Final Report

for

The Traffic Monitoring Program Research Project: Comparison of TDOT Practices with those of Selected States

prepared for

Tennessee Department of Transportation

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16. Abstract

This report presents the findings of research on traffic monitoring programs undertaken for TDOT's Long Range Planning Division by Tennessee Technological University's Civil and Environmental Engineering Department. The primary purpose of the research was to determine best practices for a traffic monitoring program based on an in-depth review of the Traffic Monitoring Programs of nine selected State Departments of Transportation and the Federal Highway Administration's *Traffic Monitoring Guide*.

The project included six key research objectives, namely 1) to review and compare Tennessee Department of Transportation's Traffic Monitoring program with that of the selected States; 2) to investigate the cost of improving TDOT's Traffic Monitoring Program with the results of the best practices; 3) to investigate new technologies for traffic data collection methods and traffic data statistical analysis such as seasonal factors and variances; 4) to develop a ruleset designed to help remove questionable data reported by the permanent count stations; 5) to calculate seasonal factors based on the 2015 dataset; and 6) to review TDOT's current process for estimating vehicle miles travelled on local roads.

The report includes specific conclusions and recommendations for TDOT; however, the report narrative clearly indicates that state implementation of traffic monitoring varies widely. Most states, therefore, would likely benefit from a review of their current practice and incorporation of innovative or different methods presented herein.

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Chapter 1. Introduction

This report presents the findings of research undertaken for TDOT's Long Range Planning Division by Tennessee Tech University's Civil and Environmental Engineering Department. The overarching purpose of this research was to determine best practices for a traffic monitoring program based on an in-depth review of the Traffic Monitoring Program (hereafter TMP) of selected State Departments of Transportation (hereafter DOT) and the Federal Highway Administration's (hereafter FHWA) Traffic Monitoring Guide (hereafter TMG) (FHWA, 2013).

The interest in traffic monitoring stems from its importance in providing critical information required for highway planning, highway design, traffic analysis, highway safety analysis, and the allocation of funds to State DOTs.

A fundamental measure of traffic volume, which is central to accomplishing the analysis in the aforementioned activities, is the Annual Average Daily Traffic (AADT). Given its importance, every State DOT is required by the Federal Government to develop and maintain a traffic monitoring program based on the FHWA's recommended approach for collecting, summarizing, and interpreting information on traffic volumes and trends on their respective road networks. Ideally, each segment of roadway that is monitored should have its traffic counted continuously for the entire year for a direct computation of the AADT for the segment. Given the vastness of State road networks, this though would be a prohibitively expensive undertaking and therefore statistical sampling is employed in undertaking counts (Wright & Dixon, 2004). Succinctly, the process involves first the strategic selection of a relatively small number of locations on the roadways in each functional class in a State at which traffic counts are made continuously through the entire year. These locations are referred to as Permanent Traffic Count (PTC) stations or Continuous Count stations or Automatic Traffic Recorder (ATR) stations or sites. The purpose of the counts at these ATR sites includes the computation of AADTs, the estimation of traffic growth factors and, very importantly, the estimation of factors that capture the temporal variation in traffic namely seasonal factors, monthly factors, and daily factors. For undertaking some of the latter tasks, ATR sites and indeed all the roadways have to be grouped based on functional class. The constituent functional class/classes of each group are determined based on similarity in temporal variation in traffic patterns on their associated roadways. These groups are called ATR groups. Second, on the remaining sections of roadway in each ATR group where counts are not made continuously for the year, traffic counts are made for a short period of time only, typically 24 hours or 48 hours. These locations are also referred to as coverage stations. Estimates of AADT at these locations/coverage stations are obtained by adjusting the short period traffic counts with the temporal variation factors computed for each ATR group in the first step. The activities associated with the first step constitute the Permanent Traffic Count (PTC) Program while the activities of the second step constitute the Short Period Traffic Count (SPTC) Program.

The composition of traffic is also important to traffic analysis, highway safety, and highway design. As such, a third important sub-element of count programs is the Vehicle Classification Count program.

Originally, Long Range Planning Division set four research project objectives, namely: 1) to review and compare Tennessee Department of Transportation's (hereafter TDOT) TMP (TDOT, 2015) with that of other State DOT(s); 2) to investigate the cost of improving the TMP with the results of the best practices; 3) to investigate new technologies for traffic data collection methods and traffic data statistical analysis such as seasonal factors and variances; and 4) to write a detailed report with recommendations and guidelines on improving TDOT's TMP. During the course of the project, the research team agreed to accept three additional objectives, namely: 5) development of a ruleset designed to help remove questionable data reported by the permanent count stations, 6) calculation of seasonal factors based on the 2015 dataset, and 7) review TDOT's current process for estimating vehicle miles travelled (hereafter VMT) on local roads.

The original project schedule is shown in Table 1.

Table 1. Project Schedule

Task No.	Task Description	Duration (months)	Elapsed Time																	
			Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Month 14	Month 15	Month 16	Month 17	Month 18
1	Meet with TDOT	2	■	■																
2	Review TDOT's TMP	4	■	■	■	■														
3	Identify comparative DOTs	2			■	■														
4	Benchmark TDOT's TMP with comparative DOTs	6					■	■	■	■	■	■								
5	Review new technologies in use	6							■	■	■	■	■	■						
6	Review statistical methods	6							■	■	■	■	■	■						
7	Presentation of Preliminary Findings	2											■	■						
8	Determine methods needed for TMP	6										■	■	■	■	■	■			
9	Document best practices and recommendations	16	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
10	Submit for TDOT review	1																	■	
11	Prepare final report	1																		■

Tasks 1 and 2 provided background information to the research team, most of which will not be specifically discussed in this report. Where needed, information gleaned from these steps has been integrated into the discussion of later steps. Task 3, Identification of Comparative DOTs, was an interactive process including both research team and TDOT panel input. Task 4, Benchmark TDOT's TMP with Comparative DOTs, involved the development of a survey of practice and identification of one or more contact persons at each comparative DOT who completed the noted survey. Task 3 and some portions of the survey results from Task 4 will be discussed together in Chapter 2. Other portions of the survey results will be discussed in later chapters.

Task 5, Review New Technologies in Use, involved initial data collection via the survey created in Task 4, review of product capabilities using vendor resources, and a supplemental survey specifically aimed at capturing information from field personnel from comparative DOTs. Task 5 will be discussed in Chapter 3. While completing Tasks 4 and 5, the research team uncovered the potential for TDOT to improve its TMP with the initiation of new institutional agreements. These findings are discussed in Chapter 4.

Task 6, Review of Statistical Methods, was expanded to include work on two of the additional objectives the research team agreed to add to the project. Work on the ruleset for helping remove questionable data is presented in Chapter 5. Details regarding calculation of seasonal factors are found in Chapter 6. Finally, the review of the statistical methods for determining sample size are found in Chapter 7. The third additional objective, a review of methods for determining VMT, is discussed in Chapter 8.

