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16. Abstract

This report presents a cost-effective method for collecting statewide traffic information. It provides a means of integrating vehicle classification, truck weight and traffic volume information, and includes procedures for determining the number of each of these types of monitoring sessions to provide data estimates within specified levels of precision.

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EXECUTIVE SUMMARY

The recommendations in this report describe a statewide traffic monitoring program Peat Marwick developed as a result of FHWA's "Development of a Statewide Traffic Counting Program Based on the Highway Performance Monitoring System" project. This report includes:

- a review of federal and state traffic data needs;
- a description of a recommended traffic monitoring program designed to meet those needs in a cost effective manner;
- a sampling plan for collecting data with a given statistical precision;
- a series of default values for use in the sampling plan statistical equations;
- alternative sampling plans for estimating volumes on local roads;
- a review of available traffic counting, classification, and weighing equipment currently on the market; and
- five case studies implementing the proposed program for states chosen by FHWA.

Historically, traffic count data have been collected by state transportation agencies to support a wide range of internal and external programs and needs. Internal needs have included using traffic count data to develop estimates of annual average daily traffic (AADT) and vehicle miles of travel (VMT) for individual highway sections, individual functional classifications of roadways, and other functional or geographic divisions of the state highway system. External needs have included certain traffic count and truck weight data and estimates for submission to the FHWA. These data are used by FHWA and other federal agencies:

- to establish national travel trends;
- to prepare reports as requested by Congress;
- to plan for future transportation needs; and
- to assess overall efficiency of various programs and policies.

The HPMS was introduced in 1978 to consolidate many previous federal data requirements and to strengthen the methods used by the states for collecting, estimating, and reporting traffic count data.

Many states face severe financial difficulties due to the effects of the economic climate and the increasing needs for state funds to maintain and improve highway systems. As a result, many states are looking for ways to reduce the costs of traffic data collection and related programs without reducing the overall effectiveness of the programs.

Although states expend substantial financial resources on traffic counting and related data collection programs, their programs often reflect the continuation of past practices rather than address current data needs. In particular, most state traffic counting programs do not make effective use of statistical sampling and estimation techniques. Statistical techniques provide cost effective procedures to develop reliable estimates of AADT and VMT within prescribed levels of precision. These techniques also provide a consistent simplified process for collecting vehicle classification data for most state and federal uses. To a lesser degree, they can also be used for improving the estimates of truck weights currently derived from existing truck weight monitoring programs.

The HPMS program offers states a convenient structure with the potential to redirect their traffic counting programs. The HPMS sample provides a basic set of traffic count locations for which geometric, operational, and traffic volume data will be available on a continuing basis. By using statistical sampling concepts that complement the HPMS, states can potentially increase overall traffic monitoring program efficiency through the development of coordinated data collection processes including traffic volume data, vehicle classification data, and truck weight data.

This study was initiated to identify ways of improving the cost effectiveness of state traffic monitoring programs by developing a program based on the HPMS. The program to collect traffic volume counts, vehicle classifications, and truck weight data will satisfy most state and FHWA information needs with statistically valid data. While the objectives and needs of states may be met in other ways, using the HPMS prevents duplication of effort as it includes an established sample and a ready tie-in between the different program elements.

As not all necessary data can be collected efficiently with a statistically valid annual count program, a special data collection element is provided in the recommended program to fulfill those needs not met by the data collected as part of the recommended HPMS monitoring program. In pursuit of the project's overall goal, several objectives are addressed:

- identification of the kinds of information required by the states and FHWA as well as the level of detail needed in the data;
- development of a coordinated traffic monitoring program designed to collect information for more than one purpose when possible;
- identification of the capabilities of modern equipment to automatically collect data on vehicle classifications and weights as well as volumes; and
- development of central office analysis procedures incorporating statistical techniques, where appropriate.

This report recommends a methodology for developing a statewide traffic monitoring program based on those objectives. The program uses statistical sampling (based on the HPMS) wherever possible to reduce costs and provide statistically defensible data. It also provides cost effective solutions to data collection problems that cannot be addressed viably with statistical counting procedures. The program is designed to provide each state with sufficient flexibility in implementing the program so that the program can be adapted to address any specific needs, while providing the data normally collected by a state department of transportation, including volume counts, vehicle classification counts, and truck weight monitoring.

The HPMS portion of the program is intended to collect comparable levels of traffic data on a representative sample of segments of each state's road system. The HPMS sample locations will not be changed by this study, but our analysis:

- evaluates the frequency and amount of data collected on the HPMS sample sections; and
- incorporates the remaining data collection elements of the state's traffic monitoring program with the HPMS sample, including vehicle classification and truck weight data.

The special data collection element of the program includes traffic data taken outside the normally planned annual traffic count program. These data would include such needs as requests for volume counts at proposed construction projects and requests for intersection turning movements to evaluate traffic operations, as well as special surveys, additional truck weighings, or any other state traffic data need.

The scope of this study does not allow the enforcement aspects of traffic data to be addressed. Truck weight enforcement is discussed only where it affects the precision of weight monitoring for planning purposes. Furthermore, this report does not recommend specific makes or models of equipment. Available equipment is described, and its limitations and capabilities discussed, but each state is left to determine which equipment best fulfills its equipment needs.

STUDY APPROACH

A five-step process is used in this study used to design the program. These steps include:

- determine objectives and data requirements of data users;
- review capabilities and limitations of equipment used to collect the data;
- analyze existing data to determine the amount of data required to provide estimates within specified amounts of uncertainty;
- develop the statistical sample design; and
- determine the consequences of phasing in the program, since it will be implemented gradually in most cases.

OBJECTIVES AND DATA REQUIREMENTS

To develop a monitoring program covering the maximum number of data user needs while expending the minimum amount of resources, the objectives of the data users were examined and the actual data needs from both the state and federal perspectives were determined. Not all data requested is collected by the proposed program. The analysis shows that some of the requested data could not be efficiently provided by a statistically-based monitoring program, and should be collected on an as-needed basis instead.

State and federal data needs are often very similar. However, there are areas where the states require more data than is needed by FHWA, and there are instances where the state might not collect some data if FHWA did not request it. An examination of the actual uses of traffic data shows that the majority of the data uses at both the state and federal levels could be served by a single comprehensive monitoring program producing statistically representative estimates of traffic characteristics. The remaining data needs can be met through a special data collection program to collect site-specific data as each funding authority deems appropriate. This was, therefore, recommended.

RECOMMENDED PROGRAM

The recommended statewide traffic data collection program is divided into three major parts:

- the Continuous Element, consisting of continuous traffic counters (ATRs);
- the HPMS Element, consisting of statistically representative statewide samples of volume, vehicle classification, and truck weight data; and
- the Special Data Collection Element, consisting of site-specific traffic measurements and other data necessary to fulfill state needs not met by the other elements.

Each part collects data for different purposes and in a different manner, yet they are interrelated in that data collected in each program will often be used in one of the other programs in an altered form. Each element is described in detail in this section of the report, along with the methodology used and the issues considered in developing the element.

PROGRAM IMPLEMENTATION

Certain issues are involved with the actual implementation of the recommended program; in particular, phasing in the program slowly, as is recommended, will have certain effects. The effects from delaying the implementation of particular program elements and procedures fall under the following headings:

- seasonal factor procedures;
- changes to the HPMS volume counting schedule;
- axle correction factor procedures;
- growth factor procedures; and
- vehicle class and weight elements.

These effects were considered in the study, but final determination of how each state would time implementation of the recommended program was beyond the scope of this report.

I. INTRODUCTION

This report describes Peat Marwick's recommended traffic monitoring program developed as a result of FHWA's "Development of a Statewide Traffic Counting Program Based on the Highway Performance Monitoring System" project. Included in this report are:

- a review of federal and state traffic data needs;
- a description of a recommended traffic monitoring program designed to meet those needs in a cost effective manner;
- a sampling plan for collecting data with a given statistical precision;
- a sampling plan for estimating volumes on local roads;
- a series of default variances for use in the sampling equations;
- a review of available traffic counting, classification, and weighing equipment currently on the market; and
- five case studies implementing the proposed program for states chosen by FHWA.

This introductory section includes discussions of:

- the project's background;
- the purpose of the project;
- the scope of the project; and
- the organization of the report.

Subsequent sections detail the specifics of the count program, the analysis used to develop the program, and default statistics that can be used when applying the program to specific states.

BACKGROUND

Historically, traffic count data have been collected by state transportation agencies to support a wide range of internal and external programs and needs.

- <u>Internal</u>. States have used traffic count data in developing estimates of annual average daily traffic (AADT) and vehicle miles of travel (VMT) for individual highway sections, individual functional classifications of roadways, and other functional or geographic divisions of the state highway system.

- <u>External</u>. For many years, states have submitted certain traffic count and truck weight data and estimates to the FHWA. These data are used by FHWA and other federal agencies:

  - to establish national travel trends;

  - to prepare reports as requested by Congress;

  - to plan for future transportation needs; and

  - to assess overall efficiency of various programs and policies.

The introduction of the HPMS in 1978 was intended to consolidate many previous federal data requirements and to strengthen the methods used by the states for collecting, estimating, and reporting traffic count data.

Most states face severe financial difficulties due to the effects of inflation and the increasing needs for state funds to maintain and improve highway systems. As a result, many states are looking for ways to reduce the costs of traffic data collection and related programs without reducing the overall effectiveness of the programs.

Although states expend substantial financial resources on traffic counting and related data collection programs, their programs often reflect the continuation of past practices. In particular, most state traffic counting programs do not make effective use of statistical sampling and estimation techniques. Statistical techniques provide cost effective procedures to develop reliable estimates of AADT and VMT within prescribed levels of precision. These techniques also provide a consistent simplified process for collecting vehicle classification data for most state and federal uses. To a lesser degree, they can also be used for improving the estimates of truck weights currently derived from existing truck weight monitoring programs.

The HPMS program offers states a convenient structure with the potential to redirect their traffic counting programs. The HPMS sample provides a basic set of traffic count locations for which geometric, operational, and traffic volume data will be available on a continuing basis. By using statistical sampling concepts that complement the HPMS, states potentially can increase overall traffic monitoring program efficiency through the development of coordinated data collection processes including:

- traffic volume data;
- vehicle classification data; and
- truck weight data.

OBJECTIVES

The goal of this study is to identify ways of improving the cost effectiveness of state traffic monitoring programs by developing a program based on the HPMS. The program to collect traffic volume counts, vehicle classifications, and truck weight data will satisfy most state and FHWA information needs with statistically valid data. While the objectives and needs of states may be met in other ways, using the HPMS prevents duplication of effort as it includes an established sample and a ready tie-in between the different program elements.

Because not all necessary data can be collected efficiently with a statistically valid, annual count program, a special count element is provided in the recommended program to fulfill those needs not met by the data collected as part of the recommended traffic monitoring program. In pursuit of the project's overall goal, several objectives are addressed:

- identification of the kinds of information required by the states and FHWA as well as the level of detail needed in the data;
- development of a coordinated traffic count program designed to collect information for more than one purpose when possible;
- identification of the capabilities of modern equipment to automatically collect data on vehicle classifications and weights as well as volumes; and
- development of central office analysis procedures incorporating statistical techniques, where appropriate.

PURPOSE

This report presents a program methodology for developing a statewide traffic monitoring program. The program is intended to fulfill several purposes:

- build on the existing HPMS concept and data base;
- integrate both federal and state data requirements;
- coordinate volume, vehicle classification, and truck weight data collection programs; and
- incorporate recently developed equipment and data collection techniques.

The program uses statistical sampling wherever possible to reduce costs and provide statistically defensible data. It also provides cost effective solutions to data collection problems that cannot be addressed viably with statistical counting procedures. The program is designed to provide each state with sufficient flexibility in implementing the program that each state can adapt the program to address any specific needs.

SCOPE

The traffic monitoring program is designed to provide the data normally collected by a state department of transportation. These data include:

- volume counts;
- vehicle classification counts; and
- truck weight monitoring.

In addition, this report deals with field data collection, the equipment used to collect data, the manpower used for each kind of equipment, and the processing of the data collected.

Several types of volume counts are examined in the report. Among the types examined are counts on HPMS segments, continuous counts, control counts, coverage counts, and special counts.

The HPMS program is intended to collect comparable levels of traffic count data on a representative sample of segments of each state's road system. The sample locations will not be changed by this study, but our analysis:

- evaluates the frequency and amount of data collected on the HPMS sample sections; and

- incorporates the remaining data collection elements of the state's traffic count program with the HPMS sample, including vehicle classification and truck weight data.

The special count category includes traffic volume counts taken outside the normally planned annual traffic count program. These counts would include such needs as requests for counts at proposed construction projects and requests for intersection turning movement counts to evaluate traffic operations.

This report does not address the enforcement aspects of traffic data. Truck weight enforcement is discussed only where it affects the precision of weight monitoring for planning purposes. Furthermore, this report does not recommend specific makes or models of equipment. Available equipment is described, and its limitations and capabilities discussed, but each state is left to determine which equipment best fulfills its equipment needs.

ORGANIZATION

This report consists of five sections. Section I is this introduction.

Section II describes the study approach used to develop the traffic monitoring program. The approach entails:

- a determination of both state and federal needs;
- a review of available equipment, its capabilities and limitations;
- an analysis of available data to determine the variance in the data to be collected;
- the development of statistical formulas; and
- an analysis of the consequences of following the recommended program.

Section III presents the data needs of both federal and state data users. This information is used to determine a set of objectives used to develop the recommended program.

Section IV contains the recommended program. The program is divided into three major parts:

- continuous counts;

- a statistically valid data collection program element based on the HPMS; and
- a special monitoring program designed to provide the states with a mechanism for collecting data not readily collected using an annual count program.

This chapter also contains statistical formulas for determining necessary sample sizes and levels of precision. Finally, the processing of the raw data is discussed to outline the ability of states to trim their processing costs and at the same time improve the accuracy of their traffic estimates.

Section V discusses the implications of the recommended program in terms of the many programs currently used by some states. This includes the steps taken to implement the program, and the effect of phase-in on existing programs.

Appendix A presents default statistics for use in the sample size equations presented in Section IV. These estimates will be used until the states obtain more statistically valid data bases.

Appendix B contains a summary of the capabilities and limitations of existing data collection equipment, and estimated costs and uses for that equipment.

Appendix C presents a cost summary of the changes recommended in state traffic monitoring procedures. This appendix uses assumed cost estimates, and details the steps involved in making the cost versus precision tradeoffs presented in the main body of the report and in the five case studies.

Appendix D presents the five case studies, in which the recommended program is applied to five states: Georgia, Kansas, Maine, Ohio, and Oregon.

Appendix E includes an explanation of the derivation of statistical formulas used in the text, and a glossary of the terms used in the formulas.

II. STUDY APPROACH

This chapter discusses the study approach used in designing the recommended traffic monitoring program. The essence of the approach is the recognition that each state may have different data needs, and that the structure of any recommended program must be sufficiently flexible to meet these different needs.

OVERVIEW

The study approach uses the existing HPMS sample to provide a basis for efficiently collecting integrated, statistically valid data. The recommended program is intended to provide a framework for meeting system data needs, while providing flexibility for each state, so that state-specific data needs can be fulfilled as well.

A five-step process is used to design the program. These steps include:

- determine objectives and data requirements of data users;
- review capabilities and limitations of equipment used to collect the data;
- analyze existing data to determine the amount of data required to provide estimates within specified amounts of uncertainty;
- develop the statistical sample design; and
- determine the consequences of phasing in the program, since it will be implemented gradually in most cases.

PROCEDURE

Three sources of information were used to develop the recommended traffic monitoring program's objectives and data requirements:

- published studies;
- interviews with FHWA personnel involved in the HPMS program or otherwise concerned with the reporting of traffic data by the states; and
- interviews with five state DOTs to discuss the conduct of their state traffic monitoring programs.

The literature review included Peat Marwick's files of related engagements, such as the Guide to Urban Traffic Volume Counting; FHWA files; and the DOT library.

The interviews with FHWA personnel were with individuals working in various aspects of the collection and analysis of traffic data reported to FHWA by the states, including HPMS program data, continuous traffic count data, and truck weight data.

The state interviews provided the major source of information with which to analyze existing traffic monitoring programs and identify recommendations for improvement. FHWA identified five states to participate in this study. Interviews were conducted with personnel who manage state traffic monitoring programs and with personnel who use the traffic data collected. The interviews included questions such as:

- What data are collected?
- How are the data collected and what types of equipment are used?
- How are the data edited, adjusted, analyzed, and reported?
- What are the relative sizes of the costs of the different data collection programs?
- Who uses the data and for what purposes?

The first step was to analyze the current traffic monitoring program methodologies and to look for areas that can be improved, either through changes in the data collected or the manner in which the data are collected, or through the use of statistical techniques to obtain the information at lower cost.

The second step was to examine the ability of available equipment and data collection techniques to collect the data required. Equipment is examined to determine its ability to collect:

- volume data;
- vehicle classification data; and
- truck weight data.

Reports by FHWA and various states were used along with information provided by manufacturers to determine equipment capabilities and costs. Equipment types examined included:

- manual;
- automatic;
- portable;
- semi-portable; and
- fixed.

Details of this review are included in Appendix B of this report.

The third step consisted of an examination of existing data sources to determine the variation that exists in the data being collected. The variation in the data directly affects the precision of the collected data. The data was examined for variation due to:

- spatial uncertainty;
- temporal uncertainty;
- seasonal uncertainty;
- axle correction error; and
- measurement error.

All of these terms, except for measurement error, are used in determining the precision levels achieved by the program as a result of the number of sample locations counted.

Data to estimate the relative sizes of the above variance terms are taken from existing data bases provided by FHWA. The principal data bases used include:

- the FHWA continuous count file (ATR data);
- the HPMS vehicle classification case study; and
- the HPMS truck weight case study.

This data is supplemented by state-specific data collected during the state interviews, or from subsequent telephone calls. It is acknowledged that these data bases have serious limitations in terms of statistical rigor. It is therefore suggested that states utilize their own data wherever they have a statistically valid estimate of their own. If such a data base is not available, the implications of the default data values should be carefully examined before they are used in a specific application.

Statistical equations to determine precision levels that can be achieved with various sample sizes are developed in the fourth step. The equations include all composite errors with the exception of measurement error. Equations are included for the majority of data uses, so that the precision of specific traffic estimates can be determined as well as the precision of statewide averages. The most important statistical formulas are also presented in graphic form to simplify the selection of sample sizes for each of the states. This conversion of an equation to graphic form is performed using default values determined in step three and presented in Appendix A.

The final step included determining the consequences of phasing in the recommended program. This phase-in may be affected by several factors including:

- lack of necessary modern equipment;
- the gradual planning process necessary for implementation; and
- jurisdictional issues within a state DOT.

The phase-in will delay the financial benefits of the recommended program, but will also allow a state to make changes to its existing program more slowly. This may help a state ensure a smooth transition from one count process to another, resulting in an improvement in the quality of the data collected.

III. OBJECTIVES AND DATA REQUIREMENTS

To develop a monitoring program covering the maximum number of data user needs while expending the minimum amount of resources, it is necessary to examine the objectives of the data users and determine the actual data needs from both the state and federal perspectives. Several sources were examined to determine the objectives of state and federal data collection programs. The most significant of these sources are:

- interviews with the staffs of the five participating state DOTs;
- interviews with various Federal Highway Administration personnel; and
- an exhaustive literature review on the uses of traffic volume, vehicle classification, and truck weight data.

The resulting data is organized to show the amount of information and degree of detail needed by data users. This information is then used to design the monitoring program. Not all data requested is collected by the proposed program. The analysis shows that some of the requested data could not be efficiently provided by a statistically-based monitoring program, and should be collected on an as-needed basis instead.

OVERVIEW

State and federal data needs are often very similar. However, there are areas where the states require more data than is needed by FHWA, and there are instances where the state might not collect some data if FHWA did not request it. An examination of the actual uses of traffic data shows that the majority of the data uses at both the state and federal levels could be served by a single comprehensive monitoring program producing statistically representative estimates of traffic characteristics. The remaining data needs can be fulfilled through a special data collection program to collect site-specific data as each funding authority deems appropriate.

Study Perspective

To develop a comprehensive list of data needs, the study focused on both the needs of federal and state data users. The initial step in developing the recommended program was to provide data that would fulfill both federal and state needs. The program was expanded to provide data necessary for either state or federal users, but not required by both. As stated above, some requests for data from both federal and state users are not appropriately provided by a statistically based annual count program. These data needs are indicated in the report, and should be met through the expansion of state special count programs. Systemwide data needs can normally be met efficiently using sampling techniques. Most site-specific needs cannot be met through sampling. The proposed annual count program is flexible enough to permit further expansion should a state have additional data needs that can be met efficiently using a statistically based count program.

Development of Data Objectives

On-site interviews were conducted with the five states participating in the study to determine the objectives and data needs of the state traffic count programs. Discussions with FHWA employees were used to determine the basic objectives and traffic data needs from a federal perspective. The information obtained from the interviews were corroborated by the information obtained from the literature review. The literature review covered:

- ongoing research topics;
- recent surveys; and
- FHWA policy statements.

Documents included in the review were obtained from several sources, including:

- the Department of Transportation Library;
- Peat Marwick's project files; and
- documents submitted to FHWA by various research organizations and states.

The composite federal and state objectives developed from this data were then submitted for review to FHWA and the participating states. FHWA gave final approval to the objectives after receiving comments from the states.

Organization of This Chapter

As a result of the interviews and literature review, it became apparent that traffic data needs could be incorporated into three basic objectives:

- roadway system management and maintenance;

- future system improvements; and
- reporting and research.

Within each of these three categories, the specific data needs are discussed for each of three traffic count program elements:

- traffic volume counts;
- vehicle classification counts; and
- truck weight data.

Vehicle speed data are not considered within this section, as required vehicle speed data are specifically defined in existing federal regulations, and not open to review under this contract. Both the type of data and the level of detail needed for that data are discussed in this chapter for each of the traffic monitoring program elements within the broad objective categories. The volume, vehicle classification, and truck weight data needed for performing specific activities within each of the above general categories are discussed below. Exhibit III-1 contains a summary of these data needs.

ROADWAY SYSTEM MANAGEMENT AND MAINTENANCE

Data on roadway system management and maintenance are needed to make day-to-day decisions that provide for the upkeep of the road system. The data user is primarily concerned with short-term goals, and has limited resources budgeted for attaining those goals. Among the tasks that fall under this broad category are:

- road maintenance;
- capacity analyses;
- safety analyses;
- taxation enforcement; and
- environmental impact analyses.

Each task requires similar, site-specific data input. In most cases, the data required should be collected on an as-needed basis rather than as a part of a regularly scheduled count program. A coverage count or a similar scheduled count system large enough to ensure collection of the appropriate data would not be cost effective.

EXHIBIT III-1

TRAFFIC DATA REQUIREMENTS

	Volume	Vehicle Class	Truck Weight
Roadway System Management and Maintenance			
Maintenance	Site-specific AADT	Average by functional class	(None)
Capacity Analysis	Site-specific AADT and turning movements	Site-specific or average by functional class	(None)
Safety Analysis	Site-specific AADT and turning movements	Site-specific	(None)
Taxation/Enforcement	N/A	N/A	N/A
EIS	Site-specific AADT	Site-specific (average by functional class if necessary)	(None)
Future System Improvements			
Trend Analysis	VMT by functional class (by region)	Average vehicle class by functional class (by region) by year	Average weight (EAL) by vehicle class by functional class
Project Identification and Selection	(Optional site-specific AADTs)	(Optional site-specific vehicle classification)	(None)
Project Design	Site-specific AADT	Site-specific vehicle class or average vehicle class by functional class	Average weight by vehicle class by functional class
Highway Investment Analysis	Site-specific AADT	Average vehicle class by functional class by region	(None)
EIS	VMT by functional class	Average vehicle class by functional class (optionally by region)	(None)
Reporting and Research			
System Usage Monitoring			
- fund allocation	VMT by functional class by region	Average by functional class (by region)	Average by vehicle class by functional class
- trend analysis	VMT by functional class by region	Average by functional class (by region)	Average by vehicle class by functional class
Public Policy and Public Legislation	VMT by functional class by region or site-specific	Average by functional class by region or site-specific	Average by vehicle class by functional class
Taxation	VMT by functional class	(Optionally vehicle class by functional class)	(None)
Research	VMT by functional class	Vehicle class by functional class	Weight by vehicle class by functional class

Road Maintenance

Daily maintenance includes routine activities, such as:

- pothole repair;
- minor road overlays; and
- street repair due to damage caused by building construction, utility maintenance, and various other projects.

All repairs to damaged pavement on existing streets are included in this objective. Daily maintenance projects are mostly determined through:

- observer surveys (both formal and informal);
- public requests;
- engineering department notifications by contractors and utility companies; and
- the political process.

Routine maintenance projects are not usually identified through the analysis of annually collected traffic data.

Traffic data used to plan for maintenance projects are usually routine and tend to consist, at most, of a site-specific volume estimate and a measure of the amount of truck traffic or equivalent axle loadings. The volume data should be collected through a special count program, and the required truck data can be obtained through the use of statewide vehicle classification data by functional classification. Site-specific truck weight data are not necessary for this work.

Capacity Analyses

Capacity analyses at the day-to-day level include:

- signalization projects;
- various Transportation System Management (TSM) measures; and
- intersection capacity studies.

To a large degree, the above tasks require similar data input, site-specific volume counts, and knowledge of the percentage of various vehicle types in the traffic stream. In rare instances, the percentage of loaded versus unloaded trucks in the traffic stream is desired because acceleration and deceleration characteristics are different. However, site-specific truck weight data are not needed for this kind of capacity analysis.

In most instances where vehicle classification data are necessary, a site-specific value is desired but often cannot be collected because of fiscal constraints. In these cases, statewide or regional averages of vehicle class distribution by functional roadway type are used, combined with site-specific volume counts. As previously stated, site-specific data cannot be collected cost effectively through an annually scheduled count program, and should be collected through a special count program.

Safety Analyses

On a daily basis, the traffic engineer's role in safety analysis is concerned primarily with reducing the number of accidents at specific locations. To do this, the engineer uses site-specific volume and vehicle classification data to analyze the frequency of accidents at a location. Truck weight data is only rarely a part of such a study. As in the capacity analysis above, this work requires up-to-date, site-specific data on volumes, turning movements, and vehicle classifications, which should be collected as part of a special count program rather than through a regularly scheduled count program.

Safety analysis can also be a very broad topic including monitoring of accidents and exposure. Data to support such analyses are beyond the scope and capability of a blanket monitoring program.

Taxation Enforcement

The taxation enforcement task consists primarily of enforcing truck weight laws and restricting vehicles from designated portions of the road system. Even though data in a state traffic counting program might be useful in enforcing various laws and collecting user taxes, detailed consideration of this subject is beyond the scope of this report.

Environmental Impact Analyses

The data uses covered under this environmental task include the analysis of the effects of traffic on noise and air pollution levels. In the context of day-to-day operations, this task entails using site-specific data to analyze the effects of current traffic volumes and vehicle mixes at specific sites. (Regional environmental issues such as NOx are dealt with under

Future Systems Improvements.) Statewide average vehicle classification data by functional class may be used along with site-specific traffic volumes, but statewide average data may lead to unacceptably high errors in some analyses.

FUTURE SYSTEM IMPROVEMENTS

The basic objective in preparing for future system needs is to provide information for planning and constructing new facilities, and to project the effects of current and historical traffic levels on the future life of existing roads. This projection includes estimating trends, determining where possible needs will surface, and analyzing plans that can be used to meet those needs.

Data used in these analyses often cannot be site-specific because the projects may consist of roads which do not yet exist, or affect more than one existing road. As a result, data needs for most tasks included in this objective are more aggregate than data needed to manage daily operation of the road system. Data needed in these tasks can best be described as estimates of traffic volumes, vehicle classifications, and truck weights (EALs) by functional classification of road. For some state uses, a regional division of this data is also advisable because of significantly different traffic characteristics in portions of the state. For example, the amount of truck travel in a mountainous, mining-oriented portion of a state can be quite different from that in an agricultural portion of the state.

The objective of preparing for future system needs can be broken into several specific tasks:

- trend analysis;
- project identification and selection;
- project design;
- highway investment analysis; and
- environmental impact analysis.

As with the objective of managing and maintaining the road system, these tasks tend to have similar data needs.

Trend Analysis

State engineers need data to examine the growth and changes in state highway traffic to determine where new road construction will be needed and where to expect heavier or lighter maintenance needs than current programs are designed to provide. These data are usually provided by using trend analyses to extrapolate historic travel volumes and vehicle characteristics.

Data to be used should represent all aspects of the highway system and should be collected within a specified tolerance to determine when significant changes are taking place. Such data would include estimates of VMT, vehicle classifications, and EALs by vehicle type for each functional road classification. Some states may need these data by regional stratification as well. Use of a randomly selected volume and vehicle classification sample, such as one based on the HPMS, is appropriate for this data collection task.

The ability to differentiate truck weights by region as well as by functional class could add significantly to the value of this analysis, as it is possible that EALs per truck type differ between regions within a state. Available truck weight data do not indicate whether this variation is significant. The need to collect these data and the cost effectiveness of collecting them will depend on the variation within the state and on the equipment used to collect it.

Project Identification and Selection

States need a way to identify potential projects for investing in transportation system improvements. Transportation projects are suggested by numerous sources:

- trained observer surveys;
- high accident location studies;
- citizen complaints;
- the experience of the district engineers; and
- the political process.

It does not seem necessary to collect traffic information for the purpose of identifying additional projects.

Considerable traffic data are needed to prioritize the projects identified. The data typically requested by the project selection divisions of the five state DOTs interviewed include:

- AADT for the present and a 20-year forecast;
- the present daily peak-hour volume or the 30th highest design hour volume and 20-year forecasts; and

- truck percentages for daily and peak-hour travel for today and the 20-year forecast.

The volume and truck data for the 20-year forecast are calculated from existing conditions and the trend analysis data described above. Site-specific data on volumes, truck percentages, and peaking characteristics should be collected on a special count basis. The states interviewed only needed such data for 100 to 200 projects annually. In addition, the information required is more detailed than can be collected efficiently by a coverage count or an annual random sample process.

Project Design

Providing traffic data for road construction or reconstruction is probably the single most important use of data under the objective of preparing for the future. To a large degree, the data provided for project design will be the result of the planning and forecasting just described. Site-specific AADT and vehicle classification data are used for many projects, but most design work relies even more heavily on the projection of data for 20 years in the future. These projections are the direct result of the trend analysis described above. Due to the large effect of this 20-year forecast on the design process, the site-specific vehicle classification count may not be appreciably better than the use of a statewide or regional average of vehicle classification data by functional classification.

Traffic volumes, variation of vehicle types by functional class (and region) and statewide EALs, as all are projected for the roadway design life, will produce the data needed for estimating axle loadings for the design of new roads. Although it would be ideal to obtain a historical record of traffic volumes, vehicle types, and weights for each road segment in question, the collection of this kind of data is too expensive to be seriously considered. A more realistic data collection approach is to use site-specific volume counts in conjunction with average (statewide or regional) vehicle classification and truck weight data by functional roadway classification for input to the design process.

Highway Investment Analysis

Highway investment analysis includes examination of the cost effectiveness of the road system. Data are needed to compare usage and cost of new construction versus significant reconstruction of existing highways. Data for these uses is usually sufficient if they include VMT by section of roadway by vehicle classification. These data can be estimated by combining site-specific volume counts with regional data to vehicle types by functional classes.

Environmental Impact Analysis

Environmental impact analyses are performed primarily for urban areas or air basins. Required data are mostly VMT by vehicle type by functional classification for a specific area. These data are used as input to air quality models and the resulting pollution estimates are included in state air quality plans. A regularly scheduled counting program will probably supply appropriate estimates of these data inputs. However, in large urban areas, the metropolitan planning organization (MPO) may collect data that can supplement information provided through the DOT regular count program. Weight distributions by vehicle type are not usually an issue in such an analysis.

REPORTING AND RESEARCH

The final objective is to provide data to users not directly involved with the operations, construction, or maintenance of the road system. These users are analysts and public officials who monitor the changes in the highway system as a whole, and estimate the effects of those changes on budgets and design criteria. Specific uses of data for this objective include:

- system usage monitoring;
- public policy and legislation formulation;
- taxation requirements; and
- research.

Data needed for these analyses tend to be at an aggregate level of detail. For the most part, statewide or regional estimates of VMT by vehicle class by functional highway system fulfill these data needs.

System Usage Monitoring

The highway system is monitored both at the state and federal level. Statistics used for monitoring the highways serve two purposes:

- cost allocation; and
- trend analysis.

Even though the federal government currently allocates federal monies on the basis of statewide VMT estimates, there will be a continued desire by various federal and state agencies and elected officials to test the impact of alternative funding policies using truck VMT estimates. Some states currently use estimates of truck VMT and passenger car VMT in their calculation of highway cost allocations. As a result, the annual state traffic monitoring program should collect data to estimate statewide VMT by vehicle class by functional highway class.

Similar data will also be useful for the trend analysis performed for reporting and research purposes. Several studies for which these data might be used include:

- effects of gasoline prices on national levels of VMT;
- effects of the federal law raising the maximum legal truck weight and vehicle length; or
- trends of state and national VMT.

In all cases, a statistically valid estimate of statewide VMT by vehicle class by functional class is the most appropriate data base that could be used.

Public Policy and Legislation Formulation

State and federal officials generally deal with the highway system in either a highly aggregate or highly disaggregate sense. That is, they deal with either the weight limits on the entire interstate system, or with the limits imposed on a particular bridge in their legislative district. Their information needs are therefore focused at the ends of the data spectrum. Aggregate data for vehicle travel on road systems is used for policy formulation. Specific information on individual locations is necessary for project issues.

A monitoring system based on the HPMS sample is therefore the preferred mechanism for providing statistically valid data to be used in policy formulation and analysis. To satisfy the information needs of public policy and regulation analyses, the data should provide estimates of VMT by vehicle type for each functional classification of road, and possibly region, within a state. Data for site-specific projects should be collected on a project by project basis, not included in an annual monitoring program.

Taxation Requirements

The issue of taxation can be considered a sub-issue under public policy and legislation. It may be appropriate for this analysis to use statewide estimates of VMT by vehicle type along with estimates of the costs of road system upkeep to help determine the need for user fees and other taxes that provide revenue used to maintain the system. The appropriate level of taxation for each type of vehicle (e.g., weight/distance taxes) is also a major subject being researched at this time, as many authorities seek a method of attributing highway costs to the vehicles causing them.

Research

At the policy level, research consists of broad areas of concern about the effects of vehicle types and weights on the severity and frequency of accidents, pavement deterioration, and other subjects. Aggregate data, such as VMT by vehicle type by functional class, is necessary to provide statewide and national statistics for analysis. (For example, does the nation's accident rate increase as a result of the law legalizing 80,000-pound gross vehicle weights in all states?) However, some analyses will require site-specific data. These data needs should justify the expense of collecting the additional data necessary rather than attempt to design an annual program supplying data for all possible research subjects.

CONCLUSIONS

Based on the data requirements discussed above, it can be concluded that the statewide annual traffic monitoring program should provide the following information:

- VMT by functional class, optionally by region;
- vehicle classification distributions by functional class; and
- axle weights by vehicle class by functional class.

These data will allow the computation of VMT and EAL estimates by functional class for use in the various analyses performed at the state and federal levels. Some regional stratification of the above estimates may also be necessary for state needs.

Many requests for volume, vehicle classification, and truck weight data are for specific locations for particular projects. It is too expensive to collect site-specific data through the general monitoring program, so site-specific data requests should be referred to the special data collection program. If a project does not warrant the cost of a special count, the analyst has the option of using a regional or statewide average, based on the functional class of the roadway, which should be available as a result of a statistically based annual vehicle classification program. Annually scheduled vehicle class counts should be restricted to those locations that will provide a statistically valid estimate for all general vehicle classification data uses.

The term regional refers to the fact that traffic characteristics within a state often vary significantly within a functional highway classification based on the location of individual highways. For example, a highway classed as a "rural principal arterial" in a mountainous region including a heavy concentration of mining activity will have a different distribution of vehicles than a rural principal arterial in a flat farmland area. Not only will the distribution of vehicles be different, but the weights of the vehicles within each vehicle category could conceivably be substantially different. As a result, a regional outlook at this information is recommended whenever possible.

The largest drawback to the above recommendation is the cost of obtaining acceptable truck weight data for each functional highway classification and region within a state. In some states it may not be economically feasible to collect sufficient data to provide this level of detail. Also, a state with uniform traffic characteristics may not require a regional breakdown of these data. In cases where a regional parameter is needed but data collection costs are too high, statewide averages will have to suffice until the more cost-effective vehicle classification and weight data collection procedures described in Appendix B are validated and readily available to the states.

A second drawback is that some states do not currently use data for these needs on the basis of functional classification. In these states, data are requested by such categories as highway jurisdiction (state highways, county highways, local roads, and so on) or federal-aid highway system, and individual state DOTs may resist altering their procedures to accommodate a change in the manner in which data are collected and reported.

The advantages of the proposed system are:

- cost savings in the collection of data;
- easier administration of the monitoring program;
- improvements to the representativeness and statistical validity of the data collected; and
- integration of the various elements of the program.

By conforming to the existing HPMS sampling base, the need for development of a new sample framework is eliminated, duplication is avoided, and a direct, statistically valid linkage to other HPMS variables is automatically provided.

IV. RECOMMENDED PROGRAM

This chapter presents the recommended statewide traffic monitoring program developed using the previously described data collection objectives. The chapter includes an overview of the entire program as well as its various elements. Following the overview, the specific program elements are examined in detail. This examination includes:

- a description of the purpose of the program elements;
- changes to the current state programs that would result from the recommended program;
- instructions for determining appropriate sample sizes for each program element;
- selection of the data collection locations;
- the data collection schedule;
- processing of the data collected; and
- procedures for estimating the precision of traffic data.

OVERVIEW

The recommended statewide traffic data collection program is divided into three major parts:

- the Continuous Element, consisting of continuous traffic counters (ATRs);
- the HPMS Element, consisting of statistically representative statewide samples of volume, vehicle classification, and truck weight data; and
- the Special Data Collection Element, consisting of site-specific traffic movements necessary to fulfill state needs not met by the other elements.

Each part collects data for different purposes, yet they are interrelated in that data collected in each program will often be used in one of the other programs in an altered form. For example, the continuous counters will provide seasonal factors for adjusting volume counts to AADT estimates for both the HPMS elements and the special data collection element. Similarly, the HPMS element will be able to provide estimates of the percentage of trucks using a road on which a special volume count is taken.

All factoring is based on the functional classification of the roadway to facilitate the interrelationship of these three elements and to provide an easily identifiable characteristic to use in applying these elements. Functional class was chosen because it is the basis for the HPMS sample, and offers continuity of roadway designations between states. In states where substantial variations in traffic characteristics occur due to regional differences in population density and land use (e.g. mountainous mining areas versus oceanside roads subject to heavy recreational travel), functional classifications may be supplemented by some regional stratifications.

The program is structured to minimize changes to most states' continuous count programs. However, it is recommended that solid state recorders be utilized at ATR sites instead of paper tape recorders to improve the accuracy of data collection storage and facilitate the processing of the collected data.

The statistically-based HPMS element consists of the HPMS sample and subsamples drawn from the existing HPMS sample for collecting vehicle classification and truck weight data. The procedure to be followed in developing the vehicle class and truck weight elements includes:

- estimating the required sample size;
- selecting sample locations from the existing HPMS sample sections;
- scheduling the counts;
- collecting the data; and
- processing the data to include seasonal adjustments, axle correction factors, and other necessary adjustments.

The data collected from the selected locations is then used in the equations presented in this chapter (and in the HPMS Field Implementation Manual) to develop estimates of traffic characteristics and determine the precision of those estimates.

The special data collection element is designed to provide each state with a mechanism for collecting site-specific data and other data deemed necessary for state use, but not provided by the continuous or HPMS elements. In the Special Data Collection Element, the state highway agency will determine what additional counts are needed and funded to fulfill state-specific data uses. Several examples of counts that a state might include under this special count element are:

- site-specific data requested by county engineers, project engineers, and elected officials for use in the design and decisionmaking processes;
- additional vehicle classification and truck weight data on roads designated by the state as "heavy truck routes"; and
- volume counts at high accident locations throughout the state, with the locations determined using criteria set by the state.

Many other types of measurements could conceivably be included in this last program element. Each state will have the option of utilizing this program for their highest priority purposes, given their funding constraints.

CONTINUOUS COUNT PROGRAM ELEMENT

This program element consists of permanently located ATR stations. Each station provides, at the minimum, hourly volume data for that location every day of the year.

Purpose

The primary purposes of the proposed Continuous Element are to provide seasonal adjustment factors and to collect short- and long-term trend data. This is consistent with the current use of ATR data. Some ATR stations are also capable of providing some combination of vehicle classification, vehicle weight, and vehicle speed data, depending on the equipment available at the site and the type of sensing device used. This additional information is not required by the Continuous Element, but it is one of the goals of an integrated program, and can be of considerable use to the state. Thus, while this program design does not require construction of these "enhanced" ATR locations, their use is encouraged as being consistent with the HPMS program philosophy.

Recommended Program Element

Peat Marwick recommends a structured continuous program element that combines ATRs by functional classification to provide seasonal and day-of-week adjustment factors for other count locations within those functional classifications. Available data show that roads of the same functional classification generally exhibit similar seasonal traffic patterns. In practice, different functional classifications of roads may also exhibit similar seasonal characteristics. In this case, more than one functional class may be combined into one seasonal factor group. This approach is recommended where appropriate to reduce the number of ATR locations required.

There may be more than one pattern per functional class within a state as a result of differences in the regional composition of traffic. For example, a highway classified as a rural primary arterial in a mountainous region with heavy mining activity may have different traffic characteristics than a rural primary arterial in an area of flat farmland. In this case, functional classes may be stratified into more than one seasonal factor group based on the region of the state containing the road. The number of regions within a state should be strictly limited because the number of regions directly affects the number of ATR stations needed to compute seasonal factors.

For example, the existing Maine ATR stations will be formed into seasonal factor groups, based on functional classification. It was determined that the seasonal characteristics of roads along the Maine coast were substantially different from those found in the rest of the state. It was also found that within this regional stratification, several functional classes of roadway could be combined into one group, because of their similar seasonal patterns. Exhibit IV-1 shows the seasonal patterns of Maine's rural interstate and rural other primary arterial functional classes which were combined into one seasonal factor group. Exhibit IV-2 shows the effect of combining these two function clases on the standard error of the average monthly seasonal factors. Computation and use of seasonal and day-of-week factors is discussed under the "Processing of Data for Reporting Purposes" heading, presented later in this section.

Changes to A Continuous Count Program

A procedure for converting an existing state continuous count program into the recommended continuous program element consistent with the other elements of this statewide program is detailed below. It assumes that all states currently have an operating ATR program. The procedure can be broken down into several steps:

- use professional knowledge of the state's traffic patterns and analysis of available state ATR data to determine any obvious regional stratification(s);

- use existing ATR data to compute means and standard errors, and develop seasonal factors for each functional class of road within the state or region, if regions are necessary;

EXHIBIT IV-1

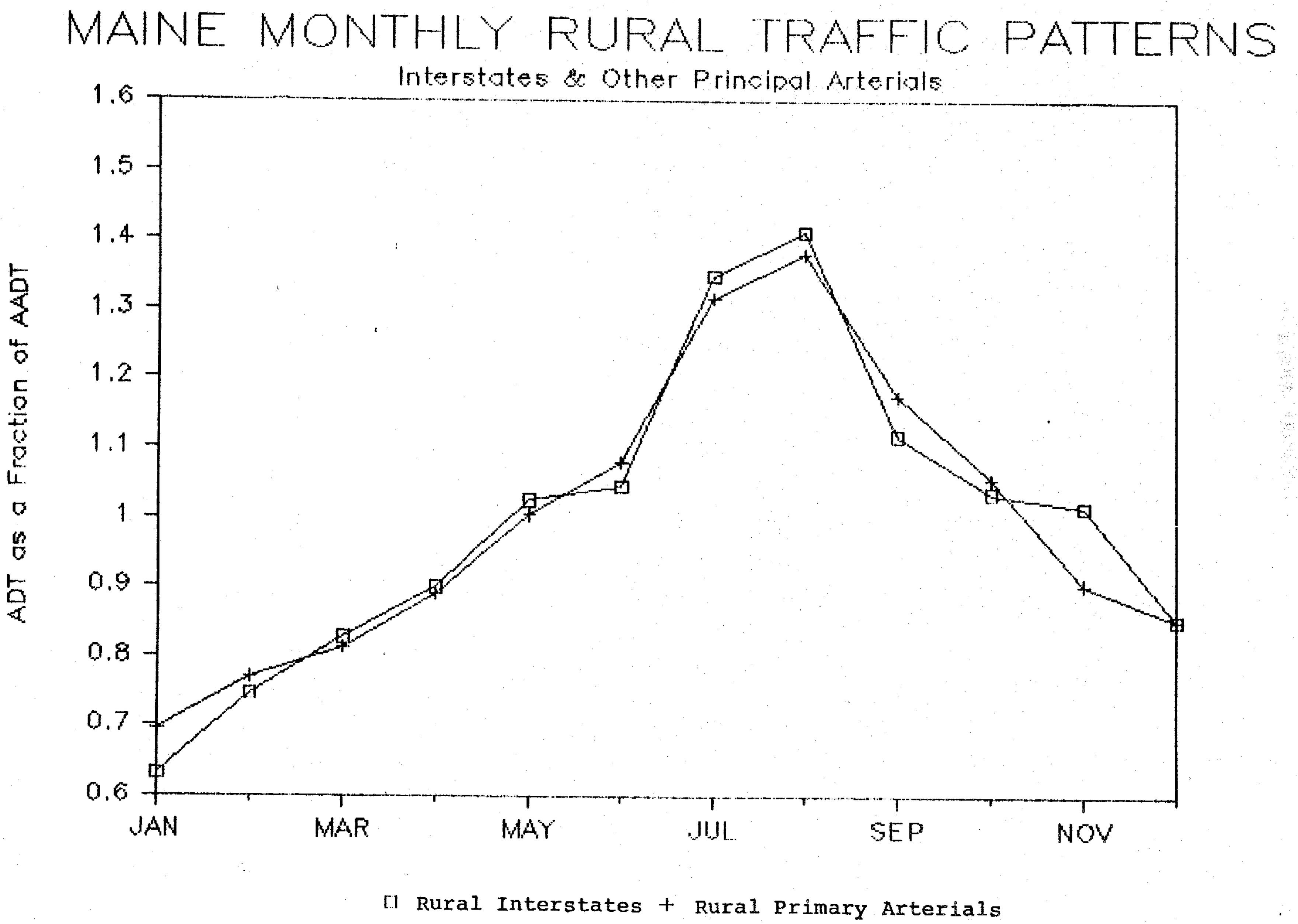

MAINE MONTHLY RURAL TRAFFIC PATTERNS
Interstates & Other Principal Arterials
ADT as a Fraction of AADT
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
JAN
MAR
MAY
JUL
SEP
NOV
□ Rural Interstates + Rural Primary Arterials

EXHIBIT IV-2

COMPARISION OF STANDARD ERROR BEFORE AND AFTER FACTOR GROUP COMBINATION

	Standard Error*		
Month	Rural Interstates	Rural Primary Arterials	Combined Factor Group
January	0.056	0.091	0.080
February	0.113	0.079	0.092
March	0.089	0.071	0.079
April	0.088	0.059	0.073
May	0.049	0.021	0.035
June	0.084	0.030	0.062
July	0.084	0.133	0.129
August	0.106	0.169	0.136
September	0.098	0.034	0.070
October	0.129	0.036	0.085
November	0.051	0.048	0.083
December	0.051	0.078	0.065
Mean	0.083	0.071	0.082

*Standard error of the monthly average daily traffic as a fraction of AADT.

