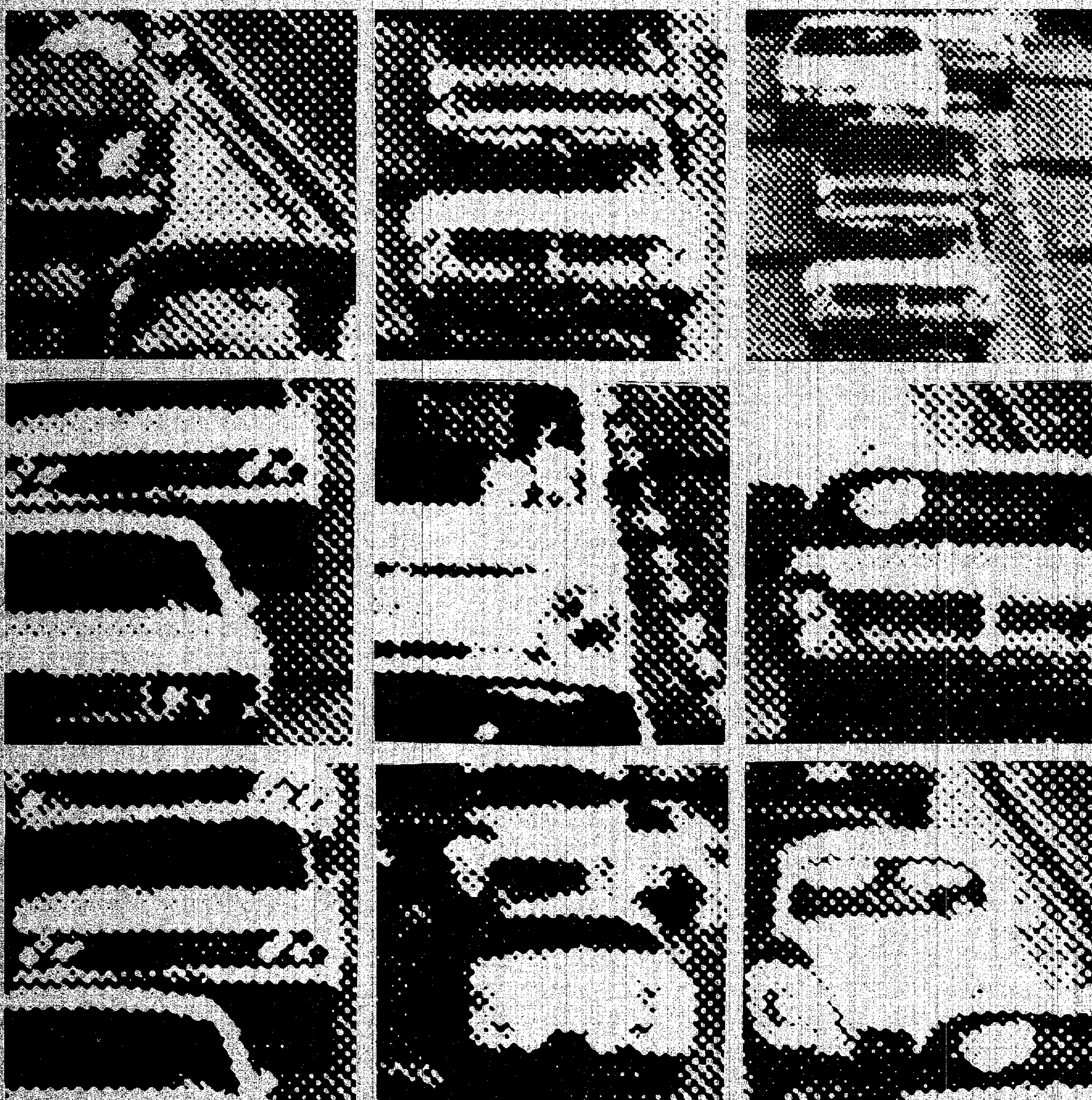
U.S. Department of Transportation
Federal Highway Administration

Guide to Urban Traffic Volume Counting

Urban Planning Division

September 1981



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16. Abstract

This report presents methods by which urbanized areas can develop and implement integrated traffic counting programs to serve the volume data needs of all agencies. Methods for estimating volume at a single location, volume across a cordonline or cutline, VMT within a corridor or other small area, and regional VMT are presented. Sound statistical sampling concepts permit the collection of volume data at predetermined levels of precision and in a cost-effective manner.

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PREFACE

Traffic volume counts have historically provided a sound basis for transportation planning, design, and monitoring activities by State and local agencies. Count data has also served the needs of the local business community. More recently, transportation planning agencies have been showing greater interest in using count data to estimate regional (areawide) vehicle miles of travel (VMT). Volume count data supports a wide range of transportation planning activities at the local, regional, and national levels.

Recognizing the increasing importance of volume count data, the Federal Highway Administration has supported the development of innovative traffic counting and VMT estimating procedures and is assembling a comprehensive national data base as part of the Highway Performance Monitoring System (HPMS).

The purpose of this manual is to provide methods by which urbanized areas can develop and implement integrated traffic counting programs to serve the volume data needs of local, regional, and national agencies. By using the statistical sampling concepts documented here, urbanized areas should be able to satisfy national reporting needs specified in the HPMS as well as their own volume data needs in a cost-effective manner.

This manual updates and extends the methods contained in the original *Guide to Urban Traffic Volume Counting* (GUTVC) manual prepared in 1975. The original GUTVC was rigorously tested by State and regional agencies around the country. The detailed procedures presented in this new GUTVC, therefore, reflect the experiences gained during this extensive testing program.

Many individuals contributed to the procedures described in this manual. The authors would like to especially acknowledge the assistance of the agencies that tested the original GUTVC:

- Delaware Valley Regional Planning Commission
- Florida Department of Transportation
- Georgia Department of Transportation
- Iowa Department of Transportation
- North Central Texas Council of Governments
- Rhode Island Department of Transportation
- City of Tulsa, Oklahoma

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I. INTRODUCTION

Traffic volume counts have historically provided a sound basis for transportation planning, design, and monitoring activities by State and local agencies. Count data has also served the needs of the local business community. More recently, transportation planning agencies have been showing greater interest in using count data to estimate regional vehicle miles of travel (VMT). Table 1 summarizes potential applications for volume count data for four basic measures:

- Volume at a single location
- Volume across a cordonline or cutline
- VMT within a corridor or other small area
- Regional VMT

State, regional, county, and other local government agencies have met these needs for volume data by implementing their own counting programs for streets and highways under their jurisdiction. But because such programs often focus on the particular needs of the individual agencies, the regional volume data base is often incomplete. In some cases, the methods of selecting the locations and dates for counting sessions either do not permit the development of unbiased estimates of regional VMT or else result in unnecessarily costly counting programs to develop such estimates. In other cases, counts are duplicated due to lack of coordination between agencies.

PURPOSE OF THE MANUAL

This manual presents methods by which urbanized areas can develop and implement integrated traffic counting programs to serve the volume data needs of all agencies. Sound statistical sampling concepts are used to permit collection of volume data at predetermined levels of precision and in a cost-effective manner.

The volume counting procedures documented in this manual complement similar procedures developed previously for measuring vehicle classification and occupancy.[1] By conducting parallel traffic monitoring of volume, vehicle classification and occupancy, an urbanized area can estimate person miles of travel (PMT) as well as VMT by vehicle type.

[1] *Guide for Estimating Urban Vehicle Classification and Occupancy*, U.S. Department of Transportation, Federal Highway Administration, 1981.

TABLE 1

POTENTIAL APPLICATIONS FOR VOLUME DATA

Application \ Measure	Volume at a Single Location	Volume Across a Cordonline or Cutline	VMT within a Corridor or Small Area	Regional VMT
Programming	x			
Operational Improvements	x	x	x	
Safety Assessments	x		x	x
Data Services	x			
Planning	x	x	x	x
Policy Assessment		x	x	x
Environmental and Energy Analysis		x	x	x
Revenue Allocation and Estimation				x

ORGANIZATION OF THE MANUAL

The manual is organized into five major sections, including this introduction and five appendixes. Section II discusses the development of an integrated traffic counting program and the definition of program objectives. It also provides an example of an integrated traffic counting program design.

Section III presents detailed sampling procedures for estimating regional VMT. These procedures can be used to determine the number of counting sessions required to estimate VMT at a predetermined level of statistical precision.

Section IV presents sampling procedures for estimating: volume at a single location, volume across a cordonline or cutline, and VMT within a corridor or small area.

Section V describes how an integrated traffic counting program can be organized and administered: organizing the program, preparing a work plan, collecting data, and reducing and analyzing data.

The appendixes include three sections: an index to sampling parameters, methods of computing special parameters, and an alternative method for specifying the desired level of precision of an estimate.

II. TRAFFIC COUNTING PROGRAM DESIGN

This section discusses the factors to be considered in designing an integrated traffic counting program for an urban area. The various steps in developing the count program are illustrated, and a sample program is presented.

DEVELOPMENT OF AN INTEGRATED TRAFFIC COUNTING PROGRAM

Developing an integrated traffic counting program to meet the volume data needs of an urban area includes five tasks:

- Define program objectives
- Select data collection locations for regional estimates
- Select data collection locations for focused studies
- Develop a data collection plan
- Identify supplementary study needs

Define Program Objectives

The traffic counting needs within an urban area can vary greatly. As was illustrated in Table 1, these needs include volume data for single locations, cordonlines, corridors, small areas, and regions. The State Department of Transportation, the local Metropolitan Planning Organization, and the County and City Traffic Department have data needs within an urban area ranging from single locations to regional estimates. The regional traffic counting program should be designed to meet the multiple needs of the various agencies in a cost-effective manner.

Developing a master list of volume data needs is the first step in integrating the count program. This list should include the volume data requirements of the various affected agencies. After the regional master list has been developed, the items should be translated into a series of specific program objectives. This process will include three steps for each objective:

- Determining the type of volume count required
- Defining the sample population
- Specifying the desired level of precision

The type of volume count required depends on the application. For example, turning movement counts are required for intersection studies at single locations. Midblock volume counts are more appropriate for cordon lines and regional VMT estimates.

The sample population should then be defined for each of the measures. Sample populations for areawide objectives should be defined in terms of geographic scope, types of highways, time-of-day, day-of-week, and seasonal coverage. Sample populations for focused objectives should be defined in terms of specific locations, time-of-day, day-of-week, and seasonal coverage. Stratification—dividing a population into smaller component population—is also defined at this stage. *Reporting* strata represent specific sample populations for which an estimate of a volume or VMT measure is desired. If, for example, an agency wants to estimate VMT for three types of highways and two geographic areas, six separate reporting strata will be defined. Independent samples will, therefore, be drawn in each of these reporting strata.

Finally, the desired level of precision for each of these objectives should be specified. Level of precision can be defined here as the combination of two parameters, (1) the tolerance level, representing the acceptable difference between the estimated measure and the true value and (2) the level of confidence, representing the probability that the sample estimate will fall within this range. Level of precision is therefore viewed as an acceptable range of error about the mean value estimated from the count. This approach allows the analyst to estimate the required sample size to achieve a specified level of precision, or conversely, to determine the level of precision associated with an established sample size.

Higher precision levels will require larger sample sizes and result in higher costs. Also, if a single population is divided into multiple reporting strata, the sample size required to estimate a measure at the same level of precision for *each* reporting stratum may not be significantly smaller than the required sample size for the *single* population. But stratification can also *reduce* the sample size required in other circumstances. The complex tradeoffs between stratification method, precision, and cost can be addressed by the sampling procedures presented in Sections III and IV.

An important issue to address at this stage is the need to estimate VMT for local roads. Local roads account for most of the roadway mileage in an urban area but handle a small percentage of the total travel. The number of count locations required to obtain a statistically significant VMT estimate may be large. The relative value of this information to the involved agencies versus the associated costs should be considered when this decision is made.

Methods of reducing the overall costs of the counting program by serving multiple objectives with the same counts should also be explored. The rotational sampling method discussed in the next subsection integrates the need for regional VMT estimates with existing coverage counting programs. Even when smaller scale sampling methods are employed, the counts made for purposes of regional estimates can serve some needs previously met through the coverage count program. For example, traffic flow maps can be prepared from the results of the detailed stratification methods described in Section III.

Select Data Collection Locations for Regional Estimates

An efficient method for measuring regional VMT is to take traffic counts at a randomly selected sample of highway links throughout the region. Through stratification, VMT estimates by geographic area and functional class of highway can also be obtained. The use of a random sample of highway links leads to an unbiased measure of regional VMT with a known level of statistical precision.

There are three approaches to selecting a regional sample: (1) rotational, (2) new sample every year, and (3) same sample every year. As will be described in Section III, most urbanized areas will likely count a series of locations every year (third method) as well as a new set of additional locations selected every year (either the first or second method). By combining the sample selection methods, urbanized areas should be able to satisfy the wide range of needs for volume data in a cost-effective manner.

Rotational

The rotational method consists of counting every location at some minimum time interval. This approach would be compatible with an existing coverage count program for an urban area. However, to yield an unbiased VMT estimate, the count locations must be randomly selected. For example, if all links are to be counted every 3 years, then the count locations can be randomly ordered. The first third will be counted during the first year, the second third in the second year, and the final third in the last year. The sample must be updated every year for new roads. The count interval may be varied, but locations with different count frequencies must be placed in separate strata. One approach would be to count the different functional classes of highways at different intervals. Key locations might be counted on an annual basis while other locations might be counted much less frequently.

New Sample Every Year

The yearly sample approach requires selecting a new, different sample of count locations every year. For smaller sample populations, this approach is simpler to implement than the rotational method because the analyst does not have to develop and maintain a detailed counting schedule covering the links in the region. The addition of new links to the regional system does not pose any problem as long as the population of links is updated each year before the sample is drawn. However, there is no control over the interval in which a specific link is counted.

Same Sample Every Year

The third basic approach is to use the same sample every year. This approach requires that the initial sample be randomly chosen, but the same locations are counted in subsequent years. It has two major advantages: the administrative ease of counting the same locations each year and the direct comparability of the annual estimates. It also includes two drawbacks: the loss of the sample's representativeness as the highway network groups and traffic patterns change and the inability to assess the correctness of the estimate by comparing it with the estimate of a different sample.

Select Data Collection Locations for Focused Studies

Once the count locations for the regional VMT estimate have been selected, the sites required for the various focused studies should be chosen. The focused studies would include volume counts at individual intersections, screen lines, and cordonlines. If any focused study location is the same as a location selected for the regional estimate, then that location should still only be counted once. The count should be scheduled to meet the requirements of the regional estimate.[2] If a focused study site is immediately upstream or downstream of a regional location and if traffic patterns are similar, the count made for the regional estimate may be used for both purposes. However, no attempt should be made to

[2]Procedures for factoring counts with adjustment factors derived from automatic traffic recorder (ATR) data to provide average annual estimates are described in Section IV.

change the location of a regional count location to a nearby focused study location because this might result in a biased regional estimate.

Develop a Data Collection Plan

The data collection plan is designed for two primary purposes:

- To ensure that the traffic counting program objectives are met in a cost-effective manner
- To ensure cooperation and coordination between the various agencies collecting count data within the urban area

Every effort should be made to prevent duplication of counts. The responsibilities of the involved agencies should be clearly defined. Existing traffic counting programs can be modified to produce unbiased estimates if the statistical techniques introduced here and discussed in detail in Sections III and IV are employed.

Defining program objectives and selecting regional and focused study count locations are the first steps for ensuring that program objectives are met, but efficient scheduling will help produce a cost-effective program. It is important to make the best possible use of available personnel and equipment.