Task 7, Presentation of Preliminary Findings, was completed at a meeting on December 19, 2016. Task 8, Determination of Methods Needed for TMP, was an ongoing, interactive process involving both the research team and the TDOT panel. The results of that step are spread throughout the document and will be briefly summarized along with the research team's conclusions and recommendations in Chapter 9. The remaining steps are procedural and as such will not be specifically discussed in the report.

Chapter 2. Comparison of Tennessee Department of Transportation's Traffic Monitoring Program to the Programs of Nine Selected State Departments of Transportation

2.1. Introduction

This chapter presents the defining characteristics of the traffic monitoring program of Tennessee Department of Transportation (TDOT) and those of nine selected state Departments of Transportation (DOT). Similarities and differences between TDOT's program and those of the selected nine state DOTs, which are used to define best practices, are presented. Where applicable, comparisons are also made with the recommendations of the Federal Highway Traffic Monitoring Guide (FHWA TMG) (2013).

The traffic monitoring program characteristics of prime importance to this study organized by count program include:

1) Permanent Count Program
   - the number of road miles monitored per permanent count station;
   - the technology used for vehicle counts in the permanent count program and their reliability and accuracy;
   - the number of office staff responsible for monitoring and processing data from the stations;
   - how seasonal adjustment factors for adjusting coverage counts into estimates of annual average daily traffic are estimated; and
   - agreements with other agencies for the collection and sharing of traffic data
2) Coverage Count Program
   - the number of DOT field staff for undertaking coverage duration counts;
   - the number of counts undertaken by each DOT field staff annually;
   - the number of road miles monitored per coverage count station;
   - the duration of counts undertaken in the coverage count program;
   - the cycle for counts undertaken in the coverage count program;
   - the technology used for vehicle counts in the coverage count program; and
   - agreements with other agencies for the collection and sharing of traffic data
3) Classification Count Program
   - the vehicle classes defined for the program;
   - the number of classification counts undertaken per road mile monitored;
   - the percentage of coverage count stations at which vehicle classification counts are simultaneously undertaken; and
   - reliability and accuracy of vehicle classification count equipment

2.2. Motivations for the Survey of Selected State Departments of Transportation

At the onset of the project, a meeting was held with the TDOT project panel and the personnel responsible for the traffic monitoring program in TDOT's Planning Division to discuss in-depth TDOT's traffic monitoring guide, current and anticipated needs for collected data, technology for data collection and their reliability and accuracy, staffing challenges in undertaking counts, and the opportunities for data sharing. This meeting took place on January 28, 2016. A second meeting was held on February 4, 2016, with personnel from TDOT's Strategic Investment Division to again discuss TDOT's traffic monitoring guide, current and anticipated needs for collected data, technology for data collection, and estimation of annual average daily traffic from coverage counts using ADAM. A third meeting was held on February 4, 2016, with the director of the Traffic Operations Division to discuss data collected by the Division through its Intelligent Transportation System program and the opportunities for joint data collection and/or data sharing.

In the first two meetings, TDOT's traffic monitoring guide was examined in a sequential fashion with staff from the respective divisions providing responses to prepared questions on each pertinent section of the guide. The full record of these meetings is presented in Appendix A. However, a summary of responses to some of the questions is reported below to provide context for this study.

On the question of the motivation for the study, TDOT Planning Division personnel noted first that there were no documented reasons for some aspects of their count-programs. Practices were developed long ago and those with knowledge of the rationale for them have retired. Second, the data collection unit of the division is currently short staffed, making it more challenging to undertake the over 12,000 short duration counts they are responsible for annually. There is therefore interest in finding out what the number of counts undertaken per field staff, a measure of their workload, is in other states and, based on this, determining whether the workload of TDOT traffic count field staff merits reduction either through increased staffing or reduction in the number of coverage counts undertaken annually or a combination of the two. Third, there is interest in learning about how other states address a number of practical issues associated with undertaking short duration counts. Fourth, there is interest in learning about the types of technologies other states are using in their count programs and the reliability, accuracy, merits, and demerits of these technologies. Fifth, there is interest in a statistically-based analysis to demonstrate whether additions or deletions should be made to the current number of permanent count stations. Finally, there is interest in learning about the characteristics of the classification count programs of other states. Tennessee's class count frequency and duration differ from that recommended in the federal monitoring guide and TDOT personnel would like guidance on how the class count program can be improved.

Addressing this list of study motivations pointed to a need to survey a selected number of states on their traffic monitoring programs to define best practices and, based on these practices, to recommend improvements to TDOT's count programs.

2.3. Literature Review

There have been very few survey studies of traffic monitoring reported in the open literature. The first of three studies that were found examined traffic monitoring programs in urban areas with a population in excess of 200,000 (Mergel, 1997). A complete census of all agencies/jurisdictions which met the population criterion was not attempted. Further, no attempt was made to formulate a statistically valid random sample of those agencies. All told, information on the traffic monitoring programs of 128 agencies was obtained.

Responsible program managers or staff in the selected metropolitan areas were interviewed on several aspects of their monitoring programs including staffing, data sharing, funding, objectives, data collection equipment, and program size. Conclusions of the study included (Mergel, 1997): 1) a general lack of knowledge existed regarding which agencies collected what types of data and the manner in which the data were collected within the states and within individual urban areas; 2) there was no central source of information on the extent of use of new technology for traffic data collection within urban areas; 3) quality of data collection efforts in urban areas and of the resulting data obtained varied widely; 4) collection of data in many urban areas was not done in a coordinated fashion, and data exchange was informal; and 5) funding and staff cutbacks at the time had hurt data collection efforts. New technology appeared to hold promise in addressing some of the effects of funding and staff reductions.

The second study investigated procedures used by 13 selected States to estimate and report traffic on high-volume routes (Fekpe, Gopalakrishna, and Middleton, 2004). The criteria for selection of the States were highway mileage and traffic volumes. States with the highest highway mileage and with high traffic volumes were identified using HPMS 2001 data and National Highway Planning Network databases. The top 13 States from this list were selected.

Information on the traffic monitoring programs of these states was obtained through a review of published literature and telephone interviews of the appropriate DOT personnel. Conclusions of the study included (Fekpe, Gopalakrishna, & Middleton, 2004): 1) data collection on major highways was done by State DOT staff and contractors; 2) review of traffic counts was done with either in-house or off-the-shelf software packages; 3) few of the sampled states used Intelligent Transportation Systems (ITS) data for sections of their highway systems HPMS reporting; 4) data and resource sharing were becoming more common place; and 5) non-intrusive equipment were not widely used for data collection even though DOTs recognized the advantage of such devices.