- plot the mean ATR data and examine standard errors;

- consolidate functional classes or regions where possible;

- determine the number of existing ATRs within each grouping;

- determine the costs or savings of adding, eliminating, and moving ATRs;

- compare the above costs with the resulting changes in the estimated sample variance to determine the need for adding, eliminating, or moving ATR locations; and

- randomly select new ATR sites and eliminate or relocate extraneous old ATR locations.

It is also recommended that states periodically check their ATR groupings by repeating the above procedures at regular intervals. A recommended cycle for checking ATR groups is every six years, which is two cycles of the recommended HPMS program element.

Compute Initial Seasonal Factors

The staff of the state DOT should include only full years of ATR data for the examination of seasonal factors. Using their knowledge of the state's traffic patterns, the staff should be able to make an initial estimate of whether a regional stratification of functional classes will be necessary or desirable. A plot of individual ATR seasonal factors, as in Exhibit IV-1, may be helpful when determining the need for regional stratifications.

Once the initial classification of ATRs to functional class seasonal factor groups is made, means and standard deviations should be computed for each monthly factor for each group. A comparison of the mean factors for these groups will show which groups can be combined into larger groups, and which groups may need regional stratification. As can be seen by examining Exhibit IV-1, plotting the seasonal factors for each ATR or functional classification group helps in visualizing the various seasonal patterns, and in determining which functional classes can be combined.

The combination of functional classes into larger seasonal factor groupings, or their breakdown into smaller regional stratifications, is performed using statistics tempered by professional judgment. The standard deviation of the average monthly seasonal factor affects the precision of the AADT estimates computed using that factor. The standard deviation should therefore be kept as small as possible. However, the need for less variation in the seasonal factor must be weighed against the cost of collecting additional data (i.e., more ATR locations).

Some professional judgment is necessary to make this tradeoff. No hard rule was determined for the appropriate size of the standard error within a seasonal factor group. Instead, when determining the number of ATR stations, the number of new ATR stations needed should be minimized, and the variation in the seasonal factors should be minimized as well. A similar philosophy should be used for combining functional classifications with similar seasonal patterns. These basic criteria are followed in the case study examples included in Appendix D of this report.

The procedure described above of combining and splitting functional classes continues until a satisfactory set of factor groups is achieved. No more than two iterations of the process should be necessary. The seasonal factors will contain some variation, since they are computed from ATRs in different locations, and therefore have slightly different traffic patterns. The seasonal factors will also vary slightly from year to year as traffic at those ATR stations varies. However, the factors will be representative of the functional classification as a whole, and will contribute a known magnitude of error to the factoring process. This is an improvement over most seasonal factoring techniques, which induce errors similar in type, but of an unknown magnitude.

As a general rule, eight factor groups were initially examined for the five case studies included in Appendix D:

- rural interstates;
- rural other primary arterials;
- rural minor arterials;
- rural collectors;
- urban interstates and other freeways and expressways;
- urban other principal arterials;
- urban minor arterials; and
- urban collectors.

These initial groups were then split regionally as necessary, or combined whenever reasonable. Consideration should be given to the possible need to separate the interstate system from other roads due to the fact that using regions will increase the number of ATR stations necessary, and to the fact that some specific roads in a state may need to be treated as special cases due to unusual seasonal loadings (such as ski resorts).

Determine the Number of ATRs per Factor Group

After the factor groups have been established, the state must examine the need for altering ATR locations. This involves a tradeoff between the number of ATR locations (and the consequent reduction in the error associated with the seasonal factor) and the costs of processing ATR data, maintaining ATR locations, and adding new ATR sites. Exhibit IV-3 provides some insight into the costs of ATR sites versus the reduction in the seasonal factor variation provided by each additional ATR location. Exhibit IV-3 is calculated using a unit cost approach, because individual state costs for ATRs vary greatly. The actual costs a state may experience are dependent on the state's equipment, the number of lanes counted, and other costs specific to that state.

In Exhibit IV-3, the annual cost of an ATR station increases linearly with each additional ATR station (i.e., one ATR has a unit cost of one, two ATRs have a cost of two, and so on). This cost does not include the one-time cost of installing new ATR locations. The precision of the seasonal factor is computed as:

$$d^2 = (z^2 * COV^2) / sqrt(n) \qquad (1)$$

where d = the accuracy of the count as a fraction
n = the number of ATR locations in that factor group.
z = the normal variate for the specified level of confidence equal to 1.95 in the exhibit).
COV = the coefficient of variation of the seasonal factor (assumed equal to 0.1 in the exhibit).

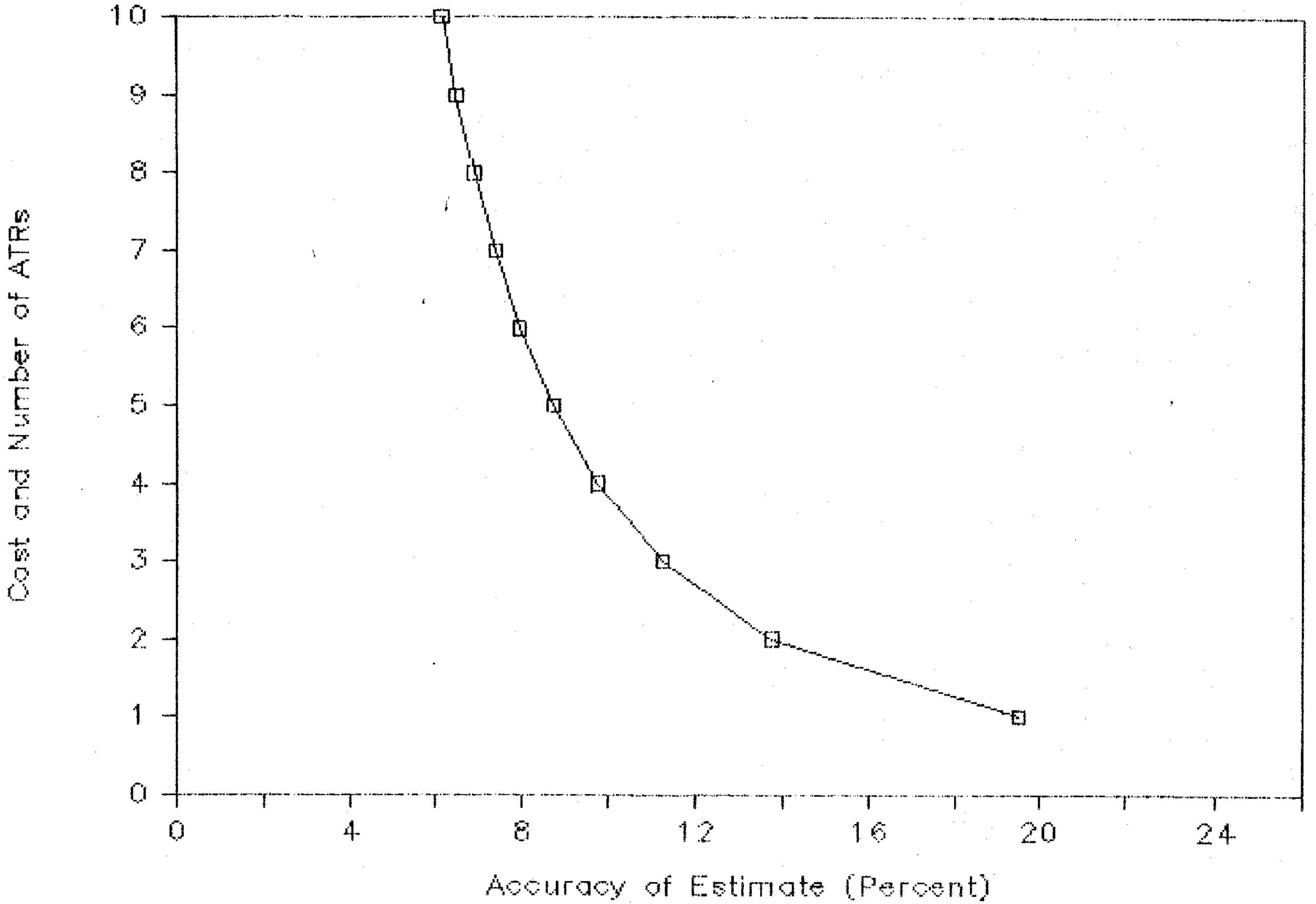
The exhibit shows that each additional ATR station reduces the precision of the factor by a decreasing amount. It is therefore not cost effective to add an infinite number of ATR locations. It should be noted that the location of the curve in Exhibit IV-3 is determined by the COV term and will be different for each seasonal factor group, but the shape of the curve will always be the same.

Several other rules must be considered when deciding the proper number of ATR locations:

- Two ATRs are needed to determine variance.

EXHIBIT IV-3

COST OF ATRs VERSUS PRECISION*



*Precision is defined as the accuracy of an estimate with a confidence level of 95 percent.

- Since ATRs can fail due to maintenance needs, construction, weather, and other causes, it is useful to have at least one additional ATR location per factor group, so as to maintain the minimum two counters if one fails.

- Since ATR data is useful in examining long-term trends on roads, it makes sense to maintain the majority of stations that already exist.

The example state cases in Appendix D will lend some additional clarification to the recommended methods for determining the appropriate number of ATR locations. In general, it is recommended that the factor groups should have between 3 and 8 counters, and have a standard deviation of 10 percent of AADT or less.

Selecting ATR Sites

Existing ATR sites should be used whenever possible to reduce costs. If new ATR sites are necessary, a random sample of roads in the appropriate functional class should be drawn from the existing HPMS sample. The HPMS volume sections may be weighted by VMT on each section for this selection process if the state desires. This procedure is covered fully under the heading "Select Sample Locations and Times" within the HPMS program element section of this report. Another alternative would be to utilize existing speed monitoring locations if they were located on the appropriate functional class of roads.

Adoption of the new factor groups may also result in the elimination of existing ATR sites. The states will determine which ATR sites will be eliminated or moved. A random elimination technique may be used here, although professional knowledge of the ATR locations may also be useful. ATR locations that are on HPMS sample segments should be kept whenever possible.

ATR Equipment

The use of modern solid state traffic counting equipment at ATR locations is strongly recommended. Solid state counters have significant advantages over paper tape counters. These advantages include:

- the reliability of the counter and recording mechanism;

- the relatively low cost of processing the collected data; and

- the capability to collect more than just volume data.

The cost of new solid state equipment can almost always be recovered from savings in labor costs. The time needed for this cost recovery varies, depending on various state-specific costs. A complete analysis comparing the cost of processing ATR data using both paper tape and solid state counting equipment is included in Appendix C.

The use of telemetry is not specifically recommended as telemetry may or may not be cost effective for a state. State-specific factors substantially affect the cost and functioning of a telemetry system. Such factors include:

- the size of the state;
- the number of ATR locations;
- the availability of telephone lines at ATR locations;
- the cost of telephone service within a state; and
- the compatibility of existing solid state ATR equipment with telemetry.

Some of the currently available solid state equipment can be used as either a telemetry site or as a traditional ATR site requiring periodical visits to collect data. By purchasing equipment with this flexibility, it is possible to switch from paper tape equipment to solid state equipment, and then at a later date convert to telemetry. This kind of equipment may be appropriate for a state that does not wish to use telemetry at this time, but wishes to reserve that option for later, without incurring substantial new equipment costs.

Some of the newer solid state devices are also capable of collecting vehicle classification, speed, and truck weight data. This kind of data collection is also a function of the type of vehicle sensor used. The costs of an ATR station and sensors capable of these functions increase as the complexity of the collected data increases. The high cost of these enhanced stations prohibits Peat Marwick from recommending their construction by all states. The data collected at such a station would, however, be quite useful for any state purchasing one.

HPMS ELEMENT

The following discussion describes the collection and processing of data that will provide estimates of volume, vehicle classification, and truck weights which may be in the form of Equivalent Axle Loads (EALs), which are needed for planning, design, and reporting purposes by both state and federal users. This discussion includes:

- the purpose of the HPMS program element;
- the design of the sampling approach;
- the sources of error, their magnitude, and their effect on sample size;
- the changes recommended in the frequency and duration of volume counts on HPMS sample sections;
- the definition and computation of a vehicle classification subsample of the HPMS volume sample (the classification subelement); and
- the definition and computation of a truck weight subsample of the vehicle classification subsample (the truck weight subelement).

Default statistics that may be used by states performing this analysis without their own data are presented in Appendix A. These statistics are used in the computations presented in this section and those performed for the case studies presented in Appendix D. The data used to compute these statistics were the best data available to FHWA and Peat Marwick at the time of the analysis. These data were not collected in a statistically rigorous manner. Therefore, some of the values used in this section and presented in Appendix A may vary significantly from their "true" value. Statistically valid data should be substituted for these values whenever possible.

Purpose

The purpose of the HPMS program element is to provide statistically representative data for the user needs described in Section III--Objectives and Data Needs. The program element consists of three subelements:

- traffic volume data;
- vehicle classification data; and
- truck weight data (transformed into EALs).

The program is designed to produce estimates of the above data by highway functional classification, within a regional stratification if one is established. These estimates can then be applied to any road in the state HPMS inventory with a given level of precision.

The data collected by this program element are not intended to address needs for data on specific road segments, although they may be used as site-specific estimates for those road sections on which data is collected. Averages determined from this program element (e.g., the average percentage of 3S2 trucks on a rural interstate highway) may be used to supplement site-specific data.

Design Approach

The HPMS program element is designed to be a repeating subsample of the existing HPMS sample. It follows the same basic procedures of the HPMS[1] sampling plan, and relies on the existing HPMS sample as a starting point for further sampling. The design approach can be briefly described as:

- defining the population and sample strata for reporting information and reducing sampling error;
- computing sample size by stratum;
- selecting sample locations and times of measurement; and
- expanding the results to represent the population.

Define Population and Sample Stratum

The population defined for this program element is the same as for the HPMS; i.e., it excludes roads functionally classified as local. The sampling strata for volume data are also unaltered from the HPMS sample; i.e., stratification of roads by types of area, functional classes, and volume group.

For the vehicle classification subelement, the stratum is defined as functional class of roads. Further stratification of the vehicle classification sample by high volume versus low volume road is suggested. Each state should determine its own definitions for high and low volume roads, as well as the need to fit these definitions to its own traffic conditions in that state.

Stratification allows a state to determine the percentage of each type of vehicles travelling on high volume roads with greater accuracy. This step was chosen due to the common wish of many states for better information on high volume roads than on low volume roads. If a state does not need such information, the high volume versus low volume stratification may be discarded. In either case, the vehicle class sample must be selected from the HPMS volume sample sections.

The truck weight subelement sample is also stratified by functional class and by high volume/low volume roads for the same reasons as the vehicle class stratification. Truck weight locations are to be drawn from the vehicle classification sample locations (which are already stratified by high and low volume roads). Because of the limitations of truck weighing equipment as well as the prohibition of trucks from some roads, the selected locations must be reviewed to prevent the selection of inappropriate locations. This issue is dealt with more fully under the truck weight subelement heading later in this section.

Compute Sample Size

The sample size for each of these subsamples will be determined using similar procedures. The number of sample locations depends on:

- the estimated composite variation of the population which the subsample will represent;
- the frequency and duration of the counts; and
- the desired precision of the collected data.

The reliability of the sample depends on sampling error and external (non-sampling) error. Sampling error includes:

- temporal error (the variation at a location across days); and
- spatial error (the variation across locations).

External error includes:

- seasonal variation and errors in seasonal adjustment factors;
- variation in the axle correction factor needed by counts made with road tube counters; and
- measurement errors (axles miscounted by road tubes).

Estimates of temporal, spatial, seasonal adjustment, and axle correction errors are included in the sample size equations presented later in this section. The extent of measurement error is also discussed later in this report, but no effort is made to directly account for that error in the sample size equations. The equations do not include any measure of the amount of error in a traffic estimate that is not affected in some manner by the sampling process.

A discussion of the effects of count frequency and duration on the precision of the count data is also included. The resulting improvements in precision from longer and more frequent counts are then compared with the cost of taking counts. The results are used to determine sampling frequency and duration for the program element. Appendix C includes the complete cost analysis performed to compute the frequency/duration/cost tradeoffs presented here.

Although the frequency and duration of the count program affects the level of precision of the data, the selection of the precision desired actually drives the sample size equations. The precision selected for each application of the sample size equations results from a combination of user needs and the cost of collecting data.

Select Sample Locations and Times

Sample locations have already been established for volume counts as a result of the existing HPMS program. The selection of vehicle class sample locations from that sample can be performed in one of several ways. The essence of each procedure is to select a series of representaive locations randomly from the volume locations. The two most applicable means for selecting these locations are:

- a simple random sample;
- a random sample of sections, with the sections weighted by the VMT on each section.

The first procedure is the easiest to accomplish. It requires creating a listing of (and sequentially numbering) HPMS volume segments within a stratum. Each location should be listed once for each day in the count cycle. The random selection of monitoring location-days should be chosen from this list. The result of the selection will be that some locations are selected for monitoring on more than one day. The random selection can be performed using a computerized process or by using a published random number table.

This procedure assumes that there is no significant difference in vehicle class distributions between the different volume groups that make up a stratum. It will result in a probability of a sample being selected equal to one divided by the total number of volume samples taken in that stratification. This means that the volume groups with higher sampling rates in the HPMS volume sample will have higher representation in the vehicle classification sample.

The second procedure is more complicated to perform, but may yield a more representative number. (This is unclear because of a lack of statistically valid vehicle classification data.) The weighting of each sample location by VMT assumes that vehicle class percentages are different for different volume stratifications. This procedure automatically weighs the probability of a section being selected for a vehicle class location according to that location's contribution to the stratum's average vehicle classification (based on VMT).

To perform a weighting by VMT, a state should first create a listing of HPMS volume locations by functional class strata. Each location should be asigned a weight equal to the VMT for that section divided by the sampling rate for that volume group. All the weighted volume sample sections in the strata should then be combined into one list with each weighted location listed once for each day in the count cycle. A computerized or manual process should then be used to select locations for vehicle class locations with each location-day having a probability of selection equal to the weight calculated for that location divided by the sum of all weighted location-days in the strata.

All states will use a simple random sample for determining truck weight locations from within the vehicle class sample. The vehicle classification sample selection will provide any weighting that a state should apply to sample selection (i.e. selection of location proportional to VMT). Any further weighting of the sample will bias the collected data. Truck weight locations will also be selected based on the equipment available to each state for collecting weight data.

The tempering of statistically rigorous sampling with the practical realities of manpower utilization and equipment capabilities will also affect the timing of data collection. The computation of VMT for a state or entire functional class is statistically cleaner if volume counts are taken evenly throughout the year and seasonal factors are not used. This procedure may not be practical at this time because states often rely on inexpensive summer help to perform much of their data collection. Summer collection makes the sample seasonally biased, and requires the use of seasonal factors to correct the summer weighting. One of the goals of the integrated program is to emphasize the need to develop monitoring programs equally distributed across seasons so as to eliminate or at least diminish seasonal bias.

It is expected that a majority of states will use some kind of systematic process to collect data. From a cost standpoint, this makes sense. The systematic collection of data, however, may reduce the precision of the data collected. The magnitude of this additional error is hard to estimate, and is generally ignored because it is not cost effective to try to eliminate it. Two examples of common types of systematic error that some states will encounter are:

- restricting truck weighing operations from certain roads and road segments, due to equipment limitations and crew safety requirements; and
- focusing on the collection of data from specific areas of a state at one time, rather than collecting data from locations randomly (e.g., counting all HPMS sections in a county before counting any HPMS sections in another county of the state).

One important advantage of this integrated program element is that the volume, vehicle class, and truck weight counts all coincide. That is, a volume count and a vehicle classification count should be taken at the same time and location as every truck weight monitoring session. A volume count should be taken at the same time and location as every vehicle classification count. In this manner, the amount of travel for data collection is reduced in that the same crew (or equipment) can perform the labor necessary for all three measurements.

Sample Expansion

The vehicle classification and truck weight data do not need to be expanded in the same manner as the volume data. The results of the vehicle class and truck weight data collection efforts are ratios that will be applied to volume estimates, both at the individual site level and at the functional class or system level.

The result of the various truck weighings are truck weights, axle weights, or an average EAL for each truck type for each road stratification. If the EAL estimate is used within the sample stratum from which it is drawn (e.g., for high volume, rural interstates), no weighting or expansion is necessary. If an average EAL is desired for a combination of sampling strata, the estimates must be combined proportional to the strata sampling rates. The actual calculation of this procedure is presented under the truck weight heading of the HPMS program element. An example of combining two strata would be the combination of high and low volume rural interstate strata into a single rural interstate stratum.

Vehicle classification data is expanded in the same manner as truck weight data. The purpose of the sampling and data collection is to provide estimates of the percentage of traffic by vehicle type. No expansion factor is needed. If sample strata are to be combined, the data must be weighted by the respective sampling probabilities of the two strata. These actual calculations are discussed under the vehicle classification heading of the HPMS program element.

To obtain the total VMT of a particular vehicle type for a functional classification, the average percentage of travel by that vehicle type for that class of road would be multiplied by the total amount of vehicle miles traveled on those roads. To obtain total VMT by vehicle type for a state, the above procedure would be followed for each functional class of road and the results summed. The expansion process is described more fully later in this section.

The HPMS Field Manual contains the methodology for expanding the HPMS sample volume counts to represent the entire HPMS population. The manual also contains instructions for computing VMT for various reporting purposes.

HPMS VOLUME DATA SUBELEMENT

The purpose of this study is to develop an integrated state traffic data collection program based on the HPMS. The HPMS program yields estimates of statewide traffic volumes and VMT for reporting purposes and trend analysis.

The HPMS sample strata and count locations are accepted unchanged in the recommended data collection program. Within these constraints, some analysis was performed to show areas where the data collection process could be improved to benefit an integrated statewide traffic count program. The areas of analysis included:

- evaluating the frquency and duration of traffic counts taken at HPMS sample locations; and
- building on the HPMS sample to provide data for estimation of growth rates.

Frequency and Duration of HPMS Element Traffic Volume Counts

One of the fundamental tradeoffs in data collection is reducing costs versus reducing uncertainty. This involves questions such as how many counts to take, how long to collect data at a single count location (duration), and how frequently to take counts at those locations.

States typically take volume counts with 24-hour machine counts (with or without hourly breakouts) for use in estimating annual average daily traffic (AADT). These counts are often taken annually at the same location. This use of a volume count to calculate or represent AADT creates an uncertainty that that count value is the true term (i.e., that the volume for that day or the value calculated with that volume is the actual AADT). This uncertainty is a function of the variation in the amount of traffic at that location and the growth of traffic at that location between the time of the count and the day for which the AADT value is desired.

The magnitude of daily traffic variation is much larger than the long-term growth trends of most locations. As a result, analysis shows that it is more cost effective to count less frequently for longer periods of time. For cost effectiveness, Peat Marwick recommends that HPMS volume counts be taken for 48 hours at a time, but at three-year intervals. FHWA has expressed the desire to maintain annual counts on interstate sections to monitor annual volume changes on these sections. The following equations show how Peat Marwick's recommendation was reached.

The uncertainty in a specific daily volume count at the time the count is made is represented by the following equation:[2]

$$\mathrm{SVOL}_j^2 = \frac{\mathrm{SVOLD}^2}{\mathrm{nd}} + \mathrm{SVOLS}^2 \cdot \left(1 + \frac{1}{\mathrm{ncc}}\right) + \mathrm{SVOLA}^2 \cdot \left(1 + \frac{1}{\mathrm{nvc}}\right) \qquad (2)$$

where:

SVOLj = the standard deviation of the volume count at location j

SVOLD = the standard deviation of volume across days

SVOLS = the standard deviation of volume across seasons

SVOLA = the standard deviation of the average number of axles per vehicle per day

ncc = the number of counts locations used to calculate seasonal factors

nvc = the number of vehicle classification counts taken to calculate the axle correction factor

nd = the length of the count in days

Each of these variance terms can be reduced by taking longer counts, e.g., for 48 or 72 hours. For an entire sampling stratum, this expression can be expanded to:[3]

$$\overline{\mathrm{SVOL}}_h{}^2 = \frac{\mathrm{SVOLD}_h{}^2/\mathrm{nd}}{n_h} + \frac{\mathrm{SVOLL}_h{}^2}{n_h} + \mathrm{SVOLS}_h{}^2 \, \frac{1}{n_h} + \frac{1}{\mathrm{ncc}_h} + \mathrm{SVOLA}_h{}^2 \left(\frac{1}{n_h} + \frac{1}{\mathrm{nvc}_h}\right) \qquad (3)$$

where:

$SVOL_h$ = the standard deviation of the average volume for stratum h
$SVOLD_h$ the standard deviation of the volume across days for stratum h
$SVOLL_h$ the standard deviation of the volume across locations for stratum h
$SVOLS_h$ the standard deviation of the volume across seasons for stratum h
$SVOLA_h$ the standard deviation of the average number of axles per vehicle for stratum h
n_h = the number of volume counts taken in stratum h
ncc_h = the number of locations counted to determine the seasonal factors for stratum h
nvc_h = the number of vehicle classification counts taken to compute the axle correction factor in stratum h

For combining strata, the uncertainty of the estimate can be computed as:

$$\overline{SVOL}^2 = \sum_h \left[\overline{SVOL_h}^2 * \left(\frac{Miles_h^2}{\sum_h Miles_h} \right) \right] \qquad (4)$$

where:

SVOL = the standard deviation of the combined volume estimate
$Miles_h$= the total number of miles in stratum h
$SVOL_h$ = See equation 3

Another source of uncertainty is introduced if growth trend data are used to adjust an old count for current use:

$$VOL = VOL_i * GF \qquad (5)$$

where:

VOL = the volume estimate corrected for growth
VOL_i = adjusted AADT traffic count taken earlier
GF = the growth factor between the year of the count and the present time

The additional uncertainty introduced by applying a growth factor to an old count is represented as follows:[4]

$$SVOL_{GF} = SGF^2(1+ \frac{1}{ngf}) \qquad (6)$$

Where:

$SVOL_{GF}$= the uncertainty of the volume estimate as a result of the growth factor

SGF = the standard deviation of the estimated growth factor

ngf = the number of data points available to calculate the growth factors

The use of growth factors in the HPMS data collection effort also means that some additional error is included in the computation of volumes by sample stratum. The revised error can be determined by combining equations 3 and 6:

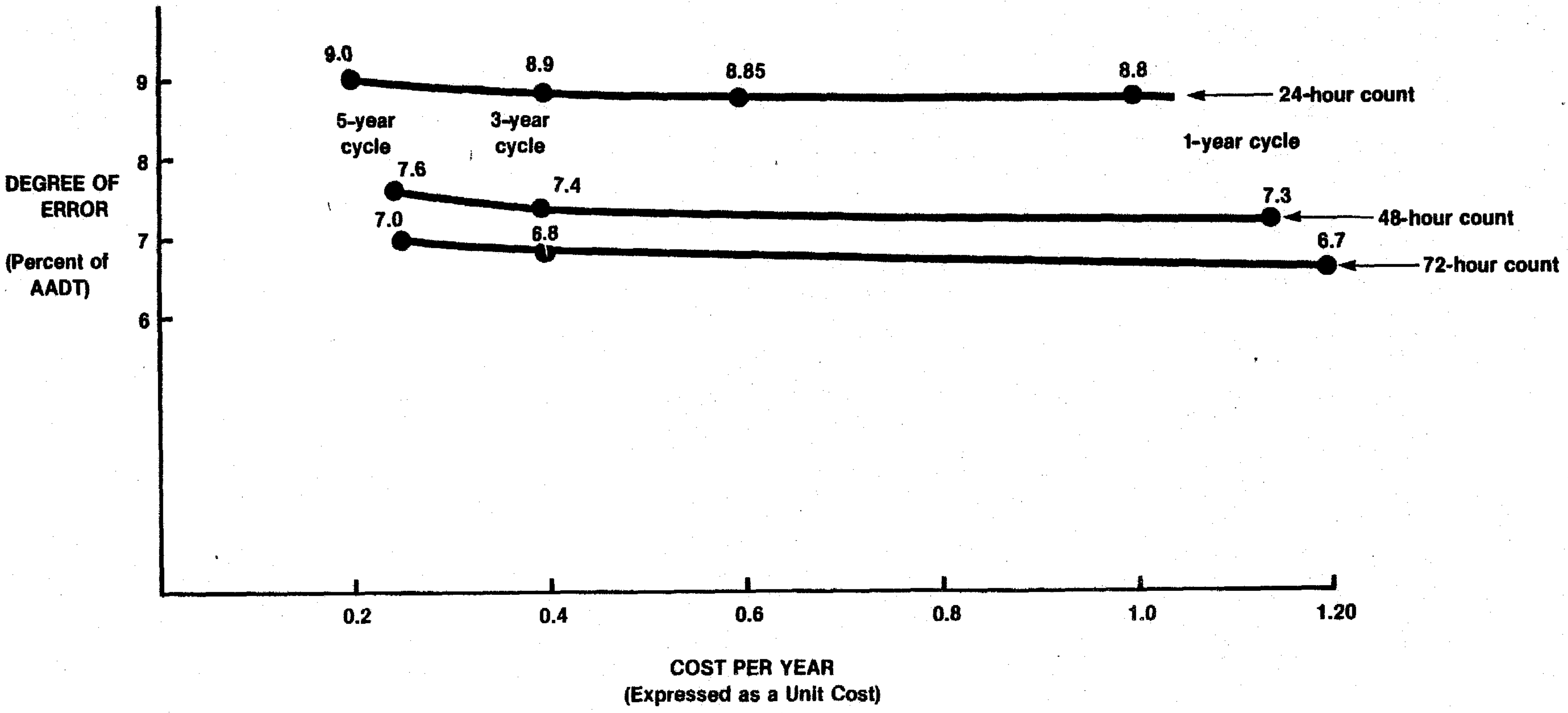
$$SVOL_h{}^2 = \frac{SVOLD_h{}^2/nd}{n_h} + \frac{SVOLL_h{}^2}{n_h} + SVOLS_h{}^2\left(\frac{1}{n_h} + \frac{1}{ncc_h}\right) + SVOLA_h{}^2\left(\frac{1}{n_h} + \frac{1}{nvc_h}\right) + SGF^2\left(1 + \frac{1}{ngf}\right) \qquad (7)$$

Exhibit IV-4 illustrates the relative costs and accuracy of a variety of count durations and frequencies, based on the following assumptions drawn from Appendix A, and assuming appropriate numbers of counts for each factor:

SVOLD = 0.07 of AADT
SVOLS = 0.04 of AADT
SVOLA = 0.03 of AADT
SGF = 0.01 of AADT
n_{cc} = 6.0 (locations used to determine seasonal factors)
n_{vc} = 12.0 (vehicle classification counts)
n_{gf} = 40.0 (counts used to estimate the growth factor)
$cost_2$ (second day of count) = 0.15 of first day cost
$cost_3$ (third day) = 0.05 of first day cost

EXHIBIT IV-4

RELATIVE COST AND ACCURACY OF COUNT DURATION AND FREQUENCY



Assumes:
SVOLD = .07
SVOLS = .04
SVOLA = .03
Ncc = 6
Nvc = 12

SGF = .01
N_{gf} = 40
Cost of 1-Day Count = 1
Cost of 2nd 24 hours = 0.15
Cost of additional 24 hours = 0.05

The exhibit uses example data. It does not indicate the accuracy of counts on any specific functional class of roads. The actual accuracy of any count will depend on the variability of the traffic at that location. Exhibit IV-5 presents a graph of the same data to help the reader visualize the effects of increasing the duration of counts and decreasing the frequency of counts.

As can be seen in Exhibits IV-4 and IV-5, the increase in count duration significantly affects the accuracy of the count. The decrease in count frequency (and use of a growth factor) has only a marginal effect on count accuracy, but does have a significant effect on reducing the cost of the count program. Exhibits IV-4 and IV-5 also show that a three-year-old volume count with a growth factor is only slightly less accurate than a new count (roughly 1.2 percent of the above percentages). This is because the error from daily variation in traffic at a location is considerably larger than the error in estimating a comparatively small growth rate, even after several years of growth. The sum of the daily variation error and the growth factor error for equal length counts is therefore only slightly larger than the error from the daily variation by itself.

For the same reasons, a 48-hour count with a three-year cycle and growth factor is more precise than an annual 24-hour count. Therefore, it is logical to collect data for multiple-day periods once every several years. The lengthening of the count cycle reduces the cost of the program, while the longer counts improve accuracy. In practice, the count schedule would be constrained by non-statistical issues such as:

- the deteriorating reliability of road tubes left in place for long periods of time;

- the occurrence of major development in the area for which growth factors cannot be accurately estimated; and

- the scheduling of counts to make cost effective use of manpower and equipment.

Given these other considerations, it is recommended that a 48-hour count and a three-year count cycle be adopted for the HPMS volume count program. This data collection plan yields more accurate data on the vast majority of sections for a reduced cost in comparison to the existing plan of annual 24-hour counts. This procedure's principal disadvantage is that it reduces the effectiveness of the HPMS program in detecting large changes in volume on an annual basis. Since few locations exhibit major volume changes within a year, this should only be a problem at a few locations. As a result, the special data collection program can be used to collect data at those few locations which require counts before the three-year cycle ends.

EXHIBIT IV-5

RELATIVE COST AND ACCURACY OF COUNT DURATION AND FREQUENCY

Count Schedule	Total Cost of Count	Cost of Count Per Year for Cycle	Accuracy at End of Cycle
24 Hours Every Year	1	1	.0880 standard deviations
24 Hours Every Other Year	1	0.50	.0886 standard deviations
24 Hours Every Three Years	1	0.33	.0891 standard deviations
24 Hours Every Five Years	1	0.20	.0903 standard deviations
48 Hours Every Year	1.15	1.15	.0727 standard deviations
48 Hours Every Three Years	1.15	0.38	.0741 standard deviations
48 Hours Every Five Years	1.15	0.23	.0755 standard deviations
72 Hours Every Year	1.20	1.20	.0669 standard deviations
72 Hours Every Three Years	1.20	0.40	.0684 standard deviations
72 Hours Every Five Years	1.20	0.24	.0699 standard deviations

One significant advantage is that the use of a three-year count cycle results in a two-thirds reduction in the number of volume counts taken in a year. This results in a reduction in the resources needed to collect HPMS data. A reduction of half the total HPMS budget for a state may be achieved by a two-thirds reduction in HPMS traffic volume counts. The actual cost reduction each state would achieve is highly dependent on the manner in which each state collects HPMS data, and could only be calculated after a specific analysis of each state's budgeting and counting procedures.

Growth Factors From the HPMS Volume Sample

If the above recommendation to count HPMS segments on a three-year cycle is accepted, growth factors must be used to update old counts to current year estimates. States have historically relied on ATR stations and control counts to estimate growth factors. Control counts are rarely used for purposes other than estimating growth or seasonal adjustments. Peat Marwick recommends that the HPMS sample be used to provide growth factors.

The analysis shows that the HPMS sample provides a better data base for estimating growth than does a limited control count program. Like a control count program, the HPMS sample essentially consists of a very large fixed panel survey. Each location is counted either every year or every third year. The reliability of growth estimations increases with the number of counts used to estimate that growth. The HPMS sample is invariably larger, better distributed, and randomly selected. It is therefore better than the control count programs performed by the states examined in the analysis. Furthermore, the HPMS sample is already counted for other reasons (e.g., reporting to the federal government). The use of the data for computing growth factors is therefore essentially free.

The use of the HPMS sample for computing growth and the ATR program for computing seasonal factors means that the control count program serves no useful purpose. This means that it can be discarded, and those resources used for other purposes.

A state's ATR stations by themselves may be used to calculate annual growth factors, but this could cause some states to rely on a very small number of locations to determine growth. A small number of counters is highly susceptible to local effects (e.g., the construction of a shopping center). It is therefore probable that the accuracy of statewide growth estimates from many 48-hour HPMS volume counts is greater than the accuracy of estimates computed from ATR data.

Vehicle Classification Program Element

The vehicle classification program element is designed to produce estimates of the percentage of each vehicle type traveling on each functional classification of highway. The program element requires a subsample of the HPMS sample locations. The selection of the vehicle classification sample is accomplished in five basic steps:

- defining the sample;
- estimating the sources of error;
- determining the required precision;
- computing the sample size; and
- selecting the sample locations and times.

The data collected at these locations are then arranged within each strata to provide estimates of percentage of travel by vehicle type.

Define the Sample Strata

Peat Marwick recommends using the same functional classification strata used in the HPMS volume sample, but without the use of the HPMS volume substrata. In addition several of the functional classes exhibit similar traffic characteristics and thus have been combined (e.g., urban interstates, urban freeways, and other expressways). The recommended strata are:

- rural interstates;
- rural principal arterials;
- rural minor arterials;
- rural collectors;
- urban interstates, other urban freeways, and expressways;
- urban principal arterials;
- urban minor arterials; and
- urban collectors.

States may wish to combine some of these strata, if those strata show similar vehicle traffic characteristics. The individual states may also need to further stratify the above classifications. Three possible reasons for needing further stratification are:

- the desire to separate high volume from low volume roads for sampling purposes;
- the existence of two or more regions in the state (within the urban or rural stratification) that experience distinctly different truck travel characteristics; and
- an interest in stratifying by other characteristics, such as toll roads or roads prohibiting trucks.

A state might choose to use either of these additional stratifications if its data showed that the variance within a larger stratum (e.g., a functional class) would be significantly reduced by creating the additional strata (e.g., functional class by high and low volume). If the new strata have substantially different traffic mixes from each other, a net reduction in sample size will result because the variance within each of the new strata is less than the variance within the old stratum. If there is no decrease in variance, the total sample size necessary to achieve a specific precision will increase because of the stratification.

<u>Sources of Composite Variation</u>

Several factors in addition to the actual variance within a stratum affect the reliability of volume estimates by vehicle classification. The volume of vehicles of a particular type for a location is dependent on two primary factors:

- the total volume at the location; and
- the percentage of that vehicle type in the traffic stream.

Volume estimates may be from actual counts on a road section or average values for a strata. Similarly, vehicle classification percentages may be derived from a classification count taken at a specific location, or may be a stratum average. Where these estimates come from determines how the reliability of the estimate is calculated.

For an actual vehicle classification count at a specific location, the volume by vehicle type and uncertainty of that count can be expressed as:[5]

$$VOL_{ij} = VOL_j * PVC_{ij} \quad (8)$$

$$SVOL_{ij}^2 = (VOL_j * PVC_{ij})^2 \left[\frac{SVOL_j^2}{VOL_j^2} + \frac{SPVC_{ij}^2}{PVC_{ij}^2} + \cancelto{0}{\frac{2COV\ (VOL_j,\ PVC_{ij})}{VOL_j * PVC_{ij}}}\right] \quad (9)$$

$$SVOL_{ij}^2 = VOL_{ij}^2 \left[\frac{SVOL_j^2}{VOL_j^2} + \frac{SPVC_{ij}^2}{PVC_{ij}^2}\right] \quad (10)$$

where:

VOL_{ij} = the volume for vehicle type i at location j

VOL_j = the total volume at location j

PVC_{ij} = the percentage of vehicle type i in the traffic stream at location j

$SVOL_{ij}$ the standard deviation of the volume for vehicle type i at location j

$SVOL_j$ = see equation 2

and where:

$$SPVC_{ij}^2 = \frac{SPVCD_{ih}^2}{nd} + SPVCS_{ih}^2 \left(1 + \frac{1}{nvc_{sh}}\right) \quad (11)$$

where:

$SPVCD_{ih}$= the standard deviation of the percent of traffic across days for vehicle type i and stratum h

$SPVCS_{ih}$= the standard deviation of the percent of traffic across seasons for vehicle type i and stratum h

nvc_{sh} = the number of vehicle classification count locations used to determine seasonality in vehicle classifcations in stratum h

The sampling procedure will produce estimates of the percentage of travel for each vehicle classification for each functional class of road with a known standard error. These estimates can then be used along with actual volume counts (adjusted for the true number of axles per vehicle) to estimate the actual number of vehicles by vehicle class for any road section on which no vehicle classification count is taken. This is expressed mathematically as:

$$VOL_{ij} = VOL_j * \overline{PVC}_{ih} \qquad (12)$$

with the uncertainty of that estimate being calculated from:

$$SVOL_{ij}^2 = VOL_{ij} * \left[\frac{SVOL_j^2}{VOL_j^2} + \frac{S\overline{PVC}_{ih}^2}{\overline{PVC}_{ih}^2}\right] \qquad (13)$$

where:

$SVOL_j$ = see equation 2

$SPVC_{ih}$ = the standard deviation in percentage of traffic for vehicle type i in stratum h

PVC_{ih} = the average percentage of vehicle type i in stratum h

and:

$$S\overline{PVC}_{ih}^2 = \frac{SPVCD_{ih}^2}{nd} + \frac{SPVCL_{ih}^2}{n_h} + SPVCS_{ih}^2\left(\frac{1}{n_h} + \frac{1}{nvc_{sh}}\right) \qquad (14)$$

with:

$SPVCD_{ih}$= the standard deviation of the percent of traffic across days for vehicle type i and stratum h

$SPVCL_{ih}$= the standard deviation of the percent of traffic across locations for vehicle type i and stratum h

$SPVCS_{ih}$= the standard deviation of the percent of traffic across seasons for vehicle type i and stratum h

nvc_{sh} = the number of vehicle classification count locations used to determine seasonality in vehicle classifcations in stratum h

Cost limitations prohibit a state from collecting data to determine the daily, locational, and seasonal variation in vehicle class data directly. Therefore, equation 14 can be simplified to:

$$SPVC_{ih}^2 = \frac{SPVCT_{ih}^2}{n_h} \tag{15}$$

Where: $SPVCT_{ih}$ = The total standard deviation in the percentage of vehicle types across all factors.

This term is easier to both calculate and use, and is therefore recommended for use by the states.

$SPVCT_{ih}$ may be calculated by taking a series of random vehicle classification counts at various locations in a stratum throughout the year. The standard deviation of the mean percentage for each vehicle type from that sample can then be used in later precision estimates.

The advantage of this method of determining standard deviations is the simplicity of the necessary data collection. The disadvantage is that the sampling plan cannot directly address those areas causing the greatest variation in the data, because the components of variation are not treated separately. However, a more detailed analysis of component variation can be carried out if desired.

Equation 12 allows a state to take only a volume count and still have a reasonable estimate of the number of vehicles within each vehicle type on that road. Thus a state can reduce the number of special vehicle classification counts needed.

The use of a subsample also permits the statistically valid computation of total travel by vehicle type within a stratum. The average volume (to be converted to VMT) for a vehicle class within a stratum (functional class) can be expressed as:

$$\overline{VOL_{ih}} = \overline{VOL_h} \cdot \overline{PVC_{ih}} \tag{16}$$

This is the average stratum volume times the average percentage of travel for vehicle class i. Multiplying this estimate by the number of miles in a stratum gives VMT by vehicle type i within that stratum.

The standard error of this estimate is calculated from:[6]

$$S\overline{VOL}_{ih}^2 = \overline{VOL}_{ih}^2 \left[\frac{S\overline{VOL}_h^2}{\overline{VOL}_h^2} + \frac{S\overline{PVC}_{ih}^2}{\overline{PVC}_{ih}^2} \right] \tag{17}$$

where:

$SVOL_{ih}$ = the standard deviation of volumes for vehicle class i in stratum h

$SVOL_h$ = see equation 3

$SPVC_{ih}$ = see equation 15

This equation would be used primarily for developing VMT estimates by functional class for reporting purposes, or for comparing the differences in travel on different functional classes of highways.

More than one sample stratum can be combined for reporting or other purposes. For example, a state with a high/low stratification of rural interstates might want to produce a report indicating the amount of truck travel on all rural interstates.

For an aggregation or combination of strata, the average volume for a vehicle class can be computed as:

$$\overline{VOL}_i = \sum_h \overline{VOL}_{ih} \cdot \frac{Miles_{ih}}{\sum_h Miles_h} = \frac{\sum_h VMT_{ih}}{\sum_h Miles} \tag{18}$$

with a standard error equal to:

$$S\overline{VOL}_i^2 = \sum_h \left[S\overline{VOL}_{ih}^2 \cdot \left(\frac{Miles_h}{\sum_h Miles_h} \right)^2 \right] \tag{19}$$

where:

VOL_{ih} = see equation 16

$SVOL_{ih}$ = see equation 17

As can be seen in the above equations, the precision of the average daily traffic volume estimate by vehicle type is dependent on:

- variation of the volume estimate (also affected by variation across days, seasons, average numbers of axles, and so on);
- daily variation in the percentage of traffic at that site by that vehicle type;
- seasonal variation in the percentage of traffic at that site by that vehicle type; and
- variation between the percentage of travel by vehicle type at that location and the mean percentage of travel by that vehicle type for the stratum to which the location belongs.

The effect of the variability from all these terms on the precision of the estimate can be reduced by taking more counts, more frequent counts, or longer counts. The precision for a stratum can also be reduced by stratifying the sample so that the variance within the stratum ($SPVC_h$) decreases. As with volume counts, a tradeoff must be made between increased precision and the cost of collecting more data.

