AASHTO Guidelines for
Traffic Data Programs
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CHAPTER 1

Introduction

1.1 Introduction

1.1.1 Objective

The objective of the guidelines is to improve the quality of the traffic information that supports decisions at all levels of the transportation profession. Traffic data programs are essential for state Departments of Transportation to accomplish their mission of ensuring safety and mobility to the traveling public. Traffic data supports capital investment programs and budgets, as well as effective design and maintenance programs.

This document is a reference for professional traffic monitoring and establishes recommended national traffic monitoring practices that reflect current practice and advances made in the past several years.

1.1.2 Background

The first edition of the American Association of State Highway and Transportation Officials (AASHTO) Guidelines for Traffic Data Programs was developed by an AASHTO Task Force that was formed in 1990 and was composed of members of two AASHTO Committees and representatives of the Federal Highway Administration (FHWA) and the Strategic Highway Research Program. That edition built upon and supplemented the 1985 edition of FHWA’s Traffic Monitoring Guide (TMG).

Since publication of the first edition of the guidelines in 1992, many advances have been made in traffic monitoring procedures, and updated editions of the TMG were published in 1994 and 2001. This new edition of the Guidelines represents a general updating of all material so the content reflects the current state of the art and complements the TMG.

The guidebook is intended for use by state and local transportation agencies, as well as others involved in traffic data programs.
1.2 Principles, Themes, and Emerging Issues for Guidelines

Principles underlying the development of the Traffic Data Guidelines include:

- **A Common Traffic Monitoring Practice**—It is the intent of these guidelines to document common practices for establishing and operating a traffic monitoring program. The intent also is to document common and best procedures, processes, and methods related to all aspects of a traffic data collection program.

- **Practical and Capable Implementation**—The guidelines allow for agencies to easily apply some or all portions to their program. Not all of the documented approaches are appropriate for every traffic program.

- **Oriented Toward Providing Quality Data for Decision-Making**—In designing and implementing a traffic data program, managers should always ensure that quality data are being provided to support decision-making in a transportation agency.

- **A Dynamic Approach to Traffic Data Programs**—Traffic data programs need to be tailored to the needs of customers and applications. The program must be flexible and improved as appropriate while keeping in close contact with users of the data.

In addition to these principles, the new edition of the guidelines highlights:

- **Data Business Plans to Identify Changing Needs for Traffic Data Programs**—Many transportation agencies have recognized that traffic data programs support a growing variety of functions within their agencies. These include performance monitoring and asset management. As these needs grow, so does the potential for conflicting requests from a variety of customers as well as competing needs for more, higher quality traffic data. These needs must be balanced against available resources to implement the traffic data program. An approach to systematically identify all existing and future customer needs and make recommendations as to how to balance these needs with available resources is being used by many agencies.

- **Quality Assurance Throughout the Life Cycle of Traffic Data Programs**—Quality assurance should include actions taken throughout the design, implementation, operation, and maintenance of the traffic monitoring program to ensure that traffic data meet or exceed customer expectations. Data quality actions that are restricted to simply fixing data that already have been collected (referred to as “scrap-and-rework”) are ineffective in the long term because they address the symptom but not the root cause of poor data quality.
1.3 Summary of Traffic Data Programs

Traffic data programs have many facets that can generally be described under the following headings:

- **Who**—Traffic Data Office with assistance from contractors;

- **Why**—To support transportation agency programming, planning, design, and evaluation as well as to meet Federal requirements;

- **What**—Collection of volume, classification, speed, and weight data; and


Figure 1-1 shows a summary of traffic data programs.
1.3.1 Types of Traffic Data

The four principal types of traffic data collected by state data programs are:

1. Volume counts;
2. Classification counts;
3. Speed data; and
4. Weight data.

A combination of the four types of data are collected throughout the year at some sites (continuous) and for shorter periods of time at larger numbers of sites (short-duration).

In the case of volume and classification counts, data at selected sites are collected as nearly continuously as practical throughout the year in order to develop factors (or ratios) that reflect seasonal and day-of-week (DOW) variation in total volume and in truck volume. These factors are then used to convert short-duration counts (or “short counts”) to estimates of annual average daily traffic (AADT) and AADT by vehicle class. In this way, AADT and AADT by vehicle class can be estimated for a large number of roads and used for a variety of purposes while continuous counts are collected at a much smaller, and more manageable, number of continuous count sites.

To provide information about how vehicle weights and axle weights vary over the course of the year, weigh-in-motion (WIM) monitoring is used to collect weight data. However, in the case of weight data, current practice is to obtain detailed data for every vehicle weighed and to limit data-storage requirements by only collecting and saving data for one week each month. Also, procedures for adjusting weight data for seasonal and DOW variations are less developed than those for adjusting vehicle counts;¹ and so annual WIM data are most frequently used only to provide an indication of how weights vary rather than to adjust short-duration data for these variations. WIM data also could provide traffic volume and vehicle classification information if all lanes are instrumented.

Other types of traffic data collected by state and local data programs include speed, travel time, lane occupancy, and vehicle occupancy data. Data collected by these programs are discussed further in Chapter 2.

¹ Procedures for adjusting axle-load data for seasonal and DOW variation have been recently developed under NCHRP Project 1-39. These procedures are described in NCHRP Report 538 (Traffic Data Collection, Analysis, and Forecasting for Mechanistic Pavement Design, 2005) and incorporated in the TrafLoad software, available from NCHRP.
1.3.2 Components of a Traffic Data Program

Consideration of all components as integral parts of an overall data program is essential for the production of quality traffic data. All of these components are considered in the guidelines:

- **Planning of Program**—The program must take into account the customer’s traffic needs and available resources for the program. Once a program is in place, it must be managed and monitored on a continuous basis. Chapter 2 provides more detail.

- **Design of Program**—The design of a traffic data program needs to take into account a variety of details. These include equipment, quality control, summarizing, reporting, and managing the data. These are covered in Chapters 3, 4, 5, and 6 of the guidelines.

- **Collection**—Issues related to the actual collection of data are covered in Chapters 3 and 4.

- **Analysis**—The use of factors and the assurance of quality are covered in Chapters 4 and 5.

- **Reporting**—Methods of reporting data for customer use are covered in Chapter 6.

- **Maintenance**—Data collection devices must be maintained to ensure quality data. This is addressed in Chapters 3 and 6.

1.3.3 Customers and Traffic Data Applications

Traffic data are essential elements in programming, planning, designing, and evaluating the performance of individual roads (AADT and axle-load data) and systems of roads (vehicle-miles of travel, or “VMT”). These elements support a variety of customers, including state department of transportation, metropolitan/local planning, Federal Highway administration (FHWA), and the public.

Specific applications of traffic data include:

- **Programming**—Traffic data are an important element in determining Federal funding allocations. Resource allocation decisions at the state level also rely heavily on traffic data.

- **Capacity and Congestion Analysis**—Estimates of hourly capacity for most roads are affected by the percentage of trucks that they carry, and, except for limited-access roads, by conflicting flows at intersections. Capacity estimates, in turn, are combined with estimates of AADT and peak-period traffic to: optimize signal timing; produce analytic estimates of speed, congestion, and delay; and identify roads on which measures to increase capacity warrant consideration.
CHAPTER 1  INTRODUCTION

- **Traffic Forecasts**—All forecasts of future traffic volumes on an individual road depend, at a minimum, on an estimate of the current traffic volume on the road. Forecasts developed using sophisticated Travel Demand Forecasting Models require estimates of current traffic on the entire system of roads represented in the model.

- **Project Evaluation**—Estimated traffic volumes are required for the evaluation of the expected speed, accessibility, safety, and ride benefits of any proposed improvement to a particular road, and in the comparison of these benefits to those of any alternative improvements to this road or to other roads in the highway system. Estimated traffic volumes are similarly required for the evaluation of the benefits of alternative alignments for any proposed new road.

- **Pavement Design**—Determining the appropriate thickness of a new pavement or an overlay requires a forecast of the total amount of stress to which the pavement will be subject over its life—both the number of heavy axles that are forecast to traverse the pavement, and the stress produced by these axles. In the recent past, data on axle loads were commonly collapsed into a single summary statistic, the “Equivalent Single-Axle Load” (ESAL), and used in that form. However, the new Mechanistic-Empirical Pavement Design Guide (MEPDG) requires more complete data about the numbers of heavy axles by axle type (single, tandem, tridem, etc.), seasonal and diurnal variations in these numbers, and the distribution of weights (or “load spectra”) of each type of axle.

- **Safety Analyses**—The basic statistic underlying nearly all analyses of highway safety is the crash rate—the number of crashes per unit of exposure. When examining all crashes on a road segment or on a road system, the relevant unit of exposure is AADT on the segment or VMT on the system. Similarly, when focusing on crashes involving a particular class of vehicles (e.g., triple trailers), the relevant unit of exposure is AADT (or VMT) of that vehicle class.

- **Emissions**—Vehicular emissions of any pollutant in any area are estimated by multiplying emission rates estimated for each of several classes of vehicle by VMT of that class of vehicle in the area and summing over the several vehicle classes. Techniques also are used to transform vehicle classification data into VMT mix and vehicle registration distributions.

- **Other Applications**—Other applications of traffic data include:
  - Cost Allocation Studies, which estimate the share of highway costs for which each class of vehicles is responsible;
  - Estimating the economic benefits of highways;
  - Preparing vehicle size and weight enforcement plans;
  - Pavement and bridge management systems;
  - Signal warrants;
  - Planning for mitigation of traffic noise; and
  - Site selection for private businesses.
1.3.4 Comparison to the Traffic Monitoring Guidelines (TMG)

The AASHTO guidelines are designed to complement the TMG, though there is a fair amount of intentional overlap between the two documents. The focus of the TMG is on characteristics of traffic data and what data to collect. The focus of the AASHTO guidelines is on how to collect the data and how to process and store it. The following table summarizes the difference between the two documents.

Table 1-1. Comparison of TMG to Guidelines

<table>
<thead>
<tr>
<th>Intended Audience</th>
<th>Traffic Monitoring Guide</th>
<th>Updated AASHTO Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus</td>
<td>Meeting national data requirements.</td>
<td>Meeting customer needs (national, state, and local). Emphasis will be on state programs and coordination with others.</td>
</tr>
<tr>
<td>Author</td>
<td>FHWA (OHPI)</td>
<td>AASHTO</td>
</tr>
<tr>
<td>Contents</td>
<td>Introduction to traffic monitoring, traffic volume monitoring, vehicle classification monitoring, truck weight monitoring, and traffic monitoring data formats.</td>
<td>Same as existing, add: Integrating Operations Data.</td>
</tr>
<tr>
<td>Themes</td>
<td>Improve volume, vehicle classification, and truck-weight data and count programs.</td>
<td>Value/importance of traffic data in decision-making and performance monitoring, improving quality assurance throughout the life cycle of data programs, focus on client/customer needs, and maximizing other sources.</td>
</tr>
</tbody>
</table>
CHAPTER 1  INTRODUCTION

1.4 Structure of the Document

The guidelines are divided into seven chapters:

1. Introduction—This chapter describes traffic data programs in general and lays the framework for the guidelines.

2. Traffic Data Collection Needs—This chapter discusses the role of other traffic data collection guidance. It discusses the use of traffic count data and the specific types of data. The chapter also discusses high-level issues related to estimating.

3. Traffic Monitoring Equipment—This chapter describes issues related to purchasing, using, and maintaining equipment. It includes data collection procedures as well as potential equipment errors.

4. Quality Control and Editing of Traffic Data—This chapter deals with issues such as defining and assessing data quality, performing quality checks, data quality metrics, and describes the components of an effective quality assurance/quality control program.

5. Summarizing Traffic Data—This chapter describes factoring processes and methods to summarize short- and long-term counts.

6. Reporting and Managing Traffic Data—This chapter discusses details related to database tools and traffic data reporting. It also recommends best practices for disseminating traffic data to customers.

7. Integrating Operations Data—This chapter describes the key benefits, implementation issues, and ways of overcoming technical and institutional barriers to integrating operations data.
CHAPTER 2
Traffic Data Collection Needs

2.1 Introduction

Traffic data collection programs vary widely. The scope and execution of these programs are functions of both the needs of traffic data users and available resources. In order for traffic data programs to be run efficiently, annual estimates are needed of the traffic counts that are collected and of the field and office personnel required to collect and publish the data. Data collection agencies should document their needs and perform periodic reviews to identify and make process refinements. This chapter addresses how an agency should estimate its traffic data collection needs.

In designing and implementing a traffic data program, an agency must often balance Federal requirements for traffic data with customer needs while at the same time ensuring efficient resource allocation. The two principal guidance documents for traffic data collection at the national level are the Traffic Monitoring Guide (TMG) and the Highway Performance Monitoring System (HPMS) Field Manual. Both documents are typically referenced in or provide the foundation for a state's Traffic Monitoring System for Highways (TMS/H).

2.1.1 Role of the Traffic Monitoring Guide (TMG)

The TMG, published by the Federal Highway Administration's (FHWA) Office of Highway Policy Information, provides recommendations for developing new or refining current traffic data programs. The TMG's intended audience is state departments of transportation (DOT), with metropolitan planning organizations (MPO), and local transportation agencies as secondary users.

The TMG provides specific examples of how statewide data collection programs should be structured, describes the analytical logic behind that structure, and provides information highway agencies require to optimize the framework for their particular organizational, financial, and political structures. It is the basic document for providing guidance about what traffic data to collect. The TMG is not a prescriptive reference. Instead, it recognizes states' uniqueness and provides a flexible framework for states to develop their programs in a sound statistical manner.
2.1.2 Role of the Highway Performance Monitoring System (HPMS) Field Manual

The HPMS is an integrated database that contains data describing the nation’s highway system. It is used by FHWA for a variety of public purposes, including reports to Congress and the apportionment of Federal-aid highway funds to the states. Data in this database is provided primarily by the states, using procedures specified by FHWA in the HPMS Field Manual. These data include summary traffic data for each state and more detailed data for a sample of highway sections in the state. The HPMS Field Manual is a procedural reference which defines the type of data to be collected, the data format for transmittal, and the sampling rate. Traffic monitoring procedures are based on those presented in the TMG and are discussed in one of the Field Manual’s appendices.

2.1.3 Growing Importance of Operations and ITS Data

Since the 1990s, the role of traffic operations and traffic management and traveler information centers as data contributors to the statewide data collection program has increased. These centers collect large amounts of data in very small time increments—some under one minute. These data typically include volume data, but also may include speed or vehicle classification data. These data usually are not integrated into traffic planning databases. The integration of operations data presents both technical issues and institutional barriers and this lack of integration may represent opportunity losses and higher overall data collection costs as a result of duplication.

2.1.4 Chapter Organization

This chapter is organized into four topic areas: discussion of the types of traffic counts and needs (2.2); process and considerations in estimating the traffic count needs (2.3); mechanisms to reduce count needs (2.4); and estimation of staff and resource requirements (2.5).

2.2 Traffic Count Types and Needs

This section describes the reasons state departments of transportation need a traffic data collection program. It also discusses the basics related to specific types of counts.

Data characterizing the use of public roadways have wide application in engineering, planning, finance, and government. Agencies collect use characteristics by counting traffic volumes, classifying vehicle types, weighing trucks and their axles, and monitoring point speeds. Table 2-1 provides examples of some of the uses of this data.

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State traffic data programs collect and publish information for many customers. Customers range from Federal, state, and local governments to the general public. The primary source of data for these customers is the coverage count program. The coverage count program is the predominant traffic count need. Other needs include Federal/state research initiatives, project-related counts, special count requests, performance measurement counts, and data obsolescence counts. Table 2-2 shows examples of the types of data used by various customers.

### 2.2.1 Coverage Counts

The coverage count program involves the collection of short-term and continuous vehicle weight, classification, volume, and speed data for the production of system-level traffic estimates. System-level refers to traffic estimation for the road system and classifications of roadways, rather than for site-specific traffic estimates. The TMG and HPMS Field Manual provide requirements and guidance for structuring the coverage count program.

Coverage count programs typically include weigh-in-motion, vehicle classification, volume, and speed data collection programs. The short-term coverage count sample size recommended for traffic volume and vehicle classification, is based on a system-wide statistical sample. The short-term volume, vehicle classification, and weigh-in-motion counts, and supplemental counts taken within the special needs part of the program comprise the coverage count program.

**Weigh-in-Motion (WIM)**

Weigh-in-motion systems record dynamic (in-motion) vehicle weights, vehicle classification, volume, and speed. WIM systems require a significant investment relative to other traffic data collection systems. WIM investments include the pavement structure, sensors and electronics, and equipment calibration and maintenance. This automated equipment can collect data continuously or for short-term periods.
### Table 2-1. Examples of Highway Traffic Data Uses*

<table>
<thead>
<tr>
<th>Highway Activity</th>
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<th>Vehicle Classification</th>
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<td>Congestion Monitoring Systems</td>
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<td></td>
<td>of Highway Systems</td>
<td>by Vehicle Type</td>
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<td>Air Quality Analysis</td>
<td>Forecasts of Emissions</td>
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<td></td>
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<td>Type of Vehicle</td>
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<td>Safety</td>
<td>Design of Traffic</td>
<td>Safety Conflicts Due</td>
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<td>Design of Safety Systems</td>
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<td>Control Systems and</td>
<td>to Vehicle Mix and</td>
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<tr>
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<td>Accident Rates</td>
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<td>Average Daily Traffic</td>
<td>Travel by Vehicle Type</td>
<td>Average Weight by Vehicle Class</td>
<td>85th Percentile</td>
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<td>Private Sector</td>
<td>Location of Service Areas</td>
<td>Marketing Keyed to</td>
<td>Trends in Freight Movement</td>
<td>Accessibility to Service Areas</td>
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<td></td>
<td>Particular Vehicle</td>
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<td></td>
<td></td>
<td>Types</td>
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### Table 2-2. Examples of Customer Needs for Traffic Data

<table>
<thead>
<tr>
<th>Customer</th>
<th>Traffic Counting</th>
<th>Vehicle Classification</th>
<th>Truck Weighing</th>
<th>Speed Monitoring</th>
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<td>Site-Specific AADT</td>
<td>Vehicle Mix</td>
<td>Overweights</td>
<td>Speed Distributions</td>
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<tr>
<td>Businesses</td>
<td>Site-Specific AADT</td>
<td>Percent Heavy Commercial</td>
<td></td>
<td></td>
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<td>Advertising Agencies</td>
<td>AADT</td>
<td>Travel Peaks</td>
<td></td>
<td>Speed Distributions</td>
</tr>
<tr>
<td>Realtors</td>
<td>Site-Specific AADT</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Journalists</td>
<td>Busiest Roads/ Times of Year</td>
<td></td>
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<tr>
<td>Developers</td>
<td>Peak-Hour Data</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Tourism Bureau</td>
<td>AADT</td>
<td>Travel Peaks</td>
<td>Vehicle Mix</td>
<td></td>
</tr>
<tr>
<td>Economic Development Agencies</td>
<td>AADT</td>
<td></td>
<td></td>
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<td>Chambers of Commerce</td>
<td>Count Maps</td>
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<tr>
<td>Consulting Engineers</td>
<td>AADT</td>
<td>Turning Movements</td>
<td>Vehicle Mix</td>
<td>Speed Distribution 85th Percentile</td>
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<tr>
<td>University Researchers</td>
<td>Hourly Volumes</td>
<td>Adjustment Factors</td>
<td>Axe Factor</td>
<td>Load Spectra</td>
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<td></td>
<td></td>
<td>Vehicle Mix</td>
<td>Speed Distributions</td>
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<tr>
<td>Traffic Engineers</td>
<td>Hourly Volume</td>
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<td>Hourly Vehicle Mix</td>
<td>85th Percentile 10 mph Pace</td>
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<td>Highway Designers</td>
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<td>Directional Factor</td>
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<td>Safety Engineers</td>
<td>AADT</td>
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<td></td>
<td>Speed Distributions</td>
</tr>
<tr>
<td>Transportation Planners</td>
<td>AADT</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pavement Designers</td>
<td>Future AADT</td>
<td>Truck Mix</td>
<td>Load Spectra</td>
<td>18K ESAL</td>
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<td>Motor Carrier</td>
<td>AADTT</td>
<td>Percent Heavy Commercial</td>
<td>Overweights</td>
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<td>Emergency Operations</td>
<td>Real-Time Volumes</td>
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<td>Centers</td>
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<tr>
<td>Metropolitan or Rural</td>
<td>AADT, AAWDT, AAWET</td>
<td>Percent Heavy Commercial</td>
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<td>Speed Distributions</td>
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<tr>
<td>Planning Organizations</td>
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<tr>
<td>Road and Bridge Authorities</td>
<td>AADT</td>
<td>Vehicle Mix</td>
<td>Load Spectra</td>
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</tr>
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<td>State Environmental Agency</td>
<td>VMT</td>
<td>Truck Classes</td>
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<td>Speed Distributions</td>
</tr>
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<td>State Highway Patrols</td>
<td>Truck ADT</td>
<td>Vehicle Mix</td>
<td>Overweight</td>
<td>Speed Profiles</td>
</tr>
<tr>
<td>State Parks/ Wildlife Agency</td>
<td>AADT</td>
<td>Vehicle Mix</td>
<td>Load Spectra</td>
<td></td>
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<tr>
<td>Legislatures or Assemblies</td>
<td>VMT</td>
<td>Axle and Gross Vehicle Weights</td>
<td>85th Percentile</td>
<td></td>
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<tr>
<td>Tribal Nations</td>
<td>VMT</td>
<td>Vehicle Mix</td>
<td>Load Spectra</td>
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</tr>
<tr>
<td>Federal</td>
<td>VMT</td>
<td>Vehicle Mix</td>
<td>Load Spectra</td>
<td>85th Percentile</td>
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</tbody>
</table>
CHAPTER 2  TRAFFIC DATA COLLECTION NEEDS

Vehicle Classification

The vehicle stream is classified through either manual observation or use of automated equipment. Manual observation by its nature is short-term and is based on the number of axles and the vehicle’s body style. Automated equipment can be used continuously or for short-term periods and classifies vehicles through either axle distances or total vehicle length. Vehicle classification data also can be aggregated to fulfill a volume count requirement. Some automated vehicle classification systems also can provide speed data.

Volume

The most basic form of traffic data collection is the volume count. Volume counts are collected as a combination of continuous counts and short-term counts. Continuous counts are collected from permanently installed equipment in, along, or above the road bed that are operated continuously. Short-term counts frequently are collected through the use of pneumatic tubes gathering axle impulses that are later factored. Short-term volume counts, which can number in the thousands annually, represent the bulk of any coverage count program. Both on- and off-state system roadways should be measured. A more thorough discussion is available in Section 3.3.4.

It is recommended that, when physically and financially possible, vehicle classification counts be taken in place of simple volume counts. While this may slightly increase the cost per count for data collection, the need for truck volume data continues to grow. Most agencies will be well served to collect classification data instead of simple volume data whenever the marginal cost difference between these two data collection efforts is small. (See “Count Nesting” in Section 2.3.1 below.) While in many cases, collecting classification data is not an acceptable option—and therefore a simple volume count is the appropriate data collection choice—agencies are encouraged to increase the percentage of count locations at which classification data are collected in place of simple volume count data.

Speed

Speed data can be captured through automated systems collecting weigh-in-motion, vehicle classification, and some volume data (depending on the equipment used), or by using trailer-mounted radar systems or floating car techniques. Speed data could be reported as an average speed for periods of the day (e.g., morning peak) by day of week, month, or annual average. These would be calculated directly as a weighted average of the daily averages. Speed distributions also can be reported, including percent of traffic exceeding the speed limit. Speed data may be binned when collected and the volume within each speed bin would be used to represent the distribution. Speed data also can be aggregated so that it fulfills a volume count requirement.
2.2.2 Federal or State Research Initiatives

States may participate in cooperative research conducted by the state or Federal government. A Federal example is the Long-Term Pavement Program (LTPP). The data collection discussion presented here for this particular program could be applied to all cooperative data collection efforts supporting research.

Data reported for LTPP include the measurement of traffic on the pavement research lane. For many state agencies, the benefit of acquiring data from all lanes of traffic at a site will outweigh the additional expense of permanent sensor installation or field work on all lanes at the site. LTPP traffic counts, if not included in the coverage count sample, will have to be added separately to the traffic data program. Some states install permanent equipment and other states use portable equipment for LTPP and other ongoing traffic monitoring.

The importance of LTPP to the state’s count program depends on the number of general and specific project sites in each state. It is possible to add LTPP sites to the coverage count sample. For states that have not incorporated LTPP counts into their coverage count program, some or all of the LTPP sites will be an element of the count program.

2.2.3 Project-Related Counts

Agencies typically conduct traffic studies for project-level design if the project is not included in the coverage count program. This effort is an important function of the traffic monitoring program. A shared concern among agencies is to provide the needed quality and quantity of counts to support road project development. Project-related counts are made beyond the needs of the coverage count program. Project-related traffic counts are used widely from planning studies and preliminary engineering to final geometric and pavement design.

To estimate the number of project-related counts, traffic data collection programs should open and foster communications with project development and design engineers. The agency’s annual and multi-year plan (Transportation Improvement Program, Statewide Transportation Improvement Program, Long-Range Plans, or Metropolitan Transportation Plans) for upcoming projects should be reviewed. Input should be sought from the project development and design engineers for the type and timing of traffic data collection needed to support project development. Their responses will provide an indication of the number of counts needed and the general timeframe in which they should be completed. Existing traffic data may be used rather than recounting for highway projects if data have been collected within a reasonable time and can be factored for growth. In most instances, agencies will collect vehicle volume and vehicle classification data. It also should be noted that there is an increasing interest not only in site-specific volume and classification counts, but also in site-specific vehicle weight counts in support of the Mechanistic-Empirical Pavement Design Guide. Successful planning and collection for this component of the count program is dependent upon communication with project personnel.
Project-related counts should be retained and used to produce system-level estimates. If these counts are not used to supplement the coverage count program, greater benefits from investments in these counts are lost.

### 2.2.4 Special Count Requests

Agencies receive requests for counts which are not directly related to coverage, research initiatives, or road projects. Special count requests include rail crossing studies, bridge crossing studies, legislative requests, air quality impact studies, signal timing, traffic flow maps, traffic simulation calibration and validation, signal warrants, site impact studies, and capacity analyses.

It is recommended that state agencies include site-specific traffic data collection as part of all contract and in-house pavement and materials research. If this decision has been or will be reached, these counts should be included in the estimate of special count requests.

A three-year average of the number of special counts taken is recommended to estimate an annual need. To estimate the annual number of special counts:

- List the types of special count requests made of the collection program;
- Record the number of special counts by type and by year within the past three years;
- Average the sums of the past three years of special counts requests; and
- This three-year average of requests is used to anticipate this portion of the count program.

If an agency has changed its policies (such as counts in support of materials research) or cyclical counts are not accounted in the three-year average, these additional requests should be estimated and added to the three-year average.

### 2.2.5 Performance Measurement

Performance measures are “objective measurements and observations to determine the degree of success a project, program, or initiative has had in achieving its stated goals and objectives.” Performance measures are usually focused on tracking inputs, outcomes, or outputs of individual day-to-day elements. Traffic data collection programs may already, or may soon, be asked to support monitoring these measures.

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Data Types

There are three classes of performance measures. First, input performance measures relate to the quantities of resources used to produce goods or services and the demand for those goods and services. Outcome measures are indicators of the actual impact or public benefit of a service. Finally, output performance measures gauge the actual service or product delivered by an agency.4

Traffic data collection programs are likely resources to collect performance data for input and outcome measures. Table 2-3 displays a sampling of the performance measures agencies may be interested in tracking. The performance measures also are classified by type: input, outcome, or output. Some measures may be viewed as satisfying more than one performance type.

When agencies initiate performance measurement, the data collected to support them are considered part of the special count program. Because of the regular monitoring frequency required for these counts, the measurement needs should become part of the annual count projection.

Examples

Florida’s traffic data collection program contributes to several performance measures reported by Florida’s Mobility Performance Measures Program. Some of these measures include person-miles traveled, truck-miles traveled, vehicle-miles traveled, maneuverability, and vehicles per lane-mile.

A regional congestion management process may identify volume/capacity (V/C) ratios as a performance measure. Segment volumes are required to generate these measures. The Southwestern Pennsylvania Commission Congestion Management Process monitors travel time in peak periods, average speeds, delay per vehicle-mile, total delay, and total delay per mile.

An NCHRP report provides additional examples. Washington State monitors system performance for daily vehicle hours of delay per mile, sample commutes measured by delay, and time-of-day distributions of delay. Measuring reductions in peak-period work zone lane restrictions is important to Pennsylvania. Finally, Minnesota monitors their interregional corridors to measure the percent of corridor miles meeting speed targets, and hours and miles of congestion per day.

### Table 2-3. Sample Performance Measures by Type

<table>
<thead>
<tr>
<th>Agency Type</th>
<th>Sample Performance Measures</th>
<th>Performance Measure Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Transportation Agency</td>
<td>Vehicle miles traveled</td>
<td>Output</td>
</tr>
<tr>
<td></td>
<td>Vehicle miles traveled</td>
<td></td>
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<tr>
<td></td>
<td>Vehicles per lane-mile</td>
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<tr>
<td></td>
<td>Truck miles traveled</td>
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<tr>
<td></td>
<td>Person miles traveled</td>
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<tr>
<td></td>
<td>Average travel time</td>
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<td></td>
<td>Person-miles of travel in congested ranges</td>
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<td></td>
<td>Average travel rate</td>
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<td></td>
<td>Growth in annual delay per peak road traveler</td>
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</tr>
<tr>
<td>Metropolitan Planning Region</td>
<td>Average travel time</td>
<td>Output</td>
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<tr>
<td></td>
<td>Travel reliability</td>
<td></td>
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<tr>
<td></td>
<td>Person-miles of travel in congested ranges</td>
<td></td>
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<tr>
<td></td>
<td>Person-hours of travel in congested ranges</td>
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<tr>
<td></td>
<td>Person movement speed</td>
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<td></td>
<td>Total delay</td>
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<td></td>
<td>Person movement</td>
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<td></td>
<td>Delay per vehicle-mile</td>
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<tr>
<td></td>
<td>Total delay</td>
<td></td>
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<tr>
<td></td>
<td>Total delay per mile</td>
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<tr>
<td></td>
<td>V/C ratios</td>
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<tr>
<td>Municipalities</td>
<td>Average travel time</td>
<td>Outcome</td>
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<td></td>
<td>Accident reduction</td>
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<tr>
<td>Managed/HOT/HOV Lane Operator</td>
<td>Person movement</td>
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<tr>
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<td>Vehicle occupancy data</td>
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<tr>
<td></td>
<td>Average travel time</td>
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<tr>
<td></td>
<td>Travel reliability</td>
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<td>Revenue</td>
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<td>Traffic Management Centers</td>
<td>Lane occupancy data</td>
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<td>Average travel time</td>
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<td>Duration of incident</td>
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<td></td>
<td>Time to incident detection</td>
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</table>
2.3 Estimating Traffic Data Collection Needs

An effective traffic-monitoring program includes the collection of short-duration traffic counts, or “short counts,” at a relatively large number of sites, and collection of continuous counts at a much smaller number of sites. Short counts provide information about traffic volumes on a large number of road segments, or “traffic count segments,” over a short time period, typically a 48-hour weekday period, but they do not provide information on average volumes over the course of a year. The principal purpose of the continuous counts is to provide the basis for converting short counts to estimates of annual average conditions at the short-count sites.

Volume counts are collected at all short- and continuous-count sites. Classification counts should be collected at all continuous-count sites and at a significant share of the short-count sites. WIM data should be collected at a more limited number of sites, most or all of which are continuous sites, and all of which also are used to produce volume and classification counts.

The use of one site to produce multiple types of traffic data (volume, classification, and WIM) is referred to as “count nesting.” Count nesting makes efficient use of traffic monitoring resources, since it allows a single site to be used to produce multiple types of data. Also, the more sophisticated equipment used at WIM sites produces more accurate counts than equipment used at other sites (and classification counters frequently produce more accurate counts than volume counters), so count nesting has the additional benefit of improving the quality of counts collected at nested sites.

The first part of this section discusses the data collection sampling plan, the second discusses continuous counts and seasonal factor groups, and the third discusses short counts.

2.3.1 The Sampling Plan

Agencies benefit from having well documented data collection procedures. One document is a formal sampling plan. This document serves as a basis for future program revisions and as a support tool for acquiring and retaining the resources needed. Good process documentation also provides for consistency through periods of staff turnover. A sampling plan for the coverage count program, for instance, should be based on statistical analysis of the system-level data and should properly document the target statistical confidence and precision levels for all relevant systems and for more discrete analysis units (e.g., seasonal factor groups).

The Development Process

In general the steps for developing or refining the sample size for each data type within the coverage count program are:
• Define the Test Statistic—In creating or refining any sampling plan, the test statistic must be identified first. For volume counts, the appropriate test statistic is annual average daily traffic (AADT). Other test statistics of interest include: monthly or seasonal factors from continuous volume sites; axle correction factors for vehicle classification; or, for WIM, gross vehicle weight (GVW) or equivalent single-axle loads (ESAL) for a specified vehicle class. Agencies should seek input from their customers to help define test statistics.

• Define Stratification Groups—Stratification groups may be structured by geography, area type, roadway use, functional classification, volume group, or other criteria important to the agency. Deciding the stratification groups will have a direct effect on the total sample size.

• Define the Statistical Confidence and Precision for the System and Subsystems of Interest—For each test statistic, a statistical confidence interval and precision should be selected. The HPMS Field Manual provides guidance for these levels. Agencies should decide on the confidence and precision levels that they desire to attain for the entire system and for the subsystems of interest. The precision of estimates obtained for an entire system of roadways will be greater than the precision obtained for any subsystems. Estimates obtained for individual strata may be of no interest in themselves, in which case there is no need to specify confidence or precision levels for the strata.

• Process the Test Statistic’s Average and Standard Deviations—Currently available data should be used to estimate averages and standard deviations for the test statistic.

• Calculate the Required Sample Size—The test statistic’s average and standard deviations with the statistical confidence and precision levels are required to calculate the required sample size.

• Determine Additional Sampling Needs for Failed Counts—The required sample size estimates should be slightly inflated to allow for samples that may not be available for the production of system-level estimates due to roadway construction or equipment maintenance. This number is then added to the calculated sample size. Methods are presented later in this section.

**Statistical Basis**

Many agencies collect traffic counts on a 100 percent sample of the higher functional systems and on smaller samples of the lower systems. In both cases, the sample of segments consists of both segments having sites that are continuously monitored and those at which only short counts are collected. That is, for the purpose of understanding traffic (e.g., estimating VMT) on a particular system of roads, data from both types of sites are used.

A particular concern in the sampling of road systems is that the sample be created and maintained in a way that minimizes any bias in the resulting estimates of VMT for the state’s entire road system and for

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5 FHWA. *HPMS Field Manual*, 2000, Appendices C and D.
all subsystems of interest. For this purpose, stratified sampling is useful. The strata that are used should distinguish all subsystems of interest as well as other characteristics that are likely to have significant influences on traffic volumes. Potentially useful strata include:

- Functional system;
- Geographic jurisdictions (such as counties or highway districts);
- Highway ownership (state, county, local, etc.); and
- Number of lanes.6

One of the advantages of stratification is that the strata can be designed to have more uniform values of traffic volume and AADT than the system or subsystems to which they belong.7 This property means that, for a given sample size, a stratified random sample generally will produce better estimates of average AADT for the system and subsystems than will a simple random sample. Also, when stratified random sampling is used, there is no disadvantage to increasing the sample size of certain strata of interest (such as those corresponding to the State Highway System), as long as the sample sizes of the other strata are maintained.

When stratified random sampling is used, the preferred procedure for estimating (daily or annual) VMT for an entire system of roads involves the use of expansion factors. For this purpose, for each stratum, an expansion factor is calculated by dividing the total length of roadway in that stratum by the total length of the stratum’s traffic count segments that have been sampled (and, on which, traffic has been counted). Multiplying AADT on each of the sampled segments by segment length produces estimated (daily) VMT on the segment. Adding the resulting estimates of VMT for all segments in a stratum and multiplying by the stratum’s expansion factor then produces estimated VMT for the stratum. Finally, an unbiased estimate of VMT for the subsystem (or for the entire highway system) is obtained by summing the VMT estimates for all strata of the subsystem.

**Count Nesting**

As noted above, the use of higher data collection systems to provide information for lower data collection systems is termed count nesting. For example, weigh-in-motion systems collect data on weight, speed, total traffic volume, and volume by vehicle class. Thus, in addition to providing WIM data, a weigh-in-motion system can be used to provide a set of speed data, a volume count, and a classification

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6 An alternative to stratification by ownership and number of lanes is stratification by volume group (as required by HPMS). However, stratification by volume group presumes knowledge of the volume group to which all traffic segments belong, which may not hold for the lower functional classes.

7 As an example, consider a road system that has 500 miles of four-lane road and 500 miles of two-lane road. An unstratified random sample is likely to be split close to 50/50 between miles of four-lane road and miles of two-lane road, but, most likely, the split will not be precisely 50/50. Such a slightly uneven split is likely to introduce a small amount of bias into the resulting estimate of VMT for the road system. On the other hand, a stratified random sample can be constructed to have exactly a 50/50 split between the two types of road, thus avoiding this bias. Alternatively, a stratified random sample can be used in conjunction with “expansion factors” (described below) that adjust for any over or undersampling of any of the strata.
count. Likewise, vehicle classification counts also provide volume counts.

Florida uses a simple graphic to convey this nesting, the size of the count program, and method of data collection, as shown in Figure 2-1. The right side, or white area, of the pyramid represents permanent data collection sites in, alongside, or above the road bed that can remotely transmit data back to the office. The left side, or shaded area, of the pyramid represents short-term data collection sites that may use portable equipment or manual data collection. Because WIM is able to collect weight, classification, and count data, it resides at the top and signifies that the information collected can be used for both the classification and count programs. The volume or coverage count program is limited to vehicle volume and cannot be used to supplement the classification or WIM programs, thus representing the basic foundation for traffic data collection.

![Figure 2-1. Example of Count Nesting.](image)

Count nesting allows the number of required counts to be reduced, eliminating redundancy, improving overall efficiency of the traffic data collection program, and freeing resources to be invested elsewhere.

**Random Selection**

Sample bias is eliminated through random selection of traffic count segments. Random selection is performed most efficiently using electronic maps that provide the necessary roadway attributes. These attributes include functional class, ownership (state, county, city, etc.), and area type (rural, small urban, or urbanized). If key attributes are not available electronically, the process becomes less efficient, and comparisons of hard copy maps may be required. The random selection process also may be structured

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so that road segments are numbered, and a random number generator used to select potential segments for the sample.

The list of potential segments may be reported as randomly selected. If random selection is automated, sample selections should be spatially sorted in sequence by road. As an example, the sample may be printed by road and milepoint. This will facilitate the review of the potential segments, selection of the final sample, and scheduling of coverage counts.

There are cases in which random selection cannot be used. The phrase “potential segments” is used to emphasize that the randomly selected segments must be reviewed for appropriate field data collection. Effort is required to validate the physical condition of randomly selected segments for their appropriateness for data collection. Most potential segments will include sites that are appropriate for use as volume-count sites, but not necessarily for WIM sites or even for classification sites (as discussed in the next subsection). It may be prudent to generate 10 percent more potential segments than that indicated by the sample size determination. Alternatively, roadway segments may be sampled without replacement, and additional segments randomly selected if required.

**Classification Sites and WIM Sites**

The above discussion of selecting sample segments and monitoring sites ignores some practical considerations that affect WIM and classification sites.

**Classification Counts and Classification Sites.** The principal purposes of classification counts are to learn how vehicles are distributed among vehicle classes and for developing axle factors for converting axle counts collected using road tubes into vehicle counts. For these purposes, the best information is road-specific information.

Ideally, all traffic counts would be classification counts, so that roadway agencies can fully understand the truck volumes on their roadways. While this is currently impractical, classification count data should be collected whenever practical. At a minimum, classification counts should be collected periodically on all roads in the higher functional systems. In the case of longer roads on which vehicle-class distributions are likely to change over the length of the road, these counts should be collected at multiple sites on the road. Short-duration classification counts should be factored using class-specific seasonal and day-of-week (DOW) factors (as described in Section 5.3.3) to produce estimates of AADT by vehicle class (VC). For each classification count, these estimates, in turn, are used to produce distributions of AADT by VC that are used on the same road (or on nearby parts of the road) to distribute estimates of total AADT over the vehicle classes.

For the lower functional systems, it may be impractical to collect classification counts on all roads. For such roads, the recommendation is that roads in a given area and functional system that are believed to
have reasonably similar vehicle-class distributions be grouped. For each of these groups, one classification count site should be identified and measured to derive a group axle factor and a set of distributions of AADT by VC for use at other short-term volume count sites within the same group.

The above discussion has some implications for selecting sites within a traffic count segment at which volume and classification counts are collected. Accuracy requires that continuous classification counting be performed only at locations where vehicle speeds are as constant as practical (minimum acceleration and deceleration). Although this requirement is less applicable to short-count sites where only volume counts are collected, it is still desirable to apply it, if practical, when selecting a site for volume counting on a traffic count segment. Such a site would have the advantage of also being usable for classification counting if it is subsequently decided to collect classification counts on the segment.

WIM Sites. The considerations affecting WIM sites are somewhat more complex. It generally is inefficient to select WIM sites at random. WIM sites are relatively expensive to establish and maintain, and they require strong, smooth, level pavement and straight sections of road. For this reason, it is generally efficient to install new WIM sites only as part of resurfacing projects, and the particular sites considered for such use should be limited to those that meet the criteria for producing reliable WIM data. Once WIM equipment has been installed at a particular site, it generally should be used as a source of WIM data as long as the site continues to meet the data accuracy criterion set by the collecting agency and is confirmed by periodic calibration validation tests.

In order to make the maximum use of data from a new WIM site, any such new site should be used to provide volume and class data as well as WIM data. If a new WIM site is located on a traffic segment which is already part of a volume-count sample, then the new site simply replaces the existing site in the sample. If not, it is recommended that the new site replace an existing site belonging to the same stratum and, to the extent practical, having seasonal and day-of-week variations in traffic volume that are similar to the new site.

Since WIM equipment generally produces higher quality classification data, WIM sites should be operated as continuous classification sites. For this purpose, the WIM sites are simply added to the appropriate classification-count seasonal factor group. Also, if the data collection sensors continue to function correctly, WIM sites should continue to be used as sources of continuous classification data after being retired as WIM sites.

Field Review for Site Adequacy

Site adequacy is a paramount consideration in the deployment of both permanent and short-term data collection devices. The field crew manager or assigned staff should review the randomly selected potential sample segments to determine if they contain sites that are adequate for field data collection. It is important to recognize that simply identifying a road segment for sampling does not guarantee that an
appropriate traffic count site exists on the segment. Agencies should develop a list of minimum standards for each data type. These minimum standards may be based on manufacturer specifications or organized technical standards, such as those produced by the American Society for Testing and Materials.

The field review should evaluate the geometric and operational characteristics of the roadway. Randomly selected segments may be on a horizontal curve, making them unsuitable for vehicle classification. Similarly, the speed of vehicles on part or all of a randomly selected segment of roadway may be outside the manufacturer-specified speed range for some vehicle classification devices. As previously noted, many automated data collection systems do not collect accurate data under congested traffic conditions. These conditions are unsuitable for vehicle classification and WIM systems. Site reviews should also include roadway surface characteristics. Other considerations that should be included in site review may include equipment tie-down, and the availability of telephone lines and power supply. Safety and equipment limitations also should be reviewed on a site-by-site basis.

The site review can use existing engineering plans and other sources, but physical inspection of potential sites is recommended. A photo video system may be helpful in the process of reviewing randomly selected traffic monitoring segments, but such a system is not an adequate replacement for physical inspection of the segment.

Based on the review, the field crew manager or assigned staff may delete potential segments which do not contain any acceptable sites. The reason for deleting potential segments must be documented and provided to the Traffic Data Program Manager. Documentation can be via a printed form or via other recorded notes identifying the characteristics that failed to meet minimum standards. The end product of this process will be a randomly selected sample acceptable for field data collection.

**Failed Counts—Machine/Collector Error or Malfunction**

Sampling plans should provide for extra samples so that the desired statistical confidence and precision can be maintained even if there are a few failed counts. It is not uncommon for machines or staff to generate data errors.

The number of failed short counts must be estimated so that these counts may be rescheduled without disrupting the data collection program. Existing records should be used to estimate the rate of failed counts for both short-term and continuous data collection. Estimates of failed short-term counts can be derived from completed schedules, contractor invoices, or machine repair logs. Estimates of extra samples for failed counts can be made from these historical records; e.g., by using a three-year average of the failure rate.
Periodic Review

The goal of every traffic data collection program is the production of useful data for its customers. Periodic adjustments to the plan are necessary to reflect the effects of changes in the highway system and in the use of various roads and also to incorporate improvements in traffic monitoring procedures. It is recommended that traffic monitoring plans be reviewed at least once every five years. These reviews should include a review of the seasonal factor groups and factoring procedures used, the continuous monitoring sites providing data for these procedures, and the size and distribution of the short-count sample.

2.3.2 Continuous Counts

The principal purpose of continuous counts is to provide data on how traffic volumes vary by time of year and by day of week. These data are used to convert short counts into estimates of AADT and AADT by vehicle class (AADT by VC). Continuous counts also are used to produce estimates of growth in traffic that are used to adjust AADT estimates developed in one year for growth in subsequent years.

In order to obtain reliable estimates of the seasonal and DOW patterns in traffic volume (or truck volume), continuous counts should be collected on roads that have moderate to high traffic volumes. Patterns on roads that have low traffic volumes are more likely to be affected by random events than patterns on higher volume roads.

For the purpose of estimating AADT, each continuous count site and each short-count site is assigned to one of several seasonal “factor groups.” Data from continuous counts collected at sites in a given group is then used to develop a set of seasonal and DOW adjustment factors that are used to convert short counts obtained at other sites in the group into estimates of AADT and AADT by VC. Current procedures for forming seasonal factor groups focus on total traffic volume and estimates of total AADT, although the same factor groups usually are also used for developing factors to be used in developing estimates of AADT by VC.

The development of seasonal and DOW factor groups is discussed below. The computation and application of seasonal and DOW volume and vehicle-class factors and ratios is discussed in Section 5.2.1.

In developing factor groups, two goals should be kept in mind:

• To the extent practical, all sites in a given seasonal factor group should have reasonably similar seasonal and DOW patterns in traffic volume; and

• To the extent practical, factor groups should be distinguished from each other on the basis of roadway characteristics (such as functional class, location, or roadway direction) that can be applied to road segments for which little or no previously collected traffic pattern data are available.
It is recommended that most seasonal factor groups contain five to eight continuous count sites. However, seasonal factor groups, such as recreational groups, that contain relatively few short-count sites may be defined using data from fewer continuous count sites. In order to minimize the number of continuous count sites required, seasonal factor groups should only be distinguished from each other if they have seasonal and/or DOW traffic patterns that are at least moderately different from each other.

**Developing Seasonal Factor Groups**

In defining a set of seasonal factor groups, the principal goal is to group sites that have seasonal patterns in traffic volume that are as similar as practical and DOW patterns that are as similar as practical. Factors developed using data from continuous sites at which traffic volumes drop on weekends (typical of rural roads carrying relatively little long-distance traffic) should not be applied to short counts collected at sites at which volumes tend to rise on weekends (typical of rural roads carrying significant amounts of long-distance traffic).

Some observations that are useful in defining seasonal factor groups are:

- In rural areas, DOW variation usually differs between the interstate system, which tends to have high through volumes) and the non-interstate system (with lower through volumes);

- Differences between seasonal and DOW patterns on the various non-interstate system rural functional systems are small and probably do not warrant separate seasonal factor groups for the different functional systems;

- In some large states, seasonal variations in volume on rural roads may differ in different parts of the state and may warrant separate rural factor groups that are defined geographically;

- Roads in recreational areas usually have seasonal and DOW patterns that warrant separate factor groups. In some states, these roads warrant separate recreational groups for different peak travel periods (summer, winter, fall foliage, etc.);

- In urban areas, interstate system and non-interstate system roads are frequently assigned to separate factor groups, though the seasonal and DOW variations on the two systems usually are quite similar;

- In urban areas, it may be worth distinguishing between roads that tend to have relatively low weekend volumes (e.g., those serving employment centers that have little activity on weekends) from roads serving shopping areas and other areas with significant weekend activity; and

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9 This goal suggests that it might be desirable to assign road segments to factor groups on the basis of the predominant use(s) of the segments. However, such a system of assignments is relatively difficult to implement because roadway uses generally do not correlate with readily observable roadway characteristics (such as functional class). Also, it should be observed that similar road uses (such as transport of different crops) do not necessarily mean that seasonal patterns of traffic will be the same (since different crops may have different harvest seasons).
• There may be some value in establishing separate ("semi-urban") factor groups for small urban areas and/or for the urban fringe of major urbanized areas; the latter groups might include roads located near the edge of urbanized areas and on either side of the boundaries of these areas.

**Issues Relating to the Development of Seasonal Factor Groups**

**Similarity of Seasonal and DOW Patterns**

Factoring procedures work best when all sites assigned to a given seasonal factor group have seasonal and DOW patterns of traffic volume that are reasonably similar. However, in practice, this degree of similarity is not always attainable. There will almost always be some sites that have volume patterns that do not fit well in any group; and some short-count sites may be inadvertently assigned to the wrong group. Such poor assignments have disadvantages for both short-count sites and continuous count sites.

In the case of short-count sites, a poor assignment adversely affects the quality of the AADT estimates that are produced for the site by the factoring procedure. For example, if a site at which traffic volumes rise on weekends is assigned to a group that otherwise consists entirely of sites at which volumes drop on weekends, AADT estimates produced by factoring weekday counts collected at the site will be downwardly biased.

As a somewhat different example, consider a site on a recreational road on which traffic peaks during the fall foliage season and assume that this site is assigned to a recreational group whose factors were developed from continuous count sites on roads with summer peaks. For such a site, AADT estimates produced from factored counts taken during the summer will be downwardly biased, while AADT estimates produced from factored counts taken during the fall peak will be upwardly biased. For such a site, AADT estimates produced from factored counts taken during the spring are likely to be better; but, for various reasons, these estimates also may not be very good.

In the case of continuous count sites, poor assignments indicate a factor group that has been defined in a way that results in the inclusion of sites that have moderately dissimilar seasonal and/or DOW patterns of traffic volume. For such a group, it may not be possible to achieve the precision level for the seasonal and/or DOW factors recommended by the TMG (pages 3-47 to 3-48) without increasing the number of continuous monitoring sites above eight. This deficiency can be addressed either by redefining the factor group (possibly by splitting it) in order to increase the similarity of the seasonal and DOW patterns, by increasing the number of continuous sites belonging to the group or by forming different factor groups for seasonal versus DOW factor types.

If practical, it is preferable to redefine the factor group. Increasing the similarity of the traffic patterns will reduce or eliminate the number of short-count sites in the group that have seasonal or DOW traffic patterns that are atypical of the group. Since poor estimates of AADT are more likely for sites with atypical traffic patterns, reducing the number of such sites is a desirable goal of any traffic monitoring program.
The second alternative, increasing the number of continuous count sites belonging to the group, improves the precision of the factors used for the group and thus improves the resulting estimates of AADT. However, only slight changes are likely in the AADT estimates for sites with atypical traffic patterns, and not all of these changes will be improvements.

The third alternative, forming separate seasonal and DOW factor groups, allows continuous count sites to be assigned independently to seasonal and DOW factor groups. This approach solves the problem of continuous count sites that have different seasonal and/or DOW characteristics from other sites within the group, while increasing the complexity of forming the groups.

The appropriate number of factor groups to establish depends on circumstances, including available resources and the degree to which different seasonal and DOW patterns in volume are readily distinguished.

**Recreational Roads**

The development of procedures for monitoring traffic on recreational roads presents some issues alluded to above that can only be partially solved under the typical resource constraints applied to Traffic Monitoring Systems.

One issue is the number of recreational groups to be distinguished. Recreational roads differ both in the timing of their recreation-season peaks and in the intensity of these peaks. Some states define two or three recreational groups representing the different peak seasons for recreational traffic in the state. Other states have only a summer recreational season, but define separate groups for “high summer” and “moderately high summer.” In concept, some states could create separate “high” and “moderately high” groups for each of several peak seasons, but establishing that many groups is likely to stretch available resources. In general, states simply accept AADT estimates for recreational roads that are less reliable than estimates for other roads. Since the resulting errors in AADT estimates for different recreational road sections are likely to partially cancel each other out, and since VMT on recreational roads generally is a fairly small part of statewide VMT, these errors are generally considered to have an acceptably small effect on estimates of statewide VMT.

A second issue relates to the assignment of sections of road containing short-count sites to recreational groups. These assignments generally are made on the basis of local knowledge of whether or not the peaking characteristics of traffic on these road sections follows a recreational pattern. In some cases, extending a short count to include a full weekend during the recreational season could be helpful in determining whether or not a site carries significant amounts of recreational traffic (and whether it should be classified as “high” or “moderately high” recreational); volumes on rural non-Interstate System roads generally drop on weekends, but, on recreational roads, these volumes rise on weekends during the recreational season.
CHAPTER 2  TRAFFIC DATA COLLECTION NEEDS

Truck Weight Roadway Groups

For the purpose of collecting data on vehicle weights, the 2001 TMG recommends that each state divide its road system into truck weight roadway groups (TWRG) with the average gross weights of trucks in a given class being reasonably similar on all roads in the group. The TMG suggests establishing between 2 and 10 TWRGs, depending on the size and diversity of a state’s roadway system.

A basic set of TWRGs for a state with relatively little geographic diversity might consist of three TWRGs: urban; rural Interstate System; and rural other. For this set of TWRGs, it is recommended that all WIM sites in the urban TWRG be located on the urban Interstate System, and all WIM sites in the rural other TWRG be located on the rural other principal arterial system. There are several reasons for this last pair of recommendations. In general, WIM data are of greatest interest when designing pavements for the higher functional systems. Also, axle loads and the resulting pavement stresses are likely to decline as one moves to lower functional systems, so it is a conservative approximation to use WIM data collected at sites on a high-functional system when analyzing pavement stresses at a site on a lower system. Finally, in urban areas, most of the appropriate locations for WIM sites are likely to be on the Interstate System. The formation of TWRGs is discussed further in Section 5 of the TMG and in NCHRP Report 538.10

If practical, there should be between three and eight WIM sites in a TWRG. However, one or two WIM sites may be used for some small TWRGs. Three sites is the minimum number necessary to provide some confidence that all sites in the TWRG have reasonably similar load spectra. On the other hand, as the number of WIM sites in a TWRG grows, opportunities also grow for splitting the TWRG so as to produce smaller TWRGs, each with more uniform sets of load spectra. Since it is difficult and expensive to calibrate portable WIM equipment, it is recommended that all WIM sites use in-pavement sensors. It also is recommended that the design lane of all WIM sites be monitored for at least one week per month throughout the year. The TMG recommends that all new WIM installations have WIM coverage in at least one lane in each direction, and that each TWRG contain a minimum of one site with WIM coverage in at least two travel lanes in each direction.

2.3.3 Short Counts

The two principal types of short count are coverage counts and special counts.

For purposes of traffic counting, all roads should be divided into traffic count segments (also called “traffic segments” or “traffic sections”), with traffic volumes on each segment being reasonably homogeneous. On limited access roads, traffic count segments should extend from interchange to interchange. On other

roads, the TMG recommends (pages 3-9 to 3-10) that, except in the case of the lowest volume roads, traffic volume on each segment remain within a range of plus or minus 10 percent. For very low-volume roads, the TMG suggests that a wider range may be appropriate. Traffic segments need not be broken at urban/rural boundaries or at jurisdictional boundaries. For the purpose of factoring, judgment should be used in choosing the seasonal factor group to which a segment that crosses an urban/rural boundary is assigned.

For each highway system and subsystem of interest, coverage counts are collected periodically on a sample of traffic count segments to estimate VMT on the system and to provide a more general understanding of traffic on the system. The size of each sample is determined by the highway agency and reflects both the availability of resources for collecting these counts and the agency's intended uses of the data. Many state highway agencies (SHA) collect coverage counts on a 100 percent sample of the interstate system, and a few collect coverage counts on a 100 percent sample of the entire State Highway System (SHS).

Although not explicitly stated, all traffic count segments on which continuous count sites are located are part of the coverage count sample. Most other traffic count segments in the coverage count program are counted for short periods of time (“short counts”) once every few years, with growth factors used to adjust all estimates of traffic on the segment for changes in traffic volume that are likely to occur in intervening years. For specific segments, frequency of counting may vary with the importance of the segment. The TMG recommends that most segments be counted at least once every six years, with important segments and those experiencing unusual changes in traffic volume counted more frequently. FHWA requires that HPMS sample and universe sections be counted at least once every three years.

For planning or design purposes, agencies frequently require traffic data that are not produced by the coverage count program. These needs are met by collecting special counts. Such special counts may meet needs for: counts on segments on which coverage counts are not collected; detail that is not provided by the coverage counts (e.g., classification counts on segments on which only volume counts are available); or more accurate estimates of current traffic volume than can be obtained by applying a growth factor to a five-year-old count.

### 2.3.4 Estimating Overall Data-Collection Needs

In order to estimate the overall data collection needs, one should sum the count needs for the coverage count program defined by the sampling plan, research initiatives, roadway project development, special counts, performance measures, and replacement counts for field failures to estimate a comprehensive traffic count total for the year. The count needs should distinguish data type and collection method for later estimates of staff and resource needs.
2.4 Reducing Traffic Data Collection Needs

Traffic data collection needs can be reduced by means of count nesting and other multipurpose uses of sites, cooperative data sharing, identifying obsolete sites, and managing special counts. Count nesting was discussed earlier in this section, and cooperative data sharing (with substate jurisdictions and with neighboring states) is addressed in a subsequent section.

Over time, data collection sites may cease to meet their original mission. Texas aggressively reduced the number of its short-term volume counts. Many of the short-term volume locations had been selected previously to fill needs that were rarely documented. Over time, these count locations were perpetuated through tradition, and their original purpose lost. Texas eliminated almost all sites having 24-hour volumes below 300 and not at bridges and at railroad at-grade crossings. These counts were replaced by volume counts at a statistical sample of sites in five types of area (rural unincorporated, rural incorporated, small urban, small urbanized, and large urbanized). The randomly selected count locations result in statistically valid mean values that are used to estimate volumes on road segments for which no counts are performed.