The third study, which of the three is the most directly related to the traffic monitoring research project, had as primary objective to gather information on the characteristics of the traffic monitoring programs of all fifty State Departments of Transportation and the District of Columbia through an online survey (Stolz, 2007). Invitations to participate were sent to 51 agencies and 49 of them responded to the survey. Pertinent findings of this study included (Stolz, 2007): 1) that most state travel monitoring programs required from one to twenty staff members - this included both in-house and outsourced staff. The greater the number of centerline miles managed by a DOT, the larger the size was of its traffic monitoring program in terms of number of staff, and hardware and software to manage the program more effectively and efficiently; 2) when DOTs outsource traffic data collection activities, data quality is managed by performing on-site inspections. However, only 36 percent of DOT respondents indicated having a formal inspection program. Twenty-two percent of the respondents indicated not having a formal inspection program. A heavy reliance was therefore placed on the contractor or other agency partner to provide quality data; 3) all DOT respondents indicated undertaking short-term counts on Tuesday, Wednesday, and Thursday. Ninety-three percent undertook short-term counts on Monday, 42 percent undertook short-term counts on Friday, and 15 percent collect data on Saturday and Sunday; 4) the number of short-term count stations varied from 300 sites in Vermont to 80,000 sites in Virginia while the number of permanent count stations varied from 31 sites in Tennessee to 2,728 sites in California. With such high variability in both the number of permanent and short-term count stations, Stolz called for more standardization in how traffic monitoring program sites are selected and in the determination of the number of sites required to obtain the most accurate and statistically valid data as possible; 5) Finally, seven percent of the DOT respondents indicated use of an off-the-shelf software for monthly and year-end data processing of traffic counts while 66 percent of them reported use of a customized product. Use of customized software was found to ultimately cost each DOT more for this activity.

2.4. Selection of States whose Traffic Monitoring Programs were to be used in Defining Best Practices

Given the research objectives, the initial step was to identify states whose traffic monitoring programs would be used to define “best practice” in statewide traffic monitoring. Since this was a benchmarking study, states were selected to satisfy the specific goals of the study rather than selecting a random sample of states to perform a statistical analysis. TDOT agreed that a review of the monitoring programs of nine states would be adequate for this purpose.

A number of criteria, arrived at in consultation with the TDOT project panel, were used to guide the State selection process namely 1) being among the leaders nationally in the use of technology to undertake traffic monitoring; 2) being similar to Tennessee in annual vehicle-miles traveled (VMT); 3) being similar to Tennessee in climate since climate can have an impact on the performance of vehicle count equipment; and 4) being among the leaders nationally in traffic monitoring (that is, in the development and application of statistical methods to various aspects of traffic monitoring). For this last criterion, relevant publications in Transportation Research Record journal issues and/or presentations at Transportation Research Board conferences dealing with traffic monitoring were considerations. Additionally, a staff of the FHWA was contacted to provide names of a few of the states whose traffic monitoring programs could serve as the definition of best practice. Based on the above criteria, the nine states listed in Table 2 were selected. The reason for the selection of a particular state is provided above the state in the column label shown in the first row of the table. It should be noted that even though a single reason only is cited for the selection of each state, reasons given for the selection of other states may have been equally applicable as well. The TDOT project panel approved this list of states.

Table 2: States Selected for Defining Best Practices and the Primary Reason for Their Selection

National Leaders in Traffic Monitoring	National Leaders in Technology	Southeastern Comparatives
Florida	California	Kentucky
Indiana	Texas	Georgia
Utah		North Carolina
		Virginia

2.5. Design of Survey Instrument for Eliciting the Characteristics of the Traffic Monitoring Programs of the Selected States

To determine the defining characteristics of each State's traffic monitoring program, a questionnaire was developed. The questionnaire was structured by type of count-program with the first set of questions devoted to the permanent count program, the second set was devoted to the coverage count program (short duration count program), while the third set was devoted to the vehicle classification program. The questionnaire structure and questions were developed after careful review of FHWA TMG (FHWA, 2013), TDOT's Traffic Monitoring Guide (2015), and the guides of other states including Florida DOT (Florida DOT, 2007), and Georgia DOT (Georgia DOT, 2013).

To test the questionnaire and simultaneously collect information on TDOT's traffic monitoring program, a pilot survey was undertaken in which TDOT traffic monitoring personnel were asked to provide responses to the survey questions. Feedback on the questionnaire structure and survey questions was provided by the TDOT traffic monitoring staff who completed the survey at a subsequent meeting of the research team with the TDOT project panel. Given the about two-and-a-half-hour duration required for completing the survey, a concern of the TDOT project panel was with the possibility of partial (incomplete survey) or total non-response to the survey. Hence, the panel requested that questions relating to staffing of the count programs be placed at the beginning of the survey since this subject was of most importance to them. Were a survey only to be partially completed, then, most likely, responses to staffing questions would already have been provided. The panel also indicated that obtaining cost figures was of minor importance since dollar costs associated with staffing differ from state to state and also because those related to equipment can be obtained directly from vendors. Additionally, the TDOT project panel requested that TDOT's procedure for estimating VMT on local roads be reviewed for its efficacy. To gain some insight into how other States estimate VMT on local roads, a question relating to this was included. The TDOT project panel was also curious as to the equipment/technology other states use in their truck weight program (it should be noted that TDOT discontinued its truck weight program in 2007). Thus, a question relating to this was also included in the questionnaire.

The questionnaire was updated to reflect TDOT's feedback and its final version is available in Appendix B. The questionnaire was sent by e-mail to the Director of each DOT's Planning/Monitoring Division together with a message that provided information on the survey objectives, the research sponsors, the names of the members of the research team, and appropriate contact information. It was decided that a telephone interview would be the preferred survey method. However, after initial review, some DOTs preferred to provide written responses to all the survey questions and did so, allowing for re-contact should any of their responses require clarification or change. For those that did not, the surveys were completed through phone interviews that lasted about two-and-one-half hours. The research team is grateful to all the respondents from the state DOTs for their participation in the survey. The actual completed surveys are in Appendix C.

2.6. Results of Survey of Selected DOT Traffic Monitoring Programs and their Comparison to Tennessee Department of Transportation's

The survey response rate was 100% as each of the nine selected states completed the survey. This notwithstanding, it is noted that not all the answers provided to questions were necessarily as responsive. Three good examples of this are as follows. First, answers provided to questions on the reliability and accuracy of technologies for undertaking counts were not necessarily reflective of the experience with the technology (DOT count staff do not appear to have systematic procedures in place to collect data on equipment performance – the experience is therefore anecdotal). Hence, the answers provided tended to reflect the manufacturer specified performance measures of the technologies. The second example relates to the costs associated with the operation and maintenance of the different count technologies in which it appears cost data are not collected and/or stored; hence, accurate figures could not be provided. The third example relates to the question on the agreements, if any, that the state traffic monitoring unit has with other jurisdictions, say, a city government or metropolitan planning organization or even the intelligent transportation systems (ITS) unit of the DOT (that is, if the two units are separate) for the collection and sharing of traffic data. The answers provided addressed the sharing of data. None explicitly addressed agreements for the collection of data.

The results of the survey of the selected states and how Tennessee compares to them on various descriptors and metrics are presented by count program and are organized into a series of tables with a discussion provided. Reviewed first are the results of the permanent count program. This review is followed by that of the short duration count program and then finally, by the vehicle classification program.

2.6.1. Permanent Count Program

Presented in Table 3 are the attributes that reflect the scale of a state's road network that is monitored as well as the scale of the permanent count program.