Determining the Precision

As shown in equation 15 the standard error of an estimated percentage of traffic for any one vehicle type is a function of the variance in the percentage of travel by that vehicle type, and the number of locations counted. Using a simple random sample the precision of the estimate can be determined by assuming a confidence interval and turning the standard error into a coefficient of variation. This is expressed mathematically as:[7]

$$d^2 = \frac{(Z^2)\left(\frac{SPVCT_{ih}{}^2}{PVC_{ih}{}^2}\right)}{n_h} = \frac{(Z^2)(COV^2)}{n_h} \qquad (20)$$

where:

d = the accuracy of the estimate as a fraction

z = the normal variate for the specified level of confidence

COV = the coefficient of variation for the percentage of vehicles in class i stratum h

n_h = the number of counts taken in stratum h

In theory, the user specifies the precision level at which the data is desired, and determines the number of samples to be taken using the above equation. Unfortunately, the sample size required to achieve a stated precision level differs for each vehicle type. This is because the variation of the percentage of traffic by each vehicle type is different. This results in a single sample size being chosen and different levels of precision being obtained for each vehicle type. To select a single sample size the different variations for each vehicle type must be reduced to one number. There are two ways of looking at this problem:

- use the coefficient of variation (COV) of the most important vehicle type; or
- combine the COVs of the different classes into one number.

Regardless of which of the above methods is used, the chosen sample size will still result in precision levels calculated from the number of sample locations, and the variation within each of the individual vehicle classes. This precision level can be estimated for each vehicle type.

The choice of a "most important" vehicle type is left to the decisionmaker. An appropriate choice might be 3S2 trucks, because of the large number of these vehicles on the road, and their fairly high weight.

Combining COVs can be done in several ways:

- simple averaging;
- weighting the averaging by percentage of vehicles in the traffic volume;
- weighting the averaging by average EAL per vehicle type; or
- weighting the averaging by total EAL per vehicle type.

Each of these methods produces a slightly different sample size versus precision curve.

The simple averaging will most likely cause the mean COV determination to be larger than is necessary. This is because the variance in the percentage of trucks in unusual categories (i.e. non 3S2, five-axle trucks) can be quite large, while the need to know the true percentage of these vehicles is fairly low. Therefore, we do not recommend this option.

The weighting of COVs by the amount of traffic in that vehicle type gives a more representative "average" COV in that the COV used in the sampling equation reflects the amount of travel contributed by each vehicle type.

The final two weighting procedures use a measure of the damage the vehicle type causes to the roadway. This method gives emphasis to collecting data in such a way as to be better able to estimate axle loadings within the stated precision levels.

Exhibit IV-6 presents examples of how to perform the various weightings described above using data for rural interstates from Appendix A. Exhibit IV-7 presents sample size versus precision estimates using the different weighting procedures for the rural interstate functional classification, using default values contained in Appendix A. Exhibit IV-8 compares sample size versus precision curves for 3S2 trucks, standard automobiles and the COV weighted by the volume of traffic for each vehicle type. Both Exhibit IV-7 and Exhibit IV-8 are plots of equation 20 using the data calculated in Exhibit IV-6. A confidence interval of 95 percent is assumed for these curves.

The curves in Exhibits IV-7 and IV-8 are most easily explained by an example. Exhibit IV-8 shows that a sample size of 30 vehicle class count locations will result in a level of accuracy of 31 for 3S2s. This means that the estimate of the percentage of 3S2 trucks derived from those 30 counts is within 31 percent of the true value with a confidence interval of 95 percent (e.g., 12 percent ± 3.7 percent). The precision level for any other vehicle type could be computed by using equation 20 and substituting the number of sample locations (n_h = 30 in this case), the z score for the chosen confidence interval (z = 1.95) and the COV from Appendix A, Exhibit A-1, for that vehicle type and functional class (COV = SPVC/PVC).

The sampling size procedure described above must be repeated for each vehicle classification sampling stratum. Default sample size curves are included in Appendix A for each of the recommended functional classification strata.

Sample Selection

Sample locations are chosen from the HPMS sample sections. There are two recommended methods for choosing the appropriate locations. The two methods are:

- simple random sampling; and
- sampling proportional to VMT.

EXHIBIT IV-6

CALCULATION OF WEIGHTED VEHICLE CLASSIFICATION COVs

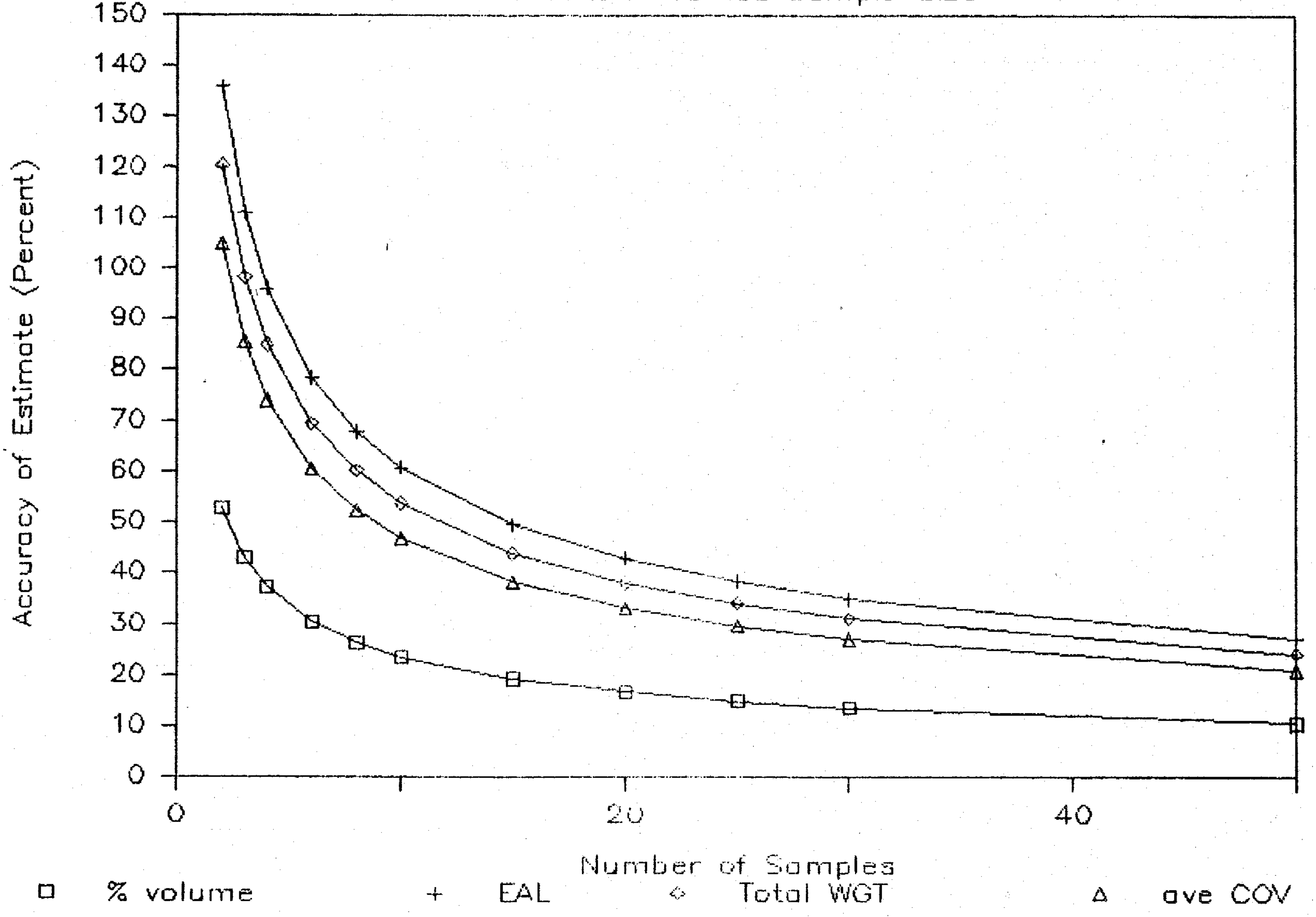
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
						Weighted By		
Vehicle Type	Proportion of Traffic	Deviation of Percent	COV (3)/(2)	EAL	Total Weight (2)(5)	EAL (4)(5)/sum(5)	Percent Volume (3)	Total Weight (6)(4)/sum(6)
Standard Car	0.416	0.074	0.178	0.0005	0.0002	0.00001	0.074	0.00020
Small Car	0.183	0.079	0.428	0.0005	0.0001	0.00003	0.079	0.00021
Motorcycle	0.005	0.005	1.000	0.00001	0.0000	0.00000	0.005	0.00000
Bus	0.003	0.001	0.363	0.4080	0.0013	0.02055	0.001	0.00260
2 axle, 4 tire	0.182	0.050	0.276	0.0012	0.0002	0.00004	0.050	0.00032
2 axle, 6 tire	0.025	0.008	0.323	0.1120	0.0028	0.00500	0.008	0.00482
3 axle single unit	0.006	0.003	0.672	0.4630	0.0027	0.04313	0.004	0.00960
3 axle combination	0.006	0.006	1.053	0.4080	0.0023	0.05955	0.006	0.01279
2S2	0.008	0.009	1.184	0.6620	0.0050	0.10860	0.009	0.03167
Other 4 axle combinations	0.005	0.007	1.347	0.1980	0.0010	0.03695	0.007	0.00695
3S2	0.149	0.126	0.847	0.9810	0.1457	0.11513	0.126	0.65589
Other 5 axle combinations	0.009	0.009	0.989	2.3590	0.0215	0.32322	0.009	0.11284
6 and larger axle combinations	0.003	0.004	1.212	1.6250	0.0054	0.27288	0.004	0.03455
SUM	1.000	0.382	9.873	7.2182	0.1882	0.98512	0.3818	0.87243
COV Used For Sample Size Calculation			0.7595			0.9851	0.3818	0.8724

Note that the numbers presented in this table have been rounded from their actual values, therefore, some columns appear to contain errors when in fact the values are correct.

EXHIBIT IV-7

EFFECT OF VEHICLE CLASS COV WEIGHTING

Precision* Versus Sample Size

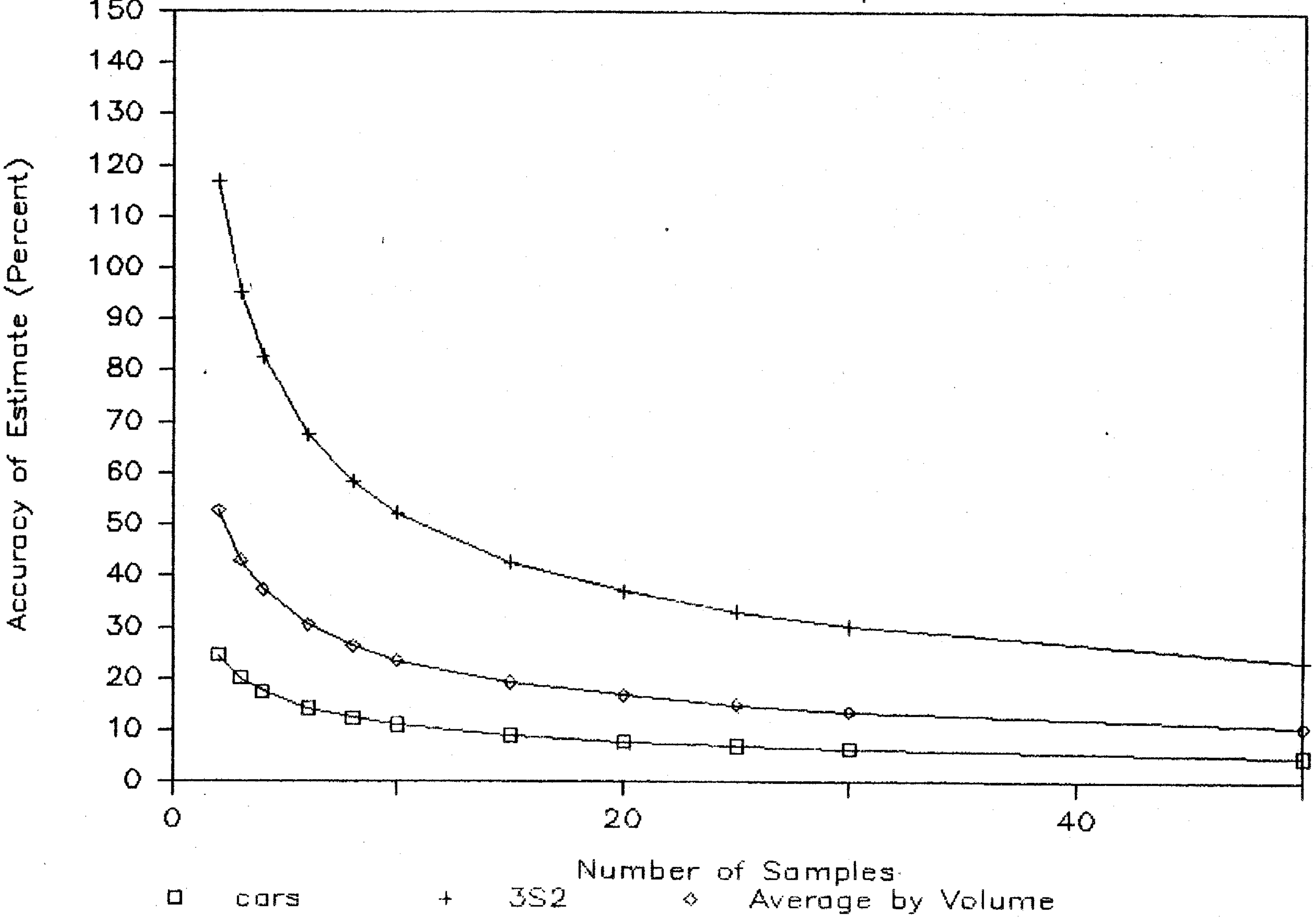


*Precision is defined as the accuracy of an estimate with a confidence level of 95 percent.

EXHIBIT IV-8

EFFECT OF VEHICLE CLASS COV WEIGHTING

Precision* Versus Sample Size



*Precision is defined as the accuracy of an estimate with a confidence level of 95 percent.

Either of these methods should provide an acceptable means of selecting session locations. The random sample does not take the length and volume of the HPMS segment into account when calculating the probability of that section being selected as a count location. Sampling proportional to VMT makes the probability of a section being selected equal to the ratio of that section's VMT to the total VMT of all sections in the sample. See the heading "Select Sample Locations and Times" presented earlier for a description of the steps entailed in these procedures.

Count Scheduling

We recommend that the vehicle classification counts be taken every three years on the same cycle used for volume counts. The samples should be taken in each season of the year, if possible, to avoid the problem of seasonal variations in the composition of the traffic stream. This will provide an annual estimate of the percentage of vehicles operating on each functional type of highway. Ideally, count days should be sampled randomly to determine the counting schedule. Given the realities of manpower and equipment utilization, a systematic random sample approach is acceptable. Each state must work within its limitations, but every effort should be made to reduce the possibility of bias in the sample from obvious sources (e.g., taking all counts during the summer).

Many states will not be able to collect vehicle classification data all year round. If vehicle class data is collected predominately during the summer months due to the availability of labor or equipment, some seasonal adjustment of the data may be necessary. The HPMS vehicle classification study indicated that the traffic makeup of functional classes of roads changed by season of the year for some states. For other states, this study showed that seasonal change was insignificant. Each state will have to determine whether a seasonal adjustment to their collected vehicle class data is necessary. This may be done by analysis of existing data in each state.

Two methods for comparing seasonal variations in traffic composition are:

- using ATR stations to examine the seasonal changes in makeup of a limited number of vehicle length categories; and
- a special study of vehicle classification makeup to determine seasonal changes.

The first of these two methods is probably the most cost effective, if the recommendation to use solid state equipment for ATR stations has been accepted. The majority of solid state equipment is capable of determining basic vehicle length categories as well as the number of vehicles. The state must install a second inductance loop at each ATR location and program the counting device to collect the appropriate vehicle length classes to provide year round vehicle class data for calculating seasonal adjustments. An example of how vehicle length categories might be used to adjust complete vehicle classification data is included in Exhibit IV-9.

Vehicle classification data should be collected for 24 hours at a time whenever automatic equipment can be used. If manual classification counts are performed, 16-hour classifications with a 24-hour volume count is normally sufficient. The HPMS vehicle classification study, consisting of data from four states (Arkansas, Iowa, Minnesota and Washington) and one urban area (Philadelphia), showed a considerable change in traffic composition of the night hours from the day hours. However, the total volume of vehicles in the night hours is often so small compared to total daily volumes that the increased percentage of night truck travel does not significantly affect the total daily vehicle percentages calculated from 16-hour classification data. The small amount of precision added in most data collection locations when late night hours are counted does not justify the cost of the additional 8 hours of manual counts. In addition, counts should be taken during all seven days of the week to account for differences between weekdays and weekends.

Both the use of a seasonal adjustment factor for vehicle classification data and a factor to correct for short count data add error to the vehicle classification estimate. Equation 11 would become:[8]

$$\mathrm{SPVC}_{ih}^2 = \frac{\mathrm{SPVCD}_{ih}^2}{\mathrm{nd}} + \mathrm{SPVCS}_{ih}^2 \cdot \left(\frac{1}{\mathrm{n}} + \frac{1}{\mathrm{nvc}_{sh}}\right) + \mathrm{SPVCH}_{ih}^2 \cdot \left(1 + \frac{1}{\mathrm{nhr}_h}\right) \qquad (21)$$

where:

SPVCH_{ih} = the standard deviation of the 16 to 24 hour correction factor

nhr_h = the number of locations used to calculate the hourly correction factor

Both the seasonal and short count adjustment terms are equal to zero if all vehicle classification counts are for 24 hours and the counts are evenly distributed throughout the year.

EXHIBIT IV-9

SEASONALLY ADJUSTED VEHICLE CLASSIFICATIONS BASED ON ATR VEHICLE LENGTH DATA

For Vehicle Class*	Apply Seasonal Factor For
Motorcycles	Group 1
Passenger Cars	Group 1
Two Axle, Four Tire Trucks	Group 2
Buses	Group 3
Two Axle, Six Tire Trucks	Group 2
Three Axle Single Unit Trucks	Group 3
Four or More Axle Single Unit Trucks	Group 3
Four or Less Axle Single Trailer Trucks	Group 4
Five Axle Single Trailer Trucks	Group 4
Six or More Axle Single Trailer Trucks	Group 4
Five or Less Axle Multi-Trailer Trucks	Group 4
Six Axle Multi-Trailer Trucks	Group 4
Seven or More Axle Multi-Trailer Trucks	Group 4

Given Length Categories of:

Length < 14' = Group 1
14' ≤ Length < 25' = Group 2
25' ≤ Length < 34' = Group 3
Length ≥ 34' = Group 4

*Based on proposed FHWA vehicle classes

It is advised that automatic equipment be used to collect vehicle classification data whenever possible. The advantages of this equipment include:

- reduced field crew needs;
- less expensive data collection (with savings of up to 50 percent over manual counts; see Appendix C);
- simultaneous collection of volume data with classification data, so a separate volume count is not necessary; and
- automated transfer of data to the factoring process.

The equipment does have several drawbacks. It cannot be used in all traffic locations, or on some multi-lane roads. FHWA-sponsored tests[9] have shown that error rates of up to 25 percent can occur if the axle-sensing devices used are not kept in excellent condition. However, a study performed by P. Davis and D.R. Salter of the Transportation Road Research Laboratory in England[10] indicates that errors from manual vehicle classification counts are often as high as 35 percent. This points to the conclusion that the data provided by well maintained and correctly set up equipment is at least as good as manually collected data, and certainly less expensive. More information on automatic data collection equipment is included in Appendix B.

As part of the vehicle classification element, it is recommended that the newly proposed national vehicle classification categories be adopted by the states. These categories are presented on page B-8, in the appendix.

This classification scheme has several advantages. Among the most important are:

- it can be collected with automatic equipment; and
- it would make data between states comparable.

While this classification scheme does not necessarily fulfill all state needs, it should provide data for the majority of them. States have the option of collecting more detailed data, but this will reduce the effectiveness of the automatic equipment, and probably increase the cost of vehicle classification data collection.

Data that is needed by states but not collected by this stratification can be supplied by the manual classification counts that are taken in locations where automatic equipment is not appropriate. A prime example of this is data on in-state versus out-of-state vehicle travel. Results from the manual count locations or through special counts could be applied to the data collected with automatic equipment if necessary.

Truck Weight Program Element

The design approach for the vehicle weight program element is similar to that used for the vehicle classification program element. It is designed to be a subsample of the vehicle classification sample sections, in the same manner that the vehicle class sample is drawn from the volume sample sections. The vehicle weight sample, however, is affected by several major limitations not experienced by the vehicle class sample:

- The available equipment for collecting weight data cannot be used on all road sections.
- There are inherent biases of an unknown magnitude in the collection of weight data caused by enforcement of weight laws.
- The equations used to calculate EALs from axle weights are essentially fourth order polynomials. This results in the variance of weights for heavier trucks having a greater effect on the precision of total EALs for a road segment than the variation for lighter vehicle types.
- The existence of loaded and unloaded trucks causes the data to have a bi-modal nature with one average weight per truck type for loaded trucks and one for unloaded trucks. This causes significant increases in the variability of the data and error in EALs calculated from any size sample.

Many of these factors cannot be addressed directly through the use of statistics. For example, bias is not affected by sample size. Therefore, the truck weight portion of this sampling plan uses professional judgment liberally to ensure that the sample plan can be realistically implemented by each state. Unfortunately, this relaxation of statistical rigor means that the stated errors determined by the formulas presented here may underestimate the standard error actually occurring. Until there are technical advances allowing accurate, inexpensive, random sampling of vehicle weights, little can be done about these problems. Each problem affects the selection of the sample size and data collection. They will be discussed in detail as they directly affect the sampling process described.

The basic sampling process is similar to that used for the vehicle class program element. It includes:

- definition of the sample population;
- estimation of the sources of composite error;
- determination of the precision required for the data collected;
- computation of the required sample size; and
- selection of the sample, locations, and times.

The result of the data collection is axle weights that can be used to estimate average gross weight, average axle weight, average EAL values, or other statistics such as the percentage of overweight trucks for each vehicle type for each functional class of road and additional strata required by the state. Vehicle types for the weight element are the same as for the vehicle classification element.

Define the Sample Strata

Peat Marwick recommends that the same strata used in the vehicle classification element be used for the vehicle weight element. A statistically reliable estimate of vehicle weights by functional road type does not exist at this time, so it is unknown whether further stratification will decrease variance within the sample sufficiently to result in sample size savings. The variance that already exists because of the loaded/unloaded dichotomy of trucks illustrates that accurate differentiation between even moderate differences in weight per vehicle type may be difficult, and further stratification would be a waste of resources. Also, the cost of collecting vehicle weight information places strict constraints on the total sample size that can be used.

Sources of Composite Error

The sources of error in estimates of total vehicle weight are very similar to those for vehicle classification. The precision of an estimate of the number of vehicles of a particular type is dependent on the errors in two principal estimates:

- the volume count; and
- the composition of vehicles in that volume count.

The errors in the use of weight data are composed of very similar terms, with the addition of a third area of uncertainty, that due to the error in the average weight per vehicle type.

These three basic terms must be considered together because weight data are normally used in some kind of estimation of the daily (or annual) number of loadings experienced by a particular roadway segment. Only occasionally is a data user interested in the average EAL for a vehicle type without some corresponding estimate of the number of vehicles in that classification. As a result, this discussion will deal primarily with the error in the estimate of total EALs for a location or stratum.

It is assumed that the average EAL per vehicle type for a specific location is not a function of the vehicle weight subelement of the recommended traffic monitoring program. If site-specific weight data is needed, it should be collected as part of the special data collection element. It is further assumed that the only time the accuracy of EAL data by itself will be used is for trend analysis reporting purposes, or for investigating the need for increasing the sample size at a later date. The HPMS vehicle weight subelement is designed to provide an estimate of EAL (or other vehicle weight statistics) per vehicle type for a stratum. The EAL estimate can be computed as:

$$EAL_{ih} = \frac{\sum_{n_h} \left(\frac{\Sigma EAL_{ihk}}{k} \right)}{n_h} \qquad (22)$$

where:

EAL_{ih} = the equivilent axle load for vehicle type i in stratum h

EAL_{ihk} = the equivilent axle load for vehicle type i in stratum h for day k

k = the number vehicles weighed during a session

with an uncertainty that would be computed as:

$$SEAL_{ih}^2 = SEALD_{ih}^2/nd + SEALS_{ih}^2 \left(\frac{1}{n_{ih}} + \frac{1}{ntw_{sh}} \right) + SEALL_{ih}^2 \left(\frac{1}{ntw_{lh}} \right) \qquad (23)$$

where:

$SEAL_{ih}$ = the standard deviation of EAL for vehicle type i for stratum h

$SEALD_{ih}$ the standard deviation of EAL for vehicle type i across days for stratum h

$SEALS_{ih}$= the standard deviation of EAL for vehicle type i across seasons for stratum h

$SEALL_{ih}$= the standard deviation of EAL for vehicle type i across locations in stratum h

ntws = the number of truck weight locations used to compute seasonal differences

ntwl = the number of truck weight locations used to calculate the deviation of EALs due to locational differences

Equation 23 can be simplified by combining the component variation terms into one value. The standard deviation would then be expressed as:

$$SEAL_{ih}{}^{2} = \frac{SEALT_{ih}{}^{2}}{n_h} \qquad (24)$$

Where: $SEALT_{ih}$ = The total standard deviation in the mean EAL for vehicle class i and stratum h.

As for equations 14 and 15, this simplified form allows an easier examination of sample size versus precision and subsequent design of the data collection program. The simplified form does not, however, allow for the design of the sampling plan to address the specific components of variations of EALs.

These equations detail the size of the measurable error in the EAL estimate. They do not take into account such factors as the bias in truck weight data due to overweight trucks bypassing weigh stations, or the measurement errors occurring in the data collection. This means that the reliability of the data, and thus the error in any EAL estimate, may be higher than that calculated using any statistical equation.

As can be seen in equation 23, the same factors that affect the variation in traffic composition and volume affect truck weights:

- seasons;

- daily variation; and

- locational differences.

The effect of the variation due to these factors on the precision of the EAL estimate is directly related to the sample size of the counts used to make that EAL estimate. The cost of collecting weight data makes it doubtful whether the sample size can be increased sufficiently as a part of this count program to significantly reduce this error.

One possible method for reducing this error, other than taking more counts within the program, is to use data collected by the state in its weight enforcement function, if available, to calculate seasonal adjustments. Most enforcement data may be heavily biased towards trucks carrying below the legal weight limit due to avoidance problems. In other cases the opposite may be true, since only loaded trucks are weighed. It can be argued, however, that the seasonal variation within this sample of trucks is equivalent to the seasonal variation within the true population (i.e., the enforcement data estimates are biased consistently to the same degree).

The use of a large enforcement data base to calculate the seasonal variability and adjustments could considerably reduce the variation in the data base. For example, enforcement data might show a stable average EAL for 3S2 trucks for 10 months out of a year, but a 60 percent increase in July and August. The mean annual EAL would then be computed more accurately by using an appropriate seasonal adjustment.

Equation 24 serves as the basis for estimating the variation in the EAL per vehicle for each vehicle type. This in turn allows the calculation of sample size, given stated precision levels. As for vehicle classification, a difficulty arises in that the variation of EALs for each vehicle type is different. This means that a different sample size is needed for each vehicle type to achieve the same level of precision. Since only one sample size can be chosen, a method must be used to determine a single variance term for computing the required sample size.

As for vehicle classification, two basic approaches can be taken for determining a single sample size. One vehicle type can be chosen as the most important, and that vehicle type's COV can be used, or a composite of the COVs for all vehicle types can be used. Three methods for weighting EAL COVs are presented:

- use the percentage of VMT for each vehicle type within the stratum;

- use the mean EAL per vehicle for each vehicle type; and

- use the total EAL attributed to each vehicle type.

The first of these weighting schemes applies weights equal to the percentage of traffic due to that vehicle type. This results in a weighting of the COV towards the smaller, lighter, but more numerous trucks. The second method applies the heaviest weights to the heaviest truck types. This may lead to an overemphasis on very heavy trucks that occur infrequently in the strata. The third method provides for weighting the COVs by the amount of damage each vehicle type causes on the road. This method is recommended as providing the best overall weighting.

Exhibit IV-10 includes examples of how to perform the various weightings described above. Data for rural interstates from Appendix A is used to compute the exhibit. The first four columns are taken directly from Appendix A. The COV is calculated for each vehicle type by dividing the standard deviation of the EAL estimate by the EAL estimate for that vehicle type. Total weight by a vehicle type is the average EAL times the percentage of vehicles for that vehicle type. The various weighted COVs for each vehicle type are then computed by multiplying the COV for that vehicle type by the weighting variable (EAL, total weight, or percentage of volume) and divided by the sum of the weighting variable for all vehicle types. For example, the COV for 352 trucks, weighted by total weight, is the COV (.246) times the total weight (.1457) divided by the sum of all total weights (.1884). The weighted COVs for all vehicle types are summed, and this value is used in equation 20 to estimate precision versus sample size. Precision in this equation is expressed as a fraction of the estimated EAL.

Exhibits IV-11 and IV-12 present graphs of precision versus sample size for the various weighting methods used in Exhibit IV-10. These curves are plots of equation 20, substituting EAL COVs for vehicle class COVs (i.e., substituting EAL for PVC and SEAL for SPVC). To use the curves in Exhibit IV-11 and IV-12, read the calculated precision level (accuracy at a 95 percent confidence interval) from the Y axis and sample size from the X axis. Using Exhibit IV-12, a sample size of 10 weight monitoring sessions would provide an estimate of 3S2 EAL within ±15 percent. The same sample size would provide estimates of all EALs (weighted by total weight contributed by each vehicle type) within ±20 percent. This indicates only that the 3S2 category has a smaller amount of variation than some other vehicle types, and that those other vehicle types have EAL estimates from the 10 monitoring sessions that are less reliable than those for the 3S2 vehicle type. Equation 20 and the values from Appendix A, Exhibit A-1 could be used to estimate the specific precision of the EAL estimate for any particular vehicle type.

EXHIBIT IV-10

CALCULATION OF WEIGHTED EAL COVs

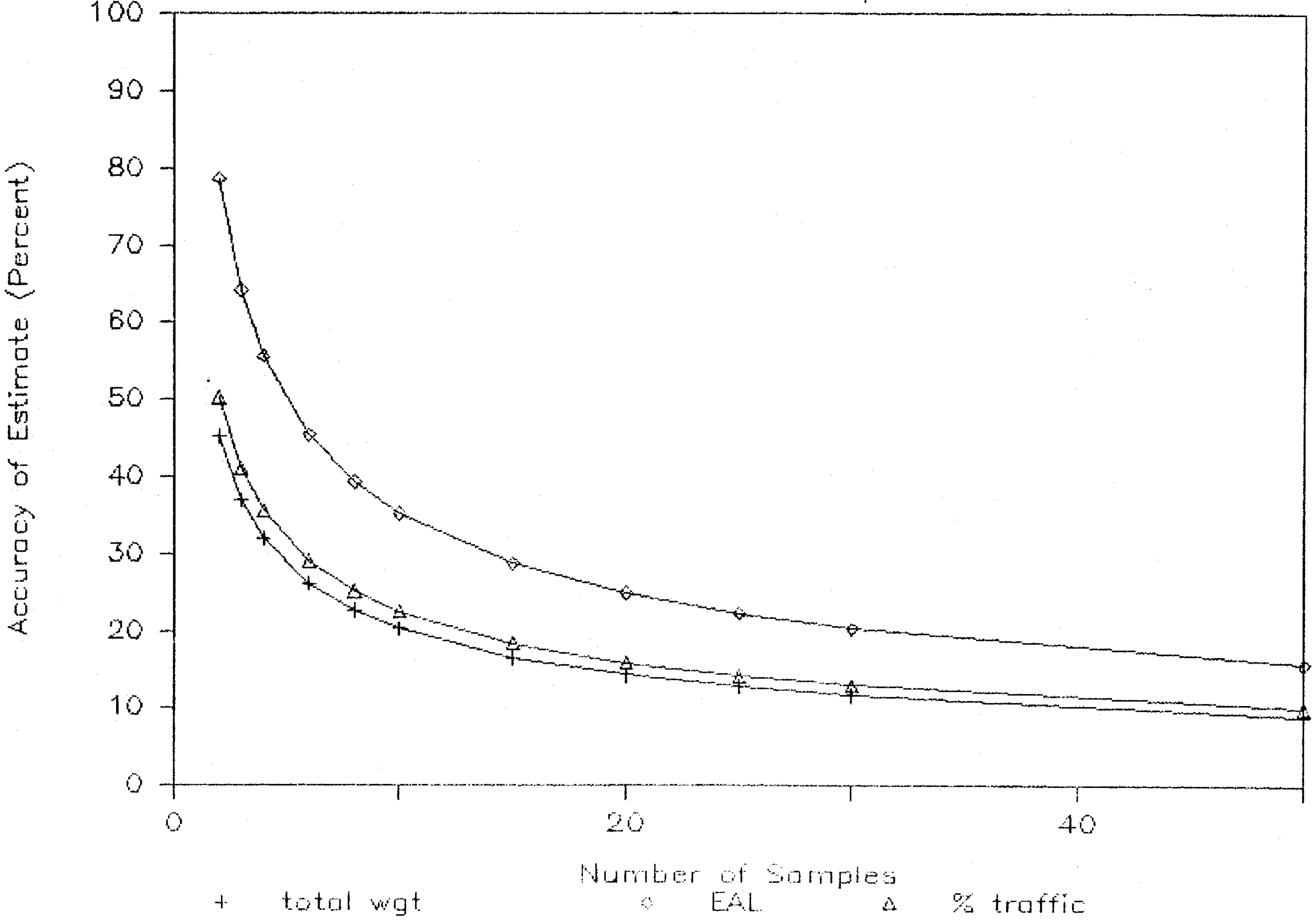
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
						Weighted By		
Vehicle Type	Average EAL	Deviation of EAL	Percent of Traffic	COV (3)/(2)	Total Weight (2)(4)	EAL (2)(5)/sum(2)	Percent Vehicles (4)(5)	Total Weight (6)(5)/sum(6)
Standard Car	0.0005	0.001	0.416	0.200	0.0002	0.00001	0.083	0.00022
Small Car	0.0005	0.001	0.183	0.200	0.0001	0.00001	0.037	0.00010
Motorcycle	0.00001	0.0001	0.005	0.100	0.0000	0.00000	0.001	0.00000
Bus	0.4080	0.171	0.003	0.419	0.0013	0.02369	0.001	0.00300
2 axle, 4 tire	0.0012	0.001	0.182	0.917	0.0002	0.00015	0.167	0.00107
2 axle, 6 tire	0.1120	0.069	0.025	0.616	0.0028	0.00956	0.015	0.00920
3 axle single unit	0.4630	0.416	0.006	0.898	0.0027	0.05763	0.005	0.01282
3 axle combination	0.4080	0.114	0.006	0.279	0.0023	0.01579	0.002	0.00339
2S2	0.6620	0.283	0.008	0.427	0.0050	0.03921	0.003	0.01143
Other 4 axle combinations	0.1980	0.228	0.005	1.152	0.0010	0.03159	0.006	0.00594
3S2	0.9810	0.241	0.149	0.246	0.1457	0.03339	0.036	0.19021
Other 5 axle combinations	2.3590	1.479	0.009	0.626	0.0215	0.20490	0.006	0.07153
6 and larger axle combinations	1.6250	1.114	0.003	0.686	0.0054	0.15433	0.002	0.01954
SUM	7.2182		1.000		0.1882	0.57027	0.365	0.32845
COV Used For Sample Size Calculation						0.5703	0.365	0.3285

Note that the values presented in this table have been rounded from the acutal values used in the calculations. This gives the appearance of mathmatical errors in some of the computations.

EXHIBIT IV-11

EFFECT OF EAL COV WEIGHTINGS

Precision* Versus Sample Size

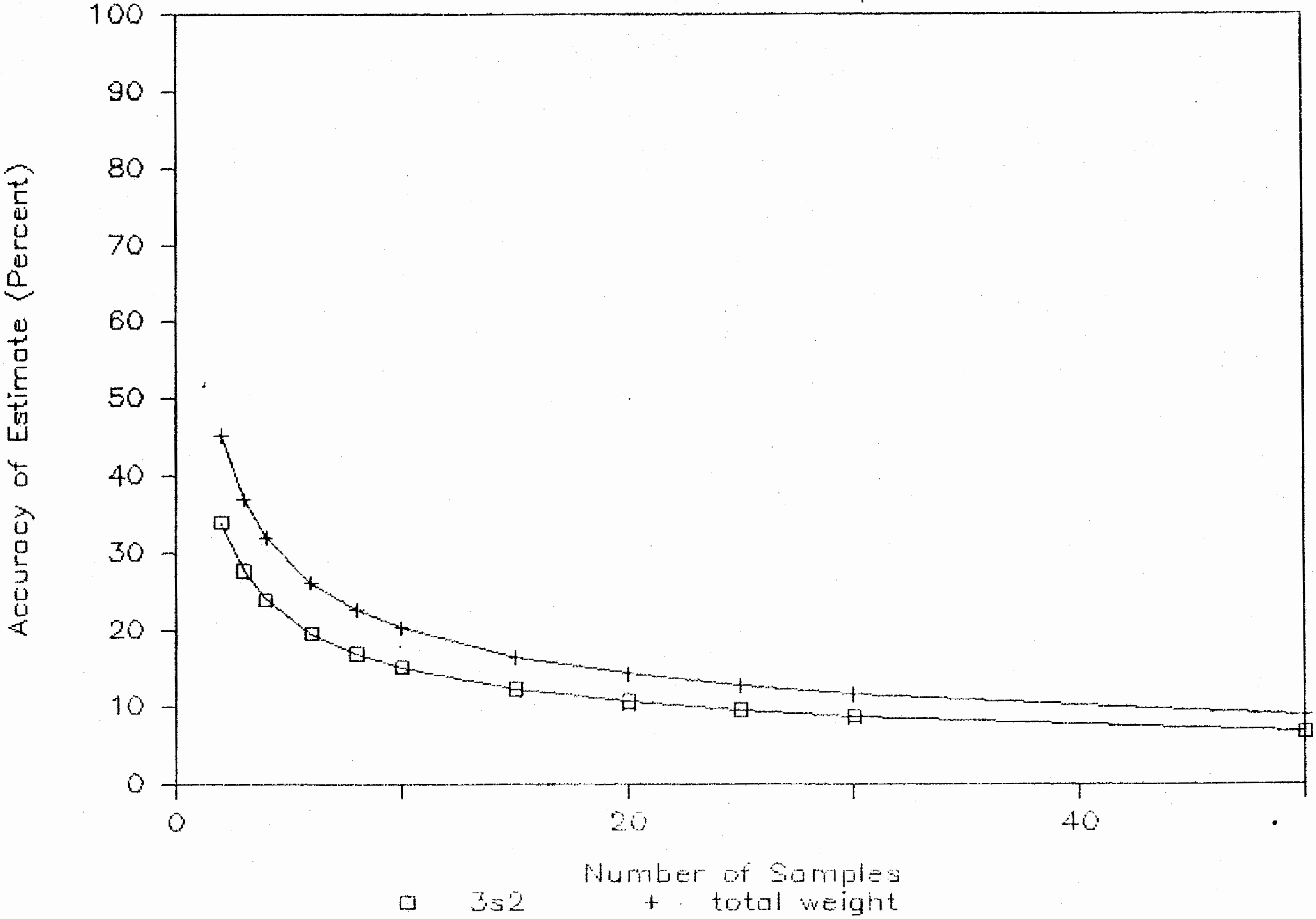


*Precision is defined as the accuracy of an estimate with a confidence level of 95 percent.

EXHIBIT IV-12

EFFECT OF EAL COV WEIGHTINGS

Precision* Versus Sample Size



*Precision is defined as the accuracy of an estimate with a confidence level of 95 percent.

It should be remembered that the error associated with using EAL data is not limited to the error in the EAL estimate, but also includes error in the estimates of the composition of the traffic and in the total volume of the traffic. These components are discussed below.

For road design, the engineer needs an estimate of total EALs per day or year projected for the design life of the road. The precision of the total EAL estimate is a function of the precision of volume, vehicle classification, and vehicle weight estimates. Peat Marwick selected several possible alternatives for computation of total EALs based on available data, and developed equations for estimates of variance based on that data. These alternatives include:

- total EALs for a location, based on a site-specific vehicle classification and volume count, and an average EAL per vehicle type for a stratum;
- total EALs for a location, based on a site-specific volume count, average vehicle classification for a stratum, and an average EAL per vehicle type for a stratum; and
- Total EALs by vehicle class for a stratum.

The standard error in a sample can also be computed for other data permutations, but these equations were omitted here for the sake of brevity. Estimates for other weight characteristics (average weight, number of overweight trucks, and so on) can also be computed with these formulas by substituting the appropriate value and deviation of that value in place of the EAL estimate and deviation of the EAL estimate. These equations can be derived by using the vehicle classification equations as a guide for extrapolating the EAL equations listed below. (See also Appendix E.)

For a location, using site-specific volume and vehicle class data, the total EAL can be expressed as:

$$\mathbf{EAL_j = \sum_i \left(\overline{EAL}_{ih} * VOL_{ij} \right)} \qquad \mathbf{(25)}$$

EAL_j = the total EAL at location j
EAL_{ih} = see equation 22
VOL_{ij} = see equation 8

with the uncertainty of that estimate computed from:

$$SEAL_j^2 = \sum_i \left[EAL_{ij}^2 \left(\frac{\overline{SEAL}_{ih}^2}{\overline{EAL}_{ih}^2} + \frac{SVOL_{ij}^2}{VOL_{ij}^2} \right) \right] \qquad (26)$$

where:

$SEAL_j$ = the standard error in the estimate of total EALs at location j

EAL_{ij} = the total EAL for vehicle type i at location j

$SEAL_{ih}$ = see equation 24

$SVOL_{ij}$ = see equation 10

VOL_{ij} = see equation 8

The total EAL at one location for a day using average vehicle classification data with a site-specific volume count can be expressed as:

$$EAL_j = \sum_i \overline{EAL}_{ih} * (VOL_j * \overline{PVC}_{ih})$$

$$= \sum_i \overline{EAL}_{ih} * V\hat{O}L_{ij} \qquad (27)$$

with the uncertainty of that estimate computed from:

$$SEAL_j^2 = \sum_i \left[E\hat{A}L_{ij}^2 \left(\frac{\overline{SEAL}_{ih}^2}{\overline{EAL}_{ih}^2} + \frac{SV\hat{O}L_{ij}^2}{V\hat{O}L_{ij}^2} \right) \right] \qquad (28)$$

Where the EAL for vehicle type i at location j; is equal to the average EAL for that vehicle type within that stratum times the volume of that vehicle type; or

$$E\hat{A}L_{ij} = \overline{EAL}_{ih} * V\hat{O}L_{ij} = \overline{EAL}_{ih} * VOL_j * \overline{PVC}_{ih} \qquad (29)$$

with: $SEAL_{ih}$ = see equation 24

$SVOL_{ij}$ = see equation 10

VOL_{ij} = see equation 8

The average EAL for a vehicle type for roads within a stratum is calculated as:

$$EAL_{ih} = \overline{EAL}_{ih} * \overline{VOL}_{ih} \qquad (30)$$

where:

EAL_{ih} = the total EAL for vehicle class i and stratum h

EAL_{ih} = the average EAL for vehicle class i and stratum h

VOL_{ih} = the average volume for vehicle class i and stratum h

with the uncertainty computed from:

$$SEAL_{ih}^2 = \hat{EAL}_{ih}^2 \left[\frac{\overline{SEAL}_{ih}^2}{\overline{EAL}_{ih}^2} + \frac{\overline{SVOL}_{ih}^2}{\overline{VOL}_{ih}^2} \right] \qquad (31)$$

where:

EAL_{ih} = see equation 22

VOL_{ih} = see equation 16

$SEAL_{ih}$ = see equation 24

$SVOL_{ih}$ = see equation 17

Sample Selection

The vehicle weight locations are selected from the vehicle classification sample sections. This subelement's goal is random selection, but practical considerations must be analyzed on a case-by-case basis. Ideally, the vehicle classification sections would be randomly sampled. In reality, because of limitations in equipment capabilities, weight data cannot be collected on all roadway sections. Some weighing devices need wide shoulders, or pull-outs where trucks can safely park. Other devices can only be placed on bridges. Some WIM equipment can be placed on any road section, but the collected data is biased because of vertical and horizontal sloping in the road. The net result is that a true random sample of vehicle classification count locations might result in count locations where a state cannot physically collect vehicle weight data.

Two recommended alternatives are provided for selecting the sample given these limitations. Both alternatives begin with vehicle classification sites as the basis for choosing truck weight locations. The first is more statistically rigorous while the second allows for more professional judgment.

The first involves:

- choosing a random sample of locations for truck weighing for each stratum;
- determining for each location whether weight data collection at that location is plausible, including such considerations as safety and reasonableness of results (i.e., no stations next to cement plants);
- if the location is not plausible, selecting an additional site (randomly) to replace it; and
- continuing this process until all locations have been determined.

The second method depends on the ability of the engineer selecting the sites to pick representative locations. This method requires that an engineer select locations based on his or her judgment, knowledge of the equipment to be used, and the candidate road segments. Guidelines for choosing sites in this manner are taken from a Wisconsin DOT[1] paper:

- Where possible, establish stations on high volume routes, as they are the routes most data users are interested in, and the larger number of weighed trucks will improve the reliability of the data.
- Locate stations on lower order roads with special attention to avoiding atypical traffic conditions.
- Existing weighing sites should be used, if they are part of the sample.

Additional considerations for choosing truck weight sites can be found in Truck Traffic Volume and Weight Data For 1971 and Their Evaluation, by R. Winfrey, P.D. Howell, and P.M. Kent, FHWA, 1976. FHWA prefers the statistical approach, but realizes that practical considerations must be incorporated in the plan.

Both methods result in the addition of some systematic error to the estimated EAL value. The second method will more than likely add more error than the first method. The degree of this increase is not known. The second method, however, does a better job of allowing a state to maintain high levels of safety for its truck weight crews, and limits the cost of collecting data by allowing the state to take these factors into account when selecting sites.