2.4.1 Managing Special Counts

A helpful way to manage demand for traffic data collection is to establish and enforce procedures for responding to special count requests. Some special requests may be satisfied by using existing traffic data without requiring a new traffic count. Prior to scheduling and collecting a special count it should be determined whether a count was taken recently on the same segment and if the customer will accept either observed data or estimated data from the past count. In general, except for areas with significant changes in traffic patterns and volumes and roadway characteristics, data from counts collected within the past three years and factored for growth should be adequate for most planning needs.

2.5 Estimating Staff and Resource Requirements for Traffic Data Collection

This section will assist in assessing current resources and guiding the delivery of new programs and resource needs. As discussed below, state traffic data programs use a mixture of agency and contract forces. In an ideal situation, an agency can design a program from scratch and estimate required resources accordingly. However, in most cases, a traffic count program manager is faced with tailoring the program’s counting capacity to its available financial or FTE resources. This section suggests guidelines for estimating staff and contracting requirements for a typical count program. Needs will vary significantly for different programs. A careful assessment of customer needs for the traffic program is highly recommended.

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2.5.1 Agency Forces

The types of staff required to manage a traffic count program include collection staff, inspectors, office support, and site installation/maintenance support. These positions are discussed in more detail below.

Collection Staff

The productivity of collection staff is influenced by several factors. Staff are limited in the number of counters they set each day by the complexity of the equipment, coordination with traffic control, travel time between count locations, and the crew vehicle’s capacity for transporting counters and supplies. Efficient count scheduling can maximize staff productivity. The following subsections discuss the factors that must be considered in determining collection staff resources. The guidance could be used in establishing a new program or maximizing the productivity of an existing one.

Counters Set per FTE

Short-term data collection relies on field staff to deploy and retrieve the equipment and the collected data. The number of full-time employees (FTE) required to conduct a given number of annual counts (agency productivity level) depends in part on the number of counts that each FTE can take in a week.

The agency productivity level is dependent on several factors, including the devices used, roadway cross section, safety factors, and even work schedules. Following are some examples:

- Multilane facilities require more than one counter for each data collection site.
- An agency estimate of field personnel productivity should consider the number of persons in a field crew.
- Vehicle classification devices require somewhat longer to set up, adjust sensor distance, and calibrate.
- Portable WIM devices are more difficult to set up and monitor, even if the devices have self-calibrating features.

After estimating unique agency productivity levels, the next step is to identify the number of weeks during the year in which traffic counts may be conducted. Because of different prevailing weather conditions, the available weeks will vary among states. The number of available weeks for counting establishes the number of weeks each year that each FTE may be employed in meeting traffic data collection needs.

The anticipated number of weekly FTE counts is then multiplied by the number of weeks available for counting during the year. This is the estimated annual productivity for each FTE. Separate estimates of FTE productivity should be developed for volume, classification, and WIM counts. Dividing the annual FTE productivity into the estimated number of traffic data counts produces the number of FTEs
needed to meet data collection needs. The benefit of this approach is that it ties traffic data collection FTEs to specific data collection needs. Increases or decreases in field personnel should be directly related to specific data collection needs rather than being adopted independently of specific elements of the traffic data program. Often agencies are faced with applying FTEs according to resource availability rather than having the luxury of assigning an unlimited number of FTEs.

**Travel Time**

Travel times between count locations directly influence the number of counts taken each day. Productivity can be enhanced by arranging count schedules that minimize distances between count locations. Because urban count locations are more closely spaced than rural locations, productivity in urban areas could be twice that in rural areas.

Agencies that operate centralized data collection systems—where collection staff are all based in a single central location—are subject to productivity losses due to the travel times between this location and the areas where the counts are to be collected. Lower travel times can be obtained if there are several separate data-collection teams based at district offices in various parts of the state.

**Vehicle Capacity**

Deployment of short-term data collection equipment is limited by several factors, including the cargo capacity of the transport vehicle and the size and number of counters and materials. A factor in weekly FTE count productivity is the vehicle fleet used to transport traffic volume and classification devices. For example, if an agency uses a van to transport traffic recorders, the vehicle may not be capable of hauling more than 50 portable devices, tubes, and tools for installation and calibration.

**Inspectors**

Inspectors are required to ensure that short-term data are collected on the scheduled dates, at the proper locations, with equipment that is properly placed, using appropriate worker safety procedures, and that data collection is properly performed.

Each agency should define the minimum level of inspection for their short-term counts and inspections should be scheduled randomly. This may include inspections during overnight periods if manual crews are responsible for data collection. Agencies may require more frequent inspection of new contractors, while the agency builds trust in the contractor’s performance.

**Safety Considerations**

Attention should be given to all work schedules to guarantee worker safety. Additional staff may be warranted in certain conditions—high-volume roadways, high-crime locations, and under certain geometric sections where sight distance may be limited.
Office Support

Office support staff play an important role in traffic data collection. Office staff are responsible for scheduling routine traffic counts and special requests, for reviewing and processing incoming data, for generating reports, and for processing contractor billings. Central offices also typically have staff that repair equipment.

Count Scheduling

Efficient count scheduling is an important factor in maximizing field data collection productivity. Successful traffic data collection programs strive to improve the efficiency of their count scheduling process. Office staff are needed to produce annual and special count data collection and maintenance schedules for both state and contract forces. Constant communication between the staff scheduling counts and the data analysts is vital. Analysts and collection personnel should know and understand each others’ needs and limitations. This communication will produce reasonable expectations and prevent misunderstandings.

To schedule traffic counts, agencies will find it helpful to map the count locations and to group all routine coverage counts by geography or roadway route and by time of year. Also, when practical, special counts should be scheduled to occur when coverage counts in the same area are being collected. If possible, deferring or advancing special counts for this purpose also will help to reduce program costs.

Schedules prepared by decentralized systems may have one FTE perform this function with other routine duties at each remote location.

Initial Processing of Data

Data collected either through machine or manual processes will be submitted to or retrieved by the agency. Though the use of computers and communications to poll telemetry sites is common, the data must be packaged, reviewed for completeness, screened for accuracy, and transmitted by data collection office staff to the data analysts. Problems or errors identified in this initial screening may be resolved by the screeners or passed on to others for further analysis and action.

The same staff also may be responsible for processing contractor billings. This function involves verifying contractor production against submitted bills, and approving bills for payment.

Production of Traffic Data

The staff resources required to produce and publish traffic data are as important as the resources dedicated to collecting the data. The number of office staff required are proportional to the number of traffic counts made annually. For comparison, data analysis and report production in one small state has six staff where in one large state eight staff are used.
Agencies maintain enough staff to produce annual reports, though agencies may desire additional staff to perform more in-depth research or studies of its traffic data to uncover new trends or identify unique characteristics. Without adequate analysis staff there is little or no time for these endeavors.

Agencies should strive to cross-train staff to avoid creating data analysis “silos.” This is especially important for agencies with a staff nearing retirement or where there is a trend of increasing turnover. Staff are one of an agency’s greatest assets and loss of institutional memory can have severe impacts on the program’s efficiency.

Agencies may find efficiency gains by assigning staff to defined regions. For example, Texas assigns two FTEs for each third of the state. There are several advantages to this staffing approach. Staff become familiar with the seasonal and annual characteristics within their assigned region. Staff work with all data types and gain proficiency. If vacancies occur on other regional teams, staff can be shared between regions to ease the vacancies’ impact. One disadvantage to consider for cross-training is that the ability to maintain analysis consistency, or to reduce the variability of professional judgment, is reduced or lost with many analysts if business rules for traffic monitoring are not developed and followed.

Some agencies are beginning to create large database systems with defined business rules to identify suspect data for further review. These systems free valuable staff time to concentrate on those counts that fall outside of normal ranges. Agencies should document the business rules used by staff when exercising their professional judgment. These documented business rules can then be programmed so that software programs or database queries can be built. These systems require a significant investment, but can provide agencies with greater staff productivity and the possibility of conducting nonroutine research work to improve their traffic data program.

Site Installation/Maintenance Support, Including Inspectors

High-quality traffic data are a product of both a strong sampling plan and aggressive maintenance programs for continuous count sites. Agencies should strive to identify mechanisms that promote efficiency and improve maintenance response. For centralized programs, efficiency can be gained through cooperative agreements with other agency staff in remote areas performing light maintenance work. Some states use a decentralized model where technicians are assigned regional work areas and are responsible for maintaining sites within their region. If contractors are used to perform maintenance, agencies will require a more modest level of resources for inspecting and verifying contractor performance.

Maintenance and repair of portable equipment is usually performed at a central facility.

States may benefit from support mechanisms, such as regional or district assistance from state DOT offices or the use of contractors, for data collection equipment installation and, more importantly, maintenance. The benefits of using local staff are travel time and overnight travel cost savings for centrally located staff to conduct minor or routine maintenance functions.
It is important to note that well-trained inspectors play just as an important role in monitoring the installation of permanent count stations installed by contractors. Remote staff that perform part-time inspector duties can be trained by central staff to ensure quality installation or maintenance is performed.

**Estimation Procedure**

The state force staff estimate is the sum of the field data collectors; field inspectors; office data collection support staff for scheduling, data processing, maintenance, installation and maintenance inspectors, and production staff. There are opportunities to reduce the number of FTEs through the use of contractors, and coordinated and cooperative data collection and sharing agreements. Use of these other available forces are discussed in the next section.

**2.5.2 Other Available Forces**

There are effective ways of reducing traffic data collection needs. Agencies should consider the efficiency benefits gained from using traffic data collected by other sources. Agencies may be hesitant to use data from other sources when they cannot confirm the data were collected in a manner consistent with the quality standards of their own agency. These issues should be identified and effort put toward their resolution. Other available sources for traffic data collection are use of contractors, urban traffic management centers, local agencies, and bordering states or countries.

**Use of Contractors**

Recent trends indicate that state traffic data collection programs will continue to use or shift more data collection responsibility to contractors. These contracts are necessary with reductions in state agency employees. Agencies cannot support the demand for traffic data collection with greatly reduced staff. Contractors frequently are used for the collection of short-term, volume, and vehicle-classification counts. Contractors also are used for the installation and maintenance of permanent sites.

Agencies should consider using performance-based specifications within their contracts where possible. Illinois, for example, issues payment only for accepted short-term volume counts. Texas operates under a similar payment policy but also includes provisions for half payments if it is not possible for the contractor to physically setup a count (e.g., count schedule for a roadway under construction) or if there is physical damage to the counter.

Installation or maintenance contracts can be structured in a similar manner. Installation contracts should base payment on a successful demonstration that the installed equipment is working properly. The demonstration method should be described in the contract. Maintenance contracts may be structured on a work order basis for on-demand repairs. Agencies should not guarantee quantities in the con-
tracts. Performance also should have established timelines. Ohio allows contractors to complete main-
tenance within 30 days of receipt of the work order. If there are problems with the work, contractors
should be required to correct the problem before payment is made. Contracts also should include war-
rants. For example, Ohio requires a one-year warranty on all maintenance work performed.

Successful contract management requires validation through the use of inspectors, open dialogue with
the contractor, and a conflict-resolution process. Inspectors are important to validate contractor perfor-
ance in collecting data, installing permanent sites, or conducting routine or on-demand maintenance.
Agencies should maintain an open dialogue—pre-work meetings, telephone calls, and e-mail—with
their contractors to identify any problems or concerns before they become schedule delays or conflicts. If
conflicts do arise, the agency should seek to resolve them through a defined conflict resolution process.

Coordination with State Regional Traffic Management Centers

Urban areas are developing and operating regional traffic management centers. There is typically one
traffic management center for a region that monitors in real time the traffic flow conditions on
freeways and possibly some arterial streets. Traffic management centers are used to promote the op-
erations of the transportation system. Which is clearly a different mission than that of the traffic data
collection program.

These centers can collect data at very small time increments (e.g., 20 seconds) that could be aggregated
later into large time increments (e.g., hourly or daily). The data collected are volume, lane occupancy,
point speed, or travel time. Some centers archive this data that could possibly be used in generating
system-level estimates.

Agencies may wish to open discussion to create agreements for archiving this data. Additional discus-
sions should identify how the data will be shared from the traffic management center with the agency.
Agencies may question the quality—site locations, thoroughness/completeness of data, maintenance
procedures, or installation methods—of the traffic management center data for planning purposes.
Open discussion should address these quality concerns and negotiate to resolve them, if possible.

Suggested steps to incorporate these resources into the traffic data collection program include:

- Traffic data collection agencies meet for open discussion with traffic management center. This discus-
sion initiates the discovery phase for each group.

- Operations agencies identify the data collected, site locations, collection frequency, archive frequency,
  and quality issues. Questions data collection agencies should ask at this phase are:
  - Do the data collected complement the agency traffic data collection program?
  - Are gaps in the system-level monitoring filled by the traffic management center?
– Are there other uses for traffic management center data (e.g., anchor points for the ramp balancing process)?

• Data collection agencies negotiate issues to resolve differences between the monitoring systems. Agencies may wish to offer maintenance support or other assets to balance the demands for the traffic management center data.

• Data collection and operations agencies identify mechanisms for accessing or transferring the data from traffic management center. Mechanisms for exchanging data may need to be designed for frequent data transfer.

**Local Agency Involvement**

One way to reduce the need for resources is through cooperative traffic programs within states. Other governmental agencies and the private sector may be collecting traffic data on some state roads, and likely non-state roads. If the counts are in accord with documented agency guidelines or other citable reference such as an American Society for Testing and Materials (ASTM) standard or practice, the data are being collected and summarized in a way compatible with recommended state practice.

Data quality is improved by using local agencies. These local agencies have a vested interest in obtaining quality data to accurately represent their system and for their use in engineering and planning functions. Local agencies provide an invaluable knowledge base on current road conditions and special events so that abnormal counts are avoided on these traffic segments and times of the year. Local agency data collection also presents opportunities to improve cost efficiencies.

Local and regional agencies are working toward creating and populating data warehouses. These data warehouses can be a central submission point for traffic counts in the local area or region. State agencies also could participate by allowing links to or populating data within the warehouse.

Cooperative traffic monitoring within a state by all interested parties presents the possibility of satisfying all coverage, special, and data obsolescence needs within a state. It is recommended that dialogue be established within each state to assure quality in standard data and to exchange both traffic base data and summary statistics.

**Cooperative Sharing Agreements with Border States/Countries**

Agencies may reduce some data collection needs by sharing base data and summary statistics on roads shared with bordering states and countries. Provided the guidelines are followed by neighboring agencies, the issue of differing traffic volume summary statistics can be resolved by adjoining agencies using the most recent traffic count at or near the shared border.
CHAPTER 2  TRAFFIC DATA COLLECTION NEEDS

Factors to Consider in Negotiating Effective Traffic Data Partnerships

Agencies entering partnerships to collect traffic data must identify and resolve various issues. Some issues to consider include:

- Equipment accuracy and confirmation of routine maintenance;
- Timeliness of data collection;
- Sufficient metadata (where, when, duration, raw count, factored count, factors, etc.);
- Uniform data format;
- Fiscal responsibility for installation and maintenance, or manual collection; and
- Potential for reallocation of total resources (when duplication is avoided).

Agencies must identify critical issues early in the process. By not doing so, negotiations may unexpectedly halt or progress very slowly. Critical issues to either party will require time to resolve, and may impact data collection targets. Therefore, agencies should strive to negotiate to a cooperative agreement.

2.6 Conclusion

The recommended traffic data collection plan requires more than adoption of preferred field procedures. It requires that field procedures take place in the context of a statistically sound and well-planned sampling plan and efficiently scheduled data collection. Such a plan includes identifying the different types of data collect needs, the annual extent of each need, and the number of employees required to plan, collect, process, and analyze the data.

With this information, agencies have the ability to make informed decisions matching data with field personnel needs. When field procedures are clarified and adopted, and a data collection plan established, traffic data may be effectively and efficiently collected.
2.7 References


CHAPTER 3
Traffic Monitoring Equipment

The traffic statistics that are provided to end users are only as accurate and reliable as the data that are collected in the field. If the data collected in the field do not accurately reflect the traffic stream, or are not sufficiently complete, no amount of data editing is likely to make them accurately reflect that traffic stream, and the sophistication of the data collection sampling plan will have little effect on the accuracy of overarching summary statistics like areawide VMT.

This chapter provides information about the equipment required to collect traffic volume, classification, weight, and speed information. The equipment technologies explored are those currently available to and expected to be used by highway agency traffic data collection organizations. This chapter covers the technologies used for permanently placed, continuously operating traffic monitoring devices, as well as those used for short duration, portable data collection sessions. This chapter does not cover technologies and equipment that are primarily used to provide traffic monitoring information for freeway management, toll collection, or traffic signal control purposes.

This chapter first presents introductory information on equipment, followed by a discussion of the basic technologies that are available for collecting traffic volume, classification, and weight data. The relative strengths and weaknesses of each technology are briefly presented along with the types of data collection errors to which each technology is prone. The next section provides guidance on selecting equipment that uses these different technologies, as well as selecting among different vendors. Section 3.5 of this chapter presents key information on the set-up and maintenance activities that are necessary to obtain the best results from the equipment. Section 3.6 discusses the issue of collecting traffic data on congested roadways. Section 3.7 discusses the implications to traffic data collection programs of the need for travel time and delay data associated with the growing emphasis on roadway operations.

3.1 Introduction to Data Collection Equipment

A variety of alternatives exist for collecting traffic volume, speed, classification, and weight data. Different technologies measure different traffic flow attributes, ranging from vehicle axles to vehicle presence to vehicle motion or speed.
CHAPTER 3  TRAFFIC MONITORING EQUIPMENT

Not only are a number of sensor technologies available for observing traffic, but different equipment vendors often use different algorithms for converting sensor inputs into traffic statistics. How well any specific technology works in any given data collection effort is a function of the specific physical attributes/capabilities of the data collection sensor itself, the environment in which that sensor is deployed and operates, and the quality/robustness of the algorithm employed by the data collection electronics to interpret the signal provided by the sensor.

Unfortunately the complexity of these factors means that there is no simple answer to the age old question, “which equipment works best?” Several detailed equipment studies have concluded the same as a Minnesota non-intrusive detector test: “The differences in performance from one device to another within the same technology were found to be more significant than the differences from one technology to another.”

In addition to the differences in specific vendor implementations, each data collection technology has its own strengths and weaknesses. Each technology “works best” under specific circumstances. Each technology can be completely unreliable when used in the wrong circumstances or when badly installed, calibrated, or maintained. Some technologies work well only on moderate volume roads with free flow traffic conditions. Some are capable of measuring only traffic that is moving. Others work extremely well in all conditions but are very expensive and require extensive, permanently installed sensor systems.

Predicting equipment performance becomes more difficult when it becomes clear that different vendors implement given technologies very differently. Equipment based on the same technology from different vendors may use very different signal processing algorithms, and thus take the same basic sensor output, and produce markedly different traffic statistics. Even different equipment models from a single vendor can have significantly different internal software, resulting in decidedly different data collection performance from the same set of sensors.

Specific offerings from different vendors also may differ in cost; the number of data that can be stored in the data collection electronics; the nature of how those data are stored, retrieved, and summarized; how communications to the data collection electronics are achieved; and the type and quality of support the vendor supplies to the agency purchasing equipment. All of these factors need to be considered when equipment is selected. They are all discussed in more detail later in this section.

The most important actions necessary for collecting good data are as follows:

- Carefully test data collection equipment under the expected data collection conditions before buying large numbers of those devices to ensure that these specific devices work well under the conditions in which they will be used;

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• Closely follow the agency approved installation instructions for placing the equipment;

• Calibrate and test the installed equipment once it has been installed to ensure it is working as intended; and

• Periodically check on the performance of that equipment (when picking up the data collection device if it is a short-duration, portable count, or as part of routine equipment maintenance and data checking if it is a permanently mounted, continuously reporting data collection site).

These actions can increase the cost of individual data collection activities, but they will ensure the quality of the data being collected. They will increase the number of high-quality data collected and decrease resource expenditures on the collection of “random numbers,” thus decreasing the actual cost of collecting good data. It is better to collect less data at fewer locations, while ensuring that those data are valid, than to collect data at many locations and throw away many of them because the equipment did not work properly.

3.2 Equipment Technologies

This section introduces the technologies that currently are being used to monitor traffic flow and its attributes. The diversity of the technology and the speed with which it is changing make it difficult to produce a report of lasting relevance. As a result, this section only summarizes currently available literature. Readers are encouraged to visit the many on-line resources identified in this section to obtain up-to-date information on equipment and equipment performance before beginning the selection process. Good resources to start with are as follows:

• The Vehicle Detector Clearinghouse, maintained by New Mexico State University (http://www.nmsu.edu/~traffic/);


• Minnesota Guidestar Non-Intrusive Traffic Detection (http://www.dot.state.mn.us/guidestar/2001_2005/nit2.html);

• The Long-Term Pavement Performance project traffic data collection guidance (http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=383);

• ITS Decision, a web site maintained by the California Center for Innovative Transportation, a group within the University of California, Berkeley (http://www.calccit.org/itsdecision/serv_and_tech/Traffic_Surveillance/road-based/road_based_subtopics.html).
GUIDELINES FOR TRAFFIC DATA PROGRAMS

CHAPTER 3 TRAFFIC MONITORING EQUIPMENT

- Federal Highway Administration, Office of Highway Policy Information, Travel Monitoring Publications and Products (http://www.fhwa.dot.gov/policyinformation/);

- European COST 323 (Weigh-in-Motion of Road Vehicles) (http://wim.zag.si/cost323/);


- Data Collection Technologies for Road Management (http://www.road-management.info);

- Freeway Management and Operations Handbook, Chapter 15, Detection and Surveillance, (http://www.ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter15_01.htm) and


For this report, traffic monitoring technologies are divided into two basic categories: those that require placement of a sensor in or on the roadway surface (intrusive detectors) and those that are placed above, beside, or below the roadway so that sensor placement does not disturb the flow of traffic (non-intrusive detectors).

In some installation configurations, “non-intrusive” detectors require lane closure for placement, even though neither the sensor itself nor its installation actually intrudes on the roadway or impedes traffic flow. This condition most commonly occurs when sensors must be placed in overhead locations. If that overhead location is directly above a lane of travel (e.g., the sensor is being hung from a bridge or gantry), safety regulations frequently require the lane below the installation (or maintenance) activity to be closed to prevent a dropped tool or other item from harming motorists. This “exception” means that some equipment classified as “non-intrusive” should not be selected if a lane cannot be closed to allow its installation or maintenance.

Many of the technologies introduced below can be used for multiple traffic monitoring purposes. Changing the location or number of sensors deployed at a given location, or the data collection electronics attached to those sensors, can change the type of traffic attributes that can be obtained. For example, a simple road tube placed across a road “senses” the passage of individual axles. The collected axle count data can be stored in a traffic counter and converted to an estimate of vehicle volume by applying an axle correction factor. But if two road tubes are placed parallel to each other a known distance apart and are connected to a vehicle classifier, data on traffic volume by vehicle classification also can be collected.

² A third edition of the Traffic Detector Handbook currently is being published. A full reference for that document was not available at the time of publication of this report.
The subsections below discuss only the basic attributes of each sensor technology. The use of these technologies for collecting specific traffic flow attributes is described later in this chapter.

### 3.2.1 Intrusive Technologies

Most “traditional” traffic data collection involves the use of “intrusive” sensor technologies. This subsection briefly introduces these sensor technologies, discusses what vehicle attributes each senses, discusses the primary strengths and weaknesses of each technology, and presents key information that any user of that technology should be aware of before adopting or using them.

The two most common intrusive traffic counting sensors are the “road tube” and the inductive loop. Over the years, a large number of alternative intrusive sensors have been developed and deployed. These sensors generally differ from each other in what traffic attributes they sense and how they sense them. In addition, traffic sensors often differ in the speed with which they respond to passing traffic. This affects how quickly they “reset” or “cycle.” Equipment that “resets” quickly is less likely to experience data collection errors in high-volume, high-density, or high-speed data collection settings. Equipment that cycle slowly (such as road tubes) can undercount passing axles or vehicles when vehicles move quickly or are closely spaced.

The intrusive technologies discussed below are as follows:

- Road tubes;
- Contact closure, resistive, and other electrical switch sensors;
- Inductive loops;
- Magnetic detectors;
- Piezoelectric sensors (polymer-film, ceramic, quartz);
- Fiberoptic cable;
- Capacitance sensors (strips, pads);
- Bending plate;
- Hydraulic load cells; and
- Other weigh-in-motion (WIM) sensors (bridge, fiberoptic).

The first four of these technologies are conventional axle or vehicle counting technologies. The last 6 technologies can be used to provide axle weight information in addition to simple axle sensing. Note that this list is not exhaustive. Research continues to occur on newer, better, more robust intrusive sensor technologies. Data collection agencies are encouraged to send representatives to conferences such as the North American Travel Monitoring Exhibition and Conference (NATMEC) and to visit web sites such as the Vehicle Detector Clearinghouse (http://www.nmsu.edu/~traffic/) to stay up to date on emerging intrusive sensor technologies.
Axle Sensors—General Issues to Be Aware Of

All axle sensor technologies share some common problems. These errors include the following:

• Axle sensors not placed at a 90-degree angle to the direction of travel on a roadway can “observe” the same axle twice, as the wheels on either side of the vehicle will strike the incorrectly placed sensor at different times, generating two different signals.

• Axle sensors placed on top of the roadway can be easily damaged or torn loose from the roadway by objects dragged by passing vehicles. When this occurs, the dislodged sensor will either generate false signals (if only partially dislodged) or generate no signals at all. In both cases a portion of the intended data collection effort will become invalid.

Road Tubes

Road tubes are perhaps the most frequently deployed traffic sensors for short duration counts. They are long hollow tubes traditionally made from rubber or a rubber-like substance. They are stretched across the road surface and attached to an air switch. When an axle (or wheel) passes over a road tube, the tube is depressed, forcing air through the switch, which closes and sends an electrical signal indicating an axle passage to the data collection electronics. Road tubes are inexpensive to purchase and easily installed on low- and moderate-volume roadways.

The “traditional” road tube, like all axle sensors described in this section, is a single sensor. Unlike some axle sensor technologies, the road tube can be stretched across multiple lanes of traffic. When this is done, the single sensor observes passing axles in all lanes over which it is placed. The “traditional” version of the road tube cannot differentiate between air pulses generated by traffic in different lanes. Multiple vendors have developed newer versions of road tube sensors that can differentiate traffic by lane. These sensors generate air pulses only when traffic moves across a specific section of the sensor. These segmented designs allow road tubes to be stretched over multiple lanes but to “observe” traffic only in the one lane desired for that sensor.

While this is a significant improvement in data collection capability, errors can occur if the segmented tube is not correctly positioned within the roadway. (That is, if the “active” portion of the sensor is placed partly in a second lane it may “observe” some traffic in that lane as well as the lane in which it is intended to collect data.)

Road tubes are particularly vulnerable to being dislodged from the roadway because 1) they have a fairly high profile in comparison to other commonly used axle sensors, and 2) they are routinely held in place at a limited number of points (often on the lane lines), which allows them to be snagged by items dragged by passing vehicles more easily than sensors that are taped to the road surface along the entire length of the sensor.
When road tubes are used for classifying vehicles, it also is very important that both the tubes monitoring a given lane be the same length. If the two road tubes are different lengths, the time required for a given axle’s air pulse to reach the data collection device’s air switch will be different for the two sensors. This will lead to inaccurate estimations of vehicle speed.

Finally, road tubes are “slow” sensors. That is, the rubber requires a modest amount of time to recover before a second “tire pulse” will provide a clearly defined air pulse. This means that road tubes can undercount traffic on high-volume facilities where axles strike the sensor in rapid succession. The more lanes being counted by a road tube, the higher the traffic volume on those lanes, and the faster the vehicles are traveling, the more likely that road tubes will undercount passing axles.

**Contact Closure and Other Switches**

Contact closure switches, or treadles, consist essentially of a switch that is closed by pressure exerted on a sensor. A common design uses two wire contacts placed in a protective sleeve and secured to the roadway surface with road tape or road nails. As a tire passes over the sensor, the two contacts touch, and an electrical signal is produced, indicating that an axle (tire) has crossed the sensor. For permanent installation, the contact switches are placed in a rugged frame, which provides protection to the sensor.

The oldest of these sensors was known as a “tape switch” because the sensor was taped to the roadway with bituminous road tape. Several manufacturers currently market axle sensors that use these or similar technologies. Tape switch sensors generally cover a single wheel path or lane of traffic. Sensors placed in middle or inside lanes of traffic must be connected to the roadside by an electrical wire that is taped to, and crosses, the intervening roadway lanes.

Contact switches are “faster” sensors than road tubes, and therefore work more accurately on high-volume roadways. Like road tubes, if they cover more than one wheel-path, they need to be placed perpendicular to traffic flow or they are likely to record two axle “detections” for many passing axles.

Because they sit on top of the road surface, these sensors also can be ripped free from their mounting location. Because they are generally taped to the road surface along their entire length, they are less likely to be dislodged from the roadway than road tubes. However, the need to tape the sensor to the roadway for portable data collection means that the road surface must be dry for the tape to stick to the road surface. This means that placement of tape switches and other “taped down” axle sensors can be problematic in poor weather conditions.

Contact switches are generally more expensive than road tubes. They are not used as commonly in the United States as road tubes.
**Inductive Loop Detectors**

Inductive loop detectors are probably the most commonly used permanent vehicle detector in the United States. Inductive loops consist of a wire loop placed in or on top of the road surface. The shape and size of the loop differs from application to application, with the most common sizes/shapes being a 6-ft-square and a 6-ft-diameter circle. A small electrical current flows through the wire loop and the inductance of the wire is monitored. When a vehicle passes over the loop, metal in the vehicle causes the inductance in the wire to change. A sensor attached to the loop wire detects this change in inductance and reports the presence of a vehicle.

Inductive loops differ markedly from road tubes and other axle sensors in that they measure vehicles, not axles. This increases their accuracy as a volume counter, in that no conversion is required from the number of axles observed to the number of vehicles. However, loop detectors do not actually measure “vehicles”; they measure “the presence of metal.” Therefore, one limitation in the use of loops is that they frequently do not accurately count vehicles with little or no metal, e.g., motorcycles. If the sensitivity of the data collection electronics is set high enough to “observe” motorcycles, the result is often that vehicles with large amounts of metal (e.g., heavy trucks, buses) trigger the sensors in neighboring lanes as well as in their own lane.

Most inductive loop installations are “permanent.” Loop wires are placed into slots cut into the pavement surface. When done properly and in pavement that is in good condition, loops tend to be very long-lived. When installed poorly, or in pavement that is in poor condition, the loop wires can be easily broken by pavement forces such as those associated with freeze–thaw cycles. Water infiltration also can adversely affect loop performance. ASTM currently is completing the document “Standard Practice for the Installation of Inductive Loop Detectors” to provide assistance to agencies looking to improve the longevity and performance of their inductive loop systems.

To work well, loop detectors also require that a good “inductance sensor” be attached to the loop wire. A large number of urban loop installations have failed, in large part because the sensing electronics attached to the wire were not of high quality.

**Magnetic Detectors**

Magnetic detectors use much the same idea for sensing vehicle presence and passage as inductive loops but a somewhat different physical mechanism. Magnetic devices measure the change in the earth’s magnetic flux created when a vehicle passes through a detection zone.

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3 There is at least one notable exception. One traffic monitoring device sold in the United States uses multiple, smaller-sized inductive loops placed in specific locations to detect the metal present in passing axles and wheels. The result is an inductive loop detector system that can count axles and classify vehicles on the basis of the number and spacing of axles.
Like loops, magnetic detectors detect the metal in passing vehicles and thus measure “vehicles” rather than axles. Like loops, minor accuracy problems can occur in counting vehicles that contain only small amounts of metal. Depending on the manufacturer, magnetic detectors are designed to be placed on top of, in, or underneath the roadway pavement surface in a horizontal bore.

Magnetic detectors placed under the roadway surface are more properly classified as “non-intrusive” detectors, although their installation does require placement of the conduit for the sensor underneath the roadway. This may or may not require lane closures.

**Piezoelectric Sensors**

With piezoelectric sensors, the force (pressure) applied by passing axles to a sensor generates an electrical signal by compressing the sensor material. This is different than an electrical switch, in which pressure simply completes a circuit of electricity supplied by an external source. This difference is important in that the size of the signal produced by a piezoelectric sensor is a function of the force applied to that sensor. Thus, piezoelectric sensors provide a more robust signal than road tubes or closure switches, and the signal, when properly analyzed, can be used to estimate the axle or wheel weight applied to the sensor.

A variety of materials exhibit piezoelectric properties (i.e., generate electricity when compressed), and consequently, there currently are three different types of piezoelectric traffic sensors on the market. These technology variations have somewhat different properties. All tend to be more expensive than older, conventional axle sensors (road tubes, tape switches), but all are also more robust and can be used for more tasks than just simple axle detection.

Because piezoelectric sensors can be considered “fast” sensors, care should be taken when sensors are placed. Sensors that are not placed perpendicular to traffic flow, so that both wheels on an axle strike the sensor simultaneously, are likely to record the same axle more than one time. The speed of these sensors is useful in making them quite accurate for collecting data on high-speed roadways, as they “cycle” fast enough to capture all axles of closely spaced axle groups.

As WIM sensors, piezoelectric sensors have one major drawback. While their thin design reduces their impact on pavements and speeds their installation, the thin sensor is “bridged” by passing tires. That is, the tire being weighed is never entirely supported by the piezosensor. At all times when the tire is in contact with the piezosensor, some portion of the tire is being supported by the pavement that surrounds the sensor. This effect, called “bridging” of the sensor, means that the structural response of the pavement will affect how much weight is actually applied to the piezosensor. In general, the harder and stiffer the pavement, the less weight that is applied to the piezosensor.

Similarly, the thin nature of the sensor means that unusual tire tread patterns or abnormal tire pressures can cause some axles to be inaccurately weighed. Tread patterns that do not evenly distribute load...
over the tire footprint can cause either unusually high or unusually low forces to be applied to the thin sensor strip as the tire passes. The remainder of the load is carried by the “bridged” tire and surrounding pavement.

*Piezoelectric ceramic* sensors were the first of this class of sensors brought to market for traffic applications. The piezoceramic sensor is roughly the size of a coaxial cable. The sensor can be placed on top of the roadway, but it is most commonly placed in a slot cut into the roadway surface and held in place with an epoxy resin. When placed in the roadway, the cable is most commonly placed in an aluminum U-channel filled with hardened resin, although the sensor can be placed directly in a slot in the road surface. The sensor is generally about 6 to 12 ft (2 to 4 m) long, and the aluminum channel tends to be about 1.5 to 2 in. wide and high.

Piezoceramic sensors are very “quick” sensors. Therefore, it is very important that they be placed perpendicular to the flow of traffic so that both wheel paths strike the sensor simultaneously. They are commonly used as permanent axle sensors for vehicle classification and are often used in lower cost WIM systems. Because the response of piezoceramic sensors to pressure is temperature dependent, their performance as a WIM sensor is significantly affected by the equipment vendor’s ability to account for that temperature dependence. Temperature dependence is less of an issue for vehicle classification data collection, which only requires a “pulse” from the detector indicating that an axle passed over it.

Like inductive loops, permanent piezoceramic sensors need to be placed in pavement that is in good condition. If the sensors are placed in poor pavement, forces in the pavement can cause stray signals to be reported as axles (often called “ghost axles”). An example of this is when piezoceramic cables are placed in Portland cement concrete pavements in which the joints between pavement slabs fail. When this failure occurs, the pavement slabs “rock” as vehicles pass over the joints, and this slab rocking motion generates false signals in the piezoceramic sensors. This problem is exacerbated in the piezoceramic sensor because the sensor is omnidirectional (that is, forces applied in any direction cause generation of an electrical signal). A variety of forces transmitted through the pavement can result in “false” axle signals in piezoceramic sensors, and these forces are far more prevalent in deteriorated pavement.

In addition to generating false signals, pavement deterioration near the sensor installation can cause failure of the bond between the sensor and the pavement. This condition leads to both the generation of false signals and the eventual failure of the sensor itself.

*Piezopolymer film* is another commonly used piezoelectric axle sensor. Piezopolymer sensors differ from piezoceramic sensors in that the sensor is responsive to load in only one direction (the vertical plane). Rather than looking like a coaxial cable, the piezofilm sensor looks like a very long piece of linguini, which has led to its nickname, “the brass linguini”—or BL—sensor.

BL sensors can run from 6 to 123 ft long but are most commonly found in full- or half-lane lengths. Like the piezoceramic sensor, the BL sensor can be placed on top of the roadway or into a slot cut in the pave-
When placed on top of the roadway surface, it is generally inserted into a protective sleeve, which is then taped to the roadway, much like the tape switches discussed above. As with other taped sensors, wet conditions can make it difficult to install these sensors so that they remain in place. When installed in a pavement slot, BL sensors can either be placed “bare” or in a resin-filled aluminum channel. The combination of its flat shape and its unidirectional force sensitivity makes this sensor more reliable than the original piezoceramic cable for portable data collection on top of the roadway surface.

Like the piezoceramic sensor, the BL sensor is temperature sensitive. This factor detracts from the accuracy of the axle weight estimates it can be used to generate. However, it is fairly rugged and is widely used for classification applications by state DOTs around the country.

Piezoquartz sensors are the newest of the commonly available piezoelectric sensors. The piezoquartz sensor was developed in response to the weaknesses of the piezoceramic and piezopolymer sensors. The primary functional difference between these sensors is that the piezoquartz sensor is not temperature sensitive. Sensor output is constant under different temperatures. As a result, the piezoquartz sensor is more accurate for axle weight measurement than the other piezoelectric technologies.

The drawbacks to the piezoquartz technology are cost and, to a lesser extent, flexibility. Piezoquartz sensors cost more than either the piezoceramic or BL sensors. They also are shorter (currently sold in either 1.0 m or 0.75 m lengths) than either of the alternative piezoelectric technologies. A single, permanent lane installation requires a minimum of four piezoquartz sensors to cover an entire lane, whereas that same installation requires only one BL or piezoceramic sensor. In addition, whereas the two older piezo-sensors can be placed “bare” on top of the pavement, the piezoquartz sensor is pre-installed in a “sensor bar” that is too wide and thick to be placed on top of the roadway surface. Therefore, it can only be used where it can be permanently mounted within the roadway surface.

**Fiberoptic Cable**

Fiberoptic cable has emerged since around the year 2000 as an axle sensor alternative to the piezoelectric technologies. With fiberoptic technology, light is passed through the sensor, much like a small current passes through an inductive loop. As tires pass over the fiberoptic cable, the cable is compressed, and the amount of light passing through the sensor changes. This change in light intensity is measured by a detector, which indicates the passage of an axle/tire.

The fiberoptic sensor is a very fast axle sensor. As a result, fiberoptic sensors need to be placed perpendicular to traffic flow, or they are likely to record the same axle more than once. Fiberoptic sensors range in length from 6 to 32 ft, depending on the number of lanes of traffic to be monitored. Vendors offer fiberoptic sensor systems that are capable of measuring traffic in multiple lanes.

Like piezoceramic sensors, fiberoptic sensors can be placed either on top of the roadway or in slots cut in the pavement. When placed on top of the roadway surface, they are generally placed in a protective sleeve, much like the tape switches discussed above.
sleeve and taped to the roadway. As with other taped sensors, wet conditions can make it difficult to install portable sensors so that they remain in place. When installed in the pavement, the sensor is put into a rigid mounting bracket before being placed in the road surface. The slots cut into the pavement to mount the fiberoptic cable are slightly smaller than those normally cut for piezoelectric sensors.

**Capacitance Sensors**

Capacitance sensors consist of two or more electrical conductors separated by a dielectric (nonconducting) material and carrying equal but opposite charges. When an axle/wheel passes over the sensors, the force applied by that axle/wheel causes the distance between the two conductors to decrease and the capacitance of the combined electrical system to increase. The greater the weight applied to the sensor, the closer the plates become, and the larger the change in capacitance. Electronics attached to the sensor estimate axle weight on the basis of the signal produced as an axle passes over the sensor.

Because they cost more than simpler axle sensors, capacitance sensors, which have been marketed in both strip and pad (mat) forms, are mostly used as axle weight sensors. Capacitance pads (mats) are the most common form of this sensor found in the United States, but their use has been declining in recent years. Capacitance mats are most commonly used as sensors for portable weigh-in-motion systems, although they can be used as permanently mounted sensors by placing the pads in steel frames mounted in the road surface.

Capacitance mat systems suffer from three major shortcomings. The first problem is that the pad itself creates a “bump” because of the height of the sensor as it sits on the roadway. This limits system accuracy because it alters the dynamic force being applied to the sensor by the axles being weighed, thus decreasing the accuracy of the scale as it attempts to convert that measurement of force into an estimate of the static weight of that axle. (See the discussion of static weight versus dynamic forces in the section on weigh-in-motion later in this chapter.) The second problem is that in the most commonly used configuration, the pad only weighs one wheel path of passing trucks. Because axle loads are often not evenly distributed between wheel paths, this decreases the ability of the system to accurately estimate total axle weight. The final problem is that the design of the sensor makes it fairly visible to passing truck drivers and the half-lane design makes it fairly easy for a truck driver to drive around the sensor, thus preventing the truck from being weighed or classified.

**Bending Plates**

Bending plates, along with piezoelectric sensors, are the most common weigh-in-motion technology currently used in the United States. The basic sensor for a bending plate WIM consists of strain gages bonded to the bottom of a steel plate, which is placed in a metal frame built into the roadway pavement. As individual axles pass over the plate, the plate flexes, and the strain gauges measure that deformation. The larger the deformation, the heavier the axle. This relationship is used to estimate the force (and thus load) being applied to the scale platform by the passing axle.
Bending plate sensors are generally about 6 ft long (i.e., they cover one-half of a travel lane) and roughly 6 to 8 in. wide (i.e., in the direction of travel as vehicles cross over them). However, some manufacturers make longer bending plate sensors.

A bending plate installation can consist of one, two, or three sensors. Use of two sensors allows measurement of both wheel paths, increasing the accuracy of the axle-weight measurement. Sensors are often (but not always) staggered so that the left and right wheel paths are measured at different points in time and space. This is done to reduce the effect of vehicle dynamics and improve the accuracy of the static weight estimate and to allow computation of vehicle speed based on the known spacing between the staggered sensors.

Bending plate installation requires a far larger pavement removal effort than the simple saw cuts used to place piezoelectric or fiberoptic sensors. This significantly increases the time and cost for installing bending plates in comparison to those for piezoelectric strip sensors.

On the positive side, bending plate technology is generally not sensitive to changes in environmental conditions. The larger width of bending plates in comparison to piezostrip sensors also provides a measurement advantage because the larger weighing surface makes the sensor less susceptible to “bridging” of the tire over the sensor by increasing the duration of time the tire is physically in contact with the sensor.

As with capacitance pads, the cost of these sensors makes them impractical for any data collection activity other than axle weighing. When used in conjunction with other sensors such as inductive loops, they do provide excellent vehicle volume and classification data in addition to axle-weight information.

**Hydraulic Load Cells**

Hydraulic load cells consist of a large rigid upper plate built into a rigid frame that has been dug into the pavement. Loads from axles passing over the sensor plate are transferred to one or more oil- (or other fluid) filled load cells to which sensors are attached. The pressure resulting from the force of the passing axles, as measured by the pressure in the load cell, is then used to determine the weight of the axle.

Hydraulic load cells are generally considered the most accurate, but also the most expensive, of the WIM technologies. Both the greater expense and higher level of accuracy result from the effort involved in placing the sensors. Hydraulic load cell installations require the construction of a deep pit into which the load cell frames are placed. During this installation, pavement up- and downstream of the sensors is also usually repaired. This creates a very smooth pavement approaching the WIM scale, which helps dampen out much of the dynamic motion of trucks before they reach the load cell scales. The result is a more accurate estimate of static loading conditions.
In addition to the advantages of a smooth approach pavement, the load cell technology shares three major advantages with bending plates. The first is that the large weighing platform (the sensor plate that the tires pass over) allows the entire tire being weighed to be completely located on the weighing sensor. Thus, unlike the piezoelectric strip sensors, load cells do not experience problems caused by tires “bridging” the sensor. The second advantage is that because the load cell weighing platform sits within a frame, the scale’s response is not affected by seasonal changes in roadway strength or stiffness. Finally, like bending plates, the responsiveness of the load cell technology is not sensitive to changes in temperature.

Similar to bending plates, however, the load cell must be accompanied by other sensors (usually inductive loops) to compute each passing vehicle’s speed. Speed is used for a number of purposes in the weight estimation process, but it is also a key statistic for converting the timing of axle arrivals in vehicle classification data.

### 3.2.2 Non-Intrusive Technologies

While intrusive data collection technologies are most commonly used for traffic monitoring, the requirement that sensors must be placed in or on the roadway has significant drawbacks. One drawback is that with intrusive sensors, staff must work in hazardous situations (i.e., within travel lanes), and another is that often traffic flow must be disrupted in order to place the sensors in the roadway. In some cases, roadway agency policy states that short duration counts cannot be taken with intrusive sensors on some roadways (so-called “red zones” or “no count zones”). These restrictions are usually established because traffic volumes on those road segments are so high that 1) crews cannot work safely, 2) temporary (portable) sensors are not expected to stay in place long enough to collect the desired data, or 3) the roadway agency is unwilling to disrupt traffic flow long enough for crews to install the sensors. Nonetheless, traffic data are still needed on these roadways.

As a result, researchers have developed a variety of new traffic data collection technologies that do not require access to the roadway lanes to collect traffic monitoring data. These “non-intrusive” sensors observe traffic flow from above or beside the roadway. Use of these vantage points allow data collection without closing lanes or subjecting staff to dangerous conditions.

Non-intrusive sensor technologies are not without their own drawbacks. The first of these drawbacks is that the vast majority of non-intrusive sensors do not “see” vehicle axles. This means that vehicle classification systems based on the number and location of axles cannot be used. Thus, non-intrusive sensors usually (but not always) cannot collect data according to FHWA’s 13-category classification system (see Figure 3-1). Another common problem is that vehicles observed from beside or above the roadway are sometimes hidden from the view of the sensor by other vehicles. This is called “occlusion” and is a

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possible source of error for any non-intrusive technology that requires line-of-sight from the data collection sensor to passing vehicles. Finally, each individual technology has technical weaknesses as well as strengths. These technical issues tend to make specific technologies work well under some conditions and poorly under others. (For example, video image-based sensors do not work well in poor visibility conditions such as heavy snow storms. Acoustic technologies can have difficulties under high levels of ambient noise.) Thus, no traffic monitoring data collection technology is “best” or “perfect” in all situations.

The following subsections briefly introduce currently available non-intrusive sensor technologies, describing the vehicle attributes that each technology senses, discussing the primary strengths and

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**Figure 3-1. Illustrations of FHWA’s 13-Category Vehicle Classification System.**
weaknesses of each technology, and presenting key information that any user of that technology should be aware of before adopting or using it. The technologies discussed are:

- Video image detection systems (VIDS);
- Doppler and microwave radar;
- Magnetic detectors;
- Infrared;
- Laser detectors;
- Acoustic arrays;
- Ultrasonic; and
- Automatic vehicle identification (AVI) systems.

### Video Image Detection Systems

Video image detection systems are video camera-based systems that use digital image processing techniques to extract traffic information from camera images of the roadway. There are three basic video image analysis technologies: “tripline” systems, video tracking systems, and feature extract systems. All three systems start with digital camera images and identify groups of pixels (“objects”) that represent a vehicle.

Tripline systems act as virtual inductive loop systems. They produce the same basic statistics as one or more inductive loops, that is, vehicle volume and lane occupancy. For this technology, “virtual loops” or “detection zones” are placed on the roadway image observed in the camera monitor. When “objects” (i.e., vehicles) are observed to be moving on the roadway and cross a detection zone, that “loop” is “activated”—counting the vehicle and making possible the computation of the time the loop is “occupied.” By placing two detection zones in series a known distance apart along the roadway image, it also is possible to compute vehicle speed (the distance between trip lines divided by the time it takes for the object to move from the first to the second tripline). This also allows the system to estimate the length of the object being observed (by dividing the speed of the vehicle/object by the time the detection zone is occupied). Because multiple detection zones can be drawn for each camera image, tripline-based video image systems can monitor more than one lane of traffic from a single camera. Thus a single camera can perform the data collection task of multiple “real” inductive loops.

Video tracking techniques employ algorithms to identify and track vehicles (objects) as they pass through the field of view. The groups of pixels associated with a specific vehicle are tracked through the monitor image from frame to frame of the video. The tracking of specific objects along with knowledge of the image background (e.g., location of lane lines, the length of roadway covered by the video image, and the distances between specific points of reference) allows traffic attributes such as vehicle speed and number and location of lane changes to be determined automatically.
The last technique, “feature extraction,” is still primarily a research endeavor. Feature extraction examines the detailed pixel image associated with an object and attempts to determine specific vehicle features from that image, just as the human eye and brain do. While “tripline” systems can only classify vehicles on the basis of overall vehicle length, feature extraction systems attempt to classify vehicles on the basis of vehicle features. Thus, a school bus observed by a tripline system is simply classified as a “40-foot-long vehicle,” whereas a video extraction system might actually classify it as a “school bus,” given its height, width, length, and color.

Video image processing systems, regardless of the analysis technology they employ, are only as good as the digital images that are the basis for the calculations. Video images, in turn, are a function of how well the camera can see the traffic stream. A variety of factors affect how well a camera can “see” traffic. These include, but are not limited to, the following:

- The quality of the camera lens being used;
- Changing lighting conditions, particularly during sunrise and sunset;
- Lack of light;
- Camera angle, height, and position;
- Adverse weather conditions;
- Direction of traffic flow relative to the camera; and
- Camera vibration.

Camera quality defines the number of pixels available for analysis, the clarity of the image being analyzed, and whether the image system is working with color or gray-scale pixels. A related issue is the need to keep camera lenses clean. Even high-quality cameras produce poor quality images if the lenses are not kept clean, and poor image quality invariably results in data collection errors.

Camera placement is perhaps the most important part of making sure that video-based sensors work accurately. Cameras should be placed so as to minimize the factors listed above that can disrupt traffic detection. In particular, they should be high enough in the air to “see” traffic and limit problems with occlusion. In general, the higher the camera, the less occlusion that occurs in the image, and therefore the less undercounting that occurs. However, placing a camera very high in the air increases the distance between the camera and the objects being observed, which increases the chance that poor visibility (due to heavy rain, fog, snowfall, or dust) will obscure vehicles being observed.

Camera systems can be operated from above or beside the roadway. Overhead placement generally results in more accurate data collection, but side-fired systems are generally easier and less costly to set-up and maintain.
**Doppler and Microwave Radar**

Doppler and microwave radar systems transmit low-energy microwave radiation at a target area on the pavement and then analyze the signal reflected back to the detector. *Microwave or “pulse” radar systems* transmit a pulse of energy and measure the time it takes for that energy to be reflected back to the sensor. These devices use a pulsed, frequency-modulated, or phase-modulated signal to determine the time delay of the return signal, thereby calculating the distance to the detected vehicle. *Doppler systems* transmit a continuous wave of energy and measure the change in signal frequency caused by the Doppler effect as that signal reflects off of moving vehicles.

Microwave radar devices have the ability to sense the presence of stationary vehicles and to sense multiple zones through their range finding ability. Doppler radar devices are generally not able to detect stationary vehicles accurately.

Radar devices are capable of measuring vehicle presence and speed. They are generally not capable of classifying vehicles. As with other non-intrusive sensors, they can be placed above or beside the roadway. Some radar sensors can observe more than one lane of traffic. Likewise, some radar sensors can differentiate between traffic in different lanes; however, these capabilities are a function of the specific sensor design and where the sensor is placed.

For example, when placed over a lane, microwave radar detectors generally only observe one lane per sensor. However, this placement tends to reduce problems with vehicle occlusion and thus increases the accuracy of the sensor measurements. The same sensor can be placed along the side of a roadway and be capable of measuring all traffic on that roadway, regardless of the lane. However, this side-fired sensor placement is likely to degrade data accuracy.

**Magnetic Detectors**

Magnetic detectors placed under the roadway surface are classified as “non-intrusive” detectors, although their installation does require placement of the conduit for the sensor underneath the roadway. This may or may not require lane closures. (See the previous discussion of magnetic detectors under “Intrusive Technologies” for a detailed description of this technology.)

**Infrared Systems**

Infrared systems can be either active or passive. Passive sensors detect changes in the amount of energy being transmitted in the infrared wave lengths from the roadway and its environs. Active sensors emit a low-energy infrared laser beam and measure the time required for that beam to be returned. The presence of a vehicle is measured by the reduction in time for the signal return.

Passive detection is easiest to illustrate by referring to the low-light, infrared camera systems seen in modern action movies. These systems use infrared (heat) energy signatures, displayed as camera images,
to detect a variety of heat sources, and then convert that information into statistics concerning different vehicle characteristics, generally volume and speed. These sensors can be placed above or beside the roadway, depending on the specific technology implementation. These systems generally produce estimates of vehicle volume and speed.

Active infrared systems create a light beam that is “broken” when a vehicle passes through it. (Similar concepts are used as safety switches on almost all new motorized garage door openers now sold in the United States) The systems can measure either “vehicles” or “axles,” depending on the height at which the beam is positioned and its direction. Use of multiple active infrared sensors in series allows measurement of vehicle speed and, consequently, allows computation of vehicle classification based on the number and spacing of axles.

At least one vendor has produced an active infrared system that is capable of accurately collecting volume, speed, and classification data on multilane roads. This system requires that an active infrared transmitter be placed at tire level on one side of the roadway and that a receiver be placed at tire height on the opposite side of the roadway. The only major limitation in the system is that the crown of the pavement must be flat enough that the two sensors have a line of sight to each other and that the line of sight remains below the chassis height of passing vehicles.

*Laser Detection Systems*

Laser detection systems are functionally similar to the active infrared systems discussed above, but the light generated is of a different frequency. Like many non-intrusive sensors, they can be mounted above or beside the roadway.

When mounted overhead they can be used for counting or classifying vehicles. Each sensor (laser) provides detection information (when the vehicle breaks the laser beam), as well as vehicle height information. Placing two sensors in succession yields vehicle speed information and allows vehicle classification based on a combination of overall vehicle length and height.

When side-mounted, laser systems can be used as axle detectors, similar to the infrared system described above. Side-mounted laser systems also can be used to identify and classify vehicles on the basis of their profile. As with all “side-fired” devices, a key concern with roadside-mounted lasers is vehicle occlusion. This is particularly an issue for lasers attempting to measure vehicle profiles, as this can only occur for vehicles that are not blocked from the laser source by other vehicles. Axle-sensing lasers are less affected by occlusion because the system is only affected when the tires of two vehicles in separate lanes arrive at the sensor location simultaneously.

For portable data collection, lasers also have joined radar guns as commonly used, hand-held speed monitoring devices.
Passive Acoustic Systems

Passive acoustic arrays consist of a vertical dipole array of microphones aimed at the traffic stream. The microphones “listen” to the tire and engine noise of approaching vehicles. At higher speeds, tire noise is the primary mechanism by which vehicles are detected. At lower speeds, engine noise becomes the primary means of detection. Passive acoustic detectors are capable of measuring volume, speed, and presence.

Passive acoustic devices operate best when placed beside the roadway pointing at the tire tracks of the lane of traffic being monitored. The accuracy of these devices is affected by environmental conditions that hinder the propagation of sound. These include strong winds and heavy snowfall or precipitation. Very loud vehicles have been shown to sometimes cause false readings.

Ultrasonic Systems

Ultrasonic systems emit ultrasonic sound energy and measure the reflection of that energy. There are two basic types of ultrasonic systems, which are analogous to the two types of radar systems described above. Ultrasonic pulse detectors measure the time required for the emitted energy to reflect back to the sensor. Ultrasonic Doppler devices emit a continuous ultrasonic signal and utilize the Doppler principle to measure the shift in the reflected signal caused by its reflection off of moving objects.

Both types of detectors can measure volume, lane occupancy, and vehicle speed, although Doppler sensors have difficulty measuring stopped vehicles. Pulsed ultrasonic detectors, when placed above the lane of travel, can be used to classify vehicles on the basis of vehicle height and length. The technique used for this system is analogous to that for laser-based systems described above.

Automatic Vehicle Identification Systems

Automatic vehicle identification (AVI) systems are used for electronic toll collection and other intelligent transportation system control functions. With AVI systems, vehicles carry an electronic transponder that, when interrogated, provides the identity of that vehicle to the device requesting the information. The vehicle ID is then used to retrieve attributes associated with that vehicle stored in a database.

The most common AVI technology uses Radio Frequency Identification (RFID) technology. RFID tags can be active or passive. Active tags carry a battery and allow communication of longer ID message sets over longer distances. Passive tags do not contain a battery. Instead, they absorb and reflect energy transmitted by the interrogating device.

AVI systems are generally not considered “traffic monitoring devices,” as the devices that read AVI tags detect only vehicles carrying tags. However, an increasing number of toll roads exist in this country, and a small but growing percentage of those roads require electronic payment of tolls with RFID tags. When
all vehicles using a roadway are RFID tag-equipped, it will become possible to collect traffic volume and speed (travel time) data by using the AVI system.

If the toll road associates specific tags with specific vehicles (that is, motorists are not allowed to shift an AVI tag from one vehicle to another), then the databases that describe that vehicle can allow the use of AVI technology for vehicle classification as well. If multiple AVI readers are placed along a roadway, it is possible to collect average vehicle speeds (travel times) between any of those two detectors on the basis of the time when any given vehicle passes both detectors. Thus, on toll roads, it is often possible to obtain a very rich data set of vehicle speeds (travel times) simply by mining the existing tolling information.

**Multitechnology Devices**

Multitechnology systems are a growing area of development. A number of the non-intrusive units tested as part of the Minnesota non-intrusive detector tests included two or more sensors within a single data collection unit. The idea was to take advantage of the strengths of different technologies to overcome the weaknesses of any single technology. These data collection units generally cost more than single technology units but have considerable potential for overcoming the data collection limitations inherent in some technologies that are otherwise very promising.

At the time this report was written, the number of multisensor non-intrusive data collection units was small, and field experience with those technologies was limited.

**Manual Counts**

Manual counts are the original traffic monitoring data collection method. For manual counts, one or more staff are sent to a location to observe and record traffic statistics, usually traffic volume, but also often vehicle classifications and other statistics that can be observed with the human eye. (For example, the number of in-state versus out-of-state license plates.) Manual counting of video images is a related option that can be used, particularly in the case of congested urban roadways and locations where there is no place for an observer to stand or sit.

Manual counts are still commonly used for conducting short duration counts where traffic monitoring equipment is difficult to place. They also are used for collecting data that automated technologies have yet to be able to collect reliably, such as the number of people inside of passing vehicles (i.e., vehicle occupancy). Manual counts are most frequently used for turning movement counts and for vehicle classification counts in areas where automated classification equipment cannot be safely placed, or where that equipment will not work accurately because of variable traffic speeds (i.e., high levels of acceleration or deceleration in the vehicle stream).