One approach for increasing the flexibility of scheduling counts is to use seasonal factors to convert counts to an average annual daily traffic (AADT) or average weekday traffic (AWT) volume basis. This approach allows for the use of temporary seasonal help at reduced cost and avoids the problems of collecting data during adverse weather conditions. A location can easily be counted once and meet both regional and focused needs.

In order to use seasonal factors, however, an appropriate volume data base must exist for calculating the factors. These data are generally obtained from continuous permanent count stations, which should be representative of the highway network. Using seasonal factors also increases the variability of estimates and reduces their precision. This issue is addressed in Sections III and IV.

The data collection plan should make the best use of existing resources. Existing volume data are used for the volume stratification of highways (see Section III). Sources include volume maps and diagrams. The random selection of count locations requires a listing of highway links. Sources include urban area transportation study network files and GBF/DIME files.[3]

[3]U.S. Department of Commerce, Bureau of the Census, *GBF/DIME System: Description and Uses*, February 1978.

Identify Supplementary Study Needs

Three different types of studies can supplement the basic traffic counting studies and should be considered when the overall monitoring program is developed:

- Vehicle classification studies
- Vehicle occupancy studies
- Permanent count station (ATR) placement studies

Vehicle classification studies can be used to develop axle correction factors for translating axle counts from road tubes into volume counts and provide a basis for estimating truck miles of travel. Vehicle occupancy studies are useful in assessing shifts in occupancy patterns and estimating person miles of travel. Parallel procedures for developing vehicle classification and occupancy monitoring programs are available.[4] Some of these manual counts could replace machine volume counts for sites required for the volume counting program, although the manual counts would need to be factored to 24-hour totals. Regions presently without ATR's at representative locations on all classes of highway may wish to establish a small number of additional permanent counting stations to provide a consistent basis for identifying trends and developing seasonal adjustment factors.

EXAMPLE OF AN INTEGRATED TRAFFIC COUNT PROGRAM

Because the needs for traffic count data will vary markedly from one urbanized area to the next, a single model traffic counting program cannot realistically be recommended. The following example of an integrated traffic count program is intended only to *clarify* the issues raised and suggestions made in the preceding subsection. The assumed set of program objectives for the hypothetical urban area is presented in Table 2. Each objective is defined in terms of application type, responsible agency, sample population, and desired level of precision.

The first objective of the example count program is to develop a regional estimate of VMT stratified by functional class of highway and geographic subarea. Highway classes include local streets, arterials (including collector streets), and freeways. Geographic strata are the central business district (CBD), the city outside the CBD, and the region outside the city. A separate random sample will have to be drawn for each stratum. The regional VMT estimate is assumed to be needed by the

[4]*Guide for Estimating Urban Vehicle Classification and Occupancy*, U.S. Department of Transportation, Federal Highway Administration, 1981.

Metropolitan Planning Organization (MPO). The actual traffic counting would most likely be performed by the City Traffic Engineering (TE) Department and the State Department of Transportation (DOT). The estimate would be an average annual weekday VMT measure. The sample population would accordingly represent travel (1) on all streets, (2) from January to December, (3) for all 24 hours of the day, and (4) only on weekdays. However, seasonal adjustment factors could be used to ease scheduling constraints by converting counts made during a shorter time period (such as April-June) to an AWT basis. Because this VMT estimate could be a prime measure of traffic growth in the area, the agency desires to estimate VMT within tolerance levels of ± 25 percent for local streets, ± 5 percent for arterial streets, and ± 5 percent for freeways—all with a 95 percent level of confidence. Although VMT for the entire region and for the geographic subareas will also be estimated, no minimum precision levels are specified for these estimates.

The second objective requested by the MPO in this example relates to screen line counts. The counts must be conducted in the same time frame as the original household travel survey. If any of the screen line count locations correspond to the regional VMT sample sites, then the counts should be used for both purposes.

The third program objective is for the City Traffic Engineering Department to conduct weekday coverage counts on one-quarter of the nonlocal city street network. Through the rotational sampling approach, these coverage counts could also be used for estimating the city portion of regional VMT. The counting effort would be roughly the same as before, only the process for selecting the count locations would change. The resulting counts could be adjusted using seasonal factors that would allow for efficient scheduling.

TABLE 2

ILLUSTRATIVE PROGRAM OBJECTIVES

Objective	Type of Application	Responsible Agency	Sample Population	Precision
1. Regional VMT estimate by highway functional class and geographic subarea	Regional	MPO	• All streets • Jan. - Dec. • 24 hours • Weekdays	• ± 25% Local Streets • ± 5% Arterial Streets • ± 5% Freeways
2. Screen line counts for forecast model validation and update	Screen Line	MPO	• Selected streets on screen lines • Same months as original household survey • 24 hours • Weekdays	10%
3. Coverage count of one-quarter of nonlocal city street network	Single Location	City Traffic Engineering (TE) Department	• Selected streets • Jan. - Dec. • 24 hours • Weekdays	Count for 1 day.
4. CBD cordon count	Cordon Line	City TE Department	• Same stations as used in previous years • May • 7:00 am - 7:00 pm • Weekdays	Count for 1 day. Calculate precision
5. VMT estimate for a specific transportation improvement corridor	Corridor	MPO City TE Department State DOT	• Street segments in corridor • May • Peak periods (am and pm) • Weekdays	2%
6. Volume counts at specific locations	Single Location	City TE Department	• Jan. - Dec. • Varied times • Weekdays	Count for 1 day.

The fourth objective is to conduct an annual cordon count to monitor travel to and from the CBD. The city is assumed to conduct this count every May by counting traffic from 7:00 a.m. to 7:00 p.m. at all stations on the cordon line surrounding the CBD on the same weekday.

The fifth objective involves collecting volume data for the analysis of a corridor improvement project. This joint effort of the State DOT, MPO, and city TE departments requires a stricter level of precision (2 percent) because changes in corridor VMT may be small and the analysis should be designed to detect these changes.

The sixth and final objective is a catch-all for additional traffic count requests. Volume data may be needed for single location applications such as signal warrant analyses, intersection improvement, and capacity analyses. If any of these special requests coincide with the regional VMT sites or the sites for any other objective, the possibility of using only one count should be explored.

Although not stated as a specific objective, the State DOT's continuous count program would likely provide the data required to calculate the seasonal adjustment factors and other factors needed to expand counts made for less than a 24-hour period.

This example demonstrates how cooperation and coordination between the various regional agencies collecting and using volume data can result in a cost-effective data collection program that fills the needs of the various agencies. It also demonstrates that by changing the coverage count site selection approach from a judgmental to a random sample approach, regional estimates of VMT can be made with minimal increase in the counting effort. The number of regional counting locations required to meet the objectives can be determined with the procedures described in Section III.

III. REGIONAL SAMPLING PROCEDURES

This section presents detailed sampling procedures for estimating regional VMT. These procedures can also be applied to other area definitions (e.g., county) where data are collected at only a sample of locations. But if data are collected at all locations in an area, the simplified sampling procedures presented in Section IV should be used instead. The sampling procedures can be used to compute the number of volume counts needed to attain specific survey objectives for regional VMT estimates (discussed in Section II). The discussion is divided into two major sections:

- Estimating the sample size for regional surveys
- Selecting the sample

ESTIMATING THE SAMPLE SIZE FOR REGIONAL SURVEYS

A relatively complex sampling plan is needed to estimate VMT at the regional level because (1) regional estimates are typically needed for different functional classes of highway and/or geographic subareas, (2) data collection is often performed by several different agencies, and (3) the necessarily large scope of the surveys requires use of the most efficient sampling methods.

Defining Sample Strata

The first step in developing a sampling plan is to define the stratification method. Two types of stratification apply to regional VMT estimation: reporting strata and sample strata. *Reporting strata*, as introduced in Section II, define specific populations for which VMT is to be estimated. *Sample strata*, on the other hand, define specific populations considered in the sampling plan. In some cases, the sample strata will be identical to the corresponding reporting strata. In other cases, a single reporting stratum will be divided into two or more sampling strata solely to increase the efficiency of the sampling plan. Estimates of VMT for the sample strata are not necessarily of interest, but simply serve as a convenient means of estimating VMT for their reporting stratum. Independent samples must be drawn in every sample stratum.

The specification of reporting strata will reflect national and regional needs. Reporting strata for national needs should follow the guidelines provided for the Highway Performance Monitoring System (HPMS)[5] as summarized in Table 3. Reporting strata for regional needs will mainly reflect revisions and additions to the basic HPMS reporting strata such as the following three examples:

- Creation of additional strata for geographic areas outside the Urbanized Area (i.e., for which the

[5] *Highway Performance Monitoring System: Field Implementation Manual*, U.S. Department of Transportation, Federal Highway Administration, January 1979.

TABLE 3

INDIVIDUAL URBANIZED AREA VOLUME GROUPS

Volume Group (Code)	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials	Collectors
1	0- 24,999	0- 24,999	0- 2,499	0 - 2,499	0- 999
2	25,000- 49,999	25,000- 49,999	2,500- 4,999	2,500- 4,999	1,000- 1,999
3	50,000- 74,999	50,000- 74,999	5,000- 9,999	5,000- 9,999	2,000- 4,999
4	75,000- 99,999	75,000- 99,999	10,000-14,999	10,000-14,999	5,000- 9,999
5	100,000-124,999	100,000-124,999	15,000-19,999	15,000-19,999	10,000-14,999
6	125,000-149,999	125,000-149,999	20,000-24,999	20,000-24,999	15,000-24,999
7	150,000-174,999	150,000-174,999	25,000-34,999	25,000-34,999	25,000-35,000
8	175,000-200,000	175,000-200,000	35,000-44,999	35,000-44,999	
9			45,000-55,000	45,000-55,000	

Source: *Highway Performance Monitoring System: Field Implementation Manual*, U.S. Department of Transportation, Federal Highway Administration, January 1979. These are the minimum reporting strata required for the HPMS, but HPMS does allow for more detailed stratification.

HPMS urbanized area estimates must be developed) but within the region

- Division of HPMS reporting strata into geographic subareas (e.g., county, city boundaries)
- Creation of additional reporting strata for local streets (i.e., presently not needed for the HPMS estimates)

The specification of sample strata will reflect both the reporting needs for which the survey is designed and the need to obtain better efficiency by further breaking down reporting strata into sample strata based either on the expected volume level (if known) or on a measure that may be related to volume, such as the number of lanes. The choice of a particular method of stratification will reflect the reporting strata, desired level of precision, availability of current volume data for highway system links (or sections), and the functional class of highway.

The local street network does not provide a good opportunity for further stratification. Historical volume data are not likely to be available. Even if they were, the level of precision needed for local street VMT estimates is not likely to be high — thus reducing the need to stratify to achieve greater efficiency.

Collectors, arterials, and freeways offer a much greater opportunity to gain efficiency through stratification. Stratification is needed because the range of volumes carried by each of these classes of street is typically very wide. Current volume data are also likely to be available. Although the detailed reporting stratification needed for HPMS (as summarized in Table 3) should meet most needs, further division of some reporting strata into sample strata may still be beneficial. For example, urban areas that have a large number of other principal arterial streets accommodating volumes in the range of 25,000 - 34,999 ADT may form additional sample strata (e.g., 25,000 - 29,999 and 30,000 - 34,999).

Although most urbanized areas are expected to specify extremely detailed stratification methods as needed for the HPMS reporting requirements, this report will emphasize a more limited stratification method for purposes of simplicity and ease of undertaking as illustrated in Table 4. In this example, statistically precise estimates of regional VMT are desired by regional and local agencies for each of three types of highway. The reporting stratum for arterial highways has been divided into eight sampling strata, based on expected volume levels, to improve the efficiency of the sampling plan. The reporting stratum for freeways has similarly been divided into three sampling strata based on the number of lanes.

TABLE 4

ILLUSTRATIVE STRATIFICATION METHOD FOR REGIONAL VMT

REPORTING STRATA[1]	SAMPLE STRATA
Local Streets	Local Streets
Arterials	Arterials ADT: 0- 5,000 5-10,000 10-15,000 15-20,000 20-25,000 25-30,000 30-35,000 35,000+
Freeways	Freeway Lanes: 4 6 8+

[1]Only three reporting strata are assumed for this illustration for purposes of simplicity. The minimum set of 41 reporting strata expected for urbanized areas was summarized in Table 3.

The definition of sampling strata for estimating regional VMT is likely to be an iterative process. The initial stratification method will typically be revised after the initial sample size estimates for each stratum are computed. As discussed below, sampling plan efficiency can be increased markedly by reducing the expected range of volumes within individual sample strata.

Computing Regional VMT

An efficient way to estimate regional VMT with a sample of traffic counts is to estimate the average volume in each sample stratum, multiply the average volume by the known total mileage for the links in the stratum, and aggregate the stratum-specific VMT estimate to produce estimates for the desired reporting strata. This approach does, however, require that count locations be selected using procedures similar to those described later in this section. An estimate of regional VMT can be computed as:

$$\overline{VMT} = \sum_{h}^{H} \overline{VMTh} \quad (1)$$

$$\overline{VMTh} = Mh * \overline{VOLh} \quad (2)$$

$$\overline{VOLh} = \frac{1}{Nh} * \sum_{i}^{Nh} VOLhi \quad (3)$$

where:

$\overline{\text{VMT}}$ = estimated average regional VMT during the period of interest

$\overline{\text{VMTh}}$ = estimated average VMT in sample stratum "h" during the period of interest

$\overline{\text{VOLh}}$ = estimated average volume in sample stratum "h"

VOLhi = volume measured on count "i" in sample stratum "h"

Mh = mileage of stratum "h"

Nh = number of volume counts made in stratum "h"

H = number of sample strata

In the above formulas, the summations over "h" and "i" should be assumed to start with h = 1 and i = 1. This convention will be followed throughout the report. The above formulas also assume that the reporting stratum was defined as the total region, but estimates of VMT for other reporting strata can be similarly obtained by aggregating the appropriate sample strata.

Estimating Sample Parameters

Certain key sample parameters must be estimated before the sample size required for each sample stratum can be computed. These sample parameters reflect three distinct sources of uncertainty:

- *Spatial:* variability of volume between locations
- *Temporal:* variability of volume over time
- *Measurement:* uncertainties due to mechanical counter errors

The specific sample parameters that correspond to these three sources of uncertainty are summarized in Table 5 and discussed below.

Spatial

Spatial variability is introduced because volume data used to estimate regional VMT come from only a sample of links. The sample parameter that accounts for spatial variability is "SVOLL," the standard deviation of volume across locations. This parameter reflects the size of the differences in volume from one link to another within a given stratum.

For sample strata that have been formed on the basis of expected volume ranges, the SVOLL parameter can be most easily estimated as:

$$\text{SVOLLh} = \frac{\text{VRANGEh} + 1{,}000}{3.5} \tag{4}$$

where:

SVOLLh = standard deviation of volume across locations in stratum "h"

VRANGEh = difference between highest and lowest volumes specified for stratum "h"

The second term in the numerator of the above formula is included to approximate the effects of misclassified

TABLE 5

REGIONAL SAMPLE PARAMETERS

SOURCE OF UNCERTAINTY	SYMBOL	DEFINITION	METHOD OF ESTIMATION	DEFAULT VALUE
Spatial	SVOLL	Standard deviation of volume across locations	$\text{SVOLL} = \frac{\text{VRANGE} + 1{,}000}{3.5}$ $\text{SVOLL} = \text{CVVOLL} \cdot \overline{\text{VOL}}$	Locals: CVVOLL = .60 Arterials: CVVOLL = .60 Freeways: CVVOLL = .30
Temporal	SVOLD	Standard deviation of volume across days within a season	$\text{SVOLD} = \text{CVVOLD} \cdot \overline{\text{VOL}}$	Figure 1
	SVOLS	Standard deviation of volume across seasons of the year	See Appendix B	0
	SEADJ	Standard error of seasonal adjustment factors across ATR's	See Appendix C	$\text{SEADJ} = .05/\sqrt{\text{NATR}}$
Measurement	SEAXL	Standard error of assumed axle correction factor	See Appendix D	SEAXL = .02

links. The size of the SVOLL parameter is almost directly proportional to the size of the volume range for a given stratum. This is why stratification by expected volume levels is so important for arterials and freeways. Even when strata are defined on the basis of increments of 5,000 ADT, the SVOLL parameter will typically contribute greater uncertainty to the VMT estimate than the other sample parameters.

