conditions.

Unfortunately, manual classification counts are expensive and prone to error. It is very difficult for a person to count accurately for more than about three consecutive hours. After three hours, the concentration of most observers tends to wander, causing the number of errors to increase. Counting traffic can be a very boring job for a person. Substantial supervision is needed to ensure the quality of the data reported. In addition, most human observers cannot count accurately under high volume, multi-lane conditions (additional observers are needed, further increasing the cost of data collection).

AXLE SENSOR BASED COUNTERS

Automated classification was developed to help resolve the limitations of manual counting. Automated classifiers became common in the 1980's with the advent of microchip equipment that relied on two carefully spaced axle sensors (usually road tubes). These counters measure the number of axles associated with each passing vehicle and the spacing between axles. The axle spacing is computed from the speed of the vehicle and the time between axle pulses on each sensor. Vehicle speed is commonly computed by measuring the time it takes for the front axle to travel from the first axle sensor to the second (a known distance). The number and spacing of axles is then fed into an algorithm that associates a given number and spacing of axles with a particular class of vehicles.

The accuracy of axle sensor based counters is a function of several factors, including (but not limited to) the following:

- the accuracy of the distance measurement between the two axle sensors
- the need for constant vehicle speed over the two sensors (changing vehicle speeds cause errors in the axle spacing computation)
- the need for a vehicle to stay in a single lane until it has passed completely over both sensors
- the speed with which the axle sensor can respond to axles crossing the sensor,
- the accuracy of the axle sensors themselves (that is how often they either report non-existent axles (ghost axles) and/or miss axles that pass over them)
- the presence of different types of vehicles with similar axle spacing
- the care with which the classification algorithm was developed that converts the number and spacing of axles into vehicle.

Some of these factors are a function of the type of axle sensor used. Others are a function of the roadway geometry at the site where the sensors are placed. Others are a function of the quality of the equipment installation and/or the pavement on which the sensors are placed. Others are simply a function of the types of vehicles that actually operate on the road site.

Most classifiers report not only the number of vehicles in each class but also the number of vehicles that crossed the sensors but could not be classified. These “unclassified” vehicles normally fall into two categories, “errors” and “unclassified.” Errors are normally vehicle measurements in which the two axle sensors reported different numbers of axles (usually because the vehicle changed lanes as it crossed the sensors); significant changes in vehicle speed occurred over the sensor, making it impossible to accurately measure axle spacing; or extraneous noise in the sensors made the system unable to determine the type of vehicle passing. Unclassified vehicles are normally vehicles for which the system measurements are complete but that do not fit within any of the proscribed vehicle categories.

Each agency should carefully examine the types of vehicles that are not being successfully classified so that it can both improve its classification algorithm over time and allocate the reported “unclassified” vehicles to the appropriate vehicle classes. This is necessary, or the reported volumes by class will underestimate the true number of vehicles. **Agencies should identify and document the classification scheme being**

used to collect classification data and the procedures used to assign "unclassified" vehicles to the standard 13 categories.

In general, axle sensors either are designed for portable operation (they are taped or nailed to the pavement on a temporary basis) or are permanently imbedded in the pavement by cutting a slot in the roadbed and using an adhesive to fix the sensor in that slot.

Portable sensors have the advantage of being usable at many locations. However, they are usually difficult to place on lanes that are not next to the shoulder of a road, thus making it difficult to use these classifiers on multi-lane, undivided arterials. It is also easy to make a mistake when placing portable sensors so that the distance between the sensors is incorrectly reported and/or is not consistent from the right hand edge of the lane to the left. Finally, portable sensors can come loose during data collection yielding invalid results after the sensor pulls loose but before the sensor has become completely detached from the roadway.

Permanent sensors are often used for both long-term data collection sessions and for collecting data on multi-lane highways, where portable axle-sensors cannot be placed. The primary drawbacks to permanent sensors are:

- higher cost to acquire than portable sensors
- more expensive to install
- require lane closure for installation
- can only be used in one location.

In general, axle based classifiers work very well on smaller (two-lane) rural roads and divided four-lane rural roads where congestion is not a problem. This type of counter has difficulty counting accurately on roads where traffic speeds are highly variable. This includes roads that are frequently congested and roads where vehicles are constantly accelerating or decelerating, such as on urban arterials. They have difficulty differentiating between closely spaced vehicles (i.e., tailgating cars). Two closely spaced cars are often reported as a single four-axle combination truck. Lastly, unless these devices use axle sensors that actually detect axle weight, they are unable to reliably differentiate between cars pulling trailers and multi-axle trucks, because of similar axle configurations.

VEHICLE LENGTH BASED COUNTERS

One of the earliest alternatives to axle sensor based counters was the "dual loop" classifier. Inductance loops were selected because they allowed for reliable, long lasting installation of the vehicle detector. Thus, many of the earliest permanent, continuously operating vehicle classifiers were dual loop systems.

This style of counter uses two inductance loops to estimate the total length of vehicles crossing the loops. Vehicle length is computed by dividing the total time a vehicle is over the loop by the speed of that vehicle. Vehicle speed is determined by the difference in time taken for the vehicle to be detected by the first loop and the second loop. This simple equation is then calibrated to account for each loop's sensitivity and the fact that the "zone of detection" is not a "point" on the roadway, so that a vehicle is "detected" for slightly longer than it takes to pass over the loop. The length of this "detection field" is a function of a number of factors related to loop sensitivity and vehicle characteristics.

Dual loop sensors generally classify vehicles into fewer, more general, categories than the FHWA 13 vehicle classes. This is for several reasons, including the following:

- Most of the length classifiers are not accurate enough to measure small differences in vehicle length. Thus, broad vehicle length categories are used to reduce the amount of misclassification. (That is, by using only four categories, there are only three boundaries where a one-foot error in measurement will cause a vehicle to be misclassified. This leads to more accurate classification.)
- Most length classifiers can not differentiate between a single long vehicle unit and two smaller units hitched together because the length between hitched units is too small to detect.
- Length alone is a poor variable for differentiating among vehicle classes. For example, five-axle, tractor, semi-trailer trucks come in a variety of lengths. Yet these trucks are commonly classified together.

Still, four classes are sufficient for many analytical purposes. When this is combined with the inability of axle sensors in many conditions, the low cost of the basic loop inductance sensor and the general reliability of these systems; it is easy to see why basic length classifiers remain popular.

However, length classifiers have many of the same operational problems that axle classifiers have. That is, on roadways where vehicle speeds are not constant over the detectors because of congestion, signalization, street parking, or operational conditions (e.g., driveways), the computation of vehicle lengths is not accurate. This makes the classification inaccurate and results in significant data collection errors. Dual loops also have difficulty differentiating among closely spaced cars (tailgaters) and tend to report two closely spaced cars as one mid-sized truck. Thus, these detectors tend to work most accurately in locations where free-flow traffic is assured.

MACHINE VISION BASED EQUIPMENT

Machine vision systems, most of which are based on video image processing, were developed in response to the desire by many transportation agencies to use a vehicle detector that did not have to be placed on or in the roadway. Camera systems allow the detector to be placed above or beside the roadway, in a location that is more accessible to maintenance crews. This provides a significant advantage for locations where access to the roadway is extremely limited and expensive, such as high volume urban freeways.

Machine vision systems are a much newer technology than axle sensor and traditional dual loop counters. As a result, the classification systems used by vision systems are still being refined. The early vision systems mimicked dual loop counters. They create “virtual loops” from the camera images being collected, and then compute vehicle speed and length from those loops.

These systems have performance characteristics that are similar to traditional dual loop counters. They are subject to the same limitations in terms of vehicle speed measurement and problems in differentiating between closely following vehicles. Image sensing systems are also subject to inaccuracy caused by occlusion (the blocking of the line of site by a second vehicle).

The primary advantage these systems provide is that they do not require installation of sensors in the roadway, thus eliminating one major cause of equipment failure (freeze/thaw damage to loop wires) and making sensor maintenance easier and less disruptive. In some cases, cameras are also able to transmit traditional video images to system operators, allowing for dual use of the data collection equipment.

Considerable research is being done in the area of image processing. New approaches to image processing (e.g., edge detection algorithms) are being developed to improve on the performance of the existing image processing algorithms. Systems currently on the market still tend to classify vehicles on the basis of their overall size and are thus likely to use classification schemes similar to those supplied by current loop based systems.

Information on image-processing technology for traffic data collection is available from the New Mexico Vehicle Detector Clearinghouse and from equipment manufacturers. Research efforts are underway in several States.

OTHER TECHNOLOGIES

Development with new technologies is moving very quickly. Research and development of new sensors using infrared, microwave, and radar technologies is in progress. Several traffic monitoring systems using these technologies are on the market and are capable of providing vehicle volumes by at least length classification. Highway agencies are encouraged to investigate these devices to determine where and when these new technologies can provide more cost-effective solutions to the accurate collection of classification data.

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APPENDIX 4-A
FREQUENTLY ASKED QUESTIONS

How many vehicle classifications should I collect data for?

> There is no simple answer. In most cases, when using portable vehicle classification equipment, the 13 FHWA vehicle classifications have become the standard. However, it is certainly appropriate to further sub-divide these classifications to provide data on specific vehicles of interest. For example, Oregon DOT collects data on the use of triple trailer vehicles. This classification is a sub-set of class 13 (Multi-trailer vehicles). Thus for their own purposes, these vehicles are a specific class of trucks. When Oregon reports data to the FHWA, the "triple trailer" class vehicles are simply combined with the other multi-trailer vehicles measured, and the total is reported as the volume in FHWA Class 13. Permanent, axle classifiers and WIM scales should also collect the FHWA 13 vehicle classes.
>
> On many roadways, it is not possible to place axle sensors so that they accurately collect the 13 FHWA vehicle categories. However, it is possible to use two inductance loops or magnetic units to differentiate vehicles by total length. Four vehicle classes are recommended when collecting data in this fashion. These classes should reflect cars (and pick-up trucks), single-unit trucks, single-trailer combination trucks, and multi-trailer trucks. In some states, the multi-trailer truck category may be unnecessary, and these trucks can be incorporated into the "combination" category because there are few multi-trailer trucks. As the truck fleets and truck size and weight laws change, States not collecting data on these vehicles may have to revise their data collection process to collect the data. While use of the simplified vehicle classes does not meet the desired level of reporting for many purposes, collecting data in the simplified categories is far better than collecting no vehicle classification data at all, and it allows monitoring the presence of trucks in urban traffic.

How many permanent, continuously operating vehicle classifiers should my State install and maintain?

> A reasonable answer to this question cannot be given without first understanding how the State proposes to factor short duration vehicle classification counts. If a traditional factoring approach is selected (i.e., something similar to the ATR program operated by almost all states), then as many continuous classifiers as ATRs should be operated. If the State chooses a classification count factoring approach that measures and applies road-specific factors, the number of counters required will increase significantly.

How many portable classification counts should my State undertake?

> They are many factors to consider in the answer. As a rule of thumb, 25 to 30 percent of volume counts should be classified. In general, each State should undertake a vehicle classification count at least once every counting cycle that can

be applied to each road segment under its control. This does not mean that each road segment should be counted. Instead, "super segments" consisting of combined roadway volume segments should be counted. Each "super segment" should be "relatively" homogeneous for truck traffic along its length. Each "super segment" should be counted at the same interval used by the State for collecting volume counts. Annual truck travel estimates can be derived from the counts. The annualized truck percentages can then be converted to estimates of truck travel for the entire "super segment".

How can my State collect classification data in urban areas?

Traditional vehicle classifiers have difficulties operating accurately in urban areas because vehicle acceleration/deceleration makes speed and length calculations inaccurate, and because closely following vehicles result in misclassification of cars as trucks. On freeways, careful placement and calibration of either video or loop based classification equipment can produce accurate truck volume counts. To date, no inexpensive classifier is available that works accurately under stop-and-go arterial conditions.

For higher systems, permanent classifiers using loops or video may be the only alternative. On lower systems, there are locations where axle or magnetic (length) portable classifiers will work. In many cases, visual counts may be the last resort.

How do I define a "vehicle classification road segment?"

In simple terms, a traffic road segment is a section of roadway that has similar (or homogeneous) volume or classification characteristics. The difficulty comes from the fact that a "homogeneous segment" for traffic volume may not be a homogeneous segment for other purposes such as classification or pavement design purposes. For example, the road may change from asphalt concrete to Portland cement concrete even though the volumes being carried on that road do not change appreciably. When developing a count program for vehicle classification, it may be necessary to create classification roadway segments where truck volumes do not change significantly. A single classification count taken within a properly defined "super segment" provides the classification data for all segments within that super segment. The use of these "super segments" reduces the number of physical classification counts needed to provide adequate roadway coverage for truck volume information.

What vehicle lengths should I use for vehicle classification?

An analysis of available data examined this issue. It was determined that no single set of vehicle lengths worked "best" for all States, as truck characteristics vary from State to State. The vehicle length classification scheme that worked "the best" on combined data from all States is shown in the tables on the next page.

These criteria did an acceptable, but by no means perfect, job of classifying vehicles into the four general categories. Considerable "error" was found in how well the length bins (and the corresponding classification results) performed when estimating aggregations of the FHWA 13-category classification scheme. A classifier can accurately measure vehicle length (for example as 34 feet for a given small tractor-trailer combination), place that count in the correct length bin (in this example, the bin from 13 to 35 feet), but "incorrectly" classify that vehicle (in this case calling a small combination truck-trailer a single unit).

Table 4-A-1
Length Based Classification Boundaries

Primary Description of Vehicles Included in the Class	Lower Length Bound >	Upper Length Bound < or =
Passenger vehicles (PV)	0 m (0 ft)	3.96 m (13 ft)
Single unit trucks (SU)	3.96 m (13 ft)	10.67 m (35 ft)
Combination trucks (CU)	10.67 m (35 ft)	18.59 m (61 ft)
Multi-trailer trucks (MU)	18.59 m (61 ft)	36.58 m (120 ft)

Table 4-A-2 shows the errors associated with using vehicle lengths to estimate the four vehicle categories (cars, single unit trucks, combination trucks, multi-trailer trucks) shown in Table 4-A-1 when using the vehicle length boundaries shown in that table.

Table 4-A-2
Misclassification Errors Caused By Using Only Total Vehicle Length As The Classification Criteria

Classification Based on Total Vehicle Length					
Classification Based on Configuration and Number of Axles		PV	SU	CU	MU
	SU	17.7%	81.9%	0.4%	0%
	CU	0%	1.8%	84.2%	14.0%
	MU	0%	0.1%	20.8%	79.1%

Many States will be able to improve on these results by fine-tuning the length spacing boundaries to account for the characteristics of their trucking fleets. However, no amount of fine-tuning will lead to a perfect length classification scheme (where perfection is defined as the ability to use overall vehicle length to classify vehicles based on the number of units they include or the number of axles they use). This is because total vehicle length is not a consistent indicator of vehicle class as defined by these attributes. Consequently, highway agencies should be aware of the size and type of misclassification error that exists, and set their length boundaries to minimize error.

APPENDIX 4-B
EXAMPLE TRAFFIC FACTOR GROUP COMPUTATIONS USING THE "TRADITIONAL" METHOD

This appendix shows an example of how to use the traditional method of factor group development to create truck factor groups. It uses data taken from 11 sites on four Interstate highways in Washington State. The locations include facilities east/west, north/south, and on both the eastern and western sides of the Cascade mountain range. The initial assumption going into the factor group creation process was that the Interstate highways fit a single factor group. However, the economic development patterns on the eastern side of the Cascades are very different from those on the western side. In addition, there is a significant possibility that east/west Interstates will have different truck travel patterns than north/south Interstates, since the commodities moving east/west tend to be very different than those moving north/south. These different "professional judgment" assumptions will be tested as part of the factor group development process.

In the example, factors are computed for four vehicle types: passenger vehicles (primarily cars), single-unit trucks (including most of the recreational vehicle population), combination trucks, and multi-trailer trucks. The factor group computations are based on the conversion of monthly average weekday traffic (MAWDT) to annual average daily traffic (AADT) by vehicle classification. This conversion accounts for both day-of-week and seasonal (monthly) variation in a single factor. It converts any count value (by class) taken from a weekday count into an estimate of AADT (by class). Combining both weekday/weekend and monthly effects into a single factor does add to the variability of the seasonal adjustment factors being computed, but it eliminates the need to compute separate day-of-week and monthly factors, and thus removes the need to create separate factoring procedures for the two factors.

Figure 4-B-1 shows the means of the four monthly patterns computed for eleven sites. As expected, the four different vehicle classes have different seasonal patterns. Single-unit trucks have the greatest change in volume over the course of the year. The other three vehicle classes have more consistent volume patterns. Much of the seasonal variation in the single unit truck classification is caused by the presence of recreational vehicles (RVs) and the fact that RVs are both numerous and highly seasonal.

Multi-trailer trucks have the "flattest" seasonal pattern. These trucks travel more consistently throughout the year. Still, these vehicles exhibit a seasonal volume peak in late summer and early fall, and a reduction in these volumes during the primary winter months (December through February). Because so much of the truck travel takes place during the weekdays, the vast majority (9 of 12) of the monthly adjustments for multi-trailer trucks are greater than 1.0. This means that a weekday classification count taken on any "normal" weekday from March through November is likely to over-estimate annual average multi-trailer truck volumes for the year, unless those weekday counts are factored appropriately as shown in Figure 4-B-1.

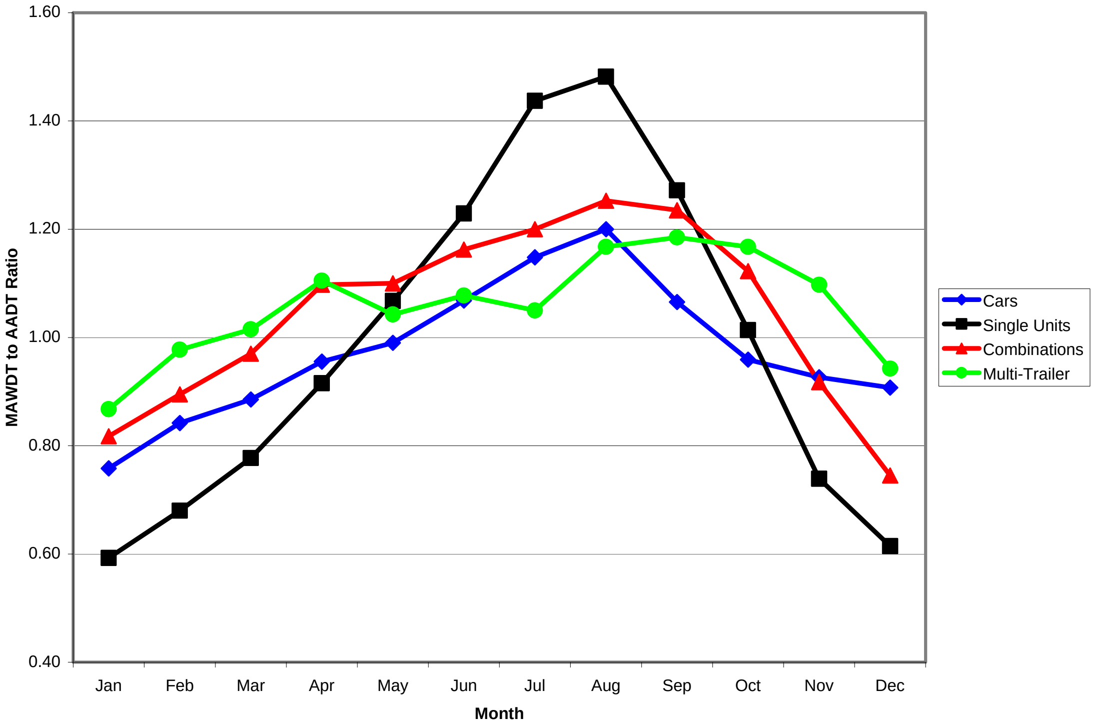

Figure 4-B-1: Seasonal Patterns by Vehicle Type on Interstates in Washington

The seasonal factors in Figure 4-B-1 are the mean values for the 11 locations. If all the Interstates in the State of Washington are treated as a single factor group, the mean value for each month is the factor that would be used to adjust any short count taken on the Interstate system. Thus, the question becomes, are these mean factors "good enough"? This can be answered by looking at the seasonal patterns for the individual sites and at the variation inherent in the computed monthly factors.

Figures 4-B-2 through 4-B-5 illustrate the variation in these seasonal patterns from site to site. Tables 4-B-1 through 4-B-4 show the individual seasonal adjustment factors used in these computations. These tables also show the mean and standard deviation for each adjustment factor for all sites combined. Not surprisingly, the count locations exhibit a wide range of traffic patterns, and the amount of variation present is dependent on the class of vehicles.

In general, there is a reasonably large amount of variation within these sites. Within any given month, the range between the highest and lowest of the individual adjustment factors is between 0.2 and 0.6 (or 20 to 60 percent of AADT). Another measure that describes the variability of these monthly factors is the standard deviation of the mean factor. This factor is the best of the available statistical measures for examining the effectiveness of the factoring process.

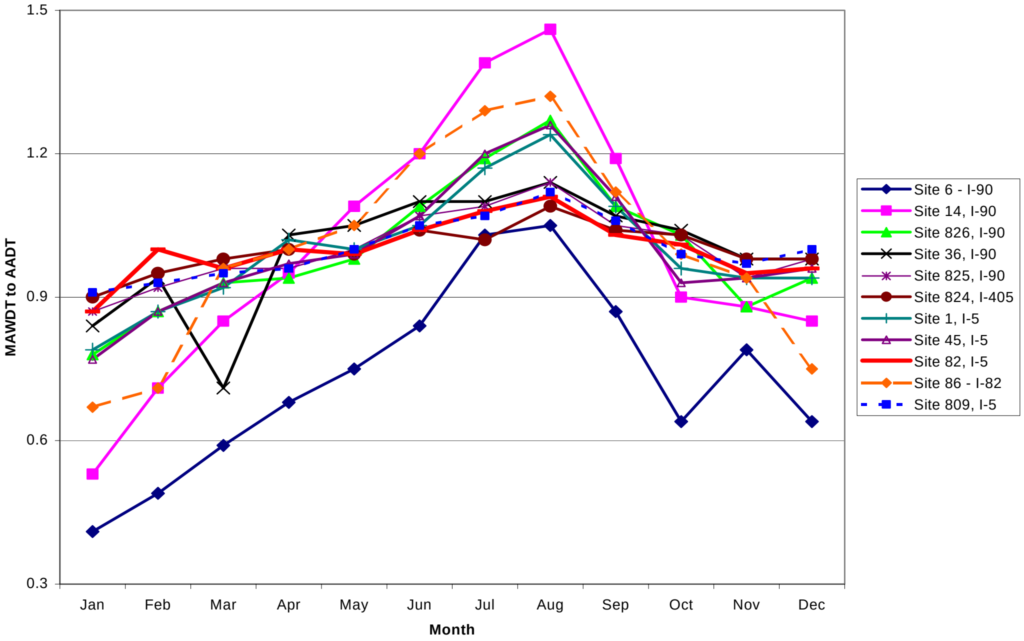

Figure 4-B-2: Ratio of Average Monthly Weekday Traffic to Average Annual Daily Traffic for Passenger Vehicles

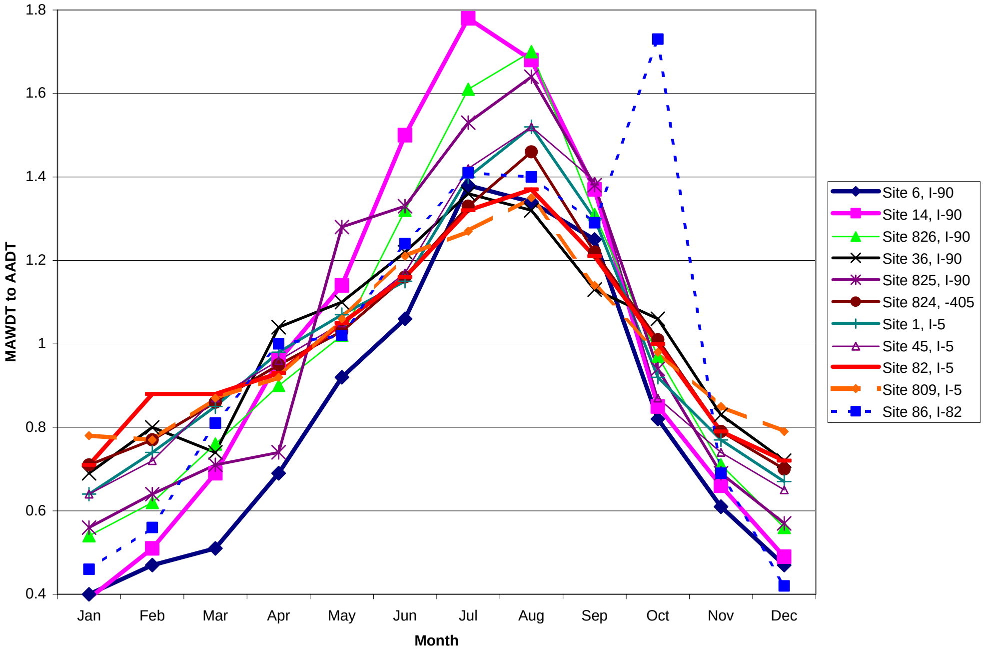

Figure 4-B-3: Ratio of Average Monthly Weekday Traffic to Average Annual Daily Traffic for Single-Unit Trucks