The quality of manual counts is a function of the quality of the staff performing those counts and the ability of those staff to clearly see the traffic stream. Research has shown that manual data collection
accuracy tends to decline after about three hours, as an individual’s attention span tends to wander after concentrating for longer than that. To obtain even three to four hours of valid count data, observers must have a comfortable location from which to observe the traffic. They must have good sight lines to the traffic, a place to sit, and at least some protection from bad weather.

A number of manual count aids exist. These aids include devices such as “automated count boards,” which produce an electronic record of the manually entered traffic monitoring data, and a variety of computer programs for both laptop computers and personal digital assistants (PDAs) that allow direct entry of manual count observations. Data entry can be handled through a keyboard or through voice recognition software. Data also can be handwritten onto paper and then keyed into the desired electronic format.

Although extremely flexible, manual counts have a variety of limitations, starting with their cost, which generally precludes their use for anything other than short duration counts. A second limitation is the lack of locations on some roadways where data collection crews can safely stand/sit and view traffic. Safety of crews also is a concern in areas with high crime rates. Lastly, even under good conditions, the abilities of manual counters are finite. As a result, on high-volume roadways, one person is generally needed for every lane of travel being counted to collect traffic details other than simple volume. This results in a significant increase in costs for manual counts on larger roadways.

3.2.3 New Equipment Development

The previous sections describe the technologies currently on the market in the United States. However, the fast pace of technological innovation in traffic flow sensing is expected to make this section quickly obsolete.

The fast pace of innovation in the traffic data collection market is in part driven by growing interest in improving the operational efficiency of the roadway system. If roadway operations are to be improved, then data are needed that describe current traffic flow and its characteristics. Only after the current conditions are known can an agency determine how to change its ongoing traffic control strategies to more efficiently move people and goods. The result is a push at the national level for a program called vehicle infrastructure integration, or VII. The idea behind VII is that modern, intelligent roadside sensors will communicate with electronics carried by vehicles in order to improve the information available for making roadway control decisions. Information will be both collected by and provided to vehicles, drivers, and roadway agencies.

As VII is implemented, a variety of new data sources and data sensors will need to be developed and deployed. The result will be a continuing evolution in the types of equipment purchased and deployed and the types of traffic flow information obtained by roadway agencies. Traffic data collection groups within

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roadway agencies need to stay abreast of the equipment developments being driven by VII deployment in order to take advantage of these new technologies for both new data needs and to collect more traditional traffic flow statistics.

VII, however, is still several years from significant deployment. As a result, the traditional forms of data collection are likely to be relied on for collecting traffic data for a number of years. Even if VII is heavily deployed as quickly as possible, data collection equipment purchased in the next few years will continue to be heavily utilized throughout its useful life. That specific equipment is discussed in the following section of this chapter.

### 3.3 Data Collection Equipment

This section discusses the use of the technologies described above to collect volume, vehicle classification, and weigh-in-motion data. Each of these types of data are discussed in separate subsections. Each subsection is further subdivided to discuss portable, short-duration data collection versus permanent (or semi-permanent), longer duration, continuous counting sites.

All modern traffic monitoring devices allow storage of traffic monitoring statistics for a wide range of intervals. Traffic counters that do not record interval data should not be purchased, and such limited devices that are already owned should be retired from active use. Interval data (at a minimum of one-hour and preferably much shorter intervals) is required by a large percentage of engineering analyses that require traffic monitoring data. The lower the interval, the greater the ability of the collecting agency to examine the performance of the roadway. In addition, the ability to record traffic flow data at very short intervals allows a variety of additional quality control analyses that are not possible with equipment that only collects data in larger time increments.

For example, one class of traffic monitoring equipment is called “event recorders.” These devices use axle sensors and record (and store) the time each axle crosses the sensor. This sensor record is then analyzed in the office to produce traffic monitoring records at any time period requested (e.g., one-hour count intervals or five-minute count intervals). The very detailed axle pulse recordings can be used to examine total vehicle volume, analyze vehicle classification (by axle classification system), and perform a variety of error checking. The office software that comes with the data collection device allows the analyst to produce any aggregated time-interval statistic desired.

The advantage of using these devices is that a single device can collect a variety of data that can be easily converted into a variety of traffic flow statistics for different agency users. The drawback to these devices is that storing such detailed data requires considerable electronic storage space. This may limit the time a data collection device can be left unattended in the field. It also will increase the total data storage requirement in the central office and will slightly increase the cost of total data storage, although given recent price decreases in computer storage media, this last issue is becoming less and less impor-
tain. Lastly, this will modestly increase the time required in the central office to process the summary data most users need. In many cases, these additional costs are considered modest in comparison to the greater flexibility and utility this type of data collection system can provide.

### 3.3.1 Count Duration

As discussed in Chapter 2 of this document, traffic data are collected for a variety of reasons and for a variety of time periods. Different types of equipment are often needed to address these different traffic data collection needs. The equipment attributes that are important for conducting counts that will last only a few days and that are needed at a large number of locations around the state tend to be different from those needed to collect data for long time periods at a single location. The following section discusses the equipment attributes that are needed for equipment that fall under these basic categories.

**Portable Counters**

Portable counters are used to perform short-duration counts at a large number of locations. Portable counters and the sensors they use, regardless of the traffic monitoring attributes to be collected, require the following attributes:

- They must be easily transportable;
- They must be easy to install, and that installation should require very little time;
- They must contain a sufficiently large power source to allow the device to operate until it is retrieved;
- They need to be theft and vandalism resistant. (Traditionally, this has meant that the data collection electronics have been stored in a rugged case that can be chained to a light fixture or guardrail post to prevent theft.); and
- They need a robust mechanism for transferring data from the data collection electronics to the central traffic data repository.

In addition to the above equipment requirements, proper short duration data collection includes a variety of other tasks that should be performed at all data collection sites:

- Every data collection session requires a written log entry that describes the device (e.g., serial number) used, the time and date the device was deployed and picked up, the location the device was placed relative to the roadway (preferably a simple map illustrating where the sensors were placed relative to features present on the roadway), and notes that describe unusual occurrences the data collection staff observed at the site that might have influenced the performance/accuracy of that count (e.g., congestion was present at the site, or very heavy truck/motorcycle volumes).
• The “data collection log” entry is often most effectively written onto the work order that describes the location and type of count that is to be performed.

• All equipment should be tested/observed after it has been placed in/on/beside the roadway to ensure its accurate performance. A written record of the tests performed (and their results) should be included with the data collection log discussed above. This ensures that all axles/vehicles are being counted in each lane and that basic parameters such as vehicle speed are being accurately measured and reported.

• Equipment that does not perform as intended should be replaced immediately.

• When a short-duration count has been completed and the data collection equipment will be picked up, another short duration equipment performance check should be performed. As with the initial equipment performance check, this check consists of making sure that all axles/vehicles are being recorded, that “ghost axles” are not being measured, and that vehicle speeds are still being accurately measured. This “confirmation” check provides assurances to the traffic data analysts that the equipment worked as intended throughout the data collection session, or it shows that the equipment failed or began to fail and that a more careful quality control analysis of the collected data is required. This check also may tell the data collection crew that these sensors or this piece of electronics requires servicing and should not be used further until the specific problems causing the observed inaccuracies have been determined and fixed.

**Semi-Permanent Counts**

Where it is not possible to safely or easily place portable sensors, agencies should consider “semi-permanent” count locations. These involve permanently placed sensors to which data collection electronics are attached for only a short duration.

Many state highway agencies have taken to using this data collection approach on high-volume rural roadways. Traditionally at these sites, traffic lanes are closed and permanent sensors (often loop detectors) are placed in the roadway with lead wires (communications lines) run to a cabinet beside the roadway. Battery-powered, portable data collection electronics are then brought to these locations periodically and connected to the sensor lead wires. The data collection electronics are then left in the roadside cabinet and retrieved when the data collection session has been completed.

With non-intrusive sensors, the same process can be performed without closing the lane. In this case, sensors (or brackets that hold sensors) can be permanently mounted (for example on a light pole) to which the data collection system can be quickly connected when data are desired at that location.

This semi-permanent approach has the advantage of allowing faster, safer site visits in high-volume locations. It also allows for the collection of traffic data (or specific types of traffic data) in locations where it is otherwise unsafe to collect those data. The downside of this approach is that it requires a much higher level of capital investment relative to traditional “portable” counts. It requires considerably more
sensors than traditional portable counts because the sensors stay at each data collection site, rather than moving with the data collection electronics. These sensors also fail periodically because they are exposed to the harsh roadway environment even when they are not actively being used for data collection, so maintenance costs for these semi-permanent sensors also tend to be higher than those for traditional portable sensors. When traditional intrusive sensors are used (i.e., loops or permanent axle sensors), this approach also requires full-lane closures to install those sensors.

**Permanent, Continually Operating Sensors**

Permanent, continually operating sensors are used to provide both current measures of traffic flow and to provide a time series record of traffic flow attributes that describe how traffic flow changes over time at that location. Current traffic flow information is used for a variety of traffic management and traveler information system purposes. The availability of time series data allows traffic engineers and planners to understand how traffic volume, speed, and other attributes change by time of day, day of week, and season of the year.

Permanent traffic monitoring locations require the following:

- Sensors that can withstand the harsh roadway environment for long periods of time;
- Power sources (either electrical power, or solar power with battery back up);
- Communications (land lines, cellular communications, or other communication systems); and
- Environmental protection (from temperature, moisture, dirt, and electrical surges on power and communications lines).

Permanent sensors represent both a large financial investment and a large data resource. As a result, the selection, installation, and calibration of that equipment is particularly important. Sensors that are poorly installed, inadequately calibrated, or that fail quickly because of poor design or construction not only do not generate useful data, but they waste resources (both money and staff time). In part this is because the money spent on equipment and installation could be used elsewhere, but also because it requires considerable staff time to determine that the “data” being provided by poorly performing sensors do not in fact accurately represent the traffic stream.

Consequently, this guide recommends that if resources are tight, data collection agencies should prioritize their equipment funding to collect better and more data at fewer permanent locations, rather than collect poor quality data at a larger number of locations. This means spending more time selecting and testing equipment prior to purchasing that equipment to ensure that it will work at the accuracy level desired. It also means spending more time, money, and effort on the installation and in-field calibration of that equipment to ensure that it is accurately reporting the traffic flow attributes it is observing and that it will have a long life.
At odds with this advice to build high-quality, long-lived permanent data collection sites is the dramatic increase in the number of permanent traffic monitoring locations desired by different groups within modern highway agencies. The growing importance of roadway operations and the consequent growth in traffic management and traveler information systems has resulted in a significant increase in the deployment of permanent traffic monitoring devices, especially for freeway traffic monitoring. The number of high-speed WIM scales associated with commercial vehicle intelligent transportation system (ITS) programs also is growing.

These trends are producing both problems and opportunities for traffic data collection organizations within those agencies. The problems result from the fact that many ITS programs are less concerned with the accuracy of traffic volume measurements than with collecting widespread, reasonably accurate traffic speed statistics. This causes problems when permanent ITS traffic monitoring systems are used to produce general traffic flow statistics. (See Chapter 7 for more discussion of how to use ITS data.) Problems also arise from the sheer volume of the data these systems produce and the resulting difficulty in efficiently and effectively collecting, storing, managing, and reporting these data.

The opportunities result from the great increase in data available to traffic monitoring programs and the significant improvement in technology available for collecting traffic monitoring information. Central traffic monitoring programs are highly encouraged to work with ITS and traffic operations groups within their agencies to help those groups select, deploy, and calibrate their equipment so that the data can be shared with the central traffic monitoring program.

### 3.3.2 Collection Equipment for Different Data Types

#### Traffic Volume Counters

Data collection equipment that measures traffic volumes can be divided into equipment that measures the passage of axles (or wheels) and equipment that measures the passage of vehicles. Both of these approaches can be performed with either intrusive or non-intrusive data collection technologies. For example, road tubes, an intrusive technology, measures axles, as do infrared sensors, a non-intrusive technology. Similarly, inductive loops, an intrusive technology, measures vehicles, as do microwave radar sensors, a non-intrusive technology.

Axle sensing technologies have the disadvantage of having to convert the number of axles they measure into an estimate of the number of vehicles being moved by those axles. In many cases, this is done by simply dividing the number of axles counted by an adjustment factor (the “axle correction factor”), which is an estimate of the average number of axles per vehicle for that roadway. (See Chapter 5 for a discussion on calculating and applying axle correction factors.) When more sophisticated axle sensor-based data collection electronics are used (e.g., vehicle classifiers), measurements of the distance between observed axles are used to determine which specific axles belong “together” and are thus part of a single vehicle. Given the combination of the computed axle distances and the assumptions of how those axle
spacings relate to vehicle classification, these counters are able to directly estimate the number of passing vehicles on the basis of the axles that are observed.

Conversely, technologies that measure vehicle volume directly have the distinct advantage of not requiring axle correction factors to convert axle measurements (which can be very accurate) to vehicle counts (which may not be nearly as accurate if the axle correction factor is not appropriate for the site).

**Portable Volume Counting**

To select a portable traffic counter, the primary issues an agency must consider are as follows:

- Can this device be placed at the location at which data are needed?
- Will it work accurately?
- How much effort/time is needed to place the device?
- Are the data collection crews safe when placing the device? and
- How long do the crews need to spend in or directly next to the travel lane?

The answers to these questions differ from location to location. The “best” volume counter for one location may not work at another. Therefore, most highway agencies need more than one type of traffic monitoring device. Because they all count “volume” and the definition of “volume” is the same for all states and vendors, the fact that different devices are used causes no problem as long as the equipment works as intended and the agency accounts for the differences between axle counts and vehicle counts.

The most commonly used portable traffic volume counter technology uses road tube sensors. Road tubes are inexpensive and easy to place on moderate and low-volume roads. Under low- to moderate-traffic volumes, they count axle passages with a high degree of accuracy (as long as the equipment is in good condition).

As traffic volume increases, the number of lanes increases, the length of the desired data collection session increases, or the geometric complexity of the roadway increases, road tubes become less appropriate. A variety of road tube sensors exist, many designed (usually in return for a slight increase in cost) to improve the capability and accuracy of road tubes under such conditions, but many agencies begin to look for other portable data collection technologies under these conditions.

Where roadway geometry or the number of lanes will negatively affect road tube performance (usually in urban settings), the most common alternative is the small magnetic sensor that can be placed in the middle of the roadway. However, if traffic volumes are high, an increasing number of agencies are using portable, non-intrusive sensors or semi-permanent data collection sites (see descriptions of these technologies in the previous section of this chapter) that utilize either intrusive or non-intrusive technologies.
Portable, non-intrusive devices generally come in three forms:

- Trailer-mounted systems on extendable poles;

- Pole-mounted systems, where the poles are attached to tripods or existing fixed structures (e.g., signposts); and

- Active infrared lasers mounted at tire height.

The original format attaches a non-intrusive sensor to an extendable pole that is mounted on a small trailer (see Figure 3-2). The trailer is towed to the desired data collection site and placed in a safe roadside location (usually behind a guardrail or other protective device). The pole is raised, and the sensor is placed at the appropriate height for data collection. The non-intrusive sensor is then aimed and calibrated before data collection begins.


Figure 3-2. Picture of a Trailer-Mounted, Non-Intrusive Traffic Volume Counter.

The trailer/pole/sensor combination includes both the data collection electronics and the power required to operate the system. The trailer is left in place as long as data are needed from that site. This
approach to portability allows the use of almost any non-intrusive sensor that can be mounted on a pole and will operate accurately from a side-fired configuration. The downside to this approach is the expense of the trailer and the need to leave the trailer at the data collection site.

The second basic version of portable, non-intrusive sensors also places the sensor on an extendable pole. In this configuration, however, the extendable poles are then either mounted on tripod systems that hold the pole steady or to an existing pole or other stable structure. The pole extension is then used to place the non-intrusive sensor at the correct height and orientation, where the sensor is then calibrated. In these systems, the data collection electronics are often placed at the base of the pole and operate off of battery power (see Figure 3-3).

The latest portable, non-intrusive technology uses active laser sensors placed at the roadside at tire height. Unlike traditional axle sensors, some active infrared-based axle sensors require that the crew installing the device cross the roadway with the sensor and that data collection equipment be placed on
both the right- and left-hand shoulders of the roadway. The laser beam itself crosses the roadway and is capable of monitoring the passage of axles in all lanes at that location.

More information on portable, non-intrusive sensors can be obtained from the Minnesota Guidestar Portable Non-Intrusive Traffic Detection System (PNTIDS) web site: http://www.dot.state.mn.us/guidestar/2001_2005/nit2.html. TTI also is performing ongoing tests of non-intrusive sensors.

Permanent Volume Counting

Permanently installed, continuously operating volume counters have been used for many years. Traditionally, the majority of these devices were inductive loop sensor-based. While inductive loops are probably still the most commonly used technology, the percentage of sites that use loops is declining. Loops are being replaced by either axle sensor-based classifiers and WIM devices that also provide traffic volume data (see below), or with non-intrusive detectors.

Because vehicle classifiers and WIM systems provide excellent traffic volume data as a by-product of their primary task, anywhere one of these pieces of equipment is installed, a permanent traffic counter exists.

Agencies that wish to avoid using intrusive sensors for permanent data collection sites, either because they are concerned about the longevity of those sensors in pavements that are in poor condition or because they do not wish to close traffic lanes for installation or sensor maintenance, have adopted non-intrusive detectors. Initially, the primary non-intrusive detector used video technology. This technology works well in many locations (i.e., where lighting is not a problem and where weather conditions do not routinely hinder visibility). However, other non-intrusive detector technologies are gaining market share because of their lower life-cycle costs. Several national tests of these devices have shown that they can provide levels of data accuracy comparable to those of traditional intrusive and non-intrusive technologies.6

In fact, non-intrusive technologies are logical choices for agencies that wish to avoid working in the roadway. The only caveat with these technologies is that, as with any new technology, careful testing should be performed in the environment in which the units are to operate to ensure that the vendor and technology selected can actually deliver the promised data accuracy. These tests should take place before an agreement is reached to purchase large numbers of these devices.

Vehicle Classification Counters

A variety of systems can be used to classify vehicles in the traffic stream. The ideal vehicle classifier would be able to measure a variety of vehicle characteristics in order to differentiate vehicles on the basis of several factors (e.g., body type, engine type, axle configuration, overall vehicle length) in order to meet

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the needs of different users. Unfortunately, such equipment currently does not exist at a price that can be afforded by highway agencies.

**Alternative Vehicle Classification Systems**

Available technology allows visual observation (usually human observers), axle-based classification, and vehicle length-based classification. These different approaches to vehicle classification result in different classification systems, and these systems are not uniform subsets of each other. For example, if a state uses both the FHWA 13-category classification system and a 4-category classification system based on overall vehicle length, not all of the FHWA Class 7 vehicles (four or more axle single-unit trucks) will fall into the same vehicle length classification. Thus, equipment that collects classification data by using the FHWA 13-category system cannot provide “accurate” estimates of the number of vehicles within each of the four length classes.

The diversity of classification systems grows even larger when the effects of state-specific truck size and weight laws are taken into account. Because states have different truck size and weight laws, the characteristics of trucks (number and spacing of axles, overall vehicle lengths) change from state to state. Trucks that look visually similar may have very different axle spacings. And since the FHWA 13-category system is based on a visual classification scheme (see Figure 3-1), most states must develop their own version of the basic algorithm for converting measurements of the number and spacing of axles into a prediction of the FHWA vehicle category that each combination of axles and axle spacings represents.

Even with state-specific algorithms, some vehicles are commonly misclassified. This occurs because two very different vehicle types (body styles) may have very similar axle spacing characteristics. Two examples of vehicles that are often misclassified are cars pulling trailers (which are often classified as trucks) and recreational vehicles (which are often classified as large trucks). These errors are not the “fault” of the classifier but are simply limitations in the assumptions that are required to convert measurements of axle spacing or vehicle length into vehicle classification decisions when that classification system is based on different vehicle attributes (in this case the number of independent body units).

When states do not refine these classification algorithms to match the truck characteristics unique to their state, the number of classification errors (the differences between what the classifier reports and the “true” classification) increases significantly. An increase in error rates cause by the wrong classification algorithm also is the major reason that highway agencies need to test every classifier delivered to them by vendors to ensure that the vendor has loaded the proper classification algorithm onto those devices.

It also is imperative that states test and refine their classification algorithms to ensure that they perform as desired. Part of this testing process should document the correlations between (and common errors found in) how their axle sensor-based and vehicle length-based data collection equipment classify

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vehicles. These differences are very important to understand when data collected in one format (e.g., FHWA's 13-category system) must be reported in another format (e.g., a simplified 3-category length system).

Before deciding on equipment, however, the data collection agency should first determine whether axle-based classifications are needed or whether less complex, length-based classification is acceptable. This decision significantly affects which equipment should be considered, regardless of whether the equipment will be used for short-duration counts or permanent, continuous counts.

For most engineering tasks, the primary classification issue is separating “heavy” vehicles from “light” vehicles because heavy vehicles cause more pavement and bridge damage and tend to have poorer acceleration and braking characteristics. In detailed pavement design calculations, the number, type (e.g., single or tandem axle), and weight of axles are the key load statistics used for designing the proper pavement thickness. However, many agencies use simplified pavement design procedures that only require the number of trucks by overall size of truck (single-unit trucks, combination trucks, or multitrailer trucks). Other agencies use “catalog design” procedures in which the designer simply identifies the most appropriate standard plan design on the basis of a more general truck volume statistic. These agencies have much less need for classification systems based on axles and are therefore more likely to select vehicle length classifiers, since their need for axle-based classification data is limited.

In addition, there are places (particularly in unstable flow conditions) where most axle-based classifiers simply will not work reliably. Under these conditions, length classifications may be required if some form of vehicle classification is needed. While vehicle length measurements are often less than optimal under these conditions, the smaller number of length classes and the less complex classification algorithms used by these devices generally mean that length-based classification is more accurate under these conditions.

Both intrusive and non-intrusive technologies exist that can measure axles, axle spacings, and vehicle lengths. Table 3-1 summarizes the characteristics of these technologies. Additional new technologies also are likely to be on the market in the next few years. Each sensor technology has its own advantages and disadvantages related to cost, reliability, accuracy, life span, ease of set up, and type of information provided. No technology has proven to be the best classifier under all conditions. Consequently, agencies must select the technologies that provide the data they most need to provide the classification information they require, at the locations for which those data are needed, at prices they can afford. The subsections below briefly discuss the available portable and permanent classification systems currently on the market.
Table 3-1. Vehicle Classification Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Intrusive or Non-Intrusive</th>
<th>Types of Vehicle Classifications Collected</th>
<th>Number of Lanes of Data Collected by Each Sensor</th>
<th>Environmental Issues/Concerns</th>
<th>Other Issues/Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piezoelectric Cable</td>
<td>Intrusive</td>
<td>Axle-Based (FHWA 13+)</td>
<td>1 per pair of sensors</td>
<td>Susceptible to snowplow damage</td>
<td>Temperature sensitive. Does not work well in stop-and-go traffic</td>
</tr>
<tr>
<td>Piezopolymer Film</td>
<td>Intrusive</td>
<td>Axle-Based (FHWA 13+)</td>
<td>1 per pair of sensors</td>
<td>Susceptible to snowplow damage</td>
<td>Temperature sensitive. Does not work well in stop-and-go traffic</td>
</tr>
<tr>
<td>Fiberoptic Cable</td>
<td>Intrusive</td>
<td>Axle-Based (FHWA 13+)</td>
<td>1 per pair of sensors</td>
<td>Susceptible to snowplow damage</td>
<td>New technology, not currently in widespread use. Does not work well in stop-and-go traffic</td>
</tr>
<tr>
<td>Other Pressure Sensors</td>
<td>Intrusive</td>
<td>Axle-Based (FHWA 13+)</td>
<td>1 per pair of sensors</td>
<td>Susceptible to snowplow damage</td>
<td>Does not work well in stop-and-go traffic</td>
</tr>
<tr>
<td>Inductive Loop (Conventional)</td>
<td>Intrusive</td>
<td>Length-Based</td>
<td>1 per pair of sensors</td>
<td>Freeze/thaw can break loops</td>
<td>New technology, not currently in widespread use</td>
</tr>
<tr>
<td>Inductive Loop (Undercarriage Profile)</td>
<td>Intrusive</td>
<td>Various</td>
<td>1 per pair of sensors</td>
<td>Freeze/thaw can break loops</td>
<td>New technology, not currently in widespread use</td>
</tr>
<tr>
<td>Side-Fired Radar</td>
<td>Non-intrusive</td>
<td>Length-Based</td>
<td>Multiple</td>
<td></td>
<td>Not as accurate as overhead-mounted, forward-, or rear-facing radar</td>
</tr>
<tr>
<td>Overhead Radar&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Non-intrusive</td>
<td>Length-Based</td>
<td>1 per sensor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrared&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Non-intrusive</td>
<td>Length or Height-Based</td>
<td>1 per sensor array</td>
<td>Can be affected by heavy fog, snow, glare, dust</td>
<td>New technology, not currently in widespread use</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>Both&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Length-Based</td>
<td>1 per pair of sensors</td>
<td></td>
<td>Initial installation cost can be high</td>
</tr>
<tr>
<td>Video (Trip Wire)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Non-intrusive</td>
<td>Length-Based</td>
<td>Multiple</td>
<td>Can be affected by heavy fog, snow, glare, dust</td>
<td>Requires proper mounting height</td>
</tr>
<tr>
<td>Video (Object Analysis)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Non-intrusive</td>
<td>Various</td>
<td>Multiple</td>
<td>Can be affected by heavy fog, snow, glare, dust</td>
<td>Requires proper mounting height. New technology, not currently in widespread use</td>
</tr>
<tr>
<td>Ultrasonic&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Non-intrusive</td>
<td>Length-Based</td>
<td>1 per pair of sensors</td>
<td>Temperature variation and air turbulence can affect accuracy</td>
<td>New technology, not currently in widespread use</td>
</tr>
<tr>
<td>Acoustic&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Non-intrusive</td>
<td>Length-Based</td>
<td>Multiple</td>
<td></td>
<td>Technology not currently in widespread use in highway applications</td>
</tr>
</tbody>
</table>
There are two basic undercarriage loop classifier technologies. One uses the “signature” from existing loops to determine classification by matching the shape of that loop to expected profiles. The other uses specific types of loops to detect changes in inductance associated with wheels, and uses that information to detect and measure axles. This device can classify by “axle,” while the other defines classes that relate strongly to axle-based classes but are not specifically based on the number and spacing of axles.

Overhead-mounted, non-intrusive detectors require a structure (usually a bridge or gantry) upon which to be mounted. Where these do not already exist, the expense of sensor installation increases dramatically.

Can be mounted overhead or side-fired. If used in side-fired configuration, vehicle classification is normally based on height, and only one lane of traffic can be detected.

Some magnetometers are installed in the pavement, and some are installed in conduit that is placed underneath the existing pavement by drilling underneath the pavement. This can be done without disrupting the existing traffic stream but does require the appropriate equipment.

Video image analysis will define classes on the basis of the features the image analysis software can detect. The simplest detection algorithms are based on length. More complex algorithms can detect and classify using axle information, provided the camera angles are capable of “seeing” different axles.

Portable Vehicle Classifiers

Historically, truck counts (i.e., classification counts) could only be performed by staff manually observing the traffic stream. Manual classification of the traffic stream has a variety of advantages. For example, visual identification can classify trucks on the basis of a vehicle’s body style (tank trucks versus dump trucks versus flat bed trucks versus box vans). Looking at trucks also can increase the accuracy with which an individual truck is classified as 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, even 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 paying attention.

Unfortunately, manual classification counts are expensive and prone to errors, often because of how the counts are performed. As noted earlier, error rates in manual classification counts tend to increase significantly after the staff member has been working for about three consecutive hours. (After three hours, the concentration of most observers tends to wander, causing the number of errors to increase.) In addition, most human observers cannot count accurately under high-volume, multilane conditions (additional observers are needed, further increasing the cost of data collection), and many roads do not have places where an observer can safely sit while counting traffic.

Therefore, manual classification tends to be restricted to short-duration count sessions (such as turning movement counts that also require classification data) and locations where automated vehicle classifiers cannot be placed or where such equipment will not work accurately because of variable traffic flow conditions. One option for performing counts where staff cannot stand/sit for data collection is to mount a camera, store the images of the passing traffic on video tape or DVD, and then have staff count vehicles by manually reviewing these images. This approach is still costly, but it has the advantages of 1) allowing staff to work in a warm, dry, comfortable environment, 2) allowing “double counting” of the same video

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8 Ulberg and Farnsworth. HOV Lane Evaluation and Monitoring. Washington State Department of Transportation, 1992, WA.RD 281.1
images to ensure accurate counts, and 3) allows staff to “slow” or rewind the images to ensure accurate vehicle classification. The primary disadvantage of this approach is that it is costly, both because of the time required to review the tape, and the need to place and remove cameras.

As a result, when longer traffic data collection activities are warranted, the automated data collection technologies discussed in the previous section must be used.

The vast majority of portable vehicle classification counts taken in this country are performed with axle-based classifiers that use two road tube sensors. These devices generally work accurately and are easy to set-up on low and moderate volume two-lane and divided four-lane roads. These roadways constitute a large percentage of the roadway miles on which classification counts are required.

Conventional road-tube-based equipment is a less obvious choice on higher volume roadways and on roads that contain lanes that are not adjacent to shoulders. On high-volume roadways, road tubes are frequently knocked loose partway through a count, invalidating that count. On some roads, conventional road tubes cannot be placed safely or do not work effectively.

For these situations, agencies have basically four options for collecting short duration vehicle classification counts:

1. They can purchase specialized axle sensors and spend additional installation time and effort attempting to keep those sensors attached to the road surface long enough to collect the desired data;
2. They can install permanent sensors, but only attach data collection electronics to those sensors periodically;
3. They can use traditional, non-intrusive sensors that collect vehicle length data; and
4. They can adopt the newer non-intrusive axle sensor-based devices.

To perform portable axle-based classifications on a multilane road where all lanes are not located next to a shoulder requires the selection and placement of an axle sensor that is sensitive only to traffic in one lane while the sensor or its lead wires are stretched across multiple lanes. There are road tubes that fit this description. Michigan DOT demonstrated the use of fiberoptic cables for this type of application at NATMEC in 2002. Other intrusive axle sensors also exist that can perform accurately under these conditions. The advantage of this approach is that it allows the agency to continue to use its existing data collection electronics. The drawbacks of this approach include the facts that 1) it is very hard to keep axle sensors in place in high-volume facilities, as vehicles that drag parts tend to rip them up, no matter how they are held in place; 2) placing sensors across multiple lanes and placing sensors in the middle of

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multilane facilities can be very dangerous for data collection crews; and 3) provision of traffic control to place and retrieve sensors on large facilities greatly increases the cost of the data collection effort.

It is precisely because of these limitations that some states have decided to use the “semi-permanent count locations” discussed earlier in this section. These agencies install permanent sensors at locations where classification data will be routinely collected but do not connect data collection electronics to those sensors permanently. Instead, the site is only visited periodically. Portable data collection electronics are attached to the sensor leads that remain in place permanently, and short-duration counts are performed. This approach limits traffic control needs to the one time that the sensors are installed and those few instances when sensor maintenance is required. It also increases the speed with which data collection electronics can be placed when data are to be collected. The primary downside of this approach is the cost of purchasing and installing sensors that are not routinely used.

Non-intrusive sensors were developed in large part to address the problem of being unable to set traffic counters on high-volume roadways. Several traditional non-intrusive sensors can measure vehicle lengths and can therefore be used to collect vehicle classification data based on overall vehicle length. While these sensors have been primarily used as permanent sensors, a number of state DOTs have designed portable versions of these sensors, and vendors are beginning to market more portable versions of these sensors.¹⁰

The last option is to adopt the new, non-intrusive laser sensors that allow axle classification across multiple lanes. According to the Minnesota DOT’s non-intrusive detector tests referenced above, two vendors currently market devices with these capabilities, and discussions with members of the state DOT data collection community as part of this project have indicated that they are gaining increasing market penetration in response to favorable experience with the devices by several state DOTs.

Permanent Vehicle Classifiers

Because of the desire to collect data that allow classification of traffic into FHWA’s 13-category, axle-based classification scheme, the majority of permanent vehicle classification systems are axle sensor-based. No definitive data are available to indicate which sensor technology is most frequently used for this application, but discussions at the NATMEC conferences suggest that a large percentage of agencies use one or more of the piezoelectric sensor technologies as their primary permanent axle sensor.

While all three piezosensor technologies can be used with vehicle classifiers, piezopolymer film and piezoceramic cable sensors are the most commonly selected technologies for permanent vehicle classifiers that also do not provide axle weights. These piezosensors are chosen over the piezoquartz sensor because of their lower cost and easier installation. Because most axle-based vehicle classification algorithms only require the number and spacing of axles, the technologies’ temperature sensitivity problems,

which affect the magnitude of the piezosensor signal output, are not a significant issue for permanent classification sites.

To improve the accuracy of their vehicle classification algorithms, many agencies build, buy, or specify their permanent classifiers with both inductive loops and axle sensors. The inductive loop output is used to determine the presence of a vehicle, while the axle sensor provides information on the location and number of axles associated with that vehicle. (When the loop turns off, it signals the end of one vehicle and the beginning of the next, thus insuring that axles are assigned to the correct vehicles.)

If longevity of a site is an issue and/or if working in the roadway is difficult, the life of an installation can be extended at modest cost by using an extra sensor. One possible configuration is shown in Figure 3.4. The extra sensor provides some redundancy. Vehicle speed can be determined on the basis of either the time between the two axle sensors or the time between the two loop sensors. In addition, only one loop is needed to detect vehicle presence, and only one axle sensor is needed to measure axle arrival time. Thus, if one sensor fails, the site can be reconfigured to use the three working sensors. A limitation of this approach is that, for at least some vendors, all lanes at a given site must be similarly configured; so the approach does not work when one lane loses a loop and another loses a piezo.

Where axle-based classification is not required, or where an agency does not wish to place axle sensors in the pavement, many agencies have turned to length-based classification. Vehicle length classification can be performed with a number of non-intrusive vehicle detectors, as well as with inductance and magnetic detectors.

Wherever video detection exists and traffic speeds are stable, vehicle classification data can be gathered. Similarly, wherever dual inductive loops have been installed to collect vehicle speed data, it is possible to collect vehicle length data. This latter fact has allowed many state DOTs to inexpensively convert their traditional permanent traffic volume counters into permanent vehicle classifiers. Agencies also have converted “speed monitoring sites,” originally installed to monitor compliance with the 55 mph national speed limit, into length-based classification sites without having to add additional sensors.
Figure 3-4. Common Sensor Layout for a Permanent, Axle-Based Vehicle Classifier.

**WIM Counters**

The goal of weigh-in-motion equipment is to collect the axle and vehicle weight data required to estimate the traffic loads that pavements and bridges experience. This same data can provide information on the approximate size and nature of overloaded vehicles operating on monitored roadways. Along with collecting axle weight information, WIM devices also must classify the trucks to which those weights belong.

The “weight” desired as the output from a WIM-scale measurement is the weight applied by each axle/vehicle as that axle/vehicle stands at rest. This is commonly referred to as the axle’s/vehicle’s “static weight.” Unfortunately, one of the major technical difficulties in weighing vehicles while they are in motion is that the force applied by a given axle varies over time as a result of that vehicle’s motion. Axle weights vary because the road profile (bumps in the pavement) interacts with each truck’s suspension system to cause vertical motion in the vehicle. That is, trucks “bounce” as they travel down the road.

Consequently, the force applied at any one point in time and space by every axle is a function of whether that specific truck/axle is bouncing up (in which case the force is less than the static axle weight) or down (the force is greater than the static axle weight). Dynamic motion of truck axles is a very complicated process that is affected not only by the road surface profile but also by the nature of the tires on the truck, the tire inflation pressure, the type of suspension, the condition of that suspension, the type of
truck body, the size and nature of the load, and a variety of other factors. As a result, each truck tends to "bounce differently" as it moves down the road.

The accuracy of any given WIM system is a function of both 1) how well the WIM sensor measures the force actually being applied to it, and 2) how well the data collection electronics can determine how that force relates to the static condition of that axle. Even if the sensor reports exactly what force is applied to it, if the data collection electronics cannot remove the effects of truck motion (dynamics) on that measurement, the accuracy of the static weight estimate will be poor.

As a result, WIM data should only be collected where vehicle dynamics are at a minimum. This is accomplished by placing WIM scales on flat, straight stretches of roadway, where the pavement is smooth and in good condition. Both ASTM and the FHWA Long-Term Pavement Performance Program have published specifications that describe the pavement conditions under which WIM scales can be expected to measure static axle loads effectively.\(^{11}\)

The impact of the road profile on vehicle dynamics also means that every WIM scale should be carefully calibrated where it is installed. Only site-specific calibration allows a scale system to account for the unique characteristics of vehicle motion at a specific location.

Another consequence of the impact of vehicle dynamics on WIM-scale accuracy is that any "bump" in the road causes WIM-scale accuracy to decrease, because every bump increases vehicle dynamic motion. This fact causes accuracy problems for portable WIM scales. When a WIM sensor is placed on top of the roadway, that sensor creates a bump, and that bump causes a dynamic reaction in the vehicle being weighed, causing errors in the calculation of the "static" condition of that axle/vehicle. Thus, portable equipment that relies on temporarily placed sensors on top of the road surface tends to be less accurate than WIM equipment that relies on permanently mounted sensors that have been placed flush with the roadway surface. The physics of vehicle dynamics works against the accuracy of portable WIM systems.

**Portable WIM**

Ideally, as with classifiers and volume counters, WIM equipment selection would be divided into both permanent and portable devices, because weight data also are needed both at geographically diverse locations and over long periods at some locations. Unfortunately, the need for site-specific calibration, discussed above, means that portable scales must be calibrated each time they are placed on the road surface. WIM-scale calibration generally takes a crew of three to five people at least one day. This roughly doubles or triples the cost of setting up a portable weighing session because calibration often takes as many, or more, resources (staff time) as the sensor placement and pick up. In addition, because portable WIM sensors must invariably be placed on top of the road surface, the added “bump” caused by

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the sensor’s profile tends to negatively affect the accuracy of the scale.

Therefore, although several WIM technologies (most notably capacitance pads and some piezoelectric strip sensors) can be used as portable WIM sensors, the use of portable WIM currently is discouraged by FHWA because of the limited accuracy that normally results from those efforts. When the calibration costs and decreased accuracy are accounted for, many states find that portable WIM becomes cost prohibitive relative to the use of “semi-permanent” WIM (placing WIM sensors permanently in the ground but collecting data from those sensors only periodically for moderately short periods).

**Permanent WIM**

Permanent data collection sites are preferred for collecting weigh-in-motion data, because the WIM sensor can be mounted flush with the road surface, thus removing (or at least significantly decreasing) the horizontal impact force of the tire on the sensor and consequently improving the accuracy of the sensor. A number of the axle sensor technologies presented earlier in this section are commonly used as WIM scales. In the United States, the most common sensors are:

- Bending plates;
- Piezoelectric quartz;
- Piezoelectric ceramic cable;
- Piezoelectric polymer film (BL); and
- Hydraulic load cells.

In some countries in Europe and Asia, bridge WIM (and the highly related culvert WIM) and capacitance pads also are used routinely. Newer WIM technologies such as fiberoptic WIM and multisensor WIM are primarily used only for research. Table 3-2 summarizes the basic attributes of each of these technologies. The strengths and weaknesses of the commonly available technologies are summarized below.
## Table 3-2. Comparison of WIM Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Installation Requirements</th>
<th>Length of Traffic Disruption During Installation</th>
<th>Environmental Issues/Concerns</th>
<th>Other Issues/Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Plate</td>
<td>Moderate frame installation</td>
<td>Moderate</td>
<td></td>
<td>Measures both wheel paths independently</td>
</tr>
<tr>
<td>Piezoelectric Cable</td>
<td>Narrow slot</td>
<td>Short</td>
<td>Temperature sensitive</td>
<td>Accuracy affected by changes in pavement strength</td>
</tr>
<tr>
<td>Piezo-Polymer Film (BL)</td>
<td>Narrow slot or portable</td>
<td>Short</td>
<td>Temperature sensitive</td>
<td>Accuracy affected by changes in pavement strength</td>
</tr>
<tr>
<td>Piezoquartz</td>
<td>Narrow slot</td>
<td>Short–Moderate</td>
<td></td>
<td>Accuracy affected by changes in pavement strength</td>
</tr>
<tr>
<td>Hydraulic Load Cell</td>
<td>Deep pit</td>
<td>Long</td>
<td></td>
<td>Most expensive system currently on the U.S. market. Measures both wheel paths independently</td>
</tr>
<tr>
<td>Capacitance Mat</td>
<td>Portable or moderate frame installation</td>
<td>Short–Moderate</td>
<td></td>
<td>Only measures one side of each vehicle. Portable operation subject to errors caused by impact loads. When used as portable devices, accuracy is affected by changes in pavement strength</td>
</tr>
<tr>
<td>Fiberoptic Cables</td>
<td>Narrow slot</td>
<td>Short</td>
<td></td>
<td>Not actively marketed in the United States. Still primarily under development. Accuracy affected by changes in pavement strength</td>
</tr>
<tr>
<td>Bridge WIM (Culvert WIM)</td>
<td>Weight sensors under bridge</td>
<td>Short</td>
<td></td>
<td>Currently out of favor in the United States but not in Europe or Australia. Currently works accurately only on specific styles of bridges/culverts</td>
</tr>
<tr>
<td></td>
<td>Either no axle sensors, or narrow slot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsurface Strain Gage</td>
<td>Deep pit</td>
<td>Long</td>
<td></td>
<td>New system design, only in testing in the United States. Accuracy affected by changes in pavement strength</td>
</tr>
<tr>
<td>Multisensor WIM</td>
<td>Multiple narrow slot</td>
<td>Moderate</td>
<td>Depends on technology used</td>
<td>While excellent potential, not currently marketed in the United States other than as two-sensor systems using the above technologies</td>
</tr>
</tbody>
</table>
Bending plates are in the middle of the cost/performance (accuracy) curves for WIM systems. Bending plate technology is very mature. Bending plate scales are generally robust and have reasonably long life spans if installed correctly in strong pavements that are in good condition. The moderately large weighing platform eliminates “bridging” effects when passing tires/axles are weighed, and the fact that the sensor platform is held entirely in a steel frame means that changes in the pavement’s structural strength caused by changing environmental conditions do not affect the scale’s performance or calibration. The drawbacks of bending plates are the longer time required to perform the installation of the larger sensor and the fact that if a sensor is ever dislodged from its frame, it becomes a significant hazard to passing vehicles and motorists.

Piezoelectric quartz is most likely the fastest growing segment of the WIM sensor market. It is comparable in cost and performance (accuracy) to bending plate technology, but the smaller sensor enables a faster, lower-cost installation process. Piezoquartz sensors, like most “strip” sensors, are often installed in two parallel rows. This means that each passing axle/vehicle is weighed by two independent sensors. The two measurements occur at different points in the dynamic motion profile of the truck/axle, thus increasing the ability of the WIM system to estimate each vehicle’s static weight. Piezoquartz is the most accurate and most expensive of the “strip sensors” currently on the market. It is most accurate because the sensor itself is not temperature sensitive (thus making the calibration of the WIM system more stable). However, because the sensor is thin and mounted directly in the pavement, its accuracy is affected by “tire bridging” and changes in pavement structural strength caused by environmental conditions.

Piezoelectric ceramic cable was the original “piezostrip sensor.” It is among the most inexpensive of the WIM sensors and as such has often been used as a “low cost” WIM scale. Unfortunately, this means that it has often been placed in pavement that is in poor condition and scheduled for repair. (“Low cost” WIM efforts have often meant that few resources have been provided for calibration and maintenance of the WIM scale and its surrounding pavement. The poor condition of the pavement has meant that the road surface has been rough and that vehicle dynamics have been high. In addition, piezoceramic sensors are temperature sensitive, as is the structural performance of roadways that are in poor condition. The result is that piezoceramic cable WIM often has a poor reputation for both performance and longevity. The reality is that if properly installed in good pavement, piezoceramic sensors can have a very long life. However, the fact that their output is temperature sensitive means that a much more robust calibration system is required to maintain the accuracy of these devices under changing temperature conditions. Many equipment vendors underplay this limitation when making sales to cost-conscious agencies. The result is that many of these sensors produce calibration errors when temperatures change, and the resulting weight data is often of suspect quality.

Piezoelectric polymer film (BL sensors) has cost and performance characteristics similar to those of piezoceramic cable. BL sensors have been used for WIM but are more commonly used as vehicle classification sensors.
Hydraulic load cells (also known as “deep pit scales” because of the size of the hole that must be dug to install the sensor platforms) are the most expensive of the WIM systems. They are generally considered “the Cadillac” of WIM systems. The technology itself is generally long lived, is not sensitive to temperature or other environmental changes, and uses a moderately large weighing platform that does not suffer from “bridging problems” and is not affected by the structural performance of the pavement in which the scale is placed. A large portion of the expense of the hydraulic load cell is the installation cost of the sensor. Installation normally requires multiday lane closure of the roadway and at least a moderate amount of paving work. As a result, hydraulic load cells are usually placed in specially built concrete “pads” that provide a smooth “run up” to the scale sensor. While these pads are expensive, the marginal cost of the pad beyond the cost of simply buying and installing the sensor is modest because installation already requires paving equipment and traffic control. The fact that a smooth, strong pavement is provided as “run up” to the hydraulic load cell scale contributes significantly to its accuracy, its long life, and its cost. It improves scale accuracy because vehicle dynamics are damped out by the smooth approach to the scales. In addition, the smooth, strong pavement (with no ruts) decreases tire impact loadings on the scales which further decreases dynamic forces and also results in longer lived sensors.

Bridge (and culvert) WIM are infrequently used in the United States but are used fairly extensively in some countries. These systems are especially good at removing vehicle dynamics from the weighing system. However, their accuracy is badly affected when the trucks being weighed are not isolated on the bridge/culvert that serves as the scale sensor, and where the expected response of that structure to traffic loads is not easily calculated. These systems tend to work best on moderate to low volume roads where vehicles are alone when crossing the instrumented structures, and where these facilities are reasonably “simple” from a structural point of view. For example, when bridge WIM was being initially explored in the United States in the late 1980s the “best” bridges for use as weighing platforms were two-lane, short span, simply supported, steel girder bridges. The response to different loads on these bridges is easily analyzed, and the limited number of lanes and short span increases the odds that any truck crossing the bridge will be the only vehicle on the bridge for the majority of the time the truck is on the span. Tests in the 1980s showed that system accuracy declined significantly on longer bridges of complex design (e.g., curved, box girder bridges).

Capacitance pads can be used as permanent WIM sensors by placing the weighing sensor in a frame cut into the pavement. In the United States, few capacitance pad systems have been used in this manner. Instead, most capacitance pads in this country are used in portable applications. They are most commonly classified as being on the lower end of the cost/performance (accuracy) curve. In part this is because of their use in portable applications. Their accuracy is not helped by the fact that most available capacitance pad systems place sensors in only one wheel path. This decreases costs but reduces the accuracy of the resulting axle weight estimates. Some improvements over reported accuracies can be expected by using these systems in a permanent installation because placing the pad in a frame flush with the pavement surface removes two sources of error, the bump that is caused by the sensor and the variability in sensor support that results from placing the portable sensor on top of the road surface, which itself has structural characteristics that are affected by environmental conditions.
3.4 Equipment Selection

If there is no simple answer to the question of “What is the ‘best’ data collection equipment?” How should an agency select data collection equipment to purchase and use?

This section of the chapter presents the key attributes of the equipment from which data collection agencies must choose. It is then up to each roadway agency to determine how to weigh these various attributes to select the “best” equipment to meet its needs.

This guide recommends that, at a minimum, the following attributes be considered when traffic data collection equipment is selected:

- The traffic attributes that the equipment collects and stores;
- The accuracy with which those attributes are collected, and any limitations on where and when the device can be used without compromising that accuracy;
- The expected longevity of the system along with any warranties that support that expected life cycle;
- The installation requirements of the system (in time, cost, and staffing);
- The operational requirements of the system, including power and communications needs;
- The cost of the system;
- The amount of vendor support provided; and
- The compatibility of the data and the data retrieval software with the agencies’ existing and planned databases and data management systems.

Each of these subjects is briefly described below.

3.4.1 Traffic Attributes Collected

The starting point for any equipment selection process is whether the equipment can collect the data required by the agency. Therefore, the agency must decide what traffic attributes it requires. Total volume? Volume by vehicle classification? Are simple length classifications good enough, are the 13 FHWA classes required, or are state-specific classifications required? Does the equipment need to provide axle weight or even wheel weight information?

As well as determining what traffic flow attributes need to be collected, the agency must examine where and for how long those data need to be collected. Are the data to be collected for short durations (24 to 72 hours) at a variety of locations, or is the equipment needed at a more limited number of permanent locations?

What are the physical attributes of the locations at which traffic data are required? Are they high-volume, multilane locations, or are they low-volume, two-lane roads? Are the data to be collected on
segments of roadway that operate with free flow traffic, or is there congestion or the effects of signalization? Are the sites some combination of these?

If the data collection needs are diverse, the agency may be best served by purchasing more than one type of equipment, each type of equipment optimized for specific kinds of locations. (Note that many vendors sell data collection electronics that can be used with multiple types of sensors. If this is the case, one brand/model of data collection electronics could be purchased, but the equipment would use different sensors at different locations.)

### 3.4.2 Accuracy of the System

Any request for proposal (RFP) for new equipment should include a requirement that the responding vendors describe the types of traffic flow attributes that their equipment can produce and the accuracy with which that equipment (the combination of sensors and data collection electronics) can provide those data. The RFP also should require a description of the traffic conditions under which those accuracy levels can be obtained, the types of conditions that adversely affect the performance of the proposed equipment, and the approximate degradation in performance that can be expected to occur under those conditions.

The responding vendors should be requested to submit documentation of the achievement of those accuracy levels, including the traffic flow conditions under which the tests were performed. It is preferable (but not required) that these tests have been performed by an independent agency. Lastly, the vendors should be requested to provide a guarantee that their equipment (when installed properly and in the conditions they have specified) will operate at the stated accuracy levels.

While the submitted accuracy levels should be used for initial equipment selection, no equipment should be purchased until it has demonstrated that it can achieve the accuracy levels stated in the proposal for the purchasing agency. After initial equipment selection, a single unit should be obtained and tested rigorously. If the equipment meets the desired level of accuracy, then the planned purchase should proceed. If the equipment does not meet the agency’s requirements (or at least the vendor’s claimed level of accuracy under the desired data collection conditions), then the agency should reject that piece of equipment and return to the equipment selection process.

There is relatively little information available on expected levels of accuracy for traffic data collection equipment. While both ASTM and the European Union (COST) have published WIM specifications, neither organization has adopted a standard for vehicle classification or volume counting. The

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Long-Term Pavement Performance Program (LTPP) has adopted some device calibration/validation protocols, but these protocols have not been widely adopted outside of the LTPP program.

Consequently, it is up to individual agencies to set data collection accuracy requirements. When doing so, agencies must remember that no data collection device is 100 percent accurate. All traffic monitoring systems have some error; however, these errors are often modest in comparison to the size of the errors inherent in the adjustment of short-duration counts to estimates of average annual daily conditions.

### 3.4.3 Longevity of the System

The next major topic area for consideration is the longevity of the sensors being purchased and the data collection electronics attached to those sensors. This is best described in terms of the Mean Time Between Failure that can be expected of the sensor when it has been placed in a good location (for intrusive sensors, this means in good quality pavement). As with system accuracy, it is recommended that warranties be requested from the vendors for the service lives of their equipment. Vendors may specify the conditions under which those warranties may be voided. These clauses are an excellent way for the agency to learn about the factors that are likely to affect the lifespan of the sensors/equipment they are about to purchase.

This information provides the purchasing agency with a better understanding of how long a specific type of data collection equipment can be expected to operate. This in turn allows the computation of life-cycle costs for the data collection equipment. It also allows more accurate financial planning by the data collection agency.

### 3.4.4 Installation Requirements

Each vendor’s proposal should describe the approximate time, resources, and procedures required to place and use the proposed equipment at each data collection location. The installation requirements include any recommended system calibration both before and after installation at the site.

The bid documentation does not need to include complete installation instructions (these must be provided if the equipment is selected for purchase), but it must include enough information for the purchasing agency to develop a generalized cost estimate for installing the equipment. These instructions, combined with the accuracy statement described above, also are intended to allow the purchasing agency to determine whether the equipment can be effectively installed and used at the key locations for which traffic data are desired.

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3.4.5 Operational Requirements

The bid documents should describe the operational requirements of the proposed equipment. These include the power requirements of the system (if the device is intended for portable use, this includes the possible duration of a data collection session on a single battery charge), the communications required/available to the equipment, and any periodic maintenance required to keep the system operating at the level of accuracy submitted in the proposal. Maintenance requirements described by the proposing vendor should include sensors, data collection electronics, and any specific site considerations (e.g., review and repair of pavement/sensor bonds for intrusive sensors). Maintenance activity descriptions should include the expected timing of these maintenance visits (e.g., once a year, twice a year, once every five years).

3.4.6 Cost of the System

The RFP should request information on the capital cost of the system and the expected costs required to operate and maintain the system. These costs should be cross referenced with the installation, operation, and maintenance tasks described in the previous two tasks. The intent of these requests is to provide enough information for computing a valid life-cycle cost estimate for each proposed data collection device.

Included in the cost section should be information on how many lanes of traffic can be monitored with each sensor or set of data collection electronics. These statements must be cross referenced to the data accuracy statements for devices that can be installed in a variety of configurations. (That is, for non-intrusive detectors that can be located either above or beside the road, the vendor should clearly describe the tradeoffs between different sensor installation options in terms of the number of lanes each sensor can cover, the accuracy of the data collected, and the cost of the device.) The intent of this request is to ensure that the purchasing agency understands how many sensors/sets of data collection electronics should be purchased to collect traffic data at the desired number of count locations.

It is up to the purchasing agency to review this material and determine the relative merits obtained from each of the cost/configuration combinations.

3.4.7 Vendor Support

A key to satisfaction with a data collection system is often the quality of support of that equipment offered by the vendor. Discussions with data collection staff from around the country indicate very different attitudes toward specific vendors. Further exploration of specific issues with these agencies almost always reveals that some agencies receive far better vendor support from specific vendors than others. Consequently, it is important to learn what level of support can be expected.

Of specific interest are the warranties discussed above, the amount of training that is offered as part of the equipment purchase, the quality of documentation that comes with the equipment being purchased,
the availability of telephone support, the availability of equipment repair assistance, the provision of replacement parts on short notice, and the availability of software support.

3.4.8 Compatibility with Existing Data, Databases, and Data Management Systems

The final area of consideration recommended for inclusion in the equipment selection process is the nature and flexibility of the software provided by the vendor that enables extraction of data from the roadside data electronics and insertion of those data into the agency’s data management system.

Some vendors have highly proprietary data extraction and analysis systems that may not integrate easily with an agency’s existing data processing system but that offer fully functional analytical systems on their own. Other vendors supply bare bones software intended to simply retrieve data from the field and enter it into an agency’s existing data processing system. Other vendors’ software falls somewhere in between. Each of these approaches might be preferred by a particular agency, depending on the functionality of (and perhaps expected replacement of) the agency’s existing traffic data processing system.

In general, most agencies are well served when, at a minimum, vendors allow a fast, efficient extraction of collected data from whatever internal format is used by the equipment to standardized data formats that can easily be read by traffic data processing software supplied by other vendors. This capability allows the agency to select data collection equipment based on its ability to accurately monitor traffic flow, without having to spend significant resources on fusing those data with other traffic data collected with other equipment.

3.5 Equipment Installation and Maintenance

Installation and maintenance of the sensors, data collection electronics, and communications modules are critical to the accurate collection of data. Unfortunately, the space and resource limitations associated with this document prevent a comprehensive discussion of the diverse installation and maintenance instructions for each of the different types of traffic data collection equipment. As a result, this section can only provide general guidance on installation and maintenance activities to agencies looking to improve their data collection program. Specific issues known to affect the performance of specific technologies already have been discussed as part of the introduction to those individual technologies.

3.5.1 General Installation Advice

Agencies are encouraged to fully test the equipment and then to follow (if those tests prove to be successful) the installation procedures and advice provided by the vendor. When the agency believes that alternative equipment installation procedures may provide better equipment performance, these ideas need to be thoroughly tested, documented, and discussed with both the equipment vendor and other
agencies that use those same devices to ensure that those procedures do not create “hidden” problems when used at other locations. The best installation systems result from the combined knowledge of both the vendors and the agency data collection personnel.

Often, agencies have a better understanding than the vendors on how to most effectively perform a specific task related to equipment installation on their roadway system. For example, the data collection staff for a lightning prone state often have a better understanding of the performance of alternative lightning protection systems than a vendor that lives and works in a geographic area not affected by frequent lightning storms. Similarly, data collection personnel often know more about how to design an equipment cabinet to protect it from dust or pests common in a specific part of a state. The state agency also may have considerable experience in the selection and application of sealants and other materials used to place or protect sensors and their connective wiring.

Discussing these ideas with both vendor personnel and agency staff from neighboring states allows ideas to be refined and allows “best practices” to be shared among multiple users. It also allows knowledgeable users who have experienced a specific problem to pass along the solutions to other users. The Vehicle Detector Clearinghouse (http://www.nmsu.edu/~traffic/) maintains information on state and other agency contacts in the data collection field that can be used to facilitate these contacts.

Once a state is comfortable with an installation procedure for a sensor it has chosen to use, comprehensive training of the staff that will perform the sensor installations is required. These staff need to understand not only the proper installation procedures, but why those procedures are being undertaken. This will allow the staff to effectively overcome unusual problems they encounter in the field. The staff that will supervise or inspect the work being performed need this same level of training. This is particularly important when the highway agency must hire contractors to perform the equipment installation work.

3.5.2 General Advice for WIM System Site Selection, Installation, and Maintenance

The single greatest factor in the success or failure of any WIM system’s performance is the location of the axle weighing sensors; that is, these sensors should be installed at a location where the pavement profile is conducive to accurate estimation of static weights. Poor pavement condition increases vehicle dynamics, decreases system accuracy, and significantly shortens sensor life. Consequently, the selection of the location used to weigh trucks is often more important than the choice of a specific technology to ensure accurate axle weight data. The placement of a scale in rough, uneven pavement will result in poor quality weight data, regardless of the WIM technology selected. Similarly, if the pavement condition at a WIM site deteriorates after a scale has been installed, the performance of that scale can be expected to deteriorate as well, regardless of the technology selected.