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[1] Gardner, W.D., Truck Weight Study Sampling Plan in Wisconsin, for presentation at 1983 Transportation Research Board Meeting.

Scheduling of Truck Weight Monitoring

The vehicle weight data should be taken over a three-year cycle, the same as the vehicle classification and volume counts. A third of the data should be collected each year. This will allow the state to meet federal requests for truck weight data such as the current truck weight survey. (This program does not include a driver survey, as does the current federal truck weight survey. Such a survey would have to be addressed in the special program element.) The weight data should be collected throughout the year. A year-round count program will eliminate the need for seasonal variation correction in the data.

Scheduling weight monitoring sessions may be primarily a function of equipment and crew availability. While a random selection of monitoring days is statistically correct and the recommended approach, it will probably have an unduly large effect on the cost of the program. Therefore, a state should make every effort to evenly distribute monitoring sessions so as to obtain a representative sample while conforming to the limitations imposed by budgets and equipment capabilities.

Session duration should be a minimum of eight hours if manual procedures are used with a 16-hour vehicle classification count taken simultaneously. If an automated WIM system can be used, a 24-hour weight session is preferable. This session length may not be practical if large crews and conventional portable static scales are used. If conventional static weighing equipment is used, the data will be less biased if CB radio announcements are made indicating that the station is taking weight data for planning purposes only.

SPECIAL DATA COLLECTION PROGRAM ELEMENT

The purpose of this program element is to collect data that cannot be collected cost effectively using a statistically-based approach. This element is meant to be independent of the HPMS-based program element and the continuous counters, although the averages determined from those elements should be used to factor count data collected in this element.

This element is intended to provide each state with a vehicle for collecting additional data not provided for in the other two program elements but necessary to the state's function as a data provider. This element should be used to fulfill specific data requests made by various data users. Such data might include:

- truck driver interview surveys;

- traffic volume, vehicle classification, or weight monitoring sessions at specific locations;

- traffic data at a disaggregate level below that of the HPMS;

- project-specific vehicle class and weight studies;

- cordon line counts; and

- special purpose studies.

The combination of this program element and the HPMS element render much of many existing coverage count programs unnecessary. The HPMS element provides statistically reliable estimates of traffic volumes and VMT. The data from the Continuous and HPMS Elements should be sufficient to provide data for reporting, trend analysis, and general statewide traffic flow maps. This special count element provides a vehicle for providing data for all other specific data needs. The combination of the two elements fulfills the same purposes as a coverage count program.

The content of this program element should be reviewed every year. Each request for data can then be compared annually with the cost for collecting that data, thus providing a mechanism for maintaining the cost effectiveness of the traffic monitoring program.

Special data collection program locations should be chosen by the state so as to best fulfill the data requests. No sampling techniques need to be applied when selecting locations. Session duration and timing should be determined so as to best use the state's manpower and equipment.

As a means of simplifying scheduling, the state should consider scheduling the HPMS program elements first, since they require the same effort every year, and then schedule the special data collection efforts to take advantage of available manpower and equipment. Factors derived from the ATR and HPMS program elements should be used in the special data program to make representative average annual numbers.

PROCESSING THE DATA FOR REPORTING PURPOSES

This section deals with the steps involved in collecting and processing traffic data for the three monitoring program elements previously described. Peat Marwick's recommendations for streamlining manipulation of the large amounts of traffic data collected by a state are discussed here, and areas outlined in which significant cost savings can be made over processing techniques commonly used by states.

An effort should also be made by each state to coordinate monitoring sessions with lower jurisdictions within the state to minimize duplication of effort. States should also work toward keeping all data in a single place where it is available to all users.

Overview

State DOT data collection and processing efforts can be broken down into two basic activities:

- data collection; and
- data refinement.

Collection includes the act of placing a monitoring device at a data collection location and transformation of that data into a usable format. Data refinement includes the editing of obvious errors in data transfer from the recording medium to a more usable form, and the adjustment of that data to account for limitations in the raw data. These limitations can be summarized as having three causes:

- seasonal variations in traffic;
- use of data collection equipment which counts axles rather than vehicles; and
- growth in the data between the time of the monitoring session and its use as a data point.

Collection

The methods used for collecting traffic data are dependent on:

- the equipment used;
- personnel constraints; and
- jurisdictional issues specific to each state.

Because of these multiple issues and their site-specific nature, no single report can make detailed recommendations for improving the cost effectiveness of data collection in all states. Therefore, only broad recommendations will be made on what technologies and methodologies offer cost advantages over common current practices.

The principal nationwide recommendation that Peat Marwick makes is that solid state traffic monitoring equipment be used whenever possible to collect traffic data. In particular, paper tape recording equipment should be replaced at ATR locations as soon as practical. Portable paper tape counters should be phased out more gradually, through the normal replacement cycle, as funding permits.

Considerable savings can be achieved by using solid state counters due to electronic data transfer. In several states, data is transferred manually or by machine from paper tape to punched cards. These cards are then edited for mistakes, and finally put in a computer file. Once there, the data may be further edited or factored manually or through computer program. By using solid state equipment, data can be transferred electronically either directly from solid state memory or from a cassette tape containing the data from several counters. This data can then be edited directly on the computer, and submitted for automatic factoring, based on information contained on the data tape (e.g., the functional class of the roadway section).

The savings obtained by switching from paper tape equipment to solid state can be most dramatically illustrated with the ATR stations. Assuming that data is collected every two weeks for each station means that a single ATR station generates 26 two-week paper tapes a year. Fifty ATR stations thus equal 1300 tapes annually. While the same amount of data would still be transferred with the new counters, the speed of the electronic transfer will decrease the amount of staff needed to transfer and edit the data. A typical state uses a third of a man-year, annually, to administer the ATR data manipulation. A brief examination of the steps involved indicates that an electronic data transfer takes as little as a third of the time currently taken by the transfer. This is equivalent to a minimum saving of 22 percent of that person's time. Additional savings also result from a reduction in the number of errors requiring correction in the data, because electronic data storage of data is more accurate than the storage of data on a paper tape by mechanical means (either punched holes or printed ink).

Twenty-four hour cumulative counters do not require the same amount of data transfer, but they do require a precise setup and retrieval schedule. They also do not allow an examination of hourly data as a check on counter malfunction. Using solid state equipment in place of these counters will not result in cost savings equal to that obtained by replacing paper tape counters, but it will result in more data collection capability and greater productivity of field personnel resulting from more flexibility in the timing of counter placement.

Seasonal Adjustments

The process for determining seasonal adjustment factor groups has already been discussed under the Continuous Count Program Element heading of this report. The purpose of the recommended seasonal adjustment factors is to allow a state to estimate average annual traffic from a single raw traffic count at a location. The seasonal factors recommended for this purpose are month of the year, combined with day of the week. The other possible factoring procedures examined for this project were:

- week of the year, combined with day of the week if necessary; and
- day of the year.

An examination of weekly trend data from two Maine ATR stations (see Exhibit IV-13) shows that a weekly factor is not sufficiently stable from one year to another to be used for seasonal adjustment.

An analysis of day-of-the-year factors shows them to be even more unstable than weekly factors (see Exhibit IV-14). Daily factors are taken to mean the first Monday of June, 1983, would be used to factor the first Monday of June, 1984.

The month-of-the-year factors for the seasonal factor groups appear quite stable (see Exhibit IV-15). The monthly factors also provide a means for developing stable week of the year factors by interpolating between monthly points (see Exhibit IV-16).

The use of a day-of-the-week factor is needed because of the significant differences in traffic volumes between weekdays and weekends on most roads. Our analysis showed that a single factor can be developed for Monday through Thursday, but that separate factors should be derived for the remaining three days. Counting on weekends is necessary if seasonal and day-of-the-week adjustment factors are not used.

The use of the day-of-the-week factor also facilitates the traffic counts scheduling. The ability to factor Fridays and weekends separately from the other days allows a state to collect data whenever its manpower and equipment limitations permit. This results in a state's more efficient use of its resources, and thus results in a lower cost per count and a higher number of counts taken with the same amount of resources.

ATR data should be used to compute seasonal and day of the week factors for the seasonal groupings determined earlier in the analysis. These factors can then be applied to any count

EXHIBIT IV-13

COMPARISON OF WEEKLY TRAVEL FROM 1981 AND 1982

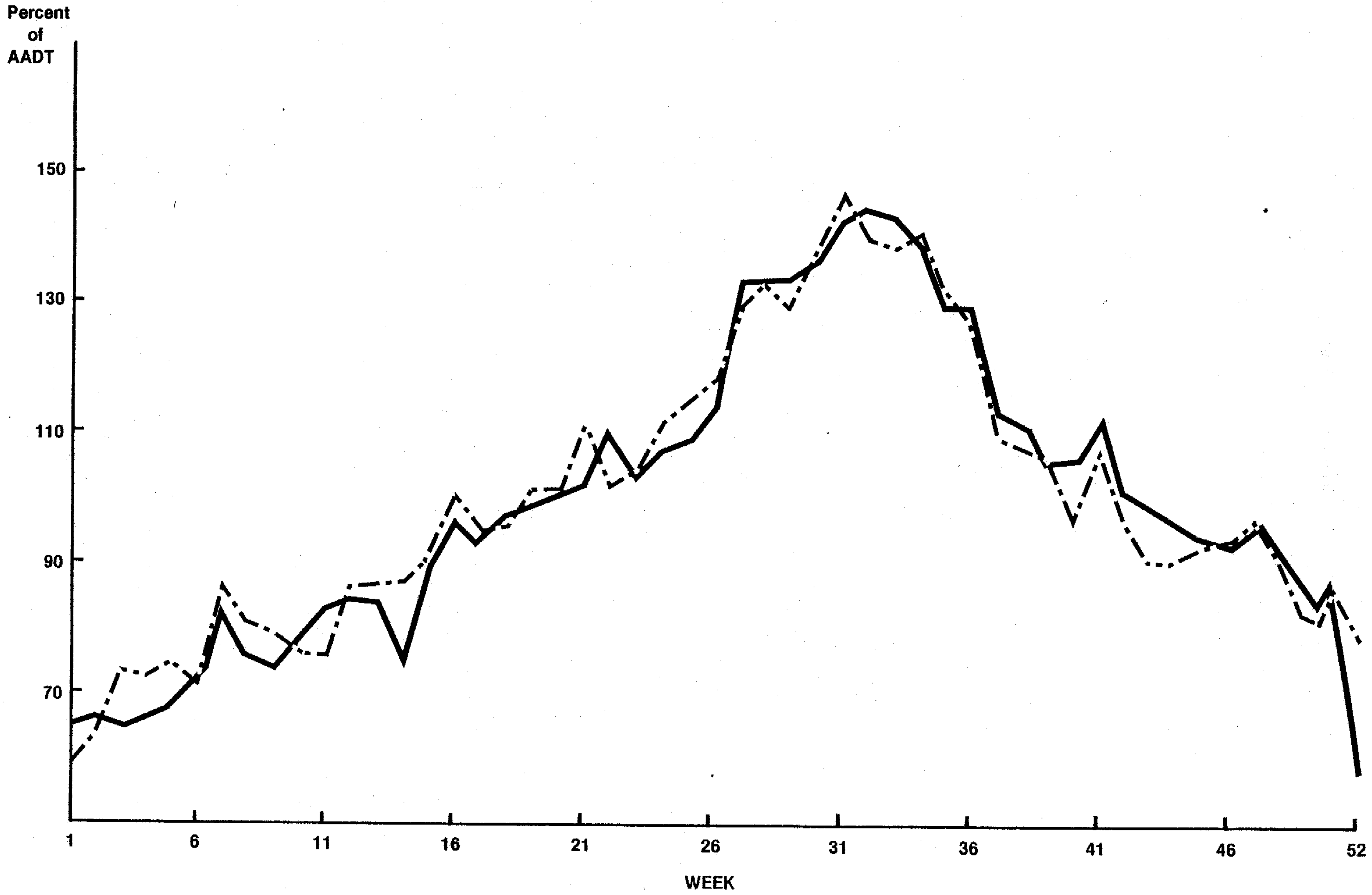


EXHIBIT IV-14

COMPARISON OF PERCENT AADT BY DAY FOR MAY 1981 AND 1982

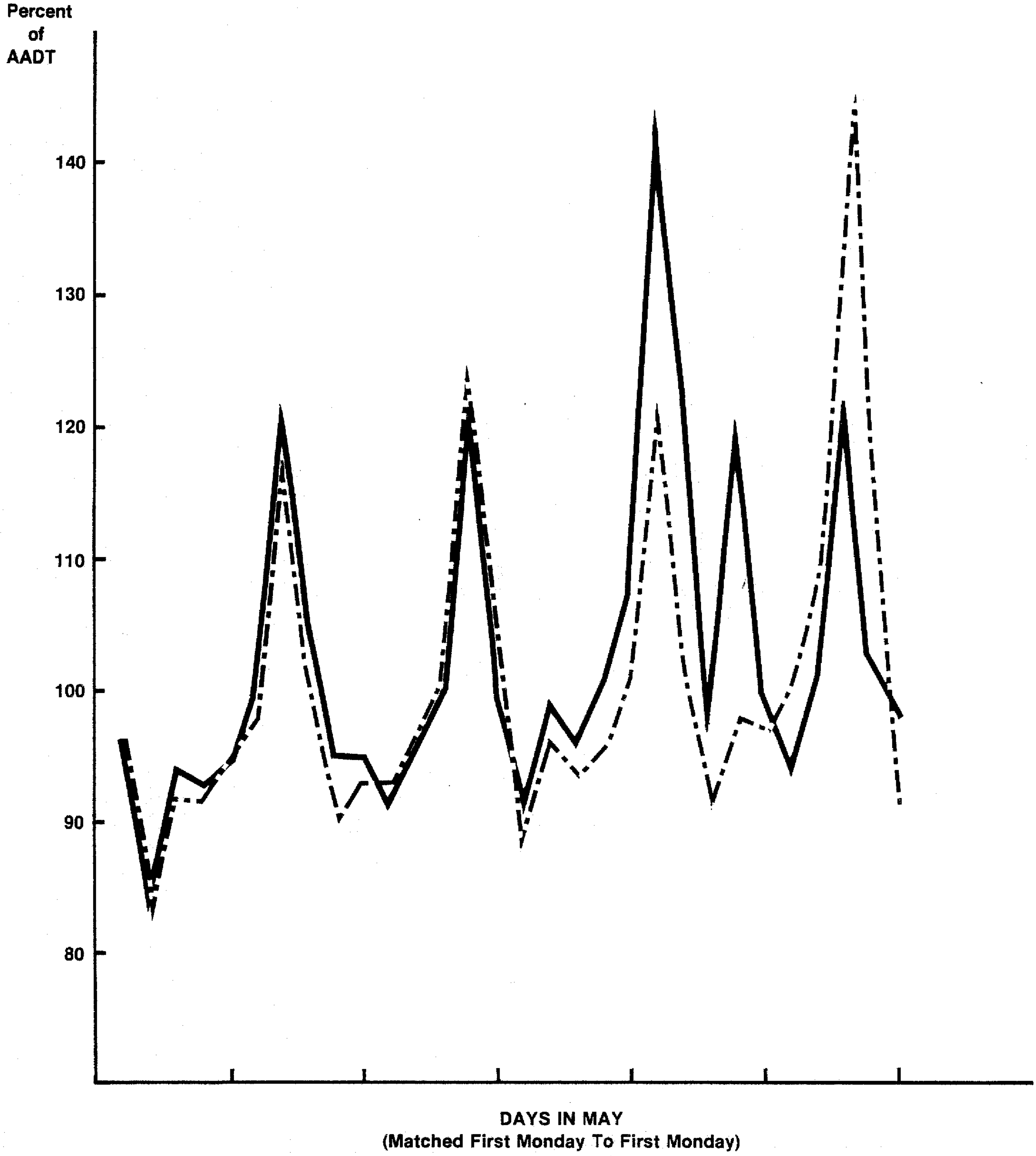
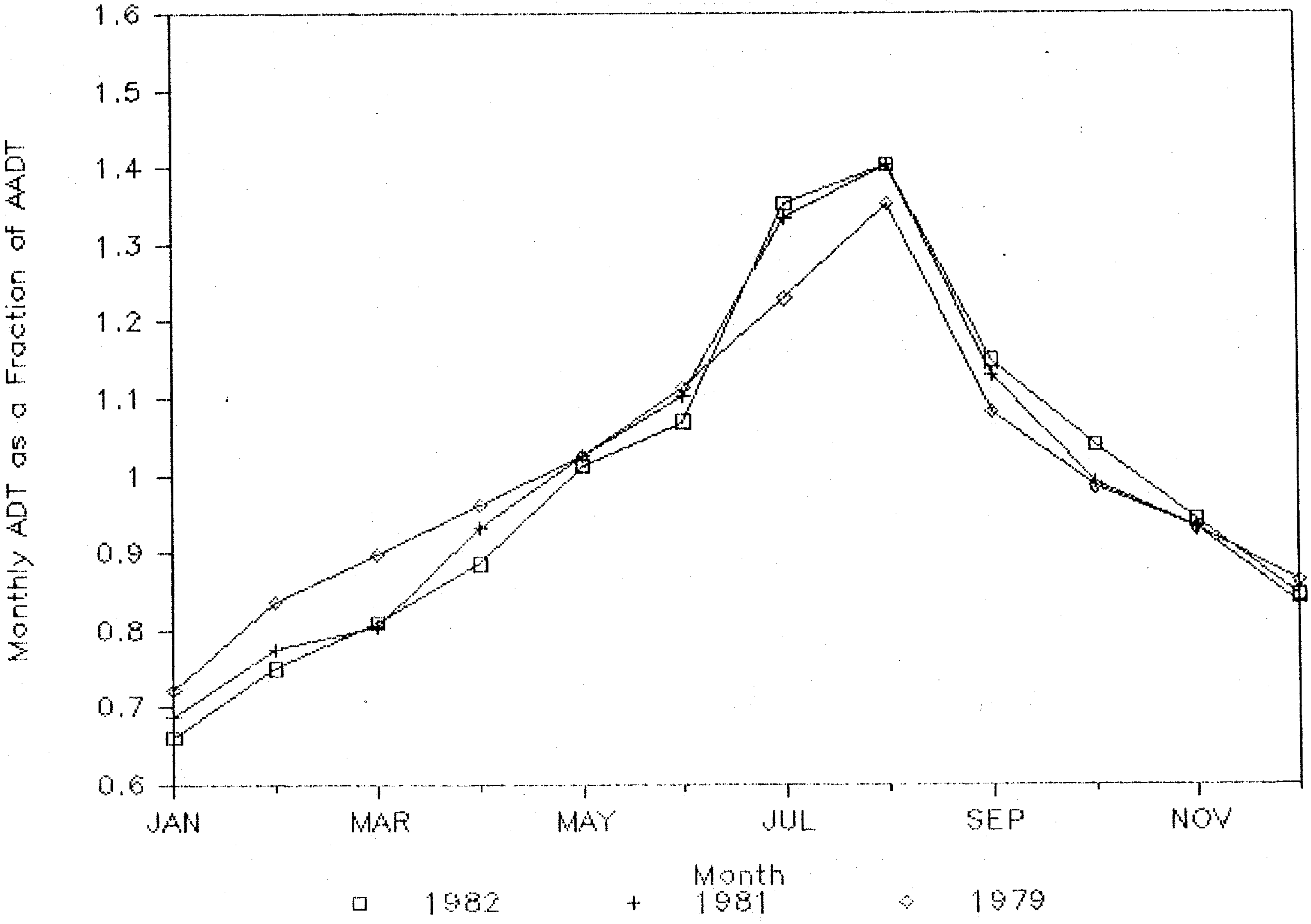


EXHIBIT IV-15

MONTHLY TRAFFIC PATTERNS*

1982 vs 1981 vs 1979

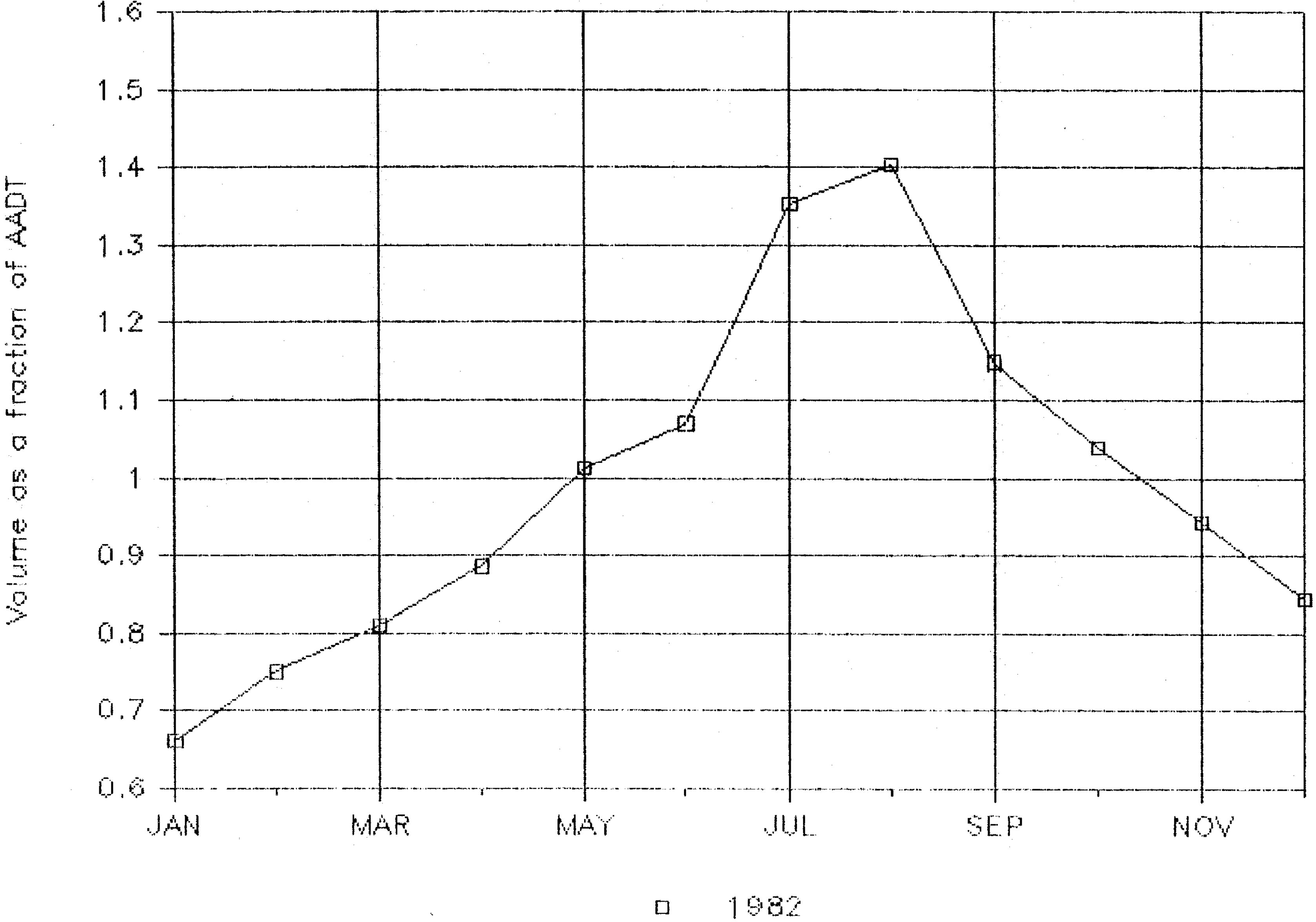


*Estimated for combined rural interstate and rural principal arterial functional classes combined.

EXHIBIT IV-16

WEEKLY TRAFFIC PATTERNS*

From Monthly Traffic Patterns



*Estimated for combined rural interstate and rural principal arterial functional classes combined.

taken within the state, as long as the roadway's functional class (and region, if there is a regional stratification to seasonal factors) is known. It is recommended that holidays be eliminated from the analysis computing day of the week factors.

Axle Corrections

Axle corrections are needed to develop volume estimates because road tubes can only collect the number of axles passing a point, rather than the number of vehicles passing that point. The true number of vehicles is calculated by dividing the number of axles counted by the average number of axles per vehicle in the traffic passing that location.

In some states, the average number of axles is assumed to be 2.0. This is correct only when no multi-axle vehicles are in the population. Data from the HPMS vehicle classification study indicates that the average axle correction factor ranges from around 2.04 for some urban roads to 2.41 for some rural roads.

The use of an estimate of 2.0 for roads with an actual average number of axles of 2.41 results in overestimating the number of vehicles by 17 percent (fifty vehicles per 100 axles versus 41.5 vehicles per 100 axles). This sizable error can be easily reduced using the vehicle classification data collected on the HPMS samples as part of the Statistically Valid Count Program Element.

Recommended Axle Correction Process

Peat Marwick recommends that the vehicle classification data collected for the purpose of estimating travel by vehicle type be used to calculate the average number of axles per vehicle within a stratum. It is further recommended that separate axle correction factors be calculated for each road stratification used to collect vehicle class data.

The recommended process includes the following steps:

- Assign an average number of axles to each vehicle classification category collected for the vehicle class program. This gives the average number of axles per vehicle type.

- Multiply the number of axles per vehicle type by the percentage of traffic volume for that vehicle type for each vehicle class location in a stratum. This gives the average number of axles at each count location in that stratum.

- Sum the average number of axles for each count location within the stratum, and divide by the number of locations. This yields the average number of axles per vehicle for the stratum.
- Use this average to compute the standard error of the axle correction for that stratum.
- Repeat the process for all the remaining strata.

An example of this process can be seen in Exhibit IV-17.

Like the seasonal factors, the computed axle correction factors can be used for any road section, provided the section can be assigned to the appropriate stratum (i.e., functional class, and possibly region).

Growth Factors

Growth factors are needed to adjust old traffic counts and thereby estimate current traffic levels, because it is too costly to count all locations every year. Furthermore, the error added to an AADT estimate by applying growth factors is small, as long as the period of growth is fairly small (i.e., less than five years). Growth rates tend to be in the range of 1 to 4 percent per year, with the exception of roads subject to major development. This means that the error in the growth factor is around 2 percent (assuming an error not larger than half the correction), while the error in an AADT estimate based on a single traffic count is around 15 percent.

Recommended Process

As stated earlier, it is recommended that the HPMS volume counts be used to estimate the annual growth factors applied to old volume counts. The growth factors should be determined for the same factor groups as the seasonal adjustment factors (i.e., by functional class and region where necessary).

The recommended HPMS program uses a three-year count cycle. This means that growth factors must be applied to volume estimates on two-thirds of all HPMS segments every year. The three-year cycle also results in three rotating fixed panels for calculating growth rates. Two methods are presented for calculating growth factors:

- a simple average of the growth calculated from the fixed panels; or
- correction of the simple average for the difference between the current three-year average growth and the previous three-year average growth.

EXHIBIT IV-17

CONVERSION OF VEHICLE CLASSIFICATION DATA TO AXLE CORRECTION FACTORS

(1) Vehicle Type	(2) Number of Axles	(3) Percentage of Traffic Obtained From Vehicle Class Counts	(4) Column 2 * Column 3/100
Passenger Cars	2	64.8	1.296
Two Axle, Four Tire Trucks	2	25.0	0.500
Buses	3	0.4	0.012
Two Axle, Six Tire Trucks	2	2.8	0.056
Three Axle Single Unit Trucks	3	0.6	0.018
Four or More Axle Single Units	4	0.2	0.008
Four or Less Axle Single Trailer Trucks	4	0.8	0.032
Five Axle Single Trailer Trucks	5	4.3	0.215
Six or More Axle Single Trailer Trucks	6	0.2	0.012
Five or Less Axle Multi-Trailer Trucks	5	0.4	0.020
Six Axle Multi-Trailer Trucks	6	0.3	0.018
Seven or More Axle Multi-Trailer Trucks	7	0.2	0.014
		Axle Correction Factor is the Sum of Column 4	2.201

The simple average method is the easier of the two growth factors to calculate. It assumes that growth is uniform over the three-year period. This growth factor is the difference between the estimated volume of a stratum for the current year minus the estimated volume for that stratum from three years ago, divided by three. This is expressed mathematically as:

$$GF = \frac{VOL_{h1} - VOL_{h2}}{3} \qquad (32)$$

where:

GF = the calculated growth factor

VOL_{h1} = the average volume for stratum h for the current cycle

VOL_{h2} = the average volume for stratum h for the previous cycle

The correction of the simple average adjusts the simple average to account more heavily for the growth occurring in the last year. This method requires that the estimated three-year growth for each volume stratum be kept for use in calculating the next year's growth factor. The growth factor is calculated by adding a third of the difference between the current three-year growth and the past three-year growth, to the average of the current three-year growth. This is expressed mathematically as:

$$GF = GF_1 + \frac{GF_1 - GF_2}{3} \qquad (33)$$

where:

GF_1 = the growth factor calculated from the counts of the current year

GF_2 = the growth factor calculated from the counts of the previous year

A comparison of these two methods is shown in Exhibit IV-18. It is apparent in this exhibit that the adjusted average yields a better estimate of annual growth. This approach is therefore recommended. The growth factors can be applied as soon as the three-year count cycle is approved, because data already exists on the sample segments due to the existing HPMS program.

LOCAL ROADS

The problem of determining VMT on local roads has been discussed for many years. For this discussion, "local roads" are defined as those roads not included in the HPMS inventory. Despite several well intentioned efforts, an accurate method of defining travel on these roads that is also cost effective has yet to be demonstrated.

EXHIBIT IV-18

COMPARISON OF GROWTH FACTOR CALCULATION TECHNIQUES

Year	Actual Growth	Measured Growth Cycle 1	Cycle 2	Cycle 3	Simple Average	Adjusted Average*	Weighted Average **
1	2.0	-	-	-	-	-	-
2	2.2	-	-	-	-	-	-
3	2.4	6.6	-	-	2.20	-	-
4	2.4	-	7.0	-	2.33	2.46	2.59
5	2.3	-	-	7.1	2.37	2.40	2.45
6	2.0	6.7	-	-	2.23	2.10	1.95
7	1.5	-	5.8	-	1.93	1.63	1.33
8	0.0	-	-	3.5	1.16	0.39	-0.38
9	-2.0	-0.5	-	-	-0.17	-1.51	-2.86
10	-1.0	-	-3.0	-	-1.00	-1.83	-2.64
11	0.5	-	-	-2.5	-0.84	-0.67	-0.52
12	3.0	2.5	-	-	0.82	2.50	4.14

*Adjusted Average = (Current Cycle - Previous Cycle)/3 + (Current Cycle/3)

**Weighted Average = (3 * Current Cycle)/3 - (2 * Previous Cycle)/3

Overview

For the most part, estimates of VMT on local roads are used only for determining total VMT in a state. Few data users have a need for volume or VMT estimates on roads carrying very little traffic, and when users do need data on these roads, their needs are invariably for specific roads or areas. Collecting data to fulfill this kind of site-specific need is not possible while still maintaining an unbiased sample for estimating statewide VMT. As a result, the methodology used to estimate local road VMT does not need to provide data for any purpose but total local road VMT. This has some advantages when alternative methods of estimating this quantity are examined.

Three alternative procedures are presented for estimating local road VMT. Each state will need to tailor its local road estimation procedure to its specific situation, so no one particular method can be deemed appropriate at this time for all states. The three methods discussed in this report are:

- taking cluster samples of local roads within the state, and expanding the results to represent the entire state.

- estimating an average miles per gallon fuel consumption rate for the state's vehicle fleet, and computing total VMT from fuel purchase data. Local road VMT is then calculated by subtracting HPMS VMT from total VMT.

- using a special survey to estimate the percentage of travel on local roads in proportion to travel on non-local roads, then using this factor and the VMT estimate from the HPMS sample to estimate local VMT.

The first two methods are quite common today. Both have significant limitations in terms of accuracy. The cluster sampling approach is also rather expensive. The third method is a new idea, based on use of a ratio estimator, similar to that presented above for estimating vehicle class and truck weight data. This method has not been tested, although indications are that it could be cost effective while also providing fairly good estimates of local road VMT.

Cluster Sampling

This approach uses cluster sampling techiques to estimate average volumes for local roads. Roads within each stratum may or may not be stratified by volume group within the cluster. The resulting average volumes are multiplied by total miles of road within the cluster. The data from the clusters are then expanded to result in estimated local road VMT for the state.

The difficulties with this procedure stem from the enormous population size, and the fact that few, if any, states and urban agencies have good estimates of the total number of miles of local roads, or the traffic volumes these roads carry. These uncertainties invariably lead to sizable variation in the data collected, and to poor estimates of total VMT. The large amount of traffic data that must be collected to provide the estimates of average volumes also constitutes a drawback.

No amount of statistical manipulation can account for the large number of unknowns in the local road population. The only way to determine accurate numbers using this procedure is to collect extremely large sample sizes. Such an approach is normally impractical because of the sheer number of local roads in a state.

This procedure is currently used by several states. It has the advantage of known weaknesses, and it fits well into the traditional traffic counting function of state DOTs. Despite the large errors associated with it, no other program at this time has been shown to provide better data.

The specific procedures for applying this methodology have been discussed heavily in other documents and thus will not be repeated here. If more data on these specifics are needed, the reader is referred to:

- "Sampling Surveys For Estimating Local, Rural, and Urban Vehicle Miles of Travel," by R. Bodle, FHWA, Highway Planning Technical Report #31, July 1973; and
- "Improved Methods For Vehicle Counting and Determining Vehicle Miles of Travel," by John Hamburg & Associates, Inc., NCHRP Report CN-8-20, January 1981.

Fuel Consumption Estimates

Several states have used fuel consumption estimates to calculate VMT. This procedure has one distinct advantage over cluster sampling in that it is less costly. The estimation of average fuel consumption (mpg) for the vehicle fleet often does not entail even a special study. Taxes on vehicle fuels are used to estimate the total gallons of fuel used in the state. The actual calculation of the local road VMT is then a very simple matter. This method, however, is not considered acceptable by FHWA.

The problems with this methodology stem from two sources. One is the estimation of total fuel consumed in the state for transportation purposes, and the other is the estimation of average fuel consumption rates. The first of these problems is much more significant than the second.

Two major errors (among others) occur in the calculation of fuel consumed in the state. Both stem from the use of fuel tax data to estimate total fuel consumption. The first is that some travel is in the state with fuel purchased outside of the state, and some fuel purchased in the state is used outside of the state. This may or may not be significant, depending on the price of fuel in neighboring states, and the amount of internal, external, and through travel occurring in each state. The second problem is that fuel tax data has been shown to underestimate travel in rural areas. This is because some untaxed fuel intended for farm use is used for travel purposes.

On top of these errors is the error in the estimate of average fuel consumption per mile. The error in this term may or may not be large, but the rapidly changing fuel consumption characteristics of the vehicle fleet will more than likely introduce more uncertainty in this estimate than would have existed a decade ago.

Ratio Estimator

This methodology is proposed as an alternative to the conventional methodologies presented above. It has not been tested for accuracy or reliability, but certainly presents the possibility of providing an improved estimate of local road VMT for an acceptable price. The essence of this approach is to survey trip makers to determine actual routings for their trips. These routings would then be used to determine the amount of travel on local roads versus those included in the HPMS inventory. The ratio of local travel to non-local travel computed from these surveys would then be multiplied by the total VMT for the HPMS inventory. This would provide an estimate of local road VMT.

The above estimate would entail two sources of error. The first is the error in the VMT estimate based on the HPMS sample. This is a known quantity. The second is the error in the local road to non-local road ratio. This error is dependent on the variability of the ratio and the sample size of the survey used to estimate that ratio.

It is logical that such a ratio would be fairly stable from year to year. As a result, a special study would not be necessary every year to provide this estimate. Instead, such a study might be performed only every several years to confirm any changes in this ratio. A six-year cycle, twice the recommended HPMS count cycle, is a logical choice for performing this kind of survey.

The survey would have to account for differences in rural and urban street systems that might affect the ratio. In addition, it might also need to account for seasonal differences, or differences due to density of development.

Because this procedure has not been previously tested, it is suggested that a pilot program be instituted by FHWA to test the feasibility of the approach. It seems logical that performing such a survey would be more accurate than either of the previous methods because of the few sources of error, and it would almost certainly be less expensive than a traditional counting approach.

FOOTNOTES

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[1] US DOT, FHWA, Highway Performance Monitoring System Field Manual, 1980, as revised, Appendices F, G, H, I, and K.

[2] Appendix E includes complete definitions of statistical terms and derivations of formulas.

[3] See footnote 2.

[4] See footnote 2.

[5] See footnote 2.

[6] See footnote 2.

[7] See footnote 2.

[8] See footnote 2.

[9] The Maine Facility Laboratory, prepared for FHWA, Evaluation of Vehicle Classification Equipment, September, 1982.

[10] P. Davies and D.R. Salter, "Reliability of Classified Traffic Count Data, Transportation Research Record 905, pp. 17-26, 1983.

V. PROGRAM IMPLEMENTATION

This chapter focuses on the issues involved with the actual implementation of the recommended program. In particular, it details the steps involved in program implementation, and the effects of phasing in the program slowly.

This section is divided into headings detailing the effects of delaying the implementation of particular program elements and procedures. These headings cover:

- seasonal factor procedures;
- changes to the HPMS volume counting schedule;
- axle correction factor procedures;
- growth factor procedures; and
- vehicle class and weight elements.

Seasonal Factor Procedures

If the recommended seasonal factor approach is delayed, the existing state method for applying seasonal factors will have to be maintained. Thus the state may have to continue collecting control counts if those counts are used to compute seasonal factors or to help allocate seasonal factors to particular roadway segments. This in turn will result in a more expensive count program with no significant advantage in accuracy, that is also more difficult to automate.

HPMS Count Scheduling

A delay in implementing the three-year count cycle for HPMS counts has numerous effects. The most significant effect is that the HPMS sections may continue to be counted on an annual basis. This results in a sizable increase in the number of counts that must be taken in a year over that needed by the recommended program, and a consequent increase in program cost.

The added number of counts does have several advantages:

- It maintains the HPMS data at the current levels of precision, rather than lowering the precision slightly.
- It eliminates the need to modify HPMS counts for growth, although it does not reduce the need for growth factors in other traffic counts.

- It modifies the procedure needed to compute annual growth factors, as it allows the annual growth to be computed directly from changes in the estimated annual volume for each HPMS stratum.

It does not have an effect on either the need for seasonal or axle correction factors.

Axle Correction Factors

This factor adjustment cannot be disregarded. If some axle correction factor is not used, the estimated volumes for those road segments counted with single-tube axle counters will be overstated. The state may continue using an axle correction factor based on some method other than the recommended process, but the accuracy of that estimate will probably be less than that of the recommended factors.

Growth Factors

Growth factors can be calculated from several sources other than the HPMS sample segments. The most common of these methods is using control counts and ATR counts to estimate growth. This method may be used while the HPMS growth factor method is being implemented, but the accuracy of the growth factors is certain to be below that of the recommended procedure because of the reduced number of counts used in the factor calculation. The use of control counts would also result in the need for an additional set of counts.

Vehicle Class and Weight Element

These program subelements may be delayed due to lack of modern classification and weighing equipment. If these program elements are delayed, the state will probably not have a statistically valid estimate of traffic composition or truck weights for the majority of roads in its highway network. The state would therefore need to continue using their existing procedures to estimate traffic composition and truck weights.

None of the states examined in this project had a statistically valid method for estimating either vehicle classification or truck weights. To achieve a statistically valid estimate for either of these quantities, a special data collection session would have to be conducted at the location of interest each time an estimate was needed. This is expensive for vehicle classification data, and unreasonable for truck weight data. Therefore, in many instances, statistically unreliable estimates may be used out of necessity.

APPENDIX A

DEFAULT VALUES FOR STATISTICAL EQUATIONS

APPENDIX A--DEFAULT VALUES FOR STATISTICAL EQUATIONS

This appendix presents the values used in the statistical equations presented in the main body of this report. These values may be used for calculating sample sizes and for determining the precision of various traffic estimates.

The values for this appendix were derived from three principal sources:

- ATR data provided by the five participating states and maintained by the FHWA;
- vehicle classification data from the HPMS vehicle classification case study; and
- truck weight data from the HPMS truck weight case study.

It is acknowledged that these data bases are not statistically valid. They were, however, the best available data. As a result, states are encouraged to provide their own data whenever possible in lieu of this data base. In particular, they are encouraged to develop their own statistically valid data base using this study as a guide. Data collected in the recommended manner can then be used to update the sample sizes derived using these tables.

This appendix is divided into two basic sections:

- vehicle classification and weight data; and
- traffic volume data.

The vehicle classification and weight data are presented in Exhibit A-1. This table shows means and standard deviations for the percentage of traffic (PVC and SPVC) and equivalent axle loads (EAL and SEAL) for each of the recommended functional classifications of roads. These data are used to compute precision versus sample size (number of monitoring sessions) graphs for each of these classifications (Exhibits A-2 through A-17). Precision is defined as the accuracy of an estimate within a stated level of confidence. In this appendix, a 95 percent confidence interval is always used. The graphs were computed using equation 20 from section IV of this report.