2.6.1.1. Road Mileage Monitored

The road mileage monitored in the selected nine states (column 5 of Table 3) ranges from 10,000 miles for Utah to 313,596 miles for Texas. The median monitored mileage is 58,000 miles for Virginia, while the mean is 83,930 miles. The road mileage monitored in Tennessee is 95,560 miles, which places the State well above the median and the mean for the selected nine states.

2.6.1.2. Number of Permanent Count Stations

The number of permanent count stations (reported in column 4 of Table 3), also known as automatic traffic recorder (ATR) stations in TDOT's TMG (TDOT, 2015), in the selected nine states ranges from 65 in North Carolina to 3,280 in California with Georgia's 230 stations being the median. Tennessee has 60 ATR stations. FHWA TMG (2013) guidelines call for the provision of 5 to 8 permanent count stations in each ATR group except the Recreational group, for which it indicates fewer ATR stations would be acceptable.

Table 3: Number of ATR Station Groups, Number of Stations in each Group, and Miles Monitored in each State's Permanent Count Program

1	2	3	4	5	6	7
State	**Number of ATR Station Groups**	**How is the number of ATR stations in each group determined?**	**Number of permanent count stations**	**Mileage Monitored (Road Miles)**	**Number of ATR stations per Group**	**No. of Monitored Miles per Permanent Count Station**
Tennessee	5 groups	Not estimated	60	95,560	12	1,593
California	HPMS program	Change in traffic flow, profile count to check if there is a 5% increase/decrease in traffic	3,280 (1,573 of the 3280 are quarterly counts)	15,100	---	5
Florida	12 groups. Rural: 6, Urban: 6	No information regarding how number of stations in each group is determined	363	29,600	30	82
Georgia	16 groups	Based upon statistical similarities in accordance with FHWA TMG	230	125,130	14	544
Indiana	5 groups. Urban: 2; Rural 3	No information regarding group determination	122	95,861	24	786
Kentucky	5 groups (FHWA)	Minimum of five ATRs per functional class with additional sites based upon the amount of statewide mileage for each functional class.	92	28,500	18	310
North Carolina	14 groups Non-interstate: 7 groups; Interstate: 7 groups	Clustering using reliability levels recommended in FHWA TMG, achieved for urban and rural but not recreational	65	79,585	5	1,224
Texas	Statewide by functional class, then by district and functional class	Minimum number of acceptable stations that is required to satisfy TMG requirements	362	313,596	---	866
Utah	---	FHWA TMG	110	10,000	---	91
Virginia	8 groups	Through a 1994 study to capture clusters of segments with similar traffic patterns	554	58,000	69	105

2.6.1.3. ATR Groups and Mean Number of Stations per Group

The estimation of the temporal variation factors namely, seasonal factors, monthly factors, and daily factors, for the adjustment of coverage counts to AADT estimates requires the permanent count/ATR stations to be organized into groups. The primary goal in the definition of these groups is reasonable similarity in seasonal patterns in traffic volumes and day of week patterns (AASHTO, 2009). AASHTO (AASHTO, 2009) recommends that, to the extent practical, the factor groups should be defined based on roadway characteristics such as functional class and location. The resulting groups defined by an agency are referred to as ATR Groups in this document. They may also be referred to as Seasonal Factor Groups.

Tennessee has five ATR groups. Thus, even though TDOT has fewer ATR stations than the DOTs of the selected nine states, it still meets Federal guidelines. In Chapter 7 of this report, an analysis to determine the number of ATR stations required in each ATR group to meet statistical criteria specified by TDOT will be presented. A comparison will be made with the current number of permanent count stations TDOT currently operates in each ATR group for judgment to be rendered on their statistical adequacy.

The average number of ATR stations per ATR group is reported in column 6 of Table 3 for the six states that indicated the number of ATR groups they have in their permanent count program. It ranges from a low of 5 stations per group for North Carolina to 69 stations per group for Virginia. The median number of stations per group for the six states is 21 while the mean is approximately 27. Tennessee has an average of 12 stations per group, which is on the lower end of the spectrum – its average exceeds that for North Carolina only. Were Tennessee to match the median, it would call for operating a little under two times the number of stations it currently does, and were it to match the mean, then it would call for operating a little over two times its current number of stations.

2.6.1.4. Road Mileage per ATR Station

The number of monitored miles per ATR station reported in column 7 of Table 3 ranges from a low of 5 miles per ATR station in California to a high of 1,224 miles per ATR station in North Carolina with Kentucky's 310 miles per ATR station being the median. Tennessee's 1,593 miles per ATR station exceeds them all. This macro average, interpreted as such, means that the variation that occurs in daily traffic volumes over the year for 1,593 miles of non-local roadways in Tennessee is assumed fully captured by the variation that is observed to occur in daily traffic volumes over the year at only one ATR station. Given differences in spatial and temporal patterns of travel across the State, it is highly unlikely that variations in traffic volumes at a single ATR station would be adequately representative of variations that occur over such a large mileage of roadway spread over a large geographic area. Further, errors in counts at a single station potentially could have a profound impact on the AADTs estimated at related coverage count stations. For the surveyed states, the mean mileage per ATR station is about 446. Were Tennessee to match this median mileage per ATR station, it would call for a little over five times the number of ATR stations in the State. Were Tennessee to match the mean mileage per ATR station, it would call for about three and one-half times as many ATR stations as the State currently operates.

2.6.1.5. Determination of Number of ATR Stations

The survey results reported in column 3 of Table 3 show that most of the states do not determine the number of ATR stations for their permanent count program based on a statistical analysis. Instead, the states indicated either that there was no documented procedure for this or they follow the FHWA TMG (2013) guide which, as stated earlier, specifies that between five and eight ATR stations be provided for each roadway functional group defined by a state.

2.6.1.6. Number of Staff

Presented in Table 4 are the staffing levels of the different areas of the permanent count program and the other responsibilities the staff have. Of the surveyed state DOTs, California DOT (also known as Caltrans), has the highest number of field staff – approximately 26 of them. It is followed by North Carolina DOT which has 21 field staff. The staffing level for the latter two DOTs is rather exceptional in that the other seven surveyed state DOTs have a field staffing level that ranges between 1 and 5 persons. Tennessee has 6 field staff which is therefore not atypical.

The number of staff that provide office support for the permanent count program ranges between 1 (three states – Indiana, Kentucky, and Utah) and 10 (one state - Florida) persons. It should be noted though that the 10 office staff in Florida serve as the field staff as well. Tennessee has 1 person dedicated to this office support role.

2.6.1.7. Other Responsibilities of Staff

Seven of the nine state DOTs surveyed undertook the maintenance of equipment used in the permanent count program in-house (see column 5 of Table 4). Only two states, Florida and Virginia, currently have it done by consultants. TDOT, similar to the majority of state DOTs surveyed, has the maintenance of its equipment done in-house.

The majority of the surveyed state DOTs, as reported in columns 6 and 7 of Table 4, have their traffic monitoring staff involved in other activities which include the processing of the collected traffic data, quality control, handling data requests, etc. TDOT in this regard is similar to the other surveyed state DOTs in that its traffic monitoring personnel are assigned significant other count-related tasks as well.