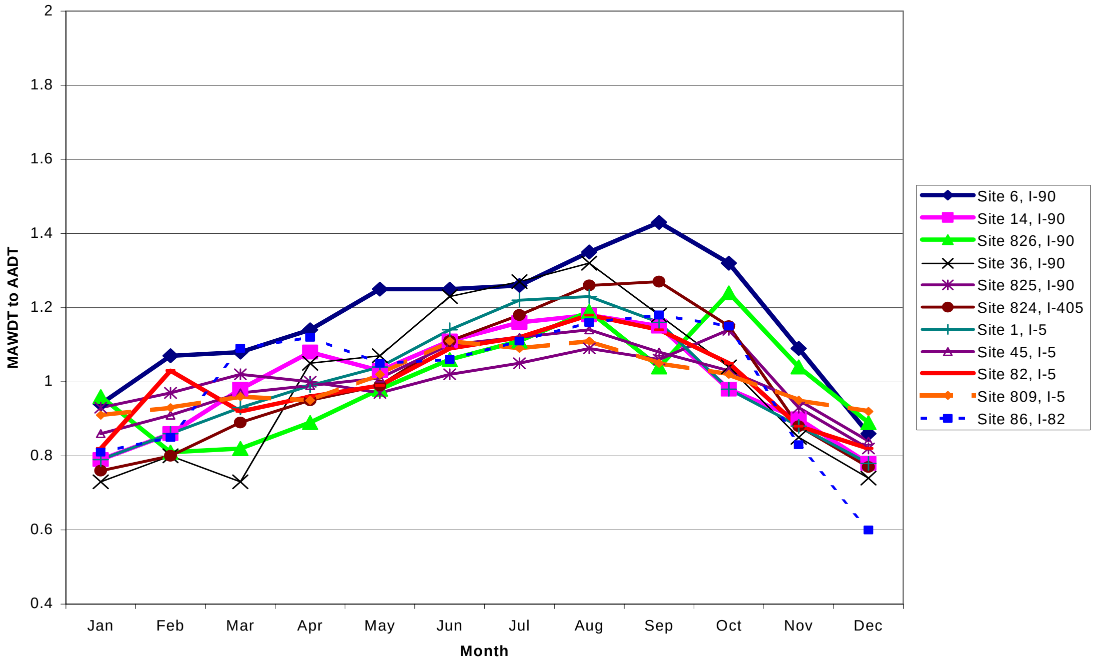

Figure 4-B-4: Ratio of Average Weekday Traffic per Month to Average Annual Daily Traffic for Combination Trucks

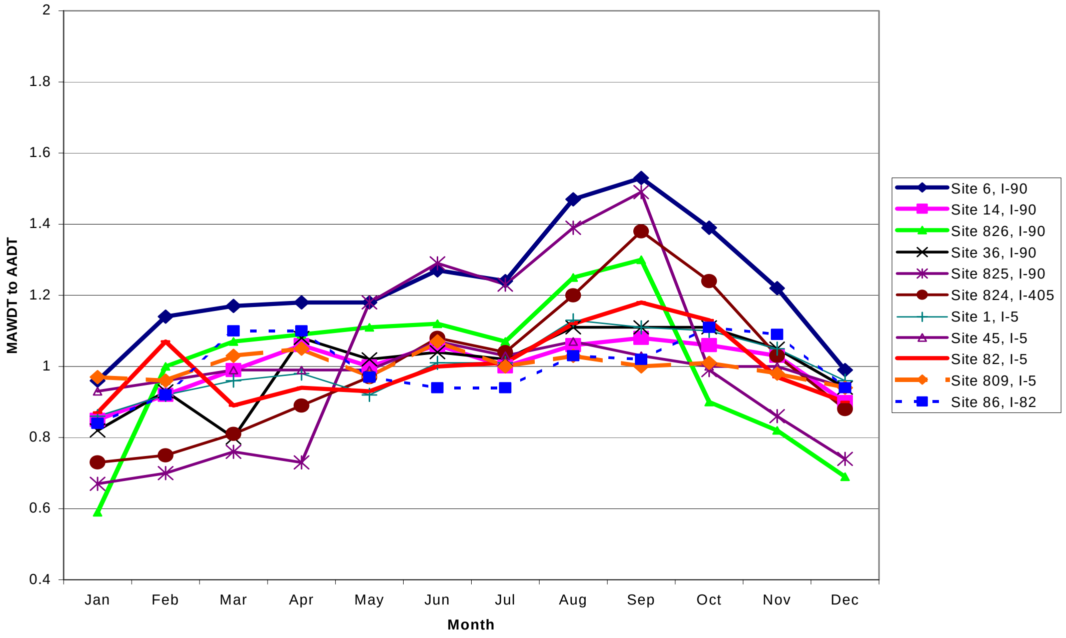

Figure 4-B-5: Ratio of Average Monthly Weekday Traffic to Average Annual Daily Traffic for Multi-Trailer Trucks

Table 4-B-1
Seasonal Adjustment Factors (MAWDTT/AADTT) for Cars

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Route	Rural / Urban
1	0.79	0.87	0.92	1.02	1	1.05	1.17	1.24	1.09	0.96	0.94	0.94	5	R
45	0.77	0.87	0.93	0.97	0.99	1.07	1.2	1.26	1.11	0.93	0.94	0.96	5	R
82	0.87	1	0.96	1	0.99	1.04	1.08	1.11	1.03	1.01	0.95	0.96	5	U
809	0.91	0.93	0.95	0.96	1	1.05	1.07	1.12	1.06	0.99	0.97	1	5	U
86	0.67	0.71	0.96	1	1.05	1.2	1.29	1.32	1.12	0.99	0.94	0.75	82	R
6	0.41	0.49	0.59	0.68	0.75	0.84	1.03	1.05	0.87	0.64	0.79	0.64	90	R
14	0.53	0.71	0.85	0.95	1.09	1.2	1.39	1.46	1.19	0.9	0.88	0.85	90	R
826	0.78	0.87	0.93	0.94	0.98	1.09	1.19	1.27	1.09	1.03	0.88	0.94	90	R
36	0.84	0.94	0.71	1.03	1.05	1.1	1.1	1.14	1.07	1.04	0.98	0.98	90	U
825	0.87	0.92	0.96	0.96	1	1.07	1.09	1.14	1.05	1.03	0.94	0.98	90	U
824	0.9	0.95	0.98	1	0.99	1.04	1.02	1.09	1.04	1.03	0.98	0.98	405	U
Mean for all Sites	0.76	0.84	0.89	0.96	0.99	1.07	1.15	1.20	1.07	0.96	0.93	0.91		
Stand. Dev. for all sites	0.16	0.15	0.12	0.10	0.09	0.10	0.11	0.12	0.08	0.12	0.06	0.11		

Table 4-B-2
Seasonal Adjustment Factors (MAWDTT/AADTT) for Single-Unit Trucks

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Route	Rural / Urban
1	0.64	0.74	0.85	0.98	1.07	1.15	1.4	1.52	1.3	0.92	0.77	0.67	5	R
45	0.64	0.72	0.87	0.96	1.05	1.17	1.42	1.52	1.39	0.87	0.74	0.65	5	R
82	0.71	0.88	0.88	0.93	1.05	1.16	1.32	1.37	1.21	1	0.79	0.72	5	U
809	0.78	0.77	0.87	0.92	1.06	1.21	1.27	1.35	1.14	0.98	0.85	0.79	5	U
86	0.46	0.56	0.81	1	1.02	1.24	1.41	1.4	1.29	1.73	0.69	0.42	82	R
6	0.4	0.47	0.51	0.69	0.92	1.06	1.38	1.34	1.25	0.82	0.61	0.47	90	R
14	0.39	0.51	0.69	0.96	1.14	1.5	1.78	1.68	1.37	0.85	0.66	0.49	90	R
826	0.54	0.62	0.76	0.9	1.02	1.32	1.61	1.7	1.31	0.97	0.71	0.56	90	R
36	0.69	0.8	0.74	1.04	1.1	1.22	1.36	1.32	1.13	1.06	0.83	0.72	90	U
825	0.56	0.64	0.71	0.74	1.28	1.33	1.53	1.64	1.38	0.94	0.69	0.57	90	U
824	0.71	0.77	0.86	0.95	1.03	1.16	1.33	1.46	1.22	1.01	0.79	0.7	405	U
Mean for all Sites	0.59	0.68	0.78	0.92	1.07	1.23	1.44	1.48	1.27	1.01	0.74	0.61		
Stand. Dev. for all sites	0.13	0.13	0.11	0.11	0.09	0.12	0.15	0.14	0.09	0.25	0.07	0.12		

Table 4-B-3
Seasonal Adjustment Factors (MAWDTT/AADTT) for Combination Trucks

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Route	Rural / Urban
1	0.79	0.86	0.93	0.99	1.04	1.14	1.22	1.23	1.16	0.98	0.88	0.78	5	R
45	0.86	0.91	0.97	0.99	1.01	1.1	1.12	1.14	1.08	1.03	0.95	0.84	5	R
82	0.82	1.03	0.92	0.96	0.99	1.09	1.12	1.18	1.14	1.05	0.88	0.82	5	U
809	0.91	0.93	0.96	0.95	1.02	1.11	1.09	1.11	1.05	1.02	0.95	0.92	5	U
86	0.81	0.85	1.09	1.12	1.05	1.06	1.11	1.16	1.18	1.15	0.83	0.6	82	R
6	0.94	1.07	1.08	1.14	1.25	1.25	1.26	1.35	1.43	1.32	1.09	0.86	90	R
14	0.79	0.86	0.98	1.08	1.03	1.11	1.16	1.18	1.15	0.98	0.9	0.78	90	R
826	0.96	0.81	0.82	0.89	0.98	1.06	1.11	1.19	1.04	1.24	1.04	0.89	90	R
36	0.73	0.8	0.73	1.05	1.07	1.23	1.27	1.32	1.18	1.04	0.85	0.74	90	U
825	0.93	0.97	1.02	1	0.97	1.02	1.05	1.09	1.06	1.14	0.93	0.82	90	U
824	0.76	0.8	0.89	0.95	0.99	1.11	1.18	1.26	1.27	1.15	0.88	0.77	405	U
Mean for all Sites	0.85	0.90	0.94	1.01	1.04	1.12	1.15	1.20	1.16	1.10	0.93	0.80		
Stand. Dev. for all sites	0.08	0.09	0.11	0.08	0.08	0.07	0.07	0.08	0.11	0.11	0.08	0.09		

Table 4-B-4
Seasonal Adjustment Factors (MAWDTT/AADTT) for Multi-Trailer Trucks

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Route	Rural / Urban
1	0.86	0.92	0.96	0.98	0.92	1.01	1.01	1.13	1.11	1.1	1.05	0.96	5	R
45	0.93	0.96	0.99	0.99	0.99	1.07	1.03	1.07	1.03	1	1	0.94	5	R
82	0.87	1.07	0.89	0.94	0.93	1	1.01	1.12	1.18	1.13	0.97	0.9	5	U
809	0.97	0.96	1.03	1.05	0.97	1.07	1	1.03	1	1.01	0.98	0.94	5	U
86	0.84	0.92	1.1	1.1	0.97	0.94	0.94	1.03	1.02	1.11	1.09	0.94	82	R
6	0.96	1.14	1.17	1.18	1.18	1.27	1.24	1.47	1.53	1.39	1.22	0.99	90	R
14	0.85	0.92	0.99	1.06	1	1.06	1	1.06	1.08	1.06	1.03	0.9	90	R
826	0.59	1	1.07	1.09	1.11	1.12	1.07	1.25	1.3	0.9	0.82	0.69	90	R
36	0.82	0.93	0.8	1.08	1.02	1.04	1.02	1.11	1.11	1.11	1.05	0.94	90	U
825	0.67	0.7	0.76	0.73	1.18	1.29	1.23	1.39	1.49	0.99	0.86	0.74	90	U
824	0.73	0.75	0.81	0.89	0.97	1.08	1.04	1.2	1.38	1.24	1.03	0.88	405	U
Mean for all Sites	0.83	0.93	0.96	1.01	1.02	1.09	1.05	1.17	1.20	1.09	1.01	0.89		
Stand. Dev. for all sites	0.12	0.12	0.13	0.12	0.09	0.11	0.10	0.15	0.19	0.13	0.11	0.09		

Table 4-B-5
Comparison of Seasonal Adjustment Factors for Different Interstate Groups

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Factors for Cars												
Std. Dev. for All Interstate Roads	0.16	0.15	0.12	0.10	0.09	0.10	0.11	0.12	0.08	0.12	0.06	0.11
Std. Dev. for Eastern Interstate Roads	0.19	0.18	0.16	0.16	0.16	0.17	0.17	0.18	0.14	0.18	0.08	0.14
Std. Dev. for Western Interstate Roads	0.06	0.05	0.02	0.03	0.01	0.02	0.07	0.08	0.03	0.04	0.03	0.02
Std. Dev. for Urban Interstate Roads	0.03	0.03	0.11	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01
St. Dev. for Rural East/West Interstate Roads	0.19	0.19	0.18	0.15	0.17	0.18	0.18	0.21	0.16	0.20	0.05	0.15
Std. Dev. for Rural North/South Interstate Roads	0.06	0.09	0.02	0.03	0.03	0.08	0.06	0.04	0.02	0.03	0.00	0.12
Factors for Single Unit Trucks												
Std. Dev. for All Interstate Roads	0.13	0.13	0.11	0.11	0.09	0.12	0.15	0.14	0.09	0.25	0.07	0.12
Std. Dev. for Eastern Interstate Roads	0.14	0.15	0.13	0.16	0.10	0.18	0.20	0.17	0.10	0.42	0.09	0.13
Std. Dev. for Western Interstate Roads	0.09	0.09	0.07	0.08	0.09	0.08	0.12	0.13	0.09	0.05	0.05	0.08
Std. Dev. for Urban Interstate Roads	0.08	0.09	0.08	0.11	0.10	0.07	0.10	0.13	0.10	0.04	0.06	0.08
St. Dev. for Rural East/West Interstate Roads	0.08	0.08	0.13	0.14	0.11	0.22	0.20	0.20	0.06	0.08	0.05	0.05
Std. Dev. for Rural North/South Interstate Roads	0.10	0.10	0.03	0.02	0.03	0.05	0.01	0.07	0.06	0.48	0.04	0.14

Table 4-B-5 (continued)

Factors for Combination Trucks	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Std. Dev. for All Interstate Roads	0.08	0.09	0.11	0.08	0.08	0.07	0.07	0.08	0.11	0.11	0.08	0.09
Std. Dev. for Eastern Interstate Roads	0.09	0.12	0.17	0.04	0.10	0.09	0.08	0.10	0.13	0.15	0.12	0.11
Std. Dev. for Western Interstate Roads	0.08	0.08	0.06	0.04	0.02	0.04	0.06	0.06	0.08	0.09	0.06	0.05
Std. Dev. for Urban Interstate Roads	0.09	0.10	0.11	0.04	0.04	0.08	0.09	0.10	0.09	0.06	0.04	0.07
St. Dev. for Rural East/West Interstate Roads	0.09	0.14	0.13	0.13	0.14	0.10	0.08	0.10	0.20	0.18	0.10	0.06
Std. Dev. for Rural North/South Interstate Roads	0.04	0.03	0.08	0.08	0.02	0.04	0.06	0.05	0.05	0.09	0.06	0.12
Factors for Multi Trailer Trucks												
Std. Dev. for All Interstate Roads	0.12	0.12	0.13	0.12	0.09	0.11	0.10	0.15	0.19	0.13	0.11	0.09
Std. Dev. for Eastern Interstate Roads	0.06	0.11	0.16	0.05	0.09	0.14	0.13	0.20	0.23	0.15	0.09	0.04
Std. Dev. for Western Interstate Roads	0.14	0.13	0.11	0.12	0.10	0.10	0.08	0.12	0.18	0.11	0.09	0.11
Std. Dev. for Urban Interstate Roads	0.14	0.15	0.13	0.14	0.10	0.10	0.09	0.13	0.18	0.12	0.09	0.11
St. Dev. for Rural East/West Interstate Roads	0.08	0.16	0.13	0.08	0.13	0.15	0.17	0.29	0.32	0.23	0.13	0.06
Std. Dev. for Rural North/South Interstate Roads	0.05	0.02	0.07	0.07	0.04	0.07	0.05	0.05	0.05	0.06	0.05	0.01

It can be seen that for car volumes, two sites on I-90 (sites 6 and 14) have travel patterns that are rather distinct from the remaining nine sites. Both of these sites show a higher degree of seasonality than is present in the other sites. Both have much lower winter volumes than the remaining sites, and both exhibit a much greater increase in traffic during the summer months. It turns out that both of these sites are in eastern Washington. In addition, a third eastern site has a similarly high summer/low winter travel pattern (site 86) on I-82. These passenger car patterns suggest that keeping eastern Washington sites separate from western Washington sites might create better factor groups.

However, looking at the other vehicle classes does not lead to the same clear-cut decision. For both combination trucks and multi-trailer trucks, Site 14 has truck volume patterns that fall directly in the middle of the pattern exhibited by the various sites. Site 6, on the other hand, does show a traffic pattern for trucks that is slightly more extreme than for the other sites. Site 6 shows a pattern in which the weekday adjustment factor is almost always greater than 1, indicating very low weekend traffic in comparison to weekday traffic, whereas the other sites have winter volumes that fall below the average daily volumes.

This mixed result is common when one is trying to apply a single factor grouping process to multiple types of vehicles. Different classes of vehicles are affected by different land-use and travel patterns, and as a result factor groups will predict travel patterns more reliably for some vehicle classes than for others.

To determine the effectiveness of splitting these roads into two different factor groups, it is necessary to look at the statistics that would be generated by splitting these routes. Three different “simple” splits are possible, given the assumptions presented earlier. The three alternative groupings to be tested are given below. Each could be considered “intuitive” to an analyst familiar with the State. The testing process will show whether the “intuitive” process provides better analytical results. Each new group does allow easy assignment of short duration counts collected at specific road locations to an available factor group.

- All Interstates on the eastern side of the Cascades can be placed in one group, and all Interstates on the western side of the Cascades can be placed in the other.
- All east/west Interstates can be placed in one group, and all north/south Interstates in the other.
- All east/west rural Interstates can be placed in one group, all north/south rural Interstates can be placed in another, and all urban Interstates can be placed in a third.

Table 4-B-5 shows the effects of forming these groups and compares them with the variability found if all Interstates are treated as a single factor group. Not surprisingly, each of these three changes to the factor groups results in improvements in some factors (that is, the factors show a decrease in variability) and increased variation of other factors. For example, splitting the “All Interstates” factor group into eastern and

western factor groups results in significant improvement (a decrease in the standard deviation for almost all monthly factors) in the factors for the car, single-unit, and combination unit factors for the western Interstate factor groups. However, the multi-trailer truck factor group for western Interstates shows a minor increase in variability for all but the summer months. Conversely, the eastern factor group generally shows an increase in variability for all factor groups, except for multi-trailer trucks during the winter months. Thus, separating eastern and western roads only appears to improve the accuracy of annual traffic estimates west of the Cascade Mountains while reducing the accuracy of counts in the eastern portion of the state.

The second effort to improve factors is to split roads traveling primarily east/west from those traveling north/south. Table 4-B-5 shows that this has the effect of making the factors for north/south roads universally more accurate than factors for all Interstates combined. However, factors for the east/west Interstates are almost universally worse than the factors for all Interstates combined. This sets up the decision of choosing between a factoring process that more accurately adjusts short counts on some roads at the expense of poorly adjusting others. Before making this tough decision, it is important to look at the last idea for improving these basic factor groups.

The final effort is to remove the urban locations from the east/west and north/south factor groups. The intent behind this effort is again to separate roads assumed to have different seasonal and day-of-week patterns (i.e., urban versus rural). If these patterns are different, the factors for both east/west and north/south factor groups should have reduced seasonal variability. Given the results above, the primary improvement desired is in the area of east/west Interstates, since those roads have the highest variability between the two groups just tested.

Unfortunately, as shown in Table 4-B-5, removing the urban sites from the east/west factor group does not significantly improve the variability of the factor being produced. As with the original east/west factor group, the rural east/west factor group has monthly factors that are almost universally more variable than the original monthly factors. Thus, the original decision point remains, is it better to maintain the one single factor group that does all Interstate reasonably well, or split the Interstates into two groups, with one group having more reliable factors than the other?

It is very difficult to answer this question without including far more information than can be presented in this report. Issues that would be important in making this decision include the following:

- How many other factor groups are already used in the State?
- Are any of the roads of higher priority than the others?
- Would it be possible to use road specific factors to deal more effectively with the higher variation on the east/west roads?
- Are there specific reasons why the east/west roads are more variable for the year(s) for which data are being examined? (For example, could an unusual series of weather events have caused more variability than is normal for those roads?)

- Are either of the factoring groups easier to implement at either the user level or the database management level? (That is, can the average user understand which factor to apply for both factor groups? Will the existing traffic database management system support both types of factor groups?)

Without the answers to these questions, the decision can only be made on the basis of statistical reliability. Assuming that the short count program can be manipulated, it would therefore be in the interest of the State to select one of the more disaggregated factor groups. The last of these groups works slightly better than the first two. So it is selected. However, to allow the best possible computation of annual traffic estimates, it is recommended that counts in the eastern portion of the State be collected during the early winter if weather permits or early spring if reliable winter data collection is not possible, since these are the times of the year when the adjustment factors for most of the vehicle classes are most stable.

APPENDIX 4-C
FHWA VEHICLE TYPES

The classification scheme is separated into categories depending on whether the vehicle carries passengers or commodities. Non-passenger vehicles are further subdivided by number of axles and number of units, including both power and trailer units. Note that the addition of a light trailer to a vehicle does not change the classification of the vehicle.

Automatic vehicle classifiers need an algorithm to interpret axle spacing information to correctly classify vehicles into these categories. The algorithm most commonly used is based on the "Scheme F" developed by Maine DOT in the mid-1980s. **The FHWA does not endorse "Scheme F" or any other classification algorithm.** Axle spacing characteristics for specific vehicle types are known to change from State to State. As a result, no single algorithm is best for all cases. It is up to each agency to develop, test, and refine an algorithm that meets its own needs.

FHWA VEHICLE CLASSES WITH DEFINITIONS

1. ***Motorcycles*** (Optional) -- All two or three-wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handlebars rather than steering wheels. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheel motorcycles. This vehicle type may be reported at the option of the State.

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

3. ***Other Two-Axle, Four-Tire Single Unit Vehicles*** -- All two-axle, four-tire, vehicles, other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single-unit vehicles pulling recreational or other light trailers are included in this classification. *Because automatic vehicle classifiers have difficulty distinguishing class 3 from class 2, these two classes may be combined into class 2.*

4. ***Buses*** -- All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-

carrying vehicles. Modified buses should be considered to be a truck and should be appropriately classified.

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

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

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

c. Vehicles are defined by the number of axles in contact with the road. Therefore, "floating" axles are counted only when in the down position.

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

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

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

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

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

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

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

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

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

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

APPENDIX 4-D
RESOURCES ON TRAFFIC DATA COLLECTION

New Mexico Vehicle Detector Clearinghouse, http://www.nmsu.edu/~traffic/

"Traffic Detection Technologies for a Modern Transportation Infrastructure," by Klein, Kelley, and Mills, presented at SPIE Conference 2592, Collision Avoidance and Automated Traffic Management Sensors, October 25-26, 1995, Philadelphia.

"Detection Technology for IVHS – Task L: Final Report," FHWA Contract DTFH61-91-C-00076, U.S. Department of Transportation, Washington, D.C., 1996.

"Accuracy of Automatic Vehicle Classifiers," Kansas Department of Transportation, July 1989.

"Field Evaluation of FHWA Vehicle Classification Categories," by Wyman, Braley, and Stevens, Maine Department of Transportation, Final Report for Contract #DTFH-71-80-54-ME-03 for USDOT, 1985.

"Autoscope Evaluation at Trunk Highway 65 and 53rd Avenue North," Minnesota Department of Transportation, January 1996.

"Evaluation of Econolite Products Inc., Machine Vision Vehicle Detection System," Indiana Department of Transportation, 1996.

"Infrared Sensors for Counting, Classifying, and Weighing Vehicles," by Garner, Lee, and Huang, University of Texas, Report #FHWA/TX 91+1162-1F, December 1990.