To use the graphs in Exhibits A-2 through A-17 the user must first choose the graph for the appropriate functional classification of road. The next step is to choose the method

EXHIBIT A-1

VEHICLE CLASSIFICATION AND WEIGHT DATA

	RURAL				URBAN			
	Interstates	Other Principal Arterials	Minor Arterials	Collectors	Interstates & Other Freeways & Expressways	Other Principal Arterials	Minor Arterials	Collectors
Standard Autos								
PVC	41.55	45.67	42.33	41.57	48.94	54.57	56.50	51.69
SPVC	7.40	10.57	8.31	7.82	10.56	14.84	14.52	16.95
EAL**	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
SEAL**	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Small Automobiles								
PVC	18.33	15.41	18.45	13.42	22.07	19.14	18.72	19.22
SPVC	7.85	6.73	7.14	6.72	6.16	6.96	6.25	7.03
EAL**	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
SEAL**	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
2 Axle, 4 Tire Trucks								
PVC	18.26	25.02	29.27	31.78	17.24	19.61	19.69	23.20
SPVC	5.04	5.50	4.10	3.72	5.27	7.33	7.94	9.37
EAL*	0.0012	0.0022	0.0023	0.0023	0.0085	0.0012	0.0016	0.0016
SEAL	0.0011	0.0008	0.0011	0.0014	0.0062	0.0010	0.0010	0.0010
2 Axle, 6 Tire Trucks								
PVC	2.51	2.86	2.64	3.56	2.12	2.14	1.69	2.17
SPVC	0.81	2.07	1.43	2.17	1.08	1.30	1.15	2.60
EAL*	0.112	0.138	0.136	0.136	0.117	0.119	0.104	0.104
SEAL	0.069	0.085	0.084	0.122	0.077	0.102	0.067	0.032
3 Axle Single Unit Trucks								
PVC	0.58	0.73	1.18	1.52	0.59	0.48	0.43	0.59
SPVC	0.39	1.02	2.51	2.61	0.63	0.47	0.59	1.11
EAL*	0.463	0.426	0.397	0.397	0.438	0.465	0.584	0.584
SEAL	0.416	0.377	0.325	0.285	0.292	0.401	0.622	0.191
Buses								
PVC	0.33	0.37	0.42	0.73	0.31	0.25	0.45	0.38
SPVC	0.12	0.43	0.52	1.14	0.28	0.23	0.71	0.41
EAL*	0.408	0.435	0.154	0.154	0.416	0.137	0.344	0.344
SEAL	0.171	0.233	0.083	0.083	0.343	0.114	0.182	0.246

**Assumed Value

*EAL For Flexible Pavement

EXHIBIT A-1 (CONTINUED)

VEHICLE CLASSIFICATION AND WEIGHT DATA

	RURAL				URBAN			
	Interstates	Other Principal Arterials	Minor Arterials	Collectors	Interstates & Other Freeways & Expressways	Other Principal Arterials	Minor Arterials	Collectors
3 Axle Combinations								
PVC	0.56	0.72	0.29	0.60	0.32	0.27	0.11	0.19
SPVC	0.59	1.09	0.60	1.18	0.34	0.28	0.16	0.43
EAL*	0.445	0.407	0.288	0.422	0.351	0.338	0.206	0.206
SEAL	0.114	0.124	0.101	0.256	0.083	0.100	0.083	0.083
2S2 Trucks								
PVC	0.76	0.49	0.21	0.31	0.56	0.24	0.12	0.27
SPVC	0.90	0.79	0.38	0.46	0.71	0.32	0.19	0.47
EAL*	0.662	0.661	0.426	0.426	0.691	1.092	0.398	0.398
SEAL	0.283	0.493	0.473	0.246	0.421	0.986	0.442	0.442
Other 4 Axle Trucks								
PVC	0.49	0.37	0.30	0.65	0.15	0.11	0.06	0.17
SPVC	0.66	0.60	0.56	0.68	0.24	0.22	0.08	0.34
EAL*	0.198	0.234	0.087	0.087	0.167	0.199	0.167	0.167
SEAL	0.228	0.350	0.088	0.088	0.225	0.481	0.268	0.268
3S2 Trucks								
PVC	14.85	7.01	3.71	4.50	6.52	2.24	1.12	1.09
SPVC	12.58	7.50	4.01	6.21	6.72	2.71	1.27	1.84
EAL*	0.981	0.874	0.917	0.917	0.919	1.259	0.630	0.630
SEAL	0.241	0.360	0.470	0.359	0.324	0.461	0.544	0.544
Other 5 Axle Trucks								
PVC	0.91	0.29	0.30	0.29	0.46	0.19	0.15	0.11
SPVC	0.90	0.44	0.45	0.42	0.67	0.20	0.24	0.33
EAL*	2.359	2.060	2.096	2.096	2.117	1.396	0.900	0.900
SEAL	1.479	1.916	1.734	1.734	0.876	1.467	0.855	0.855
6 or More Axle Trucks								
PVC	0.33	0.12	0.23	0.17	0.16	0.08	0.05	0.02
SPVC	0.40	0.21	0.33	0.27	0.19	0.11	0.08	0.07
EAL*	1.634	1.118	1.338	1.338	1.588	1.649	0.428	0.428
SEAL	1.114	1.257	1.312	1.136	0.850	1.468	0.431	0.480

**Assumed Value

*EAL For Flexible Pavement

EXHIBIT A-2

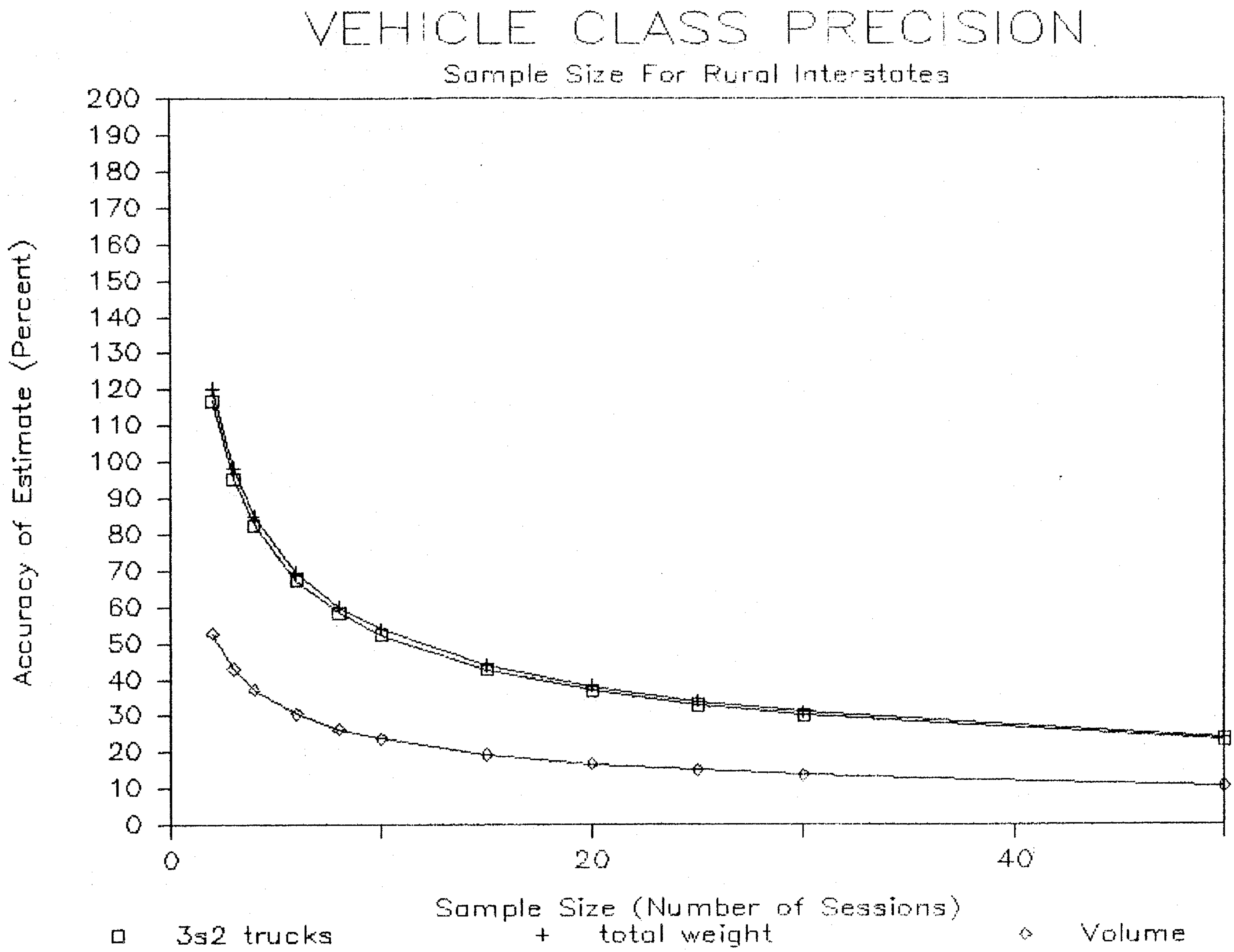

VEHICLE CLASS PRECISION
Sample Size For Rural Interstates
Accuracy of Estimate (Percent)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-3

VEHICLE CLASS PRECISION

Rural Principal Arterial Sample Size

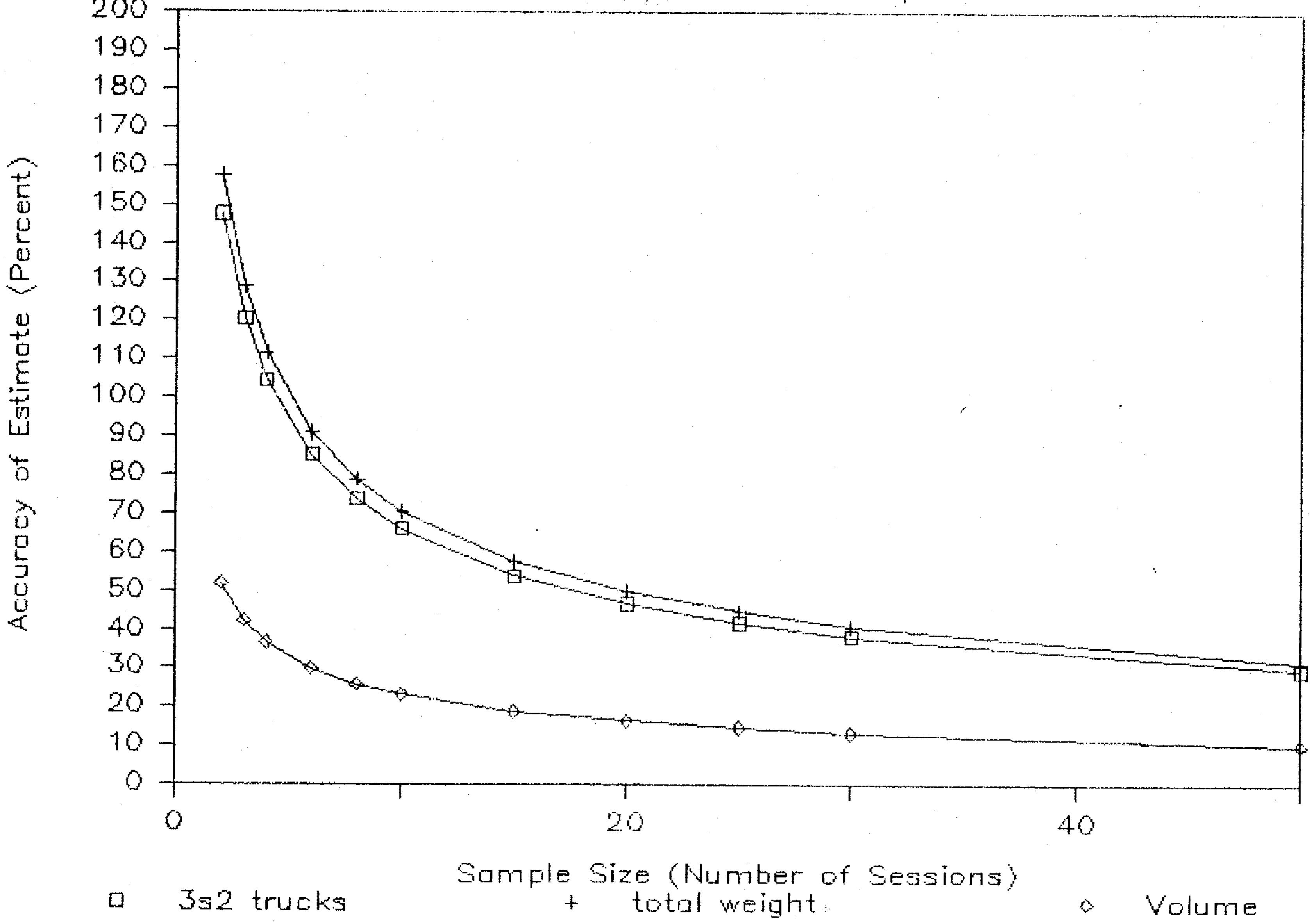


EXHIBIT A-4

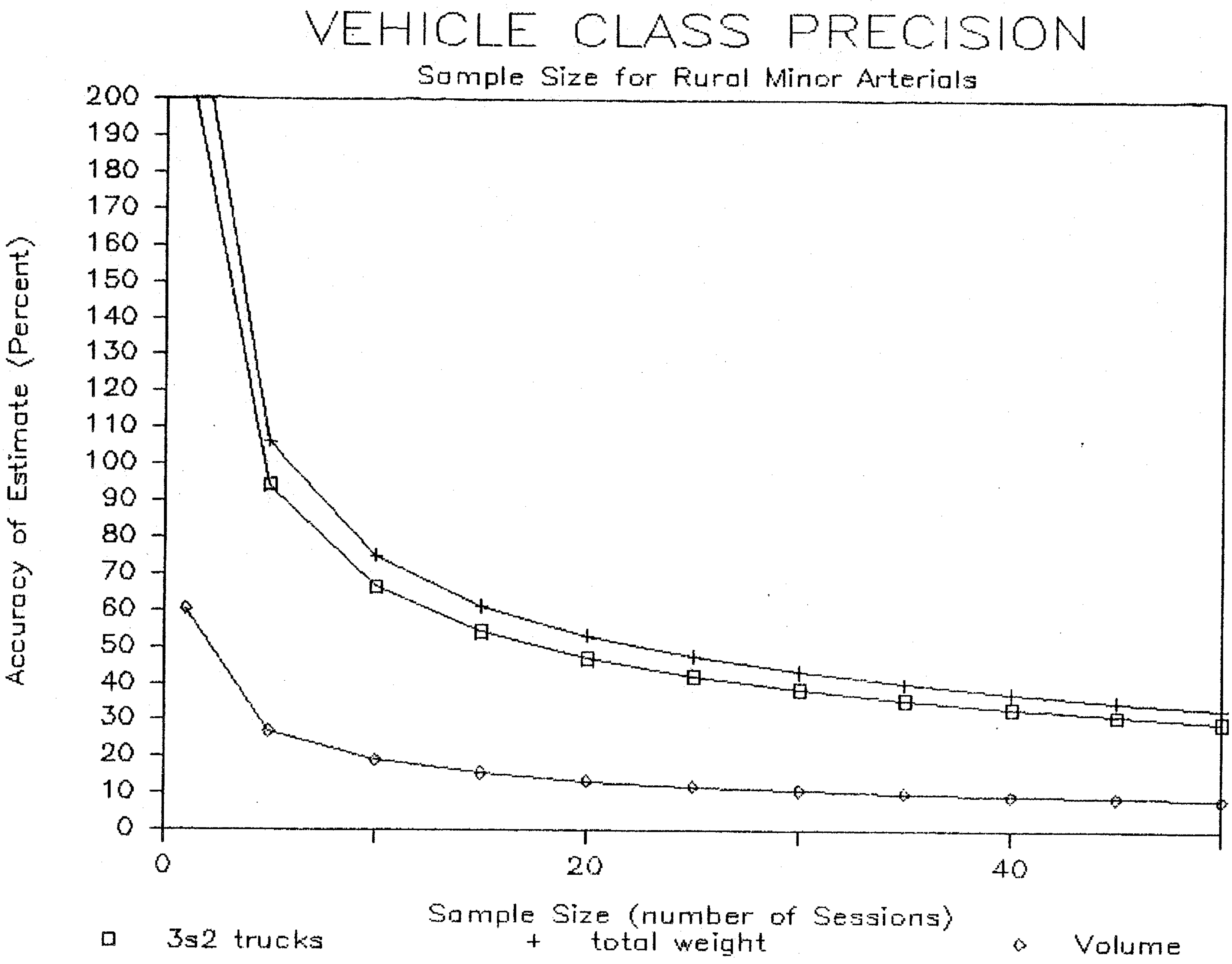
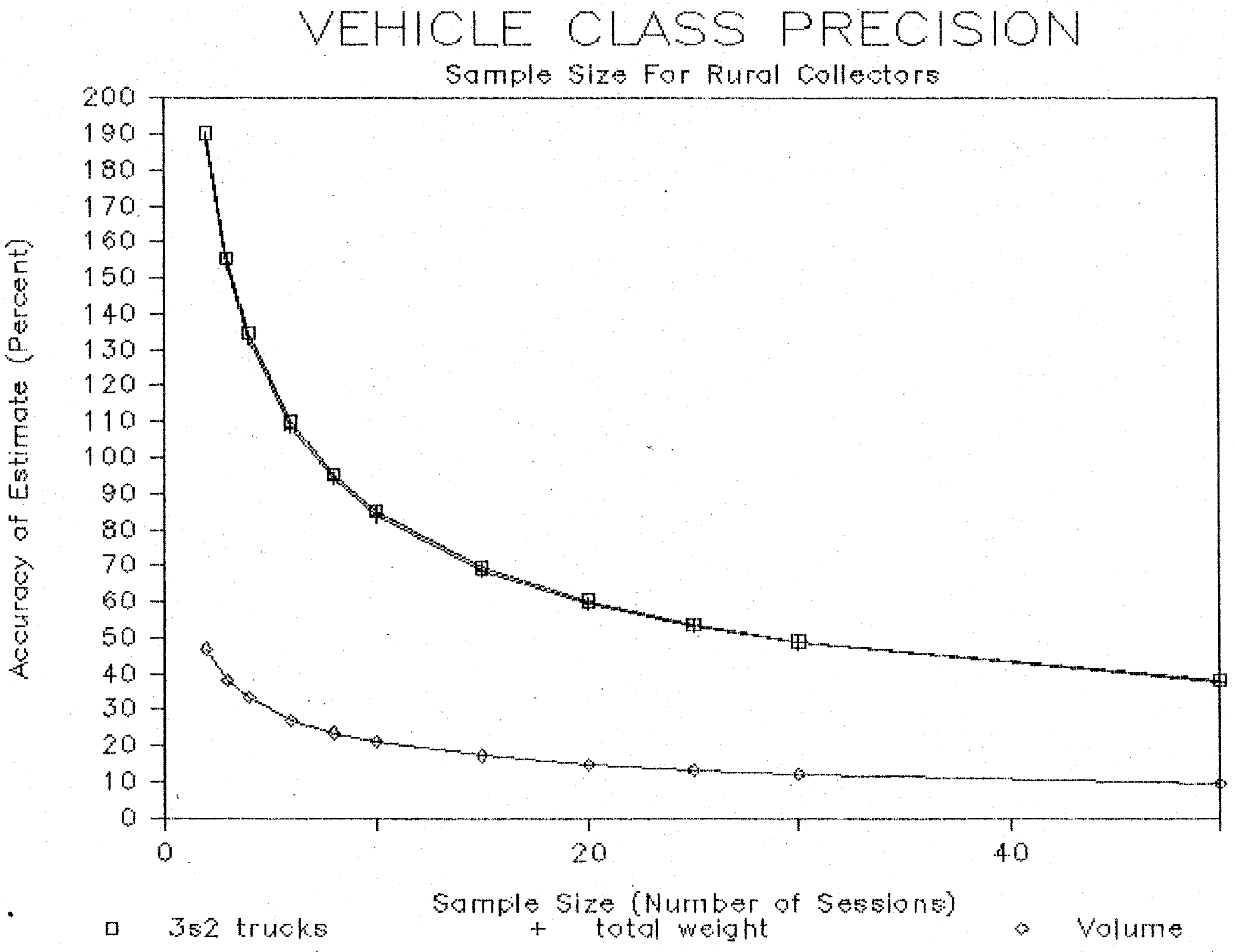

VEHICLE CLASS PRECISION
Sample Size for Rural Minor Arterials
Accuracy of Estimate (Percent)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-5



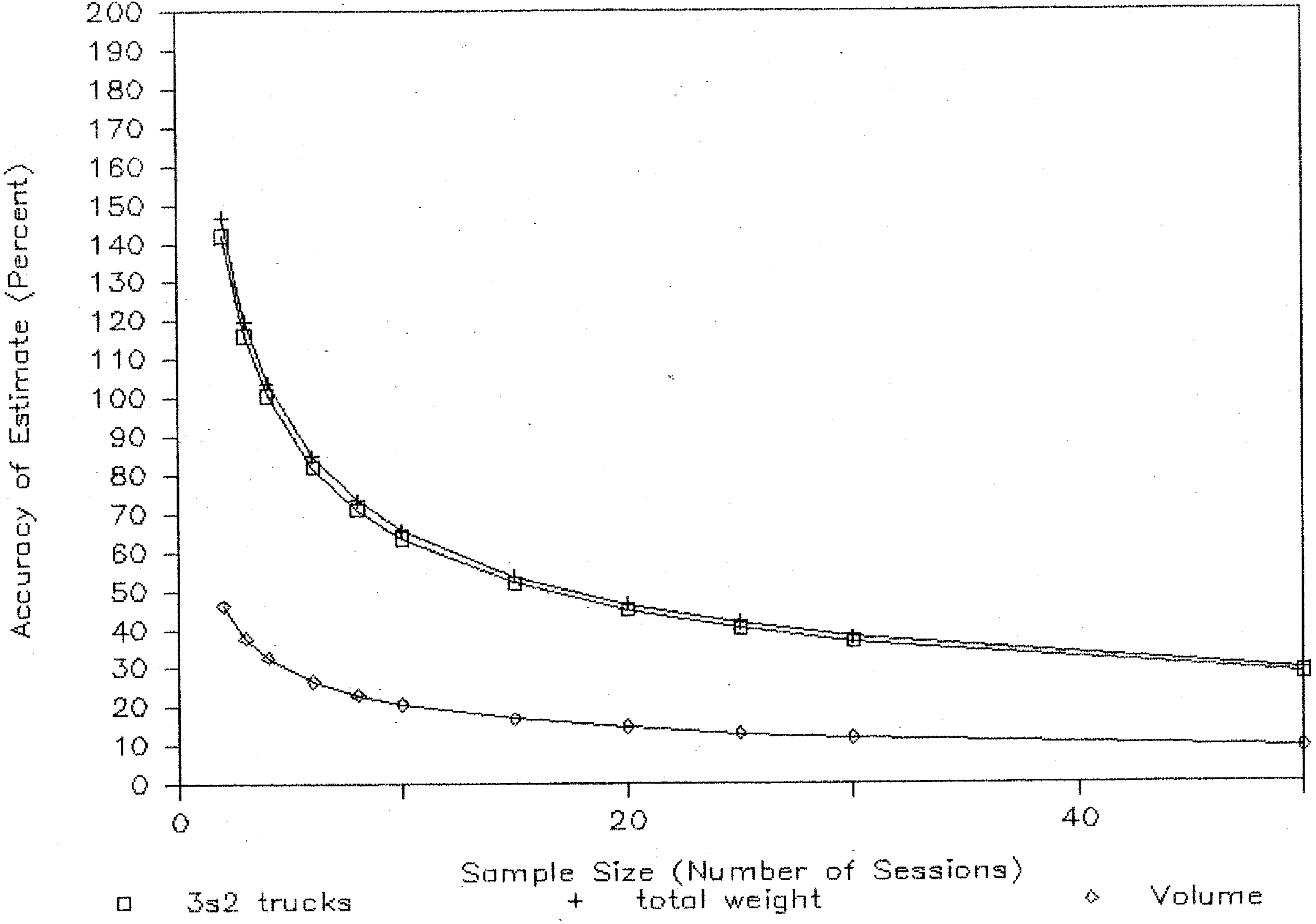
VEHICLE CLASS PRECISION

Sample Size For Rural Collectors

EXHIBIT A-6

VEHICLE CLASS PRECISION

Sample Size For Urban Interstates*



* and other urban freeways

EXHIBIT A-7

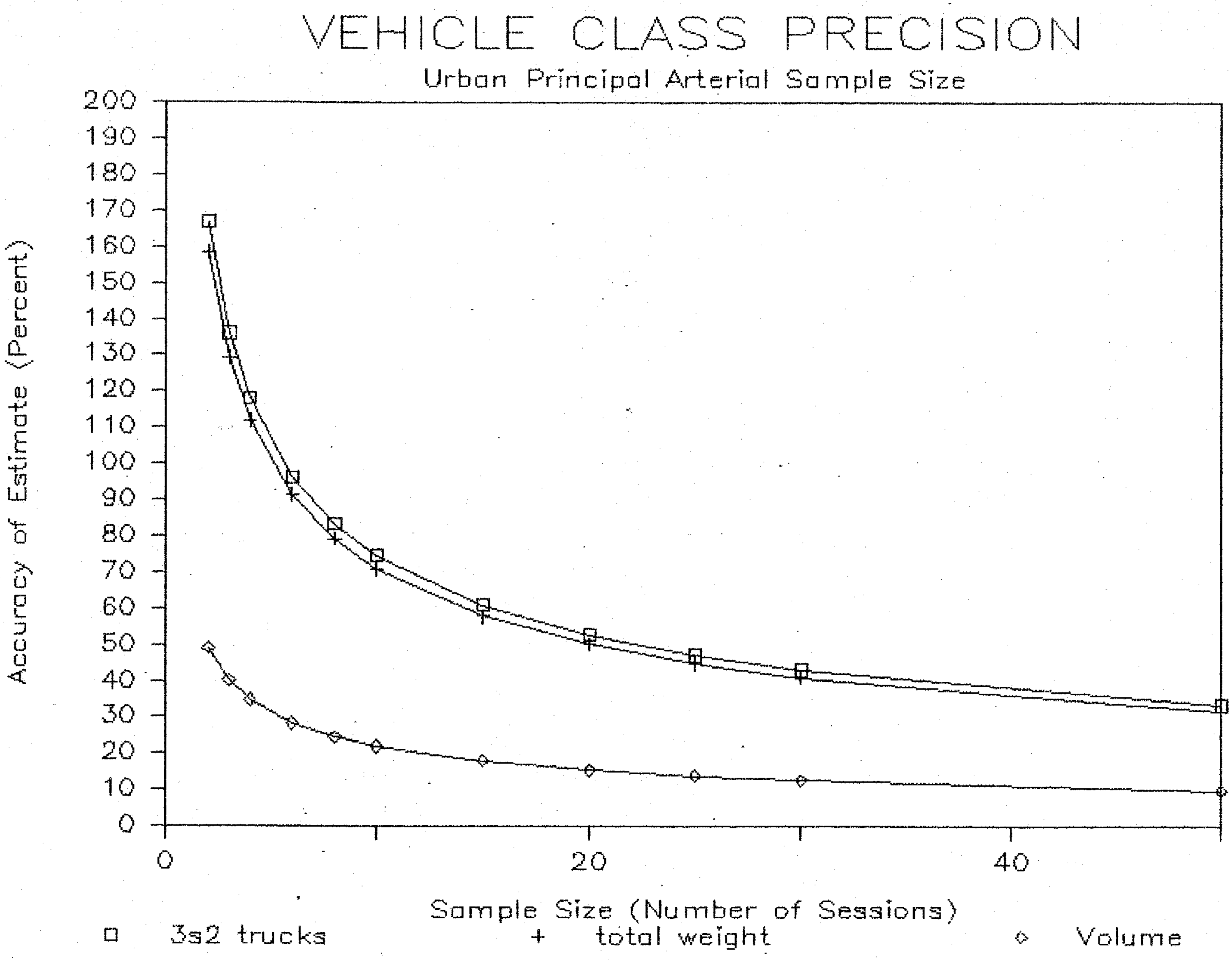

VEHICLE CLASS PRECISION
Urban Principal Arterial Sample Size
Accuracy of Estimate (Percent)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-8

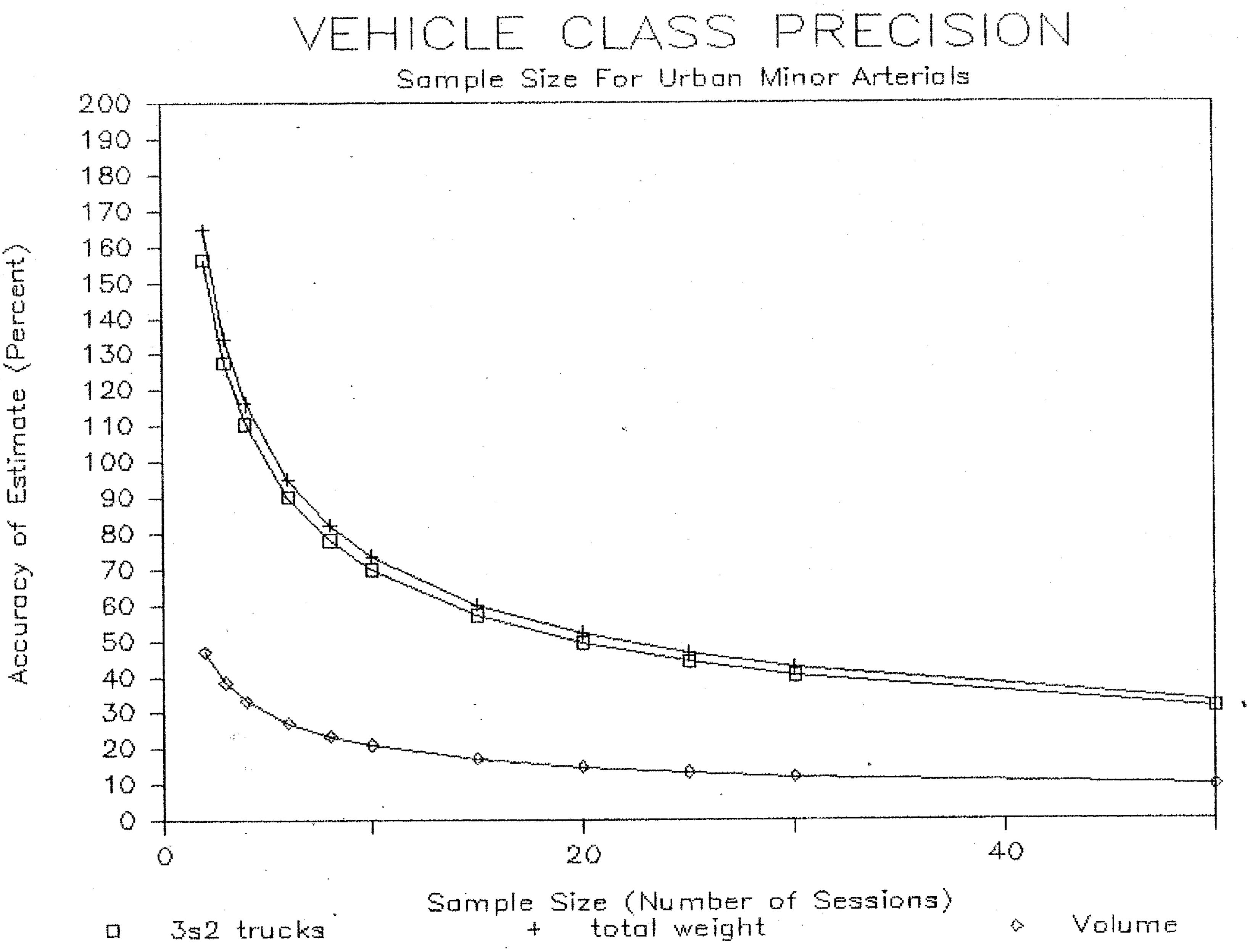

VEHICLE CLASS PRECISION
Sample Size For Urban Minor Arterials
Accuracy of Estimate (Percent)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-9

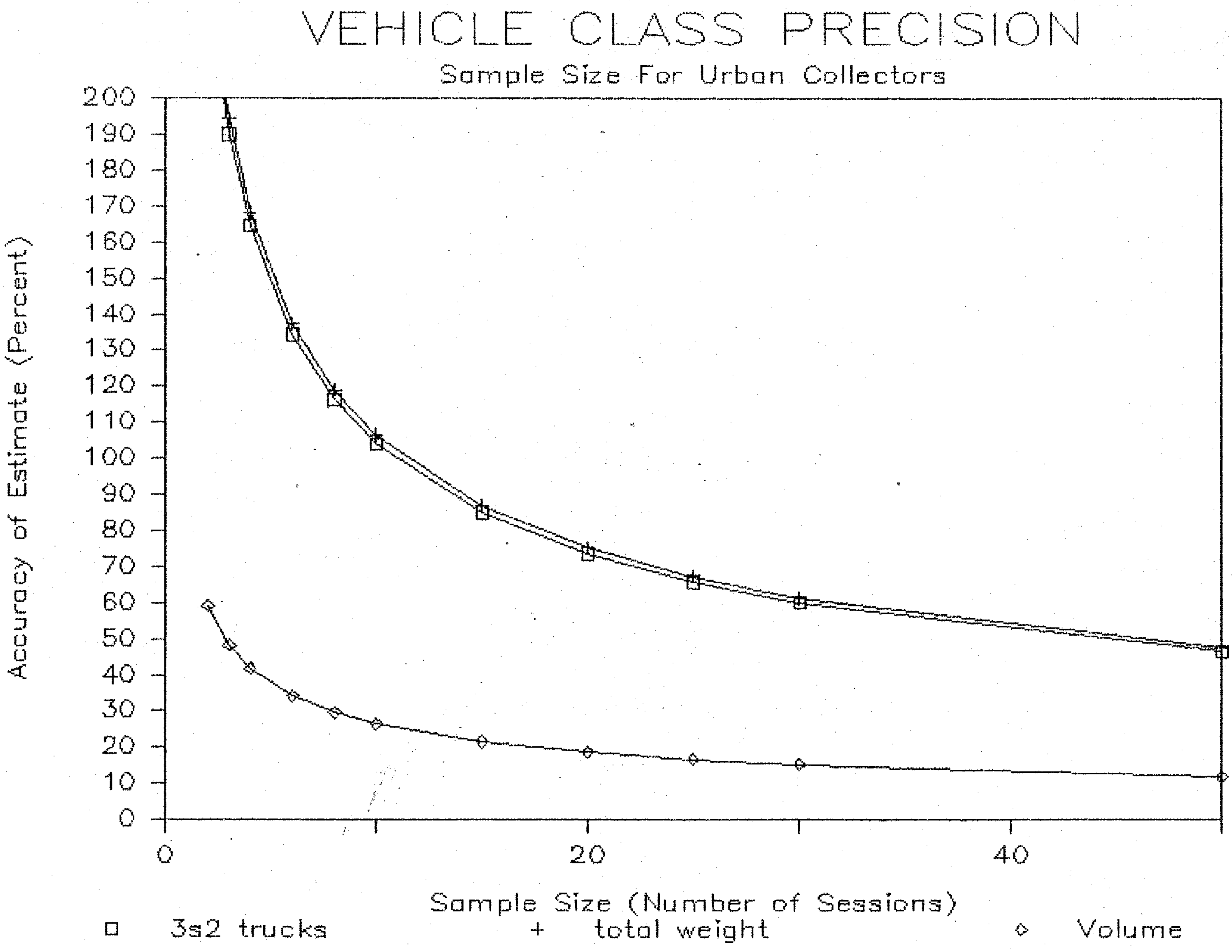

VEHICLE CLASS PRECISION
Sample Size For Urban Collectors
Accuracy of Estimate (Percent)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-10

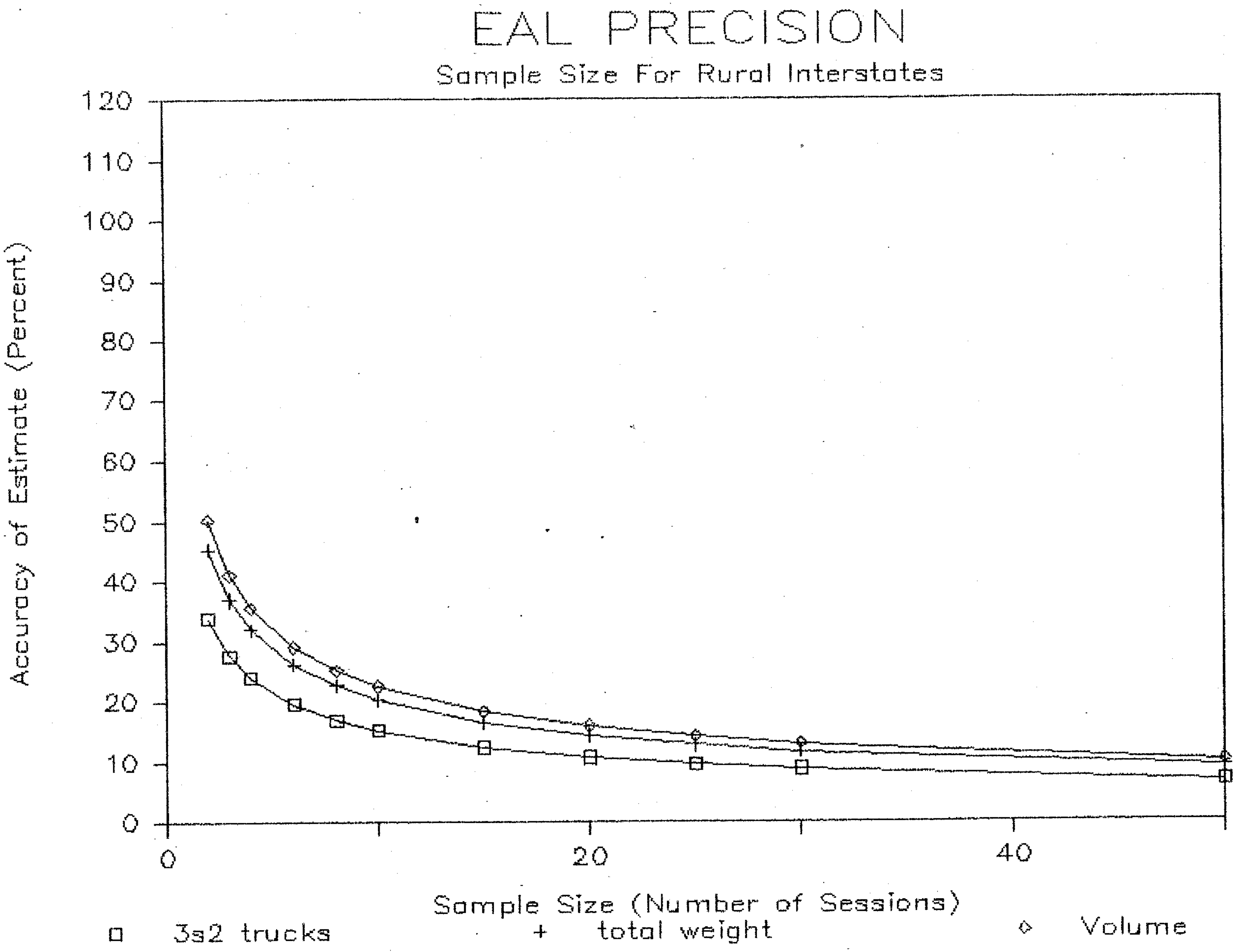

EAL PRECISION
Sample Size For Rural Interstates
Accuracy of Estimate (Percent)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-11

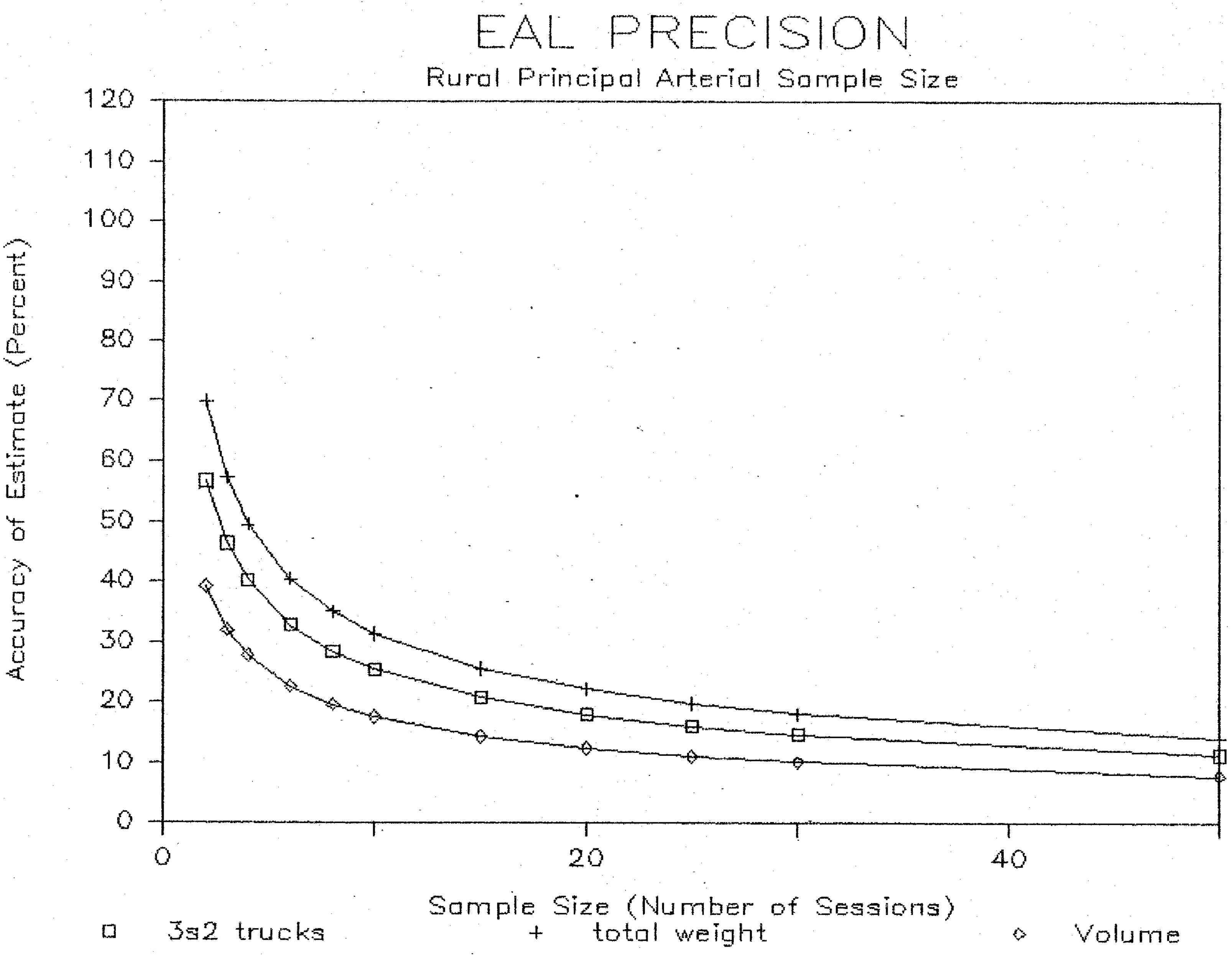

EAL PRECISION
Rural Principal Arterial Sample Size
Accuracy of Estimate (Percent)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-12

EAL PRECISION

Sample Size For Rural Minor Arterials

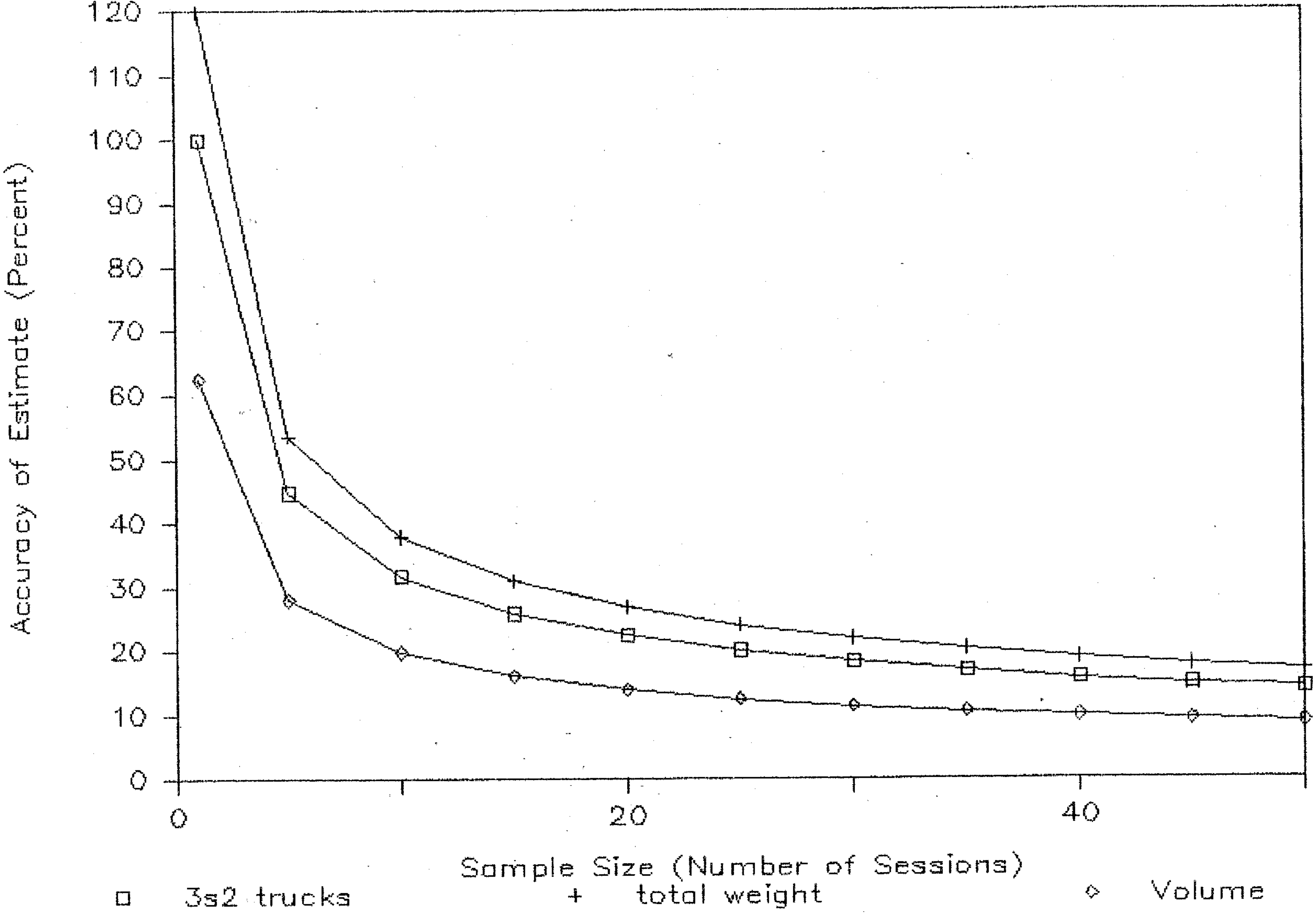


EXHIBIT A-13

EAL PRECISION

Sample Size For Rural Collectors

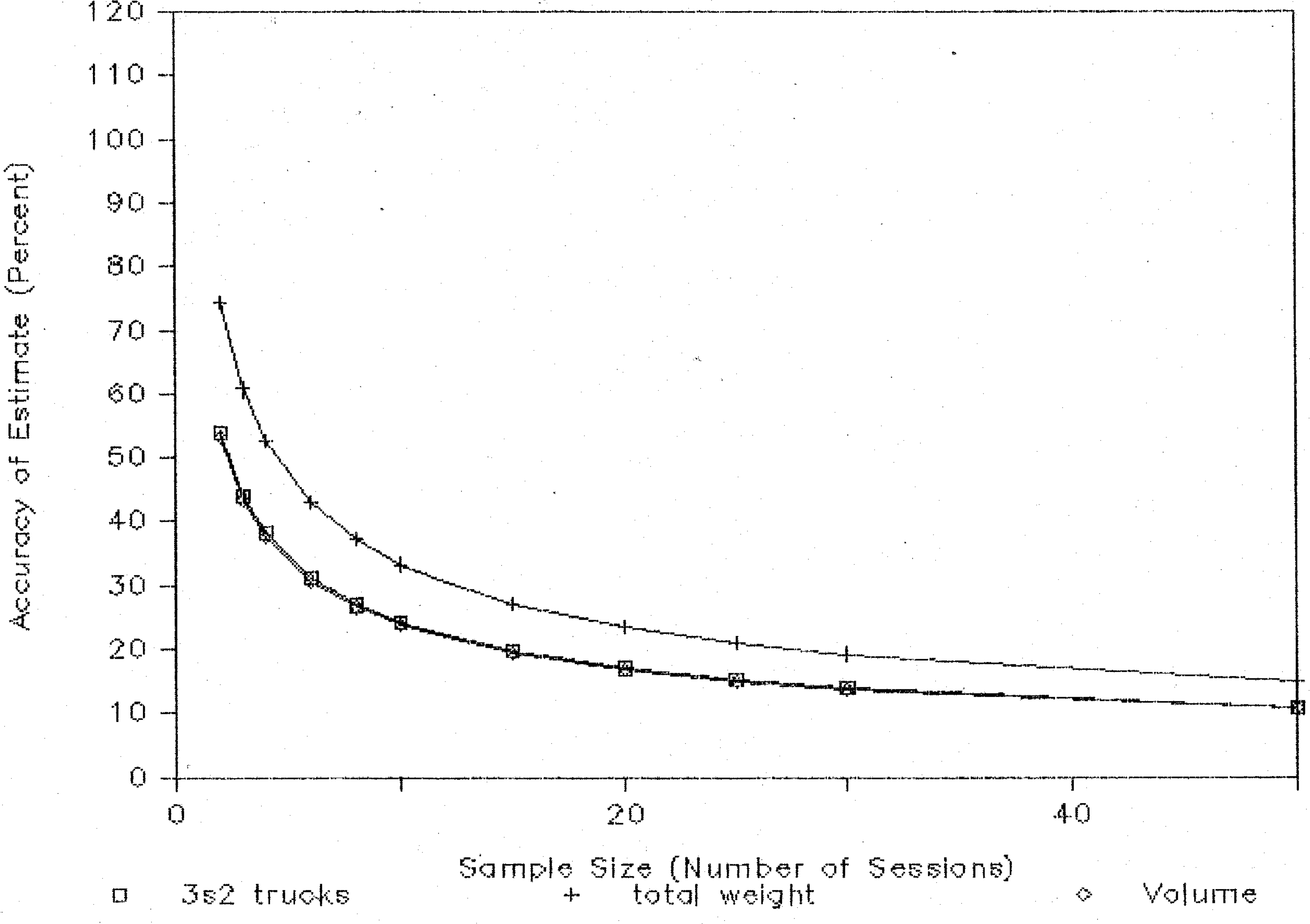
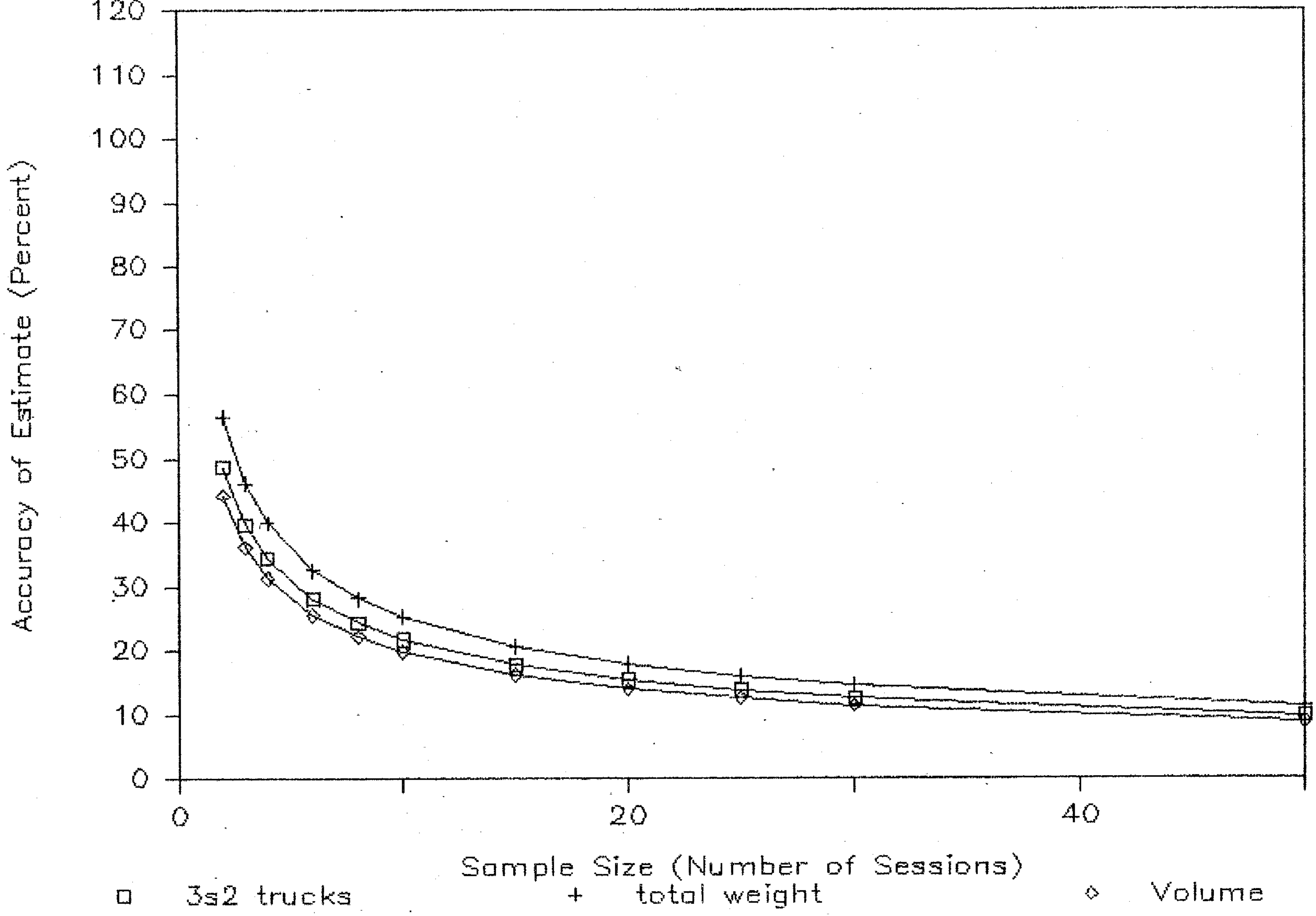