Table 4: Staffing of Permanent Count Program and Other Responsibilities of Staff

1 **State**	2 **Number of field staff**	3 **Number of office staff**	4 **Number of maintenance staff**	5 **Maintenance of permanent count program equipment: Is it done in-house?**	6 **Other responsibilities of traffic monitoring personnel**	7 **Other responsibilities of maintenance staff**
Tennessee	6	1	---	Yes	HPMS	Yes
California	26.19 PYs*; *person years – 1736 hours per year	1.9 PYs; *person years – 1736 hours per year	---	Yes	Collect counts, AADTs, answer questions from public, maintain traffic count stations and counters, repairs and maintenance	Same as the traffic monitoring personnel: Collect counts, AADTs, answer questions from public, maintain traffic count stations and counters, repairs and maintenance
Florida	10 DOT staff; 5 consultants	10	---	No, done by consultants	No	---
Georgia	2	6	0	Yes, supervise installation	Activities related to traffic processing and quality control	Collect portable traffic data and supervise CCS maintenance/installations
Indiana	---	1	---	Some of it	Monitor flow conditions; variable message signs	Routine tasks are done in-house
Kentucky	4	1	Same as field staff	Some; central office staff maintains ATR stations when possible; staff performs minor data recorder repairs. Minor station repairs are done by in-house staff	Mainly database related tasks.	Procuring/distributing equipment and materials, construction inspections, maintenance, data recorder repair and calibration, short-duration counts, some special counts, count tech training, etc.
North Carolina	21	4	6	Done in-house; may have contractors do installation	No, just for their group	---
Texas	5 TxDOT	2 TxDOT	Same personnel as field staff	Yes	Handle data requests/PIO inquiries and perform GIS mapping work and provide technical support	Process data, process payments, develop contractor schedules, and inspection of contractors
Utah	1	1	---	Yes	No	No
Virginia	1	7.5	Contract	No	No	---

2.6.1.8. ATR Groups and Estimation of Number of Stations in each Group

Presented in Table 5 are the characteristics of the ATR groups and how the number of ATR stations in each group was determined. Six of the surveyed states provided definitions of their groups. The number of groups ranges from 5 for both Indiana and Kentucky to 16 for Georgia. TDOT has 4 ATR groups for development of seasonal factors namely, Rural Interstate, Rural Non-interstate, Urban, and Recreational. (It should be noted here that, even though TDOT defines five ATR groups, for computation of seasonal factors it combines the two urban groups, Urban Interstate and Urban Non Interstate, into an Urban Group; hence, four groups are reported here). With the groups defined so broadly, the road facilities in each group are characterized by high variability in AADTs. Given that a measure of the dispersion/variability in AADTs in a group influences the number of ATR stations required to meet statistical criteria set by TDOT, the broad group definitions and the resulting greater variation in AADTs will have implications for the number of ATR stations each group requires to adequately capture the variation in daily traffic volumes. The analysis to determine the minimum number of ATR stations in Chapter 7 will address the latter concern in more detail.

The number of ATR stations in each group is reported in column 3 of Table 5. Only three of the nine surveyed states provided the needed detailed responses. North Carolina reported the smallest number of ATR stations in a group (2 for the Recreational group) while Kentucky reported the highest number of ATR stations for a group (41 for Rural General). Tennessee has 3 stations for the Recreational group, 9 for the Rural Interstate group, 16 for the Urban group, and 32 for the Rural Non-Interstate group. Its numbers are therefore not atypical. However, other states have more ATR groups and, consequently, a greater overall number of ATR stations compared to Tennessee.

The procedure for estimating the number of ATR stations in each group is repeated in column 4 for the sake of comprehension of what is reported in column 5.

Table 5: ATR Group Characteristics and Sampling Associated with Permanent Count Program

1 **State**	**2** **How are ATR groups defined?**	**3** **Number of ATR stations in each group**	**4** **Procedure for estimating number of ATR stations in each ATR group**	**5** **How often is the number of ATR stations in each group reviewed to ensure compliance with statistical requirements**
Tennessee	4 groups; rural interstate, rural non-interstate, urban interstate/non-interstate, recreational	9 rural interstate, 32 rural non-interstate, 16 urban, 3 recreational	Not estimated. FHWA TMG recommendation	Never
California	HPMS program, districts define them but they are counting an actual annual count every three years and where traffic changes (increases or decreases) is where changes are made.	Each growth factor group should contain a minimum of 5 continuous count sites	Change in traffic flow, a profile count is done if there is a 5% increase or decrease in traffic	They are updated each year with statistical methods
Florida	12 groups. Rural: principal arterial – interstate, principal arterial – other, minor arterial, major collector, minor collector, local; Urban: principal arterial – interstate, principal arterial – other freeways and expressways, principal arterial – other, minor arterial, collector, local	363 total	Unknown	---
Georgia	16 different factor groups	230 total	16 Traffic Factor Groups based on their statistical similarities (traffic trends/ patterns, high growth areas, truck traffic patterns, etc.)	---
Indiana	5 major factor groups. 2 groups for all urban roadways and 3 groups for all rural roadways: urban interstate; urban principal arterials; rural interstate; rural principal arterials, minor arterials; rural major collectors, minor collectors, locals	Rural interstates have 18 stations; urban interstates have 20 stations; rural minor collectors and locals have 15 stations; urban locals and minor collectors have 12 stations; rural arterials (principal and minor) have 17 stations.	Unknown	---
Kentucky	5 groups. FHWA – rural interstate, rural general, urban general, rural recreation, and urban interstate	Rural Interstate-19; Rural General-41; Urban Interstate-8; Urban General-24; Rural Recreation-0	A minimum of five ATRs per functional class with additional sites based upon the amount of statewide mileage for each functional class.	When it becomes apparent that something is off when calculating factors or when extra money is available or as sites age and become unusable, we evaluate whether the existing location or relocation is the better alternative.
North Carolina	14 groups. 7 non-interstate and 7 interstates, groups are broken out by Urban, Rural, and Recreational.	Urban and Rural groups have 20 to 30 stations each. Recreational has fewer in each group (2 to 6) but more groups	Clustering - less variable groups require fewer stations while groups with higher variation in seasonal patterns require more stations	Not often
Texas	Statewide by Functional Class, then by District and Functional Class	3+	Minimum number required to satisfy TMG requirements	Annually
Utah	---	5-8 per factor group	---	Annually
Virginia	8 groups. General Purpose Rural Factor Groups 1 and 2; General Purpose Urban Factor Group; Special Factor Groups 1 and 2; Recreation Group; Urban Group; Special Factor Groups 1, 2 and 3	---	1994 study to capture traffic on clusters of traffic segments identified to have similar traffic pattern	Review of site locations to capture changing traffic pattern is on-going and performed on an as needed basis.

With the exception of North Carolina, there is no clear sense that states employ a statistical procedure for estimating the number of stations required for the permanent count program (column 4 of Table 5). Instead, the five to eight stations per ATR group recommendation of the FHWA TMG is what serves as the guide for most states. California, Texas, and Utah indicated that they undertake annual reviews to determine whether or not the number of ATR stations in a group meets statistical requirements (column 5 of Table 5). TDOT, similar to most of the surveyed state DOTs, does not apply a statistical formula for determining the minimum number of ATR stations required to meet statistical criteria. It also does not undertake a periodic review of the number of ATR stations in a group to ensure compliance with statistical requirements.