"AASHTO Guidelines for Traffic Data Programs," by the Joint Task Force on Traffic Monitoring Standards, ISBN 1-56051-054-4, 1992.

Section 5

Truck Weight Monitoring

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SECTION 5
TRUCK WEIGHT MONITORING

CHAPTER 1
INTRODUCTION TO TRUCK WEIGHT DATA COLLECTION

The last of the primary traffic monitoring activities is truck weight data collection. Gathering truck weight data is the most difficult and costly of the three primary data collection activities. However, in many respects these data are the most important.

Data on the weight carried by trucks are used as a primary input to a number of a State highway agency's most significant tasks. For example, traffic loading is a primary factor in determining the depth of pavement sections. It is used as a primary determinant in the selection of pavement maintenance treatments. The total tonnage moved on roads is used to estimate the value of freight traveling on the roadway system and is a major input into calculations for determining the costs of congestion and benefits to be gained from new construction and operating strategies. Truck classification and weight information is also a key component in studies that determine the relative cost responsibility of different road users.

This section discusses the alternatives for collecting truck weight information. This first chapter introduces truck weight data collection technology and data collection strategies. The second chapter discusses the basic user needs for truck weight data and describes how those uses affect the data collection and summarization strategy. Chapter 3 recommends a truck weight data collection program that meets the needs identified in Chapter 2. Chapter 4 presents a variety of ways to summarize weight data. Finally, a discussion of the need for calibration of WIM devices is presented as an Appendix.

WEIGH-IN-MOTION (WIM) DATA COLLECTION

Of all the traffic monitoring activities, WIM requires the most sophisticated data collection sensors, the most controlled operating environment (strong, smooth, level pavement in good condition), and the most costly equipment set up and calibration.[1] WIM systems are designed to measure the vertical forces applied by axles to sensors in the roadway. This measurement helps estimate the weight of those axles if the truck being weighed were stationary. The task is complicated by a number of factors, including the following:

- Each sensor "feels" the vertical force of each axle for only a brief time.
- The "weight" applied to the sensor during that time period is normally not equal to the static weight of that axle. This is because while the vehicle is

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[1] An excellent introduction to WIM is provided in the reference "State's Successful Practices Weigh-in-Motion Handbook" by McCall, Bill, and Vodrazka, Walter, FHWA, December 1997.

in motion, the truck and its components bounce up and down. If the truck mass is moving upward when an axle crosses the WIM sensor, the weight applied by that axle is lower than the static value. If the truck mass is landing, the weight applied is greater than the static value.[2]

- Some sensors (strip) feel only a portion of the tire weight at any given time. Because the sensor is smaller than the footprint of the tire, the pavement surrounding the sensor physically supports some portion of the axle weight throughout the axle weight measurement.
- The tread on some tires is so well defined that very high concentrations of force are generated under those portions of the tread that are actually in contact with the ground. This is also mostly a problem for strip sensors.
- Sensors must be capable of weighing more than one axle in quick succession. That is, the scale must be able to "recover" quickly enough so that one axle weight does not affect the measurement of the following axle.
- Roadway geometry (horizontal and vertical curves) can cause shifts in vehicle weight from one axle to another.
- Vehicle acceleration or braking, torque from the drive axles, wind, the style and condition of vehicle's suspension system, and a variety of other factors can also cause shifts of weight from one axle to another.

The effects of many of these factors can be minimized through careful design of the WIM site. The site should be selected and designed to reduce the dynamic motion of passing vehicles. However, achieving these design controls requires restrictions on site selection, which means that WIM systems cannot be placed as easily or as universally as other traffic monitoring equipment.

WIM scales work most accurately when they are placed flush with the roadway. Sensors that sit on top of the roadway cause two problems with WIM system accuracy: 1) They induce additional dynamic motion in the vehicle, and 2) they can cause the sensor to measure the force of tire deformation (which includes a horizontal component not related to the weight of the axle) in addition to the axle weight. This means that permanent installation of the sensors and/or frames that hold the sensors is normally better for consistent, accurate weighing results. The use of permanently installed WIM sensors is recommended as a means of improving the quality of the data.[3]

WEIGH-IN-MOTION EQUIPMENT CALIBRATION

Calibration of WIM equipment is also more demanding than calibration of other types of traffic monitoring equipment. WIM scale calibration must account for the vehicle dynamics at the data collection site. Because vehicle dynamics are affected by pavement roughness, the "correct" calibration value for a scale is a function of the

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[2] In addition, truck components, such as shock absorbers, are also in motion affecting the axle weight at any given instant in time.

[3] This recommendation does not prevent the use of less accurate portable equipment.

pavement condition and the sensor installation at each site. Since these differ with each placement, a significant calibration effort is required each time WIM equipment is placed on the ground. If the scale is not calibrated, the static weight estimates provided by the scale can be very inaccurate, even if the scale accurately reports the vertical forces applied to its surface. The expense of calibrating portable WIM scales each time they are installed is another significant detriment to their use.

Because pavement conditions change over time, and because those changes affect WIM scale performance, even permanently installed WIM sensors need to be periodically calibrated.

To ensure that the equipment is operating effectively, the data produced must be promptly produced and analyzed. Changes in vehicle weight over time must be examined quickly to understand whether the equipment is malfunctioning, calibration is needed, or the scales are simply reflecting changes in freight movement. Software systems that allow rapid monitoring and retrieval of WIM system output are an important consideration of WIM data collection. The FHWA Vehicle Travel Information System (VTRIS) allows quick examination of WIM data. More information on WIM site requirements and WIM calibration requirements is included in Appendix 5-A.

CHAPTER 2
TRUCK WEIGHT USER NEEDS

Truck weight data are used for a wide variety of tasks. These tasks include, but are not limited to, the following:

- pavement design
- pavement maintenance
- bridge design
- pavement and bridge loading restrictions
- development and application of equitable tax structures
- determination of the need for and success of weight law enforcement actions
- determination of the need for geometric improvements related to vehicle size, weight, and speed
- determination of the economic value of freight being moved on roadways
- determination of the need for and effect of appropriate safety improvements.

BASIC TRUCK WEIGHT DATA SUMMARIES

State highway agencies summarize and report truck weight data in many ways. Three types of summaries are commonly used including:

- gross vehicle weight (GVW) per vehicle (usually by vehicle class)
- axle load distribution (by type of axle) for specific vehicle types
- equivalent standard axle load[4] (ESAL) for specific vehicle types.

Basic statistics such as the GVW or ESAL for a given vehicle classification can be expressed as distributions, as mean values, or as mean values with specified confidence intervals, depending on the needs of the analysis that will use this information. Each of these summary statistics can be developed for a specific site, a group of sites, or an entire State or geographic region, depending on the needs of the analysis and the data collection and reporting procedures. The role of the traffic monitoring program is to provide the user with whichever of these data summaries is needed. The summaries can be required for any one of several levels of summarization. For example, it may be appropriate to maintain axle loading distributions for each of the FHWA heavy vehicle classes (classes 4 through 13)[5] so that these statistics are available when needed for pavement design. However, even if a more aggregated classification scheme is used, such as single-unit trucks, combination trucks, and multi-trailer trucks, the more detailed summary should be retained for WIM data. These summaries can be computed with FHWA's VTRIS software, with software supplied by the WIM system

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[4] ESAL are a measure of pavement damage developed by AASHTO researchers in the 1960s that are used for pavement design by many current design procedures.

[5] See Appendix 4-C for definitions of the FHWA vehicle classes.

vendor, or with software developed specifically for use by the State highway agency as part of its traffic database.

A single statewide average statistic may not be applicable to all parts of the State. Trucking characteristics vary significantly by type of road. When a single statewide summary is not representative of all roads, it is important to collect data and maintain summary statistics for different regions or roads in the State. For example, the truck traffic in urban areas often has different truck weight characteristics than those in rural areas. Roads that serve major agricultural regions often have different loading characteristics than roads that serve resource extraction industries. Roads that serve major industrial areas within an urban area tend to carry much heavier trucks than roads that serve general urban and suburban areas. Roads that serve major through-truck movements often experience very different truck weights than roads that serve primarily local truck traffic. An effective truck weight program must identify these differences and include a data reporting mechanism to provide users with data summaries that correctly describe specific characteristics.

TRUCK LOADING ESTIMATES

Axle load distribution tables and average gross vehicle weights per vehicle are useful statistics, but they are rarely the end product that many users need. Instead, most users are interested in total load estimates for a given period (e.g., total ESAL per year, or total number of axle loads by type and weight range in the last ten years). These statistics can be derived directly only from WIM sites. Unfortunately, because WIM equipment is expensive to install and maintain, WIM data are available at only a few locations in the State. Thus, at most road sites, these WIM data items cannot be measured directly. Instead, the data are normally computed from a summary weight data set, as previously described, and a site-specific count of volume by vehicle classification category. The WIM data are imputed to the site-specific classification count to estimate total loading.

These calculations assume that the basic weight distribution developed at available WIM sites is representative of all roads within a specified group. For example, all rural Interstates are assumed to have similar truck loading conditions. Rural Interstate loading conditions are then measured at three different WIM sites and the data combined to provide the weight distribution estimate to represent all segments in the group.

Site-specific volume counts (by classification) are used to “size” the weight distribution. That is, the site-specific classification count (adjusted for day-of-week and seasonal variation) is used to determine how many trucks of a particular type actually travel on the road. The volume by classification determines how many axles of each type are present. (For example, if a road section carries 100 Class 9 trucks in a day, it experiences approximately 100 single axles and 200 sets of tandem axles.)

Multiplying the number of trucks within a given class by the average GVW for vehicles of that class yields the total number of tons[6] applied by that class on that roadway. Adding these values across all vehicle classes yields the total number of tons carried by that road. These values can be plotted graphically, creating an image very similar to a traffic volume flow map[7] (Figure 5-2-1). The graphics are useful for both public presentations and as an information tool for decision makers. Map displays allow decision makers to graphically compare roads that carry large freight volumes with roads with light freight movements. The information can also be used to help prioritize potential road improvement projects.

Multiplying the total number of vehicles in a given class by the number of axles (by type of axle) associated with that class and by the axle weight distribution associated with that class, yields the total number of axles applied at that site by that vehicle class. Adding these weight distribution tables across vehicle classes results in the total number of axles, by weight class, applied to that roadway. This type of summary table will be one of the primary data inputs for the pavement design guide being readied by AASHTO.

The axle distribution by axle weight range can also be easily converted into equivalent standard axle loads (ESAL), the most common pavement design loading value currently used in the United States. To make this conversion, an ESAL[8] value is assigned to each axle weight category for each type of axle (single, tandem, tridem). This value times the number of axles within that weight range yields the total ESAL load for that type and weight range of axles. Summing these values across all axle types and weight ranges yields the total number of ESALs applied to that roadway (Table 5-2-1).

Finally, understanding and accounting for seasonal variations in vehicle weights is becoming increasingly important for both economic analyses and pavement design procedures. New pavement design procedures being developed and refined require traffic loading data for specific times of the year. For example, in many colder regions proposed pavement design procedures will require the average daily loading rate during the spring thaw period because the pavement will be designed to withstand loads when the roadway structure is at its weakest. Since pavement strength changes with many environmental conditions, the pavement designers are likely to require data on loads at different sites at different times during the year. If loads vary (because the numbers of trucks or the weights of individual trucks vary during the year), the traffic data collection process must be able to detect and report these differences. Otherwise, the pavement design procedures will be unreliable.

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[6] Note that this value is the total tons of load carried by the roadway, not the total net tonnage of goods carried over that road (i.e., gross weight applied, not net commodity weight carried.)

[7] The accuracy of these estimates is a function of the quality of the volume by vehicle classification estimate and the degree to which the GVW/vehicle value represents the trucks actually using that roadway. Like all “flow” maps, extrapolation is required to produce the map, and users should not assume high levels of precision when reading directly from such a map.

[8] ESAL varies with pavement characteristics, flexible (asphalt) or rigid (Portland cement) pavement.

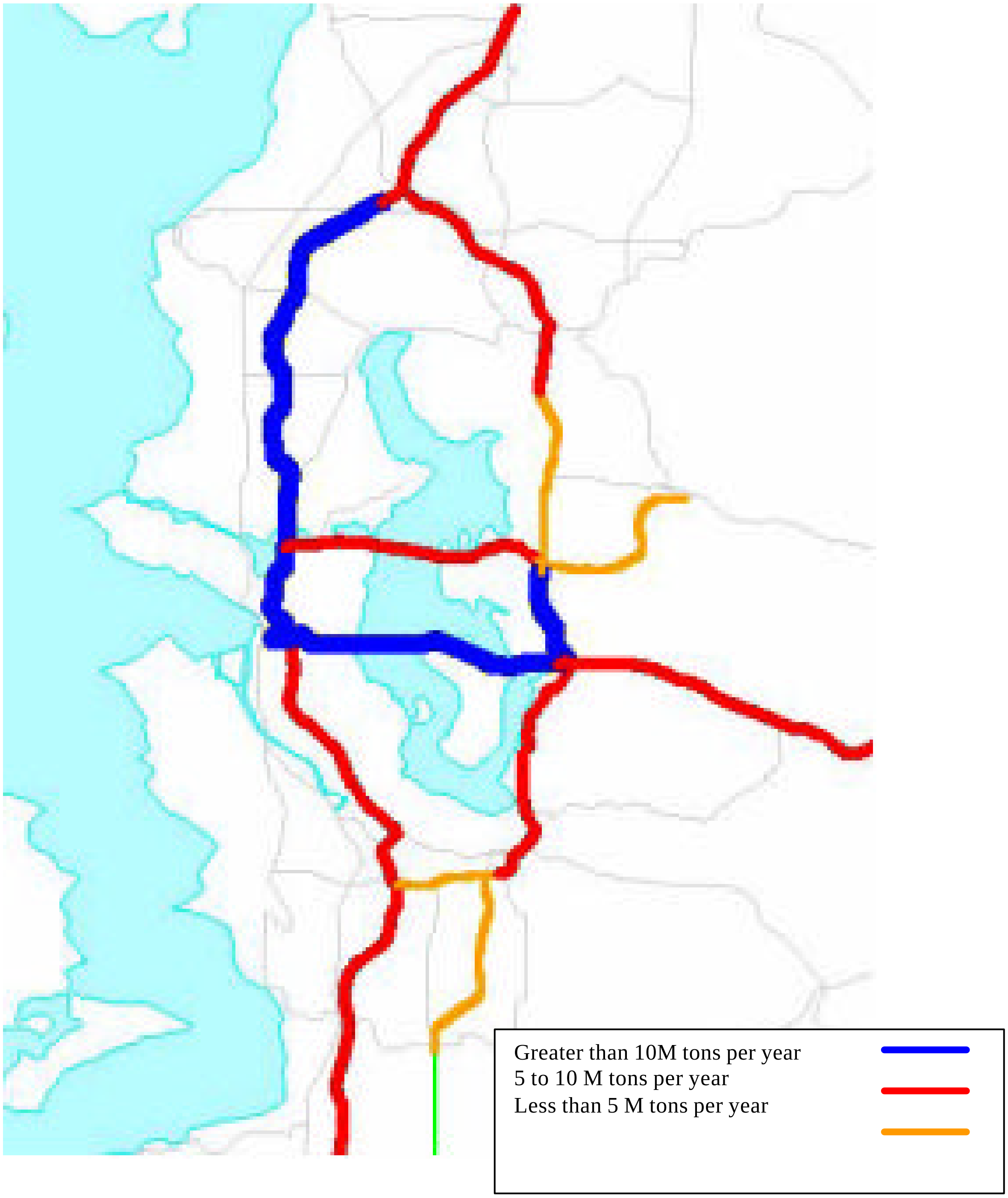

Figure 5-2-1: Example GVW Flow Map

Table 5-2-1: Example Daily Load Distribution Table (All Vehicle Classes Combined) and Computation of Total (Flexible) ESAL Loading

Single Axles				Tandem Axles				Tridem Axles			
Lower Weight Range (kgs)	Upper Weight Range (kgs)	ESAL Per Axle	Number of Axles	Lower Weight Range (kgs)	Upper Weight Range (kgs)	ESAL Per Axle	Number of Axles	Lower Weight Range (kgs)	Upper Weight Range (kgs)	ESAL Per Axle	Number of Axles
0	1,363	0.000	5	0	2,727	0.001	4	0	5,454	0.001	0
1,364	1,818	0.001	7	2,728	3,636	0.002	16	5,455	6,818	0.006	0
1,819	2,272	0.003	51	3,637	4,545	0.005	24	6,819	8,181	0.014	0
2,273	2,727	0.007	31	4,546	5,454	0.010	36	8,182	9,545	0.027	0
2,728	3,181	0.014	37	5,455	6,363	0.020	34	9,546	10,909	0.048	0
3,182	3,636	0.026	75	6,364	7,272	0.036	37	10,910	12,272	0.079	0
3,637	4,090	0.044	99	7,273	8,181	0.061	33	12,273	13,636	0.126	0
4,091	4,545	0.071	97	8,182	9,090	0.097	28	13,637	15,000	0.191	0
4,546	5,000	0.108	78	9,091	10,000	0.148	23	15,001	16,363	0.278	0
5,001	5,454	0.158	56	10,001	10,909	0.217	19	16,364	17,727	0.393	0
5,455	5,909	0.224	40	10,910	11,818	0.309	20	17,728	19,090	0.539	0
5,910	6,363	0.310	22	11,819	12,727	0.425	22	19,091	20,454	0.722	1
6,364	6,818	0.416	16	12,728	13,636	0.572	29	20,455	21,818	0.947	0
6,819	7,272	0.547	16	13,637	14,545	0.752	29	21,819	23,181	1.217	0
7,273	7,727	0.706	13	14,546	15,454	0.757	30	23,182	24,545	1.537	2
7,728	8,181	0.894	13	15,455	16,363	1.229	25	24,546	25,909	1.912	1
8,182	8,636	1.115	11	16,364	17,272	1.532	17	25,910	27,272	2.346	3
8,637	9,090	1.371	10	17,273	18,181	1.884	15	27,273	28,636	2.843	1
9,091	9,545	1.664	7	18,182	19,090	2.288	8	28,637	30,000	3.408	0
9,546	10,000	1.999	6	19,091	20,000	2.747	7	30,001	31,363	4.046	0
10,001	10,454	2.376	5	20,001	20,909	3.267	5	31,364	32,727	4.763	0
10,455	10,909	2.801	3	20,910	21,818	3.850	2	32,728	34,090	5.563	0
10,910	11,363	3.275	1	21,819	22,727	4.502	3	34,091	35,454	6.453	0
11,364	11,818	3.804	1	22,728	23,636	5.229	1	35,455	36,818	7.441	0
11,819	12,272	4.390	1	23,637	24,545	6.035	1	36,819	38,181	8.534	0
12,273	12,727	5.039	1	24,546	25,454	6.927	1	38,182	39,545	9.740	0
12,728	13,181	5.756	0	25,455	26,363	7.913	0	39,546	40,909	11.070	0
13,182	13,636	6.546	0	26,364	27,272	8.999	0	40,910	42,272	12.532	0
13,637	14,090	7.416	0	27,273	28,181	10.194	0	42,273	43,636	14.138	0
14,091	14,545	8.371	0	28,182	29,090	11.506	0	43,637	45,000	15.900	0
14,546	15,000	9.419	0	29,091	30,000	12.947	0	45,001	46,363	17.831	0
15,001	15,454	10.567	0	30,001	30,909	14.525	0	46,364	47,727	19.942	0
15,455	15,909	11.824	0	30,910	31,818	16.253	0	47,728	49,090	22.250	0
15,910	16,363	13.197	0	31,819	32,727	18.140	0	49,091	50,454	24.769	0
16,364	16,818	14.696	0	32,728	33,636	20.201	0	50,455	51,818	27.514	0
16,819	17,272	16.331	0	33,637	34,545	22.448	0	51,819	53,181	30.503	0
17,273	17,727	18.111	0	34,546	35,454	24.895	0	53,182	54,545	33.753	0
17,728	18,181	20.047	0	35,455	36,363	27.556	0	54,546	55,909	37.283	0
18,182	none	22.149	0	36,364	none	30.446	0	55,910	none	41.111	0
Total ESAL by type of axle ∑(ESAL/axle * Total Axles)			**169.8**				**269.7**				**15.6**
Total ESAL (all axle types combined)			**455.1**								

CHAPTER 3
TRUCK WEIGHT DATA COLLECTION

The objective of the truck weight data collection program is to obtain a reliable estimate of the distribution of vehicle and axle loads per vehicle for truck categories within defined roadway groups.

The data collection plan for truck weight accounts for:

- the statistical needs of State and federal agencies
- the capabilities and limitations of WIM equipment
- the resource constraints found at most State highway agencies
- the variability of truck weight data, as discussed in the literature and as observed in data submitted to the FHWA.

The truck weight data collection program is based on creating summary axle load distributions that can be applied with confidence and statistical precision to all roads in a State. The procedure is to group the State's roads into categories, so that each group experiences freight traffic with reasonably similar characteristics. For example, roads that experience trucks carrying heavy natural resources should be grouped separately from roads carrying only light, urban delivery loads. The truck weight data collection program is closely analogous to the permanent, continuous count programs for collecting seasonal and day-of-week pattern information for volume and vehicle classification data. The primary difference is that most of the truck weight data collection sites do not need to be operated in a continuous manner.

Within each of these groups of roads, the State should operate a number of WIM sites. These sites will be used to identify truck weight patterns that apply to all roads in the group. At least one of the WIM sites within each group should operate continuously throughout the year to measure seasonal changes in the loads carried by trucks operating on those roads. Where possible (given budget and staffing limitations), more than one location within each group should be monitored continuously to provide more reliable measures of seasonal change. The proper number of additional continuous sites is primarily a function of:

- each State's ability to supply the resources needed to monitor the sites to ensure the provision of accurate data throughout the year
- the proven need to monitor differences in seasonal weight characteristics.[9]

Performing additional vehicle weighing, both by operating more continuous WIM scales and by collecting data at more than the minimum number of scale sites, will allow a State to determine whether the initial groups selected do, in fact, carry similar truck

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[9] If extensive data collection shows that a group of roads has a very stable seasonal pattern, then relatively few continuous counters are needed to monitor the pattern. However, if the State has limited data on seasonal weight patterns or if prior data collection has shown the pattern to be inconsistent, then a larger number of continuous counters may be needed.

traffic. Where new data collection shows that monitored roads do not carry traffic with loading characteristics similar to those of other roads in the group, the State will either need to create new road groups (and collect more truck weight information) or revise the existing road groups to create more homogeneous groups.

TRUCK WEIGHT GROUP FORMATION

Truck weight road groups should be based on a combination of known geographic, industrial, agricultural, and commercial patterns, along with knowledge of the trucking patterns that occur on specific roads. Road groups or systems for truck weight data collection should: 1) be easily applied within each State, and 2) provide a logical means for discriminating between roads that are likely to have very high load factors and roads that have lower load factors (that is, between roads where most trucks are fully loaded and roads where a large percentage of trucks are either partially loaded or empty).

In addition, States should incorporate into their truck weight grouping process knowledge about specific types of heavy trucks, so that roads that carry those heavy trucks are grouped together, and roads that are not likely to carry those trucks are treated separately. For example, roads leading to and from major port facilities might be treated separately from other roads in that same geographic area, simply because of the high load factor that is common to roads leading to/from most port facilities.

Figure 5-3-1 illustrates the reason why roads should be stratified into road groups. It shows the distribution of tandem axle weights for Class 9 trucks from three different truck weight sites. Each of these three sites exhibits a very different set of loading conditions, ranging from heavily loaded to very lightly loaded. Use of loading information from one of these sites at either of the other two sites would result in very poor load estimates. The average flexible ESAL per tandem axle at the heavily loaded site is 0.66, while the moderately loaded site has a flexible ESAL per tandem axle of 0.35, and the lightly loaded site has an ESAL per tandem axle of 0.19. Thus, use of the “heavy” load distribution at the “lightly” loaded site would result in an overestimation of actual loading rates by a factor of over 3.

The key to the design of the truck weight data collection effort, and the use of the data that results from that process, is for the highway agency to be able to successfully recognize these differences in loading patterns, and to collect sufficient data to be able to estimate the loads that are occurring under these different conditions.