EXHIBIT A-14

EAL PRECISION

Sample Size For Urban Interstates*



* and other urban freeways

EXHIBIT A-15

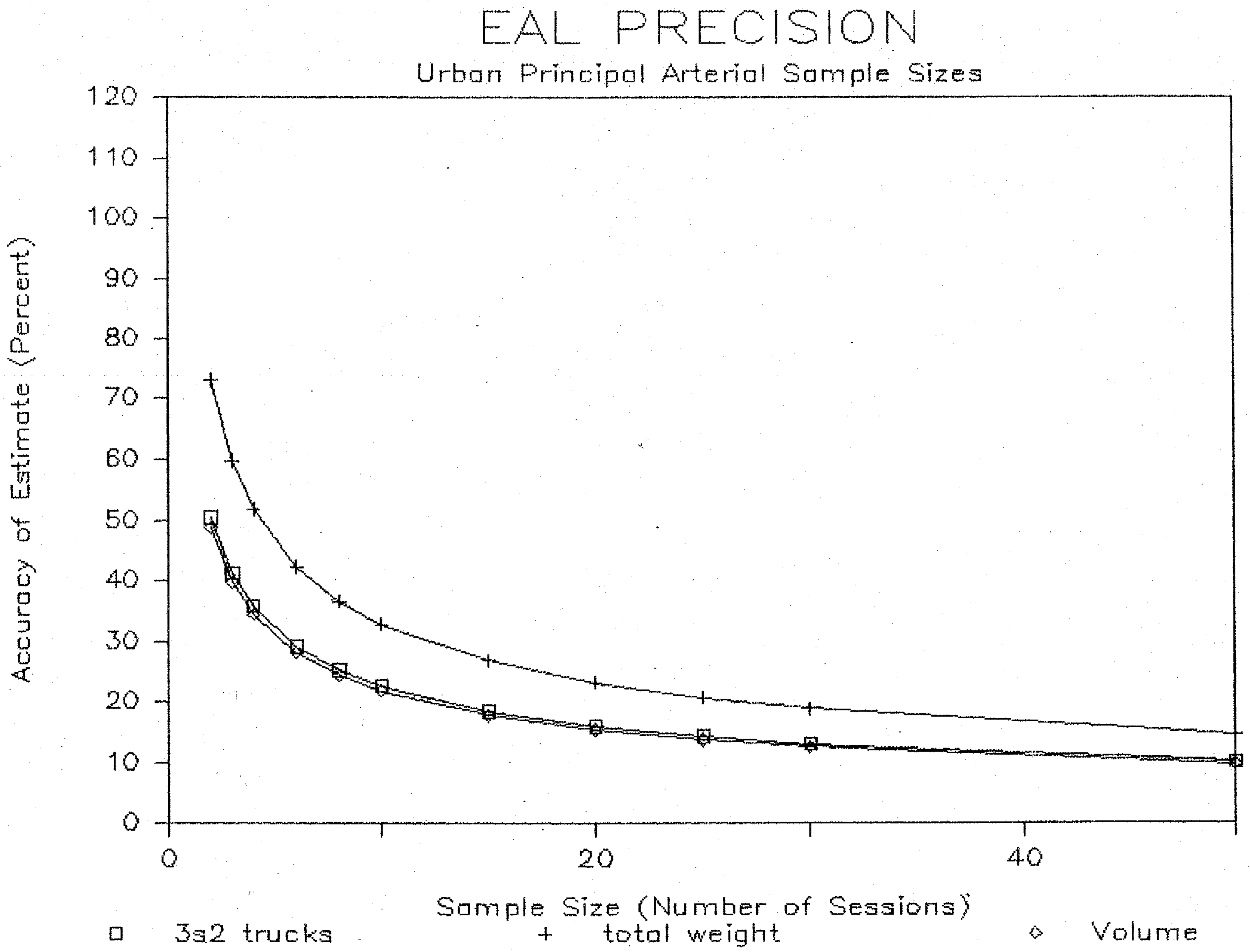

EAL PRECISION
Urban Principal Arterial Sample Sizes
Accuracy of Estimate (Percent)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-16

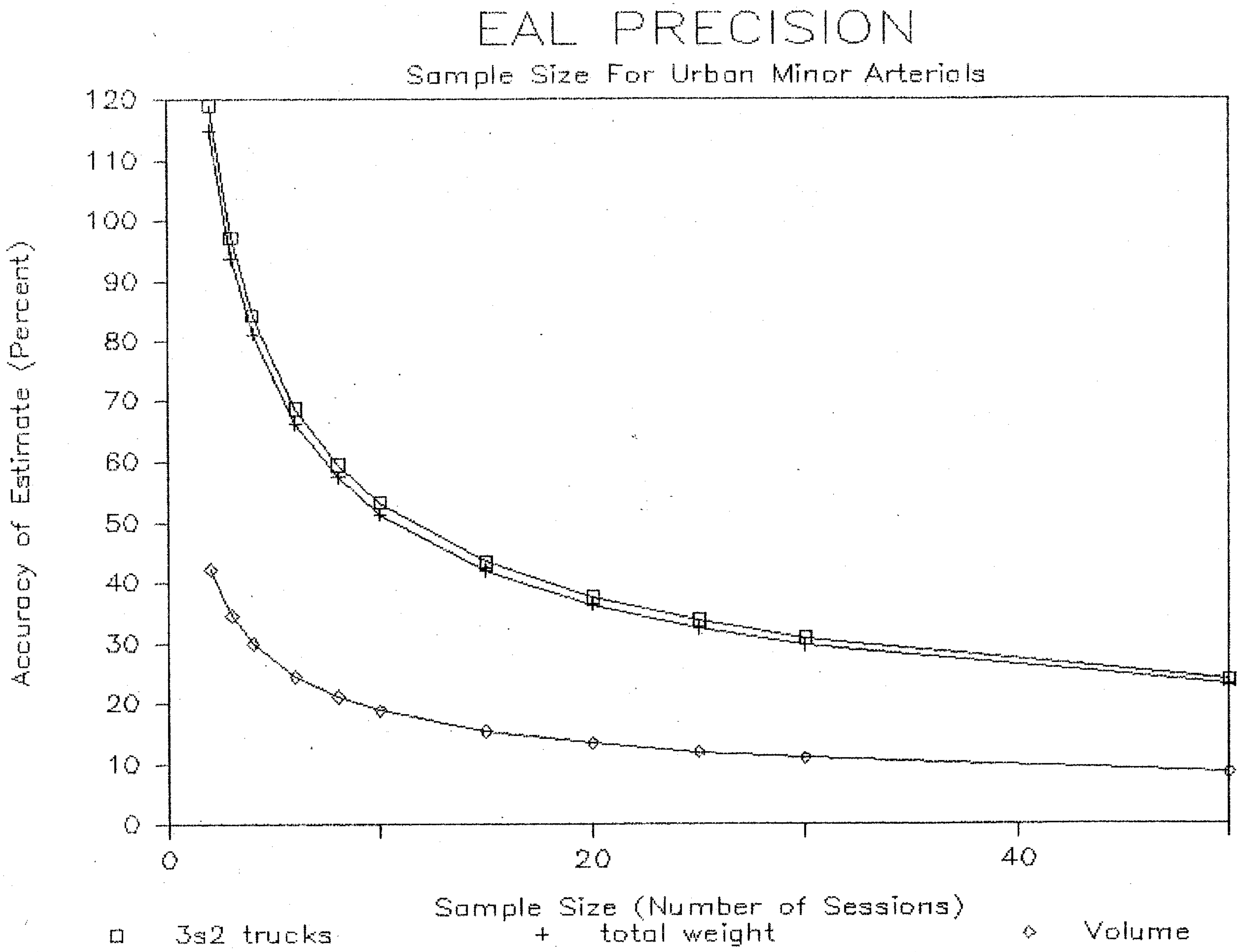
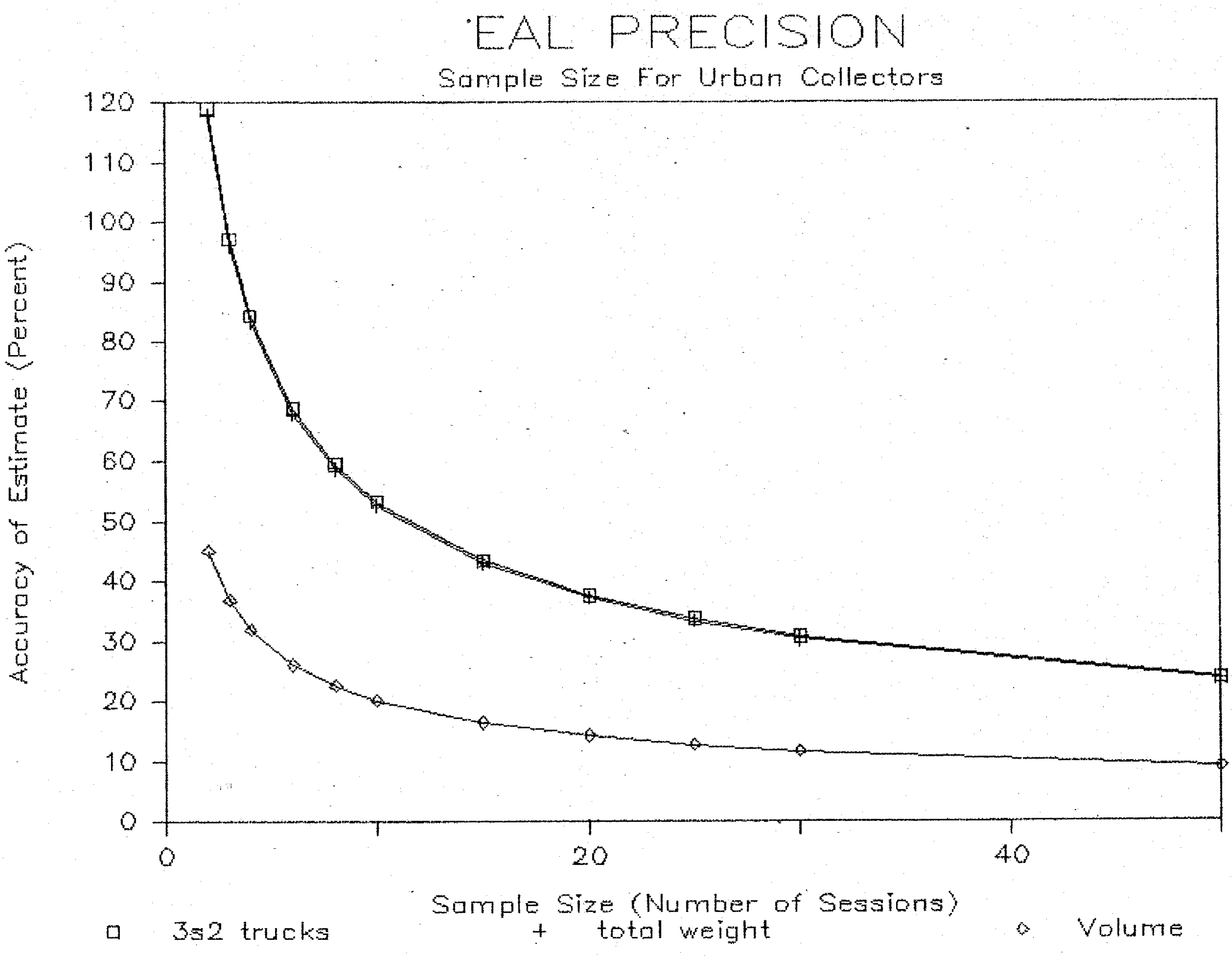

EAL PRECISION
Sample Size For Urban Minor Arterials
Accuracy of Estimate (Percent)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

EXHIBIT A-17


EAL PRECISION
Sample Size For Urban Collectors
Accuracy of Estimate (Percent)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
Sample Size (Number of Sessions)
□ 3s2 trucks
+ total weight
◇ Volume

for selecting sample size. Each graph includes a curve for three different precision versus sample size relationships, or weightings of coefficients of variation (see page IV.34). These curves represent the precision of:

- 3S2 truck estimates;
- all vehicles weighted by volume of traffic;
- all vehicles weighted by total weight contributed by each vehicle class.

The different curves show how different weightings affect the "accuracy" of estimates. The most important fact to remember is that five samples (or any other number) will result in the same level of precision for a single classification of vehicles, no matter which curve is used to select sample size. The three curves only differ in how the estimates for all individual vehicle types are weighted when they are combined.

Once a curve has been selected the accuracy for a given number of counts can be determined. For example, using Exhibit A-2, a sample size of 20 locations is chosen. This sample will result in an estimate of vehicle classifications that is accurate to within 17 percent, if the accuracy of the estimates of each vehicle class are weighted by the volume of that class. The accuracy of the estimate of 3S2 trucks is slightly worse than the composite. Twenty monitoring sessions produce an estimate within roughly 37 percent for this vehicle type.

The accuracy of other vehicle types can be calculated using equation 20 and the default values for percentage of traffic and standard deviation of that estimate for a vehicle class from Exhibit A-1. For standard automobiles, this estimate would be computed as:

$$d^2 = \frac{1.95^2 * SPVC^2 / PVC^2}{20} = \frac{3.8025 * 0.0317}{20}$$

The accuracy d is therefore equal to .077 or 7.7 percent of the vehicle classification estimate produced by the 20 counts (i.e., the estimate is 41.6 percent plus or minus 3.2 percent.)

Truck weight (EAL) estimates are performed in exactly the same manner. One of the curves in the graphs in Exhibits A-10 through A-17 is used to estimate a composite accuracy for a given sample size. The accuracy of an estimate for any specific vehicle type must then be computed using equation 20, the sample size selected, and EAL and SEAL estimates included in Exhibit A-1 for computing the COV term (i.e., substitute SEAL for SPVC and EAL for PVC in the equation above).

For volume estimations, average standard deviations for SVOLD (variation across days, expressed as a fraction of AADT) and SVOLA (the variation in the "true" axle correction factor) are provided in Exhibit A-18. The standard deviation across locations, SVOLL, can be estimated from the equation:

$$SVOLL_h = \frac{\text{Volume range in stratum h + 1000}}{3.5}$$

For example, SVOLL for a road within a stratum with a volume range between 5,000 and 10,000 ADT would be computed as:

$$SVOLL_h = \frac{(10,000 - 5,000) + 1000}{3.5}$$

$$SVOLL_h = 1,714.$$

This would then be expressed in terms of percent AADT.

It is assumed that each state will determine the standard deviation of the seasonal correction factor (SVOLS) for each factor group as a by-product of the determination of the appropriate factor groups.

EXHIBIT A-18

STATISTICAL DEFAULTS FOR TRAFFIC VOLUMES

Functional Classification	SVOLD*	SVOLA**
Rural:		
Interstate	0.117	0.140
Other Principal Arterials	0.090	0.094
Minor Arterials	0.098	0.067
Collectors	0.095	0.059
Urban:		
Interstate and other Freeways	0.078	0.067
Other Principal Arterials	0.069	0.058
Minor Arterials	0.065	0.021
Collectors	0.065	0.021

* Expressed as a fraction of AADT.
** Expressed as a fraction of the axle correction factor.

APPENDIX B

EQUIPMENT CAPABILITIES

APPENDIX B--EQUIPMENT SUMMARY

This appendix details the results of Peat Marwick's examination of existing vehicle classification and truck weighing equipment. This section is a summarization of:

- published research;
- other literature available from FHWA or from Peat Marwick's project library;
- manufacturer's specifications and test data; and
- comments from state DOT personnel who use traffic counting equipment.

No new research was performed for this contract in this area. Only equipment with working models currently available for sale or test are included in this review. Other equipment with enhanced capabilities which may soon be available is not discussed here.

This appendix is divided into two major sections:

- vehicle classification equipment; and
- truck weighing equipment.

Most truck weighing equipment currently being designed can also collect vehicle classification data, but such devices are generally too expensive to be used strictly for vehicle classification data collection. For this reason, such equipment is discussed in the truck weighing portion of the appendix.

VEHICLE CLASSIFICATION EQUIPMENT

As stated in the main body of this report, different states use different vehicle classification systems. Suggested classification schemes use as few as ten or as many as 32 vehicle classes. The FHWA has recently issued a nationwide standard for vehicle classification categories. This classification system is presented in Exhibit B-1.

Overview

The proposed national system follows the standard system of delineating vehicle classes based on the number of axles on a vehicle and the spacing of those axles on the vehicle. The principal difference between this system and many state systems is that no division is made between in-state and out-of-state

EXHIBIT B-1

FHWA-RECOMMENDED VEHICLE CLASSIFICATION

Vehicle Categories	Vehicle Description
1	Motorcycles (Optional)
2	Passenger cars
3	Other two-axle, four-tire single unit vehicles
4	Buses
5	Two-axle, six-tire single unit trucks
6	Three-axle single unit trucks
7	Four or more axle single unit trucks
8	Four or fewer axle single trailer trucks
9	Five-axle single trailer trucks
10	Six or more axle single trailer trucks
11	Five or fewer axle multi-trailer trucks
12	Six-axle multi-trailer trucks
13	Seven or more axle multi-trailer trucks

Source: FHWA, Memorandum on Vehicle Classifications: Alternative Schedule and a Recommended Grouping, June 1983, as revised on October 1, 1983.

vehicles. From a federal perspective or a design perspective, this detail is not necessary. Furthermore, automated classification counters are not capable of making this distinction. If a state wants this data, it can be collected by manual classification counts (and used to factor automated counts), or through a special survey.

Automatic classification of traffic using the FHWA's proposed system requires a traffic counter that uses some kind of axle sensor. The most common of these sensors is the pneumatic, or road, tube. Some experiments have used other devices such as coaxial cables as axle sensors, but these devices are not currently in common use in the United States.

A second kind of automatic counter can also classify vehicles. These counting devices use inductance loops which classify vehicles based on their overall body length. These counters are capable of using loops already embedded in the pavement for other purposes as sensing devices. The counters cannot, however, classify vehicles using the FHWA system, because they cannot distinguish axles.

Axle-Sensing Classifiers

From the discussion with the participating states, it is apparent that the axle-sensing classifiers are the type of equipment most acceptable to state DOTs, because they can classify vehicles in a manner similar to the manual counts currently taken. At this time, however, no type of automated vehicle classification equipment is widely used, mostly because early models were not reliable. For the most part, early problems are being worked out, although most available machines still suffer from two shortcomings:

- the inability to classify vehicles in slow moving (congested) traffic; and
- the ability to classify only one lane of traffic. This could be either the right hand lane, closest to the shoulder, or the left-hand lane, providing the counter is placed in the median strip of a road.

Each available axle-sensing classification counter:

- determines the axle spacing of passing vehicles as a function of speed;
- uses a minimum speed programmed into its software as a fail-safe signal for the end of one vehicle and the beginning of another; and
- uses a minimum speed as a guard against vehicles changing lanes and striking the sensor with only one axle.

These precautions, which enhance the validity of the data, result in an inability to classify vehicles at slow speeds, which, in turn, prevents the use of the machines on road sections experiencing stop-and-go traffic during the count period.

The restriction to one lane (either left-most or right-most) in which traffic can be counted and classified is a direct result of the axle-sensing device presently used by many American and foreign manufacturers, the pneumatic tube. The road tube registers any axle striking the tube. When stretched over two lanes, the tube is incapable of determining the lane from which the axle signal is emitted. The tube's use is therefore restricted to the lane nearest the counter.

Some manufacturers claim their counting equipment is compatible with other axle-sensing devices, but only the systems designed by the Transportation Road Research Laboratory (TRRL) in the United Kingdom and a new Canadian system manufactured by IRD are designed specifically for a different kind of sensor.

The TRRL system uses a refined triboelectric cable, a form of coaxial cable. Tests at the TRRL show that the cable sensor, if carefully manufactured, can have a useful life of up to four years. Thus, it can be installed at permanent locations to collect data on lanes other than outside lanes. A portable cable is currently under development at TRRL.

The IRD system is also designed for a permanent location. This system consists of 12 pressure sensors permanently placed in the pavement to detect axles. It too can collect data from multiple lanes.

At this time, road tubes are the most common axle sensing devices used in the United States. A Maine DOT study[1] of automatic vehicle classifiers concluded that using road tubes as sensing devices results in a high error rate. Road tubes suffer from a high degree of intentional and unintentional damage due to vehicular traffic. During the study, the tubes displayed a tendency to undercount axles, even when in working order. Maine DOT personnel were unable to trace the cause of the undercounting, but attributed it to a combination of tube deterioration, air-switch malfunctioning, and internal processing problems. The problems incurred with road tubes when used for vehicle classification did not seem to affect the same counting devices when used for speed analysis.

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[1] Maine Facility Laboratory, Evaluation of Vehicle Classification Equipment, prepared for FHWA, September 1982.

To quote from the Maine study:

> While it was not typically obvious whether the tubes or the systems being tested were responsible for some of the error, it was clear that the tube-based systems did not seem to have a high degree of reliability (e.g., a three or more axle vehicle did not have all of its axles counted). In addition, it was rarely clear when a tube was breaking down, or when it had, when that breakdown had occurred.

The Maine report estimated that the tube-based systems tended to misclassify vehicles larger than three axles, 10 to 20 percent of the time.

The Maine DOT study rated the TRRL system considerably higher than any other classification system. The Maine study achieved a 98.3 percent accuracy rate for vehicle classification during the study. The equipment classified 95.7 percent of the trucks correctly. Similar tests in the United Kingdom comparing the automatic system with manual counts achieved accuracy rates of between 96 and 98 percent (assuming no errors in the manual counts). The system tested by Maine DOT was designed for use as a permanent station, but the TRRL is developing a portable system.

The new IRD system was not available for testing at the time of the Maine evaluation, but it is currently being evaluated in Canada and Minnesota. Preliminary information shows that the counter is equal in accuracy to the TRRL system.

Length Classifiers

Most counters using pneumatic tubes are also capable of using dual inductance loops for vehicle length classification. These classifications are currently performed at several permanent speed-monitoring locations in the United States. The length data available through the loops is not, however, sufficient to classify vehicles to the level of detail needed by most highway engineers. The use of loops at ATR stations can, however, give excellent information on seasonal and hourly distribution of truck traffic, even if data are not available in the preferred vehicle classifications.

The Maine report assessed the performance of counters using inductance loops for input of raw vehicle classification data as somewhat better than the performance of axle-sensing devices. The loops were generally more accurate in classifications, although all counters showed significant quality control problems. The accuracy of the length classifications was caused in part by the simplified categories used. The four-vehicle categories used by most systems were significantly less intricate than the 14-vehicle categories that used axle sensors for classification. The Maine report indicated that automatic vehicle classifiers using loops placed up to 95 percent of passing vehicles in the appropriate category. Machine breakdowns in the test, however, considerably reduced the overall accuracy of the machines. In addition, the Maine study showed that the loop equipment tended to be very sensitive to minor adjustments in the tuning of the inductance loops. This sensitivity created some calibration problems with those counters not specifically designed to allow testing at the site.

Limitations of Automatic Counters

The discussion above suggests that improvements in automatic classification equipment have not progressed to the point where manual counts are unnecessary. Besides the shortcomings previously mentioned for both axle-sensing and length classification equipment, some states require information that cannot be collected by any existing automated counter. Among the data that must normally be collected manually are:

- in-state versus out-of-state designations;
- vehicle categories based on the number of tires per axle; and
- truck-type analysis by body type (e.g., refrigerated truck trailer versus tanker).

The need for these data, as well as the need for vehicle classification data where automatic equipment does not function accurately (e.g., in congested areas), results in a continued need for manual classification counts.

Manual classification counts are not without accuracy limitations. While manual counts are often used as the "correct" figures to which automatic counts are compared, studies have shown that manual counts can contain substantial errors. A paper written by P. Davies and D.R. Salter and published in Transporation Research Record 905 indicates that a study they performed indicated that manual classification count error ranged as high as 35 percent, even when counters were closely supervised. These results would indicate that the error from automatic counters functioning properly is not significantly different from the error in manual counts.

In summary, automatic vehicle classification equipment is rapidly developing the capability to provide the majority of data desired from vehicle classification counts. Permanent stations performing limited auto/truck splits are currently in use (for example, Illinois' telemetry system collects speed data by vehicle length class) using loop inputs. Permanent and semipermanent axle-sensing classification equipment have shown high accuracy correlations. Portable axle sensors using road tube sensors have exhibited less accuracy, but in many instances can provide the majority of data needed.

TRUCK WEIGHING EQUIPMENT

This section includes an outline of the issues affecting truck weight data collection and an overview of the equipment available on the market.

Truck weight data has traditionally been collected for two different purposes, weight enforcement and data collection for engineering and planning. The scope of this appendix allows discussion of only the planning aspects of truck weight data collection. Enforcement activities are dealt with only where they affect planning.

Overview

Historically, truck weight data has been collected as a means of determining pavement loadings. These loads in turn can be translated into design requirements and estimates of pavement life. The majority of vehicle (usually truck) weighings have been taken at fixed weigh stations on major roads. Some axle or wheel-load weighings are taken using portable loadometers at nonpermanent roadside locations to determine vehicle weights at sites away from permanent stations.

The primary federal impetus behind truck weight studies has been the biennial truck weight survey. This survey consists of truck weighings, driver interviews, and vehicle classifications submitted to the FHWA every two years. From this survey, the FHWA and states determine truck weight trends and revise estimates of equivalent axle loadings for various truck classifications to be used in design and maintenance computations. This program is currently under review, as FHWA examines:

- methods of streamlining the surveying process;
- uses of the truck weight data; and
- capabilities of the new WIM equipment.

Many states are therefore currently delaying truck weight planning studies until the results of the federal review are made available.

Obtaining accurate information on truck weights is difficult. The main problem is that the costs of collecting weight data are high, limiting the amount of data that can be collected, while several factors contribute to cause inaccuracies in the data that can be collected. Several of these factors are:

- The avoidance of weigh scales by overweight vehicles skews the data.
- The small number of locations used for weigh stations do not represent either a random or a representative sample of the state highway system.
- The cost of the manpower necessary to run a station as well as the cost of scales prevents states from expanding their vehicle weighing programs.
- The considerations necessary for weigh station crew safety and scale accuracy limit the number of sites suitable for most existing portable scales.

It is the enforcement of weight laws that causes overweight trucks to take precautions to avoid any operating weigh station. The result of this avoidance is weight data which underreports the heaviest trucks, thus making average survey weight fall below the actual average weight.

In the five participating states, vehicle weight data for planning purposes was collected separately from weight enforcement measurements. This had two primary impacts:

- The data was less affected by underreporting of heavy trucks since there were no law enforcement officers at the survey sights.
- Less data were available for planning purposes than if the vehicle weighings done for enforcement purposes were included.

Several state DOT personnel interviewed for this report conceded that drivers with overweight loads were less likely to purposefully avoid a weigh station if they knew that no enforcement activities were being conducted at that site. They disagree about whether data from enforcement weighings should be sought by planning departments. The lack of representative data on heavy trucks diminishes the quality of the data collected, but the size of the enforcement data base is usually greater than the amount of data the planning department can afford to collect. The planning departments usually lack funds and take a relatively small number of weighings in comparison with the number taken by enforcement departments.

Truck Weighing Equipment Capabilities

The latest improvements in vehicle weighing technology attempt to minimize the above problems. The newest systems are designed to operate without human observation and in such a way as to be inconspicuous to the passing motorist. In addition, several newer systems are designed to be truly portable so that more appropriate samples may be selected from the highway system. The following discussion presents the characteristics and capabilities of three types of truck weighing equipment: fixed scales, portable scales, and Weigh-In-Motion (WIM) scales.

Fixed Static Scales

Almost all states operate at least one fixed-scale location. Some stations are manned 24 hours a day, 365 days a year. Many, however, are operated for only portions of each day or during particular seasons, such as harvest time. Fixed locations are used because the cost of weigh station construction is high, and historically the difficulty in transporting and setting up weighing equipment has also been great.

Fixed stations are effective for weighing all vehicles only when no bypass routes exist. This happens primarily in the western United States, at borders between states or through mountain passes. Fixed stations are least effective at locations where numerous bypasses exist, which tends to be the norm in most of the U.S. To a limited extent, the problems of trucks routing around fixed stations can be decreased with the periodic use of portable equipment on the available bypass routes. Unfortunately, the truckers' use of CB radio and other communication techniques tends to greatly reduce the effectiveness of this practice.

Portable Static Scales

Portable scales have existed for many years. For the most part, the early models consisted of scales designed to weigh individual wheels. These scales were set up on roads with sufficiently wide shoulders or turnouts to allow the scale crews to pull trucks completely off the road.

Improvements in technology have resulted in more sophisticated scales that can weigh entire tandem axles and still be carried on trailers pulled by a large van or mobile home. These improvements have greatly increased the speed with which a crew can weigh a vehicle. These scales, for the most part, still need a wide, flat road shoulder. This type of weighing station also suffers from the same evasion problem that plagues fixed-scale weighing locations: truck drivers report the operation of the scale soon after it is set up and overweight trucks use alternative routes to bypass the scale. The quality of the data then rapidly deteriorates.

A second kind of portable scale is used in conjunction with fixed-scale locations. In this case, several fixed scalehouses are constructed with removable dummy scales. Portable weighing equipment are then rotated between them. The portable scale replaces the dummy scale in the prepared scale pits and transforms the scalehouse into a working station. The advantage of this method is the capital savings in only having to buy one scale for several fixed locations. The system suffers from the same basic deficiencies as both the fixed and "traditional" portable systems.

Several new technologies for weighing vehicles are currently being marketed worldwide. The new systems can weigh vehicles while the vehicles are in motion. Two such systems, bridge WIM and the capacitor pad, have considerable potential. Their size and location reduce their visibility to vehicle drivers. If they are not used in conjunction with enforcement practices, it may be possible to reduce the problem of truck evasion which results in unrepresentative data. However, if they are used in conjunction with enforcement activities, the trucking community will avoid them and the weight data will still fail to accurately represent heavy trucks.

Weigh-in-Motion Scales

The basic idea in WIM scales is that they weigh vehicles without forcing them to stop. WIM is viewed as a way to increase the efficiency of existing scalehouses and to obtain data not previously available through the use of static scales. Substantial obstacles, however, prevent the wholesale substitution of WIM equipment for existing static scales. These obstacles include:

- differences between weights measured with WIM equipment and those measured with static scales;
- the inability of states to use the WIM equipment by itself in an enforcement role; and
- the high cost of WIM equipment.

The main drawback to using WIM is the problem of "dynamic weight" versus "static weight." The measured weight of an axle on a moving vehicle often differs from the measured axle weight of a stationary vehicle. This difference is due to the fact that the load and suspension of a moving vehicle interact with pavement condition and road profile in such a way that the size of the load experienced by each wheel of the truck oscillates (i.e., the truck bounces, so that the load experienced by the tires is either decreasing as the truck bounces into the air, or increasing as the truck lands.) The faster the vehicle is traveling and the rougher the road surface, the greater the range of oscillation of the dynamic weight around the static weight. This oscillation causes WIM systems to measure axle loadings which differ, often substantially, from the actual static loadings, which, in turn, precludes their use for many enforcement purposes.

As a result of this problem, the majority of WIM systems currently on the market are used primarily to support enforcement activities by sorting vehicles approaching existing conventional static weigh stations. By slowing the approaching vehicle and making the approach pavement to the WIM sensors as smooth as possible, the motions of the vehicle are reduced sufficiently so that the WIM system can act as an effective sorting device. A WIM sorting device uses a signing system to route potentially overweight trucks to the static scales and legal trucks back onto the highway. This process allows static scale use to be limited to those vehicles likely to be overweight. It also decreases the time necessary to process the majority of trucks.

For planning purposes, WIM systems can be placed directly in the traffic lanes of a roadway. A complete conventional WIM installation (weigh pads, electronics and equipment housing, and often a van) can be purchased for roughly $100,000. Additional weigh pads can be purchased for another $10,000 per traffic lane. Installation in the pavement is not included in these figures. One set of electronic equipment can be moved from site to site, thus reducing the cost of a complete system. The initial capital costs for a multi-site system, however, may be high, as are the costs for maintaining the fixed sites used by the system.

To provide an alternative to these conventional fixed WIM sites, two new WIM systems have been introduced:

- the capacitor pad; and
- the bridge WIM.

Both systems, still in the development stage, have been tested in the United States, where it is hoped that they may be produced in the near future.

Capacitor Pad

This system, originally developed by the National Institute for Road Research in South Africa, is currently undergoing testing by the Arizona Department of Transportation. The capacitor pad consists of a 1.8 meter by 0.5 meter by 8 millimeter hard rubber pad containing the capacitor and attached to the roadway using nails and bituminous tape. The pad is placed in the extreme right-most portion of the traffic lane (left-most side for inside lanes), and measures the loads on the outside wheel of each axle crossing it. The latest version of this pad uses dual inductance loops to determine vehicle presence and speed, while inputs from the capacitor pad are used to determine weight per axle, spacings between axles, vehicle classification, and weight law compliance.

The pad has several distinct advantages:

- It is portable; one person can place it on almost any road segment in 20 to 25 minutes.
- The pad does not resemble conventional law enforcement equipment; therefore the intentional destruction or avoidance of the weigh site may be prevented.
- The pad costs less than a third of what most conventional WIM systems cost. An initial capacitor pad with data retrieval equipment can be purchased for approximately $35,000. Additional capacitor pads will be available for roughly $10,000 apiece.
- The pad does not require on-site personnel to operate it.

The capacitor pad has several drawbacks:

- It covers only part of a lane;
- By weighing only one moving wheel (or pair of wheels) per axle, the measurement is susceptible to both the effects of roadway curvature in horizontal and vertical directions and the effects of crosswinds.
- The pad might become dislodged by trucks passing over it, particularly if a truck intentionally tries to damage the pad.
- The pad is meant for operation in the outside lanes of traffic.
- The traffic lane to be used must be closed temporarily for pad installation.

Bridge WIM

Bridge WIM consists of sets of strain gauges placed on the support beams of bridges. The electronic gauges are attached to a mini- or microcomputer which uses strain measurements from the bridge and input from tapeswitch axle sensors on the road to classify and weigh passing vehicles. The system, tested in Maine and Iowa, appears to work fairly well.

The main advantages of the system are:

- The weighing device itself (the set of strain gauges) is invisible to the passing motorist.
- The system is portable from bridge to bridge.
- Like the capacitor pad, essentially no site construction is needed to install the system.
- It requires only one on-site person to monitor the device while it operates.

The primary drawbacks to this system are:

- It can only be placed on the underside of bridges, and cannot be used on all bridges.
- The bridge girders must be accessible to the crew member placing the strain gauges.
- The system loses accuracy when more than one vehicle is on the bridge at a time.
- The system must be calibrated for each bridge it is placed under, using one or more measured weight calibration trucks.
- The system requires that the computer be located near the bridge, usually in a van (for portability). Some concern exists about the ability to locate the van in a place both appropriate and unobtrusive.

The accuracy of individual axle weights from bridge WIM systems are uncertain. Data from an Iowa test showed that the variation between bridge WIM axle weights and static axle weights was fairly high. Total EALs computed with the two sets of axle data, however, were within 1.4 percent of each other. This would indicate that the individual axle errors were randomly distributed for the heavier loads, and the resulting data would be acceptable for many planning purposes such as computation of EALs. The data would not be accurate enough for the enforcement of truck weight laws.

WIM Limitations

WIM systems lack the weighing tolerance necessary for enforcement weighings when vehicles are traveling at highway speeds because of the dynamic effects previously discussed. On a smooth roadway surface, an error of roughly 30 percent on any individual axle can be expected.[1] With significantly greater road roughness the "impact factor" (the difference between static and measured dynamic forces) can be as high as 100 percent.[2] The variance between dynamic and static weights are highest for tandem axles and other multiple sets of axles. These errors are in addition to any errors caused by machine malfunction, and are caused by the movement of the vehicle, its suspension, and its load.

Work performed by TRRL has shown that errors caused by dynamic forces are randomly distributed. As a result, with a smooth roadway surface and a large sample size (i.e., 24 hours or greater), the median gross truck weight measured by an accurately functioning WIM system is normally within 10 percent of that measured using a static scale, according to personnel who have used this equipment in the past. Average axle weights for vehicle class categories also approximate the true norm much closer than do individual vehicle weights.

Another significant aspect of WIM systems is that they preclude the driver interview portions of the current federal biennial truck weight survey. An FHWA survey of data uses and an internal Wisconsin DOT questionnaire indicated that portions of the information from the interview portion of the survey contributed substantially to various data user analyses. Among the data items needed by these users, but not capable of determination by WIM systems, are:

- commodity type;
- permit status;
- trip routing;
- registered weight;
- truck characteristics (engine type, industry type, trailer type); and

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[1] Presentations by Dr. Clyde Lee and Dr. Robin Moore at the WIM Conference, Denver, Colorado, July 11-15, 1983.

[2] Ibid.

. origin/destination data.

Such data would have to be collected with a special survey if all truck weight data were collected using WIM equipment.

In summary, the emerging WIM systems offer the possibility of significant improvements in the quality and cost effectiveness of truck weight data collected. The WIM systems will not, however, totally supplant the use of static scales and driver interviews for the collection of planning data.

APPENDIX C

COST TRADEOFFS

APPENDIX C--COST ANALYSIS

This appendix contains the cost calculations used to estimate cost versus precision trade-offs in the main body of this report. This appendix is intended to provide the states with procedures for estimating their own actual costs. The numbers presented in this appendix are examples, and are not directly applicable to any particular state. The discussion is split into three sections:

- paper tape versus solid state equipment;
- automatic vehicle classification equipment versus manual counts; and
- cost and accuracy trade-offs for different count durations and frequencies.

Costs for performing different tasks vary considerably from state to state due to:

- varying wage rates;
- varying skill levels of the personnel performing the task;
- varying methodologies used to perform the tasks; and
- varying types of equipment used in each state.

These cost differences are illustrated by the average cost per location in each example state's speed monitoring program. The costs for these programs determined from their fiscal year 1983 budgets are shown below:

State	Cost Per Count
Kansas	$449
Maine	$306
Ohio	N/A
Oregon	$277
Georgia	N/A

The speed program is the best source for data to be used in comparing costs between the various states, as the state programs are quite similar, though they do differ in the equipment and methods used to collect and transcribe the data. Other count programs are not readily comparable because of significant differences in the amount of data collected, the manner in which the data are collected, and each state's budgeting process. Because of these differences, an average cost per count for the example states cannot be computed. Therefore, unit costs and other descriptive measures will be used in the analyses in the remainder of this appendix.

PAPER TAPE VERSUS SOLID STATE EQUIPMENT

Solid state traffic counters and magnetic tape cassette drives have some significant advantages over traditional paper tape devices. These advantages are:

- the ease and speed of data transfer between the counting device and a usable format; and
- the accuracy of the transfer process.

Both of these aspects result in cost savings to DOTs using solid state equipment. These advantages increase if large amounts of data must be transferred from a counter to another format. The more data there are (e.g., vehicle classification data or 15-minute count volumes, rather than hourly or daily volumes) the greater the advantage of the solid state device.

There are two alternatives to solid state devices using electronic transfer of data: manual data transfer or data transfer using a paper tape reading machine (either an optical reader, or a mechanical reader of punched holes). The manual techniques seem to be most common, as most counting device manufacturers have stopped making paper tape readers, and many of the paper tape readers still in use are near the end of their usefulness.

Both of these alternatives are more time-consuming and more error-prone than electronic transfer of data. In addition to errors in reading or writing of data (by hand or machine) during the transfer from paper tape, there are frequently errors in the data on the tape. Counting devices (particularly old ones) are well known for occasional malfunctions in their punch mechanisms as well as for worn print ribbons and print heads. Such errors cannot be corrected in the data transfer step, only augmented by the additional errors made during data transfer. While the electronic counterpart of the print or punch mechanism is also subject to malfunction, these errors occur considerably less frequently.

These factors lead to the conclusion that solid state recording devices have significant cost advantages over mechanical devices. The following discussion attempts to quantify that advantage. The cost and manpower figures used below reflect data collected by Peat Marwick in numerous engagements, and are not directly applicable to any one state.

It is suggested that a state follow these basic steps using state data to estimate state-specific savings.

The assumptions used were:

- Data is manually transferred from paper tapes directly onto a computer file, via a CRT.
- Each paper tape is from an ATR station, and contains hourly data gathered during a 14-day period.
- Data can be manually transferred at a rate of three tapes per hour (42 days of hourly information) including station identifiers.
- The salary of the person responsible for data transfer is $15,000 per year, including benefits but not overhead.
- The example state has an overhead of 50 percent.

The introduction of solid state equipment in lieu of paper tape equipment, given the above assumptions, would lead to several changes. The time needed to transfer data would drop slightly. The data from the solid state device would be transferred directly to the DOT computer, as were the manually transferred data. The electronic equipment would be able to operate by itself except that a staff member would need to load the appropriate tapes. This staff member could be the same person that would examine the data for errors, effectively removing the need for a person to transfer data from tape to computer.

This reduction in staffing needs due to data transfer improvements would be proportionate to the amount of data being transferred. If the state has 50 ATR locations, the cost savings in the data transfer can be calculated as:

$$\text{Cost} = \frac{\$15{,}000 \text{ (per year)} * 1.5 \text{ (overhead)} * 50 \text{ (stations)}}{80 \text{ (hrs. per 2-week period)} * 3 \text{ (stations per hr.)}} = \$4{,}700 \text{ per year (rounded off)}$$

This reduction would be even larger if, instead of the first assumption, the data were first transferred manually to a coding sheet from the paper tape and then keyed into the computer. Additional savings accrue from the electronic transfer of data, since the transfer is more accurate than a manual transfer, and the time needed to edit the data can be reduced. The savings could be as much as a 50 percent decrease in the time spent editing the data. As it is estimated that the people who edit ATR data spend 30 percent of their time at that function, a 50 percent reduction would equal 15 percent of those people's time. At a salary of $20,000 (not including overhead) the cost savings would be:

Cost = $20,000 * 1.5 * .15 = $4,500

These two cost savings would result in a combined savings of $9,200 in staff costs per year. The same types of cost reductions would be applicable to any data collection and transfer presently performed with paper tape equipment. This includes volume counts (for any purpose), vehicle classification counts and speed monitoring. The more data transferred (i.e., 15-minute volumes rather than hourly volumes), the higher the savings from the automated data transfer. Assuming the cost of a counter is $2,100 and that the cost of staff time increased proportional to the interest rate paid, the $9,200 annual savings computed above would pay for the replacement of the 50 paper tape recorders in 11.4 years (50 * $2,100/$9,200). Because the interest may actually be higher than staff pay increases, the cost of counter replacement may actually take longer.

AUTOMATIC VEHICLE CLASSIFICATION EQUIPMENT VERSUS MANUAL COUNTS

One principal reason for the development and examination of automatic vehicle classification counters is the high cost of manual classification counts. The high one-time capital cost of automatic equipment allows substantial annual reductions in labor costs of data collection. Most states using the automatic counters discount the accuracy problems found in a Maine DOT study (see Appendix B). The consensus among the user states is that the automatic counters are as accurate as the manual and short count manual count techniques used previously. No definitive study has been performed comparing the accuracy of the various manual count techniques with that of the automatic counters.

The cost of manual vehicle classification counts varies from state to state, depending on the size of the average crew, the duration of the count, and the wages paid the crew. In some instances (for example, Pennsylvania) the marginal cost to the state for the manual counts is significantly less than the actual count cost since the crew is made up of DOT construction inspectors currently without state duties who would be paid whether or not they were taking traffic counts.