Some scale sensor technologies rely on the structural strength of the pavement in which they are supported. When these sensors are placed in “weak” pavement (pavement that flexes under loading), the
accuracy of these sensors tends to degrade. Similarly, when the strength of the pavement changes with environmental conditions (usually because of changing moisture content or temperature), sensor performance can be expected to change, and calibration drift frequently occurs. Consequently, where weight data are needed for thinner, flexible pavements subject to changing strength characteristics, selection of a WIM technology that separates the weight sensor from the pavement through the use of some type of frame is a good idea. However, the pavement must be thick enough to hold the frame. Where the pavement cannot support accurate WIM data collection, the state should consider moving the data collection site to a location at which the WIM can function accurately.

Finally, as with permanent vehicle classifiers, the state should consider expected pavement life when determining the life expectancy of a WIM site, as well as the implications of that life span for the WIM technology for that site. That is, the state should not spend a lot of money on a WIM device and installation where the pavement will not support accurate weighing for more than one year. Similarly, more expensive, longer lived WIM scales should be considered for placement in high-quality pavement, where these devices can be expected to operate accurately for many years.

When installing and maintaining the actual WIM sensor, agencies must be aware that field tests have repeatedly shown that the most accurate WIM systems have sensors that are mounted flush with the existing road surface. Sensors that sit on top of the pavement create their own “bump” (even a very small bump is bad) that increases vehicle dynamics, which in turn decrease sensor accuracy. Sensors that are entirely covered by pavement are affected by changes in pavement strength associated with changes in environmental conditions, decreasing the reliability of their performance. Changes in pavement profile (such as rut formation) that decrease the smoothness of the transition from the pavement surface to the WIM sensor surface cause impact loads and increased vehicle dynamics, both of which contribute to loss of WIM system accuracy.

The presence of pavement rutting at the WIM sensor, so that the WIM sensor is no longer flush with the road surface, can both significantly shorten WIM sensor life and degrade system accuracy. When the WIM sensor is no longer flush with the roadway surface, passing tires impart a horizontal impact force on the sensor. This increases the force being applied to the sensor well beyond that of the weight of the axle, decreasing the accuracy of the weight measurement. The constant application of impact forces also tends to damage the pavement/sensor bond and eventually damages the sensor itself. Therefore, signs of rutting or other uneven surface profiles at the sensor require immediate attention.

In addition to the pavement condition at the sensor itself, WIM system accuracy is affected by the pavement condition upstream and even slightly downstream of the sensor. A significant change in pavement profile near the scale will alter the calibration of that scale. For example, the development of a major pothole upstream of a WIM scale alters the dynamic profile of the trucks approaching the scale, causing them to “bounce differently” than when the scale was calibrated, and necessitating a different scale calibration factor.
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Consequently, for WIM sites, not only should routine maintenance activity be undertaken on the data collection equipment itself, but maintenance activity should take place on the roadway leading to the scales to maintain the lowest level of dynamic truck motion possible. If pavement deterioration begins to become significant, it is unlikely that the WIM scale will provide reliable weight data. It may still provide accurate volume and classification data. However, if weights are needed at that site, it may be appropriate to shut off the equipment until the pavement upstream of the scale can be repaired or replaced.

3.5.3 General Advice on Maintenance

Proper and regularly scheduled maintenance is critical to the continued operation of any traffic monitoring program, whether that effort is meant to provide data for traffic signal actuation, vehicle classification, WIM, or freeway management applications. Yet many agencies frequently scrimp on their maintenance activities and consequently suffer a large number of equipment failures and the consequential “holes” in their data collection program.

Many factors, such as inadequate budget allocations and staffing deficiencies, contribute to a lack of adequate maintenance. For most agencies, the simple solution of requesting more funds to hire more or better technicians and buy more and better equipment does not achieve the desired goal. To obtain better funding for equipment maintenance and operations, it is imperative that the data collection group not only collect and process data but make sure that the data they collect meet the needs of their customers and that their use becomes a visible part of the agency’s decision-making process. Only when the agency understands the importance of the data being collected will the financial support needed to maintain the detection hardware become available. This often means that the data collection and analysis section undertake an active “data marketing” effort within its own agency.

All data collection programs require an ongoing maintenance program. Maintenance is required by the data collection sensors, data collection equipment, and (for permanently mounted equipment) the communications wires and other devices that connect the sensors to the data collection electronics and the data collection electronics to the central office (usually via telephone connections).

Both preventive and corrective maintenance capabilities are necessary in all agencies. Preventive maintenance is performed to limit equipment failure and the subsequent loss of data. An effective preventive maintenance program significantly increases the amount of “good data” collected and decreases the cost of collecting data (because “failed counts” do not have to be taken a second time). For portable data collection equipment, preventive maintenance is best done in two stages. The first stage consists of inspecting the equipment and sensors each time they are picked up at the end of a short-duration data collection session. Equipment that shows too much wear and tear can then be replaced or repaired prior to its use in the field at the next data collection location. The second stage is performed at the end of the data collection season (or when that equipment is not needed in the field during the data collection season), when more significant preventive maintenance actions can be undertaken.
Corrective maintenance is performed after a sensor or data collection device fails. For short-duration counts, this may be apparent when the device is picked up at the end of the data collection period. For permanent sensors—and in some cases even for short-duration counts—this may not become apparent until analysis is performed on ‘data’ collected at that site. (See Chapter 4 on data quality control report.) The key to a good corrective maintenance system is to quickly review the data being collected to determine when a device begins to function irregularly, trace the irregular data collection activity to the specific device producing those questionable results as quickly as possible, and perform the appropriate diagnostics on the equipment to locate and repair any faults.

For permanently operating equipment, agencies should have procedures and resources in place for quickly visiting a data collection site to perform the diagnostics required to identify problems causing data collection errors. For permanent equipment, the “cause” of data collection errors can often be the surrounding data collection environment, not just the equipment itself. (That is, the pole that a video camera is mounted on may vibrate excessively, or the street light that is intended to allow effective camera operation at night may no longer be working.) It is therefore often necessary to be on-site to examine not just the performance of the equipment and sensors but the entire data collection system.

Once corrective maintenance actions have been taken, good record keeping that describes the problems encountered and the “fixes” applied is important for tracking the performance of equipment. This helps identify failure patterns in equipment, as well as the fixes that work best to resolve those failures. It also provides an excellent teaching resource that can be incorporated in the training given to new installation and inspection staff. Finally, good record keeping provides the details needed to identify poorly performing equipment, thus providing a basis for rejecting certain devices or vendors the next time equipment will be purchased.

For agencies that do not already have their own installation and maintenance check lists, this section describes some of the common installation and maintenance problems experienced for permanently mounted sensors.

### 3.5.4 Problems Commonly Experienced with Permanently Mounted Sensors

All permanently mounted sensors suffer from a number of key installation and maintenance issues. Many “device failures” are typically a direct result of poor installation, poor or no inspection, and use of cheap components not suited to the roadway environment. When the installation contractor installs bare minimum components, sensors might last a year or two before they fail, but the contractor may not be responsible for them beyond that time, and therefore has no incentive to use better quality components. Agencies that award installation or equipment bids to the lowest bidder must use extreme care, through a tight bid specification and thorough inspection procedures, to ensure long-term success.

Beyond the pavement installation, all permanently mounted traffic monitoring devices can experience problems associated with splices in ground boxes and in cabinet electronics. In many areas of the country,
ground boxes and conduit fill with water. Therefore, splices must be made watertight by using a high-grade splice kit. Wire nuts should never be used.

Problems inside the cabinet include sensitivity issues, electrical interference, lack of (or failure of) environmental controls (heating systems, air filtration systems in high-dust locations), and lightning (or simple electrical surge protection). Therefore, cabinets need to be carefully designed, built, and inspected when sensors are first placed, and they are key elements that any maintenance technician should examine as part of a routine maintenance program. Similarly, in some parts of the country, specific attention must be placed on preventing insect or rodent infestation of the cabinets, as these infestations often interfere with wiring. Rodents sometimes chew connector cable insulation in ground boxes and in conduit, and cause breaks or shorts to ground.

Finally, a common source of “device failure” is the loss of communications to the cabinet or data collection equipment. Communication failures can be particularly hard to diagnose because equipment makers tend to blame communications firms, and communications firms tend to blame the equipment maker for the communications problems. Quickly resolving these “finger pointing” exercises is best accomplished when there are clear lines of responsibility for the submittal of data.

### 3.5.5 Installation and Maintenance Issues with Permanently Mounted Intrusive Sensors

In-pavement sensors suffer from a number of typical installation and maintenance related failures. Many “device failures” are typically a direct result of poor installation, poor or no inspection, and use of components not suited to the in-pavement roadway environment. In-pavement sensors typically fail in one of four different ways:

1. Failure of the sensor, often due to fatigue or impact loads;
2. Failure of the seal between the sensor and the pavement, resulting in the sensor generating bad signals;
3. Failure of the pavement, resulting in loss of bonding between the sensor and the pavement; and
4. Water intrusion into the sensor or the wiring that connects the sensor to the roadside data collection electronics.

Many of these problems are exacerbated by poor quality installation techniques. For most in-pavement sensors, a slot in the pavement is cut with a pavement saw. The slot is cleaned and dried. The sensor is then placed in the slot, and the slot is filled with sealant, bonding the sensor to the roadway.

When the installation is not performed correctly, or when the sensor is placed in old, poor-quality pavement, the seal between the sensor and pavement fails quickly. Once the seal starts to fail, environmental conditions quickly deteriorate the bond between the sensor and the pavement and increase the likelihood of all four types of failures noted above.
In addition, if the final installation is not flush with the road surface, the in-pavement sensor creates a “bump” in the road. This “bump” is actually an impact point on the installed sensor, and the impacts of multiple passing tires can greatly accelerate the failure of a sensor.

Proper installation of all in-pavement sensors pays particular attention to the quality of the pavement cut, the cleaning of that cut (to remove debris that can accelerate sensor/pavement bond failure), the drying of the cut prior to sensor installation, the installation of the sensor so that it is at the correct height in the slot, and the placement and finishing of the sealant. (Note also that the use of the proper sealant is important, and that different sealants have very different properties in different environmental conditions. They should be selected carefully by combining knowledge from the vendors with knowledge from the highway agency data collection staff.) Failure to perform any of these tasks adequately is likely to lead to premature sensor failure, regardless of the in-pavement technology used.

Similarly, maintenance activities need to pay attention both to general pavement conditions at a data collection site and to the condition of the sensor/pavement bond. Bonds that are starting to show signs of wear require maintenance attention. Pavements that are starting to show significant signs of wear may make it impossible to keep in-pavement sensors operational and may require a shift to non-intrusive detection at that location until pavement repair and rehabilitation are performed.

3.5.6 Installation and Maintenance Issues with Inductive Loop Detectors

Inductive loop detectors have been used longer than any of the other detection technologies included in this section, and if they are properly installed and maintained, they are usually the most accurate all-around traffic detector and typically last for several years. Loop errors are typically a direct result of poor installation, poor or no inspection, use of cheap components not suited to the roadway environment, or placement of the sensors in poorly performing pavement subject to water intrusion. When the installation contractor installs bare minimum quality components, loops may last a year or two before they fail, but the contractor may not be responsible for them beyond that time. Agencies that award loop installation bids to the lowest bidder must use extreme care, through a tight bid specification and thorough inspection, to help ensure long-term success. Specific guidance on loop installation will soon be available through the ASTM document *Standard Practice for Installation of Inductive Loop Detectors*, currently being completed.

Some inductive loop problems are not directly related to the installation procedure but are inherent in the nature of the loop system. Loops require copper conductors placed inside underground conduit for connections from the pavement to the cabinet, and because of its location in shallow conduit, utility work sometimes damages wire and conduit. Milling operations in asphalt pavement usually destroy loops unless they have been installed deeper than normal. Many agencies are adding a requirement to milling contracts to replace damaged loops, but there is undoubtedly a cost associated with the replacements.
Problems inside the cabinet include sensitivity issues and lightning protection. Abnormally high sensitivity can lead to crosstalk and undesirable detection of vehicles in adjacent lanes. Abnormally low sensitivity can lead to undercounting of vehicles or the “splitting” by the data collection electronics of some large combination vehicles into two or more smaller vehicles. Poor quality sensors or the sensitivity settings in the electronics unit (or both) can lead to intermittent problems that are difficult to detect by a technician. Fortunately, newer electronics units can retune themselves, record faults, and even solve some problems, at least temporarily.

A significant maintenance issue with inductive loops is not in the loop per se; it is a result of sawing the pavement and weakening the pavement structure. Failure is usually exhibited at the corners, especially where corner diagonals are used. The three saw cuts forming each corner create a triangle that sometimes breaks out completely and eventually creates a pothole. This problem, if not corrected, can cause the loop to fail. Even if the corners do not fail, they can still be a source of loop failure if sharp edges remain in the saw cuts that eventually compromise the loop wire insulation.

Another maintenance issue is the loop sealant. Its consistency must be fluid enough to flow around the wires and completely encapsulate them but not so runny as to flow out of the saw cuts. Some sealants have the wrong consistency, while others do not bond well to the sides of the saw cut and eventually release adhesion, possibly resulting in sealant or loop wire coming out of the saw cut. Sometimes the adhesion issue stems from wet-cutting the loops and not completely drying the remaining moisture.

Lightning strikes are a possible source of power surges and loop failures, but this problem is not as prevalent in loop detectors as it is for detectors mounted on poles. Countermeasures include the use of lightning surge suppressors on each loop and the use of standard ground rods.

### 3.5.7 Installation and Maintenance Issues with Magnetic Vehicle Detectors

Conventional magnetic detector systems consist of the sensor probe, connecting cable, and the electronics unit (usually in a roadside cabinet). Some magnetic vehicle detectors transmit signals to the roadside through radio frequency (RF) transmission, so they do not have connecting cable running the full length to the cabinet. However, the RF transmission requires an antenna that is sufficient to cover the desired distance. The information in this section emphasizes 3M microloops because of longer project team experience with these detectors in comparison to other magnetic detectors.

3M microloop probes can be placed under bridge decks or under pavements at depths of 24 to 36 in. For bridges, placement that avoids vertical steel is critical to proper performance, necessitating a survey of the local magnetic field around bridge members, especially beams. Placement under pavement requires horizontal boring and use of 3-in.-diameter conduit. Bore holes also can be drilled vertically from the surface, but horizontal installation under the pavement is less intrusive. For horizontal installation of 3M probes, installers must place the probes into a “carrier” system designed for this purpose by working from an oversize ground box beside the roadway. Measurement of the desired position on the roadway
relative to the ground box tells the installer how far to push the probes into the conduit. Two probes per
detection zone are more accurate than one, so accurate speed and length monitoring would require four
probes per lane (two for the entering detection zone and two for the exiting zone) spaced at 15 to 20 ft
apart along the direction of travel. Figure 3-5 shows one layout used by TTI for its research program to
test the accuracy of one probe versus two at each station. The carrier sections are modular, so the install-
er simply snaps each new 2-ft section to the preceding inserted section and slides each probe through the
conduit to the proper position. One requirement of all magnetic detectors is that they remain vertical.
Tilting of the detectors shifts the detection zone at the point of detection and changes the effective dis-
tance between detection zones along the lane.

Figure 3-5. Sketch of 3M Microloop Installation.

If installed properly, magnetic detectors inserted in conduit underneath a roadway should need very little
maintenance. The probes can operate even if completely submerged in water, as long as nothing compro-
mises waterproofing. It is best to buy cables long enough to run from the probes to the cabinet with no
splices. Lead lengths can be well over 1,000 ft without loss in performance. Therefore, these detectors are
a good choice in areas that might be prone to problems with splices. Rodents sometimes chew through
insulation and allow moisture penetration, so precautions must be taken to minimize their impact.
Rodents can enter the system by burrowing beside the ground box, so field personnel should periodically
leave mouse bait in the ground box and also should block their entry into the conduit leading from the
ground box where they can do even greater damage. One effective countermeasure is the use of concrete
aprons that surround ground boxes. TTI installed 3M microloops under a roadway more than 10 years
ago, and the only problem has been rodent damage to insulation. As with inductive loops, since lead-in
cables for magnetometers are underground and usually unmarked, there is a possibility of damage from
utility work in the immediate area.
3.5.8 Installation and Maintenance Issues with Video Detection (VID)
Sensors

VID systems consist of a digital CCTV camera (CCD), or an analog CCTV camera and analog to
digital signal converter, a processor, and the software that resides in the processor. The camera should
include a shield to block precipitation and direct sunshine, and perhaps a heater to minimize the effects
of moisture outside the camera housing. Some processors are integral to the camera unit, but the more
common format consists of a separate camera and processor. Typical camera locations are on an existing
pole beside the roadway, on a gantry or bridge over the roadway, or on a mast arm at a signalized inter-
section. If the processor is separated from the camera, it is typically located inside an equipment cabinet
near the camera. Wireless cameras are available, but most locations use hard-wired connections.

Setup of VID systems is more time consuming than some simpler devices and requires more technician
training. Likewise, system maintenance requires a higher level of expertise to troubleshoot problems in
the system. Both science and art are involved in establishing detection zones to detect the desired ve-
hicles and not detect the same vehicles multiple times. Some VID systems offer a variety of functions to
minimize double-counting or false detections, but these features also increase complexity. Features such
as directional detectors and AND/OR Boolean functions can reduce errors. Tall vehicles create specific
challenges to the setup.

The primary maintenance issue within the VID system itself is cleaning the camera lens. Other main-
tenance issues may include lightning protection and ensuring tight connections for cables. As a general
rule, lens cleaning should occur twice a year. However, cameras mounted near chemical plants or near
saltwater need more frequent attention. Precipitation during high winds may result in water or ice on
the camera housing, which can distort the image the camera sees. Even though camera housings are
designed to be watertight, water sometimes penetrates the seals and causes damage, requiring replace-
ment of the camera unit. To minimize the effects of water droplets on the outside housing surface, some
technicians apply a thin layer of “Rain-X” during scheduled maintenance. Other infrequent maintenance
needs may arise as a result of extreme weather events which can cause movement in the camera or sup-
port structure. The camera orientation must be returned to the recommended direction and detectors
must be redrawn. As with other detection systems, conduit breaks, loose connections, and rodent activ-
ity in the cabinet or conduit are possible, but their impacts on VID systems are typically minimal.

The placement of a camera can raise privacy concerns with the public. While considerable case law exists
stating that there is no expectation of privacy while an individual is on a public roadway, privacy advoc-
ates often voice concerns about the capture and storage of video images. Any video images stored by a
public agency are subject to freedom of information act requests, and all images collected may be sub-
poenaed for use in a court of law. Thus, all agencies storing video images should be prepared to retrieve
those images for use by outside agencies and individuals. For VID systems that do not store images,
these issues are moot. For those video data collection systems that will store video images for later use,
an agency should work with their legal advisors to ensure that the appropriate legal steps are taken to
protect the agency and the public.
3.5.9 Installation and Maintenance Issues with Microwave Radar Detectors

After close to 10 years of experience in testing multidetection zone microwave radar detectors in Texas, they do not appear to require much maintenance. The technology appears to be immune to most weather conditions and is not sensitive to lighting conditions. Also, the two systems that are being widely installed in the United States (primarily on freeways) have been made rugged for the highway environment. One of the manufacturers reported that of 624 units shipped to one North American buyer between April 1994 and June 2002, only 10 (1.6 percent) were returned for repair. However, these devices still require annual maintenance visits to ensure that wire connections and communications capabilities have not degraded.

3.5.10 Installation and Maintenance Issues with Acoustic Detectors

The only currently available multizone acoustic detector being installed in the United States is the SmarTek SAS-1. It involves an array of microphones housed in a single compact unit that is installed on a pole or other support beside the roadway. It is easily installed, and its exact orientation is not critical. It is intended for freeway operations, sensing noise generated by vehicles passing a point on the roadway. It is completely passive in that it only monitors its environment and does not send out energy. One unit can monitor up to five lanes of traffic in a “sidefire” orientation from about 35 ft high. Most, if not all, problems encountered with the SAS-1 sensor have been addressed by the manufacturer and would not be considered normal maintenance. For example, the performance of the device appears to be affected by some weather conditions such as heavy rain, but the reduction in accuracy is temporary.

Once the SAS-1 has been set up and calibrated, there are normally few maintenance issues to be addressed. Like any other detection system, lightning strikes or accidental bumps of the detector can cause misalignment, but these events are infrequent. Besides, the SAS-1 alignment is more forgiving than other systems such as video imaging systems.

3.6 Traffic Counting on Congested Roadways

Almost all traffic monitoring devices have difficulties counting accurately in heavily congested conditions. High traffic densities and the stop-and-go conditions that accompany those densities create difficulties for almost all traffic counting devices. In many cases, these unstable conditions violate many of the assumptions used to convert sensor outputs to traffic monitoring statistics. For example, many lane-specific, modern axle detectors can accurately count axles in congested conditions. It is the conversion of those axle pulses to vehicle statistics that causes problems.

In unstable flow conditions, vehicles are constantly accelerating and decelerating and frequently change lanes. Thus, as vehicles pass the data collection sensors, they are not traveling at a constant speed, and are frequently straddling lane lines.
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Accelerating or decelerating while being observed by the traffic sensors makes the vehicle speed estimate used to compute the distance between observed axles invalid. An invalid speed estimate means that the estimated distance between consecutive axles also is invalid. Because these distances are invalid, the data collection electronics cannot associate specific axles with specific vehicles accurately.

When one vehicle (for example, a car) is “tailgating” another (another car), axle sensors are likely to “see” all four axles, from the two vehicles. But their close spacing violates the rule used to differentiate between a single vehicle (a truck) and two cars. Thus, a vehicle classifier observing two tailgating vehicles is likely to report them as being one moderately large truck, rather than two cars.

When a vehicle is changing lanes while passing over axle sensors, it may be counted by the traffic sensors in both lanes. This is particularly true if the axle sensors are full lane sensors, and placed next to each other. On the other hand, if the sensors are “half lane” sensors and they are slightly separated from each other, the vehicle may not be counted at all.

As a result of these conditions, data collection electronics frequently make errors in determining how many vehicles are passing a site. The types of errors made will depend on the traffic characteristics, the type of sensor being used, and the layout of the sensors.

In heavy congestion, sensors that measure vehicle presence frequently perform no better than axle sensors. Because traffic density is high, these sensors often have difficulty separating closely spaced vehicles into separate, individual objects. Therefore, in heavy congestion, two closely spaced cars are often reported as a single truck, just as happens with axle sensor-based vehicle classifiers.

So how should an agency collect data in these conditions?

The first response to that question is, “How badly does the agency need those data?” There are traffic monitoring devices that can count under these conditions. They are permanently mounted, generally use multiple sensors, and require considerable calibration and tuning in order to work as desired. They also tend to be expensive. They are most commonly found in toll collection applications, where very accurate traffic counts and classifications are required for revenue control purposes.

Where the agency is unwilling to spend the amount of money required to place and calibrate permanent equipment to ensure that the traffic data collection is accurate, there are only three remaining options.

The first is to place video cameras in areas where lighting is sufficient, and use manual counts of the resulting video images to provide short duration traffic count data. These data can then be expanded using seasonal and day-of-week adjustment factors to any required summary statistics.

The second alternative is to purchase the “best affordable equipment” and accept the fact that during certain conditions, the traffic volume estimates are only modestly accurate. This means that analytical
procedures must be put in place to identify those periods when the volume counts are not acceptably accurate, and data replacement procedures must be developed and used to estimate traffic volumes during times of unreliable equipment operation. Techniques for doing these tasks are presented in Chapter 4 of the guidelines.

The third alternative is to place traffic data collection equipment at the ramps to and from the high-volume congested facilities, along with a counter that is placed outside of the congested conditions. The ramp counts are then used to add or subtract from the count taken at that mainline location (e.g., ramp balancing) in order to estimate traffic volumes at any given section of roadway. The difficulty here is that this process only works for limited access roadways, and it also requires that accurate counts be made at all of the relevant on- and off-ramps to that facility.

3.7 The Data Implications of the Growing Emphasis on Roadway Operations

While the guidelines cover the traditional traffic data collection subjects (volume, class, weight, and to a much lesser extent speed), central data collection groups need to be aware that a growing emphasis at all levels of government (national, state, and local) is on the operation of the roadway system we already have, with a declining emphasis on the construction of new roadways.

As the focus of transportation agencies shifts toward the operational performance of the roadway system, new types of traffic monitoring data are going to be requested from the central traffic monitoring office. Chief among those new data is overall travel time or delay. While traditional data collection equipment can collect vehicle speed information, a number of new, inexpensive traffic monitoring devices are being brought to market that only collect vehicle speed data. In addition, a number of companies are developing the ability to collect vehicle speed information by tracking both cellular telephones and GPS-equipped vehicle fleets.

The end product of these data collection efforts are large data sets that provide continuous (or nearly continuous) segment speed estimates that can be used to inform traffic management centers and travelers about roadway performance. Collecting and summarizing these data will allow a highway agency to report on the performance of its roadway system, analyze the effectiveness of management control systems, and report on the travel time and reliability improvements made possible by various roadway improvement projects.

All of these reporting functions have a very high degree of agency and public interest.

While these data collection efforts are not a current function of the central traffic monitoring offices, it is very likely that in the near future these data collection and analysis requirements will become part of...
their workload. Therefore, these agencies are encouraged to stay abreast of the equipment being brought to market to provide widespread data on travel times, roadway segment speeds, and motorist delay.

3.8 Conclusion

There is no “silver bullet” that describes which technology should be selected for traffic data collection. While some technologies work better than others under specific conditions, several detailed equipment studies have concluded the same as a Minnesota non-intrusive detector test: “The differences in performance from one device to another within the same technology were found to be more significant than the differences from one technology to another.” Therefore, the way to ensure that the equipment purchased works accurately and meets an agency’s specific needs is to put in place and support an equipment selection and use a plan which contains the following elements:

- Carefully test data collection equipment under the expected data collection conditions before buying large numbers of those devices to ensure that these specific devices work well under the conditions in which they will be used;
- Closely follow the agency and vendor approved installation instructions for placing the equipment;
- Calibrate and test the installed equipment once it has been installed to ensure it is working as intended; and
- Periodically check the performance of that equipment (when picking up the data collection device if it is a short duration, portable count, or as part of routine equipment maintenance and data checking if it is a permanently mounted, continuously reporting data collection site).

3.9 References

References are listed in order of first use.

3.9.1 Paper Documents


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3.9.2 Internet Sources

The Vehicle Detector Clearinghouse, maintained by New Mexico State University (http://www.nmsu.edu/~traffic/).


Federal Highway Administration, Office of Highway Policy Information, Travel Monitoring Publications and Products (http://www.fhwa.dot.gov/policyinformation/).

European COST 323 (Weigh-in-Motion of Road Vehicles) (http://wim.zag.si/cost323/).


Texas Transportation Institute reports on equipment tests are available through: http://tti.tamu.edu/facilities/index.htm?loc_id=3224).


CHAPTER 4

Quality Assurance for Traffic Data

4.1 Introduction

This chapter presents information on quality assurance and quality control processes for traffic data. The chapter begins with basic definitions and other general considerations for traffic data quality. The process of integrating quality assurance into traffic monitoring programs is discussed. Several attributes of data quality are described, along with specific measures that can be used to quantify the level of data quality. Detailed information is provided regarding numerous validation criteria that can be used to identify suspect or invalid traffic data. Finally, special considerations for traffic monitoring programs are discussed along with techniques for dealing with missing data.

4.1.1 Data Quality Control versus Data Editing

The term “quality control” is used throughout this chapter to describe the process performed after data collection but prior to data summarization and reporting to ensure that traffic data meet certain specifications. The quality control process typically includes one or more of the following actions:

- Reviewing the traffic data format and basic internal consistency;
- Comparing traffic data values to specified validation criteria;
- Marking or flagging traffic data values that do not meet the validation criteria;
- Reviewing marked or flagged traffic data values for final resolution; and
- Imputing marked, flagged, or missing traffic data values with “best estimates” (while still retaining original data values and labeling imputed values as estimates).

The term “data editing” was used in the 1992 AASHTO Guidelines for Traffic Data Programs to describe a similar series of actions that occur between data collection and data summarization and reporting. Because the literal definition of the term “edit” implies a much narrower set of actions, the term “quality control” is used in this chapter to more clearly indicate the wider scope of actions covered.
4.1.2 Quality Control and Quality Assurance

“Quality control” and “quality assurance” are often used interchangeably to mean the same thing; however, the terms as used in this chapter have different meanings with important implications for traffic monitoring.

The term “quality control” is used to describe the process performed after data collection but prior to data summarization and reporting to ensure that traffic data meet certain specifications. As used in these guidelines, quality control involves reviewing and manipulating data that already have been collected. Data quality actions that are restricted to simply “fixing” data that already have been collected (referred to as “scrap-and-rework”) are ineffective because they address the symptom but not the root cause of poor data quality.

The term “quality assurance” encompasses actions taken throughout the entire traffic monitoring program cycle to ensure that traffic data meet or exceed customer expectations. With this definition, quality assurance includes actions taken before data collection as well as after data summarization, such as the following:

- Routine staff training and professional development;
- Effective equipment procurement procedures;
- Bench testing new field equipment;
- Thorough inspection and acceptance testing of new equipment installations;
- Routine equipment testing and calibration;
- Scheduled maintenance activities; and
- Data customer feedback through various channels.

This distinction in terms is highlighted here because some traffic data programs may be focused primarily or solely on quality control, such as reviewing and editing traffic data that already have been collected. However, total quality management principles indicate that process efficiency and customer satisfaction are most cost-effectively met when quality is considered in all steps of a product cycle. This means that data quality should be considered in all steps of a traffic monitoring program, and quality assurance refers to these various quality considerations that are made throughout the traffic monitoring program cycle. The next section discusses some of the most common quality assurance considerations for traffic monitoring programs.
4.2 Integrating Quality Assurance into Traffic Monitoring Programs

This section discusses the programmatic aspects of data quality. It defines the quality assurance procedures necessary to ensure that a traffic monitoring program produces quality data. These procedures begin before traffic monitoring equipment is procured and continue throughout the life cycle of the equipment. Coupled with effective quality control, these procedures will ensure that the collection and provision of traffic data meet data customers’ needs.

4.2.1 Phase 1: Acquisition, Installation, Acceptance

Traffic monitoring technology is a difficult application area. The development of electronic sensors that reliably record vehicle characteristics at a wide range of speeds and environmental conditions is an ongoing challenge. A common example, which is far from solved, is the problem of classifying vehicles in congested, stop-and-go conditions.

Equipment procurement procedures have commonly treated traffic monitoring devices as commodities, such as pencils and calculators. The result has been that the research and development for traffic monitoring equipment is not as extensive as it could be, particularly in a “low-bid” procurement process.

The problems associated with purchasing traffic monitoring equipment as commodities through a bid process are well known. There are rarely sufficient agency resources for maintaining, calibrating, and verifying the equipment over its expected lifetime, so data quality suffers. The equipment acquired through a bid process may not be fully developed and tested, so it may fail to work in specific applications and environments. An agency often ends up testing the equipment for the manufacturer, because the manufacturer lacks sufficient resources to fully develop and test the hardware in-house.

This problem can be addressed by changing the focus of the acquisition process. Instead of thinking of acquisition as equipment purchase, it should be characterized as the procurement of a reliable stream of traffic monitoring data that persists throughout the life cycle of the equipment. Acquisition procedures should be directed toward achieving this objective.

Life Cycle-Based Purchasing

Equipment purchases should be based on proposals (not bids) that meet the objective of providing quality traffic data over a life cycle of several years. The number of years will be based on the type and expected durability of the equipment to be purchased. Sensors have much shorter life cycles than roadside processing units, so if a long life cycle is desired, the request for proposals (RFP) should include a sensor replacement requirement. Of course, this increases the cost of the procurement.
The underlying assumption is that it is much better to have fewer devices that work over a long period of time than to have a larger number of devices that have an unknown life expectancy and no mechanism for ensuring that the devices keep working. This assumption makes the RFP the most important quality assurance instrument, as it will determine the duration and quality of the traffic data stream.

A life cycle-based contract should include equipment purchase, ongoing maintenance, and resources for replacement of sensors and other parts that quit working. It also should include incentives for the vendor that would increase profitability for equipment that works reliably. The data stream will be interrupted any time the equipment ceases operation, so the vendor should be rewarded for equipment and procedures that reduce the number and duration of these interruptions. In other words, the maintenance process should be performance-based.

These goals can be met in a purchase/maintenance contract by retaining a portion of payment until the end of the life cycle. The contract can establish "uptime" percentages and associated retainage payments. For example, 95 percent to 100 percent uptime could result in 100 percent retainage paid, etc. The maintenance contract can be constructed to provide similar incentives. If a vendor repairs and returns/installs the equipment within a week, 100 percent of the maintenance payment is paid. Longer times result in reduced payments. The amount to be paid would be proposed by the vendor.

Overall reliability can be improved by including preventive maintenance requirements in the maintenance contract. These include periodic visits to a site to inspect the sensors and the roadside box to perform any needed cleaning and repairs. If the vendor is involved in calibration procedures (discussed below), the preventive maintenance can be scheduled at the same time to reduce costs. The maintenance contract may be negotiated for several years or renewed annually, depending on purchasing laws and regulations. In most cases, annual renewal will be required.

### Quality Assurance Begins with Installation and Acceptance

The RFP must specify the requirements for the initial installation and acceptance. Installation specifications will vary with the type of equipment and sensors, the type of pavement, and the expected environmental conditions. The vendor must be required to completely specify the installation procedures in the proposal.

Acceptance should include calibration and verification. Calibration procedures depend on the type of equipment, but they must be spelled out in the RFP and the vendor should respond in the proposal. Verification includes comparing the output of the installed equipment with an independent source, such as video monitoring.
4.2.2 Phase 2: Ongoing Operations and Quality Assurance

Phase 2 of this process covers the ongoing quality control and quality assurance procedures throughout the life cycle. These procedures determine when maintenance actions or calibration are required.

Daily Quality Control

The first line of defense is automated data validity checking and reviews. These procedures are discussed later in this subsection. These procedures will identify sites that may be developing hardware problems.

Ongoing Quality Assurance Procedures

Periodic quality assurance tests should be applied to the traffic monitoring system to ensure that the quality control process is working. This involves periodic calibration and verification counts to test data quality. There should be a combination of routine procedures and quality control-driven procedures. Routine procedures would be applied to all devices at specified intervals. Quality control-driven procedures would involve calibration or verification counts when quality control results indicate possible equipment problems.

Equipment should be recalibrated according to a schedule established in the contract. These should follow standard practices established by external standards where practicable. For example, ASTM has a published standard for WIM devices that includes calibration procedures.

Calibration should be performed for all traffic monitoring equipment. The need for calibrating WIM is obvious, but vehicle classifiers, speed monitoring, and even volume detectors also should be calibrated, or at least verified, throughout the life cycle. Speed calibration, which is critical for the correct operation of both vehicle classifiers and speed monitors, adjusts for any differences in the times required for measurements to travel from two sensors to a recording device (a particular problem in the case of inductive loops). Without such calibration, vehicle speed will be consistently overestimated (or underestimated), resulting in corresponding overestimates (or underestimates) of axle spacing and potential improper classification of two-axle vehicles (whose classification depends on measured axle spacing).

If practicable, the Phase 2 procedures should not be performed by the vendor supplying the equipment. They should be performed in-house or through a separate services contract.

4.2.3 Contract Considerations for Traffic Data Services

Many state DOTs and other public agencies use private contractors in their traffic monitoring program. Under such arrangements, the contractor may be responsible for collecting traffic data or maintaining traffic monitoring equipment, with the public agency playing a supervisory and contract management role.
role. Performance-based contracts are often used by public agencies as a means of ensuring data quality from these contractors. Based upon the experience to date, these contracts for traffic data collection should include the following provisions:

- Full or partial payment based upon quantity and quality of collected data;
- Clear assignment of responsibility for various types of equipment malfunctions;
- Periodic equipment audits to ensure data accuracy;
- Provisions for timeliness of maintenance activities; and
- Provisions for partial payment based upon maintenance response time.

For example, the Virginia DOT (VDOT) has contracted out a significant portion of their continuous count program since 1996. In their program, VDOT leases its traffic counters and modems from a private contractor but owns the sensors (such as inductive loops and piezoelectric sensors). The current maintenance agreement is carefully written to assign responsibilities and avoid ambiguities (such as responsibility for traffic counters that do not work due to faulty piezoelectric sensors). A state inspector checks the equipment once per year, but if there are substantial errors in the data, the contractor has to recollect the data.

VDOT has established performance-based lease criteria for payment of data collection services. Contractor compensation is based on the amount of acceptable data that is submitted by the contractor. Furthermore, VDOT requires a certain quantity of acceptable data from each continuous monitoring site to be able to use that site for traffic factor creation. Table 4-1 contains an excerpt showing key elements of VDOT’s performance-based contract.
3.11 Data Quantity and Lease Payment

VDOT requires a certain quantity of acceptable data from each site to be able to use that site for traffic factor creation. Lease payments under this contract shall be structured to encourage the contractor to make every effort to ensure that the required quantity of data is provided. The following payment criteria will be followed for stations where classification, volume and speed data are expected (see Pay Item Number 1):

a. Full monthly payment will be made for all ATRs and modems at sites where 25 or more days of acceptable and complete classification, volume and speed traffic data are available during a calendar month.

b. Seventy-five percent monthly payment will be made for all ATRs and modems at sites where 15 or more days of acceptable and complete classification, volume, and speed traffic data are available during a calendar month.

c. Seventy-five percent monthly payment will be made for all ATRs and modems at sites where 25 or more days of acceptable and complete volume and speed traffic data, but less than 15 days acceptable and complete classification data are available. If the classification or weight data shortfall continues for three months, the percent of payment rate will drop to 50 percent for the 4th month and the following months until the classification problem is corrected.

d. Fifty percent monthly payment will be made for all ATRs and modems at sites where 15 or more days of acceptable and complete volume and speed traffic data, but less than 15 days acceptable and complete classification data are available. If the classification data shortfall continues for three months, the percent of payment rate will drop to 25 percent for the 4th month and the following months until the classification problem is corrected.

e. At CCS where two ATRs and modems are located, the data from each are considered jointly, and payment will be made on the combined data availability for the entire site. For example, if ATR number 1 has data available from the 1st through the 15th of the month, and ATR number 2 has data available from the 16th through the 30th of the month, payment will not be authorized, as no complete days of data for the entire CCS are available.

f. Monthly payment will not be made for sites that have less than 15 days of volume data available during a calendar month.

g. Sites will be upgraded to full monthly payment where stations have been affected due to situations not caused by the contractor (i.e., VDOT construction/pavement activity or station hit by a vehicle that required removal of equipment). This does not include sites that have had normal sensor failures. If the reinstallation of sensors or equipment does not occur within three months, the percent of payment rate will drop to 50 percent for the 4th month and the following months until the classification, volume and speed data have been corrected.

The following payment criteria will be followed for stations where only volume and speed are expected (see Pay Item Number 2):

a. Full monthly payment will be made for all ATRs and modems at sites where 25 or more days of acceptable and complete volume and speed traffic data are available for a current month.

b. Fifty percent monthly payment will be made for all ATRs and modems at sites where 15 or more days of acceptable and complete volume and speed traffic data are available for a current month.

c. Monthly payment will not be made for sites that have less than 15 days of volume or speed data during a calendar month.
Table 4-1. Excerpt from a VDOT Contracting Agreement for Traffic Data Collection and Equipment Maintenance (continued)

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<thead>
<tr>
<th>d. Sites will be upgraded to full monthly payment where data has been affected due to situations out of the control of the contractor (i.e., VDOT construction/pavement activity or vehicle accidents that required removal of equipment). This does not include sites that have had normal sensor failures. If the reinstallation of sensors or equipment does not occur within three months, the percent of payment rate will drop to 50 percent for the 4th month and the following months until the volume/speed data have been corrected.</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Full monthly payment for this pay item will be made where 25 or more days of acceptable and complete WIM data are available for a current month.</td>
</tr>
<tr>
<td>b. Fifty percent monthly payment for this pay item will be made for 15 or more days of acceptable and complete WIM data are available for a current month.</td>
</tr>
<tr>
<td>c. Monthly payment for this pay item will not be made for sites that have less than 15 days of WIM data during a calendar month.</td>
</tr>
</tbody>
</table>

The following payment criteria will be followed for stations where the addition of real-time data collection is expected (see Pay Item Number 4). This pay item is intended to be in addition to the monthly lease payment proposed for the collection of classification, volume and speed data (see Pay Item Number 1).

| a. Full monthly payment for this pay item will be made where 25 or more days of acceptable and complete real-time data are available for a current month. |
| b. Fifty percent monthly payment for this pay item will be made where 15 days or more of acceptable and complete real-time data is available for a current month. |
| c. Monthly payment for this pay item will not be made for sites that have less than 15 days of real-time data during a calendar month. |

The Contract Administrator, or his representative, will process the data and provide a monthly report detailing which sites fall into the various categories for payment within 10 working days of the end of the calendar month and provide that information to the contractor to facilitate invoice preparation. If data transmission problems exist, and the contractor desires to manually collect and submit data, he may request an extension. All manually submitted data shall be submitted by the 10th day of the month to be considered for lease payment purposes. The VDOT Contract Administrator shall have 10 working days to provide the monthly reports after receipt of any such late data.

Monthly payment for the terms of the lease portion of the contract is defined as the annual cost bid/proposal divided by 12.

### 3.12 Service Call Procedures

As part of the lease agreement payment, the contractor shall maintain the ATR and modem equipment and respond to VDOT “service calls.” VDOT will submit an electronic service call via e mail to the contractor whenever the data analysis indicates a potential problem exists, a specific problem is discovered during a VDOT site inspection visit, or a communications/data transmission problem occurs. There will not be a separate charge (pay item) for the service calls related to ATR/modem equipment problems, telephone line problems, or failed sensors, as costs associated with the service calls shall be included in the price of the monthly lease charge, or in the case of failed sensors that require replacement, in the replacement cost. A charge will be allowed for

(Table continued on next page.)
service calls that result from VDOT road maintenance (repaving or milling) or damage from vehicle accidents. This information shall be included in contractor’s response to the VDOT Contract Administrator.

The contractor shall have 10 calendar days to investigate, make site visits, make repairs, and respond back to VDOT after notification/receipt of a service call. The response back to VDOT shall include a date and time of on-site visits, technician’s name, and a summary of the nature of the problem found and action taken. If the immediate action taken does not resolve the problem and additional time is needed, the contractor shall provide an action plan with a timeline, including interim steps, detailing how the problem will be resolved. The VDOT Contract Administrator will have the final approval authority for the extended problem resolution plan. All lost data, regardless if under an approved action plan, shall count against the contractor’s monthly lease payment. Digital photos shall be submitted to the Contract Administrator with the SC response if failed sensors or VDOT road maintenance are found or to backup the SC response. All lost days of data shall be used to compute the monthly ATR and modem lease payment in accordance with procedures outlined in paragraph 3.11. If the result of the service call site visit is that sensors require replacement, the contractor shall notify the Contract Administrator, who may arrange for verification of the requirement. The Contract Administrator will contact the contractor with repair/replace scheduling instructions. The sensor(s) shall then be scheduled for replacement as per the paragraph 3.13 of this document.

Sites being used for real-time data by the STCs may require a faster service call repair than 10 days. The contractor shall provide a pay item quote for a quick turn around repair for service within 24 hours of notification. A second pay item quote of repair within 48 hours of notification also will be provided. If the 24- or 48 hour repair time is desired, the VDOT Contract Administrator will notify the contractor of that at the time of service call submission. Sites which are not repaired within the quicker service time, regardless of whether requested and a site visit was made, will not be eligible for the faster repair service premium pay item.

A log sheet shall be maintained in the cabinet at each CCS. Each time a site visit is made, the technician or construction crew leader shall make a log sheet entry, including name, date, time, amount of time on-site, purpose of the visit and any actions taken. VDOT personnel also will make entries on this log sheet. The log sheet shall be placed in a protective cover (i.e., gallon size storage bag) in order to remain protected from the weather elements. Completed log sheets shall be submitted to the Contract Administrator. A sample log sheet can be found at Appendix H.

If the findings of a service call indicate that VDOT road maintenance is the cause for the data problem, i.e., the roadway has been recently paved or sensors destroyed by milling, the VDOT Contract Administrator shall be immediately notified. Traffic count site “down time” (site is nonoperational or produces inaccurate data) resulting from VDOT road maintenance will not be counted against the contractor’s operational readiness requirements, as long as repairs are made in a timely manner (within 30 days after direction is received from the Contract Administrator). However, if repairs are not made in a timely manner, all down time will be computed and counted against the days of data requirement (see paragraph 3.11) for ATR and modem lease payments. Note—sensor installations—especially those involving nighttime work—during the months of December through February can be difficult to complete in Virginia weather due to cold temperatures. The contractor will not be responsible for completion of maintenance work within 30 days for VDOT Contract Administrator directives issued between November 1 and March 1. The 30 day requirement will begin for these types of locations on March 1. The VDOT Contract Administrator may extend these dates if the contractor provides documentation that the materials being used are not suitable for use in the existing temperature or weather conditions.
4.3 What Is Data Quality?

So far, this section has distinguished between several data quality terms without providing a clear definition of data quality. This section explicitly defines data quality and how it can be measured for traffic data programs.

4.3.1 Definition of Traffic Data Quality

Data quality has been defined as:

“...the fitness of data for all purposes that require it. Measuring data quality requires an understanding of all intended purposes for that data.”

This definition, which is prevalent among the data quality literature, indicates that data quality is relative to whoever is using the data. For example, data considered to have acceptable quality by one consumer may be of unacceptable quality to another consumer with more stringent use requirements. Thus, it is important to consider and understand all intended uses of data before attempting to measure or prescribe data quality levels.

In practice, however, it is difficult to delineate or anticipate “...all purposes that require...” for general-purpose data such as annual traffic counts, which are used for a wide variety of intended and unintended applications. Others have described data quality as “...consistently meeting end consumer expectations.” Thus, with general-purpose traffic data that may be used for a variety of applications, it will be most productive to develop data quality specifications based on the needs, expectations, and feedback of the primary data consumers.

This definition of traffic data quality may seem academic and difficult to apply in practice. However, the data quality definition above is a philosophical principle that can be quantified through six data quality measures that are described in the following paragraphs. These data quality measures can be used to provide a quantitative assessment of traffic data quality. Traffic data program managers may wish to use one or more of these measures to provide an overall quality assessment of their traffic data products. Certain data quality measures also may be reported with summary traffic statistics, either integrated within the actual data or reported in linked metadata files. In this way, supplemental data quality information can give data consumers some perspective on the quality of original field data before summarization.

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4.3.2 Measures of Traffic Data Quality

Table 4-2 defines and describes six basic measures of traffic data quality. These measures quantify different attributes of traffic data quality, each of which may be relevant to certain elements of the traffic data program. There are several other data quality measures that could be appropriate for specific traffic data applications. The six measures presented below, though, are fundamental measures that should be universally considered for measuring data quality in traffic data applications.

Additional details for these six data quality measures, including detailed equations, specific calculation procedures, and real-world examples are contained in the FHWA report titled *Traffic Data Quality Measurement: Final Report*.

Table 4-2. Definitions for Traffic Data Quality Measures

<table>
<thead>
<tr>
<th>Data Quality Measure</th>
<th>Definition</th>
</tr>
</thead>
</table>
| **Accuracy**                      | The measure or degree of agreement between a data value or set of values and a source assumed to be correct. Accuracy can be expressed using one of the following three error quantities:  
1. Mean absolute percent error (MAPE);  
2. Signed percent error; and  
3. Root mean squared error (RMSE).  
Note that in each of these error formulations, the error is the difference between the observed value and the reference (i.e., ground truth) value, and percent error is the error divided by the reference value. |
| **Completeness** (Also Referred to as Availability) | The degree to which data values are present in the attributes (e.g., volume and speed are attributes of traffic) that require them. Completeness is typically expressed as a percentage, calculated as the number of available data values divided by the number of data values that should be available. Completeness can refer to both the temporal and spatial aspect of data quality. |
| **Validity**                      | The degree to which data values satisfy acceptance requirements of the validation criteria or fall within the respective domain of acceptable values. Data validity is typically expressed as the percentage of data values that pass data validity criteria. |
| **Timeliness**                    | The degree to which data values are provided at the time required or specified. Timeliness can be expressed in absolute (e.g., minutes, hours, days) or relative terms (e.g., percentage of data meeting timeliness criteria). |
| **Coverage**                      | The degree to which data values in a sample accurately represent the whole of that which is to be measured. As with other measures, coverage can be expressed in absolute (e.g., centerline-miles, lane-miles) or relative units (e.g., percentage of specified system). |
| **Accessibility** (Also Referred to as Usability) | The relative ease with which data can be retrieved and manipulated by data consumers to meet their needs. Accessibility can be expressed in qualitative or quantitative terms. |

4.3.3 Truth-in-Data Principle

The Truth-in-Data principle, discussed further in Section 6.6.2, is based upon a commitment to label data quality and quantity accurately, and to store and retrieve data based on equivalent quality and quantity. A conscious decision is necessary to identify the qualitative and quantitative differences in traffic data. For example, different projects may require different minimum qualitative and quantitative levels of data.

In accordance with the principle of Truth-in-Data, any database should indicate the quality and quantity of data supporting traffic statistics on a site-by-site basis. When an analyst wants to compare sites with equivalent traffic data only, the data may be sorted and accessed in this way. If the analyst chooses to examine traffic statistics based on mixed data, then the analyst must indicate the quality and quantity of traffic data required for the analysis. Additional information on the Truth-in-Data principle is provided in Section 6.6.

4.4 Assessing Data Quality

4.4.1 Identifying Data from Device Malfunctions

Most traffic monitoring devices malfunction periodically. These malfunctions may occur at any time during data collection, in both hardware and software components. Malfunctions may occur in physical roadway sensors (e.g., road tubes, loops, tape strips, etc.), system electronics, calibration settings, power supplies, and data transfer or communication links.

Typically, device malfunctions are the easiest problems to identify since they usually result in a recognizable data pattern. Most traffic data programs search for these data patterns automatically through the use of validation criteria. The data reported by a malfunctioning device may consist of one of the following:

- A consecutive series of zero values;
- A consecutive series of specified error codes, such as “–1” or “255”;
- A consecutive series of repeating values (often a device-specific, binary multiple such as 1,024; or a power of 2, such as 2, 4, 8);
- A random series of very large data values; or
- No reported data values at all.

Original data records from malfunctioning devices are not valid traffic measurements but should be retained for future audit, research, and quality assurance purposes. However, these invalid data records should not be forwarded for official traffic statistics summarization and reporting. These invalid data records may be used in computerized editing programs for identifying patterns of specific device malfunction, and in manual editing programs for training editors to recognize problems.
Historical patterns in device malfunctions also can be analyzed to assess overall downtime by specific device types, device manufacturers, time of day, or month of year. For example, these analyses could identify problems with devices from a certain manufacturer. Frequent downtime during a certain time of day (particularly overnight) could indicate problems with solar power supply. Frequent downtime during a specific month or season could indicate devices that are operating outside of recommended environmental conditions.

### 4.4.2 Identifying Data from Poorly Calibrated Devices

It is more difficult to identify data being collected from poorly calibrated traffic monitoring devices than from malfunctioning devices. Poorly calibrated devices can be caused by several actions, including inadequate or no calibration at the time of installation, calibration drift over a longer period of time, or a change in the roadway or traffic characteristics that requires a change in calibration settings. Data from poorly calibrated devices are difficult to identify because typically there are no sudden changes or recognizable patterns in the traffic data. Poor calibration mostly results in data values that are slightly to moderately lower or higher than actual traffic conditions.

In some instances, the spatial or temporal context (discussed in the next section of this chapter) can be used to identify data from poorly calibrated devices. These spatial and temporal comparisons are likely to identify those devices that have moderate to severe calibration error, but are less effective for identifying more modest calibration errors. Other methods of identifying calibration errors require a more detailed investigation of a sample or all of the devices under consideration. The most common of these methods are to:

- Compare the device calibration settings to the manufacturer’s recommendations;
- Conduct informal field audits; and
- Conduct formal accuracy evaluation procedures.

These methods are described in the following paragraphs.

The first method for identifying (and fixing, in this case) poorly calibrated devices is to compare the device calibration settings to the manufacturer’s recommendations as provided in a user’s manual or guide. All devices should be properly calibrated at the time of installation and acceptance testing. In practice, however, this may not occur or the device settings may not be tuned adequately. It also is possible that the device settings were correct at the time of installation, but changes to the device, roadway, or traffic have caused these original calibration settings to be inadequate. Regardless of the cause, the calibration settings should be thoroughly reviewed and adjusted as instructed by the manufacturer. Technical questions not covered in the user’s manual or guide should be addressed through the manufacturer’s or sales representative’s technical support channels. Because this method does not ensure that the collected data will be valid and accurate, it may be necessary to use one or both of the following methods to determine the effects of device recalibration.
Informal field audits are commonly used to determine if devices are properly collecting traffic data. A field audit consists of observing the device in operation to determine if it is detecting vehicles and if it is properly measuring and classifying traffic measures. With permanent traffic monitoring devices, this typically involves opening a roadside cabinet and observing an LED panel while also viewing the lane(s) being monitored. For most portable traffic monitoring devices, a “detection” light or indicator is visible without opening or unlocking equipment cases. For example, auditing a traffic counter would require that the detection indicator be activated for every vehicle that passed through the corresponding detection zone. The auditor would note the vehicle type(s) that were not detected and adjust the calibration settings accordingly.

In some cases, a portable computer can be connected to a traffic monitoring device to gain access to more sophisticated diagnostic and calibration tools. These diagnostic tools typically provide a means to verify the measurement of variables such as vehicle speed, weight, or class. In practice, field audits are typically performed one lane at a time, for short periods of time, and to the satisfaction of the auditor. Traffic monitoring programs should develop written procedures for these field audits, including the frequency and duration of field audits, diagnostic checklists, step-by-step instructions, and typical equipment calibration settings (if applicable).

A third method for identifying poorly calibrated devices consists of formally evaluating the accuracy of the device by comparing its output data to reference or “ground truth” data. Obtaining reference or ground truth data is done using specialized equipment or techniques that have low or no error.

For vehicle count and classification data, ground truth is typically established by collecting video and manually reducing it with two or more sets of independent human observers. When the difference between the independent observers is low (user specified, but typically two percent to three percent), then one can be fairly assured of the data accuracy. The data values from the independent observers are then averaged and serve as ground truth for comparison to the data values produced by the device being evaluated.

For vehicle speed and weight data or for other circumstances, ground truth data may be collected by specialized equipment with a known or certified accuracy. For example, professional-quality LIDAR (LIght Detection And Ranging) devices may be certified by the manufacturer to measure vehicle speeds within one to two mph. This specialized equipment then offers a more automated way to verify data output by the traffic monitoring device being evaluated. Unless the accuracy testing is performed in a permanent test bed environment, the specialized equipment must be portable and easily installed at the various devices’ field locations.
4.4.3 Identifying Data from Atypical Conditions

In addition to malfunctioning and poorly calibrated devices, traffic data (particularly short-term data) should be examined in the context of normal or typical traffic conditions. Although normal or typical traffic may be difficult to define at some locations, it should be based on two elements:

- **Temporal Context**—What is the historical pattern at this location?
- **Spatial Context**—What is the current pattern at nearby similar locations?

Traffic data may be accurate but still be atypical for a variety of reasons. The traffic database system should mark or flag atypical data, such that they could be filtered by certain applications. For example, an agency might decide that only typical data should be used to calculate adjustment factors for estimating AADT from short-term counts. The database system could then exclude any traffic data marked as atypical based on temporal and spatial context.

The temporal context is defined by the recent history of traffic conditions and characteristics at a specified location. A permanently installed traffic monitoring device should have previous years’ historical data. A short-term traffic monitoring site may have been previously counted. Validation criteria can be used to check the variance from historical traffic characteristics. Data that exceed an expected variance may be flagged or marked for further review by a data analyst.

The spatial context is defined by the traffic conditions and characteristics at other locations along the same roadway or nearby locations on similar roadways. Traffic recorded at one location along a roadway does not exist independently of the roadway as a whole. By comparing short-term traffic counts along a roadway, analysts can identify discontinuities and possible problems with one or more traffic counts.

Short-term traffic data collected during severe or inclement weather, holidays (or other days affected by holidays), major events (e.g., sports, entertainment, etc.), major traffic incidents, maintenance or construction activities, or other events creating significantly different traffic flows or patterns are commonly considered atypical. This means that although the data are actual traffic measurements, they may not be suitable for representing average or typical traffic conditions. For instance, if an event has a significant effect on the calculated average traffic during any period of interest, the data should not be summarized and used as the basis for estimates of that period. If the data user is interested in peak-hour volumes, the use of an hour in which there was a traffic interruption (such as a vehicle crash, fire, or parade) or a surge in traffic (due to clearance of an obstruction) would not be acceptable. The data should be labeled as such and retained because it may be useful in other traffic studies of actual (but not typical) traffic conditions. If conditions such as construction or detours exist long enough to affect daily volumes, data for the entire period should be labeled.
Data should not be marked or flagged as atypical when traffic events occur with regularity or when a new traffic pattern is being established. For example, the roads next to a stadium would be regularly subjected to large traffic flows associated with major events. In this situation, the 30th highest hour could be within the period of an event. Another example that should be considered typical is different traffic patterns that emerge from changes in nearby land use. For example, a major commercial development could create different traffic patterns than experienced over the past 10 to 15 years. However, these new traffic patterns have now become the typical and regular feature for affected roadways.

Short-term samples of traffic that represent atypical traffic conditions should be marked and retained, but should not be used to estimate annual traffic summary statistics. The data should be retained because they may be useful in specific traffic studies, but should be marked as nonrepresentative of typical traffic.

Later sections of this chapter present validation criteria to check the temporal and spatial context of traffic data. These validation criteria identify questionable data for further review. Ultimately, the acceptance or rejection of questionable data because it fails temporal or spatial context checks is largely dependent on the degree of failure and the end uses of the traffic data.

4.4.4 Assessing Quality of Binned Traffic Data

Traffic data that are binned into different categories provide an additional dimension for assessing data quality. For example, axle- or length-based vehicle classification is reported in several different classification bins. In some cases, other data like traffic speed, headways, and gaps also may be binned into range categories, such that the number of vehicles in a certain range is reported rather than an average value.