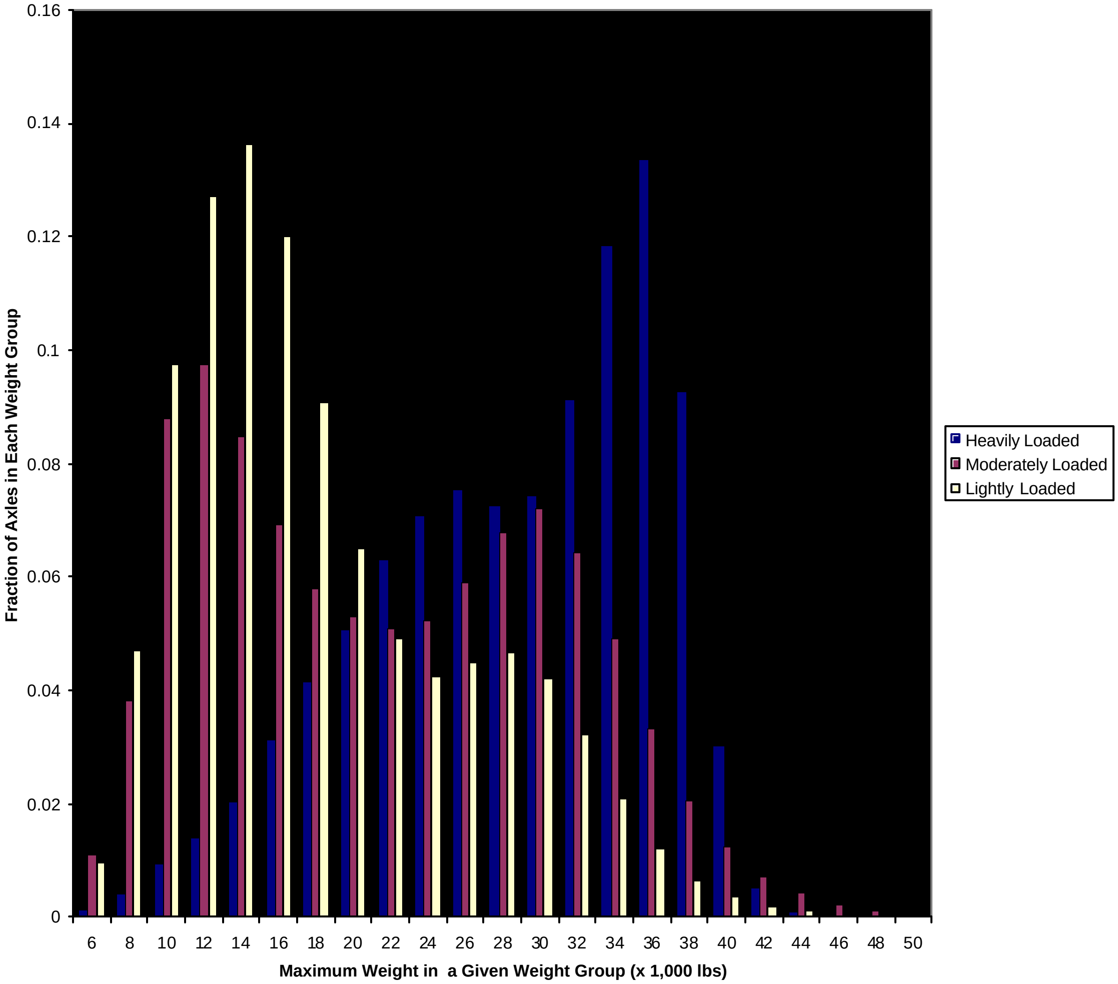

Figure 5-3-1: Tandem Axle Load Distributions At Three Sites With Different Loading Conditions. The Case For Truck Weight Road Groups

Australia recently proposed a similar grouping technique in the chapter on traffic data collection in its pavement design guide.[10] In the Australian guide, 25 different truck loading patterns are identified nationwide. These patterns are structured both by type of trucking movement, and the infrastructure linkages being served. The Australian's use the following categories of haul activities:

- General Freight
- General Freight in a Heavy Vehicle Increased Mass Permit Environment
- Predominately Industrial
- Quarry Products

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[10] Update of the AUSTROADS Pavement Design Guide – Traffic Design Chapter, Final Draft Working Document, September 1998.

- Predominately Farm Produce
- Live-Stock
- Logging Products

To further aid in classifying any given road section to one of the truck loading patterns, the Australian guide also provides a simplified description of what types of links a given roadway provides (e.g., the road connects a major port to other regional cities). "Characterizations" of the trucking patterns used include the following:

- Long-haul, inter-capital
- Long-haul inter-capital at remote sites
- Inter-regional within state/territory or nearby region
- Near town and/or where local freight movement occurs
- Developing area
- Entering and exiting port/loading sites
- Entering and exiting capitol city

This report does not recommend specific roadway grouping criteria. The Australian system has significant merit, can be applied fairly easily, and requires only a modest understanding of the traffic on a given highway. However, the Australian groupings are not directly applicable to U.S. roads because our economy and geographic distribution of cities are considerably different. Instead, States should consider creating similar styles of roadway groups that are characterized by industrial/roadway traits that fit their economic infrastructure. For example, States may want to differentiate among roads affected by specific types of industrial or agricultural activity (such as areas that grow wheat or areas that support steel manufacturing).

It may also be reasonable to start with a less detailed truck weight stratification than used by the Australians. In fact, unless extensive State data suggest the need for a more definitive grouping process, it is recommended that initial groups be based on a much more simplistic approach. This simplistic approach would then be improved (as needed) over time as more weight data are collected and analysis carried out.

Where more detailed information is not available, the initial grouping of roads into truck weight categories should be based on the percentage of through-trucks that exist on a roadway and distinct geographic regions within a State that can be associated with specific types of economic activity. The vehicle classification data provide much information as to what types of trucks are found on which roads. Other factors that can/should be used to differentiate roads into truck weight groups may include the following:

- The presence of agricultural products that create specific loading patterns and are carried in specific types of trucks. For example, wheat growing areas might need to be grouped separately from those that grow cherries because these two products have different densities, different weights on a truck and because their harvest and hauling seasons are different.

- The types of industrial areas, such as resource extraction operations that ship large amounts of material by truck. For example, coal truck traffic roads may be grouped separately from roads that experience few coal trucks.
- The distance over which the trucks are likely to travel. For example, roads where trucks deliver cargo over long distances across multiple States, or roads with truck travel between cities within a region where drivers can make a round trip in one day, or roads with truck travel within a general urbanized area where drivers make multiple trips in a day. Trucks traveling longer distances are more likely to be full, and thus heavier, than trucks operating within half a day of their base, which are likely to be full leaving their depot but are often empty when returning.
- Urban or rural roads, because urban areas often have considerably higher numbers of partially loaded trucks and trucks that travel empty after unloading at urban destinations. Note that some roads functionally classified as "rural" that are located between two large cities (say within 300 km or 180 miles of each other) may experience urban rather than rural trucking patterns because trucks routinely make day-trips between those cities, traveling full in one direction and empty in the other.

A State may also be interested in discriminating between roads because of the industrial activity they serve. For example, roads leading into and out of major seaports may experience far heavier traffic (higher load factors) than other roads in the same area. Much information can be extracted from existing truck weight databases and planning programs to determine logical and statistical differences that can be accounted for in the formation of truck weight groups.

As an example of a weight factor group, Washington State developed five basic truck loading patterns as part of a study to determine total freight tonnage carried by all State highways. These five groups were defined as

Group A - serves major statewide and interstate truck travel. These routes are the major regional haul facilities
Group B - serves primarily intercity freight movements, with minor amounts of regional hauling. These routes also serve as produce transfer routes, serving rail and barge loading facilities.
Group C - serves farm to market routes and regional commerce.
Group D - serves suburban industrial activity.
Group E - serves primarily local goods movement and specialized products.

A starting point for developing truck weight groups is shown in Table 5-3-1. The example begins with the groups identified in the vehicle classification section. The truck loading groups defined should be coordinated with the vehicle classification groups identified in section 4. Differences in the two sets of groups are likely since the groups are defined to meet different purposes (seasonal differences in volume and loading variation). However, they both reflect truck travel characteristics that are directly related. A similar group definition will greatly simplify the understanding and applicability of the patterns. The groups will need further redefinition over time as information is gained.

Table 5-3-1: Example Truck Loading Groups[11]

Rural	Urban
Interstate and arterial major through-truck routes	Interstate and arterial major truck routes
Other roads (e.g., regional agricultural with little through-trucks)	Interstate and other freeways serving primarily local truck traffic
Other non-restricted truck routes	Other non-restricted truck routes
Other rural roads (mining areas)	Other roads (non-truck routes)
Special cases (e.g., recreational, ports)	

The number of groups selected is a key consideration because of the impact on the number of WIM installations needed. The higher the number of groups, the higher the number of WIM sites needed. For large States with an established base of WIM sites, a higher number of groups is appropriate. For small States with limited number of WIM installations, smaller numbers of groups should be tried. Since the character of trucking patterns does not change at State boundaries, pursuing the establishment of regional groups in combination with neighboring States could serve to reduce the individual State level of effort required while still providing the basic information needed.

Given the fact that much needs to be learned, starting the process with a small number of groups seems very reasonable. This can be accomplished by defining the truck loading groups as would be appropriate if WIM resources were not a constraint. The groups can then be combined and aggregated until the number of groups dwindles down to the appropriate number given the currently available WIM sites. In some cases, groups could be formed with smaller number of WIM sites than recommended and then WIM installations added in the future as resources become available. It is very likely that the study of truck patterns will highlight the need for additional WIM installations in the future.

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[11] These are examples. Each State highway agency should select the appropriate number and definition of truck groups based on its economic and trucking characteristics.

TESTING THE QUALITY OF SELECTED TRUCK WEIGHT GROUPS

Just as with the formation of groups used for factoring volume and classification counts, the initial formation of truck weight groups must be reviewed to determine whether the road segments grouped together actually have similar truck weight characteristics. Examining available data from the existing truck weight sites is the first step. A substantial amount of judgment is required since the data is likely to be limited to that currently available from existing WIM sites.

For example, a State highway agency may find that in one group of roads, the class 9 trucks all have similar characteristics, but the class 11 truck characteristics are very different from each other. By changing the road groups, it may be possible to classify roads so that all class 9 and 11 trucks within a road group have similar characteristics. More likely it will not be possible to form homogenous groups for different truck classes, and trade-offs will have to be made. The type of vehicle considered the most important should be given priority.

The trade-offs can be made based on the relative importance of each weight statistic to the data user. In many cases this is simply a function of determining the relative importance of different truck statistics. For example, if 95 percent of all trucks are in class 9, then having truck weight road groups that accurately describe class 9 truck weight characteristics may be more important than having road groups that accurately describe class 11.

DETERMINING THE PRECISION OF ESTIMATES FROM TRUCK WEIGHT GROUPS

An estimate of the "precision" of the mean of a variable that any truck weight road group will provide can be found by computing the standard deviation when computing the mean statistic for that variable (refer to equation 3-3). For example, the precision of the mean gross vehicle weight for a Class 9 truck within a truck weight group can be estimated while computing the mean GVW per Class 9 truck from all of the WIM sites within that group. The standard deviation of the estimate and the number of sites provide an approximate measure of the accuracy of the mean of the group.

An example of this computation is shown below. In the example, assume that a State has determined that all rural Interstate roads have similar truck weight characteristics based on seven WIM sites. Statistics from those WIM sites are shown in Table 5-3-2. On the basis of these data, it can be assumed that all rural Interstate roads in the group have a mean gross vehicle weight of 25,000 kg for class 9 trucks. Each class 9 truck can also be assumed to apply an average of 1.63 ESAL.[12]

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[12] When comparing ESAL values between sites, the ESAL computations assume the same pavement type and structure. All ESAL examples in this document are computed assuming flexible pavements.

The precision of the group mean, referred to as the standard error of the mean, can be estimated with 95 percent confidence as approximately[13] plus or minus 1.96 times the standard deviation divided by the square root of the number of sites.

Table 5-3-2: Example of Statistic Computation for Precision Estimates

Site	Mean Class 9 GVW	Mean Class 9 ESAL
1	23000 kg	1.64
2	26000 kg	1.72
3	29000 kg	1.84
4	21000 kg	1.45
5	21000 kg	1.34
6	25000 kg	1.65
7	28000 kg	1.78
Group Mean	**25000 kg**	**1.63**
Group Standard Deviation	**3200 kg**	**0.18**
Coefficient of Variation	**0.13**	**0.11**

In the above example, note that the coefficient of variation for the two statistics (GVW/vehicle and ESAL/vehicle) are different, even though both variables come from the same set of vehicle weights. Each statistic computed for a truck weight group is likely to have different statistical reliability because of the different levels of variation found in axle weights, GVW, and the various other statistics computed from weight records.

To complicate matters further, each statistic has a different level of precision for each different vehicle class. Thus, the precision of the ESAL/vehicle value for Class 9 trucks will be different than that of the ESAL/vehicle value for Class 11 trucks.

In sampling applications, increasing the number of samples increases the precision of the mean estimate being computed. Thus, increasing the number of WIM sample locations within a given truck weight group will improve the precision of the mean value computed within a weight group. This is an important result when calculating system-level summary variables, such as annual ton-kilometers.

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[13] This is a relatively crude approximation. The value 1.96 should be used only for sample sizes of 30 sites or more. A more statistically correct estimate would use the Student's *t* distribution, which for six degrees of freedom (seven weigh sites) is roughly 2.45.

Increasing the number of WIM sites will improve the system-wide averages for each group. However, increasing the sample size only marginally improves the precision of estimates used as default values for loading rates on specific roadway sections. When a mean value of a distribution is assumed to be the "best" estimate of a value at a specific point, the variability of that estimate is measured by the standard deviation of the distribution. The error bounds can only be reduced by creating truck weight groups that have tighter distributions, or by taking site-specific WIM counts. Taking site-specific measurements ensures that the data apply directly to the site in question. This is why site-specific vehicle classification counts are requested for most pavement design projects since they provide the only cost-effective method for obtaining the accuracy needed at a specific location. Unfortunately, because portable WIM data is difficult to collect accurately, it is very difficult to obtain site-specific values for truck weights.

DETERMINING THE NUMBER OF WIM SITES PER GROUP

The precision calculations can be used to determine how many WIM systems should be included within each truck weight group. The State highway agency should determine what statistic it wants to use as the key to the analysis, select how precisely it wishes to estimate that statistic, and compute the number of WIM locations needed to obtain the desired degree of confidence.

The first step involves several decisions. The State highway agency should determine whether the truck weight groups will be developed to produce mean statistics within each group with a given level of precision (e.g., the mean ESAL/class 9 truck for rural interstates is 1.56 ± .15 with 95 percent confidence).

This decision primarily affects the grouping process. If the intention is to develop precise mean values for the group as a whole, the key tends to be the number of data collection locations included in each group. If the intention is to develop good default values for individual sites, the key to the grouping process is to have more and very homogenous groups (groups in which truck weights are very similar for all sites within the group, making standard deviations very small). States that emphasize predicting mean values for groups will have fewer groups but larger numbers of data collection sites within each group, whereas States that emphasize site-specific estimates will have more truck weight groups but fewer sites within each group.

The second decision that affects the grouping process is the selection of the statistic to be the basis for the precision estimates. Because the precision of each statistic will vary, the State should select a single statistic to use as its benchmark. Normally, this means selecting a specific vehicle classification and a specific weight variable. The recommended statistics for use in selecting sample sizes are either the mean ESAL[14]/class 9 trucks or better the mean GVW for class 9 trucks. Class 9 trucks are recommended

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[14] ESAL varies with pavement characteristics, thus the ESAL formulation used for this purpose should be a generic formulation using default pavement characteristics.

because they are the most common throughout the country, and they tend to carry a high percentage of the loadings on most major roads.

The two most likely weight variables that can be used are the average gross weight (by class) and the average ESAL per vehicle (by class). Both measures are acceptable statistics for this purpose. GVW is easily understood by technical and non-technical people and does not change. It is reasonably well correlated to pavement damage and is commonly used as a measure of the size of commodity movements. ESAL are a much better measure of pavement damage than GVW. However, ESAL are not easily converted to measures of commodity flow, and current pavement research is not emphasizing their use in the design process.

The next decision is how precise to estimate the target statistic. Precision levels are normally stated in terms of percentage of error within a given level of confidence (e.g., the GVW/vehicle estimate is within ±15 percent with 95 percent confidence). Decreasing the size of the acceptable error or requiring higher levels of confidence both increase the number of samples required. Conversely, accepting lower levels of precision and/or confidence allows smaller sample sizes and lower data collection costs.

Selecting the acceptable level of error is an iterative process. First, the desired target precision is selected. Next, the variability of data in the truck weight groups is examined. This examination may result in either the need to collect more data or to adjust the assignment of roads within truck weight groups. If the State can not meet the initially selected precision levels (either because it can not create sufficiently homogenous groups or because it can not collect data at enough sites), the desired precision levels have to be relaxed to reflect the quality of the estimates that can be obtained. The last step is to compute the number of weighing locations needed to meet the desired precision level. The number of WIM sites within a group is estimated as:

$$n = (t_{(a/2)})^2 \, (C^2) / (D^2) \qquad (5\text{-}1)$$

where: n = the number of samples taken (in this case, the number of sites in the group),
t = the Student's t distribution for the selected level of confidence (α) and appropriate degrees of freedom (one less than the number of samples, n),
α = the selected level of confidence,
C = the coefficient of variation (COV) for the sample as a proportion,
D = the desired accuracy as a proportion of the estimate.

This equation can be manipulated to solve for any variable. COV (the ratio of the standard deviation to the mean) is usually computed from available truck weight data. D is selected as part of the previous step (see above). The number of sites, n, can be computed after selecting the value for alpha (α) and looking up the appropriate term for $t_{\alpha/2}$ with n-1 degrees of freedom. Similarly, if n is given, it is possible to solve directly for the value of $t_{\alpha/2}$ and thus α. The example given below illustrates the basic process of comparing sample size with the precision levels each sample size achieves.

Table 5-3-3 shows the same truck weight statistics used in Table 5-3-2, except two additional weigh sites have been added. These two sites experience heavy vehicle weights and, consequently, have increased the mean values for GVW/vehicle and ESAL/vehicle for the group.

Table 5-3-3:
Statistics Used For Sample Size Computation

Site	Mean Class 9 GVW	Mean Class 9 ESAL
1	23000 kg	1.64
2	26000 kg	1.72
3	29000 kg	1.84
4	21000 kg	1.45
5	21000 kg	1.34
6	25000 kg	1.65
7	28000 kg	1.78
8	35000 kg	2.01
9	34000 kg	1.95
Group Mean	**27000 kg**	**1.71**
Standard Deviation	**5100 kg**	**0.22**
Coefficient of Variation	**0.19**	**0.13**
Standard Error of Mean	**1700**	**0.07**

Using this table, the following facts can be determined:

- The average GVW of Class 9 trucks for this group is 27,000 kg.
- This estimate is ± 3,900 kg with 95 percent confidence (1700 multiplied[15] by 2.31).

Increasing the number of WIM stations included in the sample to 15 sites (and assuming that those stations do not change the standard deviation of the sample) would change the standard error of the mean to 1300 kg. (5100 divided by the square root of 15). This would improve the confidence in the mean value of the GVW/vehicle estimate for the truck weight group to 27,000 kg ± 2,800 kg with 95 percent confidence.

The improvement comes from two sources. The first is the increased precision in the mean value provided by the increase in the number of samples. The second is the decrease in the value of $t_{\alpha/2}$ used to compute the multiplier in the confidence interval by having a greater sample size upon which to perform the statistical computation.

Table 5-3-4 shows the effect of different sample sizes and confidence intervals estimates of the group mean. Note that increases beyond about six sites in the group sample size has only a marginal effect on the precision of the group mean.

Table 5-3-4
Example Effects of Sample Size on the Precision of GVW Estimates

		Precision of the Mean Value Itself (Standard Error)	
Number of Weigh Sites[16]	**Mean Value**	**80% Level of Confidence[17]**	**95% Level of Confidence[18]**
3	27,000 kg	±5600 kg	±12800 kg
5	27,000 kg	±3500 kg	±6400 kg
9	27,000 kg	±2400 kg	±3900 kg
15	27,000 kg	±1800 kg	±2800 kg
30	27,000 kg	±1200 kg	±1900 kg
60	27,000 kg	±850 kg	±1300 kg
90	27,000 kg	±700 kg	±1100 kg

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[15] This table uses the Student's *t* distribution for 8 degrees of freedom because of the small number of sample sites within the truck weight road group.

[16] This table uses the Student's *t* distribution because of the small number of sample sites in the group.

[17] The value of $t_{\alpha/2}$ for each sample size using the Student's *t* distribution for a two-tailed confidence interval of $\alpha = 80\%$ ($t_{.1}$) is as follows: n = 3, $t_{\alpha/2} = 1.886$, n = 5, $t_{\alpha/2} = 1.533$, n = 9, $t_{\alpha/2} = 1.397$, n = 15, $t_{\alpha/2} = 1.345$, n = 30, $t_{\alpha/2} = 1.282$.

[18] The value of $t_{\alpha/2}$ using the Student's *t* distribution for a two-tailed confidence interval of $\alpha = 95\%$ ($t_{.025}$) is: n = 3, $t_{\alpha/2} = 4.303$, n = 5, $t_{\alpha/2} = 2.776$, n = 9, $t_{\alpha/2} = 2.306$, n = 15, $t_{\alpha/2} = 2.145$, n = 30, $t_{\alpha/2} = 1.960$.

If tighter confidence intervals are deemed necessary, it is always possible to modify the truck weight road groups. Looking at Table 5-3-3, it is apparent that sites 8 and 9 have much higher loads than the remaining seven sites. If these sites are removed from the truck weight group, the computed standard deviation of the GVW per vehicle computed for sites in the group drops from 5100 kg to 3200 kg. This has a dramatic impact on the precision of the estimates computed for the group.

Table 5-3-5 shows the precision level of the truck weight group after removal of these sites. However, note that in order to remove these two sites from the truck weight road group, they must represent some identifiable set of roads. For example, they could be located on the State's only north/south rural Interstate, while the remaining seven sites are on east/eest interstates. Thus the "rural Interstate" truck weight grouping could be divided into two separate truck weight groupings, "rural east/west Interstate" and "rural north/south Interstate."

Table 5-3-5:
Example Effects of Sample Size and Confidence Interval on Precision of GVW Estimates for the Revised Truck Weight Group

		Precision of the Mean Value Itself (Standard Error)	
Number of Weigh Sites[19]	**Mean Value**	**80% Level of Confidence**[20]	**95% Level of Confidence**[21]
3	25,000 kg	±3,500 kg	±8000 kg
5	25,000 kg	±2,200 kg	±4000 kg
9	25,000 kg	±1,500 kg	±2500 kg
15	25,000 kg	±1,100 kg	±1800 kg
30	25,000 kg	±800 kg	±1200 kg
60	25,000 kg	±500 kg	±800 kg
90	25,000 kg	±400 kg	±700 kg

The key to correctly creating these truck weight groups is that sites should only be removed from a truck weight group when they can be readily identified with a specific set of roads that experience those loads. All of those roads need to be moved to the new truck weight group.

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[19] This tables uses the Student's *t* distribution because of the small number of sample sites within the truck weight road group.

[20] The value of $t_{\alpha/2}$ for each sample size using the Student's *t* distribution for a two-tailed confidence interval of $\alpha = 80\%$ ($t_{.1}$) is as follows: n = 3, $t_{\alpha/2} = 1.886$, n = 5, $t_{\alpha/2} = 1.533$, n = 9, $t_{\alpha/2} = 1.397$, n = 15, $t_{\alpha/2} = 1.345$, n = 30, $t_{\alpha/2} = 1.282$

[21] The value of $t_{\alpha/2}$ for each sample size using the Student's *t* distribution for a two-tailed confidence interval of $\alpha = 95\%$ ($t_{.025}$) is as follows: n = 3, $t_{\alpha/2} = 4.303$, n = 5, $t_{\alpha/2} = 2.776$, n = 9, $t_{\alpha/2} = 2.306$, n = 15, $t_{\alpha/2} = 2.145$, n = 30, $t_{\alpha/2} = 1.960$

From the above examples, it is possible to see that changing the number of sites included in a truck weight road group has three effects:

- It changes the computed sample standard deviation for the group (which serves as the estimate of the standard deviation for the entire road group).
- It changes the denominator used to computed the standard error, the statistic used to determine "how well" the mean value computed from that group of roads estimates the mean value for the population being sampled.
- It changes the value of t used to compute the size of the confidence interval applied to estimates produced for that group.

In general, the more sites included in a group, the better the estimates produced by that group, although the benefit of adding sites decreases as the number of sites within a group increases. The effect of using the Student's t distribution to compute confidence intervals means that a significant decrease in the value of t can be obtained by simply adding locations up to a sample size of six. A sample size of six sites has a 10 percent smaller confidence interval at the 95 percent level of confidence than a sample size of five sites, all other things being equal. Beyond six sites, the benefits gained by adding sites begin to decrease quickly. More than six sites in a group may be appropriate, particularly if the State is unsure of its truck weight patterns.

Based on this analysis, six sites per group are recommended. The exception to the six-site rule is for truck weight road groups that contain very few roads. These will tend to be specialty roads (e.g., roads leading into and out of gravel pits) that have unusual loading conditions but that are not applicable to many other roads in the State.