The five states included in this study used either one- or two-person crews to perform manual vehicle classification counts. The counts lasted from seven to 24 hours at each location, requiring between one and three crews per count. If a $20,000 annual cost is assumed for each member of the crew (including overhead), working 220 count days per year, the cost of each person day for manual counts is roughly $91. A one-person seven-hour manual count would thus cost roughly $91 plus travel expenses. A 24-hour count would cost between $273 (three one-person crews) and $546 (three two-person crews) plus travel.

In comparison, the cost of an automatic vehicle classification counter is roughly $2,300. A single-person crew can place as many as ten counters in a single day. If it is assumed that the counter can be used 100 times each year, and that the machine is written off in one year, the per count capital cost would be $25. If the single-person crew can place 10 counters per day, the cost per count would be roughly $18. This is based on the assumption of one day to place the counter, and one day to pick up the counter, at a cost of $91 for 10 days or roughly $9 a day.) The total cost per 24-hour count is thus roughly $43, less than half the cost of a single-person manual count. Even if the assumptions for the automatic counter usage above are cut in half (five placed per day, 50 counts taken per year) the cost per 24-hour count is only $86, still less than a third the cost of a manual 24-hour count.

The cost savings from the use of automatic vehicle classification equipment become increasingly important with the size of the vehicle classification program. Oregon and Georgia perform eight- to 24-hour classification counts at or near their ATR stations every three years and each quarter, respectively. Ohio takes quarterly 24-hour counts at 14 fixed locations. Kansas takes 16-hour manual counts at 40 fixed locations quarterly and 40 supplemental locations annually. Maine takes two seven-hour staggered counts at 38 locations each quarter. Any expansion of current vehicle classification counting programs using current methodologies would substantialy affect these states' traffic counting budget. The use of automatic equipment might permit the moderate expansion of these programs without the necessity of cutting back another program.

In addition to the lower cost of data collection, the states will obtain machine readable data as a result of the microprocessor technology used by the machines, thus saving money in data processing as described earlier. The 24-hour counts are also more statistically reliable in comparison to the short counts currently used in some instances by four of the five states.

COST AND ACCURACY TRADE-OFFS FOR DIFFERENT COUNT FREQUENCIES AND DURATIONS

The cost versus frequency curve in Exhibit IV-5, presented as a table in Exhibit IV-4, shows the cost versus frequency trade-off for volume counts. (Exhibit IV-4 is repeated here as Exhibit C-1, for the reader's convenience.) The graph is determined by using equation (7):

$$SVOL_j{}^2 = \frac{SVOLD^2}{nd} + SVOLS^2 * \left(1 + \frac{1}{ncc} \right) +$$

$$SVOLA^2 * \left(1 + \frac{1}{nvc} \right) + SGF^2 \left(1 + \frac{1}{ngf} \right)$$

where: SVOLD = 0.07
SVOLS = 0.04
SVOLA = 0.03
SGF = 0.01
ncc = 6.0
nvc = 12.0
ngf = 40.0
nd = 1.0

The maximum error is assumed to take place during the final year before a new count is taken. That is, for a three-year count cycle, the maximum error occurs after two years. During the third year, a new count is taken. The minimum error occurs when the count is taken and no growth factor is applied. The effect of the duration of the count is determined by altering the variable nd, which represents the number of days counted.

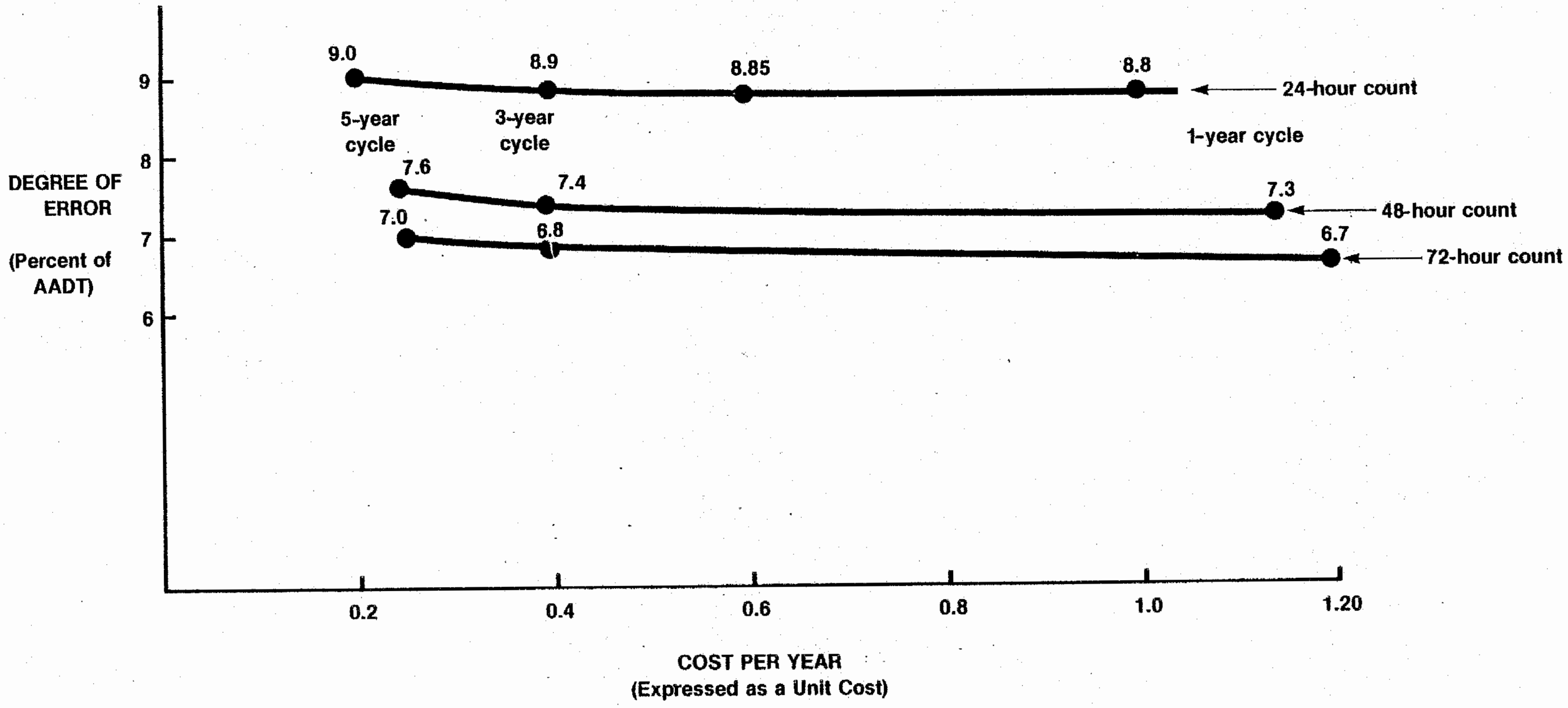
The cost of the counts were determined at the same time. It was estimated that the majority of a count's cost comes from placing the counter in the field. Therefore, leaving the counter in place would not dramatically increase the count's cost. The increased costs of the second and third day are intended to reflect the cost of processing the data, and of additional inefficiencies in the field personnel's count schedule from having to leave the counts in one location for a longer period. One "cost" not covered is that due to the equipment being unavailable for use elsewhere while collecting the second day's data.

Vehicle Classification Counts

The cost/precision relationship of manual vehicle classification counts is not similar to that of the volume counts. If manual counts are used, the costs of collecting additional data do not increase slowly, as they do for volume counts. The cost rises linearly with the number of days of data collected. The added precision of the data does not rise in the same manner (i.e., the cost doubles, but the precision is not twice as good with one additional day of data collection). The added data collection is therefore not as cost effective as taking the same count elsewhere.

EXHIBIT C-1

RELATIVE COST AND ACCURACY OF COUNT DURATION AND FREQUENCY



Assumes: SVOLD = .07
SVOLS = .04
SVOLA = .03
Ncc = 6
Nvc = 12

SGF = .01
N_{gf} = 40
Cost of 1-Day Count = 1
Cost of 2nd 24 hours = 0.15
Cost of additional 24 hours = 0.05

If automatic vehicle classification equipment is used, the cost versus precision relationship expressed in the volume calculation holds true. However, the reliability of the counting device is not similar. As explained in Appendix B, tests of automatic classification equipment have repeatedly shown that the accuracy of the collected data is highly dependent on the axle-sensing devices. Since most portable counters use road tubes, the accuracy of the count depends on the road tube, and it is not clear that these tubes can operate consistently for more than a day without becoming loose or damaged. It is therefore recommended that until better axle sensors are developed, automatic classification counts be limited to 24 hours when using portable equipment.

Truck Weighings

Truck weight measurements are similar to vehicle classification counts, only with greater problems. For the most part, existing truck weight locations must be manually operated. This means that the cost of taking truck weight data increases linearly with the number of days counted, which prevents any appreciable savings from multiple-day counts.

Other factors, however, also affect the accuracy of truck weight data. The longer a truck weight station is open, the higher the possibility that overweight trucks will bypass the station, unless no bypass route exists. In cases where no bypass route exists, the accuracy of the truck weight data will probably improve with the increased duration of the count. Unfortunately, the magnitude of the changes in precision attributable to any of these factors is not quantifiable at this time.

APPENDIX D

CASE STUDIES

APPENDIX D--CASE STUDIES

This appendix contains five examples of proposed traffic monitoring program implementation by states. The five states included in these case studies were chosen by FHWA, and contributed data used in the design of the program. The five case studies included in this appendix cover:

- Georgia;
- Kansas;
- Maine;
- Ohio; and
- Oregon.

The scope of this project does not allow for in-depth analysis of each state's budgeting process, manpower utilization, or department organization. Therefore, the recommendations included in this appendix center primarily on the number and frequency of traffic data counts taken by each state. The effect of these recommendations on the cost or manpower needs of a state's traffic counting program are dealt with only within the limits of the budget data provided by the states during the state visits.

For this appendix, vehicle classification count locations are assumed to be chosen as simple random samples of the HPMS volume locations. This assumption is made to simplify the examples and tables in this appendix. This is not intended to imply that simple random sampling is recommended over sampling proportional to VMT. It implies only that it is easier to present.

Each case study is organized by existing count program element. The proposed program will be detailed in terms of its effects on the existing program and any other necessary changes required to implement the new program.

GEORGIA

The Georgia DOT count program contains the following elements:

- Continuous Counts;
- Control Counts;

- Coverage Counts (including HPMS volume counts);
- Vehicle Classification Counts;
- Speed Monitoring; and
- Truck Weight Monitoring.

All of these programs, except the speed monitoring program, are subject to some change by the recommended traffic monitoring program. These changes include:

- altering the existing seasonal factor approach;
- eliminating the control counts;
- moving some of the ATR locations;
- reducing the total number of ATR sites by four; and
- possible reductions to the coverage count program.

These changes are discussed in detail under the following headings.

Continuous Counts

The ATR program would be modified as a result of the new seasonal factor process. The modifications are intended to redistribute the ATR locations so as to more completely cover all functional classes of roads.

The seasonal factors were derived using the process described in the main body of this report. First, a brief discussion with state DOT staff indicated three possible regions within the state that might require separate seasonal factors for each functional classification. These regions are:

- the counties north of Atlanta (region 1);
- the counties south of a line drawn between Columbus and Augusta (region 3); and
- the counties between these two areas (region 2).

These regions are shown in Exhibit Georgia-1. The seasonal patterns for these regions within each functional class were then computed and compared. This analysis showed that the functional classifications for several of the regions had similar seasonal patterns. These functional classes were then combined. The resulting seasonal factor groups are shown in Exhibit Georgia-2. This exhibit also includes the number of existing ATR counters included in each factor group.

EXHIBIT GEORGIA-1

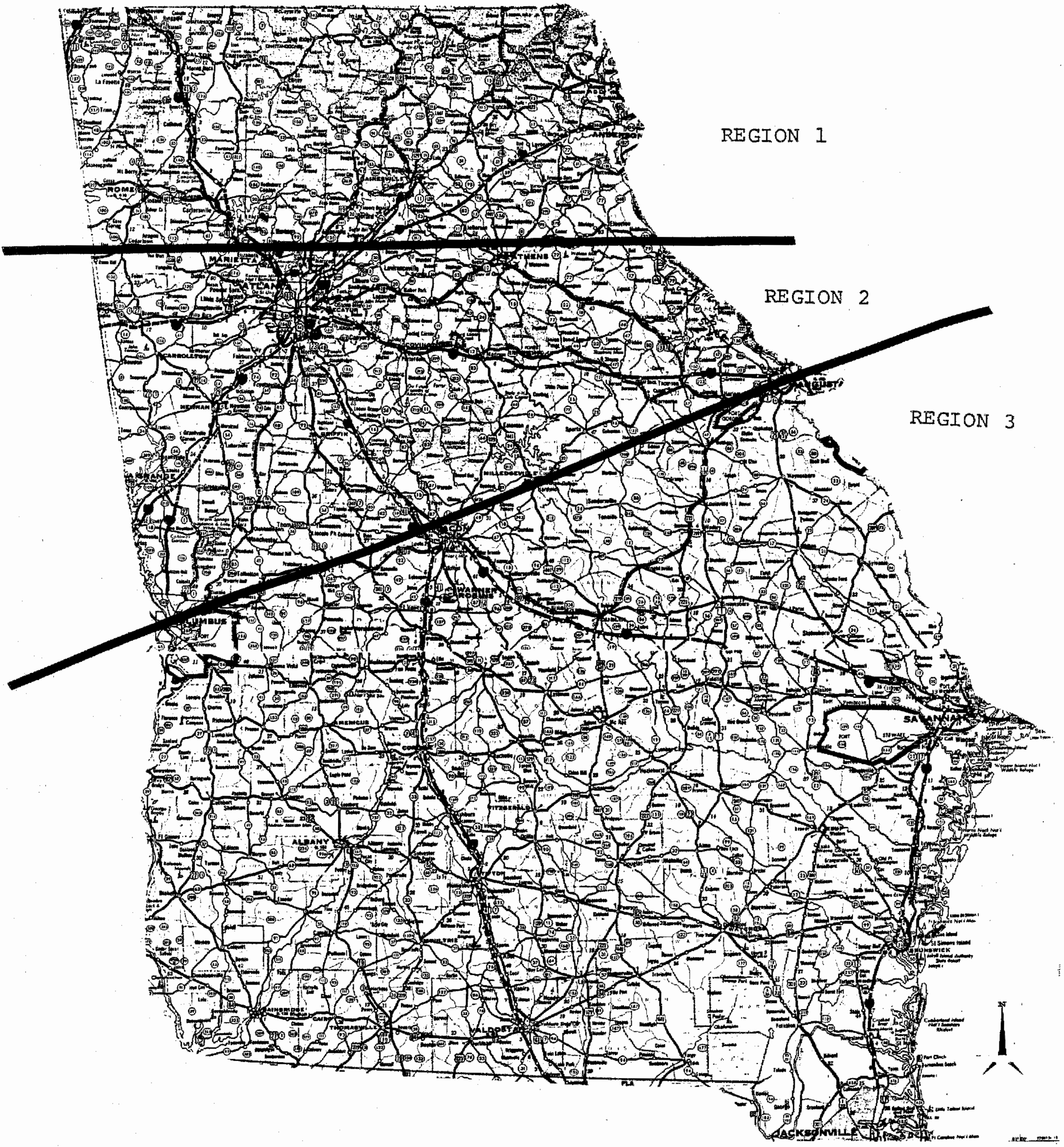


EXHIBIT GEORGIA - 2

DISTRIBUTION OF ATR STATIONS

<table>
<tr><td>Rural Region 1</td><td rowspan="2">8 stations</td><td colspan="3">6 stations</td></tr>
<tr><td>Rural Region 2</td><td colspan="3" rowspan="2">14 stations</td></tr>
<tr><td>Rural Region 3</td><td>4 stations</td></tr>
<tr><td>Urban Region</td><td>7 stations</td><td>2 stations</td><td>5 stations</td><td>10 stations</td></tr>
<tr><td></td><td>Interstate and other Freeways</td><td>Other Principal Arterials</td><td>Minor Arterials</td><td>Collectors</td></tr>
</table>

An examination of the number of ATR locations for each of these factor groups indicates that all but one of the factor groups have more than the recommended minimum of three ATR stations. The remaining groups have between four and 14 ATR stations. Exhibit IV-3, from the main body of this report, examines the cost effectiveness of the number of ATR stations per factor group. From this exhibit we see that the additional accuracy achieved by maintaining more than eight ATRs per group decreases sharply with each additional ATR location. It is therefore recommended that no more than eight ATRs be kept in any one factor group. This choice of a maximum number of ATRs per factor group is relatively arbitrary, and the state may wish to choose some other number of stations as a maximum.

The choice of eight ATRs as a maximum results in the elimination of eight ATR stations, six from group 4, and two from group 8. To standardize the number of ATRs per factor group and make use of the large number of ATRs already in each seasonal group, it is recommended that five stations be chosen as the minimum number of stations per factor group. Exhibit IV-3 shows that the additional two stations per factor group (added to the minimum three stations) add significantly to the precision of the seasonal factor. Since the state only needs to construct four new sites to achieve this minimum (three in group 6 and one in group 3), this recommendation appears reasonable from a cost standpoint.

The factor groups with numbers of counters between these extremes are left unchanged. This allows the state to take advantage of the majority of ATR locations already constructed while still collecting data in a cost effective manner.

Georgia DOT will have to alter its seasonal factor approach if it adopts the recommended count process. The new factor process is somewhat similar to their existing process in that the functional classification of a road section is a primary means of identifying the seasonal factor for a count. Georgia currently applies seasonal factors from individual ATRs to the majority of traffic counts. The combined factor groups in the recommended process should result in a slightly more stable factoring process. The application of factors should also be easier, in that the only need is for the functional classification of the roadway instead of the three tiers of information currently used. These tiers are:

- look for a factor for the specific route;
- look for a factor for the county and the functional classification needed; and
- look for a factor for the statewide functional class needed.

The recommended program also uses a monthly factor with a day-of-the-week adjustment, while Georgia currently uses a weekly adjustment. The recommended process should provide a slightly better factor in this case due to the better stability of the monthly factor. Georgia DOT may wish to use an interpolated weekly average if it chooses to continue using a weekly factor.

Control Counts

The control counts are no longer necessary once the recommended seasonal factors are accepted. The purpose of the control counts is to help assign individual traffic counts to seasonal factors. This function is no longer necessary as roads are automatically assigned to factors due to their regional location and functional class.

HPMS and Coverage Counts

The coverage count program is not necessary in its present form to provide estimates of statewide VMT for functionally classified roads. Georgia DOT has stated that it wishes to retain its coverage count program in its present form, in order to provide site specific volume counts for those locations covered by the count program. This data may also be used for estimating ADT and VMT on roads not included in the HPMS inventory, and for updating the volume group classification of HPMS sections.

By keeping the coverage count program intact as it is currently performed, the Georgia DOT count program provides an extensive amount of information that the state believes is important and worth the cost of data collection. The continued collection of this data, however, does prevent the DOT from obtaining some of the cost reductions that they would otherwise receive from relying more heavily on the HPMS system. These savings could have been quite substantial in Georgia because the coverage count program is a major part of the annual $570,000 budget for volume count data.

The HPMS volume counts are affected by the recommended changes in the length and duration of HPMS volume counts, and by the reduction of the coverage count program. Since HPMS data is collected as a part of the coverage count program, some change in the methods used to collect this data is necessary to provide for 48-hour HPMS counts. The need for HPMS data every three years rather than every year further reduces the demand for the existing coverage count program element. The adoption of this particular recommendation will therefore require some significant changes in the manner in which Georgia DOT schedules and collects HPMS volume counts.

Vehicle Classification Counts

The size of the example vehicle classification program is less than Georgia DOT's current program. The existing program includes quarterly counts at all 64 ATR locations, or 256 counts per year. The proposed count program includes 300 counts spread over three years, or roughly 100 counts per year. The number of vehicle classification counts is dependent upon the default curves in Exhibits A-2 through A-9, and the precision levels shown in Exhibit Georgia-3. Exhibit Georgia-3 also contains the distribution of the classification counts by functional classification. The number of counts and their distribution are subject to change as a result of specific state needs and requirements for specific precision levels.

The 300 counts selected for Georgia should be taken randomly from all days within the count cycle from the existing HPMS volume sections. The counts should be spread evenly throughout all three years. A systematic approach to this might be to collect data at roughly 100 locations three times each. The three sessions for each location could be selected randomly from:

- all days within the three-year count cycle;
- one year of the count cycle; or
- a different year for each count (i.e., count one in year one, one in year two, and one in year three).

Professional judgment was used to determine the appropriate level of accuracy for each functional classification. A confidence interval of 95 percent was used for all functional classes. The graphs in Exhibits A-2 through A-9 were used to determine the sample sizes.

Speed Monitoring

No changes are recommended to the speed monitoring program element.

Truck Weight Monitoring

Like the vehicle classification program element, the size of the truck weight program element is dependent on the level of precision specified by the state. Professional judgment was used to determine the level of accuracy used in the sample size

EXHIBIT GEORGIA-3

Vehicle Classification Sample

Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Rural: Interstate				
Group 1	33			
Group 2	32			
Group 3	28			
Group 4	12			
Group 5	4			
Group 6	2			
Group 7	1			
Group 8	1			
Total	113	30 counts	30%	15%
Other Principal Arterials				
Group 1	204			
Group 2	66			
Group 3	20			
Group 4	4			
Group 5	4			
Group 6	2			
Group 7	1			
Total	301	40 counts	35%	12
Minor Arterials				
Group 1	87			
Group 2	30			
Group 3	21			
Group 4	12			
Group 5	4			
Group 6	5			
Total	159	30 counts	40%	11%
Collectors				
Group 1	103			
Group 2	27			
Group 3	21			
Group 4	8			
Group 5	4			
Minor Collectors				
Group 1	79			
Group 2	17			
Group 3	7			
Group 4	17			
Group 5	17			
Group 6	3			
Total Collectors	303	48 counts	40%	10%

Urbanized and small Urban

Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Urban: Interstate				
Group 1	99			
Group 2	39			
Group 3	16			
Group 4	4			
Total	158	48 counts	30%	9%
Other Principal				
Group 1	139			
Group 2	60			
Group 3	50			
Group 4	26			
Group 5	23			
Group 6	27			
Group 7	23			
Group 8	2			
Total	350	40	35%	10%
Minor Arterials				
Group 1	55			
Group 2	39			
Group 3	41			
Group 4	36			
Group 5	15			
Group 6	11			
Group 7	5			
Total	202	30	40%	12%
Collectors				
Group 1	44			
Group 2	36			
Group 3	52			
Group 4	30			
Group 5	10			
Group 6	12			
Total	184	30	60%	18%

calculations along with a confidence interval of 95 percent. Exhibits A-10 through A-17 were then used to calculate the sample sizes shown in Exhibit Georgia-4.

The truck weight monitoring sessions are to be selected from the vehicle classification location-days. Ideally, measurement sessions should be selected randomly from the vehicle classification counts. In practical terms, a more systematic approach is more appropriate. For example, Exhibit Georgia-4 indicates that 25 monitoring sessions are necessary to collect 3S2 weight data for rural interstates within 10 percent accuracy and 95 percent confidence. A systematic approach might be to count eight different rural interstate locations three times each (plus one location a fourth time). Each of the three counts at a location would be taken during a different part of the year (e.g. March, August, November). The counts at each of the stations could be spread between the three years as best suits the budgetary restrictions of the state, or one count could be taken each year at each location. A vehicle classification count would also be taken at each weight monitoring site. The vehicle classification count would be used as part of the 300 locations necessary per cycle.

Special Studies

Special data collection may increase. Georgia's continued reliance on an extensive coverage count program significantly reduces its need for special counts. For special data needs, the HPMS sample and inventory should be utilized along with coverage count data whenever possible. Any additional data needs can be performed by personnel and equipment previously used in the control count program.

The special data collection program element should be used to collect all kinds of traffic data not supplied by countinuous counts, coverage counts or the HPMS data base. This could include, but not be limited to, site-specific volume counts, special studies for determining in-state versus out-of-state travel, or any other set of data the state may desire.

EXHIBIT GEORGIA-4

TRUCK WEIGHT SAMPLE SIZE

	Vehicle Classification Sample Size	Truck Weight Sample Size	3S2 Precision	Total Weight Precision
Rural:				
Interstate	30	25	11%	15%
Other Principal Arterials	40	15	20%	25%
Minor Arterials	30	11	30%	36%
Collectors	48	6	30%	43%
Urban:				
Interstates & Freeways	48	3	40%	47%
Other Principal Arterials	40	3	42%	60%
Minor Arterials	30	3	97%	94%
Collectors	30	3	97%	97%

KANSAS

The current Kansas traffic monitoring program consists of the following program elements:

- Continuous Counts (ATRs);
- Control Counts;
- Coverage Counts (including HPMS volume counts);
- Vehicle Classification Counts;
- Truck Weight Monitoring;
- Speed Monitoring, and;
- Special Data Collection.

HPMS volume data is collected as part of the coverage count program, and will be discussed under that heading.

Most of these program elements will be subject to changes if the recommended traffic monitoring program is accepted. The most significant of these changes are:

- the alteration of the existing seaonal factoring process;
- the elimination of the control counts;
- a reduction in the number of coverage counts taken each year;
- a reduction in the number of continuous count locations;
- a increase in the number of truck weight monitoring sessions each year; and
- an increase in the amount of traffic monitoring performed under the special data collection program each year.

The speed monitoring program is not changed as it is beyond the scope of this contract.

Continuous Counts

Kansas continuous counts are used to provide seasonal controls for other traffic counts. The recommended traffic counting program alters the current Kansas seasonal factoring process to one based entirely on the functional classification of each road section. As a result of this change, Kansas does not need to maintain all 102 of its current continuous counters.

While Kansas currently utilizes factors for six different districts, the recommended seasonal factors stratify the state only by urban and rural areas. The analysis performed for this case study did not determine a consistent difference in seasonal factors between the districts, so the recommended factor groups are not stratified by regions within the state. The proposed factor groups are delineated strictly by the functional classification of the roadway section. The proposed factor groups and the number of existing counters within each factor group are shown in Exhibit Kansas-1.

Several of the Kansas ATRs did not follow the seasonal patterns of the majority of roads within their functional classification. These ATR locations are shown in Exhibit Kansas-2. Discussions with Kansas DOR indicated that these locations were different for several reasons, ranging from proximity to major recreation sources to road construction near the count location. Kansas DOT will need to determine which of these counters needs to be treated as "special" cases, and which should be included with the ATR functional groups.

The large number of ATR locations within the Rural Principal Arterial Category and the Rural Minor Arterial Category indicates that many of these locations are not necessary for determination of seasonal factors. Exhibit IV-3 in the main body of this paper indicates that roughly eight ATRs is a reasonable maximum number of ATRs per seasonal factor group. After eight ATRs are reached, the cost effectiveness of the additional ATRs starts to decline rapidly. The choice of eight ATRs is, however, somewhat arbitrary, and the state may wish to choose a slightly different number. If a maximum of eight ATRs are used per factor group, the new seasonal factor groupings allow 53 ATRs to be discontinued for collecting seasonal data. One factor group (urban collectors) has only two ATR locations, while urban interstates and other freeways have only four counters. Kansas may wish to relocate six counters to locations (to achieve a minimum of six ATRs per factor group) within these functional classes to provide for better seasonal estimates on these functional classes.

If both of the above ATR recommendations are accepted, Kansas will have a net reduction of 47 ATR locations. This could conceivably represent a savings of $50,500 per year for the state (47/102 * $110,000 per year for the existing ATR program). However, Kansas may wish to retain some of these ATR locations for other purposes (e.g., trend analysis).

EXHIBIT KANSAS-1

NUMBER OF EXISTING ATRs IN RECOMMENDED FACTOR GROUPS

	Interstates and other Freeways	Other Principal Arterials	Minor Arterials	Collectors
Rural	7	33	27	11
Urban	4	6	7	2

EXHIBIT KANSAS-2

ATRs WITH UNUSUAL SEASONAL PATTERNS

ATR ID	District	Road
3-100-0400-00	3	US--40
5-630-9001-64	5	Douglas Ave.
2-027-1415-00	2	K-141
1-044-2370-33	1	K-237
6-038-0500-00	6	US-50

Control Counts

Kansas indicated (in comments presented in an earlier paper on state data needs) that they collect control counts four times a year for one week at two urban locations. It is unclear what these counts are used for, but they do not appear necessary within the recommended traffic monitoring program.

HPMS and Coverage Counts

Kansas collects HPMS volume data while performing its regularly scheduled coverage count program. The coverage count program currently operates on several cycles:

- interstates and principal arterials are counted every year;
- minor arterials and collectors on the rural state highway system are counted on a two-year cycle;
- the remaining county federal-aid system roads are counted on a six-year cycle;
- coverage counts are also collected in cities on arterials and collectors using a six-year cycle; and
- random counts are performed on locally classified roads in cities with a population greater than 5,000 people to help estimate VMT.

The recommended program relies on the HPMS sample and data base to provide statewide estimates of VMT. The only non-HPMS coverage counts necessary for VMT estimation are those used for estimating VMT on roads not in the HPMS data base or counts used for updating the volume group classifications of HPMS sections. Like Georgia, Kansas has specific needs for some coverage count data, and will continue to collect some data in this manner. The coverage count program does provide information that can not be supplied through the HPMS data base, and is of significant importance to the state.

The recommended program will increase the length of HPMS volume counts from 24 to 48 hours. This will require some additional changes in the manner in which Kansas schedules annual traffic counts. Volume data needs for specific road segments not counted in the HPMS or coverage count programs will be provided through the special data collection element.

Vehicle Classification Counts

Kansas currently takes 100 vehicle classification counts per year along with vehicle classification counts taken at truck weight locations. The recommended program will take essentially the same number of vehicle classification counts each year. Exhibit Kansas-3 shows how these counts are distributed across functional classes. The number of classification counts and their division between functional classes is a function of the assumed precision levels, also shown in Exhibit Kansas-3. The number and distribution of vehicle class counts may therefore change after Kansas reviews this appendix, based on their review of available statewide data, as well as their budget restrictions.

The 300 counts selected for Kansas should be taken randomly from all days within the count cycle for the existing HPMS volume sections. The counts should be spread evenly throughout all three years. A systematic approach to this might be to collect data at roughly 100 locations three times each. The three sessions for each location could be selected randomly from:

- all days within the three-year count cycle;
- one year of the count cycle; or
- a different year for each count (i.e., count one in year one, one in year two, and one in year three).

Professional judgment was used to determine the appropriate level of accuracy for each functional classification. A confidence interval of 95 percent was used for all functional classes. The graphs in Exhibits A-2 through A-9 were used to determine the sample sizes. Appendix A includes a description of how to use these exhibits.

One final change is recommended for vehicle classification counting in the state of Kansas. The state should make greater use of automatic vehicle classification equipment. Kansas currently uses two-person manual counts for its vehicle classification data. The state does own some automatic classification equipment and has indicated satisfaction with the performance of the machines. The increased use of this equipment should allow the state to take 24-hour classification counts using fewer resources than currently used to take 16-hour manual classification counts. This should free additional resources for use in other important areas.

EXHIBIT KANSAS-3

			Vehicle Classification Sample		
	Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Rural interstate					
	Group 1	62			
	Group 2	12			
	Total	74	30 counts	30%	15%
Other Principal Arterials					
	Group 1	310			
	Group 2	53			
	Group 3	11			
	Group 4	2			
	Total	376	40 counts	35%	12%
Minor Arterials					
	Group 1	109			
	Group 2	18			
	Group 3	9			
	Group 4	3			
	Total	139	30 counts	40%	11%
Collectors					
	Group 1	87			
	Group 2	11			
	Group 3	6			
Minor Collectors					
	Group 1	185			
	Group 2	3			
	Total Collectors	292	48 counts	40%	10%

Urbanized and small Urban

Vehicle Classification Sample

Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Urban: Interstate				
Group 1	149			
Group 2	66			
Group 3	13			
Group 4	1			
Total	229	48 counts	30%	9%
Other Principal Arterials				
Group 1	132			
Group 2	90			
Group 3	67			
Group 4	32			
Group 5	20			
Group 6	9			
Group 7	10			
Group 8	1			
Group 9	2			
Total	363	40	35%	10%
Minor Arterials				
Group 1	181			
Group 2	39			
Group 3	30			
Group 4	20			
Group 5	13			
Group 6	9			
Total	292	30	40%	12%
Collectors				
Group 1	163			
Group 2	68			
Group 3	49			
Group 4	25			
Group 5	8			
Group 6	2			
Total	315	30	60%	18%

Truck Weight Monitoring

The proposed truck weight monitoring program increases the number of weighing sessions that the state conducts each year from 15 sessions every two years to 80 sessions every three years (roughly 23 per year). It is recommended that the state conduct some truck weighings every year rather than every other year as is the current practice. This should result in more representative truck weight estimates.

Exhibit Kansas-4 contains the recommended number of truck weight monitoring sessions and their distribution by functional class. The data in Appendix A was used to compute these sample sizes based on assumed levels of precision. The actual sample size chosen by the state may vary from that in Exhibit Kansas-4 depending on a review of the selected precision levels and specific data needs and resources.

The truck weight monitoring locations are to be selected from the vehicle classification locations. Ideally, counts should be selected randomly from the vehicle classification location-days. The proposed sites, however, will have to be examined to ensure that the state's weighing equipment can be used at those locations.

A systematic approach to site selection may be more readily applied than the purely random site selection. For example, Exhibit Kansas-4 indicates that 24 monitoring sessions are necessary to collect 3S2 weight data for rural interstates within 10 percent accuracy and 95 percent confidence. A systematic approach might be to count eight different rural interstate locations three times each. Each of the three counts at a location would be taken during a different part of the year (e.g. March, August, November). The counts at each of the stations could be spread between the three years as best suits the budgetary restrictions of the state, or one count could be taken each year at each location.

Speed Monitoring

Speed monitoring is beyond the scope of this study, and thus is not changed by these recommendations.

Special Data Collection Element

The state traffic counting department already collects some special count data if requested data are unavailable. Most special counts are collected by coverage count personnel who are collecting data in the area. These counts are collected in such a manner as to minimize additional travel costs. Personnel in charge of data collection are responsible for determining the need for special count data and for scheduling collection.

EXHIBIT KANSAS-4

TRUCK WEIGHT SAMPLE SIZE

	Vehicle Classification Sample Size	Truck Weight Sample Size	3S2 Precision	Total Weight Precision
Rural:				
Interstate	30	24	10%	13%
Other Principal Arterials	40	24	15%	20%
Minor Arterials	30	12	28%	33%
Collectors	48	6	30%	43%
Urban:				
Interstates & Freeways	48	3	40%	47%
Other Principal Arterials	40	3	42%	60%
Minor Arterials	30	3	97%	94%
Collectors	30	3	97%	97%

The procedures currently in place appear to be well designed to determine actual data needs as well as to provide scheduling for the expected increase in special data requests.

The special data collection program element should be used to collect all kinds of traffic data not supplied by the countinuous counters or the HPMS data base. This could include, but not be limited to, site-specific volume counts, special studies for determining in-state versus out-of-state travel, or any other set of data the state may desire.

MAINE

The current Maine DOT traffic data collection program consists of the following programs:

- Continuous Counts (ATRs);
- Control Counts;
- Coverage Counts (ADT) including HPMS Counts;
- Vehicle Classification Counts;
- Speed Monitoring;
- Truck Weight Monitoring; and
- Special Study Counts.

These program elements will be subject to change if the recommended program is implemented. The most significant changes would be:

- the alteration of the existing seasonal factor process;
- the elimination of control counts;
- a reduction in the number of coverage counts taken each year;
- an increase in the number of vehicle classification counts performed in a year; and
- an increase in the number of special counts taken.

The speed monitoring program is not changed in the revised traffic count program. The Maine DOT truck weighing program is currently in the planning stage, so the proposed weigh program cannot be compared to an existing procedure.

Continuous Counts

It is recommended that the Maine ATR program be changed slightly to conform to the needs of the recommended traffic count program. These changes include:

- the elimination of five ATR locations;
- the addition of one to three ATR sites at different locations than the eliminated sites; and
- the alteration of the seasonal factoring process performed with ATR data.

The replacement of some ATR sites with new sites is necessary to provide for a better distribution of ATRs by functional classification.

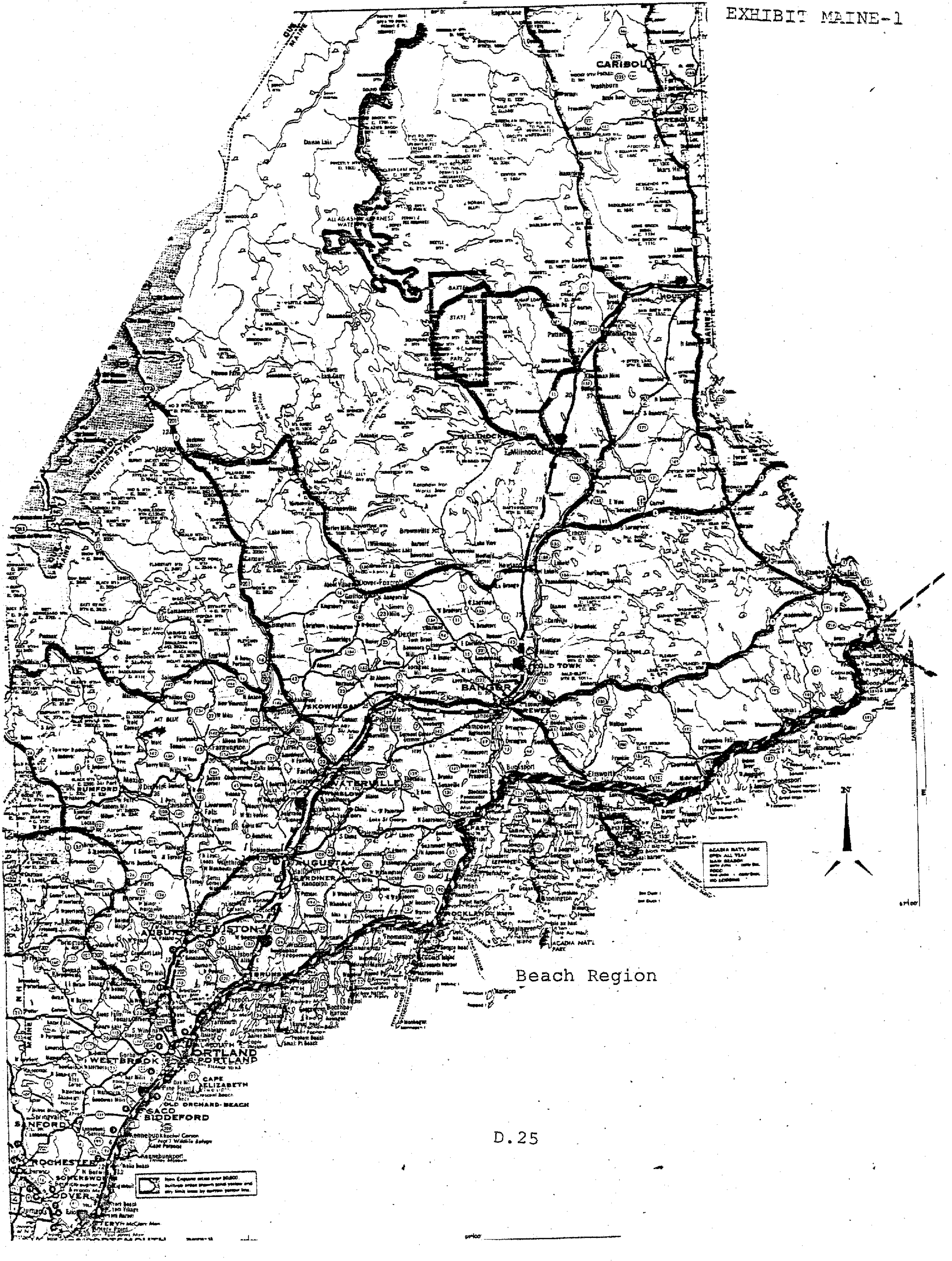
An examination of Maine's present seasonal factoring process and individual ATR data indicates that a regional stratification of factor groups is necessary. Three primary regions are apparent:

- the urban areas;
- the southern beach areas; and
- the remainder of the state.

In addition to these basic regions, there are some ski resort areas that are treated as a special case due to their unusual seasonal traffic patterns. It will be necessary for Maine DOT to designate those roads to be included in this special category, if they agree with the recommendation.

The current Maine DOT factoring groups and 1982 ATR data show substantially more seasonality to the traffic on the beach side of I-95 and US-1 (see Exhibit Maine-1) than in the remainder of the state. To confirm this tendency, seasonal factors were computed for factor groups containing all ATRs within a functional classification both with and without the beach ATRs. As can be seen in the standard deviations of these two estimates (see Exhibit Maine-2), the factor groups are more uniform with the beach sites as a separate factor group.

EXHIBIT MAINE-1



Beach Region

EXHIBIT MAINE-2

COMPARISON OF STANDARD DEVIATION WITH AND WITHOUT THE BEACH REGION

Factor Group	Without Special Beach Region	With Special Beach Regions
Rural Interstates and Primary Arterials	.082	.082
Rural Minor Arterials	.202	.158
Rural Collectors	.251	.040
Urban Interstates and Other Freeways	.041	.041
Urban Arterials and Collectors	.107	.026
Beach Group	N/A	.130
Average	.1366	.0795

The special ski areas were retained from the existing Maine factor groups because the seasonal pattern of the Kingsfield ATR showed a radically different pattern from any of the other ATR locations. Therefore it did not fit acceptably into the functional classification factor groups.

After the delineation of the beach region and special ski roads, the remaining ATR functional groups were examined for similarities. It was determined from graphs of the seasonal factors that rural interstates (Functional class 1) and rural principal arterials (Functional class 2) could be combined, as could urban arterials and collectors. (All functional classes are combined in the beach region and special ski areas.) Exhibit Maine-3 presents seasonality graphs for the two rural functional classes that were combined. Exhibit Maine-4 contains a listing of ATRs for each of the final seasonal factor groups.

With the factor groups now established, the number of ATRs within each category was examined:

Factor Group	Number of Counters	Functional Classes
Group 1	13	Rural Interstates and Principal Arterials
Group 2	5	Rural Minor Arterials
Group 3	2	Rural Collectors
Group 4	3	Urban Interstates and Other Freeways
Group 5	4	Urban Arterials and Collectors
Beach Group	5	Various

No specific number of ATR sites is recommended for each factor group. Using the logic presented in the main body of this report, the absolute minimum number of sites was considered to be three except for special cases. Two sites are needed to determine the variation in the data, and the third allows for a malfunction of one traffic counter. This logic indicates that one count location should be added to the rural collector classification.

The determination of the appropriate number of continuous counters in the remaining groups is more difficult. The table above shows that the first grouping (Rural Interstates and Principal Arterials) has considerably more ATR sites than the remaining groups. Exhibit IV-3 in the main body of this report shows that the information gained from adding ATR sites diminishes quickly after more than eight sites are included in a factor group. Therefore, it is recommended that only eight locations be kept in any seasonal factor grouping. If five ATRs are eliminated from the first factor group, a significant cost savings would be achieved by Maine DOT, while the remaining eight stations would ensure calculation of an acceptably accurate seasonal factor for that functional class.

EXHIBIT MAINE-3

MAINE MONTHLY RURAL TRAFFIC PATTERNS

Interstates & Other Principal Arterials

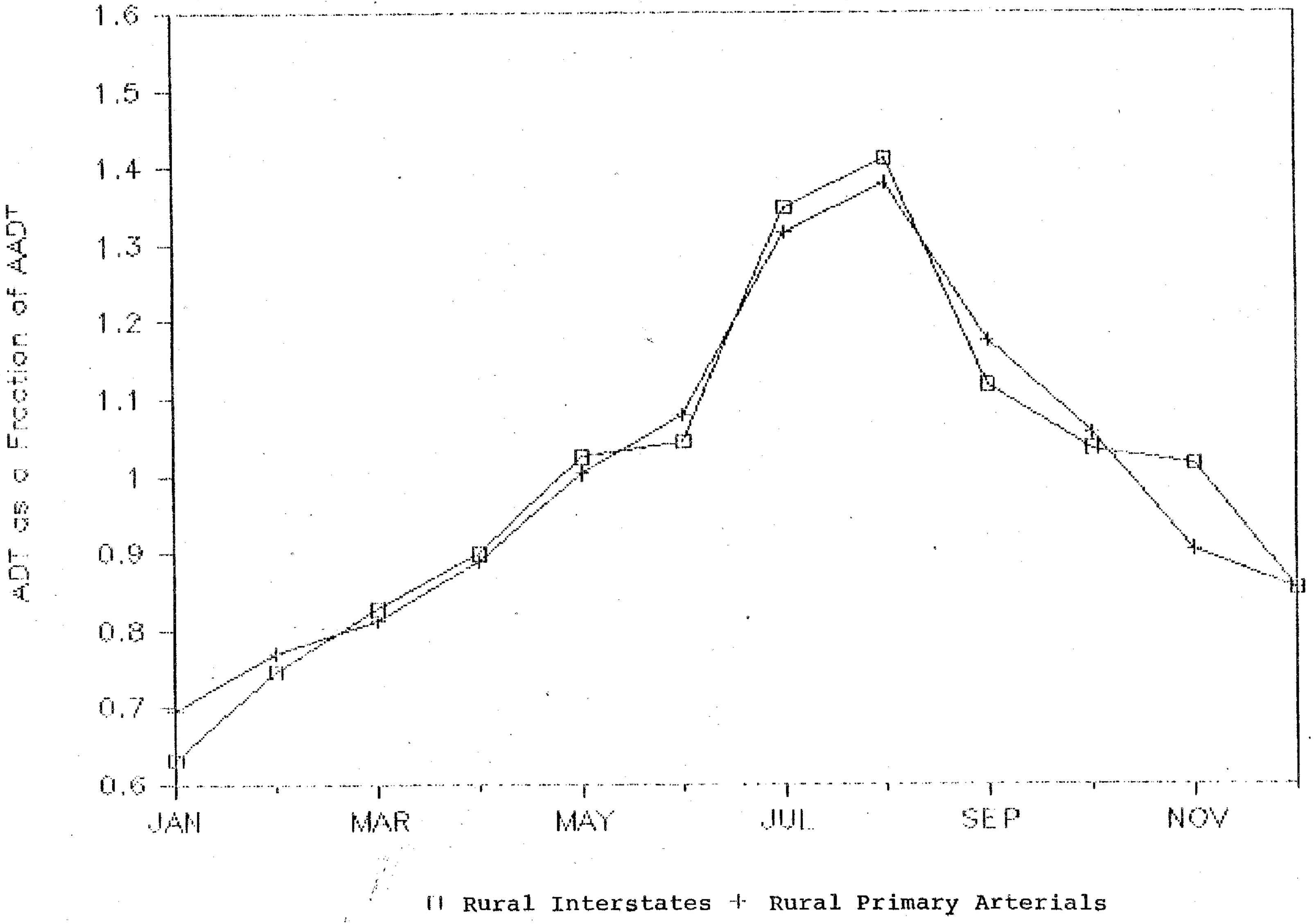


EXHIBIT MAINE-4

ATR STATIONS BY FACTOR GROUP

Factor Group	ATRs
Rural Interstates and Primary Arterials	052,092,272,382,702,080, 110,170,210,390,760,770, 020
Rural Minor Arterials	70,100,130,650
Rural Collectors	010,040
Urban Interstates and Other Freeways	262,792,800
Urban Arterials and Collectors	140,190,200,180
Beach Sites	30,230,400,670,780
Special Factor Group	280

The remaining factor groups contain an acceptable number of ATR locations. However, the state may want to add ATR sites at some of the other locations in case of multiple counter failure, or just in the interest of additional information. The most likely locations for additional ATRs would be in factor groups 3 and 4. One additional counter in each of these factor groups would provide a minimum of four counters per group, and result in a greater margin of safety in case of counter failure or construction at ATR sites. Maine DOT would need to make these decisions based on available resources and information needs.

