Section 2

Introduction to Traffic Monitoring

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INTRODUCTION TO TRAFFIC MONITORING

CHAPTER 1
INTRODUCTION

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

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

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

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

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

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

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

Examples of these refinements include the following:

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

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

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

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

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

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

CHAPTER 2
VARIABILITY IN THE TRAFFIC STREAM

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

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

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

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

INTRODUCTION

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

TIME-OF-DAY VARIATION

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

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

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

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

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

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

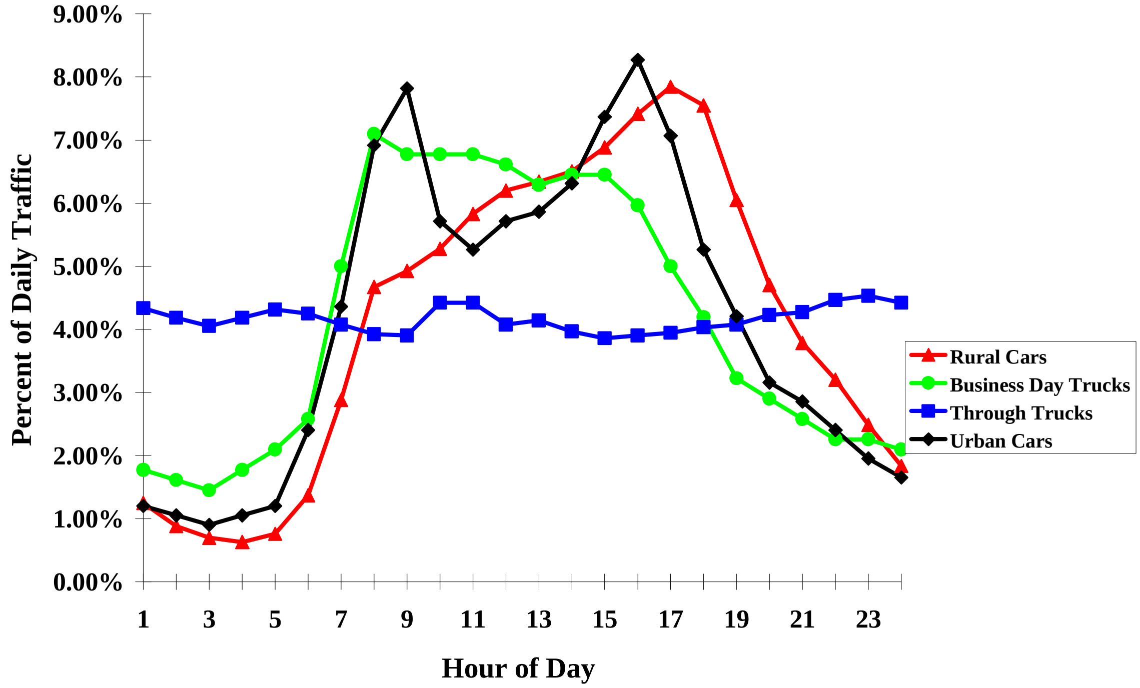

Figure 2-2-1
Basic Time of Day Patterns

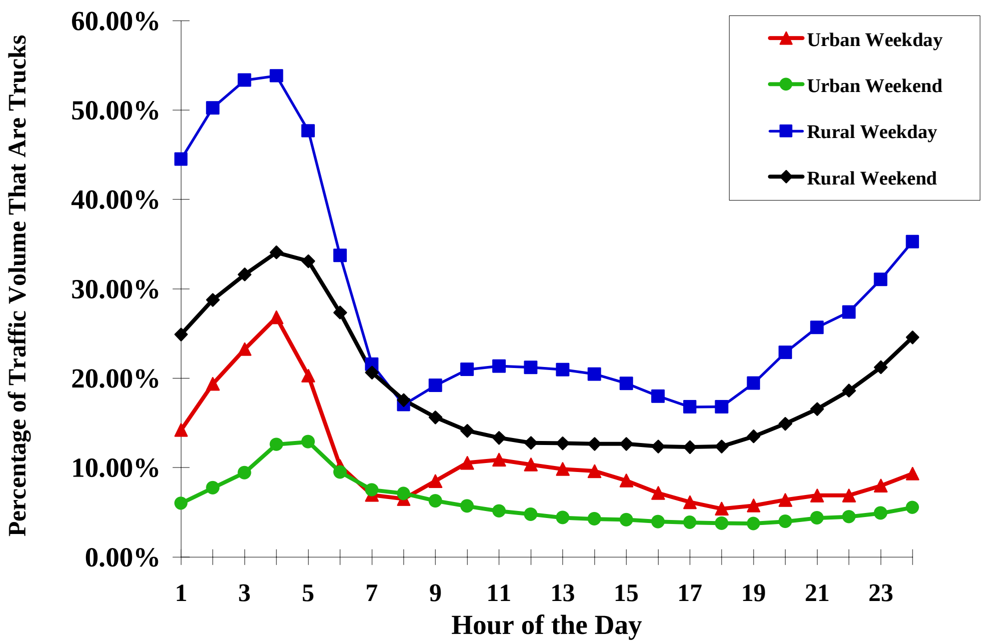

Figure 2-2-2
Weekday/Weekend Truck Percentages

DAY-OF-WEEK VARIATION

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

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

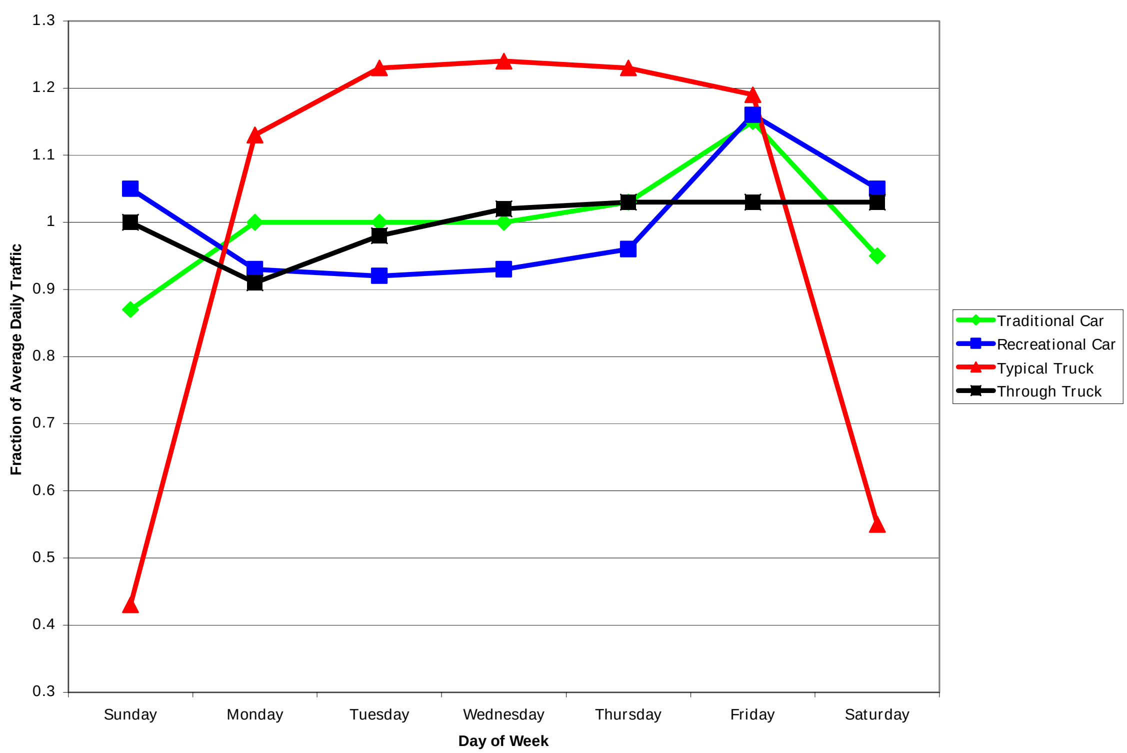

Figure 2-2-3
Typical Day-of-Week Traffic Patterns

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

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

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

SEASONAL VARIATION

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

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