If, for example, a sample stratum were defined as "arterials with 15,000-20,000 ADT," the SVOLLh can be estimated as:

$$\text{SVOLLh} = \frac{5{,}000 + 1{,}000}{3.5} = 1{,}700$$

It should be noted that the allocation of the highway system links to sample strata is not expected to be accurate in all cases because of data limitations. These misallocations will not invalidate the results of the study but may somewhat reduce the precision of the VMT estimate.

Although the development of a sampling plan is built around the need to attain a predetermined level of precision for the VMT estimate, the actual precision achieved from the study can only be assessed after the study is completed (as will be discussed in Section V). If the sample parameters are accurately estimated beforehand, the actual precision of the VMT estimate should similarly be close to the anticipated precision. If the sample parameters are not accurately estimated beforehand, the actual precision will be either higher or lower than anticipated, but the results will still be valid, in any case.

For sample strata that have not been formed on the basis of expected volume levels, the SVOLLh parameter can be estimated as:

$$\text{SVOLLh} = \text{CVVOLLh} * \overline{\text{VOLh}} \qquad (5)$$

where:

CVVOLLh = coefficient of variation of volume across locations in stratum "h"

$\overline{\text{VOLh}}$ = *expected* average volume in stratum "h"

Possible "default" values for CVVOLL are presented in Table 5. Thus, for example, if the sample stratum representing all local streets is expected to have an average ADT of 500, the SVOLLh parameter can be estimated with the default values:

$$\text{SVOLLh} = .60 * 500 = 300$$

Temporal

Temporal variability reflects variations in volume levels over time. These can potentially include short- and long-term effects, depending on the study design. There are three basic methods of accounting for temporal variability for annual studies:

- *Defining a short study period.* A year-round average regional VMT estimate may not be needed. The estimate could represent a relatively short study period which (1) provides typical VMT patterns, (2) reduces problems due to severe weather, and (3) permits efficient utilization of field personnel. Growth in VMT levels could be monitored by counting the same study period each year so that direct comparisons could be made.
- *Collecting data year round.* Volume counts could be taken on randomly selected days throughout the year, thus capturing any seasonal fluctuations. This will not be practical in areas with severe winter weather.
- *Applying seasonal adjustment factors.* Volume counts could be taken during a relatively short period (the first method) and then adjusted with factors to represent annual regional VMT. The seasonal adjustment factors would require data from permanent automatic traffic recorders (ATR's) for each day of the year. Each of these methods requires the use of a different set of temporal sample parameters, as described below.

Method 1

When a relatively short study period is used, the only source of variability is the day-to-day fluctuation of volumes. The sample parameter which accounts for daily (short-term) variability is "SVOLD," the standard deviation of volume across days. The SVOLD parameter can be estimated as:

$$\text{SVOLDh} = \text{CVVOLDh} * \overline{\text{VOLh}} \qquad (6)$$

where

SVOLDh = standard deviation of volume across days within a season in stratum "h"

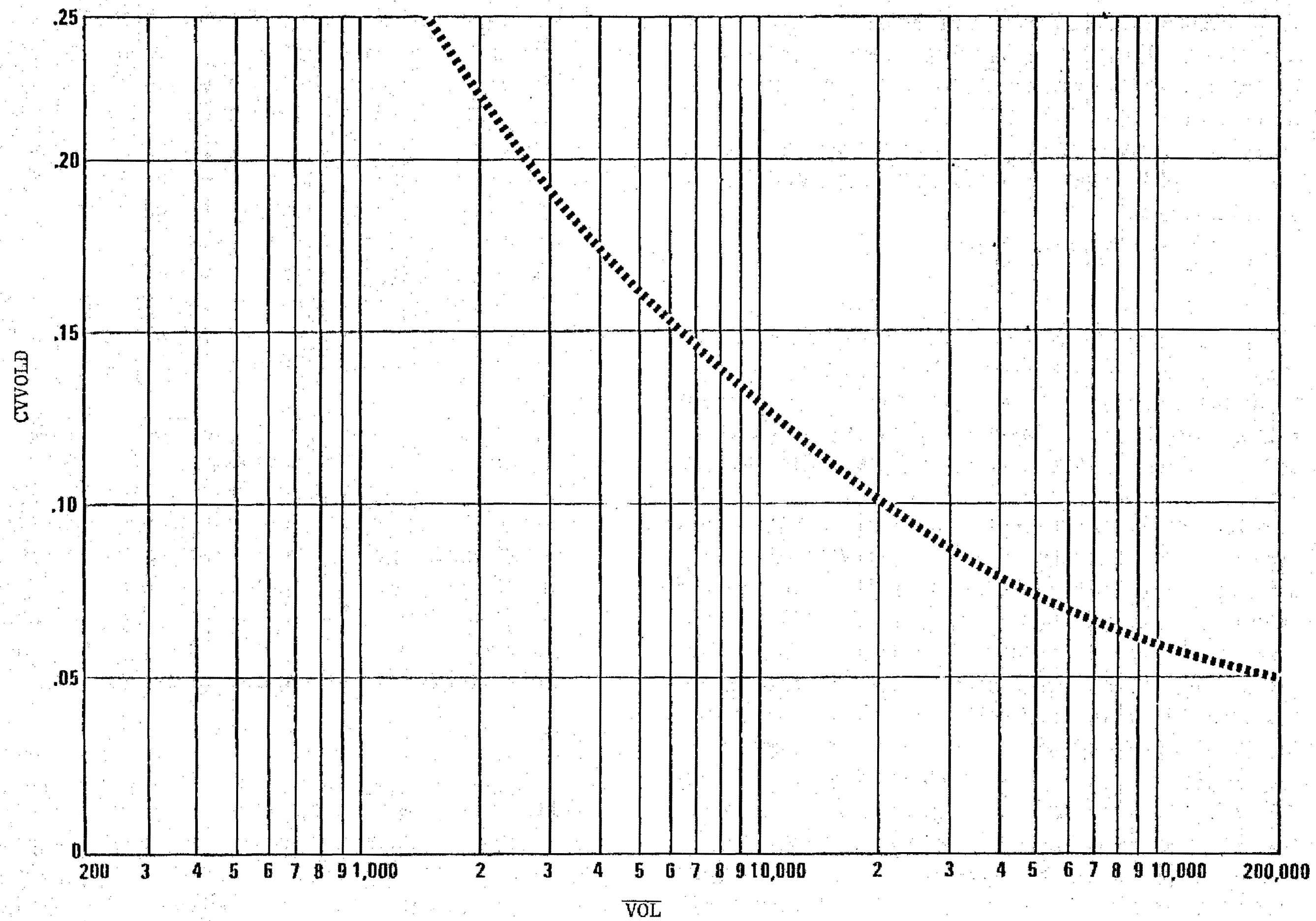
CVVOLDh = coefficient of variation of volume across days within a season in stratum "h"

The value of the coefficient of variation can be expected to vary depending on the duration of the counting period and the volume level. Figure 1 illustrates the relationship between the coefficient of variation and average daily traffic (ADT). For shorter periods, such as 2-hour peak periods, the coefficient of variation can be expected to fall in the range:

$$.05 \leq \text{CVVOLDh} \leq .15 \qquad (7)$$

FIGURE 1

DEFAULT COEFFICIENT OF VARIATIONS FOR DAILY VOLUME ACROSS DAYS



Method 2

When volume counts are to be made throughout the year, two sources of variability should be considered: the day-to-day fluctuation of volume and the long-term shifts in volume throughout the year. The corresponding sample parameters are

- SVOLDh: the standard deviation of volume across days within a season in stratum "h"
- SVOLSh: the standard deviation of volume across seasons in stratum "h"

The estimation of SVOLDh was discussed above. Estimating SVOLSh will require either (1) using volume data for a representative year from ATR's or intensive counting programs at selected locations, or (2) making assumptions about the probable range of seasonal shifts in volume levels. Formula (57) in Appendix B can be used to compute SVOLSh. If *no* major seasonal shifts are expected, SVOLSh can be disregarded and set at zero.

Method 3

When data from ATR's are available to compute seasonal factors in order to adjust volume data collected during a short study period to represent average annual patterns, two sources of variability should be considered: the day-to-day fluctuation of volume and the uncertainty introduced by using expansion factors developed from relatively few ATR's. The corresponding sample parameters are, as follows:

- SVOLDh: the standard deviation of volume across days within a season

- SEADJe: the standard error of the seasonal adjustment factors

The estimation of SVOLDh was discussed above. The estimation of SEADJe will require historical count data from the ATR's and reflect the methods used to develop the corresponding seasonal adjustment factors. Although seasonal adjustment factors should ideally be available for all sample strata, most agencies will not have a sufficient number of ATR's for this purpose. In this case, the sample strata can be grouped into aggregate sample strata representing broader classifications. For example, the illustrative set of sample strata presented previously in Table 4 could be regrouped into four larger strata: (1) local streets, (2) arterials with less than 10,000 ADT, (3) arterials with more than 10,000 ADT, and (4) freeways. Corresponding seasonal adjustment factors could than be developed for these aggregate sample strata on the basis of volume data from a small number of ATR's located at representative locations in each of these four aggregate strata.

A general discussion of the use of seasonal adjustment factors, guidelines for utilizing current ATR's and locating new ones, and a formula for estimating SEADJe are provided in Appendix C. If the seasonal adjustment factor will be generated either from new ATR's or from a single ATR representing a particular aggregated volume stratum "e", the SEADJe parameter can be estimated as:

$$\text{SEADJe} = .05/\sqrt{\text{NATRe}} \qquad (8)$$

where:

NATRe = number of ATR's which will be used to develop the seasonal adjustment factor for aggregate sample stratum "e"

This value was empirically derived from a relatively limited amount of urban ATR data.

Measurement

Measurement error reflects the limitations of mechanical traffic counting devices for counting the volume on a given day. Errors are introduced from two sources: equipment errors made in counting the number of axles and errors made in converting raw axle counts to traffic volume counts.

Measurement errors from equipment malfunctions are extremely difficult to incorporate in the development of a sampling plan because of variations in the number of counters used, variations in individual counter accuracy due to calibration or maintenance, and environmental conditions (e.g., level of traffic, roadway surface, weather) that can affect accuracy at a specific counting session. The effects of equipment errors can be disregarded for sampling plan purposes if the average error in axle counts is less than about 10 percent because their impact will be insignificant compared with other sources of uncertainty, such as spatial and temporal variability.

Measurement errors made in converting raw axle counts to volume counts should usually be considered. The major factor of uncertainty here is the percentage of vehicles with more than two axles (denoted as "multiple-axled vehicles" in this report) at a particular location on the counting day. The sample parameter is "SEAXL," the standard error of volume counts due to assumed axle correction factors.

The estimation of SEAXL will depend on the method used to develop the axle correction factor that will be applied to convert raw counts into volume data. The correction factor can be developed on the basis of either a vehicle classification study or experience and judgment.

If a special vehicle classification study has already been or will be performed, estimates of vehicle classification should ideally be available for each sample stratum. As with seasonal adjustment factors, however, a more realistic approach is to group the sample strata into larger, aggregate sample strata solely for estimating the average proportion of multiple-axled vehicles. If seasonal adjustment factors will be used, the same grouping of sample strata into aggregate sample strata should also be used to develop the axle correction factors.

If the results of a vehicle classification study will be used to develop the axle correction factors, formula (72) in Appendix D can be used to estimate SEAXLe. If the assumed axle correction factors are developed on the basis of experience and judgment, the effect on precision cannot be so readily determined. A relatively conservative default value of SEAXLe for strata whose axle correction factor has been judgmentally determined is

$$\text{SEAXLe} = .02$$

Composite Parameters

The spatial, temporal, and measurement parameters described above can be consolidated into two composite terms:

$$\text{SVIh} = (\text{SVOLLh}^2 + \text{SVOLDh}^2 + \text{SVOLSh}^2)^{1/2} \qquad (10)$$

$$\text{SVEe} = (\text{SEADJe}^2 + \text{SEAXLe}^2)^{1/2} \qquad (11)$$

where:

SVIh = composite standard deviation for the internal (i.e., related to the sample size of volume counts) variability in sample stratum "h"

SVEe = composite standard error for the external (i.e., not related to the sample size of volume counts) variability in aggregate sample stratum "e"

The sample parameters SVOLSh and SEADJe are optional and will depend on the methods of incorporating temporal fluctuations, as follows:

- If the VMT estimate will be based on field data collection over a relatively short study period and will not be adjusted to represent travel throughout the year, SVOLSh and SEADJe should be disregarded (i.e., set to zero in the formula).
- If the VMT estimate will be based on field data collection throughout the entire year, SVOLSh should be estimated, and SEADJe should be disregarded.
- If the VMT estimate will be based on the combination of field data collection over a relatively short study period and seasonal adjustment factors from permanent ATR's, SVOLSh should be disregarded, and SEADJe should be estimated.

Computing the Sample Size

The sample size of traffic counting sessions needed for each sample stratum will reflect the desired level of precision, estimated sample parameters, and the stratification method employed. The relationship between the reporting stratum and the component sample strata is particularly important. Three basic situations, summarized in Table 6, can be considered:

- Reporting stratum and sample stratum are the same
- Single reporting stratum, multiple sample strata
- Multiple reporting strata, multiple sample strata

Reporting Stratum and Sample Stratum are the Same

The most basic case occurs when the reporting stratum for which the VMT estimate is desired consists of a single sample stratum. This is most likely for the local street system (or geographic subareas) that cannot be readily divided into sample strata to increase efficiency.

The number of counting sessions that will be needed to reliably estimate the VMT in reporting stratum "r" can now be computed as:

$$Nr = [Mh^2 * SVIh^2] \div \left[\left(\frac{DVMTr^2}{Z^2}\right) + (Mh^2 * SVIh^2/NPOPh) - (\overline{VMTh}^2 * SVEh^2) \right] \quad (12)$$

where:

Nr = number of counting sessions required in reporting stratum "r"

DVMTr = acceptable difference between the estimated VMT in reporting stratum "r" and the true value

$\overline{VMTh}$ = *anticipated* VMT in sample stratum "h"

NPOPh = population of links in sample stratum "h"

Z = normal variate[6] for the specific level of confidence, two-tailed test (i.e., as represented in standard tables)

Formula (14) computes the minimum sample size required for reporting stratum "r." But since the reporting stratum "r" and the sample stratum "h" are iden-

[6]Alternatively, if the tolerance term DVMTr is intended to represent the average difference between two survey estimates that an agency would like to detect, the Z value should be modified as shown in Appendix E.