If improvements in precision are needed beyond what affordable increases in sample size will achieve, the primary option is to change the make-up of the truck weight groups, i.e., create new subsets of roads that will serve as the truck weight groups. If this change produces a significant decrease in the standard deviation that offsets the increase in $t_{\alpha/2}$ caused by the lower sample size, then the State will benefit from an improvement in the precision of its weight estimates along with a smaller data collection sample size.

DETERMINING THE NUMBER OF DAYS THAT SHOULD BE COUNTED AT A GIVEN WIM SITE

All of the statistics discussed above start with the critical assumption that each WIM site in a truck weight group produces an accurate estimate of vehicle weights for that location, so that the mean value calculated for the group is accurate. The "accuracy" assumed for the data provided by each WIM scale is not just that the scale weighs the passing trucks correctly but that those weight estimates are representative of weights at that site throughout the year.

For WIM sites where less than a year of data are collected, the assumption is that the time period measured gives an accurate measurement of weights for the entire year.

If the weight data collection period is only 24 or 48-hours long, it assumes that there is no day-of-week difference in the loading condition of trucks passing the site (that is, that trucks traveling on weekends carry the same distribution of payloads as trucks traveling on weekdays), as well as the hypothesis that there are no seasonal differences in truck loading patterns.

At some WIM sites in some States, extensive data collection has shown that these assumptions are quite reasonable. (Butler 1993) At other sites and in other States these assumptions are incorrect (Hallenbeck and Kim 1993). Where truck weights are not stable across days of the week or seasons, the weight monitoring effort has to be extended to account for these differences. For example, the count duration may be extended from two days to seven days to incorporate day-of-week differences. Seasonal differences can be detected and incorporated in the annual estimates by collecting data at each site more than once per year, such as once per quarter.

It is also possible to factor data collected during short duration WIM sessions on the basis of findings from permanent, continuous WIM sites, much like the seasonal adjustments recommended for volume and vehicle classification counts. For example, if one data collection site is operated continuously, the information learned about seasonal patterns from that one site can be applied to other weight data collected within that truck weight group. This step requires the assumption that all sites within the truck weight group experience the same seasonal variation. This process is doable for summary statistics, such as GVW, if sufficient data is available, but it becomes more mathematically complex to seasonally adjust axle weight distribution tables. As seasonality analysis for total volume and vehicle classification data have shown, a large database is needed to identify and quantify temporal variation patterns.

If two or more continuous sites are present in a truck weight group, the seasonal adjustments for both sites can be averaged before being applied to the data collected at the short duration sites. However, if the seasonal adjustments for those sites are significantly different, it is likely that the truck weight road group consists of more than one truck weight pattern. In these cases, splitting the truck weight road group into two or more new groups could be considered.

To date, little work has been published on the seasonal differences in axle weight distributions found in the nation’s truck fleet, let alone on the weight characteristics of particular trucking movements found in individual States. However, these seasonal and day-of-week weight changes can have dramatic effects on the selection of the pavement designs that rely on them. The collection and analysis of continuous data collection is the easiest method to begin to understand the temporal variation.

The key for the weight data collection program is to measure and account for both day-of-week and seasonal differences in vehicle weights within each truck weight group. The only way to do this adequately is to have each WIM station providing continuous WIM data, unless analysis has shown that temporal variability is not present. For States with large numbers of continuous WIM stations, there may exist sufficient stations to populate the groups. For smaller States facing resource limitations, the installation of many continuous WIM sites is not an option. **The general recommendation is that each truck weight group should have at least one[22] permanent WIM device collecting continuous data.** This site should be maintained in a calibrated condition, and the data obtained from it should be used to determine whether significant differences exist between vehicle weights (by vehicle class) for different days of the week and different seasons of the year.

The remaining sites within a group can have either short duration counts or additional continuous counts. As with vehicle classification and volume counting, a minimum of 48 hours is recommended. Weight data have been shown to vary by time of day, day of week, weekdays and weekends. As with vehicle classification and volume counts, it is acceptable to use different data collection periods as needs and constraints allow. Because of differences in weekday and weekend vehicle weights, the data collection program should be designed to cover those differences and account for them when statistics are produced. Counts taken for a period of one week eliminate the need for day-of-week adjustment, allow the equipment and traffic conditions to stabilize, provide data verification capabilities, and identify weekday/weekend differences in average weights. **A monitoring period of seven continuous days is recommended for all WIM sites that do not provide continuous data.**

Short duration WIM measurements should be collected with permanently mounted sensors because permanent[23] sensors can be mounted flush to the road surface, providing a more accurate weight measurement. Use of permanently mounted sensors also allows data collection periods to be lengthened at relatively little additional cost.

Portable sensors although not completely ruled out, introduce accuracy issues that may compromise the validity of the data. Organizations using portable WIM sensors, must carefully ensure that the data collected is sufficiently accurate to meet user needs.

WIM SITE INSTALLATION BY LANE AND DIRECTION OF TRAVEL

There are many issues to consider when installing WIM sites. Current installations range from full coverage for all lanes and directions of travel to the LTPP standard of a single lane in one direction. Some of the issues that should be reviewed when selecting the number of lanes of WIM to install include: available funding, the cost of installation, program objectives to be met, the design of current installations in the State, the trade-offs between obtaining more complete coverage at each site versus less coverage at each site but getting more sites covered, prior experience with WIM equipment, the type of equipment being installed, equipment installation options, specific site characteristics, truck volumes present at the roadway being monitored, use of the scale for or influence

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[22] Preferably more than one

[23] Permanent sensors include sites where the sensors are permanently installed but only used periodically; sites where the sensors are installed permanently but the electronics removed from the roadside when not in use, and sites where semi-permanent sensor frames are permanently installed but the actual sensors replaced with a “dummy” scale when not in use.

from nearby enforcement activities, the ability to perform maintenance on equipment at that site, and the ability to perform calibration of the scales.

Analyses of available WIM data have shown that significant differences in loads by direction of travel often occur. The collection of WIM data in at least one lane in each direction of travel at each site allows a clear assessment of directional differences in weights and loadings.

WIM differences by travel lane are generally less significant and difficult to generalize, although previous analyses have shown that the outside lanes tend to carry heavier vehicles. More analysis of current installations is needed before a determination of the cost-effectiveness of covering several lanes at some of the WIM sites or at all sites can be made.

A WIM site covering all lanes and direction of travel provides the most accurate data collection coverage. **At least one continuous WIM station in each weight group should provide WIM coverage for all or a minimum of two travel lanes in each direction.** This will allow future pavement design analysis to cover most possibilities. For multi-lane facilities, covering two lanes in each direction provides the most cost-effective alternative. If all lanes are not monitored by WIM scales, each WIM site should have, at a minimum, a short classification count by direction and travel lane in order to measure truck travel in the lanes not being monitored with WIM. Continuous classification in those lanes may even be preferable.

For new WIM site installations, at least one lane in each direction of travel is recommended. Additional lane/direction installations at current sites, such as LTPP sites, depend on many other considerations and should be made based on careful analysis including the examination of vehicle classification data at each site to determine cost-effectiveness. The VTRIS package allows these types of analyses by direction and lane for both vehicle classification and WIM data.

SITE SELECTION

Most WIM systems also provide counts of vehicle volume by classification and total volume. Consequently, most WIM data collection locations can also provide volume and vehicle classification count data that can take the place of counts required to meet the needs discussed in Sections 3 and 4. Unfortunately, for a variety of technical reasons, WIM data cannot be collected on all roadway sections. Physical constraints on many road sections prevent the collection of accurate weight data. In addition, most States do not have the resources to collect weight data at more than a modest number of locations. Finally, most States already have a significant investment in WIM sites, either as part of their existing truck weight monitoring program or as part of the Long Term Pavement Performance project (LTPP).

Each State should begin to apply the procedures discussed with its existing WIM data collection sites. As a result of the study the addition of sites may become necessary. As existing sites require attention because of failure of the pavement surrounding the WIM sensors or failure of the WIM equipment itself, the need for that WIM station or site should be reevaluated. Sites that are still necessary should be reinstalled. If that site is no longer needed or if other higher priority locations exist, the WIM equipment should be moved to another site.

New WIM Site Selection Criteria

The selection of new WIM sites should be based on the needs of the data collection program and the site characteristics of the roadway sections that meet those needs. The needs of the data collection program include, but are not limited to, the following:

- the need to obtain more vehicle weight data on roads within a given truck weight roadway group
- the need to collect data in geographic regions that are poorly represented in the existing WIM data collection effort
- the need to collect data on specific facilities of high importance (e.g., Interstate highways or other National Highway System routes)
- the need to collect data for specific research projects or other special needs of the State
- the need to collect weight information on specific commodity movements of importance to the State.

However, just because a roadway section meets some or all of the above characteristics does not make it a good WIM site. With current technologies, WIM systems only accurately weigh trucks when the equipment is located in a physical environment that meets specific criteria. Thus, States should place WIM equipment only in pavements that allow for accurate vehicle weighing. While individual equipment vendors may require slightly different pavement characteristics to achieve specified results, in general all WIM sites should have the following[24]:

- smooth, flat (in all planes) pavement
- pavement that is in good condition and that has enough strength to adequately support axle weight sensors
- vehicles traveling at constant speeds over the sensors
- access to power and communications (although these can be supplied from solar panels, and through various forms of wireless communications).

In addition, there should be sufficient truck traffic at the site to justify the installation of a WIM data collection site. The actual sites can be selected randomly or

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[24] An excellent reference for learning about WIM site requirements is ASTM Standard E-1318, Highway Weigh-in-Motion (WIM) Systems With User Requirements and Test Method.

judgmentally (using the previous list of criteria) from sites that meet all of the site requirements.

Smooth, strong pavement is needed to reduce the effect of vehicle dynamics. Although placing multiple sensors in series (Cebon 1999) can significantly reduce the error that vehicle dynamics produce in individual weight measurements, placement of WIM sensors on smooth, flat pavements that reduce vehicle dynamics significantly improves WIM accuracy, regardless of the equipment used.

Pavement strength can affect sensor accuracy. Weight estimates produced by strip sensors (such as piezo-cables) that are embedded directly into pavements are often affected by changes in pavement strength caused by changes in environmental conditions (e.g., spring thaw periods). A decrease in pavement strength invariably decreases system accuracy. Therefore, WIM sensors should only be placed in strong pavements that are not subject to significant changes in structural response during different seasons. Similarly, WIM sensors begin to become inaccurate as soon as pavements start to rut. In most cases, installations in pavements likely to rut are a poor investment of limited data collection funds.

The requirement for constant vehicle speed (which limits the use of WIM equipment in many urban and suburban areas where routine congestion occurs) is primarily due to the fact that braking and acceleration causes shifts in load from one set of axles to another. This shifting causes “inaccurate” comparison of WIM estimates against static loads.

The availability of power and communications allows extended operation of the WIM equipment. While this is not as crucial for sites intended for short duration WIM counts, the availability of power allows the collection of longer duration WIM measurements. This is particularly helpful for research studies intended to confirm or refute the ability of short duration counts to meet the accuracy needs of the data collection plan. It also allows the WIM site to be used as a continuous classifier or ATR even while weight data are not being collected.

Integrating the WIM Sites with the Remaining Count Program

Even with all of the constraints described above, most of the existing sites can be used to meet a given weight data collection need. When exploring alternative sites, the “deciding vote” can often be cast by examining how well these alternative sites fit within the existing State traffic monitoring program.

Sites selected for WIM data collection should be located within HPMS volume sample section, if at all possible. If two alternative sites exist to meet a specific need and one is already an HPMS sample site, it should be given priority over the alternative (all other factors being equal). If neither site falls on an HPMS sample section, the selected WIM site should become an HPMS sample section the next time the HPMS sample is revised. The HPMS volume and classification data should be collected at the same time as the WIM data, using the same equipment where practical. This reduces the staffing and resources needed to collect these HPMS data and directly ties the different data items.

TOTAL SIZE OF THE WEIGHT DATA COLLECTION PROGRAM

The recommendations discussed above lead to the conclusion that the size of the weight data collection program will be a function of the variability of the truck weights and the accuracy and precision desired to monitor and report on those weights.

For a small State that has only two basic truck weight road groups, the basic recommendation would be for a minimum of about 12 weighing locations and two to four continuously operating weigh-in-motion sites. The number of locations could be further reduced if the State worked with surrounding States to collect “joint” vehicle weight data. A larger state with diverse trucking characteristics might have as many as 10 or 15 distinct truck weight road groups, and thus 60 to 90 WIM sites, with a corresponding increase in the number of continuously operating WIM locations. Most States will be between the two extremes presented, and the number of weighing locations should fall somewhere between 12 and 90 locations.

CHAPTER 4
TRUCK WEIGHT DATA SUMMARIZATION

WIM data collection provides a number of important summary statistics. These statistics are computed both from individual vehicle weight records and from the axle weight summary distributions that are developed from the scales. The following statistical summaries should be routinely computed and used by States:

- the average number of specific axle groups (i.e., the number of single, tandem, and triple axles) per vehicle for each vehicle (truck) class
- the average number of axles (total) per vehicle for vehicle classes that do not have constant numbers of axles
- the average weight distribution for each type of axle for each vehicle class used by the State highway agency for pavement design.

The AASHTO 2002 Pavement Design Guide (being developed under NCHRP Project 1-37, and currently in draft form) uses inputs of axle load distributions and volumes by vehicle classification to determine the traffic load inputs to the design process. One important input variable that the State highway agency needs to compute and use in that process is the average number of axles (by type of axle) found in each vehicle type. For example, if the state uses the 13 FHWA vehicle classes, it needs to track how many of the 7+axles in Class 13 trucks are single axles and how many are tandem axles. These factors are easily computed as part of the load distribution process. All valid axle weights are counted (by type) for a given vehicle class, and that total is divided by the total number of vehicles weighed in that class. This yields the average number of axles within each axle type for that vehicle class.

The second category of statistical summaries allows the State highway agency to produce a more accurate axle correction factor from vehicle classification data. Several of the FHWA 13 vehicle classes do not contain specifically defined numbers of axles on each vehicle. Class 7 allows four or more axles per single unit truck. Class 8 allows four or fewer axles. Class 10 allows six or more, and class 13 allows seven or more axles per truck. Individual vehicle weight records allow the computation of more precise measures of the mean number of axles per vehicle for each of these types of truck classes.

The NCHRP Project 1-37 draft pavement design guide is designed to allow engineers to account for variation in both traffic load and material properties as environmental conditions change. This allows State highway agencies to account for the effects of spring load restrictions and seasonal changes in commodity flows as part of the pavement design process. However, to take advantage of these new design capabilities, the State highway agency must have the data that describe these load changes.

These data come from collecting and summarizing data from continuously operating WIM sites at different times of the year. Ideally, the State highway agency should create axle weight distribution tables by vehicle class for each period when axle weight distributions change. These axle load distribution tables (by vehicle class) can then be read directly into the new Pavement Design Guide software, where they supply the load information needed to complement vehicle classification volume data collected on different roads.

When analyzed, WIM data will also determine whether changes in axle load distributions occur by season of the year. These changes can (and should) then be used in the pavement design process to improve the reliability of the pavement designs. Seasonal WIM data for each truck road group should be analyzed, since each road group may exhibit different seasonal patterns. This process can result in a considerable number of axle load distribution tables (one per vehicle class, per season, per road group). While this may seem like an excessive amount of data summarization, it is necessary to understand the nature of and account for truck loading patterns in the design process. In addition, by automating the collection and reporting of WIM data, the resources required to perform these tasks can be minimized.

State highway agencies also need to compute axle distribution tables for each vehicle classification scheme the agency intends to use in the pavement design procedures. At a minimum, axle load distribution tables for each of the ten FHWA heavy vehicle categories (Classes 4 – 13) should be used. In order to use a more aggregated vehicle classification scheme (such as the four category scheme "cars, single unit trucks, combination trucks, and multi-trailer trucks"), axle load distribution tables and axle frequency tables for these vehicle classes must be developed. These tables identify how many axles of each type (singles, tandems, tridems, quads) are present on average for each truck class, and what the axle load frequency distribution is for each of those axle types.

In addition to these primary analyses, individual vehicle records from WIM data collection allow a variety of specialized analyses. For example, they can be used to monitor changes in axle spacing configurations that result from changes in vehicle size and weight regulations. Similarly, changes in the relative proportion of specific vehicle configurations that fall within the more generalized vehicle classifications can be examined. For example, what specific vehicle types are classified within the FHWA Class 13 category? This latter analysis is particularly important for summary vehicle classification categories (e.g., "multi-trailer trucks") when limited other data exist with which to monitor the changing composition of vehicles within aggregated classes.

Finally, individual vehicle records serve as an excellent data resource that can be manipulated for a variety of research and planning purposes. For example, with WIM from most types of scales, changes in overall vehicle lengths over time can be examined. This has implications for roadway geometric design and the need for new roadway design standards. Another example is that with some scales, individual vehicle records can be used to monitor the variation in loads between axles in a tandem. Scale data can also be used for a variety of economic studies (fraction of unloaded trucks) and as an independent measure of the effectiveness of applied enforcement strategies. Note that because of the effects of vehicle dynamics, WIM data cannot be used directly to measure the number of over-weight and/or illegally loaded trucks. However, under controlled conditions WIM data can be used to determine changes in the presence of overloaded vehicles. Controlled conditions include the fact that the scale is well calibrated, changes in pavement roughness do not occur during the study, and scale by-pass efforts can either be measured or controlled for. State highway agencies are thus encouraged to collect and store these data in a manner that allows them to be retrieved and used as easily as possible.

APPENDIX 5-A
WIM EQUIPMENT ISSUES

This appendix discusses two key issues concerning the use of WIM equipment and data. Both subjects deal with ensuring that the data being collected represent, to the highest degree possible, the vehicle weights being experienced by the roadways. These two subjects are 1) the calibration of WIM equipment and 2) the monitoring of the data reported by WIM systems as a means of detecting drift in the calibration of weight sensors.

WIM SENSOR CALIBRATION

The FHWA strongly encourages State highway agencies to allocate resources to the calibration of their WIM systems. Calibration of WIM sensors is especially important, because even small errors in vehicle weight measurements caused by poorly calibrated sensors result in significant errors in estimated pavement damage when those axle weights are used in pavement design analyses. Traditional pavement damage calculations use a formula developed as part of the original AASHO Road Test. This formula is a fourth order polynomial. Its is often simplified by stating that damage from a single axle can be computed from the following rule:

$$\text{Damage} = (\text{axle weight in pounds} / 18{,}000 \text{ pounds})^4$$

Figure 5-A-1 shows the general effects of scale calibration error that result from the use of this formula. In this graphic, the X-axis is the percent error in the axle weight, while the Y-axis is the corresponding error in ESAL values. Although the effect of scale drift varies somewhat from site to site, the basic trend is that every 1 percent error that a scale is under-calibrated results in slightly more than a 3 percent under-estimation of the true ESAL value.[25] ESAL computed for heavy axles are affected more by calibration drift than ESALs computed for light axles. So the ESAL error for a site with mostly heavy axles is greater than the error for a site with mostly light axles. Every 1 percent over-estimation in axle weight represents a 4.5 percent over-estimation of ESAL values. Thus, even an over-calibration of merely 10 percent would result in a 45 percent error in estimated damage.

Unfortunately, at this time, an inexpensive WIM calibration system has not been developed. The NCHRP has twice attempted to create improved, lower cost, WIM calibration techniques (Cunagin 1993; Papagiannakis 1995). In both cases, the practices developed have failed to be widely adopted, primarily because of their cost and complexity. Unfortunately, this does not remove the need for WIM system calibration. In addition to the techniques developed by NCHRP, a number of other techniques are

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[25] WIM Scale Calibration: A Vital Activity for LTPP Sites, FHWA-RD-98-104, July 1998.

used to ensure that the equipment is initially calibrated and then remains in calibration. These techniques tend to be less robust than the NCHRP procedures, but they provide a process that has a more acceptable balance between the accuracy of the WIM calibration effort and the resources needed to perform it.

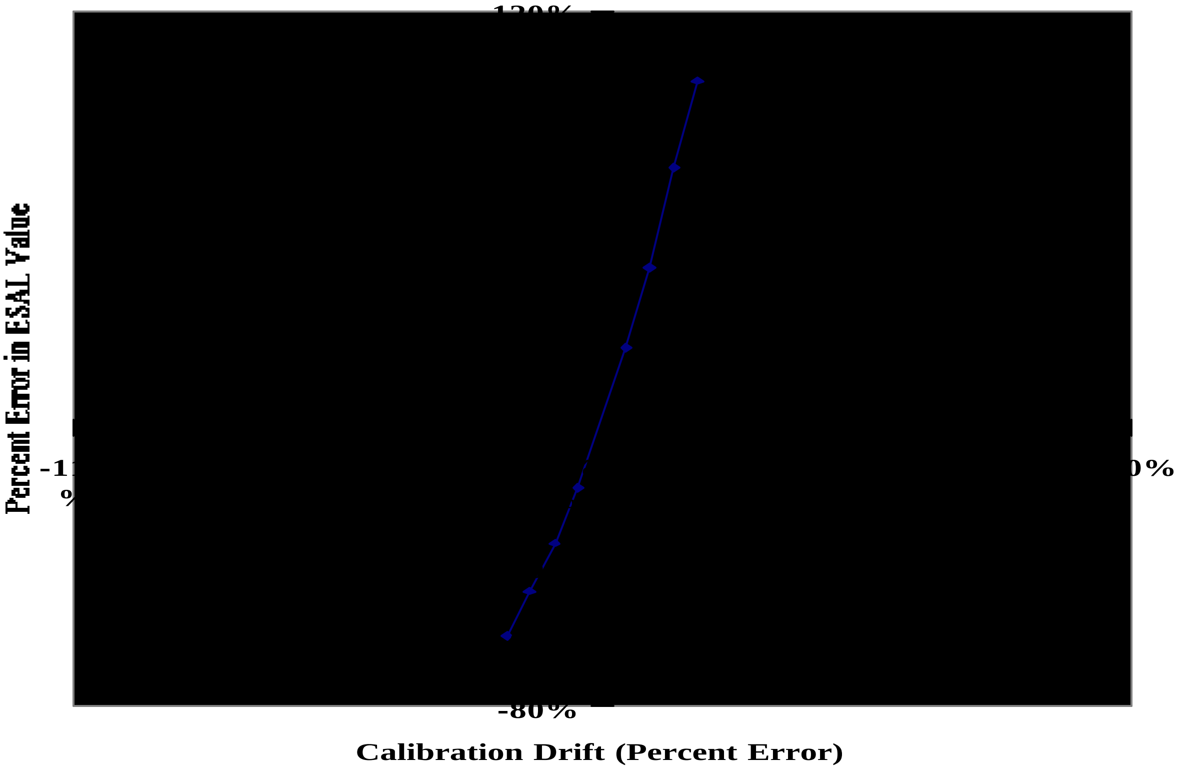

Figure 5-A-1: Effect of Weigh-in-Motion Scale Calibration Drift on the Accuracy of ESAL Calculations

The most common of these approaches is to make multiple passes over the WIM scale with one or more test trucks of known (measured) weight. The scale's performance is then compared with the known weights, and adjustments are made to the scale's calibration as necessary (McCall and Vodrazka 1997; Long-Term Pavement Performance Project 1998). Additional passes are then made to confirm that the performance of the scale has improved to the level of accuracy desired.

Several variations to this basic approach exist. These variations usually involve the use of additional vehicles, the performance of test runs at different speeds, or the performance of test runs under different environmental conditions (usually different temperatures). All of these variations have merit. The benefits gained from a specific variant depends somewhat on the specific scale technology being used, the types of environmental conditions that occur at the site while the scale is operating, the type of pavement in which the scale sensors are installed, and the structural response of that pavement.

Test trucks have the distinct advantage of being relatively easy to use and only modestly expensive. In most cases, the most common variant of this technique increases the number of passes performed, and increases the quality of the scale calibration operating under commonly experienced conditions. This improves scale calibration, but also slightly increases calibration costs.

The drawback to the use of test trucks is the fact that use of a single vehicle (or even two vehicles) to calibrate a scale can create bias in the calibration, and thus additional steps are needed to ensure the accuracy of the calibration effort. One common method for testing for scale bias is to examine summary outputs from the scale and compare those outputs against known weights (e.g., legal load limits) for trucks commonly found in the road.

Bias in the calibration when a single test truck is used comes from the fact that each truck has its own unique dynamic interaction with a given road. Calibration of a scale to a specific vehicle's dynamic performance (motion) is acceptable when the motion of that vehicle is representative of the traffic stream. Unfortunately, a single test truck is hardly representative of the traffic stream and the calibration effort actually forces the scale to weigh most vehicles inaccurately.