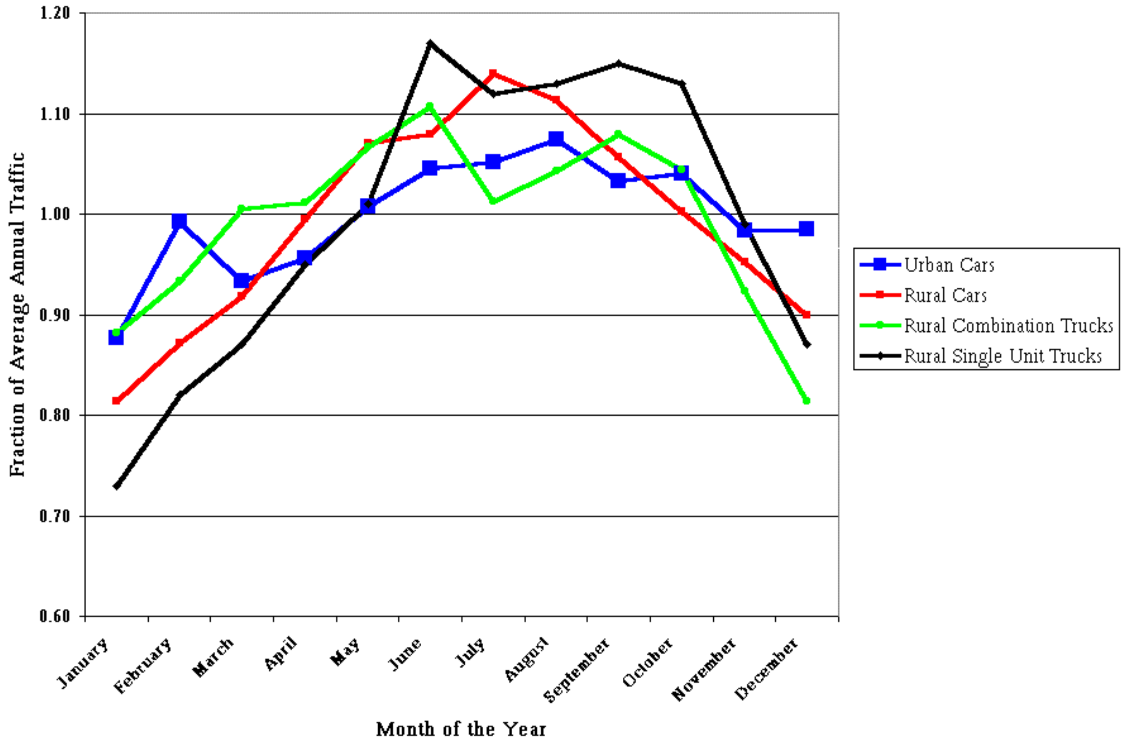

Figure 2-2-4
Typical Monthly Volume Patterns

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

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

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

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

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

DIRECTIONAL VARIATION

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

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

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

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

GEOGRAPHIC VARIATION

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

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

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

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

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

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

CHAPTER 3
DATA COLLECTION DESIGN
ACCOUNTING FOR VARIABILITY

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

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

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

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

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

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

INTEGRATION OF DATA COLLECTION EFFORTS

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

Table 2-3-1

Types of Data Provided By Different Types of Data Collection Devices

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

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

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

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

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

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

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

CONTINUOUS COUNTS

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

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

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

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

Automatic Traffic Recorders

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

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

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

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

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

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

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

Statewide Continuous Vehicle Classification Sites

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

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

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

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

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

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

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

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

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

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

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

<u>LTPP Sites</u>

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

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

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

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

WIM Scales at Enforcement Sites

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

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

Statewide Weigh-in-Motion Sites

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

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

Traffic Operations Data

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

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

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

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

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

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

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

SITE SELECTION FOR CONTINUOUS COUNTERS

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

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

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

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

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

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

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

SHORT DURATION COUNTS[5]