TABLE 6

SAMPLE SIZE COMPUTATIONAL METHODS

REPORTING STRATUM CONSISTS OF:	PRECISION RELATES TO:	TYPE	METHOD OF COMPUTING SAMPLE SIZE FOR: REPORTING STRATUM	SAMPLE STRATUM
Single sampling stratum	Reporting stratum	Reporting and sampling strata are the same	Formula (12) →	Formula (13)
Groups of sampling strata	Reporting stratum	One reporting stratum, multiple sample strata	Formula (14) →	Formula (15)
	Multiple reporting strata	Multiple reporting strata, multiple sample strata	Formula (16) ←	Already determined

tical, the sample size for sample stratum "h" is the same:

$$Nh = Nr \quad (13)$$

One Reporting Stratum, Multiple Sample Strata

The second case that must be considered occurs when the reporting stratum for which the VMT estimate is desired consists of two or more sample strata. This is likely for the arterial and freeway systems, that must usually be divided into sample strata to increase efficiency. For example, the reporting stratum could represent all arterial streets while the sample strata could represent arterial streets of particular volume levels.

The number of counting sessions that will be needed to reliably estimate the VMT in reporting stratum "r" can be computed as:

$$Nr = \left[\sum_h^H Mh * SVIh\right]^2 \div \left[\frac{DVMTr^2}{Z^2} + \sum_h^H (Mh^2 * SVIh^2/NPOPh) - \sum_e^E (\overline{VMTe}^2 * SVEe^2)\right] \quad (14)$$

where:

- Nr = number of volume counts required in reporting stratum "r"
- H = number of sample strata which comprise reporting stratum "r"
- E = number of aggregate sample strata for purposes of reflecting external errors which cannot be affected by the sample size for volume counts
- $\overline{VMTe}$ = anticipated VMT in aggregate sample stratum "e"

The inclusion of the sample parameters SVOLSh and SEADJe in computing SVIh and SVEe will, as before, depend on the method of accounting for temporal variability (as discussed earlier).

The sample size for reporting stratum "r" can be allocated among the "H" sample strata as follows:

$$Nh = Nr * \frac{(Mh * SVIh)}{\sum_h^H Mh * SVIh} \quad (15)$$

The computed number of counts for each sample stratum can generally be rounded so that the desired number of counts for the reporting stratum is achieved. Although the VMT estimate for the reporting stratum can be computed with a minimum of *one count* per sample stratum, a minimum of *two counts* per sample stratum will make it possible to compute the precision of the VMT estimate for the reporting stratum after the results of the counting program are available, (as discussed in Section V).

Multiple Reporting Strata, Multiple Sample Strata

The third case that must be considered occurs when more than one study objective must be met through the counting program. In this case, more than one reporting stratum must be considered in the sampling plan. For example, the counting program could be designed to provide VMT estimates at predetermined levels of statistical precision for:

- All arterial highways in each of the three counties of the region
- All arterial highways in the region
- All highways in the region (i.e., including local streets, arterials, and freeways)

The sampling plan would therefore need sample sizes that would permit these estimates to be made at the desired levels of precision.

In general, the sampling plan will be built around the minimum sample sizes specified for each sample stratum from the controlling objective. The controlling objective is that which requires the largest sample size for a given sample stratum. For example, the sample size of counts for the reporting strata corresponding to the arterial highways in each county may be large enough that the estimates of VMT for all arterial highways in the region may be achieved as well. In this case, the sample sizes needed for the county-specific VMT estimates are controlling. But if a lower precision is specified for the county-specific VMT estimates, the sample size needed for the estimate for all regional arterials may be controlling. In each case, the precision desired for the VMT estimates for the controlling objective will be attained, and the precision desired for the other objectives will likely be *higher* than desired.

The method of determining the minimum sample sizes needed for each sample stratum is therefore likely to be iterative in nature. The sample sizes should first be computed for each objective individually. These initial sample sizes should then be adjusted as needed so that all objectives can be achieved. The precision of an estimate of VMT for any reporting stratum consisting of more than one sample stratum can be computed as follows:

$$DVMTr = Z * \left[\sum_h^H (Mh^2 * Fh * SVIh^2/Nh) + \sum_e^E (\overline{VMTe}^2 * SVEe^2)\right]^{1/2} \quad (16)$$

$$Fh = \left(\frac{NPOPh - Nh}{NPOPh} \right) \qquad (17)$$

where:

Fh = finite population correction factor for sample stratum "h"

The effect of the finite population correction factor is only approximated in the above equation, but it should be sufficiently accurate for practical applications. This term is likely to be important only when relatively small strata are sampled at a relatively high rate, as will typically occur for sample strata representing freeways.

The precision of an estimate of VMT for a reporting stratum that represents a single sample stratum can be computed as:

$$DVMTr = Z * [(Mh^2 * Fh * SVIh^2/Nh) + (VMTh^2 * SVEh^2)]^{1/2} \qquad (18)$$

Example

Assume that a planning agency wants to estimate regional VMT for each of three reporting strata: (1) local streets with ± 25 percent, (2) arterials within ± 5 percent, and (3) freeways within ± 5 percent. A 95 percent level of confidence is specified, indicating that the agency is willing to face a 1-in-20 chance that a given VMT estimate will fall outside the indicated range. Further assume that the data collection effort will be conducted over a 3-month period and that the agency plans to monitor VMT during the same period in future years to identify trends. The agency will judgmentally specify the proportion of multiple-axled vehicles for local streets, arterials with less than 10,000 ADT, arterials with greater than 10,000 ADT, and freeways. To improve efficiency, the agency will further stratify arterial and freeway links on the basis of either anticipated volume or number of lanes. The characteristics of the highway network are summarized in Table 7. The assumed average link lengths are 0.5 mile for arterials and 0.25 mile for local streets and freeways.

These assumed network characteristics can then be translated into sampling parameters, using the formulas and default values discussed previously. Table 8 illustrates the calculation of parameters needed to compute the sample size. Because the study will be conducted over a relatively short time period, the composite standard deviation for the internal variability reflects two terms: standard deviation across locations, SVOLLh and standard deviation across days, SVOLDh. The composite standard deviation for internal variability for the sample situation representing arterials with 5-10,000 ADT can, for example, be calculated with formulas (4), (6), and (10) as:

$$SVOLLh = \frac{5{,}000 + 1{,}000}{3.5} = 1{,}714$$

$$SVOLDh = .14 * 7{,}500 = 1{,}050$$

$$SVIh = (1{,}714^2 + 1{,}050^2)^{1/2} = 2{,}010$$

The corresponding composite standard error for the external variability SVEh represents only the effects of the assumed axle correction factors. Because judgment will be used to estimate the proportion of multiple-axled

TABLE 7

EXAMPLE NETWORK CHARACTERISTICS

SAMPLE STRATUM	MILEAGE (Mh)	LINK POPULATION (NPOPh)	AVERAGE VOLUME ($\overline{VOL}h$)	VMTh	PROPORTION MULTIPLE-AXLED VEHICLES Tre
Local Streets	400	1,600	500	200,000	.02
Arterials ADT:					
< 5,000	40	80	2,500	100,000 }	.06
5-10,000	70	140	7,500	525,000 }	
10-15,000	40	80	12,500	500,000 }	
15-20,000	30	60	17,500	525,000 }	
20-25,000	10	20	22,500	225,000 }	.10
25-30,000	10	20	27,500	275,000 }	
Freeways:					
4 lanes	30	120	40,000	1,200,000 }	.15
6 lanes	20	80	80,000	1,600,000 }	

TABLE 8

EXAMPLE WORKSHEET

SAMPLE STRATA	SVOLLh	SVOLDh	SVIh	SVEe	Mh * SVIh	Mh² • SVIh²/NPOPh	VMTe² * SVEe²
Local Streets	300	150	335	.02	134,000	11.2#	16#
5,000	1,714	500	1,785	.02	71,400	63.7	
5-10,000	1,714	1,050	2,010		140,700	141.4	157
10-15,000	1,714	1,500	2,278		91,120	103.8	
15-20,000	1,714	1,838	2,513	.02	75,390	94.7	930
20-25,000	1,714	2,250	2,828		28,280	40.0	
25-30,000	1,714	2,475	3,011		30,110	45.4	
SUBTOTAL	—	—	—		437,000	489.0	1,087
Freeway Lanes:							
4	12,000	3,000	12,369		371,070	1,147.4	
6	24,000	5,200	24,557		491,140	3,015.2	
SUBTOTAL	—	—	—	—	862,210	4,162.6	—
TOTAL					1,433,210	4,662.8	1,103

Note: (#) Column Scaled by 10^{-6}

vehicles in each aggregate sample stratum, the default value can be used:

$$SVEh = .02$$

This term is assumed to be unnecessary for freeways because manual rather than machine counts are assumed to be needed for the high volume freeways in this example.

The sample size of volume counts needed to meet the specified study objectives can then be computed as shown in Table 9. The first step is to estimate the acceptable error of the VMT estimate for each reporting stratum (DVMTr) by factoring the anticipated VMT value by the specified relative error. For example, the value for local streets is 50,000 (computed as .25 * 200,000). The sample size required for each reporting stratum can then be computed with formula (12) for local streets and formula (14) for both arterials and freeways.

The resulting sample sizes are 29 counts for local streets, 84 counts for arterials, and 82 counts for freeways—a total of 195 counts. The counts for the latter two reporting strata are then allocated to the component sample strata with formula (15). For example, the required sample size for the sample stratum representing arterials with 15,000-20,000 ADT can be computed as:

$$Nh = 84 * \frac{75,390}{437,000} = 14.5 \rightarrow 15$$

The sample size allocation for all sample strata is summarized in Table 10.

Although this sampling plan was developed to produce statistically precise estimates for the three reporting strata, the results of the counting program could also be used to estimate total regional VMT. The precision of the regional VMT estimate can be calculated by formula (16); in this case a relative error of 3.2 percent would be expected. The precision of the regional VMT estimate would thus be considerably better than that of the VMT estimates for the individual functional class reporting strata.

If only the regional VMT value were important, the same 3.2 percent relative error could be achieved with only 172 counts. These additional 23 counts represent the cost of achieving VMT estimates at the specified precisions for the three functional class reporting strata rather than simply for the region as a whole. As illustrated in Table 10, the distribution of the 172 counts is substantially different from that of the 195 counts. The strata representing local streets is particularly affected because its contribution to the total regional VMT is relatively small.

SELECTING THE SAMPLE

Detailed procedures for computing the minimum sample size were presented above. Once the minimum sample sizes for each sample stratum are computed, the

TABLE 9

EXAMPLE SAMPLE SIZE CALCULATIONS

Local Streets (± .25)

VMTr = 400 * 500 = 200,000

DVMTr = .25 * 200,00 = 50,000

$$Nr = \frac{(400^2 * 335^2)}{\left(\frac{50,000^2}{2^2}\right) + \left(\frac{400^2 * 335^2}{1,600}\right) - (200,000^2 * .02^2)} = 29$$

Arterials (± .05)

VMTr = 2,150,000

DVMTr = .05 * 2,150,000 = 107,500

$$Nr = \frac{(437,000)^2}{\left(\frac{107,500^2}{2^2}\right) + (489,000,000) - (1,087,000,000)} = 84$$

Freeways (± .05)

VMTr = 2,800,000

DVMTr = 140,000

$$Nr = \frac{(862,210)^2}{\left(\frac{140,000^2}{2^2}\right) + (4,162,600,000)} = 82$$

195

location and date of the individual counting sessions can be selected.

Locations

The location of the traffic counting sessions for regional VMT estimates will fall into two classes:

- Locations selected for the HPMS
- Additional locations selected to meet local and regional needs

The locations selected for the HPMS will be counted each year. These locations will likely form the major part of the regional VMT monitoring effort for most urbanized areas. Because the same locations will be counted every year, the resulting VMT estimates should provide a sound basis for detecting even small differences in statewide or national VMT from year to year.

Additional locations will be selected for strata requiring a larger sample size to satisfy local and regional needs than is needed to satisfy the ongoing HPMS requirements. A new sample of locations for these additional counting sessions should be selected every year. Because different locations will likely be selected every year, the resulting VMT estimates should better represent possible shifts in travel patterns and in the size of the regional street network from year to year.

These additional locations should be selected with "probability proportional to size" (PPS) procedures, in which the probability of selecting a particular highway network link depends on its length. This approach is needed to prevent possible biases caused by differing link lengths. For example, links in congested areas might tend to be shorter than links in outlying areas of a region.

The efficient selection of locations will require that an accurate list of links and their lengths be available for use as a sampling frame. If a sampling frame is not available for certain types of highways or streets, an agency should consider developing one for long-term use. Most regions are likely to have appropriate sampling frames for the major street network but may not have a corresponding sampling frame for local streets. In these cases, special procedures may be needed.

TABLE 10

SAMPLE SIZES FOR EACH SAMPLE STRATUM

SAMPLE STRATUM	SAMPLE SIZE REQUIRED	
	3 REPORTING STRATA	1 REPORTING STRATUM
Local Streets	29	16
Arterials ADT:		
<5,000	14	9
5-10,000	27	17
10-15,000	17	11
15-20,000	15	9
20-25,000	5	3
25-30,000	6	4
Freeway Lanes:		
4	35	44
6	47	49
Total	195	172

Sampling Frame Available

If an appropriate sampling frame is available for a sample stratum, links can be selected with either of two PPS approaches:

- Systematic sample of a sequential link list
- Two-stage random selection

A systematic sample of a sequential list of links can be drawn using computer-based procedures, as follows:

- Prepare a sequential list of all links in each sample stratum
- Symbolically place links end to end by creating a list of the cumulative length of all links in the list
- Divide the total mileage for this sample stratum by the required sample size to compute the increment "INC"
- Randomly select a starting point "SP" by drawing a random number between 0 and INC, using any standard random number table[7]
- Proceed down the cumulative length list until the cumulative length equals SP, and select the corresponding link
- Proceed further down the cumulative length list, and stop every INC miles and select the corresponding link

With this procedure, a link can be selected more than once only if its length is greater than the increment. Also, if its length is greater than the increment, it must be selected.

Alternatively, a two-stage random selection of links within a sample stratum can be used. This procedure may be performed either with a computer or by hand, as follows:

- Identify the links with the highest and lowest identification numbers. The range of possible link identification numbers[8] will define the number of random number digits "LID" that will be required (e.g., if the range is from 29 to 3,940, a 4-digit number will be needed and LID = 4).
- Identify the longest link in the population of links in the sample stratum. Scale its length to a 2- or 3-digit number "LEN" (e.g., a link of 1.63 miles would be represented as either 16 or 1.63).
- Generate a random number that has (LID + LEN) digits, using either a computer program or a standard random number table.
- Use the first LID digits of the random number to identify a link. If no link corresponds to this number, generate another random number.
- Once a link is identified, compare its length to the last LEN digits of the random number (e.g., if its length is .22 miles and the longest link was 1.63 miles, .22 is compared to the 3-digit random number). If the link length is greater than or equal to the random number, the link should be counted. If not, a new random number should be drawn, as described above, to identify another link.
- Continue generating random numbers until the required number of links for this sample stratum is selected.

As was the case with the systematic method, links can be selected more than once. As discussed below, however, these links will be counted on different dates.

Sampling Frame Not Available

If no sampling frame is available, a sample of locations must be selected with less effective procedures. While these procedures are likely to introduce some bias into the VMT estimate, they may nevertheless be appropriate for strata that are relatively less important to the monitoring study. For example, although VMT estimates for local streets are needed to accurately estimate total regional VMT, local street travel may (1) represent only a small portion of regional travel, (2) contribute little to understanding trends or serving other uses for VMT estimates, and (3) represent a relatively large portion of the study budget if treated in a rigorous manner. For these reasons, a relatively low precision may be specified for local street VMT, and the sample selection procedures may appropriately be treated in a statistically less precise but more cost-effective manner.