In many cases, the quality of binned traffic data can be assessed by comparing vehicle counts in the different category bins. For example, comparisons among the vehicle class categories provide additional quality information. If on a rural road the proportion of FHWA Class 8 vehicles is nearly as large as, or greater than, the proportion of FHWA Class 9 vehicles, it indicates that the classifier is probably missing some axles. In this case, the device’s axle detector should be checked. The checks discussed in the earlier section on quality assurance contain other examples.

4.4.5 Assessing Quality of Nested Data

In nested data, more than one data element is measured and recorded during the same time interval. For example, weigh-in-motion counts also provide vehicle classification data. Vehicle classification equipment typically provides vehicle counts by class and speed. Nearly all types of binned data also produce volume counts.

With nested data, a problem arises when one type of data fails quality control checks, but the other does not. Usually this is a common sense issue, depending on the cause(s) of failure. A common
example is vehicle classification data that are rejected because most or all vehicles go into an “unclassified” bin. In most cases, the traffic count data derived from these measurements are still valid and should be accepted.

In rare cases, the opposite will be the case. For example, if a quality control check for zero volume between 7:00 a.m. and 7:00 p.m. fails because of a temporary outage, the agency might decide that the vehicle class distributions are still valid, and can be used when only the proportions and not the actual numbers are needed.

Default rules that specify which nested data elements should be flagged as erroneous should be established for each validity criterion. For some validity criteria, the final determination for dealing with nested data may need to be on a case-by-case basis during the data review process.

### 4.5 Validation Criteria for Vehicle Count, Classification, and Weight Data

The quality control process for traffic data programs should include a step in which incoming traffic data is compared to specified validation criteria. These validation criteria have been referred to by many names, such as quality checks, edit rules, edit checks, validity checks, business rules, etc. Regardless of the name, these validation criteria serve the same purpose: to assess data validity by comparing incoming traffic data to specified expectations such as data format, value ranges, internal consistency, temporal consistency, spatial consistency, theoretical principles, etc.

There are no universal standards for traffic data validation criteria. The number and type of validation criteria used in state and local traffic data programs vary widely. Most validation criteria are developed based upon: 1) empirical evidence from various types of data errors already experienced; and 2) expert opinions about the range of values that is plausible. Invalid data caused by certain malfunctions, such as long-term hardware failure, are easier to identify than short-term malfunctions or calibration errors that may affect traffic data in a subtle way.

Nearly all of the validation criteria should have parameters that can be customized for individual sites or site groups. Certain criteria may use parameters that do not vary regardless of the site location or traffic characteristics. For example, individual axle weights should add up the total vehicle weight regardless of location or road functional class. Other criteria, such as the maximum acceptable directional split, may utilize different parameters for rural roads with significant recreational traffic than for urban roads with bidirectional commuting traffic.

Table 4-3 summarizes the recommended minimum validation criteria for data format, vehicle count, vehicle classification, and weight data. Other validation criteria can be added to this minimum recommended set. Appendix A contains several examples of more extensive validation criteria used or developed elsewhere.
<table>
<thead>
<tr>
<th>Criteria Type</th>
<th>Criteria</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Format</td>
<td>Valid date.</td>
<td>Data not processed further until the date is clarified or corrected.</td>
</tr>
<tr>
<td>Data Format</td>
<td>Valid start and end time.</td>
<td>Data not processed further until valid start and end times are clarified or corrected.</td>
</tr>
<tr>
<td>Data Format</td>
<td>Valid site or location identifier.</td>
<td>Data not processed further until valid site or location identifiers are clarified or corrected.</td>
</tr>
<tr>
<td>Data Format</td>
<td>Valid file header information:</td>
<td>Data not processed further until error(s) is clarified or corrected. If the count information in the header does not meet the original count request, the data are further processed but an additional count is scheduled to support the original request.</td>
</tr>
<tr>
<td></td>
<td>• Count type code;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Direction code;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Number of lanes;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Number of vehicle classes;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Number of speed classes;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Data recording interval;</td>
<td></td>
</tr>
<tr>
<td>Data Format</td>
<td>Consistency between header information and data rows:</td>
<td>Data not processed further until error(s) are clarified or corrected. If the actual count (after resolving the inconsistency) does not meet the original count request, the data are further processed but an additional count is scheduled to support the original request.</td>
</tr>
<tr>
<td></td>
<td>• Number of lanes;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Number of data rows;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Data recording interval;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Start and end times;</td>
<td></td>
</tr>
<tr>
<td>Data Format</td>
<td>Consistency between split count files:</td>
<td>If split count files are inconsistent, the counts are summarized to the 'lowest common denominator.' If that is insufficient for the requested count, the count is retaken.</td>
</tr>
<tr>
<td></td>
<td>• Data types;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Data intervals</td>
<td></td>
</tr>
<tr>
<td>Vehicle Count</td>
<td>The same traffic volume count must not occur for a specified number of consecutive hours or quarter hours. The default parameter is 4 consecutive hours or 16 consecutive quarter hours; however, this can be customized.</td>
<td>A warning condition is indicated for an analyst to review the data. The analyst should review the site data and then either accept or reject the data for summary statistic calculation.</td>
</tr>
<tr>
<td>Vehicle Count</td>
<td>A traffic volume of 0 for all lanes must not occur for a specified number of consecutive hours or quarter hours. The default parameter is 8 consecutive hours or 32 consecutive quarter hours; however, this can be customized.</td>
<td>A warning condition is indicated for an analyst to review the data. The analyst should review the site data and then either accept or reject the data for summary statistic calculation.</td>
</tr>
<tr>
<td>Vehicle Count</td>
<td>The volume total in any lane for the entire day must not be 0.</td>
<td>Data are excluded from computation of summary statistics. Single lane or single direction data may still be used for specific applications. Bidirectional summary statistics are not calculated.</td>
</tr>
</tbody>
</table>

(Table continued on next page.)
### Table 4-3. Recommended Minimum Validation Criteria for Traffic Data *(continued)*

<table>
<thead>
<tr>
<th>Criteria Type</th>
<th>Criteria</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Count</td>
<td>The total volume in one direction should not be within a specified range of percent of the total bidirectional volume. The default parameter is between 60 and 80 percent.</td>
<td>A warning condition is indicated for an analyst to review the data. The analyst should review the site data and then either accept or reject the data for summary statistic calculation.</td>
</tr>
<tr>
<td>Vehicle Count</td>
<td>The total volume in one direction must not equal or exceed a specified percent of the total bidirectional volume. The default parameter is 80 percent.</td>
<td>Data are excluded from summary statistics indicating typical roadway operating conditions. Analyst should review the data to see if there is a constraint to typical operating conditions, such as a lane closure.</td>
</tr>
<tr>
<td>Vehicle Count</td>
<td>The total daily volume must fall within two standard deviations of the prior year’s annual average volume for the given day of the week.</td>
<td>A warning condition is indicated for an analyst to review the data. The analyst should review the site data and then either accept or reject the data for summary statistic calculation.</td>
</tr>
<tr>
<td>Vehicle Classification</td>
<td>Consistency between data set headers and field log entries:</td>
<td>None specified.</td>
</tr>
<tr>
<td></td>
<td>• Data set number;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Machine number;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Site identification;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Direction of travel;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Lane number; and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Pickup times.</td>
<td></td>
</tr>
<tr>
<td>Vehicle Classification</td>
<td>Compare hourly totals for Class 2 and 3 categories. Values for Class 3 that approach or exceed values for Class 2 may indicate improper road tube spacing, unmatched tube lengths, or malfunctioning switches.</td>
<td>Check adjacent lane or opposite direction values for this condition. If only one lane shows this pattern, the field staff should be contacted and the findings discussed. If the field staff indicate the device is operating correctly, continue the edit process. If it is not operating correctly and if the data application is for a single lane, data for the lane in question will have to be recounted.</td>
</tr>
<tr>
<td>Vehicle Classification</td>
<td>Check data output for consistency of vehicle type totals each hour of the day. Emphasis should be placed on Class 2, 3, and 9, and the total vehicle count because they normally constitute the majority of traffic.</td>
<td>None specified.</td>
</tr>
<tr>
<td>Vehicle Classification</td>
<td>Check the temporal consistency of the data for each lane and direction against similar data from that lane and direction taken on previous or subsequent days. Volumes will normally be very consistent from nonholiday weekday-to-weekday, particularly Tuesday through Thursday.</td>
<td>If major inconsistencies are found and no comments were recorded in the field log, the field crew supervisor should be consulted to determine if there is reason for deviation from normal traffic patterns.</td>
</tr>
</tbody>
</table>
Table 4-3. Recommended Minimum Validation Criteria for Traffic Data (continued)

<table>
<thead>
<tr>
<th>Criteria Type</th>
<th>Criteria</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Classification</td>
<td>Check the directional distribution of traffic by vehicle class (in most cases it should be close to 50–50).</td>
<td>None specified.</td>
</tr>
<tr>
<td>Vehicle Classification</td>
<td>Compare the calculated AADT and vehicle class distribution against historical count data. The total volume for Class 2, 3, and 9 should not change by more than 15 percent.</td>
<td>If changes exceed 15 percent, compare to vehicle class data from adjacent road segments. If the count data by class are questionable, then the data are not summarized and the vehicle class count is retaken. If the review suggests the count data are acceptable, the data are forwarded for summarization.</td>
</tr>
<tr>
<td>Vehicle Weight</td>
<td>Check the distribution of gross vehicle weight (GVW), which should be bimodal with one concentration between 28,000 and 32,000 pounds for unloaded vehicles and another between 70,000 and 80,000 for loaded vehicles.</td>
<td>If determined to be invalid, the weight data should not be accepted, summarized, or reported.</td>
</tr>
</tbody>
</table>
| Vehicle Weight      | Check the consistency of front-axle weights (FAW) over time, which should be close to the shown typical values, for three GVW categories:  
  - <32,000 GVW ≈ 8,500 FAW;  
  - 32,000 to 70,000 GVW ≈ 9,300 FAW; and  
  - >70,000 GVW ≈ 10,400 FAW. | The front axle weights shown are approximate only and will vary by site. If determined to be invalid, the weight data should not be accepted, summarized, or reported. |
| Vehicle Weight      | Check the consistency of ESAL factors for consecutive weekdays on a site- and lane-specific basis. | The ESAL factors should be relatively consistent for weekdays and should not exhibit extreme fluctuations. If determined to be invalid, the weight data should not be accepted, summarized, or reported. |

There are few universally accepted criteria, and the implementation of new or different validation criteria is often a trial-and-error process that may be constrained by available data review time. For example, the greater the number of validation criteria that are applied, the more likely it is that greater numbers of data records will be flagged for subsequent review.

### 4.6 Severity Levels for Validation Criteria

If traffic data do not meet any of the established validation criteria, these data should be flagged or marked as such. In most traffic data systems, these flagged or marked data are then manually reviewed by a traffic data analyst who makes an accept/reject decision based on supporting information or professional judgment. Supporting information can include local knowledge, comparative traffic data from other time periods or locations, or other anecdotal information from field data collection notes or logs.
If the data in question are accepted by the analyst, it is then typically included in data summarization and reporting procedures. Some traffic data systems provide the flexibility to exclude data that has failed validation criteria but was subsequently accepted.

The data validation process should assign a severity level to each validity criterion. The severity level is used to indicate the seriousness of the criterion failure as well as the necessity of manually reviewing the failed data. The following severity levels should be considered when flagging or marking data that have not met validation criteria:

- **Error**—An “error” is a condition that is highly likely to be caused by equipment malfunction. An example would be 24 consecutive hours of zeros in a single lane of a four-lane highway. But even here, it is possible that one lane is closed, so it could be marked as “actual.” The default action for data marked as containing an error is not to use the data for further processing.

- **Warning**—A “warning” indicates that data are outside the acceptable ranges, but not significantly so. These data should be investigated to determine whether to accept or reject them. The default action for warnings is to use the data in downstream processing.

- **Informational**—“Informational” messages indicate data toward the boundaries, but not outside them. Depending on conditions, these data might need to be investigated further. These data will be used in downstream processing unless the operator specifically changes their status.

As another example of possible validation error severity levels, the FHWA’s Vehicle Travel Information System (VTRIS) uses the following:

- **Junk**—Those records that are detected at the earliest stage of validation and result in the record being put into the JUNK file. No further validation is possible for these records until some manual editing is done.

- **Fatal**—Those records that cannot be admitted “as is” even if user would like them to. For those errors, an appropriate correction through the ERROR table Browse/Edit facility is required. Those are typically errors in the key fields and other very significant fields that would violate consistency and referential integrity.

- **Caution**—Those errors that can be fixed or can be flagged by user as acceptable and put into the VTRIS tables “as is.” If User accepts and flags them, an appropriate Flag Code will be placed into a VTRIS table along with the record.

---

4.7 Other Quality Control Considerations

Once the validity criteria have been applied to traffic data, several of the traffic data records may be flagged or marked for further review. A traffic analyst typically reviews the traffic data in the context of other accepted traffic data. The following sections discuss this data review process and include considerations for reviewing suspect data in the context of other accepted traffic data.

4.7.1 Continuous Count Data

Reviewing continuous data from permanent counters differs somewhat from reviewing short-term count data. Atypical counts caused by inclement weather conditions, accidents, detours, or construction are included. Removal of atypical data is not required to avoid sample distortion because continuous counter data typically represent a large sample of the 365 total days each year. Only invalid count interval data caused by power failures or recorder or device malfunction must be identified and excluded from summarization through the quality control process.

Each data value, in whatever time increment the records are maintained, should be checked for machine or sensor malfunction. The first step in reviewing continuous counter data should be to review the dataset for completeness. This can be done manually or electronically by checking for null (nonmeasurement) and repeated measurements. A malfunction will generally show up as a null, a zero, an error code, a consecutive repeating value, or a very low value. A common cause may be a loss of power to the device, although a traffic interruption is always a possibility.

On low-volume facilities, zero and low values during early morning hours may reflect actual traffic volumes. This emphasizes the importance of developing a historical pattern, manually or electronically, of traffic conditions at continuous counter sites.

Some general patterns may be identified and used in analyst training and preliminary electronic edits. Weekday counts, with the exception of Monday from midnight to 6:00 a.m. and Friday from noon to midnight, may fall within a narrow volume range. The range may be greater on relatively low-volume facilities or on recreational facilities that exhibit different traffic peaking characteristics. Weekend counts are typically more variable than weekday counts. Daily traffic records on a bidirectional roadway should be checked to evaluate the directional distribution and its consistency over time.

Beyond these general characteristics, traffic patterns vary significantly from site to site. The patterns vary for volume, vehicle classification, and vehicle and axle-load distributions. Each continuous counter location records sufficient information to identify the patterns and the change in those patterns across...
time. For agencies that primarily use manual edits of traffic data, automatic pattern identification at permanent sites is recommended as a long-term goal of traffic editing. For agencies that currently employ electronic edits of traffic data, automatic pattern recognition is recommended as a near-term goal.

It is important that the dates and times stored in permanent traffic databases are correct. Some permanent devices check data and time against a common time standard, such as an Internet-based time server. Other devices must be checked and reset manually to ensure that time and date labels are accurate.

On congested roads, vehicle classification data will represent data flowing both at speeds appropriate to vehicle classification and at speeds below which the device provides axle impulses only. The validation criteria should identify the speed thresholds for the device used and appropriately label the data. On multilane facilities, lane distribution is important. Separate labels may be required by direction and lane. For some applications, such as vehicle emissions, it may be important to note vehicle speed by vehicle type by lane.

**Temporal Context**

In editing continuous counter data, it is important to identify patterns of data and to examine changes in those patterns. Just as in identifying a machine malfunction, pattern recognition is important in editing continuous counter data for temporal context.

Patterns of continuous counter data are based on data distributions. In automated databases, the distribution of hourly or daily data over the course of a year can be produced. The distribution can be represented in plots. Graphic presentation along with quantiles, median, mean, variance and standard deviation, skewness, and kurtosis identify the underlying distribution of the data. These statistics also provide insight into the nature of the variability of the data. The moments of the distribution permit basic questions to be addressed, such as how to best represent the central tendency of the data.

For computer-based editing of continuous counter data, the identified patterns can be used to indicate potential error in current measurements. If the pattern of a specific traffic characteristic, such as volume, differs substantially from previous patterns during the same season, same month, and same day of week, there may be an error. Temporal context uses previous patterns of data to indicate where current measurements may be in error.

If the data exhibit patterns which do not fit previous patterns, the data should then be examined by a data analyst. The analyst should inquire about the nature of traffic experience, and may be given the responsibility to either accept or reject the data. A new pattern may be identified and the data accepted. If the data are rejected, the analyst is required to document the basis for rejection.

Agencies may use variance of daily or hourly measurements to indicate data for further review. An example of computer-based edits using specific thresholds of change is a procedure used in Kansas.
Traffic volumes with hour-to-hour or day-to-day changes in excess of 200 percent, and hourly volumes greater than or equal to 3,000 vehicles per lane, are flagged for analyst review. Other states use different flows to define the threshold. Arizona, for example, uses 2,500 vehicles per lane per hour. Kansas, Michigan, and other states, also identify questionable data based on daily volume being more than one or two standard deviations from the previous year’s volume at the same site, during the same season, on the same weekday.

**Spatial Context**

Continuous counter data are more appropriately analyzed in temporal context rather than spatial context. The amount of data available for temporal analyses means that continuous counter edits should be based on historical data variability.

### 4.7.2 Short-Term Count Data

Some of the guidelines for identifying continuous counter machine malfunction may be used in identifying machine malfunction in short-term counts. It was noted earlier that repeated null, zero, low, or high values potentially indicate equipment problems. Short-term data may be influenced by battery problems, or damaged or missing road tubes. The use of directional distribution is important in editing short-term data as well as data from permanently installed devices.

General patterns of traffic characteristics may be used in relation to short-term counts. Site-specific data and patterns may be used in editing nested traffic counts. An example of nested traffic counts is the use of a short-term, Weigh-in-Motion (WIM) device to weigh vehicles at the site of a permanently installed vehicle classifier. Agencies may collect these data for equipment comparisons, project-level data, or for specific research projects such as the Long-Term Pavement Performance (LTPP) project initiated under the Strategic Highway Research Program (SHRP).

In nested counts, more than one data element is recorded during the same field activity. The specific measurements of the continuous classifier can be compared with the specific classification measurements of the weighing device. If there is a discrepancy, manual field observations or automatic short-term counts can be taken to check the accuracy of the continuous recorder. If the continuous device is accurately collecting data, the data from the weighing device may be questioned and the device recalibrated. In this example, the nested count provides the ability to check the shared data, not the additional, different data collected by the two devices.

Short-term traffic data edits, manual or electronic, can check for appropriate month, day, and duration of count. The initial edit is the duration of the traffic count. The concern is to ensure that the minimum duration has been completed. In Chapter 5 it is noted that the minimum short-term count for estimating state program, urban annual traffic summary statistics is 24 h.
Traffic edits should check for appropriate month and day of count. If short-term count data are to be used to compute design-hour traffic, or other estimates representing typical traffic demand, care should be taken to avoid counting during atypical periods. Atypical periods include holidays, weekends, and special events and the days adjacent to those events. Substantial errors will be introduced if data collected during atypical periods are used in the computation of design hours, or factored to estimate typical travel volumes. Should the data be used for factor development and applied to other short-term counts, the errors could become widespread.

If short-term count data are to be used to investigate the traffic flows produced by special events, the count edit similarly must check for month and day of count. The count strategy would be directed to monitor traffic demand during the atypical period.

Some states maintain a record of activities which might influence traffic characteristics. For questionable counts, analysts may check the record for events such as holidays (public and religious), school and sporting events, weather conditions, construction, and accidents.

Editing should identify and label data which should not be summarized for general traffic reports representing typical annual traffic. This would, for example, restrict traffic counts used in estimating Annual Vehicle Miles Traveled (AVMT). While many states currently perform this process manually, it should be their objective to move toward computerized traffic data processing and editing.

**Temporal Context**

Some attempts have been made to use techniques based on data patterns to determine the acceptability of short-term traffic data. They have had limited success because statistical tests of traffic are commonly based on the long-term patterns described above. In the case of continuous traffic volume data, long-term data variation is more understood because the traffic sample of traffic data at the site approaches the population of traffic data at a site. Conversely, the application of statistical techniques to edit short-term counts at random locations is problematic. There are seldom historical data at most short-term count locations, and the data that exist are inadequate to establish accurate statistical limits for each hour.

While data patterns cannot be used to edit short-term traffic count data, thresholds of hourly variance can be applied. Electronic edits, such as records exceeding a defined threshold in vehicles per lane per hour, can indicate volumes in short-term counts for further analyst review.

**Spatial Context**

When short-term traffic counts exceed defined thresholds and are flagged for further analyst review, the review commonly consists of examining the data in spatial context. This examination should consist of
other continuous or short-term counts on the same road, during the same time period as the question-
able traffic count.

Examining the spatial context of a traffic count lends itself to automated analysis using Geographic
Information Systems (GIS) or manually plotted maps to display traffic count data. Multiple counts and
traffic summary statistics can be displayed graphically on a road map. Discontinuities in traffic measure-
ments along a roadway can be readily seen by data analysts. If a traffic count is inconsistent with other
traffic counts during the same period on the same roadway, and no explanation of the count variance can
be provided based on land use, the related count should not be accepted for summarization until another
count can be taken and compared.

Where there are inconsistencies, counts also should be initiated on the adjoining segments to confirm
the validity of all counts. What appear to be “consistent” counts may have been taken with the same
malfunctioning traffic recording device.

There is another benefit of a GIS for spatial context editing of traffic data. Using a GIS, land use (and
potential trip generators or attractors which might account for traffic change) can be simultaneously
displayed with traffic volumes.

When using a GIS, it is recommended in the near term that traffic measurements be examined along the
same roadway. In the long-term development of traffic edits, it is recommended that spatial traffic edit-
ing be integrated with GIS.

### 4.8 Dealing with Missing Data

Missing data is a common occurrence in traffic monitoring programs. Traffic data may be missing or
incomplete due to device malfunctions, failed validation criteria, or other unplanned events or mishaps.
The severity of missing data can be quantified in terms of data completeness (also referred to as data
availability), a data quality measure defined in Table 4-2 as the “degree to which data values are pres-
ent in the attributes that require them.” Completeness can be expressed using a percentage, as shown in
Eq. 4-1. The equation expresses the number of available data values as a percent of the number of total
expected data values.
Completeness (%) = \( \frac{n_{\text{available values}}}{n_{\text{total expected}}} \times 100 \) (4-1)

where:

- \( n_{\text{available values}} \) = the number of records or rows with available values present
- \( n_{\text{total expected}} \) = the total number of records or rows expected

There is not a clear consensus within the traffic monitoring profession about whether it is acceptable to estimate missing or incomplete data (i.e., imputation). However, if imputation procedures are used, it is strongly recommended that metadata (i.e., appropriate documentation and labeling) be used to describe the imputation procedures and the completeness of the data (e.g., 80 percent, 50 percent, etc.) used to compute each summary traffic statistic. This recommendation is consistent with the principle of “Truth-in-Data,” which is the disclosure of practice and estimate of variability (as defined in the 1992 AASHTO Guidelines for Traffic Data Programs).

Documenting and publishing the imputation practices and data completeness values for summary traffic statistics should discourage the use of long-term or continuous imputation at failed continuous monitoring sites. These long-term or continuous imputation practices, in which an entire year of traffic data is estimated without the benefit of any actual traffic measurement, should be avoided.

Traffic monitoring programs that use imputation procedures should set a data completeness threshold below which imputation is not used to estimate summary statistics. For example, if the data completeness is below the threshold (e.g., 20 percent, 50 percent, etc.), then the available data will not be used in summarization and reporting. This threshold may be based upon research findings or empirical studies of traffic data. Depending upon how the data are collected and summarized, it may be necessary to specify both temporal and spatial thresholds. The temporal thresholds address how complete the data is over time, whereas the spatial thresholds address how complete the data is across all lanes at a traffic monitoring site.

As with the practice of imputation, there are no universally accepted procedures for estimating missing or incomplete traffic data. There are numerous imputation techniques, some more sophisticated and complex than others, which have been published in the literature. The current practice, however, tends to include basic factoring procedures that are analogous to factoring short-term counts to annual estimates. Ultimately, the choice of imputation procedures should be based upon the required precision of the results and the institutional capacity to implement and understand the imputation procedures.
4.8.1 Data Completeness in Continuous and Short-Term Counts

Traffic data from continuous or short-term data collection should meet specified requirements for data completeness before the data are used in summary statistics. The completeness should be specified in spatial and temporal criteria. This topic is introduced here but addressed in more detail in Chapter 5.

Spatial criteria define the rules for traffic data completeness across all lanes in both roadway directions (if applicable). For example, how many lanes of complete data are required for site-based summary statistics? Must both directions be counted at the same time? If not, must all lanes in a single direction be counted at the same time?

Temporal criteria define the required minimum time interval duration of traffic data. For example, 24 to 48 hours of complete data typically are required for short-term traffic counts. Continuous traffic data traditionally have been managed in daily 24-hour blocks. For example, a full day (from midnight to midnight) of valid data have been required to compute a daily statistic.

Small amounts of randomly missing data are quite common in continuous counts from archived operations data. As a result, archived operations data may appear to be unusable based on traditional traffic monitoring and data completeness principles. However, it is very likely that different procedures will be required to fully utilize archived operations data. The next section discusses this issue in more depth and offers alternative procedures to deal with missing data in archived operations data.

4.8.2 Data Completeness in Archived Operations Data

Missing traffic data are typically more common when it has been collected and archived from a real-time traffic operations system (as opposed to a traditional traffic monitoring system). In real-time traffic monitoring, the traffic data are measured in shorter time intervals (e.g., 20 s to 2 min) and then sent to a central traffic database through the communications infrastructure. The real-time traffic data are typically not accumulated or stored locally on the field computers, but sent directly to the traffic center in shorter, more frequent intervals. This type of frequent data polling is required for traffic operations and management applications; however, the traffic data that are accumulated and archived at the traffic center may be incomplete due to periodic communication interruptions or missed polling cycles (up to 4,320 polling cycles per day for 20-s time intervals).

The most common pattern that results from these intermittent communication interruptions or missed polling cycles is small chunks of missing data scattered randomly throughout each day of the year. Missing data also may result from other actions common in real-time traffic management and operations:

- Intermittent device malfunction or failure;
- Routine daily computer system maintenance (e.g., backup, software updates, etc.);
• Work zones; and
• Seasonal construction.

For example, Figure 4-1 shows traffic count data completeness by time of day (y-axis) and day of year (x-axis) for a single lane being monitored by a real-time operations detector in Austin, Texas. The data completeness on this chart is color-coded, such that little or no missing data is indicated by light and dark green, and moderate to severe missing data is indicated by yellow and red, respectively. There are three patterns of missing data evident in this chart:

• Randomly scattered light green dots, which are short intervals of missing data throughout the year (most likely due to communication failures or failed validation criteria);

• Two vertical red bars on the right of the chart, which are several consecutive days of completely missing data (device or system malfunction); and

• A dashed light green line on the bottom of the chart, which are short intervals of missing data that occur during routine computer system maintenance scheduled only for weekdays.

The overall data completeness for the year at this location is 96 percent. However, only 99 of 365 d (the weekend days) are 100 percent complete. If imputation were not permitted for the weekdays with short intervals of missing data, then this traffic count data could not be used to compute an AADT based on the commonly used practice of one day of complete data for each weekday and month. The rejection of traffic data that is 96 percent complete for the year does not seem to be consistent with current traffic monitoring principles and practices.
CHAPTER 4  QUALITY ASSURANCE FOR TRAFFIC DATA

Based upon the previous example, it is recommended that traffic monitoring programs consider separate procedures and acceptable thresholds for imputation in traffic data collected and archived by real-time traffic operations systems. These imputation procedures and thresholds should accommodate the unique characteristics of missing data that is prevalent in archived operations data.

The cause of missing data (and the resulting patterns and extent) in archived operations data sets will determine the appropriate strategy for dealing with the missing data. If the missing data are extensive (e.g., less than 50 percent complete) with nonrandom patterns (e.g., missing for the same hours every day or missing for two or more seasons), then two options can be considered:

- Reject the traffic data for that location and do not use in annual traffic summary statistics; or
- Identify 48 to 72 hours of complete data that can be treated as a short-term count. Estimate annual traffic summary statistics by using day-of-week and seasonal adjustment factors.

If the missing data are not extensive (e.g., more than 75 percent complete) with random patterns throughout the day and year, then imputation procedures may be used to estimate 15-min, hourly, or daily subtotals, which can then be used in the calculation of annual summary statistics. For traffic counts with randomly missing data, the following basic formula (Eq. 4-2) is offered as a possible method to impute missing data. With randomly missing data, this formula compares favorably (in terms of error) with more sophisticated imputation techniques.

\[
\text{“Factored” traffic count} = \frac{\text{Subtotal of measured traffic count}}{\text{Completeness of subtotal (%)}} \quad (4-2)
\]

This formula is most suitable for shorter time intervals such as 5, 15, or 60 min, because it assumes that the average traffic flow rate during the measured subintervals is the same as the traffic flow rate during the subintervals with missing data. For example, assume that archived operations data are collected and archived at 1-min intervals in an urban area. Overall, the data set is 80 percent complete and the missing data is randomly distributed. To import the data into the statewide traffic monitoring system, they must be aggregated to 15-min intervals and reformatted to match the standard data template. In aggregating the original archived data, there will be several 15-min periods that do not have 15 1-min samples. Assume that for a 15-min period, there are 12 valid data records with a count subtotal of 125 vehicles. The factored traffic count for this period is calculated as follows (Eq. 4-3):

\[
\text{“Factored” traffic count} = \frac{125 \text{ vehicles}}{12/15} = \frac{125 \text{ vehicles}}{80\%} = 156 \text{ vehicles} \quad (4-3)
\]
Thus, 156 vehicles would be reported for this 15-min time period, the traffic count would be marked as an imputed value, and the 80 percent completeness value would be retained with the traffic count record.

Similar imputation procedures could be used to estimate a daily traffic statistic from 15-min periods if missing data are randomly distributed throughout the day. Other imputation procedures may be necessary to impute data for larger time periods or in the spatial context (e.g., a full lane of missing data). More specific recommendations on imputation procedures for archived operations data will become available as the traffic monitoring profession gains more experience with integrating operations data into traditional traffic data systems.

### 4.9 Quality-Level Designations

Many state DOT traffic data programs publish traffic statistics and provide traffic data that could be categorized under a single quality level: acceptable for all applications. That is, only traffic data that meets a certain “acceptable” standard for all applications is made publicly available.

Traffic data that may be suitable for one application but not suitable for other more stringent applications are typically not provided. For example, if a continuous count station malfunctioned for half of the year, many traffic data programs would not publish annual traffic statistics from that location, even though some data users may only need a single week or month of traffic counts for their purposes.

A few traffic data programs provide quality-level designations with their traffic statistics. These quality-level designations enable the best available data to be provided, even though it may not meet the quality requirements of all possible applications. By providing quality-level designations, more traffic data can be made publicly available. However, a possible downside with this approach is that data consumers may use (knowingly or unknowingly) traffic data that do not meet the quality requirements of their application. In our previous example, a data analyst may use six months of data to represent an annual estimate, which could result in a biased and incorrect result.

Table 4-4 contains an example of quality-level designations for traffic data. These designations are provided by the Virginia DOT with average daily traffic volume data that is publicly available (http://www.virginiadot.org/info/resources/AADT_228_Grottoes_Short_2002.pdf). These quality codes are designed to indicate to data consumers what the data producers believe to be the fitness of the data for various purposes. For all four types of data, Codes A and B represent the two highest levels quality, while other codes describe lower levels of quality but not in a strict sequence.
Table 4-4. VDOT Traffic Data Quality-Level Designations

<table>
<thead>
<tr>
<th>QA: Quality of AADT</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>Average of Complete Continuous Count Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Average of Selected Continuous Count Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Factored Short-Term Traffic Count Data (for current year)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Factored Short-Term Traffic Count Data with Growth Element</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Historical Estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Manual Uncounted Estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>AADT of Similar Neighboring Traffic Link</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>Provided By External Source</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Raw Traffic Count, Unfactored</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>QC: Quality of Classification Data</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>Average of Complete Continuous Count Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Average of Selected Continuous Count Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Short-Term Classified Traffic Count Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Factored Short-Term Traffic Count Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Historical Estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Mass Collective Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Classification Estimates of Similar Neighboring Traffic Link</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>QK: Quality of the Design–Hour Estimate</th>
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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>30th Highest Hour Observed During 12 Mo of Continuous Traffic Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>30th Highest Hour Observed During Less Than 12 Mo of Continuous Traffic Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Factored Highest Hour Collected at in a 48-H Weekday Period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Factored Highest Hour Collected at in a 48-H Weekday Period with Growth Element</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Manual Estimate of 30th Highest Hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Design Hour of Similar Neighboring Traffic Link</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>Provided by External Source</td>
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<table>
<thead>
<tr>
<th>QW: Quality of AAWDT</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>Average of Complete Continuous Count Data</td>
<td></td>
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<tr>
<td>B</td>
<td>Average of Selected Continuous Count Data</td>
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<tr>
<td>F</td>
<td>Factored Short-Term Traffic Count Data (for current year)</td>
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</tr>
<tr>
<td>G</td>
<td>Factored Short-Term Traffic Count Data with Growth Element</td>
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<tr>
<td>M</td>
<td>Manual Uncounted Estimate</td>
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<tr>
<td>N</td>
<td>AAWDT of Similar Neighboring Traffic Link</td>
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<td>O</td>
<td>Provided by External Source</td>
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4.10 Example of Quality Assessment for WIM Data

This section includes an example of reviewing weigh-in-motion (WIM) data. This example is part of the procedure adopted by the Minnesota DOT and was developed as a working paper. The example

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3 Dahlin, C. Techniques Used by the Minnesota Department of Transportation to Identify Invalid Weight Data. Traffic Data Collection and Analysis Task Group, Strategic Highway Research Program, March 1991.
include here emphasizes five-axle combination trucks. This vehicle classification is considered to have
the greatest impact on pavement deterioration. The goal of the quality assessment and review procedure
is to ensure that the weight data collected for this classification are correct.

WIM data are edited for distribution of Gross Vehicle Weight (GVW), front axle weights, and equiva-
 lent single-axle load (ESAL) factors. Depending on the degree of system malfunction, any of these three
areas can be used to determine if there is a problem that would cause the data to be invalid.

The distribution of GVW should be bimodal with one concentration between 28,000 to 32,000 lb for
unloaded vehicles, and another between 70,000 to 80,000 for loaded vehicles.

Figures 4-2 and 4-3 show an example of a valid set of weight data from a specific site for the period
October 22–29, 1990. The distribution of vehicles conforms to statewide truck weight distribution
patterns for 5-axle combination vehicles. In Figure 4-2 the valid data are compared with the distribution
for one set of invalid weight measurements, taken during December 3–10, 1990. The invalid dataset has
the highest percentage in the lightest category. In Figure 4-3 the valid data are compared with invalid
measurements taken during January 5–17, 1991. This invalid dataset has the highest percentage in the
heaviest category. The datasets each represent over 5,000 trucks. The invalid data should not be edit-ac-
cepted, summarized, or reported.

Figure 4-2. WIM Quality Assessment Example 1, Distribution of Gross Vehicle Weight.
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Figure 4-3. WIM Quality Assessment Example 2, Distribution of Gross Vehicle Weight.

It is highly unlikely but still possible that the December and January datasets represent seasonal variation in weight distributions. The edit rejection of the two datasets described above is verified in Figure 4-4. In Figure 4-4, the December 3–10 dataset is from the lane adjacent to the lane reported in Figures 4-2 and 4-3. The two correctly calibrated and functioning WIM records are directly comparable, so the distribution differences were correctly identified as measurement errors.

Figure 4-4. WIM Quality Assessment Example 3, Distribution of Gross Vehicle Weight in an Adjacent Lane.
The second WIM quality check is for front axle weights. The distribution of weight on the front axles establishes a pattern for data acceptance just as described for Gross Vehicle Weights. The front-axle weights are grouped into three categories, shown in pounds:

<table>
<thead>
<tr>
<th>Gross Vehicle Weight</th>
<th>Average Front-Axle Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;32,000</td>
<td>8,500</td>
</tr>
<tr>
<td>32,000–70,000</td>
<td>9,300</td>
</tr>
<tr>
<td>&gt;70,000</td>
<td>10,400</td>
</tr>
</tbody>
</table>

These values do not apply to all sites, but represent average values. Site-specific patterns should be established in editing WIM data. There should be a large number of vehicles weighed in each group to establish the pattern. A minimum of 25 vehicles should be weighed in each group when determining the validity of a set of data.

Front-axle weights by week over one quarter of the year are shown in Figure 4-5. Each of the three axle weights was relatively constant over an extended period of time. However, beginning in late November they began to show significant deviation. The system began to record some vehicles as being too light, and others as being too heavy. The weights in December indicate invalid data. The data were taken from the same site found to have invalid December data in Figure 4-2.

![Figure 4-5. WIM Quality Assessment Example 4, Front-Axle Weights by Gross Vehicle Weight Range.](image-url)
The third WIM quality check is based on ESAL factors. ESAL factors are sensitive to weight changes. The pattern of ESAL factors is site-specific and lane-specific. The ESAL factors are established by lane for weekdays and are reviewed on a daily basis. Figure 4-6 shows flexible ESAL factors on consecutive weekdays from October through December, at one site, for one lane, with a sample of approximately 900 trucks per day. The October data are relatively consistent. The data begin to become less consistent in mid-November, and are erratic during December. These data are from the same site that had WIM data during the same period. The ESAL factors confirm the previous findings.

![Figure 4-6. WIM Quality Assessment Example Factor 5, Flexible ESAL Weekday Factors.](image)

The three WIM edits are complementary. It is recommended that Gross Vehicle Weight, front-axle weight, and ESAL factor pattern-based edits be developed and applied to permanent device WIM data. With effective editing of WIM data, site-specific truck weight patterns will be established. Figure 4-7 is an example of eight consecutive weeks of site-specific edit-accepted WIM data.
Figure 4-7. WIM Quality Assessment Example 6, Eight-Week Distribution of Gross Vehicle Weight.

4.11 References and Resources

Dahlin, C. Techniques Used by the Minnesota Department of Transportation to Identify Invalid Weight Data. Traffic Data Collection and Analysis Task Group, Strategic Highway Research Program, March 1991.


Summarization is a critical step in the transformation of huge amounts of traffic data into concise and useful information. On the other hand, as traffic data are summarized, they also have the potential to be misused. If summarization is inconsistent or inappropriate, the results can be misleading.

The challenge of summarizing traffic data is to ensure that the procedures are consistent, clear, and reproducible. It also is important that sufficient information be transmitted to help ensure that data summaries are understood.

Four sets of procedures for summarizing traffic data are presented. Procedures in the first set address the summarization of data from continuous monitoring sites. Those in the second set address the use of data, primarily from continuous monitoring sites, for developing adjustment factors. Those in the third set address the summarization of data from short-term monitoring sites and the application of adjustment factors to this data to produce annual statistics. The fourth set of procedures, presented in Sections 5.4 through 5.6, address summarizing traffic data for analyses prior to use, developing estimates of precision and bias, and rounding. A concluding section discusses the use of traffic statistics by the Mechanistic-Empirical Pavement Design Guide (MEPDG).

5.1 Summarizing Data from Continuous Counters

Many site-specific uses of data require estimates of typical traffic over the period of a year. Data from continuous counters provide these estimates and, more importantly, they are used as the basis for converting short-term counts into estimates of annual averages.

It is recommended that, when using data from continuous monitoring sites, agencies adopt a one-day minimum of edit-accepted data for each day of the week and each month of the year. This minimum limits the amount of bias that might be present due to missing data in an estimate of annual traffic volumes made with data from that site.
5.1.1 Count Definition

Except when using ITS-generated data, a count obtained from a continuous counter is defined to consist of 24 consecutive hours of data across the entire roadway. The data must be complete for all road elements; i.e., for each individual lane, for all lanes in a single direction, or for all lanes in both directions. Special procedures for ITS-generated traffic data are presented in Section 5.1.6.

5.1.2 Data Types

Volume

A volume count obtained from a continuous counter consists of 24 consecutive hours of total traffic volumes. A volume count for a particular location may be obtained directly from a count of vehicles, by aggregating a set of classification counts for the location, or by applying an axle-correction factor to an axle count for the location.

Classification

A classification count obtained from a continuous counter consists of 24 consecutive hours of traffic volume counts for each of several classes of vehicle. Vehicles may be classified on the basis of various characteristics, including length, visual appearance, number of trailers, number of tires, or number and spacing of axles. The most commonly used classification system is FHWA’s 13-class system, which uses numbers of axles and trailers, as well as other factors. This system is summarized in Figure 3-1. Classification by length is discussed in the next subsection.

A classification count is converted to a volume count by summing the counts in all category ranges, or bins, including the unclassified bin but excluding “counts” in any error bins being used.

The percentage of vehicles of any class is obtained by dividing a count for that class by the sum of corresponding counts for all classes excluding the unclassified bin and any error bins.

The percentage of vehicles in any set of classes is obtained by summing the percentages for each of the classes. A basic categorization of the FHWA vehicle classes is:

- Personal-use vehicles (Classes 1 through 3);
- Single-unit trucks and buses (Classes 4 through 7); and
- Combinations (Classes 8 through 13).

States in which significant numbers of multitrailer combinations operate should further distinguish between single-trailer combinations (Classes 8 through 10) and multitrailer combinations (Classes 11
through 13). For some purposes, it also may be appropriate to create a separate category for buses (Class 4) or to move them to the “passenger vehicle” category.

**Classification by Length**

When vehicles are classified by length, three or four length classes should be used, corresponding roughly to the three categories above, with an optional further distinction between short- and long-combination vehicles (FHWA Classes 8 through 10 and FHWA Classes 11 through 13).

Since different length-measuring technologies produce different estimates of vehicle length, the actual lengths used for the three categories will depend on the technology used as well as on characteristics of vehicles operating in the state. Each state should conduct its own calibration tests, and establish classification breakpoints for each technology that it plans to use. States using loop detectors have found optimum settings for the three breakpoints to be in the ranges of 20 to 23 ft, 40 to 42 ft, and 70 to 73 ft.

When using three well-calibrated length classes, there is likely to be a 90 to 95 percent correspondence between the assignment of vehicles to length classes and their assignment to the three above groups of FHWA classes, with vehicles pulling light trailers accounting for a disproportionate share of misassignments. With four length classes, poorer correspondences are likely, mostly because some two-unit vehicles (trucks pulling trailers) can be as long or longer than some three-unit vehicles (tractors pulling a short semitrailer and a short independent trailer) forcing one or the other vehicle type to be misclassified, depending on where the length boundary is set.

In general, classification error increases with vehicle length. While the shortest length bin may classify at 99 percent accuracy, the longest bin might be on the order of 80 percent accurate. If the particular application requires accurate classification of large trucks, length classification should not be used.

**Speed**

A speed count obtained from a continuous counter consists of 24 consecutive hours of counts for each of several speed bins. The bins to be used by each state may be defined judgmentally, but all speed limits of interest to the state (55 mph, 65 mph, etc.) should be used as bin boundaries.

The percentage of vehicles with speeds belonging to a particular speed bin is obtained by dividing the count for that bin by the sum of the counts for all bins. The percentage of vehicles with speeds above a particular threshold (such as 55 mph) represented by the lower boundary of a bin is obtained by summing the percentages of vehicles in that bin and in all higher-speed bins.

Average speed is estimated by multiplying the midpoint of each speed bin by the corresponding percentage of vehicles with speeds in that bin and summing over all bins. In this process, it is suggested that the
“midpoint” of the last (highest speed) bin (a bin that has no upper bound) be obtained by treating the bin as if it has the same width as the next to last bin.

**Weight and Load Spectra**

Weight data are saved primarily in the form of load spectra. Load spectra are collected separately for all relevant combinations of vehicle class and axle-group type. The vehicle classes used for this purpose are the ones used for classification counts. If both the FHWA classes and state-defined length classes are used, separate sets of load spectra will be required for the two types of vehicle classes. The standard axle-group types distinguished are single, tandem, tridem, and quad axles. Separate load spectra for a fifth axle-group type, single steering axles (a subset of all single axles) also may be collected for use in checking WIM calibration. When referring to load spectra, the terms “axle” and “axle group” are used interchangeably.

The load spectrum for a particular vehicle class and axle type consists of a set of counts of axles belonging to each of several bins. The standard load ranges are defined in Table 5-1; though, for single, tandem, and tridem axles, use of Ranges 26 to 39 is optional. On roads on which the legal axle-load limits are 20,000 lb for single axles and 34,000 lb for tandems, observed loads in these higher ranges are indications of possible calibration problems or of very high dynamic axle motion.

A load distribution is obtained by normalizing a load spectrum; that is, by dividing all counts by the sum of the counts (for the particular vehicle class and axle type).

Weight data also may be used to collect statistics on gross vehicle weight (GVW). The GVW of any vehicle is the sum of the axle weights of the vehicle. The average GVW of any set of vehicles is obtained by dividing the sum of the weights of vehicles in the set by the number of vehicles in the set. Since data validation procedures may result in discarding weight data for some vehicles that have been correctly classified, a separate set of counts is required for GVW calculations—a set containing counts of the number of vehicles of each class for which edit-checked weight data have been obtained. These counts of the number of vehicles, by class, for which edit-checked GVW values have been obtained, also are required for developing monthly and annual average GVWs using the procedures presented below.

Load spectra and GVW distributions produced by WIM installations measure dynamic weights, and not static weights. Accordingly these distributions cannot be used to estimate the number of vehicles whose static axle weights or static gross weights exceed legal limits. Many vehicles are loaded to weights that are just below the legal limits and many fewer are loaded to weights that are just above these limits. As a result of the dynamic motion of the vehicle, the actual load applied by an axle oscillates around the static load of that axle. Because of this oscillation, distributions of dynamically measured weight developed from WIM data will imply that substantially more vehicles have weights that exceed legal limits than is actually the case.
It is recommended that all weight data be collected using in-pavement sensors that have been placed flush with the surrounding pavement and that a minimum of one week of weight data be collected in every month.

5.1.3 Daily and Hourly Summaries

Daily summaries are produced for all counts (for any road element) obtained from permanent counting equipment. The summaries are used both for preparing reports of daily traffic and for later aggregation into monthly summaries, so the summaries should include daily equivalents for any statistics for which monthly or annual values are needed. These may include volume counts, classification counts, speed counts, load spectra, and average values of GVW.

The daily summaries should always include hourly values, and, if available, quarter-hourly values. The latter are used for determining peak hours and peak-hour factors. These should be calculated at both the direction and roadway levels; and, for urban areas at least, should include both morning and afternoon peaks. If data are collected at finer levels of aggregation, such as five-minute intervals, they should be summarized to quarter-hour values in the daily summaries, with the finer-grained data retained as detailed data or in raw data files for research and ad hoc planning queries.

5.1.4 Monthly Summaries

Monthly summaries of all counts are produced in a two-step process. First, for each month and each day of the week, all counts (of a given type at a particular location) are averaged to produce a monthly average day of the week (MADW) value. Then, the seven MADW values produced for the month are averaged to produce an average value for the month. For volume counts collected at a given location, the resulting average represents an estimate of monthly average daily traffic (MADT).

For binned data (class, speed, and load spectra), separate averages are obtained for each bin. For each location, the results of this process are monthly average counts of numbers of vehicles in each (class, speed, or weight) bin. The class-bin averages represent estimates of MADT by vehicle class. The speed-bin averages are normalized to produce percentages of vehicles in each speed bin, and this distribution is used to estimate monthly average speed using the procedure described earlier in Section 5.1.2 under “Speed.” Similarly, for each location, vehicle class, and axle type, the weight-bin averages are normalized to produce a normalized monthly load spectrum.

The two-step averaging process has the advantage of producing monthly averages that give equal weight to each day of the week, regardless of the day of the week on which the month starts and regardless of any missing days of data.
### Table 5-1. Load Ranges Used for Load Spectra

<table>
<thead>
<tr>
<th>Load Range</th>
<th>Single</th>
<th>Tandem</th>
<th>Tridem</th>
<th>Quad</th>
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*One kip = 1,000 lb = 4.448 kN.*
If monthly summaries of average GVW for individual vehicle classes or sets of vehicle classes are required, they are obtained using a minor variant of the two-step process. First, for each class (or set of classes), weighted average values of the average GVWs for each day of the week are obtained from the daily average GVWs for that day of the week and that month. In this step, the statistical weights used are the counts of vehicles for which vehicle weight data are being used. Then, for each class (or set of classes), weighted averages are obtained of the seven MADW GVWs produced by the first step. In this second step, the statistical weights used are MADW values for the relevant vehicle classes developed using counts of only those vehicles for which edit-checked weight data has been retained.

5.1.5 Annual Summaries

Annual summaries of all counts are produced using a process that is analogous to that used for the monthly summaries. First, for each day of the week, the 12 monthly MADW values are averaged to produce an annual average day of the week (AADW) value. Then, the seven AADW values are averaged to produce an average value for the year. Similarly, annual summaries of average GVW are obtained using an analog of the two-step weighted average process for producing monthly summaries described above.

For volume counts, the resulting average represents an estimate of annual average daily traffic (AADT). For volume counts, separate averages also may be obtained of the five weekday AADW values and the two weekend AADW values to produce estimates of annual average weekday traffic (AAWDT) and annual average (daily) weekend traffic (AAWET). Many states exclude the AADW for Friday from the AAWDT calculation, because Friday is not typical of either weekdays or weekends.

For binned data, separate annual averages are produced for each bin and processed in the same way as the monthly averages. The results of this processing include: AADT by vehicle class; AAWDT by vehicle class; annual average speed; and normalized annual load spectra.

5.1.6 Summarizing ITS-Generated Data

Provisional procedures for summarizing ITS data have been developed, but there is some concern that they might be downwardly biased, and, in any event, they require further investigation.

For the purpose of using these procedures, the standard time period for an ITS count is set at a single hour (rather than 24 consecutive hours). With this convention, all ITS data are summarized by hour, and modified versions of the procedures for producing monthly and hourly summaries are used. These procedures distinguish the 168 hours of the week in the same way as the conventional procedures described above distinguish the 7 days of the week.

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1 At some sites, particularly on recreational roads, it may be useful to treat Friday as part of the weekend. For these sites, the relevant “weekday” and “weekend” statistics become four-day and three-day averages, respectively. The resulting statistics should be distinguished from the conventionally defined values of AAWDT and AAWET either through the use of a metadata tag, or by adopting modified names for the statistics.
In the case of monthly summaries of ITS data for a particular location, the first step is to average all counts for each month and each of the 168 hours of the week to produce a monthly average hour of the week (MAHW) value. For each month and each day of the week, the 24 MAHW values (corresponding to the hours of the day) are summed to produce an MADW value. The MADWs are then combined to produce the various monthly and annual summary statistics for the site using the procedures described above.

5.2 Adjustment Factors

One of the most important uses of data from continuous monitoring sites is in the development of factors and ratios for adjusting data from short-term counting sites for monthly and DOW variation and for growth. The development of these adjustment factors is discussed below, as well as the development of axle-correction factors for converting axle counts to counts of vehicles. The application of these factors to short-term counts is discussed further in Section 5.3.

When using data from continuous monitoring sites, a minimum\(^2\) of one non-holiday-influenced day of edit-accepted data for each day of the week and each month of the year is recommended. This standard permits the computation of a complete set of 84 MADWs. Monthly and day-of-week (DOW) factors and ratios should be developed using only data from sites for which a complete, or nearly complete, set of MADWs is available.

5.2.1 Seasonal and Day-of-Week Factors and Ratios

Continuous counts provide data on how traffic volumes vary by time-of-year and by DOW. A major use of this data is for converting short counts obtained at other sites into estimates of AADT and AADT by vehicle class (AADT by VC). For this purpose, the continuous counts are used to derive sets of traffic factors or traffic ratios that are applied to the short counts. This section discusses the development and use of these factors or ratios.

Traffic Factors Versus Traffic Ratios

There are two basic ways of converting a short count to an estimate of average volume over an extended period of time (such as a month or a year). One is to multiply the count by an appropriately derived traffic factor (i.e., to “factor” the count); and the other is to divide the count by an appropriately derived traffic ratio.

Both quantities are derived, using similar procedures, from counts collected at one or more continuous count sites; and, except for the difference between multiplication and division, both quantities are used in the same way. Furthermore, they produce very similar results. However, when traffic factors and

\(^2\) The one-day minimum should be viewed as a minimum. Data from continuous monitoring sites should be collected continuously, and the maximum practical number of days of edit-accepted data should be used in the process.
ratios are derived using data from two or more continuous count sites, the results almost always differ slightly (frequently by a very small amount), and it appears that the estimates produced by traffic ratios are slightly more reliable than those produced by traffic factors.\(^3\) For this reason, there is a slight preference for using traffic ratios, and the presentation of this section is in terms of traffic ratios. However, the advantage of using ratios generally is quite small and does not warrant a change in procedures by any state that currently uses traffic factors.

### Traffic Ratios for Volume Counts

There are several ways of using traffic ratios to convert short-duration volume counts to estimates of AADT. The two most common are:

1. The use of separate monthly and DOW ratios; or
2. The use of a single combined monthly/DOW ratio.

When the latter procedure is used, for each seasonal factor group,\(^4\) data from continuous monitoring sites is used to compute a set of 84 traffic ratios\(^5\) (\(TR_{md}\)), corresponding to the 12 mo \((m)\) and the seven days of the week \((d)\):

\[
TR_{md} = \text{Avg}_{i} \left( \frac{\text{MADW}_{mdi}}{\text{AADT}_{i}} \right)
\]

where:

- \(\text{MADW}_{mdi}\) and \(\text{AADT}_{i}\) are derived as described in Sections 5.1.4 and 5.1.5; and
- The average is taken over all continuous sites, \(i\), in the group.

If the former alternative is used, separate monthly and DOW traffic ratios are computed using ratios of \((\text{MADT}_{m}/\text{AADT}_{i})\) and \((\text{AADW}_{d}/\text{AADT}_{i})\). This alternative has the advantages of requiring a smaller number of traffic ratios (12 monthly ratios and seven DOW ratios) for each factor group, and of being a little easier to understand. The values are readily summarized in a pair of graphs, one showing the monthly ratios and a second showing the DOW ratios. Also, if this alternative is used separate factor groups could be developed for the monthly adjustments and for the DOW adjustments. On the other

---


\(^4\) The development of factor groups is discussed in Section 2.3.2.

\(^5\) The corresponding set of traffic factors (\(TF_{md}\)) are computed:

\[
TF_{md} = \text{Avg}_{i} \left( \frac{\text{AADT}_{i}}{\text{MADW}_{mdi}} \right)
\]

(The advantage of ratios relates to the fact that the denominator in Eq. 5-1, AADT\(_{i}\), varies less than the denominator, MADW\(_{mdi}\), in the equation for TF\(_{m}\).)
hand, this alternative uses the same DOW adjustments for every month of the year, while the second alternative uses different DOW adjustments for each month—a particular advantage in the case of factor groups (such as recreational groups) that have DOW patterns in traffic volume that vary by season.

**Traffic Ratios for Classification Counts**

The development of traffic ratios (or traffic factors) for classification counts is similar to their development for volume counts, except that separate sets of ratios are developed for each of several groups of vehicle classes. Leaving aside buses (FHWA Class 4) for the moment, the recommended grouping for this purpose for states that have significant numbers of vehicles in Classes 11 through 13 is:

A. Classes 1 through 3 (personal-use vehicles);
B. Classes 5 through 7 (single-unit trucks);
C. Classes 8 through 10 (single-trailer trucks); and
D. Classes 11 through 13 (multitrailer trucks).

States that have relatively few multitrailer trucks should combine the last two groups into a single group of “combination trucks.”

For each seasonal factor group,6 one set of classification-count traffic ratios is developed for each group of vehicle classes using counts of vehicles in those classes obtained from the continuous classification sites in the factor group. The procedure used for this purpose is completely analogous to that used for developing volume-count traffic ratios.

In this procedure, the ratios are developed for groups of vehicle classes to increase the amount of data used in the process. The goal is to develop ratios that provide reliable indications of how volumes (and particularly truck volumes) vary by day of the week and by month of the year. If the counts used in the process are small, they are subject to undue influence by random events or, in the case of some vehicle classes (such as Classes 6 and 7), by individual decisions (such as those relating to the timing of construction activity) that affect the operation of relatively large numbers of trucks.

Given the above considerations, the appropriate treatment of buses (Vehicle Class 4) in this process requires some judgment. On roads where most buses are transit buses or school buses, bus volumes drop on weekends, suggesting that buses be assigned to the same group of vehicle classes as single-unit trucks (whose volumes also drop on weekends). On the other hand, on most segments of the rural Interstate System, most buses are intercity buses whose day-of-week volume patterns are very similar to those of

---

6 The factor groups used for classification counts need not be identical to those used for volume counts.
personal-use vehicles and very different from those of single-unit trucks. Given these considerations, there appear to be three reasonable alternatives:

1. Include buses in Group B (the alternative that currently is most common);
2. Include them in Group A; or
3. For the purpose of developing traffic ratios, do not assign buses to any of the vehicle groups. If this last alternative is used, for the purpose of applying traffic ratios, short-duration bus counts for different segments should be adjusted using traffic ratios that are selected on the basis of characteristics of the buses that operate on the segments. Short-duration bus counts collected at locations where transit and school buses predominate should be adjusted using the Group B traffic ratios, while those collected at locations where intercity buses predominate should be adjusted using the Group A traffic ratios.

**Weekday and Weekend Traffic Factors**

For any year, the weekday traffic factor for any continuous count site for which AAWDT and AADT have been calculated is defined as the ratio of AAWDT to AADT. For any year, the weekday traffic factor for any seasonal factor group is defined as the average of the weekday traffic factors for the continuous count sites belonging to the factor group. Weekend traffic factors for continuous count sites and for seasonal factor groups are derived similarly from AAWET and AADT.

**Data Requirements**

For any year, volume (or classification count) traffic ratios (or factors) can be developed only for sites for which a complete set of 84 MADWs can be computed for total volume (or for volume by vehicle class).

**Applying the Traffic Ratios**

Traffic ratios and factors should be calculated and used internally without rounding. For publication purposes, it is recommended that they be shown using three decimal places.

There are three alternative ways in which traffic ratios (or factors) may be applied to short counts: as “historic” ratios; as “current-year” ratios; or as “rolling average” ratios. The three alternatives are described below.

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7 A fourth alternative would be to create a separate group containing only Vehicle Class 4. The principle disadvantage of this alternative is the small number of buses that are likely to be observed at many continuous classification sites.
“Historic” Traffic Ratios

“Historic” traffic ratios for use in any year are developed by averaging ratios developed using summary statistics from earlier years. For this purpose, it is recommended that ratios developed from statistics for the three preceding years be used.