Why this occurs can be explained with a picture. Figure 5-A-2 shows how the force of a truck (or any given truck axle) varies as it moves down the road as a result of the interaction between the vehicle's suspension system(s) and the road's roughness. The vehicle's dynamic motion causes the weight felt by the road to change from location to location. The goal of the WIM calibration effort is to measure this varying force at a specific location (Point A in Figure 5-A-2) and relate it to the truck's actual static weight. To do it, the scale sensor needs to be able to measure the weight actually being applied at Point A, and correct for the bias associated with the fact that at Point A, the truck is actually producing more force than it does when the truck is at rest (because it is in the process of landing as it bounces down the road).

By using a test truck, these two tasks can be performed in one pass. The truck is driven over the scale several times, and the weights estimated by the scale are compared to actual static values. The scale's sensitivity is then adjusted until the weight estimated by the scale equals the known static weight of the truck/axle.

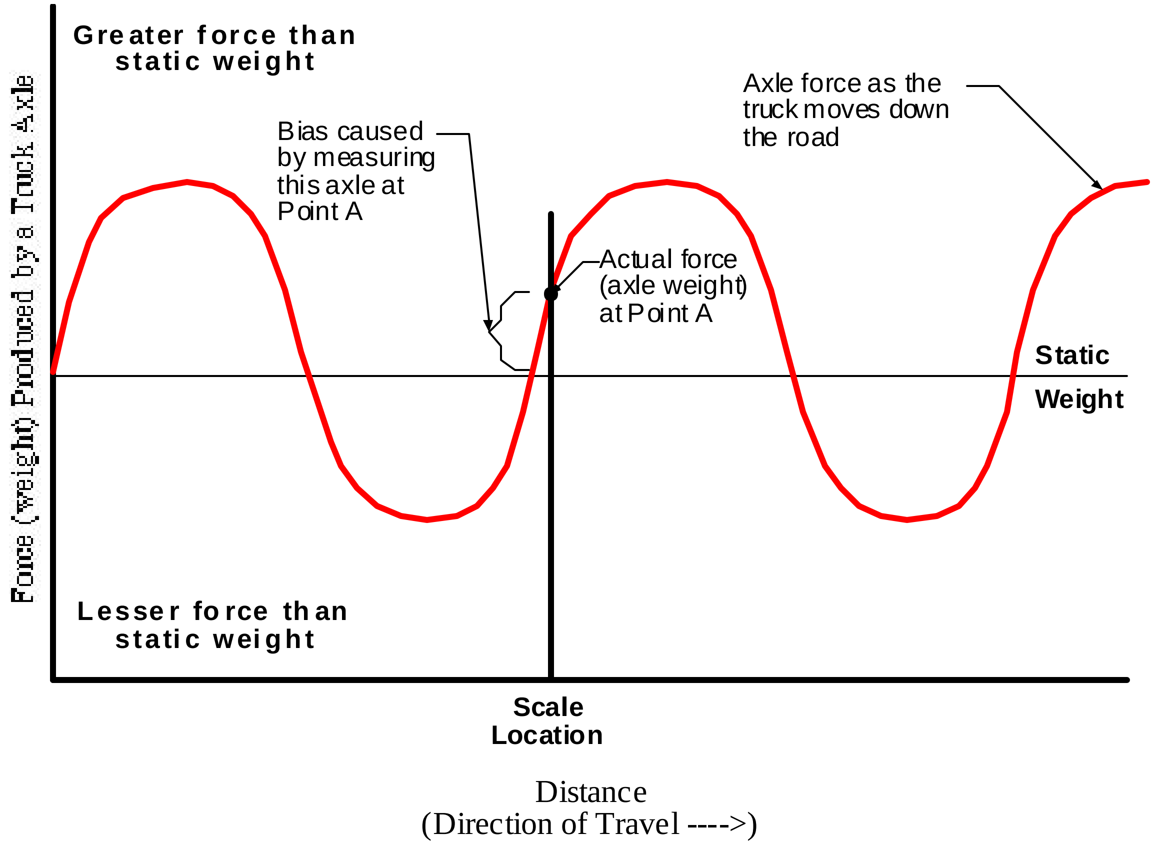

Figure 5-A-2: Variation of Axle Forces with Distance and the Consequential Effect on WIM Scale Calibration

The problem with this technique comes from the fact that each truck has a different dynamic motion. When the test truck has a different set of dynamics than the other trucks using that road, the scale is calibrated to the wrong portion of the dynamic curve (Point B shown in Figure 5-A-3). If the scale is calibrated to the dynamic motion of the test truck, it will cause the scale to overestimate the weights associated with the majority of trucks on that road.

To solve this problem there are five basic approaches:

- A scale sensor can be used that physically measures the truck weight for a long enough time period to be able to account for the truck's dynamic motion (this is true of the bridge weigh in motion system approach where the truck is on the "scale" the entire time it is on the bridge deck).
- Multiple sensors can be used to weigh the truck at different points in its dynamic motion either to average out the dynamic motion, or to provide enough data to predict the dynamic motion (so that the true mean can be estimated accurately).
- The relationship of the test truck to all other trucks can be determined. This is often done by mathematically modeling the dynamic motion of the

truck being weighed in order to predict where in the dynamic cycle it is when it reaches the scale.

- More than one type of test truck can be used in the calibration effort (where each test truck has a different type of dynamic response) in order to get a sample of the vehicle dynamic effects at that point in the roadway.
- Independent measurement can be used to ensure that the data being collected are not biased as a result of the test truck being used.

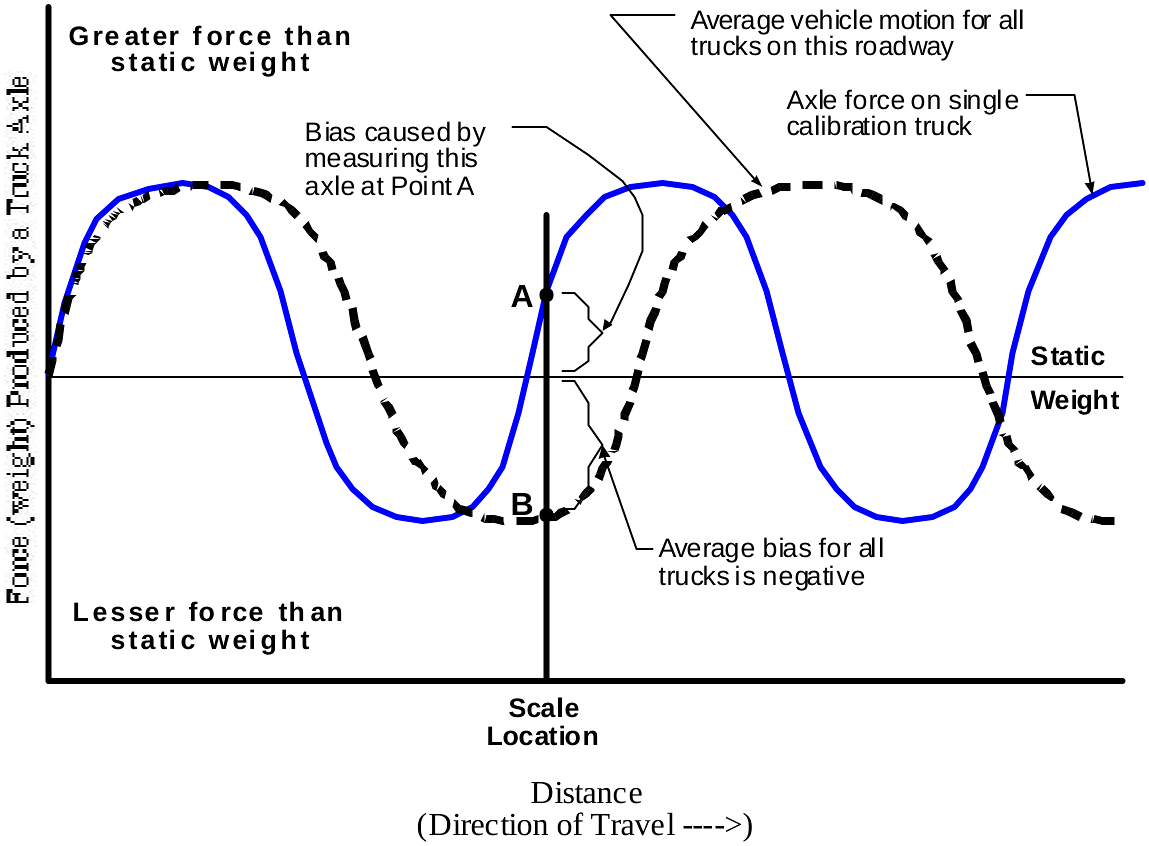

Figure 5-A-3: Variation of Axle Forces with Distance and the Consequential Effect on WIM Scale Calibration

The first of these techniques results in a series of other difficult technical problems that result in other accuracy problems. The use of multiple sensors is encouraged from a technical perspective, but most States dislike the added capital costs associated with this technique, although theoretically, it has the best long-term chance of success.

The third technique has strong theoretical backing. However, it is very difficult to perform in the field, both because it requires extensive knowledge about the test truck (dynamic response is not easily/inexpensively measured in the field) and because it requires more technical knowledge than most data collection crews possess.

The FHWA LTPP project recommends the use of multiple test trucks. These trucks should have suspensions typical of the type carrying loads on that road. This allows the calibration process to average between the dynamic relationships that are measured for the different trucks. This technique was selected as a compromise between the simplicity and low cost of using only one test truck and the increased confidence but higher cost of scale calibration performed with larger numbers of trucks.

The technique used by California DOT and presented in the Best Practices Handbook (McCall and Vodrazka 1997; Long-Term Pavement Performance Project 1998) uses independent measures to confirm the scale's performance and reduce the chance for bias. One of these measures is developed by varying the speed of the vehicle crossing the scale. This changes both the period during which the vehicle's tires are in contact with the scale and the dynamic motion of the truck. Another measure is to compare the scale's weight outputs with those of expected truck weights. Specific classes of vehicles in California, primarily the FHWA classes 9 and 11 vehicles, have consistent weight characteristics that can be used to confirm the accuracy of the scale's calibration. However, it is necessary for the individual performing the calibration to understand these characteristics as they apply to that specific WIM site in order to use these factors. That is, unusual truck loading patterns caused by local economic forces (e.g., the presence of a natural resource mining site) can cause trucks passing that scale to exhibit unusual loading characteristics.

Another independent measure that is often used for scale calibration is the front axle of the FHWA class 9 trucks. This measure can be used, but only where the State actually understands the axle weights found on the specific road that contains the scale. It has been found that as truck configurations and weights change, the weight on the front axle of these trucks varies considerably. Changes in truck configuration that are as simple as moving the King Pin[26] connection on a tractor can cause significant differences in mean front axle weight (±10 to 15 percent) on any given truck. Without having an independent measure of the actual axle front weights present at a site, use of this technique can force the scale's calibration to drift away from the appropriate calibration factor rather than improving the quality of the scale's calibration. However, where this technique is used properly, it can improve scale accuracy.[27]

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[26] The King Pin is the main connection between the tractor and the semi-trailer it is pulling. On most tractors, the connection point for the King Pin can be moved by as much as two feet. The closer the pin is set to the vehicle's cab, the better the gas mileage (because of decreased air resistance) but the rougher the ride on the driver. Thus, on rough roads, these connections tend to be set further back, while on smooth roads the connections are closer to the cab.

[27] For some types of sensors, other factors such as changes in sensor sensitivity due to changing ambient temperatures and changes in sensor sensitivity due to changes in pavement response caused by changing environmental conditions are attempted using this technique. The effectiveness of the technique is a function of its application by individual equipment vendors, the characteristics of each individual sensor installation, and the nature of the traffic crossing the installation.

MONITORING OF WIM DATA OUTPUT

The use of front axle weight for calibration purposes is as much a monitoring function as it is a calibration function. The FHWA's LTPP program and several States have concluded that one of the best methods for obtaining valid truck weight data is to carefully calibrate the WIM equipment, then use a comparison of scale output and expected truck volume and weight statistics to indicate when a scale's calibration or classification accuracy is drifting.

If a measure being tracked changes, then the staff investigate the change. The key is to limit the time spent examining "good data" while concentrating the limited staff time on review of "questionable" results and the repairs needed to fix malfunctioning equipment. If the monitored change can be independently verified as being true, the new pattern is included as an "expected" pattern for that site. When that "new" pattern re-appears at a later date, it then does not need to be investigated further.

The most common statistics applied to monitor the "health" of a WIM scale follow:

- the front axle weight of five-axle, tractor semi-trailer trucks
- the gross vehicle weight distribution of five-axle, tractor semi-trailer trucks
- the spacing of tandems axles on five-axle, tractor semi-trailer trucks
- traffic volumes for various vehicle classes, with particular emphasis on the percentage of vehicles that fall within each FHWA vehicle classification.

Front Axle Weights of Five-Axle, Tractor Semi-Trailer Trucks

For most roads, the mean front axle weight for these trucks should remain fairly constant. Most statistical tests of this value examine a rolling average of the last 100 front axle weights for vehicles of this configuration. If this mean value changes by more than a given amount (usually determined as a function of the variability of that statistic on that road), then the scale calibration is suspected of drifting.

As noted above, several factors can affect the front axle weight statistic. Among the most important of the factors that should be taken into account when examining changes in front axle weight statistics are the following:

- the total gross weight of the vehicle (more vehicle weight generally raises the front axle weight)
- the spacing between the front axle and the drive tandems on the tractor (generally, the greater the distance between the first and second axles, the lower the front axle weight)
- the roughness of the road (in general, the rougher the road, the lower the front axle weight that can be expected)

- State-specific weight laws and truck characteristics (which have a variety of effects, but often result in significantly different mean front axle weights for roads in different States).

Each of these factors has spawned improvements in the front-axle monitoring concept. One improvement is to track front-axle weights by basic gross vehicle weight category. Another is to monitor front-axle weight relative to axle spacing. A third is to ensure that site specific conditions are accounted for in initially setting the target front-axle weight against which gathered data will be compared.

It is also important to note that the 100 consecutive vehicles must be weighed within a timeframe in which the scale calibration is not expected to change in order to use this mechanism for calibration testing. For example, this statistic is often used as a self-calibration adjustment for piezo-electric cable WIM systems. It is designed to adjust the scale's calibration factor as the temperature changes. Temperature affects both the sensitivity of the piezo-cable itself and the structural response of the roadway that supports that cable.

When truck volumes are high relative to changes in temperature (for example, when over 100 of these trucks an hour cross the scale, and temperatures do not change more than 10 degrees during that hour), then all vehicles being included within any given set of 100 consecutive trucks can be considered to have been weighed under the same relative conditions, and in most cases, the calibration check represents an excellent measure of the scale's need for calibration adjustment.

However, if that scale experiences only five Class 9 trucks per day, it takes 20 days for the scale to observe 100 vehicles. The temperature conditions during those 20 days can be dramatically different for each of the 100 different measurements. In this case, computing a calibration adjustment designed to account for temperature changes is inappropriate, since the conditions under which the adjustment was calculated were not stable. This specific condition has caused many States to disconnect this feature on their scales. In many cases that is the correct decision. However, as noted above, there are situations where this feature does improve a scale's calibration.

Gross Vehicle Weight Distributions of 5-Axle Tractor Semi-Trailer Trucks

This technique was originally developed by the Minnesota DOT and was later adopted by the LTPP program (Hallenbeck 1994). The participating agency must be able to produce a histogram plot of the gross vehicle weights of class 9 trucks (mostly five-axle tractor semi-trailer trucks). LTPP uses a 4,000-lb. increment for creating the histogram plot, but a State highway agency may use any weight increment that meets its own needs.

The logic underlying the process is based on the expectation of finding consistent peaks in the GVW distribution at each site. Most sites have two peaks in the GVW distribution. One represents unloaded tractor semi-trailers and should occur between

28,000 and 36,000 pounds. This weight range has been determined from data collected at static scales around the country and appears to be reasonable for most locations. The second peak in the GVW distribution represents the most common loaded vehicle condition at that site. It varies somewhat with the type of commodity commonly being carried on a given road and each State's weight limits for five-axle trucks. Generally, the loaded peak falls somewhere between 72,000 and 80,000 lb.

For most sites, the location of these peaks within the GVW histogram remains fairly constant, although the height of the two peaks changes somewhat over time as a result of changing volumes and/or percentages (depending on whether the participating agency is plotting volume or percentage on the vertical axis of the frequency distribution; either will work) of loaded and unloaded vehicles. The reviewer must examine this distribution and decide whether the vehicle weights illustrated represent valid data or the scale either is not correctly calibrated or is malfunctioning. This is easily done when the current graph can be compared with graphs produced from data collected at that site when the scale was known to have been operating correctly.

Both Peaks Shifted

If a plot shows both peaks shifted from their expected location in the same direction (that is, where both peaks are lighter than expected or heavier than expected), the scale is most likely out of calibration. The participating agency should then recalibrate that scale at that site and collect new data.

One Peak Shifted

If a plot shows one peak correctly located but another peak shifted from its expected location, the site should be reviewed for other potential scale problems (such as a high number of classified but not weighed vehicles or scale failure during the data collection session). Additional information on that site may also be needed to determine whether the scale is operating correctly. Information that can be very useful in this investigation includes the types of commodities carried by class 9 trucks using that road and the load distribution obtained from that scale when it was last calibrated. For example, it might be discovered that a cement plant is just down the road from the WIM scale, and the loaded, five-axle cement trucks are routinely exceeding the 80,000-pound legal weight limit. This might result in acceptance of a loaded peak at that site that exceeds the normal 80,000-pound upper limit for the loaded peak.

If additional information indicates the presence of scale problems, the scale should be recalibrated. If scale calibration shows that the no calibration shift has occurred, this new pattern should be catalogued so that it is accepted in the future. For example, it is possible for shifts in the commodities carried to occur. These shifts can cause the loaded peak to shift, without changing the unloaded peak.

Number of Vehicles Heavier than 80,000 Pounds

A second check can be performed with the class 9 GVW frequency distribution by examining the number (and/or percentage) of vehicles that are heavier than the legal limit for the State. It is particularly important to look at the number and percentage of class 9 vehicles that weigh more than 100 kips. If the percentage of overweight vehicles (particularly vehicles over 100,000 lb.) is high, the scale calibration is questionable, although some jurisdictions routinely allow these weights and thus would not question the results. This check must be done with knowledge of a specific State's weight and permitting laws, as well as knowledge of the types of commodities carried by trucks operating on that road.

The 100,000 lb. check is particularly useful in detecting when piezo-electric scales begin to fail, since these scales often generate an almost flat GVW distribution when they begin to malfunction. An axle weight data set produced by such a scale results in an extremely large (and inaccurate) ESAL computation for a given number of trucks. It is also highly unusual for the class 9 trucks to carry such heavy loads. In most cases, trucks legally carrying these heavy weights are required to use additional axles, and they are thus classified as class 10 (or higher) and do not appear in the class 9 GVW graph. While illegally loaded five-axle trucks may be operating at the site in question, most illegally loaded trucks do not exceed the legal weight limit by more than several thousand pounds, and the number (or percentage) of these extremely high weights is usually fairly low. Thus, it is assumed that high percentages of extremely heavy class 9 trucks are a sign of scale calibration or operational problems. On the other hand, if a participating agency routinely permits much higher loads to be carried on five-axle trucks, this check may not be useful.

In either case (scale problems or extreme numbers of overloaded trucks), State personnel should investigate the situation. If the data are valid, notes to this effect should be written and maintained in the calibration file, so that future reviewers are aware of this site's unusual travel characteristics.

Changes in Tandem Axle Spacings

The mean axle spacing of drive tandems on tractors of class 9 trucks are fairly constant. As a result, several States monitor this statistic to determine whether WIM scale sensors are working correctly. The scale's measurement of this statistic is a function of the scale's ability to accurately measure speed. Speed determination is crucial in several aspects of the axle weight computation process. Thus if the scale is unable to accurately measure speed, it is highly likely that it is not correctly measuring axle weights. Similarly, if the scale cannot accurately measure speed, it will be apparent in the mean distance reported between axles 2 and 3 of three-axle tractors on class 9 trucks.

Changes in Measured Truck Volumes

This last category of monitoring data consists of comparing expected truck volumes by vehicle classification with expected volumes for those classes. Two different measures are effectively tracked. One is the total volume of trucks by classification. The other is the percentage of trucks within each classification.

Routinely monitoring the total volume of trucks at a WIM site is good, not only because it can provide a key indicator of scale error, but because it will show when significant changes in truck flows are occurring. Analysis performed with LTPP truck volume data show that at many sites, dramatic changes in truck volumes can occur, even on major truck routes, such as rural Interstates. On lower volume roads, 100 percent changes in class 9 truck volumes are not necessarily an indicator of scale malfunction, but knowing that such an increase (or decrease) in truck volume has occurred is critical to understanding the performance of that roadway and the expected lifespan of that roadway's pavement.

On the other hand, some dramatic changes in truck volumes, especially on high volume truck routes, are often an indication of malfunctioning data collection equipment. Malfunctioning axle detectors can result in both the undercounting of axles (resulting in the under-estimation of large truck volumes), and over counting of axles (one common condition is called "ghost axles"), resulting in the over-estimation of large truck volumes. Similarly, a malfunctioning loop detector can cause two cars to be called one truck, or can cause one truck to be split into two or more cars.

Simply monitoring summary truck volumes, such as average daily or even average weekly or monthly volumes allows the detection of changes as they occur. When significant changes occur, independent measures can be used (for example a short manual count, or a call to a local DOT office to confirm the presence of large new truck volumes) to determine the validity of the data. Data that are invalid can then be discarded. Data that are valid can then be stored and used with confidence later.

Monitoring truck percentages (i.e., the percentage of truck volumes within each vehicle classification) is another excellent tool for detecting equipment failures. When sensors fail, trucks are often misclassified. For example, the loss of one axle normally converts a class 9 vehicle into a class 8 vehicle. Thus, a significant shift in truck percentages from class 9 to class 8 is an indicator of possible equipment error.

Monitoring truck percentages and truck volumes is very beneficial. However, it is only truly useful if the State highway agency performs these checks frequently, promptly investigates abnormal conditions, and repairs or removes malfunctioning data collection equipment. Without this prompt follow-up it can be difficult to determine whether abnormalities discovered are caused by real equipment problems or are the result of changes in local traffic conditions. Quality information results from the continuous data collection, improvement, and verification of the data provided.

APPENDIX 5-B
FREQUENTLY ASKED QUESTIONS

Should WIM data be collected only on smooth and flat pavements?

WIM data is needed to address pavement design and other uses involving all types of pavement. Data collection mechanisms that provide quality data are needed under all conditions. Indeed the dynamic forces that vehicles apply to the pavement may increase as the quality of the pavement decreases. Research and equipment activities under the auspices of the traffic monitoring program must continue under a variety of roadway conditions. However, under current equipment constraints, the collection of WIM data based on calibrated equipment and comparable to static weight data may only be possible on smooth and flat pavement. The TMG emphasizes the collection of quality WIM data at permanent installations in flat and smooth pavement to insure the quality and veracity of the resulting WIM data. The limited WIM data at these sites is then expanded based on specific road groups and detailed classification data to apply WIM estimates to the complete roadway system. Extended information on these issues is available from ASTM or the LTPP program.

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Section 6

Traffic Monitoring Data Formats

SECTION 6
TRAFFIC MONITORING DATA FORMATS

TABLES

CHAPTER 1
INTRODUCTION

TRAFFIC DATA RECORDS

This section contains instructions for coding data in the formats requested by the FHWA. The record formats and coding instructions have been developed to provide input to national databases maintained by the FHWA. These include the Traffic Volume Trends (TVT) system and the Vehicle Travel Information System (VTRIS).

The TVT system is used to process the continuous traffic volume data and produce the monthly Traffic Volume Trends report. The VTRIS is used to process the vehicle classification and truck weight data collected as part of the annual Truck Weight Study. Both are microcomputer database management systems that process, validate, summarize, and maintain traffic data. TVT and VTRIS may be used by anyone with data in the formats described in this section and can be retrieved from the FHWA website at http://www.fhwa.dot.gov/ohim/tvtw/tvtwpage.htm. The data collection program has been approved by the Office of Management and Budget, OMB # 2125-0587, and has a current expiration date of April 30, 2004.

The data records are divided into four types: station description data, traffic volume data, vehicle classification data, and truck weight data. Each type of data has its own individualized record format. Specific coding instructions and record layouts are discussed separately for each type of data in the following chapters.

Note that some fields are labeled “critical.” This means that a record cannot be processed by TVT or VTRIS without them. All data files described here are ASCII flat files. For character fields with missing or inapplicable data, enter blanks. Numbers such as counts should be right-justified and filled with leading blanks or zeros unless noted otherwise. For numeric fields with missing or inapplicable data, enter blanks or "-1" right-justified.

Certain data items are common to all four types of records. For example, all records contain a six-character station identification. This allows States to use a common identification system for all traffic monitoring stations.

Several fields in the station description record were replaced with fields that are needed to tie traffic data to geographic information systems (GIS). This will allow traffic data to be overlaid on the National Highway Planning Network (NHPN) and similar systems.