The method used to select the sample should reflect the availability of information about the street network. Agencies that maintain detailed information for planning or inventory purposes should build upon their existing data base as much as possible.[9]

The following procedure may be used in cases where relatively few locations need to be counted in the stratum, relatively numerous geographic areas or "zones" can be used to represent the population of streets, and the approximate mileage of streets

[7]For example, if the increment INC is computed as 36.1 miles, the starting point SP can be computed by (1) selecting any set of three digits from any column of random numbers, (2) proceeding down the column and comparing each 3-digit random number to 361, (3) selecting the first random number greater than or equal to 361, and (4) computing SP by scaling the random number to lie between 0 and 36.1. Thus, if the 3-digit random number 283 is selected, SP = 28.3 miles.

[8]If the link identification numbers are not continuous, the random selection process may select numbers which do not correspond to links actually in the sample stratum. In this case, it may be desirable to number the links for sample selection purposes only.

[9]For example, the North Central Texas Council of Governments maintains a comprehensive planning information system and has developed special procedures for selecting representative counting locations for local streets.

(representing the sample stratum) is either known or can readily be estimated for each zone. The procedure represents a modification to the two-staged selection procedure described previously and consists of the following steps:

- Determine the number of random number digits that can represent the individual zones "ZID" and their approximate mileages "ZMI."
- Generate a random number of (ZID + ZMI) digits with either a computer program or standard tables. If the first ZID digits of the random number do not correspond to a zone, discard this number and generate another. Once a zone is identified, compare its approximate mileage to the last ZMI digits of the random number. If the mileage is greater than or equal to the random number, select this zone. If not, disregard this zone and draw another random number.
- Continue the above steps until the number of zones selected equals the required sample size of counts.
- Select one count location for each selected zone:
  - if possible, by developing a list of links in *only* the selected zones, and then using the two-staged procedures described previously, or
  - if not, by judgmentally selecting one representative location arbitrarily from a map of the zone.

The above procedure may be substantially less costly than developing a detailed sampling frame for a stratum if a very small sample is required. Relatively large sample sizes may, however, justify the development of a new sampling frame. Once developed, a sampling frame can be used for many years with only minor adjustments to reflect system changes and additions.

Dates

The actual date of the counting sessions can be selected after the locations are known. The sampling frame is simply a list of dates within the study period, exclusive of weekends, holidays, and so forth. While dates can readily be selected using random procedures, a systematic selection of dates will likely improve the resulting VMT estimate and possibly increase the efficiency of the data collection effort.

The most basic systematic method is to simply spread out the data collection effort for each sample stratum as evenly as possible throughout the study period. Dates are then matched with locations in the same order as the locations were selected, unless that order could affect the VMT estimate. For example, if a systematic selection of links ordered by identification number is made and if the identification numbers correspond to geographic location, a simple one-to-one match could result in counts being concentrated in relatively close geographic areas at the same time, rather than being spread evenly throughout the entire study period as desired. In this case, the list of locations would have to be mixed up or "randomized" before the location/date match could be performed.

An alternative systematic selection approach, which might reduce data collection costs for relatively large study regions, is as follows:

- Divide the region into a small number (i.e., 3-6) of geographic subareas, desirably consistent with any stratification needed for reporting or sampling efficiency purposes.
- Assign individual weeks to the geographic subareas in a systematic manner allowing at least 3 weeks per subarea.
- Allocate the required number of counting locations evenly throughout those weeks assigned to each subarea.

Such an approach should reduce the time required by the crew to set the counters and thus increase efficiency. While the precision of the VMT estimate will likely be reduced slightly as compared with the basic systematic method, the differences are not expected to be substantial. Also, the number of counting sessions required per day will probably vary more than if the basic systematic method is used.

Table 11 illustrates how a counting schedule could be

TABLE 11

ILLUSTRATIVE COUNTING SCHEDULE

	WEEK												
GEOGRAPHIC AREA	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
Central City	15		15				15		15		15		90
County A		17				16				17			50
County B				20				20				20	60
Total	15	17	15	20	15	16	15	20	15	17	15	20	200

developed using the modified systematic selection method. In this example, the region is divided into three geographic subareas, and the 200 required counts are to be made over a 12-week period. The number of counts per week in this example varies from 15 to 20. Although not illustrated, the counts must be carefully allocated judgmentally within each week to ensure that the counts for each sample stratum are spread evenly over the study period and that particular days of the week are not favored.

Even though the sampling procedures described in this section provide the flexibility to schedule counts during periods of relatively temperate weather and strong quality control can reduce counting errors, most studies will nevertheless experience at least some missed counts. Missed counts should be rescheduled in a systematic manner to avoid serious bias problems. One relatively safe approach is to reschedule missed counts for exactly one week after the originally scheduled counting day and at the same location.

IV. FOCUSED SAMPLING PROCEDURES

This section presents sampling procedures for focused studies of volume or VMT. These procedures can be used to estimate volume at an individual location, volume across a cordonline or corridor cutline, and VMT within a corridor or other small area.

The focused sampling procedures are generally consistent with the sampling procedures described for regional studies in Section III. The major difference is that focused studies are assumed to require a minimum of one counting session at each location, rather than a minimum number of sessions located randomly. The locations for data collection are thus judgmentally selected when the study is designed.

Since the data collection locations are fixed, the sampling plans for focused surveys are designed to ensure that the estimated measure is sufficiently precise to attain the specified study objectives. This discussion is divided into four major sections:

- Estimating the sample size for volume at one location
- Estimating the sample size for volume across a cordonline or corridor cutline
- Estimating the sample size for VMT within a corridor or small area
- Selecting the sample

ESTIMATING THE SAMPLE SIZE FOR VOLUME AT ONE LOCATION

Although most needs for volume data at a single location are typically met by conducting a count on only one day, some planning or evaluation needs may require volume estimates that are more precise than can normally be obtained with only one count. Alternatively, an agency may want to know how precise a single-day volume count is likely to be.

Computing Volume at One Location

The average volume at a single location can be computed as:

$$\overline{VOLi} = \frac{1}{NDi} * \sum_{j}^{NDi} VOLij \qquad (19)$$

where:

$\overline{VOLi}$ = estimated average traffic volume at location "i"

VOLij = number of vehicles counted at location "i" on day "j" during a specified interval

NDi = number of days for which counts of the traffic volume during the specified interval are made at location "i"

The interval could represent either a relatively short time period, such as the peak period, or a longer period up to an entire day.

Estimating Sample Parameters

The composite standard deviation for the internal variability can be computed as:

$$SVIi = (SVOLDi^2 + SVOLSi^2)^{1/2} \qquad (20)$$

where:

SVIi = composite standard deviation for the internal variability at location "i"

SVOLDi = standard deviation of volume across days within a season at location "i"

SVOLSi = standard deviation of volume across seasons at location "i"

All of these terms were previously defined (Section III) for purposes of regional (or other areawide) VMT estimation. The estimation methods and corresponding "default" values for SVOLD and SVOLS presented previously can also be used to estimate the composite standard deviation for the internal variability at a single location.

The corresponding composite standard error for the external variability can be computed as:

$$SVEi = (SADJi^2 + SAXLi^2)^{1/2} \qquad (21)$$

where:

SVEi = composite standard error for the external variability at location "i"

SADJi = standard deviation of the seasonal adjustment factor used at location "i"

SAXLi = standard deviation of the axle correction factor used at location "i"

Although this formula is similar to formula (11) in Section III, standard deviation rather than standard error terms are used to compute the composite parameter.

The estimation of the SADJi parameter will reflect the method used to compute the seasonal adjustment factor and the availability of historical data:

- if more than one ATR will be used to develop the seasonal adjustment factor and historical data are available, formula (64) in Appendix C can be used;
- if only one ATR will be used to develop the seasonal adjustment factor or if no historical data are available, SADJi can be estimated as:

$$SADJi = .05 \quad (22)$$

The estimation of the SAXLi parameter will similarly reflect the method used to develop the assumed axle correction factor:

- if a vehicle classification study has already been conducted to estimate the proportion of multiple-axled vehicles at locations similar to this location, formula (73) in Appendix D can be used
- if a new vehicle classification study will be conducted to estimate the proportion of multiple-axled vehicles at locations similar to this location (TR), SAXLi can be computed as:

$$SAXLi = \frac{.04}{(1 + TR)} \quad (23)$$

- if judgment is used to estimate the proportion of multiple-axled vehicles at this location (TRi), SAXLi can be estimated as:

$$SAXLi = .02 \quad (24)$$

- if a vehicle classification study has been or will be conducted at this location, SAXLi can be disregarded (and set at zero)

Computing the Sample Size

The number of counting sessions required at a single location can then be computed as:

$$NDi = \frac{SVIi^2}{\left(\frac{DVOLi^2}{Z^2}\right) + \left(\frac{SVIi^2}{NDPOP}\right) - \left(\overline{VOLi}^2 * SVEi^2\right)} \quad (25)$$

where:

NDi = number of counting sessions (days) required

NDPOP = total number of possible data collection days during the study period

$\overline{VOLi}$ = *anticipated* average daily volume at location "i"

DVOLi = acceptable difference between the estimated average daily volume at location "i" and the true value

Z = normal variate for the specified level of confidence, two-tailed test

Alternatively, if an agency has already determined the number of counting sessions to be conducted at this location, the expected precision of the resulting estimate of average daily volume can be computed as:

$$DVOLi = Z * [(SVIi^2/NDi) - (SVIi^2/NDPOP) + (\overline{VOLi}^2 * SVEi^2)]^{1/2} \quad (26)$$

The actual precision of the estimate can only be determined after the study has been conducted. If the sample parameters have been estimated accurately, the expected precision will be achieved. If not, the actual precision will be either higher or lower than expected.

Example

Assume that an agency wants to estimate average annual daily traffic (AADT) at a particular location. A single 24-hour count will be made on a randomly selected day during a 3-month intensive traffic counting period. The AADT will then be estimated by multiplying the count by a seasonal adjustment factor which will be derived from three ATR's located on similar types of roadway. For sampling plan purposes, the agency uses the default sample parameter values and judgmentally estimates the proportion of multiple-axled vehicles at this location. Historical data from the three ATR's are used to estimate the standard deviation of the seasonal adjustment factor as .038. The agency wants to determine the expected precision of the AADT estimate and specifies a 95-percent level of confidence. The sample parameters can now be summarized as:

NDi = 1 (data collection plan)
Z = 2.0 (desired level of confidence)
$\overline{VOLi}$ = 20,000 (anticipated AADT)
NDPOP = 66 (number of weekdays during study period)
SVOLSi = 0 (data collection plan)
SADJi = .038 (historical data)

The composite standard deviation for the internal variability represents only the effects of short-term daily variations because the study period is so short (i.e., SVOLSi = 0). It can be computed with formula (6), Figure 1, and formula (20) as:

$$SVOLDi = .10 * 20{,}000 = 2{,}000$$

$$SVIi = (2{,}000^2 + 0^2)^{1/2} = 2{,}000$$

The corresponding composite standard error for the external variability reflects both the assumed axle correction factor and the seasonal adjustment factor. It can be computed with formulas (24) and (21) as:

$$SAXLi = .02$$

$$SVEi = (.038^2 + .02^2)^{1/2} = .043$$

The expected precision of the AADT estimate can then be determined with formula (26) as:

$$DVOLi = 2.0 * [(2{,}000^2/1) - (2{,}000^2/66) + (20{,}000^2 * .043^2)]^{1/2} = 4{,}326$$

That is, the probability that the true AADT will differ from the estimated AADT by more than 4,326 vehicles per day is 1 in 20. This represents a relative difference of approximately ± 22 percent (4,326/20,000). If this precision is not considered adequate, the agency can count for more than one day at this location. But even if the agency counts for *every* day in this period, the variability due to external factors will still restrict the precision of the AADT estimate. The *best* precision that can be expected under these circumstances can be computed as:

$$DVOLi = 2.0 * [(2{,}000^2/66) - (2{,}000^2/66) + (20{,}000^2 * .043^2)]^{1/2} = 1{,}720 \text{ or } 8.6 \text{ percent}$$

ESTIMATING THE SAMPLE SIZE FOR VOLUME ACROSS A CORDONLINE OR CORRIDOR CUTLINE

The total volume across a series of stations comprising a cordonline or corridor cutline can be treated with stratified sampling plans in which each location represents a different stratum. Volume counts are therefore needed for at least one day for every station.

Computing Volume Across the Cordonline or Corridor Cutline

The average volume across the entire cordonline or cutline can be computed as:

$$\overline{VOL} = \sum_i^L VOLi \qquad (27)$$

where:

$\overline{VOL}$ = estimated average traffic volume across a cordonline or corridor cutline with "L" stations

$\overline{VOLi}$ = estimated average traffic volume at location "i"

Again, the interval could represent either a relatively short time period, such as the peak period, or a longer period up to an entire day.

Estimating Sample Parameters

The sample parameters described in the preceding subsection for application to specific locations can also be used for stratified sampling plans. The external variability parameters should, however, represent characteristics of the total cordonline or cutline rather than any single location.

Computing the Sample Size

The number of counting sessions needed at each of "L" stations in order to estimate the average total volume across a cordonline or corridor cutline can be computed as:

$$NDi = \left[\sum_i^L (SVIi^2)\right] \div \left[\left(\frac{DVOL^2}{Z^2}\right) + \left(\sum_i^L SVIi^2 / NDPOP\right) - \left(\overline{VOL^2} * SVE^2\right)\right] \qquad (28)$$

where:

DVOL = acceptable difference between the estimated average total volume across the cordonline or cutline and the true value

SVE = composite standard error for the external variability at stations comprising the cordonline or cutline

This formula assumes that data will be collected for the same number of days NDi at each station, as will probably be the most common situation.

Alternatively, it may occasionally be beneficial to vary the number of counting sessions for different stations. If the internal variability parameters SVIi vary substantially (i.e., by at least a factor of 2 or 3) between stations, a more efficient sampling plan can be developed by allocating a greater number of counting sessions to stations with larger SVIi terms. Also, it may be desirable to obtain substantially more precise estimates of the average volume at certain key stations while still obtaining a precise estimate of average volume across the cordonline or cutline. The precision that can be expected under these circumstances can be computed as:

$$DVOL = Z * [(\sum_i^L (SVOLi^2/NDi)) - (\sum_i^L (SVOLi^2/NDPOP)) + (\overline{VOL}^2 * SVE^2)]^{1/2} \quad (29)$$

Example

Assume that the average morning peak-period traffic volume across a cutline consisting of three stations is to be estimated with manual counts and that the specific objectives are to (1) estimate the average cutline volume within ± 10 percent of the true value with 95 percent confidence (i.e., 1 chance in 20 that the estimated value will differ from the true value by more than 10 percent and (2) estimate the average volume at station #1 with ± 15 percent with 95 percent confidence. If the expected volumes across the stations are approximately 1,000 vph, 1,500 vph, and 2,000 vph and the survey is to represent a 4-month period, the assumptions can be summarized as:

$\overline{VOL1}$ = 2,000 vehicles
$\overline{VOL2}$ = 3,000 vehicles
$\overline{VOL3}$ = 4,000 vehicles
$\overline{VOL}$ = 9,000 vehicles
NDPOP = 83 days
DVOL = 900 (.10 * 9,000)
DVOL1 = 300 (.15 * 2,000)
Z = 2.0

Because the survey period is relatively short, the effects of seasonal variation are assumed to be negligible. The composite standard deviation for internal variability thus reflects only the short-term daily variations, as computed with formula (20):

$SVOLSi = 0$

$SVIi = (SVOLDi^2 + 0^2)^{1/2} = SVOLDi$

The SVOLDi term can then be computed with formula (6) and an assumed default value chosen from the range specified in formula (7) as:

CVVOLDi = .10
SVI1 = .10 * 2,000 = 200
SVI2 = .10 * 3,000 = 300
SVI3 = .10 * 4,000 = 400

The corresponding standard error for the external variability can be disregarded because (1) manual rather than machine counts will be made—eliminating the need to apply axle correction factors and (2) the volume estimate will represent the 4-month study period only—no attempt will be made to apply seasonal adjustment factors. The SVE term is therefore assumed to be zero.