A major advantage of historic traffic ratios is that the ratios used in any year can be computed at the beginning of the year and applied to short counts collected throughout the year. This makes it possible to convert short counts into estimates of AADT as soon as the counts are collected. On the other hand, historic ratios have the disadvantage of producing AADT estimates that are slightly less accurate than those produced by the other alternatives. In particular, if an event (such as an economic recession) in a given year changes the DOW patterns in traffic volume from those that existed in previous years, historic traffic ratios may produce slightly biased estimates of AADT.

Historic traffic ratios (or factors) are produced in two steps. First, for each continuous monitoring site (or continuous classification site), traffic ratios produced using data from each of the last three years are averaged to produce a new set of average monthly and DOW ratios. If, because of missing or unreliable data, it was only possible to compute traffic ratios for a given site for one or two of the preceding three years, the averages for that site are developed for the years for which ratios have been computed. Then, for each factor group, an average is obtained of the average ratios produced in the first step for all sites in the group. The result is a set of (historic) traffic ratios for the group.

“Current-Year” Traffic Ratios

“Current-year” traffic ratios for use in any year are developed by averaging ratios developed using summary statistics from that year. These ratios generally will produce better estimates of AADT than can be produced using historic ratios. However, the ratios cannot be developed until the year is over, reducing the value of the resulting AADT estimates for many planning and design applications.

Since current-year ratios generally produce better estimates of AADT, they are frequently used to produce estimates of AADT and VMT that are not needed until after the year is over. These include values that are published in “Count Books” and those that are reported to FHWA as part of a state’s Highway Performance Monitoring System Manual (HPMS) submission.

“Rolling Average” Traffic Ratios

A third option for applying traffic ratios is to compute a new set of ratios every month, in each case using the most recent 12 mo of traffic data. This option can be characterized as computing the ratios on a 12-mo rolling-average basis. Some states may choose to use a 3-yr “window,” rather than 12 mo.
Whenever a set of these “rolling-average” traffic ratios is developed, they are applied to the short counts collected in the last month of the 12-mo period covered by the ratios. The resulting AADT estimates are best interpreted as representing estimated AADT for the 12-mo period covered by the ratios. However, they also can be interpreted as estimated AADT for the calendar year in which the counts are taken. As calendar-year estimates, these estimates generally have accuracies that are between those produced when historic or current-year ratios are used.

### 5.2.2 Axle-Correction Factors

Axle correction is used for short-term traffic counts that are obtained by using equipment, such as road tubes, that measure axle impulses. Dividing the total impulses by two would provide the number of vehicles if there were no vehicles with more than two axles in the traffic stream. In the vast majority of instances, on all classes of roadway, if short-term axle impulses are measured, an axle-correction ratio larger than two should be applied to estimate traffic volume.

On most roads, the percentage of vehicles with more than two axles is higher on weekdays than on weekends and varies seasonally. Since most short-term counts are collected on weekdays, axle-correction factors generally should be developed using only weekday data. Also, to the extent practical, they should be developed using data collected on the same day (or days) as the axle counts are collected.

The mix of vehicles varies from road to road and, in the case of long roads, it also may vary significantly from one stretch of road to another, particularly if the road has an intersection or interchange at which significant numbers of trucks enter or exit. Accordingly, wherever practical, axle-correction factors to be applied to axle counts collected on a given road should be developed from classification data collected on the same road; and, in the case of counts collected on long roads, they should be developed using data collected from a location that is not separated from the location of the axle count by any intersections or interchanges at which the percentage of trucks in the traffic stream is likely to change appreciably.

Many axle-correction ratios (or factors) are derived from short-duration classification counts collected on the road on which they are to be used. To the extent practical, all short-term volume counts collected on such a road should be collected at the same time as the classification count is collected. Axle-correction ratios generally are derived using a two-step procedure:

1. Weekday vehicle records from continuous WIM or classification sites on roads in the same functional system are used to develop the average number of axles per vehicle for each vehicle class, as shown in Column 3 of Table 5-2.

---

2. A weighted average of the above averages is obtained, using the short-duration classification count of vehicles by class as the weights, as shown in Columns 2 and 4 of Table 5-2. The result of this second step is the axle-correction ratio for use on the road in question.

Table 5-2. Development of Axle-Correction Ratios

<table>
<thead>
<tr>
<th>FHWA Vehicle Class</th>
<th>Daily Vehicle Volume</th>
<th>Average Number of Axles per Vehicle</th>
<th>Total Number of Axles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>2.000</td>
<td>200,000</td>
</tr>
<tr>
<td>2</td>
<td>1,400</td>
<td>2.000</td>
<td>2,800,000</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>2.000</td>
<td>90,000</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>2.051</td>
<td>30,765</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>2.000</td>
<td>40,000</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>3.000</td>
<td>120,000</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>4.023</td>
<td>20,115</td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>3.542</td>
<td>53,130</td>
</tr>
<tr>
<td>9</td>
<td>120</td>
<td>5.000</td>
<td>600,000</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>6.007</td>
<td>30,035</td>
</tr>
<tr>
<td>11</td>
<td>15</td>
<td>5.000</td>
<td>75,000</td>
</tr>
<tr>
<td>12</td>
<td>5</td>
<td>6.000</td>
<td>30,000</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>7.382</td>
<td>73,820</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,795</strong></td>
<td><strong>2.319</strong></td>
<td><strong>4,162,865</strong></td>
</tr>
</tbody>
</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 4,521 axles would indicate a vehicle volume of 1,949 \((4,521/2.319 = 1,949)\).

If the short-duration classification counts are collected using equipment that produces either individual records for each vehicle or counts of axles observed during any time period, then the two-step procedure is unnecessary—the ratios should be obtained directly by dividing the total number of axles counted by the corresponding number of vehicles.

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 0.431 \((\text{the inverse of } 2.319)\). The number of vehicles \((1,948)\) would then be estimated by multiplying the number of axles \((4,521)\) times the factor \((0.431)\). Multiplicative axle-correction factors are always less than or equal to 0.5 (just as axle-correction ratios are always greater than or equal to 2.0).

Axle-correction factors and ratios should be calculated and used internally without rounding. For publication purposes, it is recommended that they be shown using three decimal places.
An axle-correction ratio (or factor) that has been developed from a short-duration classification count remains valid until a new classification count is obtained on that road (or, in the case of long roads, on the relevant stretch of road). However, in the case of roads with seasonally varying truck volumes, to the extent practical, axle-correction ratios developed from classification counts collected at one time of the year should not be applied to axle counts collected at another time of the year. A new classification count should be obtained at least once every three years on the interstate system and at least once every six years on other roads (more frequently if significant changes occur in the character of traffic on the road).

On some roads, axle-correction ratios (or factors) can be developed from data collected by continuous WIM or classification equipment at a site on the road. For such roads, when practical, the axle-correction ratios should be developed using an estimate of AADT by vehicle class at the continuous site during the days when the short-duration axle counts are being collected. If the monitoring equipment at the site produces individual vehicle records, then the estimate of average number of axles per vehicle is developed from records collected during the same time period. Otherwise, it is developed from weekday vehicle records produced by continuous WIM or classification sites on roads in the same functional system or vehicle classification factor group.

Finally, in the case of axle counts collected on roads on which no classification data are collected, default axle-correction ratios are used. For every site that is monitored with equipment that produces individual vehicle records, an axle-correction ratio is developed using AAWDT by vehicle class and a corresponding estimate of the average number of axles for each vehicle class. Then, for each functional system or vehicle classification factor group, the resulting ratios are averaged to produce a default axle-correction ratio for use on roads in that functional class for which roadway-specific axle-correction ratios are unavailable.

### 5.2.3 Growth Factors

Agencies rarely conduct traffic counts on all road segments during each one-year period. Growth factors\(^9\) are used to adjust traffic statistics developed for a segment for a given year so that they will better reflect conditions on the segment in the next year. Prior to calculating annual system-level statistics, all volumes on all roads in the system should be either counted or adjusted for change during the year.

Growth factors are developed separately for each of several factor groups. These may be the same as the seasonal factor groups used for monthly and DOW factoring. However, somewhat better results can be obtained if a separate set of “growth factor groups” is used. For this purpose, the roadway system is divided into subsystems that are believed to have fairly similar growth rates. Some observations that are useful in forming growth-factor groups are:

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\(^9\) Growth factors are sometimes called “current-year factors”.

---
• Growth rates are likely to differ between rural areas and urbanized areas;

• Outlying parts of an urbanized area are likely to have traffic volumes that are growing faster than the center city and the older, established suburbs;

• Traffic on the interstate system in rural areas and in small urban areas consists primarily of through traffic, so growth rates on these roads are much less affected by the local economy than growth rates on other roads; and

• In a large state, rural growth rates may vary regionally, and different growth rates also may be experienced in different urbanized areas.

Given the above considerations, a basic set of growth-factor groups might consist of:

• Urbanized areas—central cities and older suburbs;
• Urbanized areas—newer suburbs (and perhaps some of the urban fringe that is still classified as rural);
• Rural and small urban interstate system;
• Other rural; and
• Other small urban.

The distinction between the two urbanized-area groups might be made on the basis of Census data on population growth rates, or on the basis of numbers of construction permits issued (relative to population). In larger states, it also may be useful to make additional distinctions between faster and slower growing urbanized areas, and between faster and slower growing “other rural” areas. It is recommended that there be at least three to five continuous monitoring sites in each growth-factor group.

Volume growth factors are developed for any pair of consecutive years in two steps. First, growth factors are computed for every continuous monitoring site for which AADT estimates have been developed for both the year that has just ended and for the preceding year. As shown in Table 5-3, each of these factors is obtained as the ratio of AADT in the most recent year to AADT in the preceding year. Then, for each growth-factor group (or seasonal factor group, if separate growth-factor groups are not used), the ratios obtained for all continuous monitoring sites in the group are averaged to produce a volume growth factor for the group. In the example, this average is 1.025, indicating average growth between the two years of 2.5 percent.
### Table 5-3. Development of Growth Factors

<table>
<thead>
<tr>
<th>Site</th>
<th>AADT Current Year</th>
<th>AADT Preceding Year</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,795</td>
<td>1,734</td>
<td>1.035</td>
</tr>
<tr>
<td>2</td>
<td>2,241</td>
<td>2,214</td>
<td>1.012</td>
</tr>
<tr>
<td>3</td>
<td>3,845</td>
<td>3,690</td>
<td>1.042</td>
</tr>
<tr>
<td>4</td>
<td>1,296</td>
<td>1,308</td>
<td>0.991</td>
</tr>
<tr>
<td>5</td>
<td>2,189</td>
<td>2,109</td>
<td>1.038</td>
</tr>
<tr>
<td>6</td>
<td>1,698</td>
<td>1,691</td>
<td>1.004</td>
</tr>
<tr>
<td>7</td>
<td>2,546</td>
<td>2,422</td>
<td>1.051</td>
</tr>
</tbody>
</table>

**Average Growth Factor**: 1.025

Growth factors should be calculated and used internally without rounding. For publication purposes, it is recommended that they be shown using three decimal places of accuracy.

Further examination of the example shows that this group of continuous-monitoring sites contains three sites with relatively stagnant traffic volumes (average growth of 0.2 percent, with a small decline at one site) and four sites with more moderate growth (average growth of 4.2 percent). The differences in the growth rates between these two subgroups suggests that consideration should be given to breaking this group into two. In particular, if a geographic distinction between the two subgroups can be identified (such as a distinction between older and newer parts of a group of urbanized areas), incorporating this distinction into the definition of the growth-factor groups is likely to produce improved estimates of traffic growth on roads in the two types of area.

For each growth-factor group, a set of classification growth factors also is developed for each vehicle class. For this purpose, the ratios are developed using estimates of AADT by VC for each continuous classification site in the factor group.

### 5.2.4 Length-Class Factors

*Length-class factors* are used for converting estimates of AADT by length class into estimates of AADT for six categories of vehicle type:

1. Motorcycles (FHWA Class 1);
2. Passenger cars (two-axle four-tire vehicles, Class 2);
3. Light trucks and other two-axle four-tire vehicles (Class 3);
4. Buses (Class 4);
5. Single-unit trucks (Classes 5 through 7); and
6. Combination trucks (Classes 8 through 13).
AADT estimates for these vehicle class categories are part of the basic areawide travel activity data required by FHWA’s HPMS.\textsuperscript{10} Also, additional AADT estimates for buses and single-unit trucks (combined) and for combination trucks are required for HPMS sample sections as discussed in Section 5.5.3. Length-class factors are required only if classification by length is used.

Length-class factors are developed using data from WIM sites that are capable of classifying vehicles both by axle-configuration and by length. For the purpose of developing these factors, length classification at the WIM sites should be performed using \textit{the same technology and same algorithms} as are used at other length-classification sites in the state. If more than one technology is used, it may be necessary to develop separate length-class factors for each technology.

The following procedure is recommended for developing length-class factors:

1. At each WIM site, obtain daily counts of the numbers of vehicles in each length class.

2. At each WIM site, for each length class, also obtain daily counts of the numbers of vehicles in the length class that belong to each of the six HPMS vehicle-type categories defined above.

3. Use the AADT-estimation procedure for estimating annual averages of each the type of count obtained in Steps 1 and 2.

4. For each type of Step 2 count, divide the Step 3 average by the Step 3 average of the corresponding Step 1 count.

For each length class, the result of this process is a set of six factors that can be used to estimate the distribution of those vehicles into the HPMS classes. For each WIM site, the process produces a set of 18 or 24 length-class factors (depending on whether there are three or four length classes).

For each Truck Weight Road Groups (TWRG), a set of 18 or 24 length-class factors is obtained by averaging the factors developed for each of the WIM sites belonging to the TWRG. These factors are used to convert estimates of AADT by length class into estimates of AADT by the above HPMS classes for use in completing the HPMS “Travel Activity by Vehicle Type” table.

The above factors also are summed to produce a set of 9 or 12 length-class factors that convert estimates of AADT by length class to estimates of AADT of personal-use vehicles (Classes 1 through 3), buses and single-unit trucks (Classes 4 through 7), and combination trucks (Classes 8 through 13). The more aggregate factors are used to estimate the “truck percentages” required for HPMS sample sections, as described in Section 5.5.3.

\textsuperscript{10} FHWA. \textit{Highway Performance Monitoring System Field Manual}, December 2000, Chapter 3. Estimates of motorcycle AADT are currently optional, but are expected to be required under the next edition of this manual. The HPMS reassessment in 2007 is evaluating this.
5.2.5 Time-of-Day Traffic Ratios

Time-of-day (TOD) traffic ratios (or “traffic fractions”) are used for converting manual classification counts into estimates of daily traffic by vehicle class. TOD traffic ratios are required only if partial-day manual classification counts are collected. Such manual counts are most often collected in urban areas, so the primary need for TOD traffic ratios is for ratios developed using data collected in urban areas. These ratios are developed from automated classification counts collected during weekdays in urban areas for periods of at least 24 hours (and, preferably, at least 48 hours). Section 3.3 provides information about equipment for collecting these automated classification counts. All urban-area classification counting programs should collect some such counts.

Separate sets of TOD traffic ratios are developed, by TOD factor group, for groups of vehicle classes. The recommended grouping of vehicle classes for this purpose is:

- Personal-use vehicles (Classes 1 through 3); and
- Buses and trucks (Classes 4 through 13).\(^{11}\)

The TOD factor groups should be established by the agency to distinguish roads on the basis of the amount of overnight truck activity relative to the amount during the mid-day period when manual classification counting is performed. When a TOD factoring program is first developed, it is suggested that two such groups be established:

- Sites in industrial areas where there is a significant amount of overnight truck activity; and
- All other sites.

If manual classification counts are collected at sites on the interstate system, a separate TOD factor group probably should be established for the interstate system.

After experience has been gained in the use of TOD factoring, it may be found desirable to establish additional TOD factor groups.

TOD traffic ratios may be developed using data from continuous classification counts or, more frequently, from short-duration weekday classification counts. For each TOD factor group for which continuous classification counts are available and for each of the vehicle-class groups, a set of TOD traffic ratios is obtained:

\(^{11}\) In the case of TOD factor groups for which traffic ratios are developed using automated counts from sites at which significant numbers of combination trucks operate, it may be preferable to divide this second group of classes into: buses and single-unit trucks (Classes 4 through 7); and combination trucks (Classes 8 through 13).
CHAPTER 5  SUMMARIZING TRAFFIC DATA

1. For each continuous classification site in the factor group, the MADW procedure is applied to hourly counts of vehicles in the classification group to produce a set of 24 annual average weekday hour-of-the-day classification counts. (Only weekday counts are used because manual classification counts are normally collected on weekdays).

2. For each of these sites, 24 hourly traffic ratios are obtained by dividing the hourly averages by the sum of the hourly averages.

3. The 24 hourly traffic ratios for the vehicle-class group and the factor group are obtained by averaging the corresponding traffic ratios produced in Step 2 for each of the sites in the factor group.

When using short-duration classification counts, the first step of this procedure becomes:

1. For each classification site in the factor group, the weekday counts obtained for each hour of the day are averaged to produce 24 weekday averages; and the second and third steps remain the same.

An example of the development of TOD traffic ratios is shown in Table 5-4. The first three columns of this table show hourly truck counts (Classes 4 through 13, combined) from a short-duration classification count for a 49-h period. Applying the second version of Step 1, above, produces averages of these counts for each of the 24 h of the day, as shown in Column 4. The average daily truck count for the site, 463, is obtained as the sum of the hourly averages. Dividing the 24 hourly averages by 463, in Step 2, produces the 24 traffic ratios shown in the last column of the table. If this site is one of several classification-count sites in a TOD factor group, then, in Step 3, for each hour of the day, the traffic ratio shown in the last column of the table would be averaged with corresponding traffic ratios for Classes 4 through 13 developed for each of the other sites to produce an average traffic ratio for that hour. The resulting set of 24 traffic ratios represent the traffic ratios for Classes 4 through 13 for the TOD factor group.
### Table 5-4. Development of Time-of-Day Traffic Ratios

<table>
<thead>
<tr>
<th>Hour</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Average</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td></td>
<td>1.5</td>
<td>0.3%</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td>1.5</td>
<td>0.3%</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td></td>
<td>0.5</td>
<td>0.1%</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
<td>1.0</td>
<td>0.2%</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
<td>2.5</td>
<td>0.5%</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td></td>
<td>6.5</td>
<td>1.4%</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>12</td>
<td></td>
<td>12.5</td>
<td>2.7%</td>
</tr>
<tr>
<td>7</td>
<td>29</td>
<td>33</td>
<td></td>
<td>31.0</td>
<td>6.7%</td>
</tr>
<tr>
<td>8</td>
<td>38</td>
<td>38</td>
<td></td>
<td>38.0</td>
<td>8.2%</td>
</tr>
<tr>
<td>9</td>
<td>41</td>
<td>39</td>
<td></td>
<td>40.0</td>
<td>8.6%</td>
</tr>
<tr>
<td>10</td>
<td>39</td>
<td>39</td>
<td></td>
<td>39.0</td>
<td>8.4%</td>
</tr>
<tr>
<td>11</td>
<td>40</td>
<td>38</td>
<td></td>
<td>39.0</td>
<td>8.4%</td>
</tr>
<tr>
<td>12</td>
<td>38</td>
<td>38</td>
<td></td>
<td>38.0</td>
<td>8.2%</td>
</tr>
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<td></td>
<td>40.0</td>
<td>8.6%</td>
</tr>
<tr>
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<td></td>
<td>41.0</td>
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<tr>
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<td></td>
<td>36.0</td>
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</tr>
<tr>
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<td></td>
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<tr>
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<td></td>
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</tr>
<tr>
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<td>9</td>
<td></td>
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</tr>
<tr>
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<tr>
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<td>3</td>
<td></td>
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</tr>
<tr>
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<td>4</td>
<td>2</td>
<td></td>
<td>3.0</td>
<td>0.6%</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>463.0</td>
<td></td>
</tr>
</tbody>
</table>

The traffic ratios shown in the last column of Table 5-4 are typical of a site at which most trucking is “business-day” trucking (accounting for the relatively high truck volumes between 6:00 a.m. and 6:00 p.m.), and a very small amount of truck activity occurs in the evening and overnight hours. For sites such as this one, trucks account for a larger percentage of total traffic during daylight hours (when manual counts are collected) than during nighttime hours. Hence, for these sites, estimates of truck traffic that are developed by multiplying total traffic by a value of percent trucks obtained from a manual classification count will tend to overestimate truck volumes. The alternative of estimating truck volume by applying TOD traffic ratios to the manual truck counts avoids this upward bias.
5.2.6 Evaluating Adjustment Factors

Before being used, all factors should be reviewed to verify that their values are reasonable.

In the case of traffic ratios and traffic factors, this review should verify that the values vary by month and by day of the week in a way that is consistent from year to year and is consistent with the patterns of traffic volume that is typical for sites in the factor group. For example, for most seasonal factor groups, traffic ratios are likely to be lowest in winter months, but traffic ratios for a winter recreational group should be highest during the winter.

If separate monthly and DOW ratios (or factors) are used, the review is readily performed with the aid of a pair of graphs—1 for the 7 DOW factors, and 1 for the 12 monthly factors. If a set of 84 combined monthly and DOW ratios (or factors) is used, a useful first step is to transform these ratios into separate DOW and monthly ratios by obtaining seven DOW averages (by averaging the 12 Monday values, etc.) and 12 monthly averages (by averaging the 7 January values, etc.).

The above procedures recommend that, for all major seasonal factor groups, traffic ratios and traffic factors be developed using data from five to eight continuous monitoring sites, and fewer sites may be used for relatively specialized groups, such as recreational groups. Missing data may cause the number of sites used in this process to drop below the planned number. But, there is no minimum on the number of sites to be used. It is more important that the resulting ratios or factors be reasonable reflections of the monthly and DOW patterns of traffic volumes than that they be developed using data from any particular number of sites. However, if missing data results in using fewer sites in the development of current-year or rolling-average traffic ratios (or factors), agencies may wish to consider using historic traffic ratios (for the same factor group) instead.

5.3 Summarizing Short-Term Counts

5.3.1 Short-Term Counts

A short-term count is defined to consist of a minimum of 24 consecutive hours of data for all lanes in a single direction or for all lanes in both directions. Short-term counts may be volume counts, classification counts, speed counts, or WIM counts. Short-term counts collected with equipment that counts axles are converted to volume counts by applying the appropriate axle-correction ratio or factor, as discussed in Section 5.2.2.

5.3.2 Daily and Hourly Summaries

Daily summaries are produced for all short-term counts. The summaries may include volume counts, classification counts, speed counts, or load spectra; and the load spectra also may be summarized in the form of average GVW. The daily summaries produced by a short-term count generally will consist of
summaries for a partial day at the beginning of the count, a partial day at the end of the count, and zero or more complete days in the middle.

The daily summaries should always include hourly values, and if available, quarter-hourly values. The latter are used for determining peak hours and peak-hour factors. These should be calculated at both the direction and roadway levels; and, for urban areas at least, should include both morning and afternoon peaks. If data are collected at finer levels of aggregation, such as five-minute intervals, they should be summarized to quarter-hour values in the daily summaries, with the finer-grained data retained as detailed data or in raw data files for research and ad hoc planning queries.

5.3.3 Estimation of Annual Statistics

**AADT**

The following procedure can be used to convert any short-term volume count (of at least 24 hours duration) into an estimate of AADT:

1. Summarize the count as a set of hourly counts;

2. Divide each hourly count by the appropriate seasonal traffic ratio (or multiply by the appropriate seasonal traffic factor);

3. For each hour of the day, average the results of Step 2, producing 24 hourly averages; and

4. Sum the 24 hourly averages to produce estimated AADT.

Use of hourly counts in this procedure makes it possible to use every hour of data collected. A simpler version of this procedure, which uses daily counts instead of hourly counts, also may be used, though it requires discarding some of the data collected when the number of hours of data are not divisible by 24.

In the above procedure, the seasonal traffic ratios (or factors) used for a count collected on a given traffic segment are the ones developed for the segment’s seasonal factor group or for a continuous monitoring site that serves as a reference site for the segment. In general, traffic ratios for the factor group should be used unless there is reason to believe that the traffic ratios developed for a reference site reflect the seasonal and DOW patterns in traffic volume on the segment better than the traffic ratios developed for the factor group. This last condition is likely to be met when the reference site and traffic segment are on the same road and not too far from each other.
CHAPTER 5  SUMMARIZING TRAFFIC DATA

**AAWDT and AAWET**

For any count collected on a particular traffic segment, AAWDT and AAWET are estimated by multiplying AADT by the weekday and weekend traffic factors developed for the segment’s seasonal factor group or reference site.

**AADT by VC**

A short-term classification count produced by an automatic vehicle classifier is converted to estimates of AADT by VC in three steps:

1. A variant of the above procedure for volume counts is used to produce preliminary estimates of AADT by VC. In the case of a classification count, the traffic ratios (or factors) used are the ones developed for separate groups of vehicle classes, as discussed in Section 5.2.1. No estimates are produced for the unclassified bin or for any error bins.

2. The annual average percentage of vehicles in each class is obtained by dividing the Step 1 estimates of class-specific AADT by VC by the sum of these estimates.

3. The previously derived estimate of total AADT is multiplied by the Step 2 percentages to produce revised estimates of AADT by VC.

If an agency collects partial-day manual classification counts on some traffic segments, the agency also should collect automated counts of total 24-hour traffic at each of the classification sites on the day of the classification count. Each of the manual classification counts is converted to an estimate of daily traffic by VC, and the above procedure is applied to this estimate to produce estimated AADT by VC for the segment. For each segment, the estimate of daily traffic by VC is developed in three steps:

1. Each of the hourly classification counts is converted to an estimate of daily traffic by VC by dividing it by the appropriate TOD traffic ratios for the hour, the VC group, and the TOD factor group.

2. These estimates are then averaged to produce a single estimate of daily traffic by VC.

3. This estimate is scaled so that, when summed over the VCs, the estimate is consistent with the automated count of total 24-hour traffic for the site.

The resulting estimate of daily traffic by VC is then converted to an estimate of AADT by VC using the same procedure as is applied to automated classification counts.
Load Spectra

The estimation of annual load spectra at sites at which only short-term WIM data are available is complex. One procedure for estimating annual load spectra has been implemented in the TrafLoad software, available from NCHRP. It is recommended that short-term WIM data be collected for a minimum of seven consecutive days.

Factoring for Growth

For each traffic segment that is not counted in a given year, AADT is estimated by multiplying the preceding year’s estimate of AADT by an appropriate growth factor. This factor may be one obtained using data from another site on the same road, or one obtained for the growth-factor group or seasonal factor group to which the segment belongs.

Similarly, for each classification-count site that is not counted in a given year, AADT by VC is estimated by multiplying the preceding year’s estimates of AADT by VC by a corresponding set of growth factors (one for each vehicle class). The growth factors may be obtained using data either from another site on the same road or from the appropriate factor group.

Vehicle-Class Estimates for Volume-Count Segments

There are two situations in which an AADT estimate derived from a volume count is used as the basis for estimating AADT by VC. The first is when the count is obtained in the current year on a segment on which a classification count was previously obtained. If the classification count is not more than five years old, after it has been factored for growth, it should be used to distribute the AADT estimate over the vehicle classes. Older classification counts also may be used for this purpose after agency review and a determination that the distribution is still valid for the segment.

The second situation is when the segment is on a road on which a classification count has been obtained in the current year at a site that is close enough to the segment in question to have a vehicle-class distribution that is similar to the distribution on the segment. In this situation, the classification count is used to distribute the AADT estimate over the vehicle classes.

Estimates of AADT by VC obtained in this way are factored for growth for use in subsequent years, as needed, in the same way as estimates developed more directly from a classification count.

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The above procedures produce estimates of AADT by VC for nearly all traffic segments of roads on which there is at least one classification count. For other traffic segments, functional-class averages are used as default percentages of AADT by VC.

Traffic Segments for Which Multiple Counts Are Available

Occasionally there will be more than one short count that can be used as the basis for estimating AADT for a given traffic segment. Extra counts for a segment may result from special requests for a count that is: more current; at a specific location; obtained at a particular time of the year on a particular day of the week; or provides specific information (e.g., a classification count on a segment that normally is only counted for volume).

When this occurs, a decision will be needed as to what use to make of the extra count. Considerations that may enter into this decision are:

- The age of the counts (current-year counts are likely to produce better estimates of AADT than older counts that must be factored for growth);

- The locations that were counted (one location may be believed to provide a better estimate of average AADT on the segment than the other);

- Perceived reliability of the counts or of the AADT estimates that they produce (reliability of a count may be affected by the equipment or procedures used, reliability of AADT estimates is likely to be lower for counts collected on weekends or, in the case of counts on recreational roads, for counts collected in certain seasons); and

- Temporal consistency (if a segment is always counted in the spring, an AADT estimate developed from a count collected in the fall, under some circumstances, may provide a misleading indication of changes in AADT on the segment).

If both counts are used, separate AADT estimates are produced from the two counts and averaged. The average may be a simple average or the estimates may be weighted by the lengths of the counts.

Estimating AADT from a pair of directional counts collected at different times of the year is undesirable and should be avoided.

5.3.4 Using Partial-Year Data from Continuous Monitoring Sites

Consider a continuous monitoring site that is down for part of the year. For such a site, it is likely that the procedures of Section 5.1 can be used to produce estimates of MADT and other monthly statistics (such as MADT by VC) for some months. However, it is not possible to use these procedures to produce estimates of annual statistics, such as AADT.
Instead, counts obtained at such a site are treated as short counts and factored using a variant of the seasonal factoring procedures presented in Section 5.2. For such a site it is recommended that each daily count be annualized by applying the appropriate monthly and DOW ratios or factors. Then a simple average is obtained of the resulting estimates for any annual statistic (AADT, etc.) to produce a single estimate for each of these statistics.

5.4 Estimating Precision of Traffic Statistics

The method for calculating AADT and other statistics in this guide is designed to permit missing days of data without seriously biasing the results. The method equally weights days of the week and months of the year without considering the number of days of data in each value of MADW. This method is felt to produce an estimate of AADT that is less influenced by missing days of data than a simple average of values for all available days of data, or even an average of annualized values. As a result, AADT estimates developed from a complete set of 84 MADW values are considered to be highly precise estimates for which error statistics are not worth calculating.

At the other extreme, short-term counts contain too few days of data to estimate reliable precision estimates. The precision of AADT estimates developed from short-term counts is best estimated empirically. A relatively simple procedure for developing empirical estimates of precision is presented in the first subsection below. The precision estimates produced by this procedure exclude the effects of errors in the short-term vehicle counts, such as those that may result from equipment limitations or inaccurate conversion of axle counts to vehicle counts. Some potential improvements to this procedure are presented in the second subsection. And the third subsection contains additional discussion of some related issues.

5.4.1 A Simple Empirical Procedure

The basic procedure for estimating the precision of AADT estimates derived from short-term counts consists of the following steps which are discussed further below:

1. Use the standard procedure for developing a precise estimate of AADT at each of several continuous monitoring sites that belong to a given factor group and for which a complete set of 84 values of MADW is available;

2. Use data from these sites to obtain a large sample of simulated short counts;

3. Apply monthly and DOW factors to the simulated short counts to produce estimates of AADT;
4. Compare the Step 3 estimates of AADT to the precise estimates of AADT developed in Step 1\(^{13}\) to obtain values for each estimate’s percentage error; and

5. Use the results of Step 4 to obtain error statistics for the AADT estimates.

The sample developed in the second step should be designed to be representative of actual short counts and may be developed using some combination of random sampling or systematic sampling.

As an example, assume that an agency’s practice is to collect 48-h short counts and to initiate these counts on Mondays, Tuesdays, and Wednesdays during 45 wk of the year. Then, the first step is to develop precise estimates of AADT at all the continuous monitoring sites that belong to a selected factor group and for which a complete set of 84 values of MADW are available.

Next, a large sample of simulated short counts is developed for the site. Assume that one of the continuous monitoring sites was in service for the entire year. A simple procedure for obtaining a representative sample of 135 simulated counts for this site is to choose one 48-h period starting in the middle of the day (say at noon) for each of the 135 days during the year when counts at this site would be initiated.

The third step is to apply monthly and DOW ratios or (factors) to these counts to produce 135 estimates of AADT. For the purpose of adjusting counts obtained from a particular continuous counter, the ratios used should be developed using data from all the other continuous counters in the factor group. (The counter used as the source of the counts is excluded to avoid biasing the error estimates downward).

The fourth step is to compare these estimates to the precise estimate of AADT developed in Step 1. The percentage error in each of the Step 3 estimates (developed from a simulated short count) is obtained by subtracting the Step 1 estimate and then dividing by the Step 1 estimate.

Steps 2 through 4 are repeated to obtain similar samples of 48-h counts, AADT estimates, and percentage errors from each of the other continuous counters in the factor group. Since many counters have some periods of downtime, the number of simulated counts obtained from some of the counters is likely to be less than 135. However, since the periods of downtime are likely to be randomly distributed, the resulting sample of several hundred simulated counts and associated errors are considered to be a representative sample of the short counts and associated errors that might be collected at sites belonging to the factor group.

\(^{13}\) As observed in the first paragraph of Section 5.4, the Step 1 values of AADT are not true values of AADT but merely highly precise estimates. However, they are considered to be sufficiently precise to be used as true values in this version of the procedure for estimating empirical precision.
Finally, the resulting set of several hundred percentage errors is summarized to produce the desired error statistics, such as root-mean-square (RMS) error, average percentage error (or bias), etc. These statistics represent empirically derived values of the errors produced when 48-hour counts are collected at short-count sites belonging to the factor group.

5.4.2 Improving the Procedure

The above procedure can be improved by modifying the way in which the sample of simulated short counts is developed to increase the correspondence between the simulated short counts and actual short counts. For example, if actual counts are initiated at various times between 9:00 a.m. and 4:00 p.m., instead of assuming that all simulated counts start at noon, the simulated counts could have randomly chosen start times between 9:00 a.m. and 4:00 p.m. Similarly, if the number of short counts actually started on Wednesdays is lower than the number started on the other days, a random procedure can be used to obtain a proportionate reduction in the number of simulated counts starting on Wednesdays. And if actual count periods range between 48 and 52 h, random procedures can be used to vary the length of the simulated counts. The procedure can also be modified to reflect the effects of equipment limitations and/or inaccurate conversion of axle counts to vehicle counts.

5.4.3 Discussion

If an agency uses both historic traffic ratios and current-year traffic ratios, Steps 3 through 5 should be performed twice, once using historic ratios and once using current-year ratios. The two sets of results can be compared to get an estimate of the differences in the quality of AADT estimates produced by these two types of traffic ratios. Similarly, the effects of using counts that are one or two years old can be evaluated by using Steps 2 and 3 to develop earlier-year estimates of AADT, factoring these estimates for growth, and comparing the results to current AADT values.

The above empirical procedure usually will produce reasonably accurate estimates of the precision of AADT estimates produced by factor groups containing four or more continuous monitoring sites, provided that the short-count sites assigned to this group have been properly assigned. However, if the factor group contains short-count sites that have monthly and DOW patterns that are significantly different than those of the continuous sites belonging to the group, the AADT estimates for these short-count sites are likely to be appreciably less precise than indicated. If there are a significant number of such sites, actual precision for the group as a whole may be lower than indicated.
For factor groups containing only two or three continuous monitoring sites, the above procedure may understate precision (that is, overestimate the errors).\textsuperscript{14}

Also, the procedure cannot be used to estimate the precision of AADT estimates produced by factor groups that contain only a single continuous site or estimates that are developed using factors obtained from a “reference site.” However, some subjective statements can be made about the precision of these estimates. In general, when a short count for a site is factored using data from a reference site on the same road as the site in question, it is likely that the resulting AADT estimate will be more accurate (perhaps, much more accurate) than if traffic ratios (or factors) from an entire group of sites are used. On the other hand, if the site in question is on a recreational road and is either not particularly close to the continuous monitoring site or it is on a different road entirely, relatively poor estimates of AADT are likely.

Finally, empirical estimates of precision indicate that AADT estimates generally are substantially less precise than commonly believed. One study found that, for urban factor groups, confidence of 10 percent precision could be as low as 75 percent; and, for rural factor groups, precision was even lower.\textsuperscript{15} Although such modest precision levels may be adequate for some purposes, they probably are inadequate when major public investments or serious safety issues are at stake. Some options for increasing the precision of estimates of AADT or AADT by VC are collecting several short counts throughout the year or extending the counting period to seven days.

\textbf{5.5 Estimating Section-Specific HPMS Traffic Statistics}

HPMS requires that several traffic statistics be reported for HPMS universe and sample sections.\textsuperscript{16} This section outlines procedures for estimating these statistics. The first subsection addresses an issue relating to some of these statistics. The second subsection presents a concept and some related methodology relating to some of the statistics. And the third subsection presents a summary of recommended sources for the statistics.

\textsuperscript{14}To understand this statement, consider the example of a factor group containing two continuous monitoring sites—one with a somewhat higher than average percentage of traffic occurring on weekends, and one with a somewhat lower than average percentage. When data from both sites are used, the variations in the percentage of traffic on weekends at the two sites tend to cancel each other out, and any resulting bias in the factored estimates of AADT developed by applying these factors to short counts will be small. However, in order for the above procedure to avoid producing downwardly biased estimates of precision, simulated short counts obtained from the first site are adjusted using only ratios (or factors) obtained using only data from the second site. The resulting AADT estimates derived from these simulated counts will be downwardly biased. Similarly, the AADT estimates derived from simulated counts obtained from the second site will be upwardly biased. Overall, the absolute percentage error exhibited by the simulated counts is likely to be greater, on average, than would be exhibited by AADT estimates developed by adjusting actual short counts by applying ratios obtained using data from both continuous count sites.


\textsuperscript{16}FHWA. \textit{Highway Performance Monitoring System Field Manual}. December 2000, Chapter IV and Appendix C.
5.5.1 The Design-Hour

For HPMS reporting, the *design-hour* at continuous monitoring sites currently is defined to be the hour of the year with the 30th highest value of total traffic volume. For all sample sections, HPMS requires the ratio of this traffic volume to AADT (known as the *K-factor*) and the percentage of traffic during this hour that is in the peak direction (the *directional factor*). This information is used in analyses of investment requirements to estimate capacity, congestion and delay, and in other FHWA analyses. For urban areas, these analyses generally assume that the design-hour occurs during the weekday a.m. or p.m. peak-period. Although this usually is true of the 30th highest hour, it is not always true. Therefore, as an aid to the FHWA investment analyses, it is recommended that, for urban sections for which traffic data is obtained directly from a continuous monitoring site, the design-hour be set to the 30th highest hour if that hour occurs during the weekday peak, and otherwise to the next highest hour that does occur during the weekday peak. This recommendation applies only for HPMS reporting, and not for the purposes of highway design.

For other sample sections corresponding to a traffic segment for which a 48-h count is available, it is recommended that the design-hour be set to the peak-hour of the count. Statistics obtained for this hour are likely to provide a better reflection of the section’s design-hour conditions (particularly the directional factor) than statistics developed from a group of continuous monitoring sites on other roads.

5.5.2 Peak-Hour Vehicle-Class Percentages

*Peak-hour vehicle-class percentages* are required for HPMS sample sections. These percentages are developed from both short-term classification counts and from continuous classification counts. In the case of a short-term count, the first step of this process is to identify, for each 24-hour period covered by the count, the hour of the highest total traffic volume. The classification counts for those hours are then averaged to produce a set of peak-hour classification counts. This set of counts is factored for growth in each year in the same way as the corresponding estimates of AADT by VC. After factoring for growth, as needed, each set of peak-hour classification counts is converted to peak-hour vehicle-class percentages by dividing each count by the sum of the counts for all vehicle classes (excluding the unclassified and error bins).

In the case of continuous classification counts, it is recommended that peak-hour vehicle-class percentages be developed by applying the same process to the classification count obtained for the design-hour.

Average values of the peak-hour vehicle-class percentages also may be obtained, as needed, by averaging the percentages obtained for one or more groups of classification sites belonging to a single functional system.
5.5.3 Values for Universe and Sample Section Data Items

The following paragraphs present procedures for obtaining values for the various traffic-related HPMS data items for universe and sample sections for a given reporting year (normally, the immediately past calendar year).

By design, each sample section corresponds to one traffic count segment; though, as a result of jurisdictional and urban/rural boundaries, there may be multiple sample sections corresponding to the same traffic segment. Similarly, each universe section corresponds to at most one traffic count segment, though there may be multiple universe sections corresponding to the same traffic segment.

No procedure is presented for developing AADT forecasts (for Item 97). For universe sections, the only traffic-related HPMS data item used is Item 33.

Item 33—AADT—AADT is the count-based AADT estimate developed for the corresponding traffic segment using the procedures of Sections 5.1 through 5.3, factored for growth, as appropriate. If no AADT estimate exists, code zero.

Item 81—Percent Peak Single-Unit Trucks.

Item 82—Percent Average Single-Unit Trucks.

Item 83—Percent Peak Combination Trucks.

Item 84—Percent Average Combination Trucks.

For purposes of HPMS reporting, estimates of the annual average percentages of personal-use vehicles, single-unit trucks and buses, and combination trucks are produced for sample sections in one of two ways. In both cases, estimates of reporting-year AADT by VC are developed for the corresponding traffic segment using the procedures of Sections 5.1 through 5.3 and converted to percentages. Then, if classification is by FHWA vehicle class, sums of these percentages are obtained for Classes 1 through 3, 4 through 7, and 8 through 13. If classification is by length, the percentages are multiplied by the length-class factors for the appropriate TWRG and summed to produce the required percentages. Values produced by this process are used for Items 82 and 84 (Percent Average Single-Unit Trucks and Percent Average Combination Trucks).

Estimates of peak-hour percentages of personal-use vehicles, single-unit trucks and buses, and combination trucks are produced for sample sections using a similar process. For each sample section, the source of classification data used in the above derivation of average truck percentages is identified. This source may be a single short-term or continuous classification count, or it may be a functional-class average. Corresponding to each of these sources is a set of peak-hour vehicle-class percentages that was developed using the procedure of the preceding subsection. For each sample section, the procedure of the pre-
ceeding paragraph is applied to the corresponding set of peak-hour VC percentages to convert it to a set of peak-hour percentages of personal-use vehicles, single-unit trucks and buses, and combination trucks. The resulting values are then used for Items 81 and 83 (Percent Peak Single-Unit Trucks and Percent Peak Combination Trucks). Note that these items represent values for the peak traffic hour, and not for the hour of peak truck traffic. In urban areas, Items 81 and 83 are almost always smaller than Items 82 and 84, respectively.

**Item 85—K-Factor**—The K-factor for any sample section is obtained using data for the corresponding traffic segment by dividing traffic volume for the design hour (as defined above) by AADT.

**Item 86—Directional Factor**—The directional factor for any sample section is obtained using data for the corresponding traffic segment by dividing peak-direction traffic volume for the design hour (as defined above) by total traffic volume for that hour.

### 5.6 System-Level Summary Data

*Daily vehicle-miles traveled* (daily VMT or DVMT) on any traffic segment is estimated by multiplying estimated AADT on the segment by the segment’s length. For any year, estimated DVMT on any traffic segment should be derived from the best available estimate of AADT for that segment for that year. DVMT on any set of traffic segments is estimated as the sum of the DVMT on each of the segments. In particular, DVMT for any road or system of roads that has been divided completely into a set of nonoverlapping traffic segments is estimated by summing the DVMT estimates for the individual segments. This process is used to estimate DVMT for the entire system of roads in any jurisdiction, for roads belonging to a particular functional system, or for any other road system or subsystem of interest, such as the State Highway System.

*Annual VMT* (AVMT), for any traffic segment, road, or system of roads, is estimated by multiplying DVMT by 365.

Estimates of daily and annual VMT by VC, for any traffic segment, road, or system of roads, are developed similarly using estimates of AADT by VC.

Average AADT for any road or portion of a road that contains more than one traffic segment is estimated by dividing DVMT for the road (or portion of the road) by its length.

The quality of a VMT estimate for any road or system of roads is affected by the quality of the AADT estimates for the individual segments. If AADT is constant on an entire traffic segment, the resulting VMT estimate for the segment has the same degree of precision as the corresponding AADT estimate. Precision of AADT estimates was discussed in Section 5.4. However, AADT usually varies over the length of most traffic segments, particularly long segments, introducing additional imprecision in the resulting estimates of VMT, both for individual segments and for entire systems of roads. This source
of imprecision can be limited by adhering to the Traffic Monitoring Guide (TMG) recommendation, repeated in Chapter 2, that traffic segments be designed so that traffic volume does not vary by more than plus/minus 10 percent over the length of the segment. For a long segment, imprecision also can be limited by selecting a monitoring site that is believed to be at a location (frequently near the middle of the segment) at which AADT is close to the average for the segment.

5.7 Traffic Statistics for the Mechanistic-Empirical Pavement Design Guide (MEPDG)

The Mechanistic/Empirical Pavement Design Guide has placed new emphasis on accurate vehicle classification and weight data for pavement design. Traffic data required for the use of the MEPDG procedures consists of:

- AADT by VC by direction for up to 13 vehicle classes;
- Monthly Traffic Distribution Factors by VC;
- Axle-Load Distribution Factors;
- Linear or Exponential Growth Rates;
- Directional Distribution Factors;
- Axle Groups per Vehicle; and
- Hourly Distribution Factors.

This traffic data is produced by the TrafLoad software developed under NCHRP Project 1-39. The principal inputs to TrafLoad are error-checked, but otherwise unprocessed, WIM data and classification counts from all WIM sites and continuous classification sites in the state. Also, for pavement designs for road segments that do not contain a continuous classifier, a 48-h (or 7-d) classification count is needed. For the latter road segments, provision of additional classification counts spaced out over the course of a year will improve the quality of the resulting pavement designs.

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20 In the absence of site-specific classification counts, TrafLoad and the MEPDG software will accept an estimate of annual average daily truck traffic on the road and a subjective categorization of characteristics of the truck traffic. However, if this is the only site-specific information provided to the software, a relatively low quality ”Level 3B” pavement design will result.
TrafLoad also requires forecast growth rates for single-unit trucks and for combination trucks, and definitions of:

- Seasonal factor groups;
- DOW factor groups;
- TOD factor groups;
- Seasonal LS factor groups;
- TWRG; and
- Vehicle-class groups.

Most of these groups are used in the data summarization process and have been previously discussed in Sections 2.3.1 and 5.2. The first two groups are the factor groups used for month and DOW factoring discussed in Section 2.3.1; TrafLoad allows (but does not require) the use of separate groups for monthly and DOW factoring.

The only type of group used by TrafLoad that has not been discussed previously in Chapters 2 or 5 is the seasonal LS factor group. These are groups of WIM sites that are believed to have relatively similar seasonal patterns of load spectra for the most significant vehicle classes (generally Class 9, sometimes Class 5). Such a group might consist of roads on which vehicles are heavier during harvest season than during other times of the year. TrafLoad uses information about these seasonal patterns obtained from sites for which 12 mo of data are available to infer seasonal variations in the load spectra of WIM sites in the same group for which less than 12 mo of data are available.

### 5.8 References


CHAPTER 5  SUMMARIZING TRAFFIC DATA


CHAPTER 6
Reporting and Managing Traffic Data

6.1 Introduction

The previous chapters were directed toward the measurement, quality control (QC), and summarization of traffic data to ensure that valid statistics can be calculated. This chapter covers an equally important topic, the publication and distribution of those traffic statistics.

In most agencies, traffic data collection is not a top priority in enterprise funding allocations. The result can be that traffic data collection is underfunded, which can be detrimental to both the quantity and quality of available traffic statistics.

It also is the case that, in many agencies, traffic statistics are not very visible to other departmental users, and to the ranks of management that are making funding decisions.

The lesson is that those collecting and analyzing traffic data and those managing traffic data collection programs should actively promote their products. Better “sales” of those traffic products to the rest of the agency would result in better decisions, when roadway use is a factor in those decisions. This promotional effort could involve several processes:

- Collecting and analyzing quality traffic data;
- Preparing useful reports, both “standard” and ad hoc;
- Creating a mechanism for effectively publishing those reports to departmental and outside consumers; and
- Publicizing products to the departmental and outside consumers.

Even if a traffic monitoring program is underfunded, and it does not have the quantity and quality of traffic data desired, these activities can enhance the program. If your consumers are not satisfied with the quality or quantity of data, they may go their own way, using numbers from other processes. Part of the sales effort requires convincing the consumers that only monitored data produces valid statistics and
that, if the quantity and quality of monitored data are not adequate, more resources should be allocated to the traffic monitoring process.

This chapter is concerned with the procedures, processes, and content that will allow production of effective traffic information and reports to disseminate to consumers. The presentation is based on several underlying policy/philosophical assumptions which are covered first. The technical section begins with a discussion of effective databases and their design.

This chapter is not intended to be a primer for information technology (IT). Its purpose is to make the traffic professional aware of the various technical options that exist. This chapter includes a discussion of ways to disseminate reports and data to the consumer community. Next is the content discussion—the design and content of effective traffic data reports. Finally, the data retention issue is addressed, i.e., how long raw data and various levels of data aggregation should be retained.

### 6.2 Basis

In most cases, traffic data are collected using taxpayer revenues. This usually results in the policy that the public “owns” the resulting traffic data in some sense of the word. The main purpose of this chapter is to present ways in which traffic data can be made accessible to both in-house consumers and to the public at large.

In an ideal world, reporting and disseminating traffic data would be a simple process. One would simply formulate a question, present it to the reporting software, and obtain the expected result. In reality, the situation does not approach this ideal because reporting is an inherently complex process.

The complexity derives from the fact that traffic databases typically contain numerous statistics calculated at many levels for numerous sites on the roadway system. Queries into such a complex database will produce erroneous results unless those queries are absolutely correct. If a query leaves out a single condition for selecting the data, it might result in the return of numerous values where a single value is expected. When placed in a report, this could result in values many times larger than the actual value for that particular query. Obviously, if such erroneous results are disseminated, serious problems could result. These could be as minor as a political embarrassment or as serious as a misuse of public funds.

So, while the public does in fact have rights to access traffic data, it is the responsibility of the collecting agency to minimize the incorrect use of those data. This can be accomplished through the careful formulation of policies that, on the one hand, maximize public access to data while, on the other hand, minimize the opportunities for misusing those data. Following are some suggestions for policies that might achieve this objective. Some of these are expanded in the following discussions:

- Provide public access to official reports generated by the collecting agency as portable document format (PDF) or hypertext mark-up language (HTML) files on a web site.
• Do not provide direct public access to the underlying, detailed traffic database.

• If public access to the database is provided, restrict access to carefully constructed views on the under-
  lying database.

• Access to underlying detailed data or raw data files should be mediated by staff within the collecting
  agency. This could be accomplished through an on-line request mechanism that is part of the overall
  data access web site.

• Any public access to traffic should be restricted to those with a legitimate need for such data, and
  to those who understand how to use the data. The mediator of requests needs to be a "customer-fo-
  cused" individual who can work with potential consumers to determine their actual needs. This is
  many times not the same as what the consumers are requesting.

None of these preclude setting up more automated procedures for sharing data with other agencies,
research functions, or other qualified customers. Those procedures might allow access by other agencies
even to underlying detailed data or raw data files with no intervention by collecting agency staff.

6.3 Database Considerations

The necessary condition for effectively publishing and distributing traffic statistics is the ability to mangle
data and statistics. This process is greatly facilitated by storing data and statistics in a repository man-
aged by a database management system.

It is certainly possible to manage data using a flat-file system, but the processes required to do this
consume significant resources. The processes of simply storing the files in a structure that allows them to
be found and maintaining the relationships among the various files become very difficult as the number
and size of the files increase. One of the basic problems in traffic data management is that the amount of
data becomes huge, so managing these data can consume a large number of resources without an effec-
tive management system.

Modern database systems provide the tools needed to manage the volumes of data collected by a traffic
data collection program. This section will discuss some of the requirements for effectively using these
systems. It leads the discussion of reporting and dissemination because it is the foundation for the database
reporting and access tools.

6.3.1 Database Tools

The sheer amount of traffic data and the need for effective dissemination of traffic statistics make it
nearly mandatory that all such measures and statistics be stored in a modern, "industrial strength" data-
base. This section will present some of the tools available. It will not cover object databases.
Relational Database Management Systems

There are many excellent relational database management systems available on the market. Each has its strengths and weaknesses and can be used to develop an effective traffic data management system. This section will present the advantages of using such a system and no particular one will be endorsed.

Effective Data Management

Relational databases exist for the purpose of managing large volumes of data. This includes many aspects, such as disk storage management, rapid data access through indexing and efficient retrieval algorithms, management of data integrity through constraints and transaction processing mechanisms, backup procedures, and many others.

Powerful Security Mechanisms

As a traffic data section makes traffic data more accessible to the public, the chances of improper access and even modification of data increases. All of the leading database management systems have good built-in security mechanisms. It is recommended that either these mechanisms or the security mechanisms built in to your operating system be used to control access to traffic data.

Useful Tools for Accessing the Data

Even though there are standards for relational databases, notably the structured query language (SQL) standards, individual vendors have found it in their best business interests to develop custom features that do not follow these standards. This has led to very vendor-specific access tools that would work only with a single database.

Microsoft addressed this problem over a decade ago by developing access software that would work with any database that had the proper drivers. Their Open Database Connectivity (ODBC) allowed the development of applications that would work against all the leading databases, at a cost of varying degrees of performance degradation. Most general reporting and analysis tools support these, or later, procedures, so that they can access a variety of databases. These tools alone would justify the effort required to store data in a modern database system.

Geographic Information Systems

Geographic information systems (GIS) provide powerful tools for the geographic analysis and display of information. Most current systems use a relational database platform for the actual storage of geographic and tabular data. GIS offers an added dimension to the analytical process, allowing spatial relationships to be much more easily evaluated than with a relational database alone.
Traffic data collection is usually point-based, and most of the problems with analyzing traffic data are nonspatial in nature, but some aspects are definitely facilitated through the use of GIS. Examples include the development of flow maps and the analysis of traffic on road networks. Also, count program management can be improved if mapping capabilities are used to reduce count placement errors.

### 6.3.2 Data Models for Traffic Sites and Traffic Data

The effectiveness of processing and accessing data and statistics in a traffic database is a function of the underlying data model for the traffic entities. If the data model is correct and optimally normalized, processing and access can be performed more effectively and correctly. This section will not present data models for traffic data, as these are discussed elsewhere. Specifically, the American Society for Materials Testing Standards (ASTM) is preparing a standard for traffic data archives that presents an effective data access model for traffic data, including data from probe vehicles.

### 6.3.3 Processing Versus Decision Support Models

Information technologists recognize that data models must be designed and optimized to meet the requirements of the applications using those data models. A broad distinction can be made between two major classes of applications: transaction processing versus decision support.

Transaction processing is characterized by high rates of data input. Processing raw traffic files is a special case of transaction processing. These models usually require a large variety of context tables and must update tables and indices at a high rate. It would not be uncommon for a traffic data processing system to contain 100 or more tables.

Decision support databases are very different from transaction processing databases in purpose and design. These are data warehouses and data marts designed to supply analytical data and statistics to a wide variety of users. Sometimes these data and statistics are organized into hypercube models for on-line analytical processing (OLAP) applications. The most common data model for these applications is the star model, in which the data and statistics repository is in third-normal form, meaning that virtually all possible redundancies in data storage have been eliminated. These tables have indices to a number of tables that define the various dimensions of the data and statistics, and are called dimension tables. Where a transaction processing data model might contain 100 tables, the star model usually contains a dozen or so.

The ASTM model mentioned above is a decision-support model. It might not be appropriate for actually processing traffic data. The processing model will probably need to be more disaggregated and will contain many more tables.
6.3.4 Data Models for Roadway Networks and Traffic Segments

Traffic data are usually collected at points along the roadway. The data model for traffic sites will usually reflect this fact. It will contain point references to a roadway system. Many of the consuming applications, for example, those that require estimates of vehicle distance traveled, will require traffic estimates for segments of the road network.

The usual process for extrapolating traffic sites to road segments is based on the definition of road segments that have consistent traffic across their length. These traffic segments can then be assigned traffic from the data collection point or points contained in their length.

There are commercial products that provide data models for roadway networks and traffic segments, however, most agencies develop their own roadway databases. Regardless of the source, the road network database can be an effective place to publish traffic statistics for general consumption. Most inquiries are simple requests for traffic volumes at various places on the road network. Having traffic statistics associated with the roadway database provides an effective way to respond to these queries, either as an in-house function or by providing public access to the roadway database.

6.3.5 Should Summaries Be Stored?

In theory, any statistic required could be calculated “on the fly” from detailed data in the database. The option is to calculate statistics in advance and to store them in the database. In earlier times, when storage was expensive and human time was relatively inexpensive, only base data would have been stored. Calculations would be performed when needed from the base data. This approach was economical in terms of storage, but the operator had to wait on the system to calculate statistics. Even more problematic, the answers to a given calculation could vary over time, based on changes in the underlying data or disparities in the database queries.

Today, storage is extremely inexpensive and human-time is more expensive. This tilts the balance sharply toward calculating statistics in advance, so they can be more quickly extracted from the database. The downside of this approach is that all statistics must have status information associated with them. If the base data change for any number of reasons, the statistics must be recalculated. When that happens, the original statistic is “expired,” and the new statistic is made current.

In addition to time savings, another advantage of calculating statistics in advance is that the system administrator has a complete audit trail. When statistics are calculated when needed, there is a significant chance that the user will select different data from time to time, resulting in variations in the values of statistics. Calculating the statistics in advance allows an agency to maintain and publish “official” statistics that are based on quality-checked data and that have been subjected to quality checks at each level of aggregation.
6.4 Disseminating Traffic Information

The mechanisms available for the dissemination of reports have completely changed since the original guidelines were prepared. Particularly, the Internet has revolutionized the dissemination of information. Much of the following discussion assumes that the Web will be used as the primary mechanism for publishing traffic reports, statistics, and data. It is, at this point, the most powerful mechanism for this purpose.

Using the Web raises many security issues. These are not addressed specifically in these guidelines, but it is assumed that a traffic agency’s IT staff will set up normal security barriers to prevent unauthorized use of the site.

6.4.1 Using Web Portals for Distributing Reports

The simplest way to get traffic data onto the Web is to generate the reports and to “print” them as PDF files. These files can then be placed on a Web site for access by the public. In this application, the web site will create some kind of menu or index that permits these reports to be easily accessed. This could involve a query form that allows the user to select parameters such as the specific report to be acquired, the traffic data collection site, and the date.