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

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

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

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

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

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

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

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

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

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

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

Short Count Program Design

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

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

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

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

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

Coverage Count Programs

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

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

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

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

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

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

The HPMS Sample

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

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

Other Statistical Samples

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

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

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

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

Other Special Needs Counts

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

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

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

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

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

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

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

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

CHAPTER 4
FACTORING TRAFFIC COUNTS

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

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

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

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

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

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

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

THE CREATION OF FACTOR GROUPS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

HOW TO CREATE FACTOR GROUPS

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

The three techniques discussed briefly below are

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

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

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

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

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

Cluster Analysis

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

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

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

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

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

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

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

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

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

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

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

Geographic/Functional Classification of Roads Factor Groups

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

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

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

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

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

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

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

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

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

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

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

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

Same Road Application of Factors

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

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

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

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

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

Combining Techniques

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

ALTERNATIVES TO FACTORING

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

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

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

TYPES OF FACTORS

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

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

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

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

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

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

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

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

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

COMPUTATION OF FACTORS[11]

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

Computing AADT

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

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

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

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

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

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

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

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

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

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

Computing the Denominator[14] for Monthly Factors

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

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

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

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

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

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

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

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

Computing the Denominator for Weekly Factors

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

FREQUENTLY ASKED QUESTIONS—FACTORING

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

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

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

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

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

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

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

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

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

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

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

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

How many ATRs should be in a factor group?

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

CHAPTER 5
COORDINATING COUNT PROGRAMS

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

WHY COORDINATE PROGRAMS

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

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

WHO TO COORDINATE WITH AND WHAT DATA CAN BE OBTAINED

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

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

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

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

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

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

<u>How to Make Coordination Happen</u>

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

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

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

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

Issues to Remember

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

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

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

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

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

Open lines of communication allow cooperating agencies to learn:

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

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

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

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

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

APPENDIX 2-A
ITS AND TRAFFIC MONITORING

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

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

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

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

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

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

WHAT CAN ITS DATA DO FOR YOU?

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

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

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

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

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

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

- day of week factors
- seasonal adjustment factors

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

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

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

CURRENT ITS CONDITIONS

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

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

AN APPROACH TO CREATING ITS DATA STORAGE SYSTEMS

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

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

Creation of the Data Mine[16]