DATA SUBMITTALS TO THE FHWA

Copies of continuous traffic volume data collected by permanent ATRs should be submitted monthly to the FHWA within 20 days after the close of the month for which the data were collected. The station description record need only be sent annually or when there is a change. The preferred method of transmission is as an attachment to an e-mail message sent to "**atrdata@fhwa.dot.gov**". Alternatively, diskettes may be mailed to:

Federal Highway Administration
Travel Monitoring and Surveys Division, HPPI-30
400 Seventh Street, SW
Washington, D.C. 20590
Attention: Traffic Volume Trends

Annually, each State should submit to the FHWA the vehicle classification and truck weight data collected at WIM sites. Data for the preceding calendar year should be submitted by June 15th. More frequent submissions are also acceptable.

If continuous weigh-in-motion data are available, send up to one week of data per quarter (select any week without a holiday). The data should be addressed as follows:

Federal Highway Administration
Travel Monitoring and Surveys Division, HPPI-30
400 Seventh Street, SW
Washington, D.C. 20590
Attention: Vehicle Travel Information System

All data should be in the record formats described in this section and edited for reasonableness. If the files are large, it is preferable that a compression program such as PKZIP be used to condense them. Please provide the name of a contact person and the telephone number in case further clarification is necessary. For further information, contact the Travel Monitoring Division and Surveys Division at (202) 366-0175.

CHAPTER 2
STATION DESCRIPTION DATA FORMATS

The Station Description record format is used for all traffic volume, vehicle classification, and truck weight monitoring stations. A Station Description file contains one record for each traffic monitoring station per year. All fields are considered to be character fields. The optional file naming convention is "ssyy.STA", where ss is state postal abbreviation and yy is the last two digits of the year. Table 6-2-1 summarizes the Station Description record.

Fields designated as *Critical* are required for entry into the VTRIS database.

1. **Record Type** (Column 1) - *Critical*

   S = Station description record

2. **FIPS State Codes** (Columns 2-3) - *Critical*

State	Code	State	Code	State	Code
Alabama	01	Louisiana	22	Ohio	39
Alaska	02	Maine	23	Oklahoma	40
Arizona	04	Maryland	24	Oregon	41
Arkansas	05	Massachusetts	25	Pennsylvania	42
California	06	Michigan	26	Rhode Island	44
Colorado	08	Minnesota	27	South Carolina	45
Connecticut	09	Mississippi	28	South Dakota	46
Delaware	10	Missouri	29	Tennessee	47
D.C.	11	Montana	30	Texas	48
Florida	12	Nebraska	31	Utah	49
Georgia	13	Nevada	32	Vermont	50
Hawaii	15	New Hampshire	33	Virginia	51
Idaho	16	New Jersey	34	Washington	53
Illinois	17	New Mexico	35	West Virginia	54
Indiana	18	New York	36	Wisconsin	55
Iowa	19	North Carolina	37	Wyoming	56
Kansas	20	North Dakota	38	Puerto Rico	72
Kentucky	21				

Canadian Provinces may use VTRIS with the following codes (based on the LTPP):

Alberta	81	British Columbia	82	Labrador	93
Manitoba	83	New Brunswick	84	Newfoundland	85
Northwest Ter.	92	Nova Scotia	86	Nunavut	94
Ontario	87	Prince Edward Is.	88	Quebec	89
Saskatchewan	90	Yukon	91		

Table 6-2-1: Station Description Record

Field	**Columns**	**Width**	**Description**
1	1	1	Record Type
2	2-3	2	FIPS State Code
3	4-9	6	Station ID
4	10	1	Direction of Travel Code
5	11	1	Lane of Travel
6	12-13	2	Year of Data
7	14-15	2	Functional Classification Code
8	16	1	Number of Lanes in Direction Indicated
9	17	1	Sample Type for Traffic Volume
10	18	1	Number of Lanes Monitored for Traffic Volume
11	19	1	Method of Traffic Volume Counting
12	20	1	Sample Type for Vehicle Classification
13	21	1	Number of Lanes Monitored for Vehicle Class.
14	22	1	Method of Vehicle Classification
15	23	1	Algorithm for Vehicle Classification
16	24-25	2	Classification System for Vehicle Classification
17	26	1	Sample Type for Truck Weight
18	27	1	Number of Lanes Monitored for Truck Weight
19	28	1	Method of Truck Weighing
20	29	1	Calibration of Weighing System
21	30	1	Method of Data Retrieval
22	31	1	Type of Sensor
23	32	1	Second Type of Sensor
24	33	1	Primary Purpose - *NEW*
25	34-45	12	LRS Identification - *NEW*
26	46-51	6	LRS Location Point - *NEW*
27	52-59	8	Latitude - *NEW*
28	60-68	9	Longitude - *NEW*
29	69-72	4	SHRP Site Identification - *NEW*
30	73-78	6	Previous Station ID
31	79-80	2	Year Station Established
32	81-82	2	Year Station Discontinued
33	83-85	3	FIPS County Code
34	86	1	HPMS Sample Type
35	87-98	12	HPMS Sample Identifier
36	99	1	National Highway System - *NEW*
37	100	1	Posted Route Signing
38	101-108	8	Posted Signed Route Number
39	109	1	Concurrent Route Signing
40	110-117	8	Concurrent Signed Route Number
41	118-167	50	Station Location

3. **Station Identification** (Columns 4-9) - *Critical*

This field should contain an alphanumeric designation for the station where the survey data are collected. Station identification field entries must be identical in all records for a given station. Differences in characters, including spaces, blanks, hyphens, etc., prevent proper match. Right justify the Station ID if it is less than 6 characters. There should be no embedded blanks.

4. **Direction of Travel Code** (Column 10) - *Critical*

Do not combine directions. There should be a separate record for each direction. Whether or not lanes are combined in each direction depends on the next field.

Code	Direction
1	North
2	Northeast
3	East
4	Southeast
5	South
6	Southwest
7	West
8	Northwest
9	North-South or Northeast-Southwest combined (ATR stations only)
0	East-West or Southeast-Northwest combined (ATR stations only)

5. **Lane of Travel** (Column 11) - *Critical*

Either each lane is considered a separate station or all lanes in each direction are combined.

Code	Lane
0	Data with lanes combined
1	Outside (rightmost) lane
2-9	Other lanes

Note: The Station ID, Direction of Travel, and Lane of Travel make up the Station Code. *There should be one Station Description record per Station Code. Stations can be either by lane or with lanes combined by direction, but not both.*

6. **Year of Data** (Columns 12-13) - *Critical*

Code the last two digits of the year in which the data were collected.

7. **Functional Classification Code** (Columns 14-15) - *Critical*

	Code	Functional Classification
RURAL		
	01	Principal Arterial - Interstate
	02	Principal Arterial - Other
	06	Minor Arterial
	07	Major Collector
	08	Minor Collector
	09	Local System
URBAN		
	11	Principal Arterial - Interstate
	12	Principal Arterial - Other Freeways or Expressways
	14	Principal Arterial - Other
	16	Minor Arterial
	17	Collector
	19	Local System

8. **Number of Lanes in Direction Indicated** (Column 16)

Code the number of lanes in one direction at the site. Use "9" if there are more than eight lanes.

9. **Sample Type for Traffic Volume** (Column 17)

T = Station used for Traffic Volume Trends
N = Station not used for Traffic Volume Trends

10. **Number of Lanes Monitored for Traffic Volume** (Column 18)

Code the number of lanes in one direction that are monitored at this site. Use "9" if there are more than eight lanes.

11. **Method of Traffic Volume Counting** (Column 19)

1 = Human observation (manual)
2 = Portable traffic recording device
3 = Permanent automatic traffic recorder (ATR)

12. **Sample Type for Vehicle Classification** (Column 20)

H = Station used for Heavy Vehicle Travel Information System
N = Station not used for Heavy Vehicle Travel Information System

13. **Number of Lanes Monitored for Vehicle Classification** (Column 21)

Code the number of lanes in one direction that are monitored for vehicle classification at this site. Use "9" if there are more than eight lanes.

14. **Method of Vehicle Classification** (Column 22)

1 = Human observation (manual) vehicle classification
2 = Portable vehicle classification device
3 = Permanent vehicle classification device

15. **Algorithm for Vehicle Classification** (Column 23)

Code the type of input and processing used to classify vehicles:

A = Human observation on site (manual)
B = Human observation of vehicle image (e.g., video)
C = Automated interpretation of vehicle image or signature (e.g., video, microwave, sonic)
D = Vehicle length classification
E = Axle spacing with ASTM Standard E1572
F = Axle spacing with Scheme F
G = Axle spacing with Scheme F modified
H = Other axle spacing algorithm
K = Axle spacing and weight algorithm
L = Axle spacing and vehicle length algorithm
M = Axle spacing, weight, and vehicle length algorithm
N = Axle spacing and other input(s) not specified above
Z = Other means not specified above

16. **Classification System for Vehicle Classification** (Columns 24-25)

This indicates the total number of classes in the vehicle classification system. The default value is 13 which indicates the standard FHWA 13 class system (see Appendix 4-C). The other vehicle classification systems are based on the HPMS and the Traffic Monitoring System (TMS) documentation. The value that is used will determine the number of count fields needed on the Vehicle Classification Record. In the following list the numbers in parentheses are from the FHWA 13 class system:

1 = One class: total volume
2 = Two classes: non-commercial (classes 1-3) and commercial (classes 4-13) vehicles
3 = Three classes: non-commercial (classes 1-3), single-unit commercial (classes 4-7), combination commercial (classes 8-13) vehicles
4 = Four classes: non-commercial (classes 1-3), single-unit commercial (classes 4-7), single-trailer commercial (classes 8-10), multi-trailer commercial (classes 11-13) vehicles
5 = Five classes as follows:
    1 of 5 = two-axle, two or four-tire vehicles (classes 1-3)
    2 of 5 = buses (class 4)
    3 of 5 = single-unit trucks (classes 5-7)
    4 of 5 = single-trailer combination trucks (classes 8-10)
    5 of 5 = multiple-trailer combination trucks (classes 11-13)
13 = FHWA's standard 13 class system (see Appendix 4-C)
14 = FHWA's 13 class system plus a class 14 (State or vendor defined)
15 = FHWA's 13 class system plus classes 14 and 15 (State or vendor defined)
Other numbers = number of classes (unsupported)

17. **Sample Type for Truck Weight** (Column 26)

B = Station used for TMG sample and Strategic Highway Research Program (SHRP) Long Term Pavement Performance (LTPP) sample
L = Station used for SHRP/LTPP sample (but not TMG sample)
T = Station used for TMG sample (but not SHRP/LTPP sample)
N = Station not used for any of the above

18. **Number of Lanes Monitored for Truck Weight** (Column 27)

Code the number of lanes in one direction that are monitored for truck weight at this site. Use "9" if there are more than eight lanes.

19. **Method of Truck Weighing** (Column 28)

1 = Portable static scale
2 = Chassis-mounted, towed static scale
3 = Platform or pit static scale
4 = Portable weigh-in-motion system
5 = Permanent weigh-in-motion system

20. **Calibration of Weighing System** (Column 29)

Code the method used to calibrate the weighing system, e.g., comparing weight-in-motion and weights from static scales.

A = ASTM Standard E1318
B = Subset of ASTM Standard E1318
C = Combination of test trucks and trucks from the traffic stream (but not ASTM E1318)
D = Other sample of trucks from the traffic stream
M = Moving average of the steering axle of 3S2s
S = Static calibration
T = Test trucks only
U = Uncalibrated
Z = Other method

21. **Method of Data Retrieval** (Column 30)

1 = Not automated (manual)
2 = Automated (telemetry)

22. **Type of Sensor** (Column 31)

Code the type of sensor used for traffic detection.

A = Automatic vehicle identification (AVI)
B = Bending plate
C = Capacitance strip
D = Capacitance mat/pad
E = Hydraulic load cells
F = Fiber optic - *NEW*
G = Strain gauge on bridge beam
H = Human observation (manual)
I = Infrared
K = Laser/lidar
L = Inductance loop
M = Magnetometer
P = Piezoelectric
Q = Quartz piezoelectric - *NEW*
R = Road tube
S = Sonic/acoustic
T = Tape switch
U = Ultrasonic
V = Video image
W = Microwave
X = Radio wave
Z = Other

23. **Second Type of Sensor** (Column 32)

If there are two types of sensors at the station, code the second using the same codes as Type of Sensor. Otherwise, code "N" for none.

24. **Primary Purpose** (Column 33) - *NEW*

This field indicates the *primary purpose* for installing the station and hence which organization is responsible for it and supplies the data.

E = Enforcement purposes (e.g., speed or weight enforcement)
I = Operations purposes in support of ITS initiatives
L = Load data for pavement design or pavement management purposes
O = Operations purposes *but not ITS*
P = Planning or traffic statistics purposes
R = Research purposes (e.g., LTPP)

25. **LRS Identification** (Columns 34-45) - *NEW*

The LRS Identification reported in this item for the station must be the same as the LRS identification reported in the HPMS for the section of roadway where the station is located. The LRS identification is a 12-character, right justified value. The LRS ID can be alphanumeric, but must not contain blanks; leading zeros must be coded. More information concerning the LRS may be found in Chapter V of the *HPMS Field Manual*, Linear Referencing System Requirements.

26. **LRS Location Point** (Columns 46-51) - *NEW*

This is the LRS location point for the station. It is similar information to the LRS Beginning Point and LRS Ending Point in the HPMS. The KMPT for the station must be within the range of the LRS beginning point and LRS ending point for the roadway section upon which the station is located. It is coded in kilometers with an implied decimal in the middle: XXX.XXX.

27. **Latitude** (Columns 52-59) - *NEW*

This is the latitude of the station location with the north hemisphere assumed and decimal place understood as XX.XXX XXX.

28. **Longitude** (Columns 60-68) - *NEW*

This is the longitude of the station location with the west hemisphere assumed and decimal place understood as XXX.XXX XXX.

29. **SHRP Site Identification** (Columns 69-72) - *NEW*

If the site is used in the SHRP/LTPP sample, give the SHRP site ID.

30. **Previous Station ID** (Columns 73-78)

If the station replaces another station, give the station ID that was used previously.

31. **Year Station Established** (Columns 79-80)

Code the last two digits of the appropriate year if known.

32. **Year Station Discontinued** (Columns 81-82)

Code the last two digits of the appropriate year if known.

33. **FIPS County Code** (Columns 83-85)

Use the three-digit FIPS county code (see Federal Information Processing Standards Publication 6, "Counties of the States of the United States").

34. **HPMS Sample Type** (Column 86)

N = No, not on an HPMS standard sample section
Y = Yes, on an HPMS standard sample section

35. **HPMS Sample Identifier** (Columns 87-98)

If the station is on an HPMS standard sample section, code the HPMS Sample Identifier per the *HPMS Field Manual* (Item 47).

36. **National Highway System** (Column 66) - *NEW*

N = No, not on National Highway System
Y = Yes, on National Highway System

37. **Posted Route Signing** (Column 100)

This is the same as Route Signing in *HPMS Field Manual* (Item 22).

Code	Description	Code	Description
0	Not signed	5	County
1	Interstate	6	Township
2	U.S.	7	Municipal
3	State	8	Parkway or Forest Route Marker
4	Off-Interstate Business Marker	9	None of the above

38. **Posted Signed Route Number** (Columns 101-108)

Code the route number of the principal route on which the station is located. If the station is located on a city street, zero-fill this field. This is the same as Signed Route Number in *HPMS Field Manual* (Item 24).

39. **Concurrent Route Signing** (Column 109)

Code same as Posted Route Signing for concurrent route if there is one.

40. **Concurrent Signed Route Number** (Columns 110-117)

Code same as Posted Signed Route Number for concurrent route if there is one.

41. **Station Location** (Columns 118-167)

For stations located on a numbered route, enter the distance and direction of the station from the nearest major intersecting route or state border or landmark on state road maps. If the station is located on a city street, enter the city and street name. Abbreviate if necessary. Left justify.

CHAPTER 3
TRAFFIC VOLUME DATA FORMATS

The Traffic Volume file contains one record for each day of traffic monitoring. All numeric fields should be right-justified and zero-filled. Table 6-3-1 summarizes the Hourly Traffic Volume record. The fields are as follows:

1. **Record Type** (Column 1) - *Critical*

   3 = Traffic volume record

2. **FIPS State Code** (Columns 2-3) - See chapter 6-2. - *Critical*

3. **Functional Classification Code** (Columns 4-5) - See chapter 6-2. - *Critical*

4. **Station Identification** (Columns 6-11) - See chapter 6-2. - *Critical*

This should be right-justified and zero-filled. - *Critical*

5. **Direction of Travel Code** (Column 12) - See chapter 6-2. - *Critical*

6. **Lane of Travel** (Column 13) - See chapter 6-2. - *Critical*

The code for combined lanes (0) is preferred.

7. **Year of Data** (Columns 14-15) - See chapter 6-2. - *Critical*

8. **Month of Data** (Columns 16-17) - *Critical*

   01 = January
   02 = February
   03 = March
   04 = April
   05 = May
   06 = June
   07 = July
   08 = August
   09 = September
   10 = October
   11 = November
   12 = December

9. **Day of Data** (Columns 18-19) - *Critical*

Code the day of the month of data, 01-31. Must correspond to the month of data.

10. **Day of Week** (Column 20) - *Optional*

1 = Sunday
2 = Monday
3 = Tuesday
4 = Wednesday
5 = Thursday
6 = Friday
7 = Saturday

11-34. **Traffic Volume Counted Fields** (Columns 21-25, ..., 136-140)

Enter the traffic volume counted during the hour covered. If the data are missing, code a -1 or blanks.

Field	Hour Covered
11	00:01 am to 01:00 am
12	01:01 am to 02:00 am
.	.
.	.
.	.
34	11:01 pm to 12:00 midnight

35. **Restrictions** (Column 141)

0 = no restrictions
1 = construction or other activity affected traffic flow
2 = traffic counting device problem (e.g., malfunction or overflow) - NEW

Table 6-3-1: Hourly Traffic Volume Record (#3 Record)

Field	Columns	Length	Description
1	1	1	Record Type
2	2-3	2	FIPS State Code
3	4-5	2	Functional Classification
4	6-11	6	Station Identification
5	12	1	Direction of Travel
6	13	1	Lane of Travel
7	14-15	2	Year of Data
8	16-17	2	Month of Data
9	18-19	2	Day of Data
10	20	1	Day of Week
11	21-25	5	Traffic Volume Counted, 00:01 - 01:00
12	26-30	5	Traffic Volume Counted, 01:01 - 02:00
13	31-35	5	Traffic Volume Counted, 02:01 - 03:00
14	36-40	5	Traffic Volume Counted, 03:01 - 04:00
15	41-45	5	Traffic Volume Counted, 04:01 - 05:00
16	46-50	5	Traffic Volume Counted, 05:01 - 06:00
17	51-55	5	Traffic Volume Counted, 06:01 - 07:00
18	56-60	5	Traffic Volume Counted, 07:01 - 08:00
19	61-65	5	Traffic Volume Counted, 08:01 - 09:00
20	66-70	5	Traffic Volume Counted, 09:01 - 10:00
21	71-75	5	Traffic Volume Counted, 10:01 - 11:00
22	76-80	5	Traffic Volume Counted, 11:01 - 12:00
23	81-85	5	Traffic Volume Counted, 12:01 - 13:00
24	86-90	5	Traffic Volume Counted, 13:01 - 14:00
25	91-95	5	Traffic Volume Counted, 14:01 - 15:00
26	96-100	5	Traffic Volume Counted, 15:01 - 16:00
27	101-105	5	Traffic Volume Counted, 16:01 - 17:00
28	106-110	5	Traffic Volume Counted, 17:01 - 18:00
29	111-115	5	Traffic Volume Counted, 18:01 - 19:00
30	116-120	5	Traffic Volume Counted, 19:01 - 20:00
31	121-125	5	Traffic Volume Counted, 20:01 - 21:00
32	126-130	5	Traffic Volume Counted, 21:01 - 22:00
33	131-135	5	Traffic Volume Counted, 22:01 - 23:00
34	136-140	5	Traffic Volume Counted, 23:01 - 24:00
35	141	1	Restrictions

CHAPTER 4
VEHICLE CLASSIFICATION DATA FORMATS

The Vehicle Classification file contains one record for each hour with the traffic volume by vehicle class. The optional file naming convention is "ssyy.CLA", where ss is state postal abbreviation and yy is the last two digits of the year. Table 6-4-1 summarizes the Vehicle Classification record.

Fields designated as *Critical* are required for entry into the VTRIS data base.

1. **Record Type** (Column 1) - *Critical*

   C = Vehicle classification record

2. **FIPS State Code** (Columns 2-3) - *Critical* - See chapter 6-2.

3. **Station Identification** (Columns 4-9) - *Critical* - See chapter 6-2.

4. **Direction of Travel Code** (Column 10) - *Critical* - See chapter 6-2.

5. **Lane of Travel** (Column 11) - *Critical* - See chapter 6-2.

Note: The Station ID, Direction of Travel, and Lane of Travel make up the Station Code. *There should be one Station Description record per Station Code*.

6. **Year of Data** (Columns 12-13) - *Critical* - See chapter 6-2.

7. **Month of Data** (Columns 14-15) - *Critical* - See chapter 6-3.

8. **Day of Data** (Columns 16-17) - *Critical* - See chapter 6-3.

9. **Hour of Data** (Columns 18-19) - *Critical*

Code the beginning of the hour in which the count was taken:

00 = 0:01 a.m. to 1:00 a.m.
01 = 1:01 a.m. to 2:00 a.m.
.
.
.
22 = 10:01 p.m. to 11:00 p.m.
23 = 11:01 p.m. to Midnight

10. **Total Hourly Volume** (Columns 20-24)

This numeric field is the total traffic volume for the hour. The total volume is needed because some vehicles might not be classified, in which case the sum of the class counts would not equal the total volume. If the total volume is not collected, leave this field blank or put "-1" (for missing data).

The following class count fields are numeric fields with the traffic volume by vehicle class for each hour of data. Field number 16 in the Station Description Record, "Classification System for Vehicle Classification," determines the number of classes expected from the station. The default classification system is the FHWA 13 class system (see Appendix 4-C).

These counts should be checked for reasonableness. For example, Class 13 should not be larger than 99. VTRIS allows users to set a limit for each class count

11. **Class 1 Count** (Columns 25-29) - Optional

Class 1 is for Motorcycles, which is an optional class. If motorcycles are not counted, enter "-1" or blanks in the Class 1 field.

12. **Class 2 Count** (Columns 30-34) - *Critical*

Class 2 is for Passenger Cars.

13. **Class 3 Count** (Columns 35-39) - *Optional*

Class 3 is for Other Two-Axle, Four-Tire, Single-Unit Vehicles. However, classes 2 and 3 may be combined, in which case the total for both classes should be entered in the class 2 field and "-1" or blanks in the Class 3 field.

14. **Class 4 Count** (Columns 40-44) - *Critical*

Class 4 is for Buses.

15. **Class 5 Count** (Columns 45-49) - *Critical*

Class 5 is for Two-Axle, Six-Tire, Single-Unit Trucks.

16. **Class 6 Count** (Columns 50-54) - *Critical*

Class 6 is for Three-Axle, Single-Unit Trucks.

17. **Class 7 Count** (Columns 55-59) - *Critical*

Class 7 is for Four-or-More Axle, Single-Unit Trucks.

18. **Class 8 Count** (Columns 60-64) - *Critical*

Class 8 is for Four-or-Less Axle, Single-Trailer Trucks.

19. **Class 9 Count** (Columns 65-69) - *Critical*

Class 9 is for Five-Axle, Single-Trailer Trucks.

20. **Class 10 Count** (Columns 70-74) - *Critical*

Class 10 is for Six-or-More Axle, Single-Trailer Trucks.

21. **Class 11 Count** (Columns 75-79) - *Critical*

Class 11 is for Five-or-Less Axle, Multi-Trailer Trucks.

22. **Class 12 Count** (Columns 80-84) - *Critical*

Class 12 is for Six-Axle, Multi-Trailer Trucks.

23. **Class 13 Count** (Columns 85-89) - *Critical*

Class 13 is for Seven-or-More Axle, Multi-Trailer Trucks.

The Vehicle Classification record may be ended here if exactly 13 classes are used. However, some automatic vehicle classification systems have one or two more classes usually designating "Unclassified" or "Unclassifiable" vehicles. If Class 14 and/or Class 15 are included such that the total of all the classes equals the total volume, then the Total Volume field may be left blank.

24. **Class 14 Count** (Columns 90-94) - *Optional*

If a Class 14 is used, enter the count for the hour here.

25. **Class 15 Count** (Columns 95-99) - *Optional*

If a Class 15 is used, enter the count for the hour here.