Another option is to allow the user to select these parameters and have the system create the reports “on the fly.” This allows more flexibility in report creation, but requires that the underlying report programs allow this kind of parameterization. It also raises the possibility that the data will be misinterpreted or misused. An example would be a monthly report that spanned several months. What do the statistics in such a report mean? There will be much more work to allow this kind of parameterization to ensure that the selected reports produce unambiguous results. It also will place more requirements on the metadata provided with such reports. Metadata requirements are discussed below.

6.4.2 Using Web Tools for Ad Hoc Reporting

Many vendors supply web-based reporting tools that allow their clients to generate reports over the Internet. These guidelines do not recommend that such products be made available to the general public, or even to internal users. Report preparation is subject to errors that are not immediately obvious to the untrained user. This theme is repeated often in the following discussion.

6.5 Database Procedures

Database implementation was discussed earlier in this chapter. This section describes specific approaches to making the data available.
6.5.1 Defining Views

All modern database packages support views. A view is a SQL query that extracts commonly used subsets of the entire database for easier access. An example might be a view that returns annual average daily traffic (AADT) estimates for both short-term and permanent locations for all traffic years. To the end user, and to the database query language, a view is equivalent to a table. The reporting tools discussed below can access both views and tables in exactly the same way.

6.5.2 Metadata Requirements

If a database of traffic reports or traffic statistics is being prepared for in-house and public access, one needs to supply metadata that defines the contents and structure of the reports and statistics. Those metadata will be more useful if they follow standard practices.

Determining the proper format and content for metadata can be confusing. There are three standards that bear on this topic. Data dictionaries prepared for Intelligent Transportation Systems (ITS) standards must follow ISO 14817 Transport information and control systems—Requirements for an ITS Central Data Registry and ITS/TICS Data Dictionaries. All other metadata should use ASTM E2468-05 Standard Practice for Metadata to Support Archived Data Management Systems. Finally, the standard for relational databases is INCITS/ISO/IEC 9075 Information Technology—Database Languages—SQL 2003. As mentioned above, ASTM is preparing a more specific standard that applies to traffic data archives for ITS and conventional traffic monitoring data.

The current terminology for a database of reports and statistics is that they constitute a data archive and the term “archive” is used ambiguously. Sometimes it refers to data that have been moved off-line. Other times, it is used to mean backups. The use intended in the standards and these guidelines is that an archive is any repository of data collected in the past. This can, and usually does, refer to data stored in an on-line database for access by various consumers.

The Archived Data User Service of the ITS architecture defines a data repository in this way. ASTM E2259-03A Standard Guide for Archiving and Retrieving ITS-Generated Data provides excellent guidelines for developing an archive of either ITS-generated data or of data from conventional traffic monitoring programs. The most useful standard for metadata for such an archive is the ASTM E2468-05 standard. It is recommended as the one traffic data producers should follow in preparing metadata for databases. If data items are submitted for inclusion into the Traffic Management Data Dictionary (TMDD) or other ITS data dictionary standards, the submittal must follow the ISO 14817 standard.

Since the standards are quite lengthy and comprehensive, these guidelines will make some specific recommendations to make their metadata preparation and publication easier. First, as mentioned above, metadata should be restricted to the ASTM E2468-05 standard. Within that standard, there are many levels of metadata in a hierarchical structure. These support the various kinds of metadata that are needed to define an archive.
There are two areas that the ASTM standard does not address. First, the standard does not clearly identify specific metadata requirements for the various levels of measurement and summarization in a traffic data program. The second major problem is that the standard intentionally does not provide information about publishing or otherwise making the metadata available to the public. The following sections describe the various levels of metadata one should use to define a traffic data archive. These sections also make some suggestions about publishing the metadata.

**Archive-Level Metadata Requirements**

Archive-level metadata describe a traffic database as a whole. The standard requires that two sections be completed for the entire archive. These are Section 1.0, “Identification Information” and Section 7.0, “Metadata Reference Information.” Since the standard was patterned after the Federal Geographic Data Committee’s metadata standard, many of the required items are spatial information about the database. If one does not have this information, available information should be completed. As a general rule for any metadata requirements, lacking some required information should not keep one from providing the metadata that is available.

Section 5.0, “Entity and Attribute Information,” should be considered required for any database. This section defines the actual structure of the underlying database. However, this should be considered technical documentation that would not be made available to the public at large. This section should be used to document the structure of the views that one does not wish to make available to general database users. This section meets the requirements for “Archive Structure Metadata” required in ASTM E2259-03A.

Section 2.0, “Data Quality Information” can be used at the archive level to provide any general data quality information that applies to the archive as a whole. Data quality information also needs to be provided at more detailed levels, as discussed below.

Archive-level metadata should include “Processing Documentation Metadata,” also required in ASTM E2259-03A. This section should include a description of QC, processing, and summarization procedures. It should include the definitions of all statistics computed by the system. These definitions could appear in a glossary form, along with other definitions for terms used in the documentation.

The archive-level metadata also should describe the traffic monitoring program as a whole. Such information and number and types of permanent count stations, kinds of sensors and traffic monitoring devices used, and number and types of short-term counts should be described here. This section also should describe QC and processing procedures applied to all incoming traffic data. These can be documented in Section 1.0, “Identification Information.”


**Report Metadata**

There are two levels of report metadata. The first level describes the contents of any instance of a given report. Those metadata would define each of the fields that exist in the report as well as any computation procedures that are used exclusively within this report. Most computation procedures, such as AADT calculation, would be described in the archive-level metadata.

If a report has significant QC issues associated with some or all of its values, these should be indicated. This could take the form of footnotes and/or links to the database entities that store the QC information.

**Detailed Metadata**

Technically, each data point and statistic in the system has associated metadata. Usually, this consists of QC information about the data or statistic. Obviously, with millions of values stored in most traffic monitoring databases, reporting this metadata would be extremely cumbersome.

The following suggestions should, in most cases, provide the needed metadata without unduly burdening data access:

- Indicate QC issues only for items that failed one or more checks, rather than for all items;
- Provide views that extract metadata for failed items. Views can extract either summarized metadata or a list of error messages associated with the data or statistic; and
- For items presented in a web page, provide links that would provide either summarized or detailed error information.

**Distribution of Metadata**

The goal in distributing or publishing metadata is to make it as easily accessible as possible. This can be achieved by integrating the metadata with the reports and data in the system. Web sites provide an excellent mechanism for publishing both reports and metadata.

The metadata format defined in ASTM E2468-05 is hierarchical. Web languages like HTML and XML fully support such hierarchical structures. Since the reports or other extracted information also will be produced in these formats, excellent integration of data and metadata can be achieved. The following suggestions will facilitate this integration:

- The report and data access Web site should contain a top-level page that provides a menu (in the form of links) of all report and data/statistics query options available;
• One or more of these links should point to the archive-level metadata;

• The archive-level metadata page should provide a “Table of Contents,” also in the form of links, that points the user to more specific parts of the archive-level metadata;

• Each of these lower-level pages also may contain links to more detailed components, if the particular component is lengthy;

• The top-level reports and data/statistics query pages also will contain links to archive-level metadata;

• When a particular report is selected, the parameter entry form for that report (which will allow things like site and date selection) will contain a link to the archive-level metadata for that report; and

• After a report or data query is executed, the result page(s) will contain a link to any detailed-level metadata.

6.5.3 Reporting Tools

There are a variety of tools that can access databases and format the data into reports or perform additional analyses. Before acquiring one of these products, one should make sure that it has the query tools needed to access one’s particular database. Unless stated otherwise, access to these tools would be restricted to traffic monitoring staff and research or other “trusted” users. As discussed above, providing data and/or statistics to the general public needs to be carefully controlled to ensure valid use of the information.

Office Products (Spreadsheets, Word Processors, Database Tools)

The day-to-day work of most agencies usually requires responding to internal and external requests for traffic information. Office products, particularly word processors and spreadsheets, are a convenient way to perform this work.

The most ubiquitous of these products is the Microsoft Office family. These products can directly access databases using Microsoft Query. The most common procedure is to use this tool to extract a subset of data into an Excel workbook. One note of caution regarding Microsoft Query: a “custom” installation must be done and Microsoft Query specifically selected, or it will not be installed (at least through Office 2003). The default installation will not install Query.

Most other office products also will have these data query capabilities, usually using ODBC and successor products. These will provide access to all of the tables and views visible to the particular user, including underlying system data tables/views. It is suggested that the database administrator set up roles that restrict access to only the tables and views in that role’s domain. Users will then be assigned to the appropriate role(s). Otherwise, the users will be faced with a large set of tables, many with arcane
names, and will have difficulty finding their particular needle in the haystack. Also, if unrestricted access is provided, serious security issues arise. A user with inappropriate read/write access to the database can completely destroy the database.

These tools will usually have graphics capabilities to provide effective data displays. Some, like Microsoft Access, will have a built-in reporting tool to allow the preparation of formatted reports with headings, summaries, and various other capabilities. Figure 6-1 is an example of an Excel plot. It shows the annual average hourly traffic as a percent for weekdays and weekends for an urban site.

Figure 6-1. Hourly Traffic by Direction.

Specialized Reporting Packages

Some products are designed specifically for report preparation from an external database. These tools usually have both powerful report formatting capabilities and data manipulation tools. They allow custom functions, subreports, charting, and other capabilities. These tools also will allow the report format to be saved and used again for periodic reporting capabilities.

These products are universally easier to use than they are to use correctly. They are subject to many hidden data query issues that can easily produce erroneous results. As discussed above, these are not problems with the reporting software, but are a direct result of the complexity of the underlying database domain.
High-Level Reporting Products

Higher-level reporting tools put a layer of abstraction between the user and the database. This layer typically defines business entities or objects that can be derived from the underlying database. Reports are generated from the business objects rather than from the underlying database entities.

These packages will always have some mechanism for making the underlying database structure less visible and more accessible to the end user. A generic name for this capability is the “end-user layer.” Another approach is to define “business objects” on the underlying database entities.

In any case, the mechanism used to accomplish this simplification will be database views (discussed above). The idea is to make the database appear more like the entities that are familiar to the software users.

None of these packages, though, can eliminate the complexity problem discussed above. Even with a well-defined user layer, the processes of selecting and using these entities are subject to the same errors inherent in using the underlying database. It is very easy to produce incorrect results using even the most sophisticated reporting software.

Analysis Tools

Most analytical tools, such as SAS, SPSS, and S-Plus, have access tools that permit data to be extracted from a database and analyzed further. A common example is extracting permanent counter data and performing cluster analysis for determining factor groups.

These tools should be encouraged for use within the traffic data collection and research functions. They permit the “traditional” analyses, such as the cluster analysis mentioned above, but they also provide a vast array of tools for innovative analyses.

6.6 Traffic Data Reports

After traffic data are collected, edited, and summarized, they are reported. This section addresses traffic data reports. It emphasizes the importance of implementing standard reports, which serve specific traffic data uses. The section begins with the uses and recommended procedures for traffic reports, covers the importance of implementing Truth-in-Data in reports, and concludes with recommended report formats.
6.6.1 Uses of Traffic Reports

Traffic reports are used throughout the transportation profession. Table 6-1 lists some basic traffic information reported by state agencies. These types of traffic reports may be either records or summaries of vehicle volume, classification, and weight measurements.

The way in which traffic data are reported should be responsive to user needs. Traffic reports are used in diverse ways. Twelve of the most common traffic data reports are shown in Table 6-2. Forty-two different users are identified for these 12 reports.

Given the diversity of report use, guidelines are suggested for enhancing traffic reports. The emphasis of the recommended practice is being responsive to data uses and users. The recommendations concern dialogue between report producers and users, traffic report sensitivity analysis, design of system-level traffic reports, and graphic presentation.

Table 6-1. Categories of Traffic Information

<table>
<thead>
<tr>
<th>Type or Statistic</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Volume</td>
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<tr>
<td>Annual Average Daily Traffic</td>
<td>AADT</td>
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<tr>
<td>Design Hour Volume</td>
<td>DHV</td>
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<td>Peak Hour Traffic Percentage</td>
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<td>Directional Split</td>
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<tr>
<td>Peak-Period Volume</td>
<td>Peak-Period</td>
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<tr>
<td>Diurnal Distribution</td>
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<tr>
<td>Turning Movements</td>
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<tr>
<td>Vehicle Miles of Travel</td>
<td>VMT</td>
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<tr>
<td>Vehicle Classifications</td>
<td></td>
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<tr>
<td>Heavy Commercial Annual Average Daily Traffic</td>
<td>HCAADT</td>
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<tr>
<td>Diurnal Distribution</td>
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<tr>
<td>Percentage of Trucks in Peak</td>
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<td>Percentage by Vehicle Class</td>
<td>VC%</td>
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<td>Truck Weights</td>
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<td>Gross Vehicle Weights</td>
<td>GVW</td>
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<tr>
<td>Equivalent Single-Axle Loads</td>
<td>ESAL</td>
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<tr>
<td>Diurnal Distribution</td>
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<td>Load Spectra</td>
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<td>Uses</td>
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<td>1  Project-Level Traffic Forecast</td>
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<td>2  Highway Geometric Design</td>
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<tr>
<td>3  Highway Pavement Design</td>
<td>3</td>
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<tr>
<td>4  Project-Level Bridge Design</td>
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<tr>
<td>5  Signal Warrants</td>
<td>5</td>
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<td>6  Intersection Design</td>
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<td>7  Vehicle Weight Enforcement</td>
<td>7</td>
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<td>8  System-Level Traffic Forecast</td>
<td>8</td>
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<tr>
<td>9  System-Level Bridge Design</td>
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<tr>
<td>10 Long-Range Transportation Planning</td>
<td>10</td>
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<tr>
<td>11 Capacity Needs Analysis</td>
<td>11</td>
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<tr>
<td>12 Highway Performance Monitoring System</td>
<td>12</td>
</tr>
<tr>
<td>13 Pavement Management System</td>
<td>13</td>
</tr>
<tr>
<td>14 Model Calibration and Validation</td>
<td>14</td>
</tr>
<tr>
<td>15 Survey Control</td>
<td>15</td>
</tr>
<tr>
<td>16 Freight Analysis Movement</td>
<td>16</td>
</tr>
<tr>
<td>17 VMT Determination</td>
<td>17</td>
</tr>
<tr>
<td>18 Flow Maps</td>
<td>18</td>
</tr>
<tr>
<td>19 Priority Array</td>
<td>19</td>
</tr>
<tr>
<td>20 Project Level Investment Analysis</td>
<td>20</td>
</tr>
<tr>
<td>21 Maintenance Programming</td>
<td>21</td>
</tr>
</tbody>
</table>

(Table continued on next page.)
Table 6-2. Users’ Traffic Data Needs (continued)

<table>
<thead>
<tr>
<th>Uses</th>
<th>Average</th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22 Maintenance Scheduling</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>23 Accident Analysis</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>24 Safety Studies</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>25 Air Quality</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>26 Water Quality</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>27 Noise Quality</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>28 Economic Impact of Development</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>29 Energy Consumption</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>30 Economic Studies and Analysis</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>31 Revenue</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>32 State Patrol</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>33 Traffic Safety Commission</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>34 Commerce and Economic Development</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>35 AAA</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>36 Motel Chains</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>37 Service Station Chains</td>
<td>37</td>
<td></td>
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<td>38 Chamber of Commerce</td>
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</tr>
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<td>39 Outdoor Advertising</td>
<td>39</td>
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<td>40 Litigation Tort Claims</td>
<td>40</td>
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</tr>
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<td>41 Construction Manpower Training</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>42 Maintenance Manpower Training</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

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Dialogue Between Traffic Report Producers and Users

In Table 6-2, 42 uses are identified for AADT reports.

Some report users currently would be satisfied with a traffic volume report based on general estimates. This would be something less than a specific traffic count on a specified highway, at a specified milepoint or milepost. An example of a request for this type of estimate might be traffic volume reports that are used in travel model calibration.

There should be common reporting conventions among state agencies so that data may be easily compared. The discussion should begin with a review of current reports. Data users would be asked to identify present traffic report needs. The importance of this review cannot be overstated. As reports tend to take on a life of their own, and traffic data reports are no exception to this rule, the need for some reports may have long disappeared.

The discussions also should include a review of the errors associated with all traffic data reports. Another common tendency is that people reading numbers generated by a computer assume that those numbers are absolutely correct. Like all measurements, traffic data are subject to measurement errors of various kinds. Report users should be made aware of the error bounds typically associated with the numbers on traffic reports.

There is a need for maintaining and reporting a statistically valid estimate of total travel by vehicle type within each state. The estimate might be derived as identified in the Traffic Monitoring Guide (TMG) (Federal Highway Administration [FHWA], 2001), and in Appendix K of the Highway Performance Monitoring System Manual.

The quality of decisions can be improved when effective dialogue is established between report users and the person or office making the report. An example of improved decision-making could involve traffic reports in travel model calibration. If the user understands the errors associated with non-site-specific traffic estimates, user requests for traffic reports may change. Reports may be requested that provide site-specific points for validating and calibrating traffic simulation models. The process of improving traffic reports through user/provider discussion may positively impact both the content and the format of the report.

Some requests for traffic volume reports are site-specific. These requests range from project-level needs (AADT and hourly distributions of traffic) for design purposes, to AADT estimates for accident rate calculations in the priority array calculation, and to requests made by private citizens for the location of outdoor advertising.

Site-specific truck weight measurements should be reported to support some road projects. This information may facilitate decisions about the need to expand current weighing programs that were designed...
to provide statewide rather than site-specific information. This becomes particularly important with the *Mechanistic-Empirical Pavement Design Guide* and associated software.

The users of site-specific traffic reports prefer to receive data that directly relate to a traffic count taken at a specific location. Some report users would be satisfied with an AADT estimate based on a traffic count on the same road close to a specified point of interest. At present, few data users are aware of the sensitivity of their data applications to errors in traffic summary statistics.

**Traffic Reports Sensitivity Analysis**

Each of the uses of volume data are sensitive to the variation inherent in the traffic (the changes in volumes on a day-to-day basis). The uses also are sensitive to the variation introduced by different traffic sampling and summarization procedures. The sensitivity changes from analysis to analysis. For example, a 50 percent underestimation of trucks in a pavement overlay calculation, in most cases, will have a significant impact on the amount of overlay being placed. An inadequate overlay will have a significant impact on the expenditure of resources, both now and in the future. Therefore, one should be very sensitive to the quality of data used in this type of analysis. However, a similar error during a water quality analysis for a roadway improvement study may have considerably less impact, and the data reliability for this analysis may be of less importance.

This does not mean that agencies should ignore the need for Heavy Commercial AADT (HCAADT) for water quality analyses (or similar analyses), or that these analyses would not be better served with higher quality, site-specific data. It does suggest that agencies cannot afford to collect all potential data. These data should have a lower priority because errors will have a smaller impact on the fiscal responsibilities of decision-makers.

It is not within the scope of the guidelines to derive the sensitivity of applications to variations in traffic. However, several sensitivity analyses should be used to develop the primary structure of the data reporting program based on the following:

- Financial impact of the various analyses on an agency’s resources;
- Amount of data required for the analyses;
- Cost of acquiring and reporting those data; and
- Sensitivity of the results of a selected number of analyses to the selected range of data inputs.

**Design of System-Level Traffic Reports**

Traffic reports based onsite-specific traffic counts are appropriate for those uses in which the cost of collecting, editing, summarizing, and reporting the information is outweighed by the financial benefits of the more precise information.
At the other extreme of data applications, there is a distinct need for maintaining a statistically valid estimate of total travel by vehicle type within a state. System-level estimates are potentially important in allocating funds from Federal and state sources. In some states, system-level estimates are used to establish trends for traffic forecasting.

System-level traffic reports can be helpful to traffic data program decision-makers. It is recommended that system-level reports include a portion of estimates that are in compliance with the guidelines, and a portion of estimates that are not in compliance. An example is shown in Table 6-3. The AVMT report by system and by functional classification is expanded to include the portion of the estimate based on traffic practice recommended in the Guidelines. The report also shows the portion of the system not counted under recommended practice.

### Table 6-3. Standard/Nonstandard AVMT Report, Thousands, New Mexico, 1990

<table>
<thead>
<tr>
<th>Functional Class</th>
<th>Total Standard AVMT</th>
<th>N</th>
<th>Total Nonstandard AVMT</th>
<th>N</th>
<th>Percent Standard AVMT*</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>444,542</td>
<td>138</td>
<td>2,998,696</td>
<td>1,910</td>
<td>13</td>
</tr>
<tr>
<td>PAR</td>
<td>419,480</td>
<td>177</td>
<td>1,249,969</td>
<td>1,516</td>
<td>25</td>
</tr>
<tr>
<td>MAR</td>
<td>431,397</td>
<td>226</td>
<td>2,041,690</td>
<td>3,560</td>
<td>17</td>
</tr>
<tr>
<td>MCR</td>
<td>164,992</td>
<td>39</td>
<td>3,694,915</td>
<td>1,979</td>
<td>4</td>
</tr>
<tr>
<td>OR</td>
<td>109</td>
<td>1</td>
<td>298</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td>IU</td>
<td>76,846</td>
<td>38</td>
<td>985,738</td>
<td>736</td>
<td>7</td>
</tr>
<tr>
<td>PAU</td>
<td>708,775</td>
<td>440</td>
<td>1,875,975</td>
<td>2,026</td>
<td>27</td>
</tr>
<tr>
<td>MAU</td>
<td>162,610</td>
<td>159</td>
<td>456,036</td>
<td>737</td>
<td>26</td>
</tr>
<tr>
<td>OU</td>
<td>305,272</td>
<td>355</td>
<td>1,648,448</td>
<td>2,088</td>
<td>16</td>
</tr>
<tr>
<td>SYSTEM</td>
<td>2,714,021</td>
<td>1,573</td>
<td>14,951,766</td>
<td>14,582</td>
<td>15</td>
</tr>
</tbody>
</table>

*Percent Standard AVMT = \( \frac{\text{Total Standard AVMT}}{\text{Total Standard AVMT + Total Nonstandard AVMT}} \).

There are several benefits to the approach of reporting system-level data. First, it is one way of identifying the extent of traffic data obsolescence for the road system as a whole. Second, by presenting the analysis by functional classification, it leads toward a traffic count system-level strategy. Counts can be scheduled that are designed to provide the greatest improvement in the portion of AVMT based on recommended practice. Third, this approach to system-level reports provides managers with a measurable means of evaluating the schedule of traffic counts. Fourth, by providing data users with what the summary statistics do and do not signify, agencies began to implement Truth-in-Data. Full implementation will require additional information about the reliability of the data.

**Graphic Presentation**

It has been observed that the most frequently requested reports are for typical traffic volumes on a roadway. One way of reporting daily traffic is to present the variation of traffic demand. The periodic
distribution of traffic within a day is termed the “diurnal distribution.” Some traffic reports, such as diurnal distributions, should incorporate graphic presentation of data.

Diurnal distributions provide users with information about changes in traffic demand or characteristics. These reports may be used in determining optimal hours for allowing closures for maintenance or construction activities. The information is sometimes used in responding to public or private sector interest in land use impact analyses.

Hourly diurnal distribution reports are the most common. Tables 6-6, 6-7, and Figure 6-6 present an example of an hourly diurnal distribution in Maryland. The data shown in Table 6-6 are monthly average weekday traffic (MAWDT). The data represent the main hourly percent of traffic by month for a group of permanent counter sites. Data from 23 counters are reported.

Table 6-7 reports, in tabular form, the monthly average weekend traffic (MAWET) distribution for the same counters. While there are important differences in the distributions, they are not readily identified from tabular values. For this reason diurnal distributions may be graphed.

Figure 6-6 shows the mean distribution of traffic volume for a typical weekday and a typical weekend in January. The weekday and weekend peaking characteristics are easier to identify from the graph.

Depending on the use, it is usually desirable to present diurnal distributions by direction rather than by roadway. This can be done only for individual sites, as it is not usually valid to assume that a direction at one site corresponds to the same direction at a different site. For a single site, this approach allows the user to determine exactly the extent of diurnal flow in each direction, rather than seeing the peaks associated with the total volumes. The directional distributions would be important for uses such as capacity planning, traffic control, and enforcement. The Excel chart shown in Figure 6-1 is an example of a graph of the diurnal distributions for both directions and for weekend versus weekday traffic. The statistics shown are the average hourly volumes for the entire year.

The distributions can be reports of specific short-term counts, or they can be data from permanent counter sites. The distributions can be based on daily, monthly, or annual summary statistics. The diurnal distribution can be combined with trip generation factors to anticipate the traffic impact of proposed changes in land use. It is recommended that, for this and similar reports, consideration be given to graphic presentation of the data.

Seasonal and day-of-week distributions also are very important. Seasonal factors and day-of-week factors are required to estimate AADTs from short-term counts. Graphic representation of the seasonal factors clearly shows the month-to-month differences in traffic volumes related to seasonal causes. The day-to-day pattern of variation within the week shows how differences in travel behavior are related to the day of the week. Graphics also can be used to identify how seasonal patterns vary by use. Figure
6-3 shows an example of monthly traffic ratios for a typical urban site. Figures 6-2, 6-4, 6-5, and 6-6 are examples of the day-of-week traffic ratios for urban, rural, and recreational routes.

It also is possible to use graphics to show the interaction between the monthly and day-of-week patterns. Figure 6-7 is a three-dimensional plot, which shows this interaction.

Figure 6-2. Diurnal Distribution, Maryland.

Figure 6-3. Monthly Traffic Ratios, Typical Urban Site.
Figure 6-4. Day of the Week Traffic Ratios, Typical Urban Site.

Figure 6-5. Day of the Week Traffic Ratios, Typical Rural Site.
Figure 6-6. Day of the Week Traffic Ratios, Typical Recreation Site.

Note: This three-dimensional plot shows 365 days of traffic volumes at Permanent Recorder Number 6, near Snoqualmie Pass in the Cascade Mountains. Located on Interstate 90, Washington's major east-west traffic corridor, the pass is kept open year round except for brief periods of closure during severe weather.

The plot illustrates the weekly and annual variations that can occur in traffic. At this location vehicle volumes are higher on weekends and during mid-year with peaks near major holidays when recreational travel is high.

Figure 6-7. Snoqualmie Pass Traffic, 1989, Volume x Day of Week and Week of Year.


6.6.2 Truth-in-Data and Traffic Reports

The commitment to accurately label data quality and quantity, and to store and retrieve data based on equivalent quality and quantity, is the principle of Truth-in-Data.

A hypothetical example may help identify the application of this principle. In the example, two separate sites are part of the same pavement performance test. They have similar pavement, geometric, and environmental characteristics. One of the sites appears to have more loading, so it should show more deterioration. However, the observed roadway deterioration is virtually identical. There appears to be more severe axle weight distribution on one of the pavements, but without corresponding shortening of the pavement life. Given the mixed data, one of the sites could have a loading estimate from traffic weighed on a nearby, but separate, roadway. The other site could have the loading estimate based on permanent vehicle weighing at that site. The error introduced by separate roadway weighing, or system-level weight samples, could account for the apparent difference in loadings between the sites. The introduction of unknown traffic summary statistic error can result in incorrect assessment of pavement performance. Under the principle of Truth-in-Data, one would initially request analysis of both sites, since the data are mixed. Then the sample could be reduced on the basis of equivalent traffic data. Finally, the analysis is repeated.

In accordance with the principle of Truth-in-Data, any database should indicate the quality and quantity of data supporting traffic statistics on a site-by-site basis. When an analyst wants to compare sites with equivalent traffic data only, the data may be sorted and accessed in this way. If the analyst chooses to examine traffic statistics based on mixed data, then the analyst must indicate the quality and quantity of traffic data required for the analysis.

The issues will initially be whether or not the traffic summary statistics are based on location (site-specific) or other collection procedures, and the period of measurement. In the future, variability that results from alternative data collection procedures may derive from extensive national databases.

Through the principle of Truth-in-Data, there is a recognition that traffic summary statistics may come from mixed datasets so they have limited application. This is, in itself, a contribution to the profession. Various research activities in the past, and likely some at present, use summary statistics such as average daily traffic (ADT) under the mistaken assumption that reported ADT statistics are commonly defined and equivalent.

Precision and Bias

Precision and bias of summary statistics also should be provided to the data user. The confidence levels should be 95 percent. If precision and bias estimates are available, the method and duration of the traffic count should be reported with the summary statistics. If multiple days of data exist for a site, the confidence interval should be based on between-day variability. If multiple days of data do not exist, the
confidence interval may be estimated. The method of confidence interval calculation or estimate shall be reported with the confidence interval, and shall be retained with the confidence interval.

### 6.6.3 Report Formats

Traffic reports exchanged among state agencies and transmitted to Federal agencies should be clearly understood to help ensure that they are appropriately used. Consistency in traffic reports is an important step in the effective exchange of information. Traffic reports should have consistent terminology and labeling. Data formats established by the FHWA in the TMG should be used for electronic transmittal of traffic data.

**Rounding**

Statistics should not be reported to a number of significant digits that would mislead the consumer as to the underlying precision of those statistics. For example, reporting AADT statistics to two decimal places would not reflect the precision of those statistics. Unless there is a significant reason to report greater precision, statistics should be rounded to the precision specified in the following table.

<table>
<thead>
<tr>
<th>Volume</th>
<th>Round to Nearest</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–999</td>
<td>10</td>
</tr>
<tr>
<td>1,000–9,999</td>
<td>100</td>
</tr>
<tr>
<td>≥10,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

This recommendation applies only to reported values. The values in the underlying database should be retained as calculated, to at least two or three decimal places of precision. These values should be used for any further calculations using these statistics.

Rounded values should never be used as inputs to subsequent analyses. The rounding error associated with reported values could cause significant inaccuracies in subsequent calculations. As stated in the previous paragraph, any subsequent analytical or modeling activities should acquire the needed statistics from the underlying database of traffic statistics.

**Consistent Terminology and Labeling**

These guidelines provide definitions that are recommended for implementation in agency traffic data programs. The use of the same acronyms, terms, and definitions is an important step in moving toward common traffic monitoring practice.

Consistent labeling is a more complex issue. No single labeling recommendation can be made because of the complexity of reports and uses. At the same time, a general labeling approach can be suggested.
has been noted that system-level reports include disclosure of the portion of the report represented by guidelines-related traffic data. Some site-specific reports also should contain this information. If a report contains some data based on recommended practice and some data not based on recommended practice, a disclosure statement should be presented.

An example of site-specific data reports that should include a recommended practice disclosure statement are urban traffic flow maps. Traffic flow maps frequently have mixed data, but the differences among the data are not commonly identified to data users. It is recommended that urban traffic flow maps differentiate between data that are reported and are based on recommended practice, and data that are reported but are not based on recommended practice.

Another example is the Annual Traffic Report. States currently report annual traffic on the basis of calendar, state, or Federal fiscal year. Calendar year is the most common and preferred summarization period. The basis for the Annual Report should be clearly stated in the publication. Typically, the Annual Traffic Report contains data derived from a number of different sources using different methods. The resulting data may be characterized by precision and bias. For example, there may be four different types of data such as:

1. Data that come directly from permanent traffic recorders;
2. Data that are derived from short-term counts taken in the same year as the report;
3. Data that are derived from short-term counts taken in some year earlier than the year of the report. They are updated to report year by some method, usually by applying a growth factor; and
4. Data for sites at which there have been no site-specific counts but were derived by some method of estimation. For example, data might be interpolated from the reported traffic volumes on adjacent road segments.

The user of the Annual Traffic Report should be informed about differences among the data types.

**Electronic Traffic Report Format**

There is a need for traffic reports to be consistent. If data are electronically reported, a common file format is necessary. It is recommended that agencies use the file formats in the TMG for electronic transmission of traffic data.

Since the original Guidelines were published, relational databases have become the common mechanism for storing traffic data. Common database access mechanisms have lessened the need for exchanging data files and common formats. These database procedures were discussed earlier in the section.


**Tracking Traffic Counts**

One of the important reporting functions is tracking the progress of traffic counts from request to transmittal to the data user. A tracking system helps build accountability in a traffic data program, and facilitates communication with report users. It is recommended that all traffic counts, including special request traffic counts, be tracked and reported to requestors and traffic data program managers on a periodic basis.

An automated tracking program provides valuable management information. Having a count schedule as part of the traffic data processing program allows management to know, at any point in time, which counts have been scheduled, which have been successfully completed, and which failed because of errors. The same system could determine which counters were subject to frequent errors and could provide information for personnel feedback.

**Conclusion**

An important part of traffic monitoring is a production of traffic data reports that are responsive to users. At the same time, report should maintain the highest standards for data integrity and disclosure.

### 6.7 Data Retention

The design of a traffic data program is not complete when data are reported. Decisions must be made concerning the storage of the traffic data for future use. This section provides guidance on the length of time that a state highway agency should retain the basic traffic data that are collected as part of its ongoing design, planning, and analysis functions.

This section covers only the storage of traffic data such as volume, vehicle class, and truck weight data collected by the highway agency, and the basic summary statistics (such as vehicle miles traveled) that are computed with that information. This section does not address the retention of traffic data collected by other agencies and individuals in the state that are submitted to the highway agency for reporting purposes. These data are not identified within the context of the guidelines, and their retention periods are left to the discretion of the individual state agencies.

The data retention periods recommended in this section should be viewed as a minimum. States are encouraged to review their data retention needs and exceed their retention periods when appropriate. Some states may have to exceed these retention periods as a result of specific internal requirements, specific state laws, or other requirements. The length of data retention should be based on a number of factors, including the following:

- Legal requirements of the state or Federal government;
- Required data retention periods of related data;
• Utility of the data;
• Availability of computer resources, especially off-line data storage;
• Life expectancy of the storage media selected;
• Space requirements of the storage media selected;
• Cost of data storage; and
• Budget available for the current year and expected for future years.

These factors are briefly discussed below.

The legal requirements for data retention are the most critical factors for selecting a data retention period. In several instances, state or Federal laws set a minimum retention for various traffic statistics. Agencies may exceed those limits, if resources and needs exist, but data retention must meet the minimum legal standard. An example of such a standard comes from the state of Washington, where accident records must be maintained for seven years from the date of the accident. Beyond seven years, individual accident records must be retained if court cases involving those accident records are still pending.

Because some data (such as the accident data described above) must be retained for a specific length of time by legislative statute, other data that are used in conjunction with those data (for example, traffic volume estimates for accident locations during the year of the accident) also may have to be retained to meet the legislative intent of the accident data retention. Thus, the retention of some data elements is indirectly affected because of an important analytical relationship to other data.

Next, some data have a utility of their own, regardless of age. That is, some datasets provide important historical records whose value may actually increase over time. These datasets include special databases developed for major research efforts, which will be used repeatedly as researchers perform or review analyses important to the highway community. Similarly, state agencies have datasets that provide important historical perspectives on the evolution of traffic over time. These datasets include permanent counter records and other data collection efforts designed specifically to track trends over time.

Another consideration for the storage of data is the physical capability of an agency to store collected information. Several items from the above list are important considerations when the storage capabilities of an agency are examined. These items include the availability of various resources (money, room space, and computer hardware such as tape drives or optical discs, and other hardware options), and the life expectancy of the storage media selected (computer tapes and even optical storage devices such as CDs and DVDs tend to degrade over time). These factors should be combined to set practical limits on the amount of data that can be retained, the manner in which they are retained, and the length of time any specific dataset is saved.

Storage costs are not nearly as important in the present day as they were when the original guidelines were written. In 1991, when the original guidelines were published, a gigabyte of hard disk storage cost
on the order of $2,000. In 2006, that amount of storage costs $0.35, which is 3,000 times less expensive. Staff costs, on the other hand, have increased dramatically during that same period. In most cases, it is actually cheaper to buy adequate disk storage than it is to pay staff to move the data to off-line storage.

Resource availability varies from state to state. In addition, it changes over time within any given state as a result of budget fluctuations and implementation of new technologies. These restraints make it difficult to implement a single standard data retention period for all traffic data. Instead, an appropriate set of standards provides recommended minimum retention periods with specific extensions where resources permit. As is true for all the guidelines in this document, the intention is to identify a common practice toward which agencies should direct their traffic programs. With data retention guidelines, agencies will hopefully be able to tailor retention criteria to guidelines for professional practice. This activity will be phased in based on individual agency resources, moving toward optimal data retention.

6.7.1 Recommended Procedure

The recommended data retention requirements were developed following a review of existing state practice with added input from both the FHWA and the ASTM subcommittee that prepared standards for highway traffic data collection. The retained data do not have to be on-line, or immediately accessible by computer, during this retention period. However, as noted above, this is usually the most economical way to maintain data.

After the expiration of the recommended retention period, these data should continue to be stored in machine-readable format if such storage is economically reasonable and mechanically reliable. It is important that each state maintain both edit accepted and edit rejected traffic data within these files. That is, if the State modifies data as a result of an editing or summarizing procedure, the state should retain both the original data (prior to data modification) and the final data that result from the editing or summarizing processes. This recommendation does not apply to computer records of machine malfunction, as described in an earlier section.

The recommended retention periods are presented below. Explanations of the data categories and recommended retention times are provided following this summary.

<table>
<thead>
<tr>
<th>Type of Count</th>
<th>Retention Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlimited-Retention Counts</td>
<td>10 years to permanently</td>
</tr>
<tr>
<td>Limited-Retention Counts</td>
<td>10 years</td>
</tr>
<tr>
<td>Research Databases</td>
<td>10 years to permanently</td>
</tr>
<tr>
<td>Summary Statistics</td>
<td>10 years to permanently</td>
</tr>
</tbody>
</table>
Unlimited-Retention Counts

Unlimited-retention counts are collected at selected locations on a continuing or routine basis. This includes long-duration counts such as those collected at permanent traffic monitoring sites. It also includes short-duration counts which are continually retaken at specific sites, such as the HPMS volume and vehicle classification counts.

These data are retained for a relatively long time because they provide historical trend information, and trends should be studied over fairly long periods in order to be useful. Because trend analysis is not just a function of permanent counter datasets (although a great deal is learned from these types of datasets), no differentiation is made between the data retention periods for short- and long-term count programs.

Limited-Retention Counts

Limited-retention counts differ from unlimited-retention counts with respect to location and scheduling of data collection, as identified in earlier sections. Limited-retention counts include data collection efforts that do not collect data at the same location on a routine basis. Standard coverage count programs may or may not fall under this category. A data collection scheme is classified as a limited-retention count program if the data are not collected at specific points within a section or if they are not collected at a consistent interval. A program like the HPMS data collection program that meets both of these criteria would be classified as an unlimited-retention count program.

The limited-retention classification count also includes all data that are collected specifically for project design or special analysis purposes (except specialized research data). These data are not as important from a historical perspective because they do not correspond to other counts at the locations. These data should be kept for a minimum of 10 years, in that, they are available to the state agency.

Research Databases

Research databases include all traffic data that are collected specifically for research purposes. Where traffic data play a critical role in a research outcome that changes the way highways are designed, maintained, or operated, the data should be retained permanently so that the conclusions reached and recorded can be reviewed and validated later.

Where the research results do not change the way highways are designed, maintained, or operated, the traffic data should be maintained, with the remainder of the project working papers, for a minimum of 10 years on computer-readable media. This schedule allows for review of the research and also allows the data-sets collected for one purpose to be used by other researchers, so the costs of future research are reduced.

Research applications may be broadly interpreted by state agencies. For example, traffic information collected specifically to validate model results or to confirm other traffic information falls under this category.
Summary Statistics

The category “summary statistics” includes summary data calculated from available datasets. These datasets are then used in analytical processes (such as a pavement management system or a statewide accident rate analysis process) or they are used to describe the functioning of some aspects of the highway system. These data include vehicle miles traveled (VMT) estimates by any number of categories, estimated volumes by milepost, and numerous other standardized published and internal agency reports. As discussed near the beginning of this section, summary statistics should be retained, along with the data from which those statistics were calculated, for audit trail purposes. It also may be desirable to retain “expired” statistics that might have been submitted to data consumers.

The statistics and reports serve a variety of uses and have different levels of significance. Computer files used by analytical procedures should be retained for 10 years and then discarded. The actual data used to calculate the summary reports should be retained on the basis of the recommendations discussed previously. Printed reports and summary values of significance to the agency (for example, VMT statistics by jurisdiction used for fund disbursement or traffic flow maps) should be retained permanently to maintain a historical record of traffic activity.

Retention Recommendations for Source Data

Source data can be retained either in its original form, or as database entities that reproduce the source data. With storage costs decreasing every year, source data can be retained on-line for a much longer period than was formerly practical. Some data, such as 20-s volume, speed, and occupancy measurements from ITS, and vehicle records from high-volume weigh-in-motion (WIM) sites, may have to be moved to off-line storage more frequently.

If an agency does collect very short-interval data, such as five-second time bins for volume data from a freeway management system, at least a sample of those data should be retained for 10 yr or longer. These fine-grained data are used for some kinds of congestion studies. The sampling rate should be determined by the amount of storage available for this purpose. The samples should consist of entire days of data, with both weekdays and weekends proportionally represented. Also, all seasons of the year should be sampled for this purpose.

6.7.2 Retention Media

The data retention process is directly tied to the media used to store the data. When the original guidelines were written, the most common forms of long-term data storage were paper reports and microfiche or microfilm. These technologies have been supplanted in large part by direct storage of digitized documents or data files. The best alternatives to microfiche, microform, and paper are computer-readable storage media.
Agencies are encouraged to evaluate the available methods of electronic data storage and data compression systems to determine which will be most cost-effective for their environment. It is recommended that highway agencies consider the use of optical or magnetic media for long-term storage of traffic data. Media degradation and environmental controls for the storage of data also should be considered in the evaluation. Other concerns such as reorganizations, staff turnover, fires, or other actions unrelated to storage media also may pose a concern. Off-site storage of duplicate datasets provides additional archival protection.

6.7.3 Database Retention Procedures

Now that most traffic data and statistics are stored in on-line databases, additional consideration needs to be given to criteria for determining when data should be taken off-line and when they should remain on-line.

Criteria for Maintaining Data On-Line

The simple criterion for leaving data on-line is usage. If the data are still being used, they should be left on-line. Again, with inexpensive storage, monthly and annual summary statistics can be left on-line indefinitely. Daily summaries could be maintained for several years.

Procedures for Taking Data Off-Line

Some databases allow data to be moved off-line, while maintaining references to the data on-line. This is the desired procedure. When someone attempts to access these data, they are notified that it has been removed from the system. If the need is great enough, they can request that the data be restored.
Table 6-6. Hourly Percent of Daily Traffic by Month—MAWDT, Group “A” Factors*

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*Maryland Department of Transportation.
### Table 6-7. Hourly Percent of Daily Traffic by Month—MAWET, Group “A” Factors*

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* Maryland Department of Transportation.

### 6.7.4 Conclusion

An intentional data retention strategy is an important part of an agency’s traffic data program. The agency retention strategy should be to move towards the recommended data retention periods. The most efficient storage medium to achieve the recommended retention periods is computer-based storage. However, even current CD and DVD media have a limited life, so some scheme for “refreshing” the media may be necessary. This normally requires occasional copying of older files onto new media.
6.8 References


As the role of traditional data programs continues to evolve in state transportation agencies, data program owners may be asked to explore alternative sources of data to supplement existing sources. Several states are looking at an overall approach to providing traffic data to meet agency needs such as performance measures and asset management. For example, VDOT is working on a Corporate Data Business Plan that will involve investigating how traditional traffic and operations data can be combined for performance measures reporting in the agency. This chapter is intended for states that are ready to embark on the integration of traditional traffic and operations data.

This chapter describes key benefits, implementation issues, and ways of overcoming technical and institutional barriers to integrating operations data. The chapter starts by describing operations data and discussing the benefits of integrating this data with other traffic data. The current practice is summarized, and case studies are presented in an appendix illustrating how several agencies have successfully integrated operations data. The chapter also summarizes the most common barriers to integrating operations data and outlines strategies for overcoming these barriers. The chapter concludes by describing several “Steps for Success” that agencies can use in their operations data integration efforts.

### 7.1 Introduction

Most traffic operations programs collect a variety of traffic data that also are collected separately by traditional traffic monitoring programs. Those collecting operations and/or Intelligent Transportation System (ITS) data are referred to as operations centers in this chapter. Traditional data collection is referred to as either planning or traditional traffic data collection. The parameters and requirements of data collection for traffic operations are quite different from those for transportation planning. Traffic operations data are typically collected continuously at closely spaced sites (e.g., every one-half to one mile) on the most congested roads (mostly urban freeways and a few major urban arterial streets) and reported in real-time at frequent intervals (e.g., every 20 seconds to one minute), with only the most recent data (e.g., past five minutes) being of interest. Though very different from the more aggregate data collected by conventional traffic monitoring, most traffic operations data can be archived, aggregated, and reformatted to match the parameters and requirements of conventional programs.
The data elements from real-time traffic monitoring that are of most interest to other programs include:

- Total vehicle volume;
- Average vehicle speed;
- Average or individual vehicle travel time;
- Volume subtotals by two or three different length-based vehicle classes; and
- Vehicle position trajectories.

In the past, most real-time monitoring data have been collected from fixed, roadway-based traffic sensors. However, techniques are now being developed that use mobile, vehicle-based sensors.

There are several potential benefits to integrating operations data into traditional traffic data programs:

- **Save Money by Reducing Duplicate Data Collection**—When short-term counts are required on sections of urban highways on which traffic operations counts already are being collected, resources can be saved by using the operations data instead of collecting separate short-term counts. There will be an initial startup cost for developing an automated process for retrieving data from the traffic operations center; but this cost could be readily recovered through reductions in the number of short-term counts required annually. For example, a single district of Florida DOT has estimated that they have saved about $750,000 by integrating ITS-generated data instead of installing permanent traffic monitoring stations or using short-term count locations.

- **Improve the Safety of Traffic Data Collectors**—The high speeds and heavy traffic on urban highways is a hazardous environment for traffic data collectors to place short-term counting equipment. The risk of collecting traffic data on urban highways can be reduced by using traffic data already collected by the traffic operations group at permanent traffic monitoring stations.

- **Improve the Coverage and Quality of Traffic Data**—In most urban areas, transportation planners have installed continuous count stations that are widely scattered, with short-term counts performed to fill in the gaps. By contrast, operations traffic managers typically install a fairly dense system of traffic monitoring stations on the most congested roads. Transportation planners could improve traffic data quality by using the operations-based traffic monitoring stations to: 1) supplement the widely scattered planning-based continuous count stations; and 2) replace the 48-h short-term counts with significantly more operations-based data throughout the year.
7.2 Current Practice

This section summarizes the current practice with respect to integrating operations data into traditional traffic data programs. A 2005 survey of state DOTs\(^1\) provides a snapshot of implementation barriers, followed by suggested approaches for overcoming these barriers. Appendix B includes several case studies with lessons learned to illustrate how agencies have successfully integrated operations data.

7.2.1 Overview of Survey Results and Integration Issues Related to ITS Data

As part of the project to update this Guidebook, a survey of all 50 state DOT traffic data programs was conducted in 2005 to gather information about current practice. Of the 36 responses, 13 state DOTs (36 percent) indicated that they currently use archived operations data in their traditional data program. Of those that currently do not use archived operations data, 80 percent indicated that they plan to in the future.

The survey also gathered open-ended responses about current barriers for using archived ITS data in traditional traffic data programs. The following barriers were mentioned most frequently:

- Archived operations data are difficult to access;
- Archived operations data are stored in an incompatible format;
- Archived operations data are of an unknown or inadequate quality; and
- Operations data are not archived or is not available.

These barriers are summarized below, and potential strategies to overcome these barriers are described as well. Some of these perceived barriers have fairly simple technical solutions, whereas some barriers may require a combination of institutional cooperation and technical solutions.

**Barrier #1: Archived Operations Data Are Difficult to Access**—Computer network security and accessibility is often more restrictive for traffic operations centers because of the traffic control (and sometimes emergency management) functions that are performed. The time-sensitive nature of collecting real-time data for operations also may be a factor in the inaccessibility of operations data. Finally, operations traffic center personnel may not realize that there is an interest in their archived data.

**Strategies**—Accessibility issues can be discussed with the operations traffic center staff and interest expressed in using the archived operations data for planning purposes. There are numerous technical solutions for making data accessible over public and private networks.

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\(^1\) NCHRP 7-16 Interim Report: Recommended Revisions to the AASHTO Guidelines for Traffic Data Programs, April 2006.
For example, the San Antonio District of Texas DOT provides public access to the TransGuide archived data through an FTP site (ftp://www.transguide.dot.state.tx.us). Other traffic centers are cooperating with state universities, who gather the data and repackage it for a variety of other data users. For example, Portland State University gathers operations-based traffic data on Portland freeways from the Oregon DOT and provides it through a password-protected web site (http://portal.its.pdx.edu/). Other traffic centers make their operations-based traffic data available through a real-time data feed. For example, Utah DOT’s traffic management center in Salt Lake City is developing a Web service that will make their real-time traffic data available to “subscribers” of the service.

Barrier #2: Archived Operations Data Are Stored in an Incompatible Format—Operations traffic managers typically collect data in time intervals as short as 20- to 60-s. In some cases, the data are stored at this level of detail in delimited text files. In many cases, the format for logging or archiving the operations data was based on convenience, not necessarily any input from archived data users.

Strategies—Data format issues can be discussed with the traffic center staff. There are numerous technical solutions for reformatting and post-processing archived operations data so that they can be imported into traditional traffic collection/planning-based traffic data systems. Depending upon the circumstances, the data can either be reformatted by operations-based computers before they leave the traffic center, or the data can be reformatted by planning-based systems. Either approach will require updating existing traffic data software, so be sure to involve the appropriate information systems staff in the early stages of discussion.

For example, statewide data managers at the Ohio DOT persuaded the operations traffic center in Cincinnati to provide archived data in a standard format that already were accommodated in their planning-based traffic database. In Minnesota, the statewide data managers have developed software (some in-house, some by university researchers) to post-process archived data from the Minneapolis–St. Paul traffic center. In California and Virginia, university researchers manage a statewide data archive that gathers operations data from traffic centers and reformats it for planners and a variety of other data users.

Barrier #3: Archived Operations Data Are of an Unknown or Inadequate Quality—Operations traffic managers use data for different applications than transportation planners, and as such, may have different data quality requirements. Because of these different data uses, many traditional traffic program staff are unsure or skeptical of operations data quality, sometimes without the benefit of any actual data comparisons. In some other cases, data comparisons and accuracy evaluations have been conducted and did raise concerns about the data quality. However, as data programs continue to evolve in agencies with expanding customer bases, varying quality standards may be acceptable. For example, the use of speed data to support the reporting of performance measurement may allow for different quality standards of the data for different uses.
**Strategies**—Data quality should be addressed in preliminary stages, as they should with any data integration project. If the operations data quality is unknown, then later sections of this chapter (Step 4 in “Steps for Success”) will help to assess and evaluate data quality.

If the operations data quality has already been evaluated and found to be inadequate, then all of the potential strategies discussed later (Step 4 in “Steps for Success”) will require the commitment of both groups (i.e., operations traffic managers and planners).

Data quality is probably one of the greatest barriers to integrating operations data. However, there are numerous strategies that can be used to overcome data quality issues. For example, if the operations data are not complete enough for continuous counts, perhaps they can be used to replace short-term counts. If the traffic management software does not address missing data properly, operations traffic managers may be able to fix this in their next software update. If the traffic equipment is not accurate, operations staff may be able to calibrate and maintain a subset of priority locations. If the equipment used by operations traffic managers does not provide the desired features (e.g., vehicle class), traditional traffic data managers may be able to offer to share the expense of new equipment. These and other strategies are discussed in detail in the “Steps for Success” section later in this chapter.

**Barrier #4: Operations Data Are Not Archived or Are Not Available**—Some operations traffic centers do not archive their data because they do not use it and nobody else had expressed interest when the data collection system was being developed.

**Strategies**—If an operations traffic center is collecting data but not archiving it, the traffic management software should be updated to provide an archiving function. Depending upon system complexity and staff expertise, the software updates can be done in-house or outsourced to a system integrator.

If no operations-based traffic sensors have been deployed, the operations staff should be contacted regarding their deployment plans as there may be plans for traffic sensor deployment. This is one of the best times to discuss a cooperative program of archiving and sharing operations data for transportation planning applications. The plans for traffic sensor deployment are usually still flexible and additional funding may be available for collecting multipurpose traffic data. The operations and traditional traffic data/planning groups can work together at this stage to develop agreed-upon equipment and data format standards. For example, transportation planners with the Idaho Transportation Department have worked cooperatively with operations traffic managers to ensure that traffic data will be archived in the preferred format when sensors are deployed on I-84 in Boise.
7.3 Steps for Success

This section discusses important considerations for integrating operations data into an existing traditional traffic monitoring program.

7.3.1 Assess Potential Benefits

The three greatest potential benefits for integrating archived operations data include:

1. Saving money by reducing duplicate data collection;
2. Improving the safety of traffic data collectors; and
3. Improving the coverage and quality of traffic data.

Data program managers should assess these potential benefits in the context of their particular program and estimate possible outcomes. For example, if archived operations data were integrated, what short-term counts could be eliminated? With this cost savings, could other elements of the data program be upgraded, such as additional WIM sites? Could traffic control delay from equipment set-up on congested roads be reduced? If the archived operations data are used to supplement existing traffic data, would this provide better or more detailed data for planners?

Data integration requires an agency-wide perspective because many of the benefits accrue to individual data users spread throughout the agency. Additionally, the benefits of data integration may accrue over a longer period of time, in some cases because the initial costs of integration are equal to the first several years of cost savings.

7.3.2 Communicate with Operations Data Source Provider

Data integration is seldom an easy task, especially between two functionally distinct workgroups. Several issues need to be discussed and coordinated. For example: different data definitions and data elements will have to be reconciled; system documentation will have to be found, or in some cases, written from scratch; and new software may have to be written and existing software may have to be revised. To make it past the initial obstacles, it is desirable to have a commitment (either written or verbal) from all parties involved. A written memorandum of understanding may be too formal for divisions within a state DOT, but something similar could be helpful in identifying roles, responsibilities, and expectations.

Discussion between different divisions could include:

- Integrating archived operations data into the traditional data program can reduce or eliminate requests for archived data made to the operations traffic center. Most operations traffic centers are equipped to share data in real-time but have little time and few capabilities to handle occasional
specific requests for archived data. Traditional data programs are better equipped to handle data requests, as they already have developed numerous methods to distribute traffic data to a variety of data consumers.

- **Insight on traffic monitoring equipment installation and maintenance practices could be shared.** For a variety of reasons, some operations traffic centers struggle to keep traffic detectors properly functioning. Therefore, it may be useful for equipment technicians to share their knowledge on the various aspects of detector installation and maintenance.

- **Traffic monitoring equipment or other data resources could be shared.** Resource sharing can happen in several ways. Traditional traffic collection staff can provide operations traffic managers with real-time access to planning-based traffic monitoring stations, particularly in outlying areas. The traffic operations center relies on a dense network of traffic sensors within a city, but they typically have few or no detectors on intercity routes or other rural but heavily traveled highways. Traditional traffic/planning staff can specify and/or purchase specialized equipment for operations-based monitoring locations (for example, see the Cincinnati case study in Appendix B).

### 7.3.3 Understand the Data Source

One of the preliminary steps in integrating operations data into a planning database is to understand the data source. For example, how are the data collected in the field? How are the data processed in the operations traffic center? The transformation and post-processing steps that are necessary to integrate archived data will depend largely upon what has happened to the data before it was archived. This step is critically important because the traditional traffic data staff may need to make adjustments to their data importation processes to accommodate the archived operations data, and the operations group may need to make adjustments to their data collection and archiving processes for the sake of data integration.

Asking many questions up front may prevent surprises during or after data integration. Table 7-1 contains a sample of questions that should be addressed to better understand the source of archived operations data. Answers to some of these questions might be included in system documentation for the traffic center software; in other cases, the questions may have to be addressed to technicians, programmers, or system integrators.

This also may be an ideal time to explain relevant data collection and summarization procedures used in the traditional traffic monitoring program to the operations staff. This could be viewed as a chance to “compare notes” about each other’s data collection and processing routines. For example, is there a standard traffic data file format that is used for continuous counters or short-term machine counts? Are there certain validation criteria that are applied to incoming data? Are there minimum standards for missing data?
Table 7-1. Questions to Better Understand Archived Operations Data

The Basics

- What traffic data are collected from field devices?
- At what time interval are the data collected and archived?
- How many detectors are installed and at which locations?
- Are data reported and archived by lane or aggregated across several lanes?
- Can you show me samples of the original source data (from field equipment) and the data that are archived?

Field Equipment

- What types of detectors are used to collect traffic data? Technology? Manufacturer? Model?
- If different detector types are used, are there consistent data definitions?
- Where are detectors installed in relation to ramps? In relation to traffic signals?
- What are the maintenance procedures for repairing malfunctioning detectors?
- How quickly are malfunctioning detectors typically repaired?
- What types of field controllers (i.e., field computers) are used? Manufacturer? Model?
- If different controller types are used, are there consistent data definitions?
- How are the controllers’ clocks synchronized? How often?
- Does the controller manipulate or substantially alter the data between polls? If so, how?
- Does the controller use certain error codes? If so, what are they and what do they mean?

Communications

- How often are the detectors polled?
- Is the polling cycle length different than the time interval for data collection?
- If a polling cycle is missed, does the controller continue to accumulate data until the next poll, or are counts and other data reset?
- Is communication with field equipment reliable?

Traffic Center Database

- Is the original source data modified, processed, or aggregated before being archived? If so, what calculations and procedures are used?
- Are error or validity checks performed on incoming data? If so, what is done with bad data?
- Are error codes or other special codes used to flag or label data? If so, what are they and what do they mean?
- Are invalid data, error codes (such as “–1”), and zero speed values (from no vehicles present) removed from data calculations?
- If there are missing data, how is this addressed in data calculations? If the data are aggregated, are the counts adjusted to account for small gaps of missing data?
- Are there system backup or maintenance procedures that prevent data from being archived at certain times?
7.3.4 Resolve Data Quality Issues

As a logical extension of understanding the data source, traditional traffic planning groups should assess the quality of the archived operations data before data integration begins. Additional quality assurance procedures may be necessary if archived data will be obtained directly from traffic operations systems. To date, the quality of archived data from traffic operations systems has been influenced by two prevailing issues:

1. The difficulty of maintaining extensive electronic field equipment (sensors and communication); and
2. Real-time traffic operations applications that have different data quality requirements than historical uses of archived operations data.

The result has been that some managers and users of data archived from traffic operations have wrestled with data quality problems.

The level of data quality may determine whether remedial actions are required to improve data quality before data integration. The data quality should be assessed using three measures (see Table 4-2 for full definitions):

- **Accuracy**—Are the field devices calibrated correctly?
- **Validity**—Does the data contain plausible values?
- **Completeness**—Is there a lot of missing data?

The following paragraphs summarize basic data quality assessment procedures that can be used to quantify these three measures. Later paragraphs in this section present strategies to improve traffic data quality.