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

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

Technical and Institutional Issues for the Data Mine

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

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

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

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

<u>Data to Be Stored</u>

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Quality Control Functions

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

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

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

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

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

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

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

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

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

Communications

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

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

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

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

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

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

Costs

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

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

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

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

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

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

Agency Responsibilities

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

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

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

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

Iterative Development Process

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

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

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

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

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

APPENDIX 2-B
SEASONAL GROUP DEVELOPMENT USING CLUSTER ANALYSIS

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

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

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

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

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

Table 2-B-1: Cluster Analysis Monthly ADT

Cluster Analysis
Continuous ATR Data
Monthly ADT

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

Table 2-B-2: Monthly Factors

Cluster Analysis
Continuous ATR Data
Monthly Factors

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

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

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

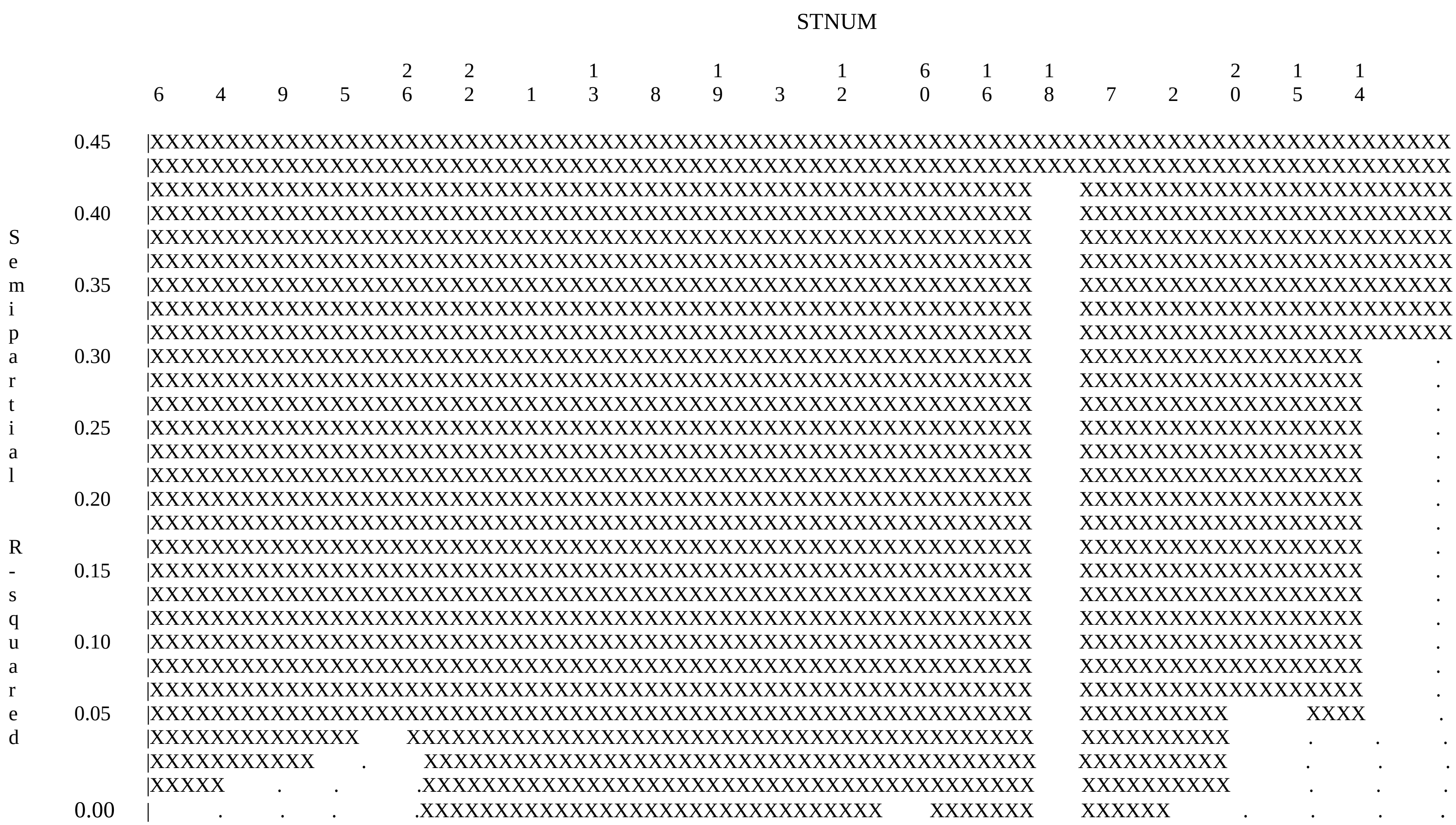
	Eigenvalue	Difference	Proportion	Cumulative
1	0.136135	0.072741	0.586741	0.58674
2	0.063393	0.048811	0.273226	0.85997
3	0.014582	0.007335	0.062848	0.92281
4	0.007247	0.003818	0.031234	0.95405
5	0.003429	0.000509	0.014777	0.96883
6	0.00292	0.000804	0.012585	0.98141
7	0.002116	0.001131	0.009119	0.99053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

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

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

Table 2-B-4: Cluster Analysis Dendogram

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



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

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

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

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

Table 2-B-5: Cluster Analysis Example

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

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