Table 6-4-1: Vehicle Classification Record

Field	Columns	Length	Description
1	1	1	Record Type
2	2-3	2	FIPS State Code
3	4-9	6	Station ID
4	10	1	Direction of Travel Code
5	11	1	Lane of Travel
6	12-13	2	Year of Data
7	14-15	2	Month of Data
8	16-17	2	Day of Data
9	18-19	2	Hour of Data
10	20-24	5	Total Volume
11	25-29	5	Class 1 Count
12	30-34	5	Class 2 Count
13	35-39	5	Class 3 Count
14	40-44	5	Class 4 Count
15	45-49	5	Class 5 Count
16	50-54	5	Class 6 Count
17	55-59	5	Class 7 Count
18	60-64	5	Class 8 Count
19	65-69	5	Class 9 Count
20	70-74	5	Class 10 Count
21	75-79	5	Class 11 Count
22	80-84	5	Class 12 Count
23	85-89	5	Class 13 Count

End the record here if the FHWA 13 class system is being used.

24	90-94	5	Class 14 Count (optional)
25	95-99	5	Class 15 Count (optional)

CHAPTER 5
TRUCK WEIGHT DATA FORMATS

The Truck Weight file contains one record for each truck with its axle weights and axle spacings. The optional file naming convention is "ssyy.WGT", where ss is the state postal abbreviation and yy is the last two digits of the year. Table 6-5-1 summarizes the Truck Weight record.

Fields designated as *Critical* are required for entry into the VTRIS database.

1. **Record Type** (Column 1) - *Critical*

   W = Truck weight record

2. **FIPS State Code** (Columns 2-3) - *Critical* - See chapter 6-2.

3. **Station Identification** (Columns 4-9) - *Critical* - See chapter 6-2.

4. **Direction of Travel Code** (Column 10) - *Critical* - See chapter 6-2.

5. **Lane of Travel** (Column 11) - *Critical* - See chapter 6-2.

Note: The Station ID, Direction of Travel, and Lane of Travel make up the Station Code. *There should be one Station Description record per Station Code*.

6. **Year of Data** (Columns 12-13) - *Critical* - See chapter 6-2.

7. **Month of Data** (Columns 14-15) - *Critical* - See chapter 6-3.

8. **Day of Data** (Columns 16-17) - *Critical* - See chapter 6-3.

9. **Hour of Data** (Columns 18-19) - *Critical*

Code the beginning of the hour in which the count was taken:

00 = 0:01 a.m. to 1:00 a.m.
01 = 1:01 a.m. to 2:00 a.m.
.
.
.
22 = 10:01 p.m. to 11:00 p.m.
23 = 11:01 p.m. to Midnight

Table 6-5-1: Truck Weight Record

Field	Columns	Length	Description
1	1	1	Record Type
2	2-3	2	FIPS State Code
3	4-9	6	Station ID
4	10	1	Direction of Travel Code
5	11	1	Lane of Travel
6	12-13	2	Year of Data
7	14-15	2	Month of Data
8	16-17	2	Day of Data
9	18-19	2	Hour of Data
10	20-21	2	Vehicle Class
11	22-24	3	Open
12	25-28	4	Total Weight of Vehicle
13	29-30	2	Number of Axles
14	31-33	3	A-axle Weight
15	34-36	3	A-B Axle Spacing
16	37-39	3	B-axle Weight
17	40-42	3	B-C Axle Spacing
18	43-45	3	C-axle Weight
19	46-48	3	C-D Axle Spacing
20	49-51	3	D-axle Weight
21	52-54	3	D-E Axle Spacing
22	55-57	3	E-axle Weight
23	58-60	3	E-F Axle Spacing
24	61-63	3	F-axle Weight
25	64-66	3	F-G Axle Spacing
26	67-69	3	G-axle Weight
27	70-72	3	G-H Axle Spacing
28	73-75	3	H-axle Weight
29	76-78	3	H-I Axle Spacing
30	79-81	3	I-axle Weight
31	82-84	3	I-J Axle Spacing
32	85-87	3	J-axle Weight
33	88-90	3	J-K Axle Spacing
34	91-93	3	K-axle Weight
35	94-96	3	K-L Axle Spacing
36	97-99	3	L-axle Weight
37	100-102	3	L-M Axle Spacing
38	103-105	3	M-axle Weight

Note: The number of axles determines the number of axle weight and spacing fields.

10. **Vehicle Class** (Columns 20-21) - *Critical*

Enter the class of the vehicle from FHWA Vehicle Classes 1 to 13. Classes 1 - 3 are ordinarily omitted.

A dummy vehicle class of -1 indicates that weight data for this hour are missing. A dummy vehicle class of 0 indicates that weight data for this hour are not missing, and thus if there are no Truck Weight records for the hour, then there were no trucks during that hour. Without these indications, no Truck Weight records for an hour might be interpreted to mean that the WIM system was not working.

11. **Open** (Columns 22-24) - *Optional*

This field is for special studies or State use such as for vehicle speed (kilometers per hour) or pavement temperature (degrees Celsius in the range -99 to +99).

12. **Total Weight of Vehicle** (Columns 25-28)

Enter the gross vehicle weight to the nearest tenth of a metric ton (100 kilograms) without a decimal point. This should equal the sum of all the axle weights except for rounding.

13. **Number of Axles** (Columns 29-30)

Enter the total number of axles in use by the vehicle (including any trailers).

The Number of Axles determines how many Axle Weight and Spacing fields will be expected. Axle Weight and Spacing fields that are not needed may be omitted. If a fixed-length record is desired, pad the record with blanks to the desired length.

The rest of the record alternates between axle weights and axle spacings, starting from the front of the vehicle. Axle weights are to the nearest tenth of a metric ton (100 kilograms) without a decimal point. Axle spacings are to the nearest tenth of a meter (100 millimeters) without a decimal point.

Reasonableness checks should be performed on the axle weights and spacings. The default limits in VTRIS are 200 to 20,000 kilograms for axle weights and 0.5 to 15 meters for axle spacings. The user may adjust these values.

14. **A-axle Weight** (Columns 31-33)

15. **A-B Axle Spacing** (Columns 34-36)

16. **B-axle Weight** (Columns 37-39)

17. **B-C Axle Spacing** (Columns 40-42)

18. **C-axle Weight** (Columns 43-45)

19. **C-D Axle Spacing** (Columns 46-48)

20. **D-axle Weight** (Columns 49-51)

21. **D-E Axle Spacing** (Columns 52-54)

22. **E-axle Weight** (Columns 55-57)

23. **E-F Axle Spacing** (Columns 58-60)

24. **F-axle Weight** (Columns 61-63)

25. **F-G Axle Spacing** (Columns 64-66)

26. **G-axle Weight** (Columns 67-69)

27. **G-H Axle Spacing** (Columns 70-72)

28. **H-axle Weight** (Columns 73-75)

29. **H-I Axle Spacing** (Columns 76-78)

30. **I-axle Spacing** (Columns 79-81)

31. **I-J Axle Spacing** (Columns 82-84)

32. **J-axle Weight** (Columns 85-87)

33. **J-K Axle Spacing** (Columns 88-90)

34. **K-axle Weight** (Columns 91-93)

35. **K-L Axle Spacing** (Columns 94-96)

36. **L-axle Weight** (Columns 97-99)

37. **L-M Axle Spacing** (Columns 100-102)

38. **M-axle Weight** (Columns 103-105)

Additional axle spacing and axle weight fields may be added in the same manner if needed.

TRAFFIC
MONITORING
GUIDE
SUPPLEMENT

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U.S. Department of Transportation
Federal Highway Administration
Office of Highway Policy Information

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Section 4S

Vehicle Classification Monitoring

Supplement

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SECTION 4 *SUPPLEMENT*

INTRODUCTION

The 2001 edition of the *Traffic Monitoring Guide* (TMG) expanded Section 4 on vehicle classification and promoted increased traffic monitoring by vehicle class. However, the emphasis was on monitoring truck movements and the special considerations that apply to monitoring motorcycles was not covered. This Supplement to Section 4 addresses this deficiency.

Motorcycles are the most dangerous motor vehicles for both operators and passengers of any age. Moreover, data from the NHTSA's Fatality Analysis Reporting System (FARS) indicate disturbing trends in motorcycle safety:

- In 2006, motorcycle rider fatalities increased for the ninth consecutive year since reaching the lowest level in 1997 from 2,116 in 1997 to 4,810 in 2006 – an increase of 127 percent.
- Trends accompanying the rising motorcyclist death toll include a dramatic increase in motorcycle ownership, particularly by riders over 40, along with changes in other factors such as motorcycle size.
- The rate of increase in fatalities has outpaced the rate of increase in motorcycle registrations.

In order to assess motorcycle safety it is necessary to know the number of crashes as well as the corresponding exposure to determine a fatality rate. One of the key exposures are the motorcycle miles traveled:

- Motorcycle exposure data are used to inform national decisions and establish motorcycle related policies and safety countermeasure programs.
- Motorcycle exposure data are an important part of current safety performance measures, which measure the number of motorcycle fatalities per vehicle registrations and per million miles traveled.
- Motorcycle travel data, especially by roadway functional system, helps the DOT to better understand the distribution of travel and devise effective design and operational measures for both reliable and safe travel of motorist. Motorcycle travel data is a critical element used in developing effective safety countermeasures.

The Highway Performance Monitoring System (HPMS) made it optional for the reporting of motorcycle travel before 2007. Historically, approximately 15% of the States did not report motorcycle travel, and the FHWA estimated for these missing data in the table VM-1, *Annual Vehicle Distance Traveled in Miles and Related Data by Highway Category and Vehicle Type*. **This Supplement revises the TMG to provide guidance to States on the collection and accurate reporting of motorcycle classification data.**

TRAFFIC DATA COLLECTION AND MOTORCYCLES

The *Traffic Monitoring Guide* recommends that a vehicle classification counting program should include both extensive, geographically distributed, short duration counts and a smaller set of permanent, continuous counters. **This guidance is extended to include motorcycle counts for both continuous and short duration counting.**

Permanent counters provide an understanding of how typical motorcycle travel varies by day of the week and season of the year. Permanent, continuously operating, vehicle classification counters (CVC) are the backbone of the vehicle classification program and should be maintained to a high degree of accuracy.

As with traditional traffic volume counting, continuous classifiers must be supplemented by classification coverage counts. A fairly large number of short duration vehicle classification counts should be performed to monitor movements of motorcycles and other vehicle classes on individual roads. They should include data for all lanes and directions for a given location.

Traffic is usually monitored during weekdays while a large portion of motorcycle travel may take place on weekends. The relationship based on continuous classification sites must be developed to adjust for motorcycle undercounting and estimate motorcycle AADT.

The travel patterns for motorcycles are usually different than those for cars or trucks but the data collection plans currently used tend to be structured around understanding the movements of cars and trucks. Motorcycle volume patterns are primarily recreational patterns although commuter travel may be significant in some cases. Motorcycle travel is heavily dependent on the day-of-week (higher on weekends), season (higher in summer), and special events (e.g., rallies).

Some short counts should be taken during rallies and in places where motorcyclists are known to travel. For example, two-lane rural roads without much truck traffic should be counted if there is reason to expect recreational travel. Special events and seasonal travel should be annualized to represent AADT and accounted for in VMT estimates. AVC systems should be placed on recreational routes with motorcycle travel.

Because of the difference between motorcycle travel and that of other vehicle classes, to better estimate the annual average travel by motorcycles on the roads, States should develop a process that factors short duration motorcycle counts, as well as the other vehicle classes. Without adjustment, short duration classification counts yield biased estimates.

A State DOT should be able to provide users with an estimate of the amount of traffic by vehicle class by road segment. Motorcycle volume and percentage estimates should be available for the date when data were collected and as annual average estimates corrected for seasonal and day-of-week variation.

This data collection effort yields the basic motorcycle traffic statistics needed on any given road including the geographic variability and the time-of-day distribution at a variety of locations.

Sufficient locations must be monitored to meet HPMS requirements. Motorcycle travel is reported under the HPMS summary travel as a proportion of total travel by roadway functional class. The State should have motorcycle and other vehicle class travel data for all of the roadway functional classes. If the stations are sufficiently distributed according to road type and by traffic volume, a simple average of the observed proportions from all stations can be reported on the summary travel table (see *HPMS Field Manual*).

In addition to the State and Metropolitan planning and research funds available for traffic monitoring, because of their importance for safety, other funding sources are available under SAFETEA-LU for collecting motorcycle travel data:

- Section 402, State and Community Highway Safety Grants: funds may be used for any highway safety purpose under Title 23.
- Section 406, Safety Belt Performance Grants: funds may be used for any highway safety purpose under Title 23, or for improvement of hazardous roadway locations or features.
- Section 408, State Traffic Safety Information System Improvement Grants: funds may be used only to improve State Traffic Safety Information Systems.

Axle, visual, and presence sensors are most frequently used for collecting vehicle class volume information and each provide a different mechanism for classifying vehicles. Within each of these three broad categories are an array of sensors with different capabilities, levels of accuracy, performance capabilities within different operating environments, and output characteristics. Each type of sensor works well under some conditions and poorly in others. For example:

- Light axle weights, low metal masses, and narrow footprint make motorcycles harder to detect;
- Motorcycles in parallel or staggered formation may confuse detectors;
- Adjusting detector sensitivity for trucks may lead to reduced detection of motorcycles;
- Some combination trucks may be misclassified as a single-unit truck followed by a motorcycle (the rear tandem axle).

Road tubes are relatively inexpensive and provide short, sharp signals but may have a problem with groups of motorcycles. Side looking radar provides length-based classification and detects motorcycles. Inductive loops can work well if properly installed and maintained but they have problems with motorcycles in groups or staggering and are hard to tune for motorcycles. Accuracy can be improved by using inductive loop signature technology. Quadrupole loops also known as figure “8” style loop detectors have enhanced sensitivity for detecting motorcycles, bicycles, and smaller cars.

Sensors that cover a small area such as magnetometers have problems detecting motorcycles or groups of motorcycles. For axle sensors which are staggered a motorcycle will usually hit one sensor but not both; the system will likely record this as a vehicle with a missing axle detection and classify it as a passenger car by default.

All vehicle classifiers need to be calibrated and tested, and it is a good idea to involve motorcycles traveling in groups to ensure that motorcycles are properly counted. It is also advisable to use a test standard such as ASTM E2532-06, “Standard Test Methods for Evaluating Performance of Highway Traffic Monitoring Devices.”

If length-based classification is used, it should accommodate motorcycle identification as one of the groups. Axle sensors, loops, and road tubes which detect the presence of vehicles should be placed in the travel way of motorcycles to assure their detection. Sensors which detect vehicles over the width of a lane are preferable to those that are partial lane.

There are several vendors who claim their automatic vehicle classification (AVC) equipment will detect motorcycles. The proper installation and calibration of the AVC device may be a critical component in its ability to count motorcycles. All vehicle classes are important; no vehicle class should be shortchanged. **It is the responsibility of each agency to make the best decision as to the types of automatic vehicle classifiers to purchase, install, calibrate, and maintain.**

MOTORCYCLE CORRECTION FACTORS

Current practice applies seasonal adjustments to the total volume and then estimates volumes for vehicle types using the observed classification proportions. This will work fine if the traffic profile of all vehicle types is the same as the total volume profile. Otherwise, traffic volume for some vehicle types will be under-estimated or over-estimated.

The day of week traffic pattern for motorcycles differs from that of other vehicle types so short counts for motorcycles need to be factored. The TMG allows flexibility in the creation of day-of-week factors (see page 3-20 of the TMG). It suggests that factors may be computed on an individual basis (seven daily factors) or as combined weekday (Monday, Tuesday, Wednesday, and Thursday) and weekend (Friday, Saturday and Sunday) factors.

In practice, few counts are taken on weekends so the only data available for weekends are from permanent traffic counters and classifiers. This is a problem for motorcycles which may have significant weekend travel on routes or areas that are not near a permanent classifier. **The solution is either to install additional permanent vehicle classifiers or to take class counts on weekends.**

Example

The following example shows how to estimate correctly the annual average daily motorcycle traffic (AADMT). First, take the data from a permanent automatic vehicle classifier and determine the monthly average daily traffic (MADT) for the total volume. The seasonal (monthly) factors are the ratio of the MADTs with the AADT.

Month	Monthly ADT	Monthly Factor
Jan	47,376	1.05
Feb	45,285	1.10
Mar	50,574	0.99
Apr	51,040	0.98
May	51,662	0.97
Jun	52,320	0.95
Jul	51,320	0.97
Aug	52,416	0.95
Sep	50,824	0.98
Oct	51,564	0.97
Nov	49,188	1.02
Dec	45,806	1.09
AADT	49,948	1.00

Next calculate the average daily traffic by vehicle type for each day of the week for the year. Then compute day-of-week motorcycle correction factors (MCF) as the ratio of the annual ADMT and the day-of-week ADMT.

The table shows an example of the annual ADMT by day of week:

Day	**ADMT**
Monday	396
Tuesday	403
Wednesday	405
Thursday	428
Friday	655
Saturday	725
Sunday	483
ADMT	499

1. For the weekday ADMT, add the motorcycle counts for Monday, Tuesday, Wednesday, and Thursday; then divide by four.
2. For the weekend ADMT, add the motorcycle counts for Friday, Saturday, and Sunday; then divide by three.
3. Compute the weekday MCF = ADMT / weekday ADMT.
4. Compute the weekend MCF = ADMT / weekend ADMT.

In this example:

1. Weekday ADMT = (396 + 403 + 405 + 428) / 4 = 408
2. Weekend ADMT = (655 + 725 + 483) / 3 = 621
3. Weekday MCF = 499 / 408 = 1.22
4. Weekend MCF = 499 / 621 = 0.80

So a short class count would first be factored for seasonality and then for the day of week. As an example, at a short term monitoring site on the same route as the above site 10 miles to the south, two class counts were taken on weekdays in August with the following results for motorcycles:

Date	**ADMT**	**ADT**
Aug. 14	518	50,761
Aug. 15	494	51,231
Average	506	50,996

The average of the two counts is adjusted by the seasonal factor for August, which is 0.95:

$$506 \times 0.95 = 481$$

However, this result is low unless it is adjusted by the weekday MCF:

$$481 \times 1.22 = 586$$

So weekday motorcycle counts are increased to estimate the annual ADMT. This takes into account the likelihood of higher weekend motorcycle travel. The other vehicle classes would need to be adjusted for the day of week, too, so that the total volume is correct.

TRAFFIC MONITORING DATA FORMATS

Travel monitoring data should be submitted to the FHWA via the Travel Monitoring Analysis System (TMAS). TMAS includes the monthly volume data for the Traffic Volume Trends and will include vehicle classification and truck weight data that in the past were processed with the Vehicle Travel Information System (VTRIS).

TMAS is accessed via the FHWA's User Profile and Access Control System (UPACS). The UPACS link is: https://fhwaapps.fhwa.dot.gov. For further information on accessing TMAS, contact your FHWA Division Office or the FHWA Travel Monitoring Team.

The record formats are specified in Section 6 of the *Traffic Monitoring Guide*. It is important that the *Station Description Record* be filled out completely because it is required by TMAS. Fields that are not applicable should be blank. In particular, if field 13 is zero, then fields 12, 14, 15, and 16 may be blank; if field 18 is zero, then fields 17, 19, and 20 may be blank.

Field 16 of the *Station Description Record*, the Vehicle Typology (formerly the Classification System for Vehicle Classification), is now a critical field because it will be used to determine the number of vehicle types in the corresponding *Vehicle Classification Records*. A typology is simply the total number of vehicle types with a description of how each vehicle type relates to the FHWA 13-class typology.

For example, a typology based on vehicle length may have 3, 4, or 5 vehicle types, whereas a typology based on axle spacings should have at least the 13 FHWA vehicle classes. *The implied typology for 5 vehicle types now classifies motorcycles as a separate vehicle type.*

16. **Vehicle Typology** (Columns 24-25) - *Critical*

This field indicates the total number of vehicle types used at the station and an implied description of what the vehicle types are. The default value is 13 which indicates the standard FHWA 13-class typology. The value for Vehicle Typology will determine the number of count fields needed on the *Vehicle Classification Records* for that station. If a typology is used that does not match one of these, attach a description of the typology and how it relates to the FHWA 13-class typology.

In the following table the numbers in parentheses refer to the FHWA 13-class typology:

Code	Description
01	One vehicle type: total volume
02	Two vehicle types as follows: Type 1 = passenger vehicles (classes 1-3) Type 2 = trucks (classes 4-13)
03	Three vehicle types as follows: Type 1 = passenger vehicles (classes 1-3) Type 2 = buses and single-unit trucks (classes 4-7) Type 3 = combination trucks (classes 8-13)
04	Four vehicle types as follows: Type 1 = passenger vehicles (classes 1-3) Type 2 = buses and single-unit trucks (classes 4-7) Type 3 = single-trailer trucks (classes 8-10) Type 4 = multi-trailer trucks (classes 11-13)

05	Five vehicle types as follows (*revised*): Type 1 = motorcycles (class 1) Type 2 = two-axle, four-tire vehicles (classes 2-3) Type 3 = buses and single-unit trucks (classes 4-7) Type 4 = single-trailer combination trucks (classes 8-10) Type 5 = multiple-trailer combination trucks (classes 11-13)
06	Six classes as follows (*cf. HPMS Summary Travel form*): Type 1 = motorcycles (class 1) Type 2 = two-axle, four-tire vehicles (classes 2-3) Type 3 = buses (class 4) Type 4 = single-unit trucks (classes 5-7) Type 5 = single-trailer combination trucks (classes 8-10) Type 6 = multiple-trailer combination trucks (classes 11-13)
07 to 11	Number of vehicle classes in the typology (attach a description of how it relates to the 13 classes)
12	FHWA’s 13-class typology except class 3 is missing (i.e., classes 2 and 3 are combined)
13	FHWA's 13-class typology
14	FHWA's 13-class typology plus a class 14 (attach a description)
15	FHWA's 13-class typology plus classes 14 and 15 (attach a description)

FHWA VEHICLE CLASSES

The FHWA vehicle typology separates vehicles into categories depending on whether they carries passengers or commodities. Non-passenger vehicles are further subdivided by the number of axles and the number of units, including both power and trailer units. Note that the addition of a light trailer to a vehicle does not change the classification of the vehicle.

Axle-based automatic vehicle classifiers need an algorithm or “scheme” to interpret axle spacing information and correctly classify vehicles into these classes. The FHWA does not endorse any algorithm or scheme for interpreting axle spacings. Axle spacing characteristics for different vehicle classes are known to change from State to State. As a result, no single algorithm is best for all cases. It is the responsibility of each agency to test and calibrate the classification algorithm they use.

FHWA VEHICLE CLASSES WITH DEFINITIONS

1. ***Motorcycles*** -- All two or three-wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handlebars rather than steering wheels. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheel motorcycles. *Note that this vehicle class is now required*.

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

3. ***Other Two-Axle, Four-Tire Single Unit Vehicles*** -- All two-axle, four-tire, vehicles, other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single-unit vehicles pulling recreational or other light trailers are included in this classification. *Because automatic vehicle classifiers have difficulty distinguishing class 3 from class 2, these two classes may be combined into class 2.*

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

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

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

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

   c. Vehicles are defined by the number of axles in contact with the road. Therefore, "floating" axles are counted only when in the down position.

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

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

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

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

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

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

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

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

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

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

RESOURCES ON TRAFFIC DATA COLLECTION

FHWA Travel Monitoring webpage
http://www.fhwa.dot.gov/policy/ohpi/travel/index.htm

Traffic Monitoring Guide (TMG)
http://www.fhwa.dot.gov/ohim/tmguide/index.htm

Traffic Detector Handbook: Third Edition
http://www.tfhrc.gov/its/pubs/06108/index.htm

Detector Technology Evaluation (2003)
http://www.ndsu.nodak.edu/ndsu/ugpti/MPC_Pubs/pdf/MPC03-154.pdf

Vehicle Detector Evaluation (2002)
http://tti.tamu.edu/documents/0-2119-S.pdf
http://tti.tamu.edu/documents/2119-1.pdf

Portable Non-Intrusive Traffic Detection System (PNITDS)
http://www.dot.state.mn.us/guidestar/projects/pnitds.html

Non-Intrusive Traffic Detection – Phase II Final Report (2002)
http://www.dot.state.mn.us/guidestar/projects/nitd.html

Traffic Monitoring Standards from ASTM International:

- E1318-02 Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Methods
- E1957-04 Standard Practice for Using Pneumatic Tubing for Roadway Traffic Counters and Classifiers
- E2259-03a Standard Guide for Archiving and Retrieving ITS-Generated Data
- E2300-06 Standard Specification for Highway Traffic Monitoring Devices
- E2415-05 Standard Practice for Installing Piezoelectric Highway Traffic Sensors
- E2467-05 Standard Practice for Developing Axle Count Adjustment Factors
- E2468-05 Standard Practice for Metadata to Support Archived Data Management Systems
- E2532-06 Standard Test Methods for Evaluating Performance of Highway Traffic Monitoring Devices
- E2561-07a Standard Practice for the Installation of Inductive Loop Detectors