2.6.1.9. Reasons for ATR Removal

Presented in Table 6 are the reasons for ATR station removal, the determination of the geographic locations of ATR stations, and quality control checks that are performed on data collected at ATR stations. Reasons for ATR station removal (column 2) are varied and include construction activity, pavement milling, realignment of a roadway, low volumes, relocation to improve upon the quality of data, and malfunction of the equipment. No state indicated removal of a station on account of the merits of a statistical analysis.

2.6.1.10. ATR Station Location Determination

Reasons given for the current locations of ATR stations on a state's road network varied (column 3 of Table 6). As examples, Florida DOT located them such that the main arterials were covered and to ensure HPMS requirements for developing seasonal factors were met. Indiana DOT indicated the locations had been previously determined. This suggests that no documentation was prepared on why the current geographic locations were selected. Georgia DOT located them based on traffic patterns and on the criterion of having at least one ATR station per interstate route and other major arterials. Kentucky DOT has the procedure of selecting a geographic area for a particular functional class of roadway and then using the judgment of technical personnel to select what is thought to be the best location in the area.

Table 6: Reasons for ATR Removal, Geographic Location of ATR Stations, and Quality Checks on ATR Data

1 **State**	2 **Reasons for removing permanent count stations permanently**	3 **Procedure for determining current geographic locations of State's ATR stations**	4 **Conditions that cause ATR data to be rejected**	5 **Types of checks made on data collected at ATR stations**	6 **When is a data point viewed as an outlier?**
Tennessee	When a road is closed	---	Not having 7 consecutive days of data	None	Not enough ATRs for that kind of statistical data
California	If equipment is bad, or area is not being traveled often	---	Consecutive series of zero values, error codes, repeating values; random series of very large or very small data values; no reported data values at all; extensive missing data with nonrandom patterns	Review data set for completeness (null, zero, error code, consecutive repeating value, low value, high value); consistency from week to week in both volume and directional split; check the variance from historical traffic characteristics	The previously mentioned invalid data records (caused by power failures, recorder, or device malfunction)
Florida	Construction, geographic reasons, or does not give good data collection	To make sure main arterials covered; HPMS – different sampling requirements were met as a basis for seasonal factors	Construction or traffic was drastically altered; daily QC at each station	Internal QC checks mentioned	QC the data manually, table, line graph, and histogram and reflag records; if traffic falls low or there is a spike then indication of a crash incident; employees use judgement or intuition before removing
Georgia	---	Minimum of 5 to 8 per Traffic Factor Group depending upon the traffic patterns and precision desired, minimum of one operational CCS site per Interstate route and other major arterials	---	Built-in QC checks on a daily or weekly basis and also conducts a comprehensive review	All data which falls out of our quality control rules are subject to further review
Indiana	Realignment of a roadway, construction, wanted better quality data	Previously determined	Incomplete data for a certain lane or hours, then all data for that day will be rejected; other major thing is poor comparison with historical data and cannot be explained to known travel changes	Compare to counts from previous year, lane counts, compare current year AADT to AADT in previous year	Programmatically – if data is within 15 percent of last year's AADT or MADT (Good), if beyond 15 percent it flags it and closer look is taken (25 percent variance if sensors are working correctly then count is thrown out)
Kentucky	Construction or wear and tear of the equipment.	Typically choose a general geographic area for a particular functional class and narrow it down to what we think is the best location in that area.	Compare to historical data.	Compare to historical data.	If deemed questionable
North Carolina	Only evaluated when there is malfunctions or it gets milled	Work with planners and forecasters to determine their needs and truck travel and generating events may occur	---	Looks at historical data and trends; look at graph line to look for unusual peaks or dips in the data (visual inspection); general rules for multiple zeros in a day or multiple hours	---
Texas	Construction, roadway reconfiguration, or age/malfunction/wear	TPP and TxDOT districts select the locations in accordance with the FHWA TMG	Machine malfunctions, equipment damage, construction, acts of nature, etc. Also, high or low counts compared with historical trends would be rejected.	Percent of increase/decrease of collected counts compared to previous historical averages, consecutive identical hours, zeroing out of data, directional splits, hourly volumes out of range, missing related counts, etc. (visual and manual comparisons)	Roadways become identified as being unique.
Utah	---	---	Construction, out of service for repair.	Historical, directional, consecutive zeros.	---
Virginia	---	Determined through a 1994 study to capture traffic on clusters of traffic segments identified to have similar traffic pattern	5 quality levels: 1. Acceptable for Nothing, 2. Acceptable for Qualified Raw Data Distribution, 3. Acceptable for Raw Data Distribution, 4. Acceptable for use in AADT Calculation, 5. Acceptable for all TMS uses	Some examples of the 100+ quality checks include: comparing daily counts with most recently calculated AADTs, directional evaluation of the data, number of hours with consecutive 0s	If the preliminary AADTs are beyond +125% and -85% of previous AADTs

2.6.1.11. Quality Control Checks

The conditions that would prompt the rejection of data collected at ATR stations essentially rested on how current year volume data collected at a station compared to historical data collected at that same station (column 4 of Table 6). Identified reasons for why major differences may exist between current volumes and the historical trend include construction activity, malfunction of the count equipment, equipment damage, and acts of nature. Evidence pointing to some of these problems includes the recording by the count equipment of a consecutive series of zero values, error codes, repeated values, a random series of very large or very small data values, no reported data values at all, and extensive missing data with nonrandom patterns. TDOT rejects monthly volume data collected by ATR equipment if it does not have daily volumes for seven (7) days.

The checks made by the surveyed states on data collected at ATR stations reflect the conditions described above that would lead to the rejection of ATR data collected at a station. These checks, as reported in column 5 of Table 6, include comparisons with historical data collected at an ATR station, the directional splits and volumes, hourly volumes that are out of range, and consecutive zero (0) volumes. TDOT reported not undertaking any checks beyond the seven-day requirement mentioned above.

2.6.1.12. Reasons for Classifying Volumes as Outliers

Central to the survey responses received on what would prompt a volume record to be classified as an outlier and therefore excluded from subsequent analysis (column 6 of Table 6) is the magnitude of year-to year percentage change, whether negative or positive, that occurs in measured traffic volumes. Indiana DOT uses a 15% year-on-year change or greater in traffic volumes as the criterion to flag a record for further scrutiny while a 25% change would prompt deletion. Virginia DOT's criterion for identifying outliers is a year-on-year positive growth that exceeds 25% or a year-on-year negative growth that exceeds 15% in magnitude. TDOT reported not having enough ATRs to provide the statistical data for such a decision.