The number of counting sessions required to estimate the average volume at station #1 can be computed with formula (25) as:

$$NDi = \frac{200^2}{\frac{300^2}{2.0^2} + \frac{200^2}{83} - 0} = 1.7 \rightarrow 2$$

Similarly, the number of counting sessions required for each of the three stations in order to estimate the average total volume across the cutline can be computed with formula (28) as:

$$NDi = \left[(200^2 + 300^2 + 400^2)\right] \div \left[\left(\frac{900^2}{2.0^2}\right) + \left((200^2 + 300^2 + 400^2)/83\right) - 0\right] = 1.4$$

While the most straightforward approach would be to simply collect volume data for 2 days for each station for a total of 6 days, it may be appropriate to selectively reduce the sample size at one of the stations to one count. For example, if station #2 is selected for only a single count, the expected precision of the average cutline volume can be computed with formula (29) as:

$$DVOL = 2.0 * \left[(200^2/2 + 300^2/1 + 400^2/2) - \left((200^2 + 300^2 + 400^2)/83\right) + 0\right]^{1/2}$$

$$= 2.0 * [190{,}000 - 3{,}494]^{1/2} = 864$$

Since 864 is smaller than the desired cutline tolerance of 900, this sampling plan should result in sufficiently precise estimates of average volume for both station #1 and for the cutline as a whole with a total data collection effort of 5 counting sessions.

ESTIMATING THE SAMPLE SIZE FOR VMT WITHIN A CORRIDOR OR SMALL AREA

The total VMT for a series of highway links comprising a corridor or other small area network can be treated with stratified sampling procedures similar to those described in the preceding subsection. Volume counts are again required for at least one day on every link. For larger networks, the regional sampling procedures described in Section III may substantially reduce the number of counting sessions required.

Computing the VMT Within a Corridor or Small Area

The average VMT for a series of links representing a corridor or small area network can be computed as:

$$\overline{VMT} = \sum_{i}^{L} \overline{VMTi} \qquad (30)$$

$$\overline{VMTi} = \overline{VOLi} * Li \qquad (31)$$

where:

$\overline{VMTi}$ = estimated average VMT on link "i"

$\overline{VMT}$ = estimated average VMT on the corridor or small area network with "L" links

Li = length of link "i" in miles

As in the case of volume, the estimated VMT values could represent specific time periods during the day or the entire day, depending on the study objectives and corresponding data collection procedures.

Estimating the Sample Parameters

The sampling parameters discussed previously for volume can also be used for VMT.

Computing the Sample Size

The number of counting sessions needed on each of "L" links in order to estimate the average VMT for a corridor or small area network can be computed as:

$$NDi = \left[\sum_{i}^{L} (Li^2 * SVIi^2)\right] \div \left[\left(\frac{DVMT^2}{Z^2}\right) + \left(\sum_{i}^{L} (Li^2 * SVIi^2/NDPOP)\right) - (\overline{VMT}^2 * SVE^2)\right] \qquad (32)$$

where:

DVMT = acceptable difference between the estimated average daily VMT within a corridor or small area network and the true value.

As was the case for estimating average volume across a cordonline or cutline, the number of counting sessions per link can be varied. The expected precision of an average VMT estimate can be computed as:

$$DVMT = Z * \left[\left(\sum_{i}^{L} (Li^2 * SVIi^2/NDi)\right) - \left(\sum_{i}^{L} (Li^2 * SVIi^2/NDPOP)\right) + (\overline{VMT}^2 * SVE^2)\right]^{1/2}$$

Example

Assume that the objective is to estimate the average VMT along an arterial with 10 links within ± 5 percent of the expected value with 95 percent confidence. Further assume that the survey period will extend for 3 months and that, for simplicity, the volumes and the link lengths for all links are expected to be very similar. Because traffic counting machines will be used and no prior vehicle classification data are available, axle correction factors will be judgmentally estimated. These assumptions can be summarized as:

NDPOP = 65

L = 10

Li = .12 mile

$\overline{VOLi}$ = 8,000 vehicles

$\overline{VMT}$ = 9,600 (10 * 8,000 * .12)

DVMT = 480 (.05 * 9,600)

Z = 2.0

As was the case with the example in the preceding subsection, the composite standard deviation for internal variability can be approximated for each of the links with formula (6) and an assumed default value from formula (7) as:

CVVOLDi = .10

SVIi = SVOLDi = .10 * 8,000 = 800

The corresponding standard error for external variability will represent only the effect of the assumed axle correction factors and can be computed with formulas (24) and (21) as:

SAXL = .02

$SVE = (.02^2 + 0^2)^{1/2} = .02$

Formula (32) can then be used to compute the number of counting sessions required for each link:

$$NDi = \left[.12^2 * 800^2 + \ldots + .12^2 * 800^2\right] \div \left[\left(\frac{480^2}{2.0^2}\right) + \left((.12^2 * 800^2 + \ldots + .12^2 * 800^2)/65\right) - 9{,}600^2 * .02\right] = 4.2$$

This indicates that 42 (4.2 * 10) counting sessions would be needed to estimate VMT for the arterial at the desired level of precision. If a special vehicle classification survey were conducted (with only one or two classification counting sessions) or if manual rather than machine counts were made, the external variability would be eliminated. The minimum number of required counting sessions can then be calculated, again with formula (32):

$$NDi = \left[(.12^2 * 800^2 + \ldots + .12^2 * 800^2)\right] \div \left[\left(\frac{480^2}{2.0^2}\right) + \left((.12^2 * 800^2 + \ldots + .12^2 * 800^2)/65\right) - 0\right] = 1.6$$

The total number of counting sessions would therefore be reduced from 42 to 16 (1.6 * 10), although this benefit would be reduced by the additional costs of conducting the vehicle classification study or making manual counts. An effective way to reduce costs in this case might be to replace 2 of the 16 machine volume counts with manual vehicle classification counts.

SELECTING THE SAMPLE

Because the counting locations for focused studies are determined beforehand, only the data collection dates need to be selected. The general procedures described in Section III for regional samples are generally applicable to focused studies as well. In fact, an agency may wish to develop—using systematic selection methods—a master schedule for the entire traffic counting program, including both regional and focused locations.

However, since the sample sizes for focused studies are typically so small, considerable care must be taken to ensure a reasonably representative selection of dates. Focused studies that use stratified sampling plans will require that data collection dates be selected independently for each location. In particular, traffic counts should normally not be made at several locations on the same days because the resulting volume or VMT estimate will not be as precise as if volume had been collected at different locations on different days.

V. STUDY ORGANIZATION AND ADMINISTRATION

This section suggests methods of organizing and administering an integrated traffic counting program to implement the sampling plans discussed in Sections III and IV. The discussion consists of five major subsections:

- Organizing the count program
- Preparing a work plan
- Collecting data
- Reducing and analyzing data
- Maintaining the data base

ORGANIZING THE COUNT PROGRAM

Integrating regional traffic counting needs into a unified program is a complex task. Careful organization is required if the program objectives are to be attained in a cost-effective manner. Four basic persons or groups are needed to implement the program:

- Program coordinator
- Agency count program manager
- Field crew
- Data analyst

The program coordinator is responsible for the successful implementation of the count program. This individual should bring the various agencies together to determine program objectives, develop sampling plans, and prepare a coordinated work plan. Other responsibilities include monitoring the data collection, reduction, and analysis to ensure that the traffic counts reach the appropriate users. These responsibilities can be divided among representatives of the various agencies if no one person has the skills or time needed to implement the program. A program coordination committee, composed of the agency personnel responsible for the collection and/or use of the data, may be an appropriate mechanism.

The agency count program manager is responsible for managing the agency's data collection effort. This involves cooperating with the program coordinator, preparing an agency work plan, and supervising data collection, reduction, and analysis.

The field crews place the traffic volume counters in the field or make manual counts as required by the work plan. While some agencies may have experienced field personnel, many agencies may have to use other technicians to perform these activities. Because of the demands placed on the crew (i.e., repetition, fatigue, and adverse environmental conditions), an agency selecting crew members should consider both their capability to perform the mechanical activities and their motivation. Data collection errors, particularly systematic errors, can seriously bias the survey results.

The data analysts reduce and summarize the data recorded by the field crew. Analysts should be able to reduce the raw data without making mistakes and compute basic statistical parameters under the direction of the program manager.

PREPARING A WORK PLAN

After the program objectives have been translated into sampling plans, the program coordinator and the agency count program managers can prepare a detailed work plan to guide the remaining effort. Developing a work plan may require the following activities:

- Estimate resource requirements
- Schedule traffic counts
- Prepare data reduction process

Estimating Resource Requirements

The cost of conducting an integrated traffic counting program will vary substantially, depending on the scope of the program and the availability of a convenient sampling frame. Table 12 presents initial estimates of person hours of effort required by the program coordinator, agency program manager, field crew, and data analysts to conduct an annual counting program. Person hour estimates are expressed in ranges to account for differences between programs. Base hours represent the estimated level of effort regardless of the program's size, while per-count hours represent the effects of the sample size. The estimates of count hours for the data collectors assume that one crew member can place one traffic counter into operation and remove it at the end of the count period in a total of 2 hours.

When resource requirements are estimated, the calculated sample sizes should be adjusted for locations chosen to be counted more than once. If a single traffic count can be used for multiple purposes, the benefits of an integrated program can be realized in terms of costs and manpower. Table 13 illustrates the total number of regional counting locations required to meet the objectives specified for the integrated traffic counting program example in Section II. The regional sample size is consistent with the example presented in Section III. The corresponding sample sizes for focused studies assume that a single counting session will be needed at

TABLE 12

INTEGRATED TRAFFIC COUNTING PROGRAM: RESOURCE REQUIREMENTS (HOURS)

TASKS	RESPONSIBILITIES							
	Program Coordinator		Agency Program Manager		Field Crew		Data Analysts	
	Base	Count	Base	Count	Base	Count	Base	Count
Program Design	32–64		32–64					
Develop Sample Plan	24–80		16–40					
Prepare Work Plan	24–40		32–80					
Data Collection	8–24	0.5	4–8	1	4–8	2		
Data Reduction & Analysis	8–24	0.5	4–8	1			4–8	2
TOTAL	96–232	1	88–200	2	4–8	2	4–8	2

TABLE 13

SAMPLE INTEGRATED TRAFFIC COUNT PROGRAM: ADJUSTMENT OF SAMPLE SIZE FOR DUPLICATE COUNT LOCATIONS

OBJECTIVE	CALCULATED SAMPLE SIZE				SAMPLE ADJUSTED FOR DUPLICATE COUNTS			
	Highway Functional Class				Highway Functional Class			
	Freeway	Arterial	Local	Total	Freeway	Arterial	Local	Total
1. Regional VMT	82	84	29	195	46	25	29	100
• City TE Dept.	41	42	15	98	14	0	15	29
• State DOT	41	42	14	97	32	25	14	71
2. Screen lines (4 lines of 20 sites each)	4	76		80	4	76		80
3. Coverage count (¼ of nonlocal streets in city)	25	50		75	25	50		75
4. CBD cordon count	4	26		30	4	26		30
5. Corridor (15 freeway and 35 arterial links)	15	35		50	15	35		50
6. Special count sites	3	7		10	3	7		10
TOTAL	133	278	29	440	97	219	29	345
• City TE Dept.	72	156	15	243	45	114	15	174
• State DOT	61	122	14	197	52	105	14	171

each location for the screenline, CBD cordonline, and corridor counts. An additional 25 percent of the freeway and arterial links located within the city boundaries are assumed to be counted each year in the coverage count program. This example assumes that the city traffic engineering department will conduct the regional VMT counts within the city, half of the screenline counts, the coverage counts, and the CBD cordonline count, and the State DOT will conduct the rest.

The total number of count locations required to meet the program objectives, without accounting for duplicates, is 440. But since many of the randomly selected locations that will be counted to estimate regional VMT will already be counted for other purposes, the total number of locations can be reduced to 345. This adjustment makes three assumptions:

- None of the count sites for the focused studies are duplicates[10]
- The coverage count locations are randomly selected beforehand such that 25 percent of the freeway and arterial links are counted each year (these counts can thus be used to estimate regional VMT as well)
- The number of locations for which counts are needed for both regional VMT and focused studies can be estimated with conditional probability methods

If it is assumed that the needs for the focused and coverage counts would be met regardless of the development of an integrated counting program, the incremental number of counts needed to produce estimates of regional VMT at the levels of precision specified in this example is only 100 counts. Although this result reflects the particular assumptions made for this example, it demonstrates how an integrated traffic counting program can serve a variety of counting needs in a cost-effective manner.

Based on the assumed number of counts and the minimum values suggested in Table 12, the approximate level of effort required to implement the example counting program can be computed as follows:

• Program coordinator:	96 + 1 * 345 =	441
• City program manager:	88 + 2 * 174 =	436
• State program manager:	88 + 2 * 171 =	430
• Field crew:	4 + 2 * 345 =	694
• Data analysts:	4 + 2 * 345 =	694
		2,695

A total of 2,695 person hours is thus the approximate level of effort required to conduct the program. If the maximum suggested values are used instead of the minimum values, the estimated total level of effort is approximately 2,951.

Scheduling Traffic Counts

The program manager should schedule the data collection and reduction activities for individuals in accordance with the fixed selection of data collection sessions derived from the sampling plan. This will minimize the chance of disruptions due to vacations or other work commitments and may highlight other scheduling problems such as the unavailability of equipment.

Preparing Data Reduction Process

Before the data collection begins, a process should be established for reducing the data to a common and readily usable format. The needs of all users should be considered when the data format is selected.

COLLECTING DATA

The field crews should not require much direct supervision from the program manager unless they have not been trained. The manager can probably limit contact to reminding crew members of upcoming sessions, answering questions, making arrangements to overcome unexpected problems, and selectively visiting the data collection sites. But it is important for the manager to ensure that the schedule is maintained. If the schedule slips due to a lack of personnel or equipment, adjustments should be made.

REDUCING AND ANALYZING DATA

The raw volume data from the ATR's or manual studies can then be reduced, summarized, and analyzed to provide estimates of the desired measures at known levels of statistical precision. Data analysis procedures are provided for:

- Volume at an individual location
- Volume across a cordonline or cutline
- VMT within a corridor or small area
- VMT for a region

Volume at an Individual Location

The volume counted at an individual location on a given day and the corresponding average volume can be computed as:

$$VOLij = AXLESij * FAi \qquad (34)$$

[10]For example, the number of stations in the screenlines in this example is likely to be more than 20; the 20 stations are in addition to stations that will be counted in other focused studies.

$$\overline{VOLi} = \frac{1}{NDi} * \sum_{j}^{NDi} VOLij \qquad (35)$$

where:

$VOLij$ = estimated volume at location "i" on day "j"

$AXLESij$ = number of vehicle axles counted at location "i" on day "j"

FAi = assumed axle correction factor

NDi = number of counting sessions conducted at location "i"

$\overline{VOLi}$ = estimated average volume at location "i"

The above estimate of average volume represents the period over which volume counts are made. If the period extends over an entire year, the average volume is equivalent to average annual weekday traffic (AWT), assuming that only weekday volume counts are made. If the period extends less than a year, the AWT at this location can be estimated if the average volume is adjusted by applying a factor derived from ATR's at similar locations, as follows:

$$\overline{AWTi} = FSi * \overline{VOLi} \qquad (36)$$

where:

$\overline{AWTi}$ = estimated average annual weekday traffic volume at location "i"

FSi = assumed seasonal adjustment factor applicable to location "i"

The composite standard deviation for internal variability and the composite standard error for external variability must be estimated before the precision of the volume or AWT estimate can be determined. If data have been collected on only 1 day, the SVIi value assumed during the development of the sampling plan should be used. If data have been collected for more than 1 day, SVIi can be estimated from the results of the survey as:

$$SVIi = \left\{ \frac{1}{NDi - 1} * \left[\left(\sum_{j}^{NDi} (VOLij^2) \right) - (NDi * \overline{VOLi}^2) \right] \right\}^{1/2} \qquad (37)$$

where:

$SVIi$ = estimated composite standard deviation for the internal variability at location "i"

NDi = number of counting sessions conducted at location "i"

The above formula computes the composite standard deviation term directly rather than by separately estimating individual sources of variation and then combining the results as described in Section III.