**Assessing Accuracy**

The accuracy of archived operations data can be assessed in two ways: 1) conduct an informal field audit; or 2) conduct a formal accuracy evaluation by establishing a benchmark or “ground truth.” These two methods were discussed in Chapter 4 and are summarized below.

Informal field audits are commonly used to determine if devices are properly collecting traffic data. A field audit consists of observing the device in operation to determine if it is detecting vehicles and if it is properly measuring and classifying traffic. With continuous traffic monitoring devices, this typically involves opening a roadside cabinet and observing an LED panel while also viewing the lane(s) being monitored. For example, auditing traffic counts would require that the detection indicator be activated for every vehicle that passed through the corresponding detection zone. In some cases, a portable computer can be connected to a traffic monitoring device to gain access to more sophisticated diagnostic and calibration tools. These diagnostic tools typically verify the measurement of variables such as vehicle...
speed, weight, or class. In practice, field audits are typically performed for traffic counts, one lane at a time, for short periods of time, and to the satisfaction of the auditor.

Another method to assess the accuracy of operations-based traffic detectors is to compare their output data to reference or “ground truth” data. Reference or ground truth data are obtained using specialized equipment and/or techniques that have low or no error.

For vehicle count and classification data, ground truth is typically established by collecting video and manually reducing it with two or more sets of independent human observers. When the difference between the independent observers is low (user-specified, but typically two to three percent), then one can be fairly assured of the data accuracy. The data values from the independent observers are then averaged and serve as ground truth for comparison to the data values produced by the device being evaluated.

For vehicle speed and weight data or for other circumstances, ground truth data may be collected by specialized equipment with a known or certified accuracy. For example, professional-quality LIDAR (Light Detection And Ranging) devices may be certified by the manufacturer to measure vehicle speeds within one to two mph. This specialized equipment then offers a more automated way to verify data output by the traffic monitoring device being evaluated. Unless the accuracy testing is performed in a permanent test bed environment, the specialized equipment must be portable and easily installed at the various monitoring devices’ field locations.

In some instances, traditional traffic groups have compared their traffic counts to other counts derived from archived operations data as a way to assess the accuracy of the archived data. It should be noted that unless the counts from the traditional traffic (or planning) group also have been verified using an accurate benchmark, then this comparison will only indicate whether the operations-based counts are comparable to the planning-based counts, not whether the counts are accurate. For example, the counts from both sources could be biased toward overcounting or undercounting. However, many practitioners still use these types of comparisons because they have confidence in their own data more so than data collected by another functional group. These types of comparisons use existing data (i.e., no additional data collection are required); thus, they are easier and less expensive to perform than collecting benchmark or ground truth data.

Assessing Validity

The validity of data describes the degree to which data values meet specified criteria. For example, do the traffic counts and speeds from archived operations data fall within plausible or expected ranges? Validation criteria can be used to compare archived data to specified expectations such as data format, value ranges, internal consistency, temporal consistency, spatial consistency, theoretical principles, etc. Chapter 4 summarized validation criteria that have been used in traditional traffic monitoring programs. These criteria are macroscopic, in that they are used to assess aggregate data such as hourly or daily traffic statistics.
Most operations-based traffic data are collected and archived in shorter time intervals, such as 30- to 60-s. As a result, different validation criteria have been developed for traffic data collected at these shorter time intervals. Table 7-2 contains validation criteria that have been recommended as part of a national synthesis of quality control procedures for archived operations data. If archived data are available in short time intervals, it is desirable to use the validation criteria in Table 7-2 as well as the macroscopic validation criteria in Chapter 4; however these macroscopic criteria will have to be applied after the data has been summarized to longer time intervals.

Table 7-2. Recommended Additional Validation Criteria for Archived Data

<table>
<thead>
<tr>
<th>Validation Criteria</th>
<th>Default Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prescreening Criteria</strong></td>
<td></td>
</tr>
<tr>
<td>Controller error codes (e.g., -1, 255, etc.)</td>
<td>n.a.</td>
</tr>
<tr>
<td>Check consistency of elapsed time and poll cycles</td>
<td>n.a.</td>
</tr>
<tr>
<td>Check for duplicate records (location ID, date, time identical)</td>
<td>n.a.</td>
</tr>
<tr>
<td>If VOL = OCC = SPD = 0, then set SPD = missing/null (no vehicles present)</td>
<td>n.a.</td>
</tr>
<tr>
<td><strong>Univariate Range Criteria</strong></td>
<td></td>
</tr>
<tr>
<td>Minimum volume</td>
<td>0 vehicles</td>
</tr>
<tr>
<td>Maximum volume</td>
<td>3000 vphpl (adjust for appropriate time interval)</td>
</tr>
<tr>
<td>Minimum occupancy</td>
<td>0%</td>
</tr>
<tr>
<td>Maximum occupancy</td>
<td>100%</td>
</tr>
<tr>
<td>Minimum speed</td>
<td>0 mph</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>100 mph</td>
</tr>
<tr>
<td><strong>Multivariate Logical Consistency</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum consecutive identical volume and occupancy and speed values (including VOL = OCC = SPD = 0)</td>
<td>8</td>
</tr>
<tr>
<td>If volume &gt; 0 and speed = 0 then invalid</td>
<td>n.a.</td>
</tr>
<tr>
<td>If volume = 0 and speed &gt; 0 then invalid</td>
<td>n.a.</td>
</tr>
<tr>
<td>If volume = speed = 0 and occupancy &gt; 0 then invalid</td>
<td>n.a.</td>
</tr>
<tr>
<td>If occupancy = 0 and volume &gt; volume\text{\textsubscript{\text{max}}} (based on maximum possible volume when occupancy value is truncated to 0)</td>
<td>[\text{VOL}\text{\textsubscript{\text{max}}} = \frac{(2.932 \times \text{SPEED} \times \text{ELAPSED_TIME})}{600}]</td>
</tr>
</tbody>
</table>

In addition to an automated review using these validation criteria, the validity and reasonableness of archived operations data also can be manually reviewed using visual techniques. For example, summary statistics (like average daily or weekday traffic counts) can be calculated and then charted by day-of-week and month-of-year. Average 15-min or hourly traffic volumes and speeds can be plotted for weekdays and weekends to confirm expected trends for urban highways (see Figure 7-1 for an example). These visual checks should provide further confirmation of the quality of the archived data.
Assessing Completeness

The completeness of archived operations data should be evaluated as the third component of the data quality assessment. Completeness (also referred to as availability) can be evaluated by comparing the number of data values that are available to the number of data values that should be available. Completeness is typically described in terms of percentages or number of data values. Completeness can refer to both the temporal and spatial aspect of data quality. For example, completeness for a single lane or site quantifies how complete the data are over time at that location. Completeness also can be reported for an entire detector system by multiplying the number the detector locations by the number of data values expected at each location.

Completeness should be evaluated before and after the validation criteria are applied. The data validation process will likely identify invalid data which should not be counted with the rest of the valid (and complete) data. Therefore, assessing completeness before and after the validation process will clearly identify what percent of data values were flagged and discarded as invalid. Additionally, it is useful to know whether data values are missing because: 1) they were never collected from field equipment; or 2) they were collected but deemed to be invalid and discarded.

If missing data are an issue (e.g., completeness below 75 percent), then it may be desirable to assess whether missing data are prevalent at specific traffic detector locations or system-wide. For example, assume that data completeness for a citywide detector system is 50 percent. This could be caused by half the detectors at 0 percent complete and the other half of the detector system at 100 percent complete.
Unless missing data are a corridor-wide issue, the density of operations-based detectors is such that malfunctioning detectors can be skipped without a significant loss of roadway traffic coverage.

More extensive analyses of missing data may be necessary to properly diagnose and fix missing data problems. For example, patterns in missing data could be analyzed by day-of-year and time-of-day using charts like that shown in Figure 7-2. In this chart, the data completeness is color-coded, such that little or no missing data are indicated by light and dark green, and moderate to severe missing data are indicated by yellow and red, respectively. There are three patterns of missing data evident in this chart:

1. Randomly scattered light green dots, which are short intervals of missing data throughout the year (most likely due to communication failures or failed validation criteria);

2. Two vertical red bars on the right of the chart, which are several consecutive days of completely missing data (device or system malfunction); and

3. A dashed light green line on the bottom of the chart, which are short intervals of missing data that occur during routine computer system maintenance scheduled only for weekdays.

![Figure 7-2. Missing Data Patterns in Archived Operations Data from Austin, Texas.](image)

**Improving Data Quality**

In the long-term, the most cost-effective way to improve data quality is to fix problems at the source of data collection. According to data quality professionals, “scrap and rework” (that is, a focus on fixing the low-quality data, instead of fixing the process that is producing low-quality data) should be avoided at all costs. Fixing problems at the source typically means improving the maintenance and calibration of traffic detectors, which can be difficult if the data consumers (e.g., planners) who want higher quality data are functionally distinct from the data collectors (e.g., operations). If this is the case, the planners

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2 See [http://www.infoimpact.com/index.cfm](http://www.infoimpact.com/index.cfm) for more information on “scrap and rework” issues related to information and data quality.
should attempt to work cooperatively with operations staff to identify and implement one or more of the following strategies to improve data quality:

- **Resource Sharing between Functional Groups**—Data consumers (outside of the operations function) could contribute funding for additional sensor maintenance. In return, data collectors might agree to a basic set of universal data quality requirements for all data applications. Or, data consumers from a traditional traffic collection group might agree to buy improved field equipment that provides necessary features or capabilities.

- **Focused Resources at Selected Locations**—Many traffic operations centers deploy their freeway traffic sensors in dense patterns (typically every one-half mile); however, this sensor density may not be necessary for some applications like performance monitoring. Thus, a limited but fixed maintenance budget could be used to provide higher quality data at fewer locations. For example, the Maricopa Association of Governments is working with the Arizona DOT to better maintain about 15 percent of the freeway traffic sensors (three-mile spacing) for a regional traffic and performance monitoring system (see Figure 7-3).

![Figure 7-3. Priority Traffic Detectors Designated in Phoenix, Arizona.](image)
• **Multipurpose Data Collection**—Future deployments of traffic data collection infrastructure could sidestep these data quality issues if they are designed to serve multiple applications, with some applications in real-time and other applications requiring the historical archived data. In this scenario, each application’s data quality requirements are determined in advance of deployment, and maintenance and/or calibration standards are put in place to ensure meeting these requirements. The Intelligent Transportation Infrastructure Program (ITIP) was intended to demonstrate this model of multipurpose data, with real-time data being collected by a private sector company for traveler information, and archived data made available for several designated planning purposes (like the Highway Performance Monitoring System database).

• **Better Construction Specifications**—Better construction specifications can help to ensure that electronic sensors are properly installed with the correct calibration settings. A 2002 report written for the Texas DOT found that having good loop detector construction and installation specifications contributed to minimal detector failures.³ This report provides numerous examples of loop detector specifications. Similar specifications for various nonintrusive detectors are typically available from the distributor or vendor.

• **Better Construction Inspection**—An established construction inspection and acceptance testing process for field devices will help a great deal, particularly for certain types of sensors like inductance loop detectors. Anecdotal experience has indicated that inductance loop detectors are particularly prone to long-term maintenance issues when they are not installed properly. In these cases, it pays to have a knowledgeable inspector who can verify that field devices have been installed and operate correctly before construction payments are made.

• **Performance-Based Contracts**—Another strategy involves the use of performance-based data collection or maintenance contracts. In these types of contracts, a private company is paid based on the performance of field equipment or the delivery of complete, quality data. For example, the planning division of the Virginia DOT contracts with private companies to count vehicle traffic on certain roads. If the vehicle count data are 100 percent fully complete, then the contractor is paid the full contract amount. If the vehicle count data falls below a certain threshold, then the contractor receives a certain percentage of the full contract amount (see Chapter 4 for more information on the VDOT contract specifications).

### 7.3.5 Develop Data Format and Storage Solutions

One of the most frequently mentioned barriers to integrating archived data are incompatible data formats. This incompatibility may be related to:

- The time interval in which data are reported; and/or
- The layout or structure of the data within the data file.

CHAPTER 7 INTEGRATING OPERATIONS DATA

Operations traffic managers typically collect data in time intervals as short as 20- to 60-s. In some cases, the data are stored at this level of detail in delimited text files. In many cases, the format for logging or archiving the operations data was based on convenience, not necessarily any input from archived data users.

There are numerous technical solutions to data format incompatibilities. Nearly all approaches will require updating existing software (i.e., the operations-based archiving software or data import software for planning databases) so be sure to involve the appropriate information systems staff in the early stages of discussion. The preferred approach will depend upon various factors, such as cooperation levels, available resources, timing of software updates, etc.

Ideally, the operations data should be archived in a format that is compatible with existing data import functions in the planning database. As documented in the case studies in Appendix B, several operations traffic management centers currently provide archived data in a format that can be directly imported into planning databases. This compatibility is accomplished by aggregating the data into longer time intervals (typically 15- or 60-min) and using standard data file formats already established for continuous counts or short-term machine counts. For example, FHWA’s Traffic Monitoring Guide (Section 6.0) outlines a specific data format for hourly traffic counts (#3 Record), in which each day of traffic count data are stored in a separate file (see Table 7-3). Similar file formats can be used for shorter time intervals (e.g., 15-min) or other data elements (e.g., speed).

If it is difficult to revise the operations-based archiving software, then the archived data can be post-processed and reformatted by software developed by the traditional traffic collection group. The software would perform the same functions in terms of aggregating data into prescribed time intervals and then reformattting the data into supported file formats. This planning-based software could be developed as a stand-alone application outside of the database management system, or it could be developed as an extension to the current system’s data import functions.

Integrating archived operations data into traditional traffic collection databases may require additional disk storage capacity, particularly if the integration involves many detector locations with detailed data (such as 15-min data by lane). The cost of computer disk storage has plummeted in recent years, and the value of having supplemental archived data in a traditional database may outweigh the incremental costs of expanding the disk storage capacity. Regardless, archived data integration efforts should involve the appropriate information systems staff to ensure that data storage issues are addressed.
Table 7-3. Hourly Traffic Volume Format (#3 Record) from Traffic Monitoring Guide

<table>
<thead>
<tr>
<th>Field</th>
<th>Columns</th>
<th>Length</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Record Type</td>
</tr>
<tr>
<td>2</td>
<td>2–3</td>
<td>2</td>
<td>FIPS State Code</td>
</tr>
<tr>
<td>3</td>
<td>4–5</td>
<td>2</td>
<td>Functional Classification</td>
</tr>
<tr>
<td>4</td>
<td>6–11</td>
<td>6</td>
<td>Station Identification</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>1</td>
<td>Direction of Travel</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>1</td>
<td>Lane of Travel</td>
</tr>
<tr>
<td>7</td>
<td>14–15</td>
<td>2</td>
<td>Year of Data</td>
</tr>
<tr>
<td>8</td>
<td>16–17</td>
<td>2</td>
<td>Month of Data</td>
</tr>
<tr>
<td>9</td>
<td>18–19</td>
<td>2</td>
<td>Day of Data</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>1</td>
<td>Day of Week</td>
</tr>
<tr>
<td>11</td>
<td>21–25</td>
<td>5</td>
<td>Traffic Volume Counted, 00:01–01:00</td>
</tr>
<tr>
<td>12</td>
<td>26–30</td>
<td>5</td>
<td>Traffic Volume Counted, 01:01–02:00</td>
</tr>
<tr>
<td>13</td>
<td>31–35</td>
<td>5</td>
<td>Traffic Volume Counted, 02:01–03:00</td>
</tr>
<tr>
<td>14</td>
<td>36–40</td>
<td>5</td>
<td>Traffic Volume Counted, 03:01–04:00</td>
</tr>
<tr>
<td>15</td>
<td>41–45</td>
<td>5</td>
<td>Traffic Volume Counted, 04:01–05:00</td>
</tr>
<tr>
<td>16</td>
<td>46–50</td>
<td>5</td>
<td>Traffic Volume Counted, 05:01–06:00</td>
</tr>
<tr>
<td>17</td>
<td>51–55</td>
<td>5</td>
<td>Traffic Volume Counted, 06:01–07:00</td>
</tr>
<tr>
<td>18</td>
<td>56–60</td>
<td>5</td>
<td>Traffic Volume Counted, 07:01–08:00</td>
</tr>
<tr>
<td>19</td>
<td>61–65</td>
<td>5</td>
<td>Traffic Volume Counted, 08:01–09:00</td>
</tr>
<tr>
<td>20</td>
<td>66–70</td>
<td>5</td>
<td>Traffic Volume Counted, 09:01–10:00</td>
</tr>
<tr>
<td>21</td>
<td>71–75</td>
<td>5</td>
<td>Traffic Volume Counted, 10:01–11:00</td>
</tr>
<tr>
<td>22</td>
<td>76–80</td>
<td>5</td>
<td>Traffic Volume Counted, 11:01–12:00</td>
</tr>
<tr>
<td>23</td>
<td>81–85</td>
<td>5</td>
<td>Traffic Volume Counted, 12:01–13:00</td>
</tr>
<tr>
<td>24</td>
<td>86–90</td>
<td>5</td>
<td>Traffic Volume Counted, 13:01–14:00</td>
</tr>
<tr>
<td>25</td>
<td>91–95</td>
<td>5</td>
<td>Traffic Volume Counted, 14:01–15:00</td>
</tr>
<tr>
<td>26</td>
<td>96–100</td>
<td>5</td>
<td>Traffic Volume Counted, 15:01–16:00</td>
</tr>
<tr>
<td>27</td>
<td>101–105</td>
<td>5</td>
<td>Traffic Volume Counted, 16:01–17:00</td>
</tr>
<tr>
<td>28</td>
<td>106–110</td>
<td>5</td>
<td>Traffic Volume Counted, 17:01–18:00</td>
</tr>
<tr>
<td>29</td>
<td>111–115</td>
<td>5</td>
<td>Traffic Volume Counted, 18:01–19:00</td>
</tr>
<tr>
<td>30</td>
<td>116–120</td>
<td>5</td>
<td>Traffic Volume Counted, 19:01–20:00</td>
</tr>
<tr>
<td>31</td>
<td>121–125</td>
<td>5</td>
<td>Traffic Volume Counted, 20:01–21:00</td>
</tr>
<tr>
<td>32</td>
<td>126–130</td>
<td>5</td>
<td>Traffic Volume Counted, 21:01–22:00</td>
</tr>
<tr>
<td>33</td>
<td>131–135</td>
<td>5</td>
<td>Traffic Volume Counted, 22:01–23:00</td>
</tr>
<tr>
<td>34</td>
<td>136–140</td>
<td>5</td>
<td>Traffic Volume Counted, 23:01–24:00</td>
</tr>
<tr>
<td>35</td>
<td>141</td>
<td>1</td>
<td>Restrictions</td>
</tr>
</tbody>
</table>
7.3.6 Focus on Priority Locations

As noted earlier, many traffic operations centers deploy their freeway traffic detectors in dense patterns (typically every one-half mile); however, other traffic data needs may not require such a dense spacing for traffic measurements. One approach to the integration of archived operations data is to focus on a subset of all operations-based traffic detector locations. Several of the case studies described in Appendix B contain examples of planning/traditional traffic data collection groups focusing on selected locations instead of trying to integrate the data from all of the traffic operations detectors.

This strategy already has been discussed in the context of improving data quality by focusing maintenance resources to provide higher quality data at fewer locations. Even if data quality is acceptable at all operations-based detector locations, this approach could be useful for other reasons. The time and effort spent in importing and reviewing data at all locations may be daunting during early stages of data integration. By taking smaller, incremental steps, the traffic planning group can better understand the archived operations data source before undertaking integration of all possible data and locations.

If this approach is used, the subset of operations-based detector locations can be determined based on one or more of these factors:

- Select locations based on gaps in existing continuous count coverage;
- Select locations based on approximate spacing and highest data quality;
- Select locations based on difficulty of existing manual data collection; or
- Select locations based on desired main lane anchor points for ramp-based freeway counts.

7.3.7 Develop or Adopt Agency Standards to Ensure Future Compatibility

The final consideration when integrating archived operations data is to develop agency standards to ensure that future traffic monitoring systems are more compatible than existing legacy systems. Within many DOTs, the operations group and the traditional traffic data group most likely have different data collection and monitoring equipment practices and procedures. Developing agency standards would provide compatibility between headquarters divisions as well as statewide districts.

The standards should be performance-based and should focus on desired outcomes (e.g., such as data exchange protocols, data file formats, data quality levels, etc.) that can be met by a variety of commercial products and applications. For example, which data elements must be measured? How accurate must the measurements be? How often must data be retrieved from field computers?

Standards development should avoid specifying certain manufacturers or technologies. It may be difficult to develop consensus on a single manufacturer or technology type, and a technology-specific standard may be quickly outdated as technologies evolve. In the long-term, specifying a manufacturer...
or technology type in standards may decrease competition, limit innovation, and ultimately increase the cost of products and services.

There are numerous national standards that have been or are being developed that relate to traffic data collection equipment, data exchange protocols, and data archiving. These existing traffic data standards should be considered for adoption where feasible, as it is likely to be counterproductive to develop local standards when national standards exist.

The traditional traffic monitoring community primarily develops standards through the American Society of Testing and Materials (ASTM). The ASTM traffic monitoring standards that currently are active are as follows:

- E2415-05—Standard Practice for Installing Piezoelectric Highway Traffic Sensors; and
- E2467-05—Standard Practice for Developing Axle Count Adjustment Factors.

Several relevant ASTM traffic monitoring standards currently are being developed:

- WK368 Specification for Highway Traffic Monitoring Devices;
- WK3556 Standard Practice/Guide for the Installation of Loop Detectors;
- WK4244 Standard Practice for Developing Axle Count Adjustment Factors; and

The U.S. DOT sponsors the development of many national standards through their Intelligent Transportation System (ITS) Standards Program. The ITS standards that are relevant to traffic data are too extensive to list here; instead the reader should consult these application areas at http://www.standards.its.dot.gov/learn_Application.asp:

- **Data Archival**—Standards in this area cover the interface between a transportation data archive and the sources of the archived data, as well as the interface between the data archive and users of the archived data. This includes ASTM Standard E2259-03—Guide for Archiving and Retrieving ITS-Generated Data and ASTM Standard E2468-05—Standard Practice for Metadata to Support Archived Data Management Systems.

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4 See http://www.astm.org (Committee E17.52 on Traffic Monitoring) for more information on ASTM traffic monitoring standards.

5 See http://www.standards.its.dot.gov/ for more information on the U.S. DOT’s ITS Standards Program.
• **Data Collection/Monitoring**—Standards in this area cover the interface between a center and a specific type of roadway equipment that monitors and collects traffic and environmental data—the data collection and monitoring (DCM) equipment. These standards are oriented primarily for non-real-time data collection, with the data being sent to a data archive.

• **Vehicle Sensors**—Standards in this area cover the interface between a center and a specific type of roadway equipment that provides vehicle detection, traffic monitoring, and extraction of traffic flow data (volume, speed, occupancy, etc.). These standards are oriented primarily for real-time data collection, with the data being sent to an operations traffic management center.

• **Traffic Signals**—Standards in this area cover the interface between an operations traffic management center and a specific type of roadway equipment that provides signalized intersection control—local traffic signal controller. Traffic sensors that detect traffic flow also are controlled by the traffic management center and are included in this application area.

### 7.4 Chapter Summary

This chapter discussed approaches to overcome the barriers most often associated with integrating operations data into traditional traffic data programs:

1. Archived operations data are difficult to access;
2. Archived operations data are stored in an incompatible format;
3. Archived operations data are of an unknown or inadequate quality; and
4. Operations data are not archived or is not available.

In many cases, these barriers can be overcome by encouraging institutional cooperation between different functional groups (i.e., typically the operations and planning divisions). Once a commitment has been made by the key stakeholders, technical solutions can be more easily developed to integrate the archived operations data.

Bridging the gap between existing operations data quality and data quality requirements for traditional data programs will remain a challenge. However, this section presented several approaches that, if implemented, will help to assess and improve the quality of archived operations data.

7.5 References


NCHRP. NCHRP 7-16 Interim Report: Recommended Revisions to the AASHTO Guidelines for Traffic Data Programs, April 2006.

Examples of Data Validation Standards

The example validation criteria included here address basic data formats, as well as vehicle count, classification, and weight data. Table A-1 summarizes a basic set of validation criteria used by a state DOT for traffic count data. Table A-2 summarizes the validation criteria from commercial traffic data software used in at least 10 state DOTs in the United States. Finally, Table A-3 summarizes the validation criteria from a transportation pooled-fund study sponsored by 15 state DOTs and the FHWA.¹

**Table A-1. Basic Validation Criteria for Traffic Counts from a State DOT**

- a. Completeness of data
- b. Hourly volume versus next/prior day—check consistency
- c. Hourly volume versus recent max/min—count too low or too high
- d. Hourly percent distributions by direction—peaks in correct position
- e. Zero volume for an hour—may be acceptable for some locations
- f. Consecutive hourly zero volumes—should not happen
- g. Consecutive hours with same nonzero volume
- h. Daily volume versus recent max/min—count too low or too high
- i. Daily directional splits

### Table A-2. Validation Criteria from Commercial Traffic Data Software

<table>
<thead>
<tr>
<th>Criteria Name</th>
<th>Criteria</th>
<th>Level of Application and Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axle Factor Threshold</td>
<td>This axle factor is used for validity checking purposes only. The axle factor is defined as the total volume for the count divided by the total number of axles for the count based on the standard FHWA axles/vehicle class figures. Typical values for this parameter might be “38 to 48.”</td>
<td>This check is applied to volume data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Directional Split—Error</td>
<td>This validity parameter represents the maximum allowable directional split. A value of “80” for this parameter means that a high alert level will be generated if more than 80 percent of the traffic is one direction for the count.</td>
<td>This check is applied to volume data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Directional Split—Warning</td>
<td>This validity parameter represents the maximum allowable directional split for a medium alert level message. A value of “60” for this parameter means that a medium alert level message will be generated if more than 60 percent but less than the value in “Directional Split—Error” of the traffic is in one direction for the count.</td>
<td>This check is applied to volume data at the detail level. It is a medium alert level message.</td>
</tr>
<tr>
<td>Interval—Weekday</td>
<td>This validity parameter represents the maximum hourly percent deviation using the “Weekday Interval” method. The Weekday Interval method of validity checking takes each individual hour for Monday through Friday and compares that value to the weekday average for that hour. If there is no weekday average for this site, the previous year’s monthly average weekday traffic (MAWDT) average hours are used.</td>
<td>This check is applied to volume data at the weekly level. It is a high alert level message.</td>
</tr>
<tr>
<td>Interval—Weekend</td>
<td>This validity parameter represents the maximum hourly percent deviation using the “Weekend Interval” method. The Weekend Interval method of validity checking takes each individual hour for Saturday and Sunday and compares it to the average of the two hours on either side.</td>
<td>This check is applied to volume data at the weekly level. It is a high alert level message.</td>
</tr>
<tr>
<td>Max Percent Lane 2 to Lane 1</td>
<td>This validity parameter represents the maximum allowable percentage of lane 2 (passing lane) volume to lane 1 (driving lane) volume. A value of “100” for this parameter means that a high alert level message will be generated if the lane 2 volume exceeds the lane 1 volume.</td>
<td>This check is applied to volume data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Max Percent Peak Hour Volume to Total Volume</td>
<td>This validity parameter represents the maximum allowable percentage of the peak hour volume to the total volume. A value of “20” for this parameter means that a high alert level message will be generated if the peak hour volume is greater than 20 percent (1/5th) of the daily volume.</td>
<td>This check is applied to volume data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Number of Consecutive Zeros</td>
<td>This validity parameter represents the maximum number consecutive zero hours allowed in the file. A value of “8” for this parameter means that a high alert level message will be generated if there are more than 8 hours of zeros in the file. The check is applied to each channel in the file.</td>
<td>This check is applied to volume data at the detail level. It is a high alert level message.</td>
</tr>
</tbody>
</table>

*(Table continued on next page.)*
Table A-2. Validation Criteria from Commercial Traffic Data Software (continued)

<table>
<thead>
<tr>
<th>Criteria Name</th>
<th>Criteria</th>
<th>Level of Application and Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Identical Values</td>
<td>This validity parameter represents the maximum number of consecutive, identical intervals allowed in the file. A value of “4” in this parameter means that a high alert level message will be generated if there are more than 4 intervals of identical values.</td>
<td>The check is done for each data channel in the file. This check is applied to volume data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Percent Difference—AADT</td>
<td>This validity parameter represents the maximum percent difference between the current AADT generated and the AADT from the prior year for continuous data.</td>
<td>This check is applied to continuous volume data at the annual level. It is a high alert level message.</td>
</tr>
<tr>
<td>Percent Difference—AADT for Short Term</td>
<td>This validity parameter represents the maximum percent difference between the current AADT generated and the AADT from the prior year for short-term data.</td>
<td>This check is applied to short-term volume data at the daily level. It is a high alert level message.</td>
</tr>
<tr>
<td>Percent Difference—MADT</td>
<td>This validity parameter represents the maximum percent difference between the current MADT generated and the MADT from the prior year and same month for continuous data.</td>
<td>This check is applied to continuous volume data at the monthly level. It is a high alert level message.</td>
</tr>
<tr>
<td>Percent Difference—Weekly Versus MADT</td>
<td>This validity parameter represents the maximum percent difference between the current weekly average generated and the MADT from the prior year and same month for continuous data.</td>
<td>This check is applied to continuous volume data at the weekly level. It is a high alert level message.</td>
</tr>
<tr>
<td>7 to 7 Allowable Zeros</td>
<td>This validity parameter represents the allowable number of intervals with zeros between 7:00 a.m. and 7:00 p.m. A value of “0” for this parameter means that a high alert error will be generated by if there are any zeroes between 7:00 a.m. and 7:00 p.m.</td>
<td>This check is applied to volume data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Classification Thresholds</td>
<td>The vehicle classification percentage for a given vehicle class must fall between the low and high values set for this parameter.</td>
<td>It is applied to vehicle classification data at the detailed level. This is a high alert level message.</td>
</tr>
<tr>
<td>Max Hourly Rise of Class 8s</td>
<td>This validity parameter represents the maximum allowable percentage hourly rise of class 8s. A value of “150” for this parameter means that a high alert level message will be generated if a given hour’s Class 8 volume increases by 150 percent from the prior hour’s Class 8 volume.</td>
<td>This check is applied to vehicle classification data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Max percent of Class 3s to Class 2s</td>
<td>This validity parameter represents the maximum allowable percentage of class 3s to class 2s. A value of “100” for this parameter means that a high alert level message will be generated if there are more Class 3s than Class 2s.</td>
<td>This check is applied to vehicle classification data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Maximum percent of Class 8s to Class 9s</td>
<td>This validity parameter represents the maximum allowable percentage of Class 8s to Class 9s. A value of “100” for this parameter means that a high alert level message will be generated if there are more Class 8s than Class 9s.</td>
<td>This check is applied to vehicle classification data at the detail level. It is a high alert level message.</td>
</tr>
</tbody>
</table>

(Table continued on next page.)
### Table A-2. Validation Criteria from Commercial Traffic Data Software (continued)

<table>
<thead>
<tr>
<th>Criteria Name</th>
<th>Criteria</th>
<th>Level of Application and Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum percent of Classes 8+9 to Class 2s</td>
<td>This validity parameter represents the maximum allowable percentage of Class 8s plus Class 9s to Class 2s. A value of “100” for this parameter means that a high alert level message will be generated if there are more Class 8s and Class 9s than Class 2s.</td>
<td>This check is applied to vehicle classification data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Number of Class 14s:</td>
<td>This validity parameter represents the maximum allowable number of class 14s. A value of “0” for this parameter means that a high alert level message will be generated if there are any Class 14s.</td>
<td>This check is applied to vehicle classification data at the detail level. It is a high alert level message.</td>
</tr>
<tr>
<td>Number of Zero WIM Hours</td>
<td>This validity parameter represents the maximum number of consecutive hours with no vehicle records allowed in a count. A value of “23” in this parameter means that a high alert level message will be generated if more than 23 hours exist with no vehicle records.</td>
<td>This check is applied to WIM data (individual vehicle records) at the detail level. This is a high alert level message.</td>
</tr>
<tr>
<td>Average Steering Axle Weight</td>
<td>The minimum and maximum values are set through the “Average steering axle &gt; (pounds)” and “Average steering axle &lt; (pounds)” parameters. A value of –1 tells to skip the check.</td>
<td>This check is applied only to Class 9 vehicles at a daily level. This check would normally not vary by site or time.</td>
</tr>
<tr>
<td>Axle spacing check</td>
<td>The “Minimum axle spacing” and “Maximum axle spacing” parameters define this check. Units are feet and tenths.</td>
<td>The check is applied to each vehicle record. This check would normally not vary by site or time.</td>
</tr>
<tr>
<td>Axle weight check</td>
<td>The “Minimum axle weight” and “Maximum axle weight” parameters are in kips.</td>
<td>This check also is applied to each vehicle. This check would normally not vary by site or time.</td>
</tr>
<tr>
<td>Axle weights do not add up to vehicle weight</td>
<td>This check is not parameterized.</td>
<td>This check also is applied to each vehicle. This check would normally not vary by site or time.</td>
</tr>
<tr>
<td>Number of annual average days of the week (AADW) for an AADT</td>
<td>This filter represents how many AADWs are required before the software can successfully calculate an AADT.</td>
<td>This filter is used during Annual Processing Phase 1.</td>
</tr>
<tr>
<td>Number of Days for an MADW</td>
<td>This filter represents how many days of data are required before the software can successfully calculate an MADW for a particular day of week</td>
<td>This filter is used during Monthly Processing.</td>
</tr>
<tr>
<td>Number of monthly average days of the week (MADW) for an AADT</td>
<td>This filter represents how many MADWs are required before the software can successfully calculate an MADW.</td>
<td>This filter is used during Annual Processing Phase 1.</td>
</tr>
<tr>
<td>Number of MADWs for monthly average daily traffic (MADT)</td>
<td>This filter represents how many MADWs are required before the software can successfully calculate an MADT.</td>
<td>This filter is used during Monthly Processing</td>
</tr>
</tbody>
</table>
Table A-3. Validation Criteria from the Traffic Data Edit Procedures Pooled-Fund Study

<table>
<thead>
<tr>
<th>ID #</th>
<th>Criteria Name</th>
<th>Criteria Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 V42</td>
<td>Date is Correct and Unique</td>
<td>If the date of the input data is not correct or unique, the record will not be loaded into the database. An input error message will be reported.</td>
</tr>
<tr>
<td>1 V43</td>
<td>Lane and Direction are Correct</td>
<td>If the lane or direction fields in the input data do not match the station record, the input data will not be loaded into the database. An input error message will be reported.</td>
</tr>
<tr>
<td>2 C49</td>
<td>Number of Axles = Number of Axle Spaces + 1</td>
<td>Any vehicle record where the number of axles does not equal the number of axle spaces plus one will be flagged.</td>
</tr>
<tr>
<td>3 W70</td>
<td>Number of Axles = Number of Axle Weights</td>
<td>Any vehicle record where the number of axles does not equal the number of axle weights will be flagged.</td>
</tr>
<tr>
<td>4 W35</td>
<td>Sum of Axle Weights Does Not = GVW</td>
<td>Any vehicle record where the sum of the axle weights does not equal the recorded GVW will be flagged.</td>
</tr>
<tr>
<td>5 V1</td>
<td>Completeness of Data</td>
<td>If the input data is insufficient or invalid in any way, an error message will be reported.</td>
</tr>
<tr>
<td>6 V2</td>
<td>Zero Volume for an Hour</td>
<td>Any hourly volume of zero in any lane will be flagged.</td>
</tr>
<tr>
<td>7 V4</td>
<td>Extreme Hourly Volume per Lane</td>
<td>The hourly volume in any lane will be reported as anomalous if exceeds this global extreme maximum.</td>
</tr>
<tr>
<td>8 V32</td>
<td>1:00 a.m. to 2:00 a.m. Volume versus 1:00 p.m. to 2:00 p.m. Volume</td>
<td>If the 1:00 a.m. to 2:00 a.m. volume is greater than the 1:00 p.m. to 2:00 p.m. volume of the same day, a warning will be reported.</td>
</tr>
<tr>
<td>9 C1</td>
<td>No Classification Data</td>
<td>If no volumes for any vehicle classes are present in the input data, an error message will be reported.</td>
</tr>
<tr>
<td>10 W51</td>
<td>Record Contains Valid Date</td>
<td>Any vehicle record containing an invalid or unexpected date will be flagged.</td>
</tr>
<tr>
<td>11 W52</td>
<td>Record Contains Valid Lane Number</td>
<td>Any vehicle record containing a lane that does not match the station record will be flagged.</td>
</tr>
<tr>
<td>12 W53</td>
<td>Record Contains Valid Class Number</td>
<td>Any vehicle record containing an invalid class number will be flagged.</td>
</tr>
<tr>
<td>13 C24</td>
<td>Number of Axles Min/Max</td>
<td>Any vehicle having more or less than the number of axles in this range will be flagged.</td>
</tr>
<tr>
<td>14 W36</td>
<td>Wheelbase Exceeds Value for Class</td>
<td>Any vehicle of this class having a recorded wheelbase greater than this maximum will be flagged.</td>
</tr>
<tr>
<td>15 W39</td>
<td>GVW Exceeds Value for Class</td>
<td>Any vehicle of this class having a recorded GVW greater than this maximum will be flagged.</td>
</tr>
<tr>
<td>16 W28</td>
<td>Front Overhang Out of Range</td>
<td>Any vehicle with a front overhang outside of this range will be flagged.</td>
</tr>
<tr>
<td>17 W26</td>
<td>Rear Overhang Out of Range</td>
<td>Any vehicle with a rear overhang outside of this range will be flagged.</td>
</tr>
<tr>
<td>18 W30</td>
<td>Sum of Axle Spaces &gt; or = Recorded Vehicle Length</td>
<td>Any vehicle where the sum of the axle spaces is greater than the recorded vehicle length will be flagged.</td>
</tr>
<tr>
<td>19 W24</td>
<td>Record Contains Off-Scale Warning</td>
<td>Any vehicle record containing a vendor’s off-scale warning code will be flagged.</td>
</tr>
<tr>
<td>20 W46</td>
<td>Wheelpath Imbalance Exceeds Threshold</td>
<td>Any vehicle with the total weight on one side exceeding the total weight on the other side by more than this maximum will be flagged.</td>
</tr>
<tr>
<td>21 C35</td>
<td>Vehicle Exceeding Speed Min/Max</td>
<td>Any vehicle with a recorded speed outside of this range will be flagged.</td>
</tr>
</tbody>
</table>

(Table continued on next page.)
The number of consecutive zero-volume hours in any one lane will be reported as anomalous if it exceeds this daily maximum.

34 V7 Consecutive Hours with Same Nonzero Volume The number of consecutive hours with the same nonzero volume in the same lane will be reported as anomalous if it exceeds this daily maximum.

35 V28 Sunday Hourly Directional Split Sunday's hourly directional split will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.

36 V28 Monday Hourly Directional Split Monday's hourly directional split will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.

37 V28 Tuesday Hourly Directional Split Tuesday's hourly directional split will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.

38 V28 Wednesday Hourly Directional Split Wednesday's hourly directional split will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.

39 V28 Thursday Hourly Directional Split Thursday's hourly directional split will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.

40 V28 Friday Hourly Directional Split Friday's hourly directional split will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.
### Table A-3. Validation Criteria from the Traffic Data Edit Procedures Pooled-Fund Study (continued)

<table>
<thead>
<tr>
<th>ID #</th>
<th>Criteria Name</th>
<th>Criteria Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>41 V28</td>
<td>Saturday Hourly Directional Split</td>
<td>Saturday’s hourly directional split will be reported as anomalous if the leading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direction’s percentage varies from its historical minimum or maximum by more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td>these tolerances.</td>
</tr>
<tr>
<td>42 V9</td>
<td>Hourly Volume versus Next/Prior Day</td>
<td>The total hourly volume will be reported as anomalous if it is greater than or less</td>
</tr>
<tr>
<td></td>
<td></td>
<td>than the total volume for that hour of the previous or following day by these</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tolerances.</td>
</tr>
<tr>
<td>43 V17a</td>
<td>Daily Directional Volume versus AADT</td>
<td>The daily directional volume will be reported as anomalous if it is greater than or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>less than the previous year’s adjusted directional AADT by these tolerances.</td>
</tr>
<tr>
<td>44 V33</td>
<td>Daily Combined Volume versus AADT</td>
<td>The daily combined volume will be reported as anomalous if it is greater than or less</td>
</tr>
<tr>
<td></td>
<td></td>
<td>than the previous year’s adjusted AADT by these tolerances.</td>
</tr>
<tr>
<td>45 V5</td>
<td>Sunday Daily Directional Split</td>
<td>Sunday’s daily directional split will be reported as anomalous if the leading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direction’s percentage varies from its historical minimum or maximum by more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td>these tolerances.</td>
</tr>
<tr>
<td>46 V5</td>
<td>Monday Daily Directional Split</td>
<td>Monday’s daily directional split will be reported as anomalous if the leading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direction’s percentage varies from its historical minimum or maximum by more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td>these tolerances.</td>
</tr>
<tr>
<td>47 V5</td>
<td>Tuesday Daily Directional Split</td>
<td>Tuesday’s daily directional split will be reported as anomalous if the leading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direction’s percentage varies from its historical minimum or maximum by more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td>these tolerances.</td>
</tr>
<tr>
<td>48 V5</td>
<td>Wednesday Daily Directional Split</td>
<td>Wednesday’s daily directional split will be reported as anomalous if the leading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direction’s percentage varies from its historical minimum or maximum by more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td>these tolerances.</td>
</tr>
<tr>
<td>49 V5</td>
<td>Thursday Daily Directional Split</td>
<td>Thursday’s daily directional split will be reported as anomalous if the leading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direction’s percentage varies from its historical minimum or maximum by more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td>these tolerances.</td>
</tr>
<tr>
<td>50 V5</td>
<td>Friday Daily Directional Split</td>
<td>Friday’s daily directional split will be reported as anomalous if the leading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direction’s percentage varies from its historical minimum or maximum by more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td>these tolerances.</td>
</tr>
<tr>
<td>51 V5</td>
<td>Saturday Daily Directional Split</td>
<td>Saturday’s daily directional split will be reported as anomalous if the leading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>direction’s percentage varies from its historical minimum or maximum by more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td>these tolerances.</td>
</tr>
<tr>
<td>52 C48</td>
<td>Full Day of Data Exists</td>
<td>If less than 24 h of data is present, a warning will be reported as anomalous.</td>
</tr>
<tr>
<td>53 C4</td>
<td>Extreme Daily Percent in Any Class Except 2</td>
<td>The daily percent of vehicles binned to any class except 2 (cars) will be reported as</td>
</tr>
<tr>
<td></td>
<td></td>
<td>anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>54 C37</td>
<td>Excessive Daily Percent by Class</td>
<td>The daily percent of vehicles binned to any class except 2 or 3 will be reported as</td>
</tr>
<tr>
<td></td>
<td></td>
<td>anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>55 C38</td>
<td>Excessive Daily Volume by Class</td>
<td>The daily volume of vehicles binned to any class except 2 or 3 will be reported as</td>
</tr>
<tr>
<td></td>
<td></td>
<td>anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>56 W16</td>
<td>Unloaded Class 9 GVW Distribution Peak</td>
<td>The majority of unloaded Class 9 GVWs are expected to fall within this weight range.</td>
</tr>
<tr>
<td>57 W16</td>
<td>Unloaded Class 11 GVW Distribution Peak</td>
<td>The majority of unloaded Class 11 GVWs are expected to fall within this weight range.</td>
</tr>
</tbody>
</table>

(Table continued on next page.)
Table A-3. Validation Criteria from the Traffic Data Edit Procedures Pooled-Fund Study (continued)

<table>
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<tr>
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<th>Criteria Name</th>
<th>Criteria Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>58 W17</td>
<td>Loaded Class 9 GVW Distribution Peak</td>
<td>The majority of loaded Class 9 GVWs are expected to fall within this weight range.</td>
</tr>
<tr>
<td>59 W17</td>
<td>Loaded Class 11 GVW Distribution Peak</td>
<td>The majority of loaded Class 11 GVWs are expected to fall within this weight range.</td>
</tr>
<tr>
<td>60 W68</td>
<td>Percent of Vehicles With GVW Out of Range for Class</td>
<td>The daily percent of vehicles flagged for excessive GVW will be reported as anomalous if it exceeds this maximum</td>
</tr>
<tr>
<td>61 W67</td>
<td>Percent of Vehicles with Invalid Class</td>
<td>The daily percent of vehicles flagged for an invalid class designation will be reported as anomalous if it exceeds this maximum</td>
</tr>
<tr>
<td>62 W21</td>
<td>Average Class 9 Steering Axle Weight</td>
<td>The daily average Class 9 front-axle weight will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>63 W21</td>
<td>Average Class 11 Steering Axle Weight</td>
<td>The daily average Class 11 front-axle weight will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>64 W65</td>
<td>Percent of Records with Invalid Dates</td>
<td>The daily percent of vehicle records flagged for an invalid date will be reported as anomalous if it exceeds this maximum</td>
</tr>
<tr>
<td>65 W66</td>
<td>Percent of Records with Invalid Lane</td>
<td>The daily percent of vehicle records flagged for an invalid lane will be reported as anomalous if it exceeds this maximum</td>
</tr>
<tr>
<td>66 W56</td>
<td>Average Steering Axle Weight for Light-GVW Class 9s</td>
<td>The average steering axle weight of all Class 9 vehicles with a GVW of less than 32,000 lb will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>67 W56</td>
<td>Average Steering Axle Weight for Mid-GVW Class 9s</td>
<td>The average steering axle weight of all Class 9 vehicles with a GVW of between 32,000 lb and 70,000 lb will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>68 W56</td>
<td>Average Steering Axle Weight for Heavy-GVW Class 9s</td>
<td>The average steering axle weight of all Class 9 vehicles with a GVW of more than 70,000 lb will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>69 W56</td>
<td>Average Steering Axle Weight for Light-GVW Class 11s</td>
<td>The average steering axle weight of all Class 11 vehicles with a GVW of less than 32,000 lb will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>70 W56</td>
<td>Average Steering Axle Weight for Mid-GVW Class 11s</td>
<td>The average steering axle weight of all Class 11 vehicles with a GVW of between 32,000 lb and 70,000 lb will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>71 W56</td>
<td>Average Steering Axle Weight for Heavy-GVW Class 11s</td>
<td>The average steering axle weight of all Class 11 vehicles with a GVW of Class 11s more than 70,000 lb will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>72 W58</td>
<td>Percent of Class 9s with Front Axle Weight Flags</td>
<td>The daily percent of Class 9 vehicles flagged for an out-of-range front axle weight will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>73 W58</td>
<td>Percent of Class 11s with Front Axle Weight Flags</td>
<td>The daily percent of Class 11 vehicles flagged for an out-of-range front axle weight will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>74 C2</td>
<td>Percent of Records with Vendor Warning Codes</td>
<td>The daily percent of vehicle records containing a vendor’s warning code will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>75 W62</td>
<td>Percent of Vehicles Where GVW Is Not = Sum of Axle Weights</td>
<td>The daily percent of vehicle records where the GVW is not equal (within rounding error) to the sum of the axle weights will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>76 W60</td>
<td>Percent of Vehicles with Overhang Flags</td>
<td>The daily percent of vehicles with overhang flags will be reported as anomalous if it exceeds this maximum.</td>
</tr>
</tbody>
</table>

(Table continued on next page.)
Table A-3. Validation Criteria from the Traffic Data Edit Procedures Pooled-Fund Study (continued)

<table>
<thead>
<tr>
<th>ID #</th>
<th>Criteria Name</th>
<th>Criteria Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>77 W8</td>
<td>Percent of Vehicles Where Length &lt; Wheelbase</td>
<td>The daily percentage of vehicles where the sum of the axle spaces is greater than the recorded vehicle length will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>78 W10</td>
<td>Class 9 Average Length Within Range + Average Wheelbase</td>
<td>The average Class 9 vehicle length and wheelbase relationship will be reported as anomalous if the average length is not within the sum of the average wheelbase and this range.</td>
</tr>
<tr>
<td>79 W10</td>
<td>Class 11 Average Length Within Range + Average Wheelbase</td>
<td>The average Class 11 vehicle length and wheelbase relationship will be reported as anomalous if the average length is not within the sum of the average wheelbase and this range.</td>
</tr>
<tr>
<td>80 W45</td>
<td>Percent of Records with Off-Scale Warnings</td>
<td>The daily percent of vehicle records containing a vendor’s off-scale warning will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>81 W47</td>
<td>Pattern of Vehicles With Wheelpath Imbalance</td>
<td>An otherwise anomalous percent of wheelpath imbalances will not be reported as anomalous if opposite wheelpath imbalances are detected in opposite directions (likely due to crosswinds).</td>
</tr>
<tr>
<td>82 W54</td>
<td>Percent of Vehicles with Wheelpath Imbalance</td>
<td>The daily percent of vehicles with wheelpath imbalance flags will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>83 W59</td>
<td>Percent of Vehicles That Exceed Extreme Max Speed</td>
<td>The daily percent of vehicles with globally extreme speed flags will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>84 C40</td>
<td>Percent of Vehicles Slower Than Speed Min</td>
<td>The daily percent of vehicles with speeds less than the station minimum will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>85 C40</td>
<td>Percent of Vehicles Faster Than Speed Max</td>
<td>The daily percent of vehicles with speeds greater than the station maximum will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>86 W61</td>
<td>Percent of Heavy Class 6 Vehicles with Close Follower</td>
<td>The percent of Class 6 vehicles flagged for excessive GVW with a closely following vehicle will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>87 C15</td>
<td>Average 3S-2 Drive Tandem Spacing</td>
<td>The daily average drive tandem spacing for 3S-2 vehicles will be reported as anomalous if it falls outside of this range.</td>
</tr>
<tr>
<td>88 W63</td>
<td>Percent of Vehicles with Wheelbase or Axle Spacing Flags</td>
<td>The daily percent of vehicles with wheelbase or axle spacing flags set by the default values for their class will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>89 W64</td>
<td>Percent of Vehicles with an Axle Weight Flag</td>
<td>The daily percent of vehicles with an axle weight flag set by the default values for their class will be reported as anomalous if it exceeds this maximum.</td>
</tr>
<tr>
<td>90 W55</td>
<td>Average Left Axle Weight Versus Average Right Axle Weight</td>
<td>The average left and right axle weights for all vehicles will be reported as anomalous if they differ by more than this maximum percent.</td>
</tr>
<tr>
<td>91 V19</td>
<td>Hourly Directional Volume Versus History</td>
<td>An hourly directional volume will be reported as anomalous if it differs from its historical minimum or maximum for that hour by more than these tolerances.</td>
</tr>
<tr>
<td>92 V40</td>
<td>Hourly Combined Volume Versus Recent History</td>
<td>An hourly combined volume will be reported as anomalous if it differs from its historical minimum or maximum for that hour by more than these tolerances.</td>
</tr>
<tr>
<td>93 V39</td>
<td>Daily Combined Volume Versus Recent History</td>
<td>A daily combined volume will be reported as anomalous if it differs from its historical minimum or maximum by more than these tolerances</td>
</tr>
</tbody>
</table>

(Table continued on next page.)
Table A-3. Validation Criteria from the Traffic Data Edit Procedures Pooled-Fund Study (continued)

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</tr>
</thead>
<tbody>
<tr>
<td>94</td>
<td>Daily Directional Volume Versus History</td>
<td>A daily directional volume will be reported as anomalous if it differs from its historical minimum or maximum by more than these tolerances.</td>
</tr>
<tr>
<td>95</td>
<td>Daily Percent Distribution by Lane Versus History</td>
<td>The daily lane distribution will be reported as anomalous if any lane differs from its historical average percent by more than these tolerances.</td>
</tr>
<tr>
<td>96</td>
<td>Daily Volume Binned to One Class Versus History</td>
<td>The daily volume binned to a single vehicle class except 2 or 3 will be reported as anomalous if it differs from its historical minimum or maximum volume by more than these tolerances.</td>
</tr>
<tr>
<td>97</td>
<td>Daily Percent Binned to One Class Versus History</td>
<td>The daily percent binned to a single vehicle class will be reported as anomalous if it differs from the historical average percent for that class by more than these tolerances.</td>
</tr>
<tr>
<td>98</td>
<td>Daily Volume of Both Class 6 and 1 Exceed History</td>
<td>The daily volumes of Class 1 and Class 6 vehicles will be reported as anomalous if both are greater than their average historical values.</td>
</tr>
<tr>
<td>99</td>
<td>Daily Ratio of Class 2 to 3 Versus History</td>
<td>The daily ratio of Class 2 vehicles to Class 3 vehicles will be reported as anomalous if the number of Class 2s per one Class 3 varies by more than these tolerances.</td>
</tr>
<tr>
<td>100</td>
<td>Daily Ratio of Class 9 to 8 by Lane Versus History</td>
<td>The daily ratio of Class 9 vehicles to Class 8 vehicles in a lane will be reported as anomalous if the number of Class 9s per one Class 8 differs from the historical minimum or maximum ratio by more than these tolerances.</td>
</tr>
<tr>
<td>101</td>
<td>Daily Ratio of Class 9 to 8 by Direction Versus History</td>
<td>The daily ratio of Class 9 vehicles to Class 8 vehicles in each direction will be reported as anomalous if the number of Class 9s per one Class 8 differs from the historical minimum or maximum ratio by more than these tolerances.</td>
</tr>
<tr>
<td>102</td>
<td>Daily Sum of Class 8 and 9 Versus History</td>
<td>The daily sum of Class 8 and Class 9 vehicles will be reported as anomalous if it differs from the historical minimum or maximum sum of these two classes by more that these tolerances.</td>
</tr>
<tr>
<td>103</td>
<td>Daily Class 8 Directional Split Versus History</td>
<td>The daily directional split percentages for Class 8 vehicles will be reported as anomalous if the leading direction’s percentage varies from its historical minimum or maximum by more than these tolerances.</td>
</tr>
<tr>
<td>104</td>
<td>Daily Class 9 Directional Split Versus History</td>
<td>The daily directional split percentages for Class 9 vehicles will be reported as anomalous if the leading direction’s percentage varies from its historical minimum or maximum by more than these tolerances.</td>
</tr>
<tr>
<td>105</td>
<td>Daily Sum of Class 8 and 9 Directional Split Versus History</td>
<td>The daily directional split percentages for the sum of Class 8 and Class 9 vehicles will be reported as anomalous if the leading direction’s percentage varies from its historical minimum or maximum by more than these tolerances.</td>
</tr>
<tr>
<td>106</td>
<td>Daily Directional Split of Any Class (not 8 or 9) Versus History</td>
<td>The daily directional split percentages for any vehicle class will be reported as anomalous if the leading direction’s percentage varies from its historical minimum or maximum by more that these tolerances.</td>
</tr>
<tr>
<td>107</td>
<td>Daily Directional Split of Sum of Class 4 Through 13 Versus History</td>
<td>The daily directional split percentages for the sum of all commercial vehicles will be reported as anomalous if the leading direction’s percentage varies from its historical minimum or maximum by more that these tolerances.</td>
</tr>
</tbody>
</table>

(Table continued on next page.)
### Table A-3. Validation Criteria from the Traffic Data Edit Procedures Pooled-Fund Study (continued)

<table>
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<tr>
<th>ID #</th>
<th>Criteria Name</th>
<th>Criteria Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>108 C47</td>
<td>Daily Directional Split of Class Groups Versus History</td>
<td>The daily directional split percentages for any class group (passenger, truck, semitruck, and multitrailer) will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.</td>
</tr>
<tr>
<td>109 C16</td>
<td>Monthly Directional Split of Sum of Class 4 Through 13 Versus History</td>
<td>The monthly directional split percentages for the sum of all commercial vehicles will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.</td>
</tr>
<tr>
<td>110 C47</td>
<td>Monthly Directional Split of Class Groups Versus History</td>
<td>The monthly directional split percentages for any class group (passenger, truck, semitruck, and multitrailer) will be reported as anomalous if the leading direction's percentage varies from its historical minimum or maximum by more than these tolerances.</td>
</tr>
<tr>
<td>111 W18</td>
<td>Unloaded Class 9 GVW Distribution Peak Shift</td>
<td>A shift in the unloaded GVWs for Class 9 vehicles will be reported if the central tendency of the input data is not within these percent tolerances of the historical central tendency.</td>
</tr>
<tr>
<td>112 W19</td>
<td>Loaded Class 9 GVW Distribution Peak Shift</td>
<td>A shift in the loaded GVWs for Class 9 vehicles will be reported if the central tendency of the input data is not within these percent tolerances of the historical central tendency.</td>
</tr>
<tr>
<td>113 W23</td>
<td>Loaded Versus Unloaded Class 9 GVW Distribution Peaks</td>
<td>A parallel shift in Class 9 GVWs will be reported if the loaded central tendency's shift from its historical value minus the unloaded central tendency's shift from its historical value is not within these percent tolerances.</td>
</tr>
<tr>
<td>114 W20</td>
<td>Incidental Class 9 GVW Distribution Peak Shift</td>
<td>A shift in the major incidental GVW peak for Class 9 vehicles (if there is one) will be reported if the central tendency of the input data is not within these percent tolerances of a matching historical central tendency.</td>
</tr>
<tr>
<td>115 W18</td>
<td>Unloaded Class 11 GVW Distribution Peak Shift</td>
<td>A shift in the unloaded GVWs for Class 11 vehicles will be reported if the central tendency of the input data is not within these percent tolerances of the historical central tendency.</td>
</tr>
<tr>
<td>116 W19</td>
<td>Loaded Class 11 GVW Distribution Peak Shift</td>
<td>A shift in the loaded GVWs for Class 11 vehicles will be reported if the central tendency of the input data is not within these percent tolerances of the historical central tendency.</td>
</tr>
<tr>
<td>117 W23</td>
<td>Loaded Versus Unloaded Class 11 GVW Distribution Peaks</td>
<td>A parallel shift in Class 11 GVWs will be reported if the loaded central tendency's shift from its historical value minus the unloaded central tendency's shift from its historical value is not within these percent tolerances.</td>
</tr>
<tr>
<td>118 W20</td>
<td>Incidental Class 11 GVW Distribution Peak Shift</td>
<td>A shift in the major incidental GVW peak for Class 11 vehicles (if there is one) will be reported if the central tendency of the input data is not within these percent tolerances of a matching historical central tendency.</td>
</tr>
<tr>
<td>119 C6</td>
<td>Daily Average Speed per Lane Versus History</td>
<td>The average vehicle speed in each lane will be reported as anomalous if it differs from the historical average speed for that lane by more than these tolerances.</td>
</tr>
</tbody>
</table>