2.6.1.13. Estimation of Seasonal Factors for Adjusting Coverage Counts

Seasonal factors (SFs) are critical to the estimation of AADTs from counts undertaken at coverage count (short duration count) stations. Presented in Table 7 are the methods used by the surveyed states in developing their seasonal factors. With the exception of Caltrans and Florida DOT whose procedures are relatively more complicated, the state DOTs estimate seasonal adjustment factors using the data collected at each permanent count station by computing the ratio of AADT at the station to the average volume for each day-type in each month of the year. The end result is eighty-four (84) seasonal factors for the year. TDOT's procedure is similar to that employed by the majority of the surveyed state DOTs.

When it comes to how many years of seasonal adjustment factors a state DOT uses in adjusting the coverage counts (column 3 of Table 7) undertaken in the most recent calendar year into AADTs, eight of the surveyed state DOTs use one year of SFs (that is, SFs computed using permanent count station data from the most recent calendar year). Caltrans uses the most recent two calendar years of data. TDOT uses five years of SFs, which makes it different from all the other states. Given that the five years of SFs does not come at additional cost (they are simply stored from analysis undertaken in previous years), there are no motivating grounds based on costs to recommend that TDOT be similar in procedure to other state DOTs. What could motivate a recommendation to TDOT to change its procedure would be the accuracy of the AADT estimates at coverage count stations obtained using these different sets (one year versus 5 years) of SFs. An analysis will be required before judgment can be rendered on this.

For TDOT and Caltrans both of which use multi-year SFs, a simple average of the SFs obtained for each year is what is applied in adjusting coverage counts into AADTs (column 4 of Table 7).

Table 7: ATR Group Characteristics and Sampling Associated with Permanent Count Program

1 State	2 Seasonal factor development from permanent count station data	3 Number of years used in computing seasonal factors	4 Are seasonal factors used in AADT estimation a weighted average or simple average of previous year's factors	5 How is the AADT at a location estimated when data is deemed unusable
Tennessee	Monthly averages of each station are inputted into ADAM	5 years	Simple average	Excel spreadsheet to calculate the missing months
California	Level (L) Factor (variation by day of week), Range (R) Factor (difference between summer and winter months L Factor), Increment (I) Factor (variations across months of the year), Daily Volume = AADT (L Factor + R Factor * I Factor)	2 years	Simple average	If quarterly counts are missing, two options for imputing data may be used: use of historical data from the traffic station and use of current data from neighboring stations; Page 5-6 (p. 114) – Page 5-7 (p.115)
Florida	Weekly Seasonal Factors (SF) are developed by interpolating between the monthly factors for two consecutive months; monthly factors are computed by dividing the AADT by the MADT; for each station, the directional monthly factors are averaged together. Computing seasonal factors – All stations assigned to the factor category are averaged together to generate monthly average factors; the monthly average factors are assigned to the week of the year that contains the midpoint of the month; weeks without factors are estimated by extrapolating from the mid-week of one month to the mid-week of the next month.	1 year	Determined by interpolating between the Monthly Seasonal Factors for two consecutive months; simple average	Use a PTC count site if 8 months or more; if missing 2 months in a row but if 3 months can still be used if consistent; not if 4 months are missing however. Interpolate and is used to develop SFs
Georgia	Monthly factors are calculated by dividing the AADT by the MADT for each location. Daily or day-of-the-week factors are calculated by dividing the AADT by the ADT. Axle correction factors are developed based on data that represents all seasons of the year.	1 year	N/A	Data will not be used
Indiana	In accordance with TMG, calculates factors for each individual station	1 year	N/A	Unknown
Kentucky	Daily and Monthly factors are calculated	1 year	N/A	KYDOT does not estimate AADTs at ATRs with bad data.
North Carolina	Two-step process used: Step 1: Distinguish between typical and atypical travel patterns by day in the count data, and Step 2: Calculate factors that adjust counts collected on typical days to an annual average.	1 year	N/A	Estimate a missing day of the week volume by interpolating between the volumes for the same day of the week in the adjacent months. We do this on a very limited basis and will not interpolate more than a few days.
Texas	STARS II develops them	1 year	STARS II derives the Seasonal Adjustment factors	Using STARS II, counts at a given location are compared with historical counts, regionally similar counts on adjacent or nearby roadways, and counts up and downstream on the same roadway. Permanent sites as anchor points for ground truth, GIS spatial analysis and land use development, special events, and holiday travel can be considered during this process. An applicable growth rate can be derived during the analysis or by using a linear regression method based on historical counts for a given location.
Utah	Functional Class, Regional, Recreational groups are developed from CCS sites.	1 year	N/A	If just a couple of months are missing, seven days are calculated for MADT based on an average week from the previous year growth factored by a nearby or relative CCS site. Otherwise AASHTO method.
Virginia	TMS Algorithms	1 year	N/A	Depending on how long the data is deemed unusable. Periods of usable data within the year can be used to produce AADT with a lower quality rating.

2.6.1.14. Technology Used at ATR Stations

Presented in Table 8 are the technologies used by the surveyed state DOTs to undertake traffic counts at ATR stations, their reliability, and their accuracy.

All the surveyed state DOTs, similar to TDOT, make use of inductive loop technology for traffic counts. Other technologies mentioned that are used for counts, classification, and truck weights include: radar technology – reported by three state DOTs; piezoelectric technology – reported by five state DOTs; video technology – reported by two state DOTs; and bending plate technology – reported by four state DOTs.

2.6.1.15. Reliability, Accuracy, and Issues with Technology

For state DOTs that provided a reliability of the technology used (column 3 of Table 8), the range was 85% to 95% reliable. Three state DOT's indicated they did not know the reliability of their technology.

On the impact of weather on the technology used at ATR stations (column 4 of Table 8), four state DOTs indicated their count technologies were not affected by weather. On the other hand, three state DOTs, similar to Tennessee, indicated their technologies were affected by weather.

On the accuracy of technologies used at ATR stations (column 5 of Table 8), five of the surveyed state DOTs indicated an accuracy that lay in the range of 95% to 99%. TDOT gave a qualitative response, reporting the accuracy of its equipment to be "average".

A more in-depth analysis of the technologies used at ATR stations and recommendations that arise from them is provided in Chapter 3.

Table 8: Technology used at ATR Stations and their Reliability

1 State	2 Technology used	3 Reliability	4 Is sensor affected by weather?	5 Accuracy	6 Other technologies for permanent counts State DOTs have experience with
Tennessee	Permanent Inductive Loop Sensors	85%	Yes - when struck by lightning	Average	Peek
California	Inductive-loop sensors – declining in use, replaced with axle-sensor-based classifiers, WIM devices, non-intrusive detectors (e.g., video technology)	90%	Radar is but not sensors, the axle-sensor-based classifier is good in weather	90-95%	Loop sensors, bending plates, radar, piezos
Florida	Permanent inductive loop sensors, several non-intrusive traffic counters that use microwave and magnetic sensors, video, and vehicle classifiers; loops and piezo for classification; WIM	Unknown	No	Above 99%	Sensys (like a hockey puck, placed in center of lane); ITS uses Wavetronix; WIM bending plates
Georgia	Two Inductive Loop Sensors and one Class II Piezoelectric Sensor embedded in each lane.	Unknown	Yes	Unknown	N/A
Indiana	Inductive loops, weight data uses load cell (manufactured by KISTLER), equipment in pavement (International Road Dynamics – Canada)	85%	No	95%	Side-fire radar stations; research with Purdue using Lidar
Kentucky	Peek ADR traffic data recorders, inductive loop detectors and /or piezoelectric sensors	Unknown	Yes, temperature affects piezoelectric WIM data collection	Unknown	None
North Carolina	Inductive loops, piezoelectric sensors, radar	---	---	---	---
Texas	Inductive loops, bending plate, Brass Linguini (BL), piezo electric, quartz sensors, HD radar, and IP modems	95%	No	95%	N/A
Utah	Inductive loops and Radar	Varies	Unknown	Unknown	None
Virginia	In road sensors (e.g., loops, piezos) and Wavetronix (dual beam) sensors, and bending plate	95%	No	Within 5%	N/A