If additional data are available from ATR's or vehicle classification studies, these data should be used to estimate the composite standard error for the external variability (see Appendices B and C). Otherwise, the value for the composite standard error for external variability assumed during the initial development of the sampling plan can again be used after the study has been completed to assess the precision of the estimate.

The precision of an estimate of average volume at an individual location and the corresponding average annual volume can be computed as:

$$DVOLi = Z * [(Fi * SVIi^2/NDi) + (\overline{VOLi}^2 * SVEi^2)]^{1/2} \qquad (38)$$

$$DAWTi = Z * [(FSi^2 * Fi * SVIi^2/NDi) + (\overline{VOLi}^2 * SVEi^2)]^{1/2} \qquad (39)$$

$$Fi = \left(\frac{NDPOP - NDi}{NDPOP} \right) \qquad (40)$$

where:

$DVOLi$ = maximum expected difference between the estimated average volume at location "i" and the true value at the specified level of confidence

Fi = finite population correction factor for location "i"

$NDPOP$ = total number of possible data collection days during the study period

$DAWTi$ = maximum expected difference between the estimated average annual volume at location "i" and the true value at the specified level of confidence

The tolerance terms "DVOLi" and "DAWTi" define the bounds of a confidence interval around the estimated average values. Thus, the probability that the true value differs from the estimated value by more than the tolerance is specified by the normal variate "Z." If Z = 2.0, as assumed for the examples presented in this manual, the probability that the estimate will fall outside the interval is only 5 percent.

Volume Across a Cordonline or Cutline

The average volume across a cordonline or cutline can be computed, as described in Section IV, as follows:

$$\overline{VOL} = \sum_{i}^{L} \overline{VOLi} \quad (41)$$

This estimate will represent the period over which volume counts are made. If seasonal adjustment factors are used to estimate average annual volume by expanding an estimate of average volume made over a shorter time period, the average annual volume can be computed as:

$$\overline{AWT} = FS * \overline{VOL} \quad (42)$$

where:

$\overline{AWT}$ = estimated average annual volume across the cordonline or cutline

FS = assumed seasonal adjustment factor applicable to the cordonline or cutline

The composite standard deviation for internal variability at each location "i" and the composite standard error for the external variability across the cordonline or cutline can be estimated as described in the preceding subsection. If possible, the results of the survey should be used to estimate the composite standard deviation for the internal variability. Otherwise, the values assumed during the development of the sampling plan should be used again. The value assumed for the composite error for the external variability during the development of the sampling plan must be used again to assess the actual precision achieved after the survey has been completed, unless better data are available to compute a more accurate estimate of this parameter.

The precision of an estimate of average volume across a cordonline or cutline and the corresponding average annual volume can be computed as:

$$DVOL = Z * \left[\sum_{i}^{L} (Fi * SVIi^2/NDi) + (\overline{VOL}^2 * SVE^2) \right]^{1/2} \quad (43)$$

$$DAWT = Z * \left[\left(FS^2 * \sum_{i}^{L} (Fi * SVIi^2/NDi) \right) + (\overline{VOL}^2 * SVE^2) \right]^{1/2} \quad (44)$$

where:

DVOL = maximum expected difference between the estimated average volume across the cordonline or cutline and the true value at the specified level of confidence

DAWT = maximum expected difference between the estimated average annual volume across the cordonline or cutline and the true value at the specified level of confidence

VMT Within a Corridor or Small Area

The average VMT within a corridor or small area can be computed, as described in Section IV, as:

$$\overline{VMT} = \sum_{i}^{L} VMT = \sum_{i}^{L} (VOLi * Li) \quad (45)$$

If an average annual estimate of VMT is made by applying a seasonal adjustment factor to a VMT estimate made during a shorter time period, the average annual VMT can be computed as:

$$\overline{AVMT} = FS * \overline{VMT} \quad (46)$$

where:

$\overline{AVMT}$ = estimated average annual VMT within the corridor or small area

FS = assumed seasonal adjustment factor applicable to this corridor or small area

The composite standard deviation for internal variability and the composite standard error for external variability can be computed or estimated as described in the two preceding subsections.

The precision of an estimate of average VMT within a corridor or small area and the corresponding average annual VMT can be computed as:

$$DVMT = Z * \left[\left(\sum_{i}^{L} (Fi * Li^2 * SVIi^2/NDi) \right) + (\overline{VMT}^2 * SVE^2) \right]^{1/2} \quad (47)$$

$$DAVMT = Z * \left[\left(FS^2 * \sum_{i}^{L} (Fi * Li^2 * SVIi^2/NDi) \right) + (\overline{VMT}^2 * SVE^2) \right]^{1/2} \quad (48)$$

where:

DVMT = maximum expected difference between the estimated average VMT within the corridor or small area and the true value at the specified level of confidence

DAVMT = maximum expected difference between the estimated average annual VMT within the corridor or small area and the true value at the specified level of confidence

VMT for a Region

The volume counted during session "i" at a location selected in sample stratum "h" and the corresponding average volume for sample stratum "h" can be computed as:

$$VOLhi = AXLEShi * FAe \quad (49)$$

$$\overline{VOLh} = \frac{1}{Nh} * \sum_{i}^{Nh} VOLhi \quad (50)$$

where:

VOLhi = estimated volume counted during session "i"

AXLEShi = number of vehicle axles counted during session "i"

FAe = assumed axle correction factor applicable to locations in sample stratum "h"

$\overline{VOLh}$ = estimated average volume for sample stratum "h"

Nh = number of counting sessions conducted for sample stratum "h"

The average regional VMT representing the period over which the volume counts have been made can then be computed as:

$$\overline{VMTr} = \sum_{h}^{H} \overline{VMTh} = \sum_{h}^{H} (Mh * \overline{VOLh}) \quad (51)$$

where:

$\overline{VMTr}$ = estimated average VMT for reporting stratum "r"

H = number of sample strata "h" contained in reporting stratum "r"

Mh = mileage of sample stratum "h"

An estimate of average annual regional VMT can be made by applying seasonal adjustment factors to an estimate of average VMT for a shorter time period, as follows:

$$\overline{AVMTr} = \sum_{h}^{H} FSe * \overline{VMTh} \quad (52)$$

where:

$\overline{AVMTr}$ = estimated average annual VMT for reporting stratum "r"

FSe = assumed seasonal adjustment factor applicable to sample stratum "h"

The composite standard deviation for the internal variability should be computed for each sample stratum from the results of the survey as:

$$SVIh = \left\{ \frac{1}{Nh-1} * \left[\left(\sum_{i}^{Nh} (VOLhi^2) \right) - (Nh * \overline{VOLh^2}) \right] \right\}^{1/2} \quad (53)$$

where:

SVIh = estimated composite standard deviation for the internal variability for sample stratum "h"

The values of the composite standard error for the external variability that were assumed during initial development of the sampling plan should be used again after the study has been completed to assess the precision actually achieved, unless more current data are available from the ATR's or vehicle classification studies.

The precision of an estimate of average regional VMT and the corresponding average annual regional VMT can then be computed as:

$$DVMTr = Z * \left[\sum_{h}^{H} (Mh^2 * Fh * SVIh^2/Nh) + \sum_{e}^{E} (\overline{VMTe^2} * SVEe^2) \right]^{1/2} \quad (54)$$

$$DAVMTr = Z * \left[\sum_{h}^{H} (FSe^2 * Mh^2 * Fh * SVIh^2/Nh) + \sum_{e}^{E} (\overline{VMTe^2} * SVEe^2)^{1/2} \right] \quad (55)$$

$$Fh = \frac{NPOPh - Nh}{NPOPh} \quad (56)$$

where:

DVMTr = maximum expected difference between the estimated average regional VMT for reporting stratum "r" and the true value at the specified level of confidence

Fh = finite population correction factor for sample stratum "h"

$\overline{VMTe}$ = estimated average VMT for aggregate sample stratum "e"

DAVMTr = maximum expected difference between the estimated average annual regional VMT for reporting stratum "r" and the true value at the specified level of confidence

NPOPh = population of links in sample stratum "h"

The following example is provided to illustrate how regional VMT can be estimated and its precision determined. This example is based on the integrated traffic counting program example presented in Section III and also discussed earlier in this section.

Table 14 illustrates the computation of the average volume and corresponding composite standard deviation for the internal variability for the sample stratum representing arterial streets with 20,000–25,000 ADT. In this case, the actual sample size of five sessions determined during the development of the sampling plan (see Table 10) was attained; the actual sample size might have been smaller or larger depending on the occurrence of missed counts and the provision of additional sessions to reduce the effects of possible missed counts. One of the counts in this example is actually outside the range of 20,000 to 25,000 ADT. This may reflect either an unreasonable axle correction factor or a misallocation of this location to the sample stratum, but this value *must* be used to compute both the average volume and the composite standard deviation for this sample stratum.[11] The average volume for this sample stratum is computed with formulas (49) and (50) as 21,893. The corresponding composite standard deviation is computed with formula (53) as 2,621. These values are slightly different from those assumed during development of the initial sampling plan (see Tables 7 and 8).

[11] If this location is counted each year for HPMS reporting purposes, it should continue to be included in its original HPMS reporting stratum. If not an HPMS location, however, it may be allocated to another sample stratum for surveys made in subsequent years.

TABLE 14

EXAMPLE WORKSHEET TO COMPUTE VOLUME AND COMPOSITE STANDARD DEVIATION FOR SAMPLE STRATUM OF ARTERIALS WITH 20–25,000 ADT

DATE	LOCATION	AXLE COUNT	CORRECTION FACTOR	VOLUME (VOLhi)	VOLUME² (VOLhi)²
4-9	187	45,064	.446	20,099	403,969,800
5-3	233	53,804	↓	23,997	575,856,000
5-22	54	55,116	↓	24,582	604,274,720
6-15	862	41,235	↓	18,391	338,228,880
6-27	491	50,220	↓	22,398	501,670,400
			↓	109,467	2,423,999,700

$\overline{VOLh}$ = 109,467/5 = 21,893

$$SVIh = \left[\frac{2{,}423{,}999{,}700 - (5 * 21{,}893^2)}{5-1}\right]^{1/2}$$

$$= 2{,}621$$

TABLE 15

EXAMPLE WORKSHEET TO COMPUTE AVERAGE WEEKDAY VMT

Sample Strata		Mileage (Mh)	Volume ($\overline{\text{VOL}}$h)	$\overline{\text{VMTh}}$	Seasonal Factor (FSe)	$\overline{\text{AVMTh}}$
Local Streets		400	755	302,000	1.03	311,060
Arterials	0– 5,000	40	4,380	175,200	1.04	182,208
	5–10,000	70	6,232	436,240		453,690
	10–15,000	40	14,072	562,880		596,653
	15–20,000	30	17,149	514,470	1.06	545,338
	20–25,000	10	21,893	218,930		232,066
	25–30,000	10	28,490	284,900		301,994
Freeways	4 Lanes	30	38,365	1,150,950	1.09	1,254,536
	6 Lanes	20	77,181	1,543,620		1,682,546

TABLE 16

EXAMPLE WORKSHEET TO COMPUTE PRECISION OF ANNUAL VMT ESTIMATE FOR ARTERIALS

Sample Strata (ADT)	Mileage (Mh)	Seasonal Factor (FSh)	FPC (Fh)	SVIh	Nh	$\overline{\text{VMTe}}$	SVEe
5,000	40	1.04	.813	1,824	15	611,440	.02
5–10,000	70	1.04	.807	2,033	27		
10–15,000	40	1.06	.800	2,116	16	1,581,180	.02
15–20,000	30	1.06	.733	2,330	16		
20–25,000	10	1.06	.750	2,621	5		
25–30,000	10	1.06	.700	3,247	6		

AVMTr = 182,208 + 453,690 + 596,653 + 545,338 + 232,066 + 301,994 = 2,402,949

$$\begin{aligned} \text{DAVMTr} = {} & 2.0 \cdot [(40^2 \cdot 1.04^2 \cdot .813 \cdot 1{,}824^2/15) + (70^2 \cdot 1.04^2 \cdot .807 \cdot 2{,}033^2/27) \\ & + (40^2 \cdot 1.06^2 \cdot .800 \cdot 2{,}116^2/16) + (30^2 \cdot 1.06^2 \cdot .733 \cdot 2{,}330^2/16) \\ & + (10^2 \cdot 1.06^2 \cdot .750 \cdot 2{,}621^2/5) + (10^2 \cdot 1.06^2 \cdot .700 \cdot 3{,}247^2/6) \\ & + (611{,}440^2 \cdot .02^2) + (1{,}581{,}180^2 \cdot .02^2)]^{1/2} \\ = {} & 109{,}988 \end{aligned}$$

Table 15 summarizes the major parameters that must either be computed from the results of the survey, be determined from standard records such as system inventory data, or be estimated from other sources. Although the seasonal adjustment factors assumed for this example are all greater than one, factors less than one might also be expected whenever the field traffic counts are conducted in periods of relatively high traffic volume levels. The average VMT and corresponding average annual VMT estimates are computed with formulas (51) and (52), as applied to individual sample strata.

Table 16 summarizes the final set of parameters needed to estimate average annual VMT and the associated precision of this estimate. The actual sample sizes for individual sample strata are slightly different from those determined for the initial sampling plan (see Table 10). The average annual VMT for all arterial streets is estimated with formula (52) as 2,402,949 (per day). The corresponding precision is determined with formula (55) as 109,988. That is, the probability that the true average annual VMT differs from the estimate by more than 109,988 (i.e., lies outside the range of 2,292,961 to 2,512,937) is only 5 percent. The relative error can be computed as approximately 4.6 percent (109,988/2,402,949). Thus, the level of precision specified when the initial sampling plan was developed (5.0 percent) has been exceeded in this example. Even if the actual error had been greater than that originally desired, the resulting VMT estimate would be valid but at a slightly lower level of precision.

MAINTAINING THE DATA BASE

The volume data collected during the integrated traffic counting program can continue to be useful in future years for identifying historical trends and serving as a sound basis for designing cost-effective counting programs. Because future needs may differ markedly from present concerns, the data base should be maintained in the most detailed manner practical.

The volume data and statistical summaries should be particularly useful for designing traffic monitoring programs and their associated sampling plans for the future. In particular, the following factors should lead to more efficient traffic monitoring programs in the future:

- The composite standard deviation and (if possible) the composite standard error parameters computed from the study results should provide better estimates than can be determined from the default estimating procedures described in this manual
- The volume counts for individual locations can be used to better classify locations by volume level, thus reducing the incidence of misallocations
- The results should highlight possible inefficiencies that can be remedied by further stratification

APPENDIX A
INDEX TO SAMPLING MEASURES

Table 17 presents an index of the pages on which the sampling measures and other parameters used in this manual are defined.