Control Counts

The control count program should be eliminated. The purpose of the control counts is to help assign traffic counts to seasonal factor groups. With the recommended factor process, all count locations are automatically assigned to a factor group on the basis of the functional class of road. Thus a series of counts to assist in this process is unnecessary. The specific cost savings associated with this reduction in counts cannot be determined because of the combination of continuous counts, control counts, and coverage counts as a single line item in the DOT budget.

HPMS and Coverage Counts

The coverage counts that Maine DOT performs include both coverage counts and HPMS sample section counts. The recommended procedure would reduce the number of non-HPMS counts in the annually scheduled data collection process. Only those counts that provide information for roads not on the HPMS system, for updating the assignment of sections to HPMS volume groups, or for specific state needs would be collected in addition to the HPMS data. The state will have to decide how much, if any, its coverage count program can be reduced. The HPMS inventory and special traffic counts would be used in place of any eliminated coverage counts.

Changes to the volume counting procedures for HPMS occur for the frequency and duration of the HPMS counts. The three-year count cycle results in roughly 510 HPMS counts each year. These counts, however, are to be taken for 48 hours, rather than 24 hours. The effect of this change on the traffic count budget is difficult to determine. The actual number of HPMS counts currently taken each year is unclear, as these counts are collected as a part of the overall coverage count program. It is recommended that the state collect the entire HPMS sample on the recommended three-year cycle, rather than over the seven years needed for the current coverage count cycle. The changes will improve the accuracy of the HPMS data.

Some changes in the scheduling of HPMS counts may be necessary due to the reduction of the coverage count program and the inclusion of vehicle classification and truck weighing into an integrated HPMS process.

Vehicle Classification Counts

The vehicle classification program is also reduced as a result of the new program. The recommended program allows for monitoring roughly 300 locations every three years, or roughly 100 per year. Each count is either a 16-hour manual count, or a 24-hour automatic count. The existing program manually counts 38 locations eight times a year, or 304 seven-hour sessions. This would compare to 200 eight-hour counts for the new program. (The state DOT may need to retain the practice of using two seven-hour counts rather than one 16-hour count due to labor issues, but this should not significantly affect the accuracy of the sample.) A recommended alternative would be to collect as much of this data as possible with 24-hour continuous automatic equipment counters.

The vehicle classification strata are defined by the functional classification of roads, without further stratification by volume group. Exhibit Maine-5 shows the sample sizes chosen for Maine's HPMS vehicle classification sample. For example, this exhibit shows that 30 monitoring sessions should be selected from the 60 HPMS rural interstate sections to achieve the estimated percentage of 3S2 trucks within 31 percent (i.e. an estimate of 12 percent plus or minus 3.7 percent.)

The 300 counts selected for Maine should be taken randomly from all days within the count cycle from the existing HPMS volume sections. The counts should be spread evenly throughout all three years. Since a true random sample may not be feasible, a systematic approach may be necessary. Such an approach might be to collect data at roughly 100 locations three times each. The three sessions for each location could be selected randomly from:

- all days within the three-year count cycle;
- one year of the count cycle; or
- a different year for each count (i.e., monitor one location in year one, one in year two, and one in year three).

Professional judgment was used to determine the appropriate level of accuracy for each functional classification. A confidence interval of 95 percent was used for all functional classes. The graphs in Exhibits A-2 through A-9 were used to determine the sample sizes. The necessary sample sizes were selected by reading the X axis of the graph for the desired accuracy off the Y axis of the graph. Appendix A includes an example of the use of these graphs.

EXHIBIT MAINE-5

Vehicle Classification Sample

Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Rural: Interstate				
0-10	39			
10-20	12			
20-30	9			
Total	60	30 counts	30%	15%
Other Principal Arterials				
0-5	246			
5-10	54			
10-15	12			
15-20	4			
Total	316	30 counts	35%	12%
Minor Arterials				
0-2.5	111			
2.5-5	25			
5-10	10			
10-20	5			
Total	151	30 counts	40%	11%
Collectors				
0-2.5	91			
2.5-5	15			
5-10	5			
Minor Collectors				
0-1	155			
1-2	25			
2-3	6			
3-5	14			
Total Collectors	311	50 counts	40%	10%

Urbanized and small Urban

	Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Urban: Interstate					
	0-10	116			
	10-20	27			
	20-30	3			
	Total	146	48 counts	30%	9%
Other Principal Arterials					
	0-5	47			
	5-10	73			
	10-15	71			
	15-20	33			
	20-25	7			
	25-30	7			
	30-35	2			
	Total	240	40 counts	35%	10%
Minor Arterials					
	0-2.5	95			
	2.5-5	52			
	5-10	45			
	10-15	13			
	15-20	15			
	20-25	2			
	Total	220	30 counts	40%	12%
Collectors					
	0-1	124			
	1-2	66			
	2-5	101			
	5-10	33			
	Total	324	30 counts	60%	18%

Speed Monitoring

No changes are recommended for the speed monitoring program element.

Truck Weight Monitoring

Like the vehicle classification program element, the size of the truck weight program is a function of the level of precision wanted by the state. Professional judgment was used to determine desirable levels of accuracy within a 95 percent confidence interval for computing sample size. The default sample size versus precision curves found in Exhibits A-10 through A-17 were used to calculate the required sample size for the selected levels of precision. The selected truck weight sample size and levels of precision are shown in Exhibit Maine-6.

The selection of actual truck weight locations for Maine should take into account the availability of the WIM system they are currently purchasing. This in turn may slightly affect the selection of vehicle classification sites, but it should not significantly affect the accuracy of the recommended data collection process.

The truck weight monitoring locations are to be selected from the vehicle classification locations. Ideally, measurements should be selected randomly from the vehicle class locations and days. In practical terms, a more systematic approach is more appropriate. For example, Exhibit Maine-6 indicates that 20 monitoring sessions are necessary to collect 3S2 weight data within 11 percent accuracy and 95 percent confidence for rural interstates. A systematic approach might be to monitor seven different rural interstate locations three times each. Each of the three counts at a location would be taken during a different part of the year (e.g., March, August, November). The measurements at each of the stations could be spread between the three years as best suits the budgetary restrictions of the state, or one count could be taken each year at each location. Each truck weight session should also include complete vehicle classification data, which will be used in place of a separate vehicle classification count at that location.

Special Study Counts

The number of monitoring sessions taken in the special study category may increase. The reduction of the coverage count program may deprive some data users of count data they need, and these needs will often have to be filled by the special count program. The HPMS sample and inventory should be utilized whenever possible, but some data needs will not be met by the HPMS data.

EXHIBIT MAINE-6

TRUCK WEIGHT SAMPLE SIZE

	Vehicle Classification Sample Size	Truck Weight Sample Size	3S2 Precision	Total Weight Precision
Rural:				
Interstate	30	20	11%	15%
Other Principal Arterials	40	15	20%	25%
Minor Arterials	30	11	30%	36%
Collectors	48	6	30%	43%
Urban:				
Interstates & Freeways	48	3	40%	47%
Other Principal Arterials	40	3	42%	60%
Minor Arterials	30	3	97%	94%
Collectors	30	3	97%	97%

The special data collection program element should be used to collect all kinds of traffic data not supplied by the countinuous counters, coverage counts, or the HPMS data base. This could include, but not be limited to, site specific volume counts, special studies for determining in-state versus out-of-state travel, or any other set of data the state may desire.

An increase in the special data program may actually benefit a majority of users when compared with the existing program, in that the special count program should quickly address existing needs in all parts of the state.

OHIO

The Ohio traffic monitoring program currently contains the following elements:

- Continuous Counts;
- Coverage Counts (including HPMS volume counts);
- Vehicle Classification Counts;
- Truck Weight Monitoring; and
- Special Counts.

The HPMS volume counts are taken at the same time the coverage counts are taken, and will be discussed under that heading.

The effects of implementing the recommended traffic monitoring program in Ohio can be summarized as follows:

- a new seasonal factoring procedure should be used;
- the coverage count program can be reduced;
- the number of regularly scheduled vehicle classification counts will be reduced, although additional vehicle classification counts may be added to the special data collection program; and
- the special data collection program will be expanded.

The effect of the program on the Ohio truck weight monitoring program is unclear because insufficient data were available as to the current size of this program now that the state is using WIM equipment.

While the state also performs speed monitoring, this particular aspect of traffic monitoring is beyond the scope of this project. The speed monitoring program is, therefore, left unchanged.

Continuous Counts

The grouping of ATRs by functional class for Ohio indicated that there is more variability in the seasonal patterns among these roads than for the majority of the other states examined. It is unclear whether this is due to the actual traffic on those roads, or whether errors in the data caused additional variation in the seasonal factor groups that does not actually exist. Considerable difficulty was experienced preparing the ATR data contained in FHWA files for this analysis of the Ohio program. The available data had a considerable number of missing data points and other obvious errors, and these and other possible errors may have had a significant effect on the outcome of the analysis.

The final selection of seasonal factor groups for Ohio is very similar to their current factor groupings. The current and recommended factor groups are shown in Exhibit Ohio-1. As stated above, the variation within the recommended factor groups was higher than for most of the other example states. Regional stratifications did not reduce this variation, so the state is treated as a whole, without regions.

The lack of a need for regional breakdowns means that considerably fewer ATR stations are needed to provide seasonal adjustment factors for the entire state. As can be seen in Exhibit IV-3 in the main body of this report, the benefits from ATR stations decrease sharply in comparison to the cost of servicing them after approximately eight counters are achieved per group. It is therefore recommended that no factor group have more than eight counters, although this is a relatively arbitrary number, and Ohio may wish to keep more or fewer ATRs in a factor group.

Three of the recommended factor groups have more than eight counters. This means that Ohio can reduce the total number of ATR locations by six. However, three of the factor groups have only four counters. It is recommended that these factor groups be increased to six counters to provide for improved data for the seasonal factors. These two recommendations together result in no change in the total number of ATRs for the state.

EXHIBIT OHIO-1

CURRENT AND RECOMMENDED SEASONAL FACTOR GROUPS

Current	Recommended
Rural Interstate	Rural Interstate
Rural Interstae (I-75)	
Rural Highways 1000 ADT South of US-30	Rural Principal Arterials
Rural Highways 1000 ADT North of US-30	
Rural Highways 1000 ADT	Rural Minor Arterials
	Rural Collectors
Rural Recreational	
Urban 40,000 ADT	Urban Interstates
Urban with ADT 15,000 and ADT 40,000	Urban Principal Arterials
Urban with ADT 15,000	Urban Minor Arterials and Collectors

HPMS and Coverage Counts

The Ohio coverage count program currently takes four years to cover the entire state. HPMS volume counts are taken at the same time as these counts. The recommended program would collect only the HPMS counts, counts for estimating VMT off of the HPMS system, counts for updating the HPMS volume group classifications, and other counts specifically needed by the state. The state DOT indicated that their coverage count program fulfilled specific state needs that could not be met through the HPMS. It is therefore unclear exactly what savings the state can make in the reduction of its coverage count program.

The recommended program would increase the frequency of HPMS counts to every three years. The counts would also become 48-hour machine counts, rather than 24-hour machine counts. (Manual counts will be discussed under vehicle classification counts.) Ohio would need to take 992 counts per year to satisfy the HPMS volume count needs of the recommended program. Other counts would be necessary for updating the volume strata of HPMS sections not included in the volume sample as well as for other reasons. These counts compare to the roughly 6,000 machine counts currently being taken for all purposes every year.

Vehicle Classification Counts

Because of the industrial nature of much of the state of Ohio, it is suggested that the state stratify its vehicle classification counts for rural interstates and principal arterials by high and low volume roads. For this appendix, high volume roads are considered to be those roads with AADT greater than 20,000 vehicles per day. Since data are not available to indicate a reduction in the variation within the vehicle class strata resulting from this stratification, this causes an increase in the vehicle classification sample size.

Exhibit Ohio-2 shows the selected vehicle classification sample sizes and levels of precision. The data in Appendix A are used to calculate these estimates, with the data for each full stratum being used for both high and low volume roads.

EXHIBIT OHIO-2

Vehicle Classification Sample

	Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Rural:	Interstate				
Low	Group 1	9			
Vol	Group 2	68	50 counts	23%	10%
	Group 3	35			
HI	Group 4	5			
Vol	Group 5	1			
	Total	118	50 counts	23%	10%
Other	Principal				
	Group 1	256			
Low	Group 2	86	40 counts	35%	12%
Vol	Group 3	24			
	Group 4	3			
Hi	Group 5	7			
Vol	Group 6	1			
	Total	377	40 counts	35%	12%
Minor	Arterials				
	Group 1	84			
	Group 2	47			
	Group 3	20			
	Group 4	7			
	Total	158	30 counts	40%	11%
Collectors					
	Group 1	71			
	Group 2	13			
	Group 3	10			
	Group 4	9			
Minor	Collectors				
	Group 1	142			
	Group 2	19			
	Group 3	3			
	Group 4	19			
	Group 5	6			
	Total Collectors	292	50 counts	40%	10%

Urbanized and small Urban

		Vehicle Classification Sample		
Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Urban: Interstate				
Group 1	305			
Group 2	193			
Group 3	54			
Group 4	22			
Group 5	41			
Group 6	4			
Total	619	50 counts	30%	9%
Other Principal Arterials				
Group 1	104			
Group 2	195			
Group 3	166			
Group 4	94			
Group 5	54			
Group 6	48			
Group 7	21			
Total	682	40	35%	10%
Minor Arterials				
Group 1	94			
Group 2	74			
Group 3	74			
Group 4	43			
Group 5	18			
Group 6	13			
Group 7	10			
Total	326	30	40%	12%
Collectors				
Group 1	105			
Group 2	73			
Group 3	132			
Group 4	55			
Group 5	26			
Group 6	8			
Group 7	3			
Total	402	30	60%	18%

The 410 counts selected for Ohio should be taken randomly from all days within the count cycle for the existing HPMS volume sections. The counts should be spread evenly throughout all three years. A systematic approach to this might be to collect data at 100 locations three times each, and data from another 110 locations once during the cycle. For those locations counted three times, the three sessions could be selected randomly from:

- all days within the three-year count cycle;
- one year of the count cycle; or
- a different year for each count (i.e., count one in year one, one in year two, and one in year three).

Professional judgment was used to determine the appropriate level of accuracy for each functional classification. A confidence interval of 95 percent was used for all functional classes. The graphs in Exhibits A-2 through A-9 were then used to determine the sample sizes. Appendix A includes a description of how these graphs are used.

Currently, Ohio takes vehicle classification counts as a part of their coverage count program. Roughly 2,200 of their 8,200 coverage counts are manual counts that include vehicle classification information. In addition, Ohio takes vehicle classification data at its 14 fixed truck weight locations four times a year. The recommended program would reduce the amount of regularly scheduled vehicle classification counts to 410 sessions every three years, or roughly 135 per year. If this reduction in counts hinders some data user needs, additional vehicle classification counts can be taken as part of the special data collection element. As an option, given Ohio's current large vehicle classification program, these counts could be taken annually.

It is recommended that Ohio reduce the number of manual classification counts it takes, and utilize more automatic counters. This should result in a more cost effective vehicle classification program.

A final change to the Ohio vehicle classification program element is the need for the state to revise the vehicle classifications used to conform to the newly issued federal guidelines. This should result in some improvement to the data available for state data users, although it will increase the number of vehicle categories collected in some instances.

Truck Weight Monitoring

The recommended number of truck weight monitoring sessions for each functional class of road is presented in Exhibit Ohio-3. As with the number of vehicle classification counts, the recommended number of weight monitoring locations is dependent on the level of precision required by the state, and may vary from those shown in the exhibit as a result of state needs. As stated earlier, it is unclear how many truck weight locations the state is currently operating, because Ohio's WIM equipment was not in operation at the time of the state interviews. It is therefore not possible to compare the recommended and current truck weight programs at this time.

The selection of actual truck weight locations for Ohio should take into account the availability of the bridge WIM system currently used. This may slightly affect the selection of vehicle classification sites, but it should not significantly affect the accuracy of the recommended data collection process.

The truck weight monitoring locations are to be selected from the vehicle classification locations. Ideally, location-days should be selected randomly from the vehicle class location-days. In practical terms, a more systematic approach is more appropriate. For example, Exhibit Ohio-3 indicates that 20 monitoring sessions are necessary to collect 3S2 weight data within 11 percent accuracy and 95 percent confidence for rural interstates. A systematic approach might be to monitor seven different rural interstate locations three times each. Each of the three sessions at a location would be during a different time of the year (e.g., March, August, November). The sessions at each of the stations could be spread between the three years as best suits the budgetary restrictions of the state, or one session could be taken each year at each location. A vehicle classification count would also be taken at each weight monitoring site at the same time as the weight monitoring. This classification count would be part of the required 410 counts per cycle described above.

Special Counts

Ohio DOT currently takes traffic counts for the MPOs in the state, as well as other "special" data. The recommended traffic monitoring program may expand this program to include other requested data not collected through one of the other program elements. This may include vehicle classification counts, additional truck weight monitoring, or any other traffic data need for specific sites that would normally be provided by the state highway department. Non-site-specific data should be available through one of the other traffic monitoring elements.

Other Ohio DOT "special" programs, such as the collection of data at railroad grade crossings, should continue, although the frequency of these counts should be reviewed by the department.

EXHIBIT OHIO-3

TRUCK WEIGHT SAMPLE SIZE

	Vehicle Classification Sample Size	Truck Weight Sample Size	3S2 Precision	Total Weight Precision
Rural:				
Interstate	100	20	11%	15%
Other Principal Arterials	80	15	20%	25%
Minor Arterials	30	11	30%	36%
Collectors	50	3	44%	60%
Urban:				
Interstates & Freeways	50	9	26%	35%
Other Principal Arterials	40	6	29%	43%
Minor Arterials	30	3	96%	94%
Collectors	30	3	96%	96%

OREGON

The Oregon DOT traffic monitoring program currently contains the following elements:

- Continuous Counts;
- Coverage Counts (including HPMS volume counts);
- Vehicle Classification Counts;
- Truck Weight Monitoring; and
- Special Counts.

Volume counts for the HPMS are obtained from the regularly scheduled coverage count program. As a result, the recommended HPMS volume counting procedures will be discussed under the coverage count heading.

As with the other states, Oregon also performs speed monitoring. This program element is beyond the scope of this project. Therefore, the recommended traffic monitoring program does not make changes to the speed monitoring program element.

The impacts of the recommended program on the Oregon DOT traffic monitoring program can be summarized as follows:

- the number of continuous counter locations is reduced with some counters being moved;
- the seasonal factoring process is changed slightly;
- the coverage count program is reduced;
- the number of vehicle classification counts taken per year is reduced, and the locations altered; and
- the size of the special count program is increased.

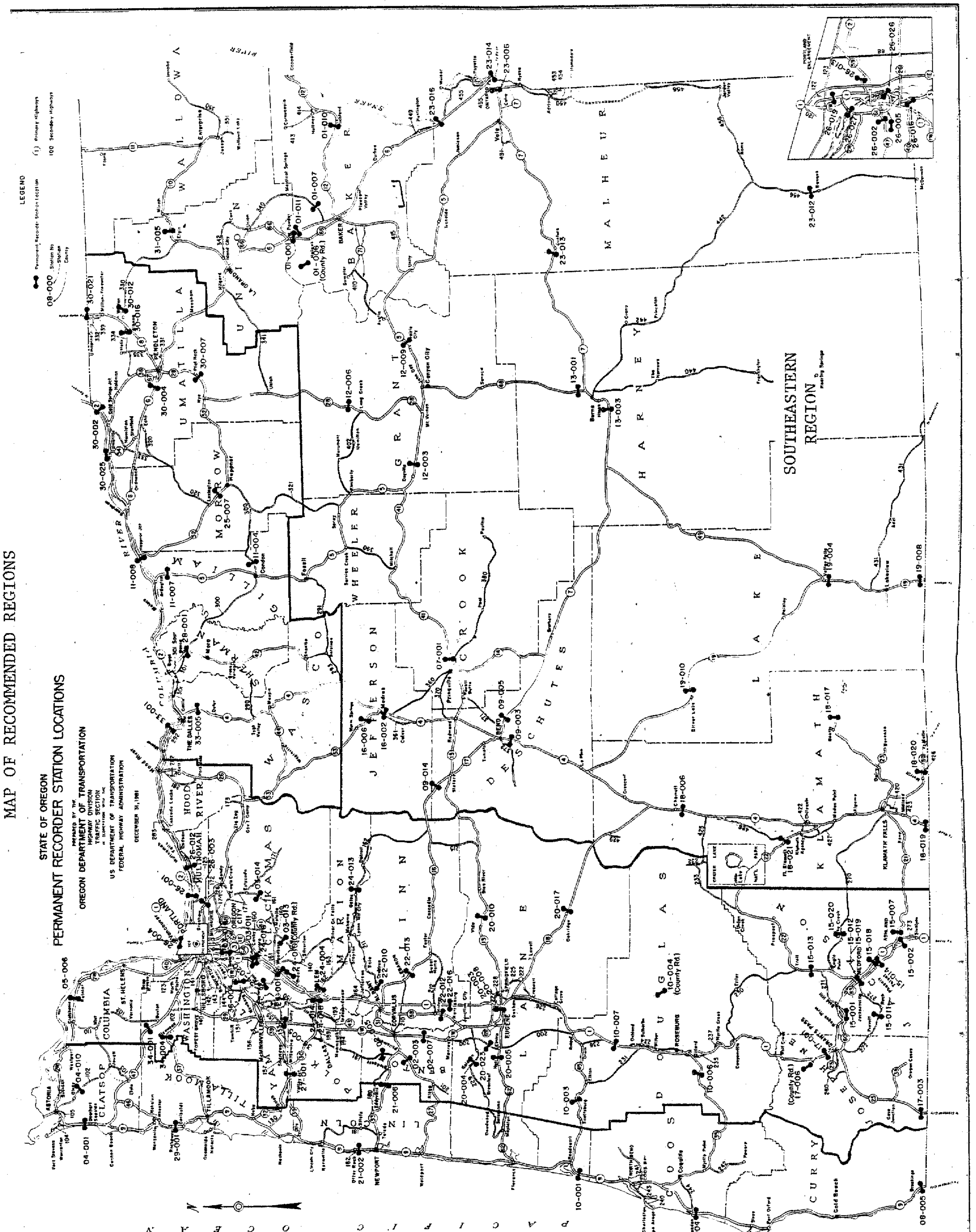
The effects of the recommended program on Oregon's truck weight monitoring cannot be analyzed, as Oregon has temporarily suspended its weight monitoring program subject to the release of new federal guidelines.

Continuous Counts

Oregon DOT currently operates 115 ATR locations in four regions of the state. The recommended program uses only two rural regions (see Exhibit Oregon-1) and one urban region within the state, although the state may decide to keep several roads separate as special recreational routes. The recommended seasonal factor groups are presented in Exhibit Oregon-2. The

EXHIBIT OREGON-1

MAP OF RECOMMENDED REGIONS



recommended groupings are based on the original Oregon regions. An examination of the available data showed that differences in the seasonal traffic patterns between several of the current regions were not large enough to warrant keeping them separate in this analysis. This is illustrated in Exhibit Oregon-3 for the Minor Arterial functional class.

As can be seen in Exhibit Oregon-1, the 115 ATR locations are split between only 8 factor groups in the recommended program. This is an average of over 14 counters per factor group. In Exhibit IV-3 in the main body of this report, the advantages of maintaining more than eight ATR locations per factor group are shown to decrease in comparison to the cost of operating them. If the state accepts the recommended factor grouping, and eight counters are accepted as a maximum number per factor group, it will be possible for the state to eliminate as many as 51 ATR locations. As stated in the other case studies, the choice of eight ATRs as the maximum number of ATRs per factor group is somewhat arbitrary, and the state may decide that another number is more appropriate.

Oregon will have to move 11 ATR locations if they wish to have eight counters in each seasonal factor group. Currently, the Urban Principal Arterial group has only 3 stations, while the Urban Minor Arterial and Collector group has only 2. The movement of count locations would result in a one time cost to the state, but this cost would be offset by the savings resulting from the the reduction in the total number of ATRs from 115 to 64. This savings could be as much as $84,000 per year for the state (51/115 * $190,000/year ATR budget). However, Oregon may wish to maintain some of these ATRs for other reasons such as trend data.

HPMS and Coverage Counts

The Oregon coverage count program is performed on a two-year cycle. During this cycle, HPMS volume counts are also collected. During one year, the state collects data for state roads, while in the second year, the state collects data on FAS county roads. It is unclear exactly how many of these road segments are included on the HPMS inventory and how many are not included in the inventory. There are, however, only 1,930 HPMS volume count sample sections in the state of Oregon.

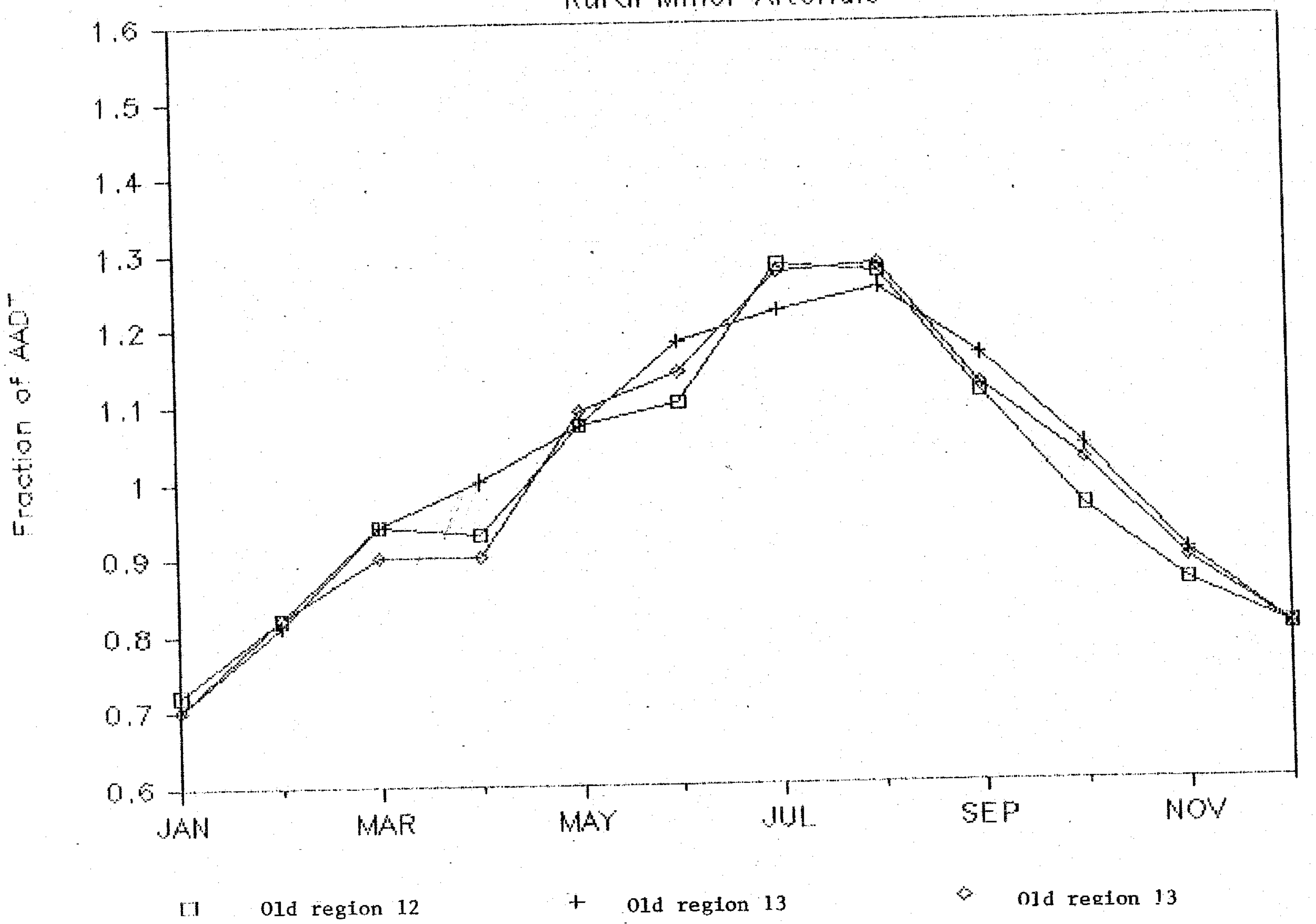
The recommended HPMS program element would cut back the coverage count program to a third of the HPMS volume sections, or 643 sections per year, plus whatever non-HPMS counts are needed by the state on a regular basis (e.g., counts for updating the volume grouping of other HPMS sections, or data for local road estimation). However, the HPMS volume counts would be counted for 48 hours rather than the 24 currently counted.

EXHIBIT OREGON-2

NUMBER OF EXISTING ATRs IN RECOMMENDED FACTOR GROUPS

	Interstates and other Freeways	Other Principal Arterials	Minor Arterials	Collectors
Southeast Rural	14	13	13	
Other Rural		27	27	
Urban	13	3	2	

EXHIBIT OREGON-3



Rural Minor Arterials

Graphs of Minor Arterial Seasonal Patterns for the three old regions that were combined into "Other Rural"

Vehicle Classification Counts

Oregon currently takes one manual vehicle classification counts at 113 ATR locations every three years, an average of 38 counts per year. The recommended program would increase the number of vehicle classification counts to roughly 105 per year (320 on a three-year cycle). These counts are broken down by functional class in Exhibit Oregon-4. The number of count locations selected for the HPMS vehicle class subelement is dependent on the level of precision desired by the state, so the actual number of counts needed by the state may vary from those shown in Exhibit Oregon-4. The state will need to examine its particular needs and budgetary constraints before determining these precision levels.

The 320 counts selected for Oregon should be taken randomly from all days within the count cycle for the existing HPMS volume sections. The counts should be spread evenly throughout all three years. A systematic approach to this might be to collect data at 105 locations three times each. The three sessions for each location could be selected randomly from:

- all days within the three-year count cycle;
- one year of the count cycle; or
- a different year for each count (i.e., count one in year one, one in year two, and one in year three).

Professional judgment was used to determine the appropriate level of accuracy for each functional classification. A confidence interval of 95 percent was used for all functional classes. The graphs in Exhibits A-2 through A-9 were used to determine the sample sizes. Appendix A includes a description of how these graphs are to be used. It is further recommended that the state make use of automatic vehicle classification equipment wherever possible.

Truck Weight Monitoring

The number of days of truck weight monitoring necessary for each functional class of roadway is shown in Exhibit Oregon-5. As for the vehicle classification data, the number of days is a function of the precision desired, and the actual number of counts taken by Oregon may change depending on the available budget and the accuracy needed.

EXHIBIT OREGON-4

		Vehicle Classification Sample		
Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Rural: Interstate				
Group 1	53			
Group 2	46			
Group 3	6			
Group 4	9			
Group 5	3			
Group 6	1			
Total	118	50 counts	23%	10%
Other Principal Arterials				
Group 1	205			
Group 2	58			
Group 3	12			
Group 4	5			
Group 5	2			
Total	282	40 counts	35%	12%
Minor Arterials				
Group 1	100			
Group 2	23			
Group 3	15			
Group 4	3			
Total	141	30 counts	40%	11%
Collectors				
Group 1	116			
Group 2	13			
Group 3	8			
Group 4	3			
Minor Collectors				
Group 1	142			
Group 2	14			
Group 3	3			
Group 4	3			
Total Collectors	302	48 counts	40%	10%

Urbanized and small Urban

Vehicle Classification Sample

Volume Group	HPMS Sample Size	Vehicle Class Sample	Precision by 3S2	Precision by Volume
Urban: Interstate				
Group 1	41			
Group 2	46			
Group 3	21			
Group 4	14			
Group 5	6			
Group 6	1			
Total	122	48 counts	30%	9%
Other Principal Arterials				
Group 1	55			
Group 2	95			
Group 3	57			
Group 4	42			
Group 5	30			
Group 6	15			
Group 7	7			
Group 8	6			
Group 9	1			
Group 10	1			
Total	309	40	35%	10%
Minor Arterials				
Group 1	93			
Group 2	88			
Group 3	73			
Group 4	28			
Group 5	14			
Group 6	6			
Group 7	5			
Total	307	30	40%	12%
Collectors				
Group 1	132			
Group 2	87			
Group 3	91			
Group 4	31			
Group 5	6			
Group 6	2			
Total	349	30	60%	18%

EXHIBIT OREGON-5

TRUCK WEIGHT SAMPLE SIZE

	Vehicle Classification Sample Size	Truck Weight Sample Size	3S2 Precision	Total Weight Precision
Rural:				
Interstate	50	25	10%	13%
Other Principal Arterials	40	25	15%	20%
Minor Arterials	30	12	28%	33%
Collectors	48	6	30%	43%
Urban:				
Interstates & Freeways	48	3	40%	47%
Other Principal Arterials	40	3	42%	60%
Minor Arterials	30	3	97%	94%
Collectors	30	3	97%	97%

The truck weight monitoring locations are to be selected from the vehicle classification locations. Ideally, counts should be selected randomly from the vehicle classification location-days, although the proposed sites would have to be examined to see if they could be used given Oregon's truck weighing equipment.

In practical terms, a more systematic approach is more appropriate. For example, Exhibit Oregon-5 indicates that 25 monitoring sessions are necessary to collect 3S2 weight data for rural interstates within 10 percent accuracy and 95 percent confidence. A systematic approach might be to count eight different rural interstate locations three times each (plus one location a fourth time). Each of the three counts at a location would be taken during a different part of the year (e.g., March, August, November). The counts at each of the stations could be spread between the three years as best suits the budgetary restrictions of the state, or one count could be taken each year at each location.

Special Counts

The number of monitoring sessions taken in the special study category may increase. Any reduction of the coverage count program may deprive some data users of count data they need, and these needs will often have to be filled by the special count program. The HPMS sample and inventory should be utilized whenever possible, but some data needs will not be met by the HPMS data.

The special data collection program element should be used to collect all kinds of traffic data not supplied by the countinuous counters or the HPMS data base. This could include, but not be limited to, site specific volume counts, special studies for determining in-state versus out-of-state travel, or any other set of data the state may desire.

APPENDIX E

STATISTICAL DEFINITIONS

APPENDIX E--STATISTICAL DEFINITIONS AND DERIVATIONS

This appendix is intended to provide the reader with a means of following the statistical equations presented in the main body of this report. The first part of this appendix presents the derivation of the equations in the main body of the paper. The remainder of the appendix presents a list of definitions of the terms used in the equations.

EQUATION DERIVATION

Several methods of estimating the standard error of a traffic estimate have been presented in the past. This document expands on the methodologies presented in the document, Guide to Urban Traffic Volume Counting, by Robert Ferlis, Larry Bowman, and Bart Cima of Peat Marwick, for FHWA, February 1980. In that document, the error in a volume estimate is divided into two terms, "internal" error and "external" error. Internal error contains locational, daily, and seasonal terms. It is affected by sample size. The external error includes axle correction and seasonal adjustment terms. It is stated that these terms are unaffected by sample size. This study differs in that we assume that the axle correction and the seasonal adjustment factors contribute errors which are affected by the sample size of the counts used to calculate the estimates. In the Guide to Urban Traffic Volume Counting, these terms were given, not calculated as a part of the counting process. A statewide traffic monitoring program, however, is in charge of collecting the data that determines these values and thus can affect their precision, by altering the data collection procedures. Axle correction adjustment terms and seasonal adjustment terms are therefore included in the equations for calculating the standard error of a traffic estimate.

The equations presented in the text of this document are also in a slightly different form than those in the Guide to Urabn Traffic Volume Counting. The main difference is that some of the variance terms on the right sides of equations are not simply divided by the sample size used to collect the data used in estimating the factor. For example, equation 2 contains the term:

$$\mathrm{SVOLS}^2 * \left(1+\frac{1}{\mathrm{ncc}}\right)$$

where this might normally be presumed to be:

$$\mathrm{SVOLS}^2/\mathrm{ncc}$$

For the above, ncc equals the number of classification counts used to estimate the seasonal factor. That factor has a standard deviation equal to SVOLS.

It is our contention that the seasonal factor contributes two sources of error, an error in the estimated mean value (the factor) and an error due to the distribution of the actual values that are the population. The first of these is the error in the factor itself, the difference between the estimate and the "true" average seasonal adjustment factor for that factor group. This error is affected by the number of samples used to estimate it. The second portion of error is that due to the difference between the "true" average for the strata, and the actual value for that road section.

For estimates of traffic at specific locations, this portion of the error is not affected by the sample size, and thus contributes the entire standard error of the factor. In equation 2 the first of these errors is that represented by the term 1/ncc, the second is represented by the value 1. It should be noted that the same data used to estimate the deviation in the mean value is also the data that provides the estimate of the deviation in the population. The standard deviation of the mean and the population are therefore the same for these cases.

This same effect occurs for axle correction and for growth. Daily and locational variance, however, do not exhibit this characteristic. These terms are therefore completely affected by the number of monitoring sessions used to compute the desired estimate.

The estimation of an average value for a stratum (as in equations 3 and 7), rather than a value for a single location, creates a slightly different form of equation 2 to develop. The two sources of error are still present for seasonal, axle, and growth variance, but the manner in which these effects are computed changes slightly. For volume estimation, the number of counts taken within a stratum affects the difference between the true mean value and that of the sample. The greater the sample, the less the difference between the sample mean and the stratum mean. Equation 2 changes to accommodate this and results in equation 3. As an example, the seasonality term presented earlier in this appendix becomes:

$$SVOLS_h{}^2 * \left(\frac{1}{n_h} + \frac{1}{ncc_h} \right)$$

This version of the basic equation indicates that the error from the seasonal factor is still affected by the number of counts taken to compute the factor. The error from the difference between the population mean and the computed stratum mean, however, decreases as the number of volume counts grows (i.e., as the sample grows, the mean of the sample will approach the mean of the population, and there will be no error from this source).

The vehicle classification and truck weight equations continue to use the basic format shown above, where several sources of error have two basic forms, the error in the mean estimate, and the error due to the difference between the actual estimate and the true mean value of the population.

The calculation of standard error for individual estimates or for stratum estimates of percentage of vehicle classification and for weight per vehicle type is a simple extension of the formulas for estimating volumes. The only differences are from the substitution of terms. For example, the variance across days of the percentage of vehicles is substituted for the variance of volume across days. In addition, there are no terms for axle correction or growth in the computation of the standard error of the vehicle classification percentage estimate or of the truck weight estimate.

A second type of formula was necessary for determining error in estimates that are made by multiplying two previous estimates together. For example, the estimated number of 3S2 trucks at one location can be computed as the estimated volume times the estimated percentage of 3S2 trucks. The error calculation for this type of estimate is determined using formulas derived for applying ratio estimates. The text Sample Survey Methods and Theory by Hansen, Hurwitz, and Madow, published by John Wiley and Sons, New York, 1953, serves as the basis for deriving these equations (see volume 1, page 163.

Equation 9 is derived from the data in this source, and the covariance term is assumed equal to zero. This results in equation 10:

which serves as a model for further derivations.

the basic form of equation 10 is used to provide the basis for estimates of volume by vehicle type and total weight by vehicle type. This form is simply the square of the products of the two estimated values times the sum of their squared coefficients of variation. This same basic formula is used in equations 10, 13, 17, 26, 28, and 31. The major differences between these equations and equation 10 are in the substitution of terms. For example, the estimated values for EALs and the deviation of the EAL estimate are substituted for the estimates of percentage of traffic by vehicle type and the standard deviation of that estimate when equation 10 is used to estimate total EALs by vehicle type as in equation 26.

DEFINITION OF TERMS

Listed below are definitions of all terms used in the equations presented in this report. Variables are defined systematically, following the protocol listed below:

- the capital letter S at the begining of a term always indicates that the term is a standard deviation or error;
- the lower case i indicates "for the vehicle type i";
- the lower case j indicates "for the location j";
- the lower case h indicates "for the stratum h"; and
- the lower case k indicates "for the vehicle k".

Once the reader becomes familiar with the system, he or she should be able to readily identify any variable using these basic notations and an understanding of the root variable. A list of the specific terms used in this report is presented below:

COV = the coefficient of variation for an estimate.

d = the accuracy of an estimate, expressed as a fraction of that estimate (i.e., multiply by 100 to express as a percentage).

EAL_{ih} = the average equivalent axle load for vehicle type i for stratum h.

EAL_{ih} = the total equivalent axle load for vehicle type i for stratum h.

EAL_{ihk} = the equivalent axle load for vehicle k of vehicle type i for stratum h.

EAL_{ij} = the average equivalent axle load for vehicle type i for location j.

EAL_j = the total equivalent axle load at location j.

GF = a growth factor estimate.

GF_1 = a growth factor estimate based on the counts from the current year and those same locations from a previous iteration of the count cycle.

GF_2 = a growth factor estimate based on the counts from the previous year and those same locations from a previous iteration of the count cycle.

$Miles_h$ = the number of miles of roads in stratum h.

n = the number of monitoring sessions taken.

n_h = the number of monitoring sessions taken in stratum h.

ncc = the number of control locations used to calculate the seasonal factor.

ncc_h = the number of control locations used to calculate the seasonal factor for stratum h.

ncc_{sh} = the number of control locations used to calculate the seasonal variation or seasonal factor for vehicle mix for stratum h.

nd = the number of days of monitoring used to estimate volume at a location.

ngf = the number of count locations used to estimate the growth factor.

nhr = the number of monitoring locations used to estimate the variation in percentage of vehicle mix across hours.

ntw_h = the number of truck weight monitoring sessions for stratum h.

ntw_{sh} = the number of truck weight monitoring sessions for determining seasonal variation for stratum h.

nvc = the number of vehicle classification counts used to estimate the axle correction factor.

nvc_h = the number of vehicle classification counts used to estimate the axle correction factor for stratum h.

PVC_{ih} = the average percentage of volume contributed by vehicle type i for stratum h.

PVC_{ij} = the percentage of volume contributed by vehicle type i at location j.

$SEAL_{ih}$ = the standard error of the average equivalent axle load for vehicle type i for stratum h.

$SEAL_{ih}$ = the standard error of the total equivalent axle load for vehicle type i for stratum h.

$SEAL_{j}$ = the standard error of the total equivalent axle load for location j.

$SEALD_{ih}$ = the standard deviation across days of the average equivalent axle load for vehicle type i for stratum h.

$SEALL_{ih}$ = the standard deviation across locations of the average equivalent axle load for vehicle type i for stratum h.

$SEALS_{ih}$ = the standard deviation across seasons of the average equivalent axle load for vehicle type i for stratum h.

SGF = the standard error of the growth factor estimate.

$SPVC_{ih}$ = the standard deviation of the average percentage of volume contributed by vehicle type i for stratum h.

$SPVC_{ij}$ = the standard deviation of the percentage of volume contributed by vehicle type i at location j.

$SPVCD_{ih}$ = the standard deviation of the percentage of vehicles of type i for stratum h across days.

$SPVCH_{ih}$ = the standard deviation of the percentage of vehicles of type i for stratum h across hours.

$SPVCL_{ih}$ = the standard deviation of the percentage of vehicles of type i for stratum h across locations.

$SPVCS_{ih}$ = the standard deviation of the percentage of vehicles of type i for stratum h across seasons.

$SPVCT_{ih}$ = the standard deviation of the percentage of vehicles of type i for stratum h across all purposes, as a composite.

SVOL = the standard error of the average volume for combined strata.

$SVOL_i$ = the standard error of a volume estimate for vehicle type i for combined strata.

$SVOL_{ih}$ = the standard error of the average volume of vehicle type i for stratum h.

$SVOL_{ij}$ = the standard error of the volume of vehicle type i at location j.

$SVOL_j$ = the standard error of a volume count at location j.

SVOLA = the standard deviation of volume due to deviation in the average number of axles per vehicle.

$SVOLA_h$ = the standard deviation of volume due to deviation in the average number of axles per vehicle for stratum h.

SVOLD = the standard deviation of volume across days.

$SVOLD_h$ = the standard deviation of volume across days for stratum h.

$SVOLL_h$ = the standard deviation of volume across locations for stratum h.

SVOLS = the standard deviation of volume across seasons.

$SVOLS_h$ = the standard deviation of volume across seasons for stratum h.

VMT_{ih} = the vehicle miles of travel for vehicle type i within stratum h.

VOL = a volume estimate.

VOL_h = the average volume estimate for stratum h.

VOL_{h1} = the average volume estimate for stratum h for the current year of the count cycle.

VOL_{h2} = the average volume estimate for stratum h for the previous iteration of the count cycle.

VOL_i = the volume estimate for vehicle type i (for combined strata).

VOL_{ih} = the volume estimate for vehicle type i for stratum h.

VOL_{ij} = the volume estimate for vehicle type i at location j.

VOL_j = the volume estimate for location j.

z = the normal variate for the specified confidence interval.