TABLE 17
INDEX OF SAMPLING MEASURES AND OTHER PARAMETERS

Definition	*Symbol*	*Page Number*
Estimated average annual VMT within a corridor or small area	$\overline{AVMT}$	32
Estimated average annual VMT for reporting stratum "r"	$\overline{AVMTr}$	33
Estimated average annual volume across a cordonline or screenline	$\overline{AWT}$	32
Estimated average annual weekday traffic volume at location "i"	$\overline{AWTi}$	31
Number of vehicle axles counted during session "i"	AXLEShi	33
Number of vehicle axles counted at location "i" on day "j"	AXLESij	31
Coefficient of variation of volume across days within a season in stratum "h"	CVVOLDh	11
Coefficient of variation of volume across locations in stratum "h"	CVVOLLh	11
Maximum expected difference between the estimated average annual VMT within a corridor or small area and the true value at the specified level of confidence	DAVMT	32
Maximum expected difference between the estimated average annual regional VMT for reporting stratum "r" and the true value at the specified level of confidence	DAVMTr	33
Maximum expected difference between the estimated average annual volume across the cordonline or cutline and the true value at the specified level of confidence	DAWT	32
Maximum expected difference between the estimated average annual volume at location "i" and the true value at the specified level of confidence	DAWTi	31
Acceptable difference between the estimated average total volume across a cordonline or cutline and the true value	DVOL	25
Acceptable difference between the estimated average daily volume at location "i" and the true value	DVOLi	22
Acceptable difference between the estimated average daily VMT within a corridor or small area network and the true value	DVMT	26
Acceptable difference between the estimated VMT in reporting stratum "r" and the true value	DVMTr	14

Definition	*Symbol*	*Page Number*
Number of aggregate sample strata for purposes of reflecting external errors which cannot be affected by the sample size for volume counts	E	15
Assumed axle correction factor applicable to location in sample stratum "h"	FAe	33
Assumed axle correction factor for location "i"	FAi	30
Finite population correction factor for sample stratum "h"	Fh	16
Finite population correction factor for location "i"	Fi	31
Assumed seasonal adjustment factor applicable to a cordonline or cutline	FS	32
Assumed seasonal adjustment factor applicable to sample stratum "h"	FSe	33
Assumed seasonal adjustment factor applicable to location "i"	FSi	31
Number of sample strata	H	9
Increment for systematic link selection	INC	19
Scaled length of longest link	LEN	19
Length of link "i" in miles	Li	26
Number of digits for random number	LID	19
Mileage of stratum "h"	Mh	9
Number of ATR's which will be used to develop the seasonal adjustment factor for aggregate sample stratum "e"	NATRe	13
Number of days for which counts of the traffic volume during the specified interval are made at location "i"	NDi	22
Total number of possible data collection days during the study period	NDPOP	14
Number of volume counts made in stratum "h"	Nh	9
Population of links in sample stratum "h"	NPOPh	14
Number of counting sessions required in reporting stratum "r"	Nr	14
Standard deviation of the seasonal adjustment factor in aggregate sample stratum "e"	SADJe	43
Standard deviation of the seasonal adjustment factor used at location "i"	SADJi	22
Standard deviation of the axle correction factor for focused applications	SAXLe	46
Standard deviation of the axle correction factor used at location "i"	SAXLi	22
Standard error of the seasonal adjustment factors	SEADJe	13
Standard error of the axle correction factor as applied for aggregate sample stratum "e"	SEAXLe	13
Starting point for systematic link selection	SP	19
Composite standard deviation for the internal variability in sample stratum "h"	SVIh	13
Composite standard deviation for the internal variability at location "i"	SVIi	22
Composite standard error for the external variability at stations comprising a cordonline or cutline	SVE	24

Definition	*Symbol*	*Page Number*
Composite standard error for the external variability in aggregate sample stratum "e"	SVEe	13
Composite standard error for the external variability at location "i"	SVEi	22
Standard deviation of volume across days within a season in stratum "h"	SVOLDh	11
Standard deviation of volume across days within a season at location "i"	SVOLDi	22
Standard deviation of volume across locations in stratum "h"	SVOLLh	10
Standard deviation of volume across seasons in stratum "h"	SVOLSh	12
Standard deviation of volume across seasons at location "i"	SVOLSi	22
Estimated average regional VMT during the period of interest	$\overline{\text{VMT}}$	9
Anticipated VMT in aggregate sample stratum "e"	$\overline{\text{VMTe}}$	15
Estimated average VMT in sample stratum "h" during the period of interest	$\overline{\text{VMTh}}$	9
Estimated average VMT on link "i"	$\overline{\text{VMTi}}$	26
Estimated average VMT for reporting stratum "r"	$\overline{\text{VMTr}}$	33
Estimated average traffic volume across a cordonline or cutline	$\overline{\text{VOL}}$	24
Estimated average volume in sample stratum "h"	$\overline{\text{VOLh}}$	9
Volume measured on count "i" in sample stratum "h"	VOLhi	10
Estimated average traffic volume at location "i"	$\overline{\text{VOLi}}$	22
Number of vehicles counted at location "i" on day "j" during a specified interval	VOLij	22
Difference between highest and lowest volumes specified for stratum "h"	VRANGEh	10
Normal variate for the specified level of confidence, two-tailed test	Z	14
Number of digits needed to represent individual zone identification numbers	ZID	20
Number of digits needed to represent the mileages of individual zones	ZMI	20

APPENDIX B
COMPUTING THE STANDARD DEVIATION OF VOLUME ACROSS SEASONS

The standard deviation of volume across seasons "SVOLS" parameter reflects long-term shifts in overall volume levels during the year. While the computational methods described here arbitrarily assume that the year is divided into four quarterly counting periods or seasons, other counting periods down to the monthly level can also be used. The methods can also be applied to estimate SVOLS for sample strata or for individual locations although the actual seasonal variations for individual locations are likely to vary substantially from one location to the next. The SVOLS parameter can be estimated as:

$$SVOLS = CVVOLS * \overline{VOL} \qquad (57)$$

where:

- SVOLS = estimated standard deviation of volume across seasons
- CVVOLS = estimated coefficient of variation of volume across seasons
- $\overline{VOL}$ = expected average volume for the applicable sample stratum or individual location

The two methods that can be used to estimate CVVOLS are (1) using available volume data from automatic traffic recorders (ATR's) or intensive field control counting programs, or (2) using judgment.

USING AVAILABLE DATA

Volume data collected on a systematic basis throughout the year by ATR's or intensive field control counting programs can be used to estimate CVVOLS. Data from ATR's located on *representative* highway segments can provide relatively accurate estimates of CVVOLS. However, data from ATR's that are *not* located on representative highway segments (as is typically the case) may not provide accurate estimates of CVVOLS. Data from relatively intensive (e.g., where volume counts are made during one week each month) control counting programs can also be used to estimate CVVOLS but may tend to overestimate the value because of daily fluctuations. The CVVOLS parameter can be estimated as:

$$CVVOLS = \frac{1}{\overline{Vk}} * \frac{1}{NK-1} * \left[\left(\sum_{k}^{NK} Vk^2\right) - \left(NK * \overline{Vk}^2\right)\right]^{1/2} \qquad (58)$$

$$\overline{Vk} = \frac{1}{NK} * \sum_{k}^{NK} Vk \qquad (59)$$

$$Vk = \frac{1}{NL} * \sum_{i}^{NL} Vki \qquad (60)$$

where:

- $\overline{Vk}$ = average annual volume
- NK = number of counting periods or seasons
- Vk = average volume in season "k"
- NL = number of locations at which volume counts are made each season
- Vki = volume counted at location "i" during season "k"

USING JUDGMENT

If volume data are not available, CVVOLS can still be estimated if the approximate range of volume variations across seasons can be judgmentally specified:

$$CVVOLS = \frac{VRANGE}{4 * \overline{VOL}} \qquad (61)$$

where:

VRANGE = approximate upper and lower limits of volume variations between seasons throughout the year

APPENDIX C
COMPUTING THE STANDARD ERROR OF THE SEASONAL ADJUSTMENT FACTOR

The standard error of the seasonal adjustment factor reflects the additional uncertainty introduced when volume data for a relatively short field data collection period are adjusted to represent average annual conditions.

While seasonal adjustment factors can be developed from volume data produced by automatic traffic recorders (ATR's) or from relatively intensive field control counting programs on a sampling basis, the loss of precision caused by the latter approach cannot typically be accurately assessed. The following approach therefore stresses the use of ATR's located on representative highway segments. Historically, ATR's were normally located only on major highways. Because the seasonal travel patterns found on major highways may not be typical of other urban highways and streets, the general application of seasonal adjustment factors based on volumes from nonrepresentative locations may reduce the accuracy and validity of a factored volume estimate. Most urban areas that want to use seasonal adjustment factors to estimate average annual VMT will therefore have to reconsider the placement of their existing ATR's and maybe also install new ATR's to represent other types of highways and streets.

The seasonal adjustment factor can be computed with annual volume data from the ATR's as:

$$FSe = \frac{1}{NA} * \sum_{i}^{NA} FSi \qquad (62)$$

$$FSi = \frac{\overline{Vi}}{Vki} \qquad (63)$$

where:

- FSe = seasonal adjustment factor applicable to aggregate sample stratum "e"
- NA = number of ATR's representing aggregate sample stratum "e"
- FSi = seasonal adjustment factor computed for location "i"
- Vki = average volume at location "i" during season "k"
- Vi = average annual volume at location "i"

This factor can be used to convert an average volume measured in season "k" to an average annual volume. The standard deviation of the seasonal adjustment factor can be computed as:

$$SADJe = \left[\frac{1}{NA-1} * \sum_{i}^{NA} (FSi - FSe)^2 \right]^{1/2} \qquad (64)$$

where:

SADJe = standard deviation of the seasonal adjustment factor in aggregate sample stratum "e"

If a series of new ATR's is to be installed to provide seasonal adjustment factors, the standard deviation of the seasonal adjustment factor can be estimated for sampling plan purposes as:

$$SADJe = .05 \qquad (65)$$

The corresponding standard error of the seasonal adjustment factor can then be estimated. The method of computation will depend on whether a regional or focused application is being considered.

REGIONAL APPLICATION

The standard error of the seasonal adjustment factor for regional applications can be computed as:

$$SEADJe = SADJe / \sqrt{NA} \qquad (66)$$

where:

SEADJe = standard error of the seasonal adjustment factor as applied for aggregate sample stratum "e"

The size of the standard error will depend on the number of ATR's from which volume data are used.

FOCUSED APPLICATION

The standard deviation of the seasonal adjustment factor for focused applications is as computed with formula (64). The size of the standard deviation will not depend on the number of ATR's.

APPENDIX D
COMPUTING THE STANDARD ERROR OF THE AXLE CORRECTION FACTOR

The standard error of the axle correction factor reflects measurement errors from using machine axle counters instead of conducting manual volume counts. If the average number of axles per multiple-axled vehicle can be assumed to be four, the axle correction factor needed to convert raw axle counts to volume counts can be computed as:

$$FAi = \frac{1}{2 * (1 + TRe)} \qquad (68)$$

where:

- FAi = assumed axle correction factor applicable to location "i"
- TRe = estimated average proportion of multiple-axled vehicles in aggregate sample stratum "e"

The standard error of the axle correction factor can either be judgmentally estimated (as discussed in Sections III and IV) or developed from the results of a special vehicle classification study. The average proportion of multiple-axled vehicles and the corresponding composite standard deviation can be computed[12] from the results of a vehicle classification study as:

$$TRe = \left(\sum_{i}^{NL} VTRi\right) \Big/ \left(\sum_{i}^{NL} Vi\right) \qquad (69)$$

$$STRe = \left[\frac{NL * \sum_{i}^{NL} (VTRi - (TRe * Vi))^2}{\left(\sum_{i}^{NL} Vi\right)^2}\right]^{1/2} \qquad (70)$$

where:

- TRe = estimated proportion of travel by multiple-axled vehicles
- VTRi = number of multiple-axled vehicles counted at location "i"
- Vi = total number of vehicles counted at location "i"
- STRe = composite standard deviation of the proportion of multiple-axled vehicles
- NL = number of locations at which vehicle classification counts were made

Formula (70) can be used to compute the standard deviation of the proportion of multiple-axled vehicles if the vehicle classification study has already been conducted. If a new study is required and will be conducted in parallel with the volume counting program, the composite standard deviation of the proportion of multiple-axled vehicles can be estimated for sampling plan purposes as:

$$STRe = .04 \qquad (71)$$

A minimum of three counts should be made for each aggregate sample stratum. If not, the accuracy of the estimate of the proportion of multiple-axled vehicles "TRe" will not necessarily exceed that of a reasonably good judgmental estimate.

The corresponding standard error of the axle correction factor can then be estimated. The method of computation will depend on whether a regional or focused application is being considered.

REGIONAL APPLICATION

The standard error of the axle correction factor for regional applications can be computed as:

$$SEAXLe = \frac{STRe}{NL^{1/2} * (1 + TRe)} \qquad (72)$$

where:

SEAXLe = standard error of the axle correction factor as applied for aggregate sample stratum "e"

[12] *Guide for Estimating Urban Vehicle Classification and Occupancy*, U.S. Department of Transportation, Federal Highway Administration, 1981.

The size of the standard error will depend largely on the number of locations at which vehicle classification counts are made.

FOCUSED APPLICATION

The standard deviation of the axle correction factor for focused applications can be computed as:

$$SAXLe = STRe/(1 + TRe) \quad (73)$$

The size of the standard deviation for focused applications will not depend on the number of locations at which vehicle classification counts are made.

APPENDIX E
ALTERNATIVE METHOD OF INTERPRETING LEVEL OF PRECISION

The sampling procedures presented in Sections III and IV are designed to provide estimates which differ from the true value by a maximum of $\pm$ d with a $(1 - \alpha)$ level of confidence.

An alternative method of specifying level of precision is to concentrate on whether the difference "d" between two survey estimates reflects true differences or simply chance variations. For example, a monitoring program may be designed to identify statistically significant changes in key measures from one year to the next. If the composite standard deviations for the two survey estimates can be assumed to be the same, the values for the normal variate $Z_{1-\alpha/2}$ can be replaced[13] in the sampling formulas by:

$$2 * (Z_{1-\alpha/2} + Z_{1-\beta}) \qquad (74)$$

where:

- α = significance level or the risk of concluding falsely that a difference between the two estimates exists
- β = risk of failing to detect a difference when the two estimates in fact differ by d[14]

[13]M. G. Natrella, *Experimental Statistics*, National Bureau of Standards Handbook 91, 1963.

[14]M. G. Natrella.

Assume that an agency wants to detect differences between annual measures of regional VMT or arterial streets that are at least 8 percent. The agency is willing to take a 10-percent chance of failing to identify a true 2-percent difference between two annual VMT estimates, but only a 5-percent chance of wrongly concluding that a difference exists. If the example situation previously discussed in Section III (and summarized in Table 9) can be assumed, the revised sampling parameters and the corresponding sample size can be computed as:

$$DVMTr = .08 * 2{,}150{,}000 = 172{,}000$$

$$Z = \sqrt{2} * (Z_{.975} + Z_{.90})$$

$$= \sqrt{2} * (1.960 + 1.282) = 4.6$$

$$Nr = \frac{(437{,}000)^2}{\left(\frac{172{,}000^2}{4.6^2}\right) + (489{,}000{,}000) - (1{,}087{,}000{,}000)}$$

$$= 239$$

A sample size of 239 counting sessions would be required for each annual survey.

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