The surveyed states were asked about issues they had experienced with current and previous technologies used at ATR stations. Six of the surveyed states, as shown in column 2 of Table 9, indicated no issues at all. Kentucky DOT mentioned a problem that dated back to when they used the old telephone service. Utah DOT mentioned the issues of occlusion and congestion which affect counts made with radar technology. Virginia DOT mentioned the issue of sensor lifespan and the quality of data obtained from them. TDOT stated their issue was with telemetry. It appears there are no technology issues that are common to all the surveyed DOTs.

Table 9: Issues with Current and Previous Technologies used at ATR Stations and Plans for Adopting Different Technologies

1 State	2 Issues with current and previous technologies	3 Plans for using a different technology and reasons why
Tennessee	Phone line issues with telemetry	None, new IPP modems
California	None	Video - trucks and motorcycles make counting data hard
Florida	---	---
Georgia	N/A	No
Indiana	---	No
Kentucky	We used to have lots of issues when we used POTS for communication	No
North Carolina	---	---
Texas	---	---
Utah	Radar has occlusion and congestion issues	No
Virginia	Efforts to extend the sensor lives, sensor health, data quality	Test new sensor arrays to better capture motorcycle traffic; we're evaluating TDC traffic counters and WIM sensors for quality and cost improvements

2.6.1.16. Additional Data Collected at ATR Stations

The surveyed state DOTs were asked about other traffic data they collect at ATR stations, the software used in processing ATR data into AADTs and, finally, whether they had agreements with other jurisdictions for the collection and sharing of data. From the responses provided in column 2 of Table 10, all the surveyed state DOTs also undertake vehicle classification counts in addition to the volume counts. TDOT has the capability of undertaking classification counts at its ATR stations as well. With the exception of North Carolina DOT, the remaining eight state DOTs also measure vehicle speeds at ATR stations. TDOT currently does not measure speed. Given its importance as a performance measure and for defining quality of travel on highways, TDOT should give consideration to collecting speed data. Finally, all the surveyed state DOTs save North Carolina DOT also collect data on truck weights at weigh-in-motion sites.

2.6.1.17. Software Used for Processing ATR Data

The type of software used for processing data collected at ATR stations to provide reports of interest varies across the surveyed states (column 3 of Table 10). Included in the list are Traffic Polling and Analysis Systems (TPAS), Transmetric Traffic Server, STARS II, and TRADAS. Only two state DOTs, namely North Carolina DOT and Virginia DOT, reported using an in-house developed system. North Carolina DOT is in the process of getting new software. Should TDOT decide to change software, there clearly are several options available. Their capabilities would have to be investigated before any recommendation can be made.

2.6.1.18. Data Sharing

On data sharing, only North Carolina DOT reported not sharing its collected traffic data (column 4 of Table 10). TDOT also reported not sharing its data with other agencies. On the question of agreements with other agencies for the collection of traffic data, none of the answers provided by the surveyed state DOTs was responsive, that is, explicitly addressed the question.

Table 10: Other Data Collected at ATR Stations, Software for Data Processing, and Data Sharing

1 **State**	2 **Other data collected besides traffic volumes**	3 **Software used in processing data to obtain AADTs**	4 **Agreements with other jurisdictions for collection and sharing of data?**
Tennessee	Only volumes; can make class counts if setup on length bins	ADAM	No
California	Vehicle class, speed	Performance Measurement System -PeMS	Publically available
Florida	Vehicle classification counts, speed surveys, and truck weight and measurements	Traffic Polling and Analysis System - TPAS	Shares data with border states
Georgia	Vehicle classification, speed, truck percentages, and weight	Transmetric Traffic Server	Publically available
Indiana	Speed, vehicle classification; WIM – collects axle weights, gross vehicle weight	Midwestern software solutions traffic count database software performs quality control checks, results are reviewed and process flagged results, calculates AADT based on factors developed; offers factor calculations but it does not look for outliers	Yes; ITS division, State Police Department
Kentucky	Classification, speed and WIM.		Publically available
North Carolina	Not taking speed, but is collecting volume and classification data	Current system was developed in-house. Working on getting new software.	No
Texas	Vehicle classifications, speed, WIM data	STARS II (TxDOT's first cloud-based relational database). Incorporates GIS functionality and can be publically accessed by any Internet browser	Yes, with Traffic Management Centers (TMCs)
Utah	Volume, Length, & Speed at all sites and WIM site.	TRADAS	Data is public
Virginia	Speed, plus for class data (inroad sensors) and weights (WIM)	In-house system	Data is shared with Transportation Operational Centers. WIM data is shared with DMVs for enforcement

2.6.2. Short Duration Count Program

2.6.2.1. Road Mileage Monitored per Coverage Count Undertaken

Some attributes of the short duration count program are reported in Table 11. In column 2 of the table, the road mileage monitored is reported while in column 3, the number of coverage counts undertaken by the surveyed state DOTs is reported. Clearly, there are differences in the mileage monitored as well as in the number of coverage counts undertaken. A useful measure for comparing states is the number of road-miles per coverage count. It is an indicator of the average length of homogeneous segment of roadway in a state's monitored system. It ranges from 2 miles per coverage count for Utah, Florida, and North Carolina to 14 miles per coverage count for Georgia with the median being 3 miles per coverage count. Tennessee averages 8 miles per coverage count undertaken, which is exceeded by the average for Georgia only.

2.6.2.2. Duration and Cycle of Coverage Counts

On the duration of coverage counts, eight of the nine surveyed states undertake 48-hour counts (see column 5 of Table 11). This is consistent with the recommendation of the FHWA Traffic Monitoring Guide. Texas DOT undertakes 24-hour counts only while Florida DOT undertakes both 48-hour and 24-hour counts, with the 24-hour counts undertaken on rural facilities. Caltrans undertakes some 7-day counts in addition to the 48-hour counts. Utah DOT undertakes 48-hour, 72-hour, and some 7-day counts. TDOT undertakes 24-hour counts making it similar only to Texas DOT.

The count cycle, that is how often coverage counts are undertaken at a station, varies considerably across the surveyed states (see column 6 of Table 11). Some DOTs perform a count at each station annually. Other states do so every 2 years while others perform a count every 3 years. Georgia, Texas, and Virginia have some of their facility-types counted on cycles of 4, 5, or 6 years.

Table 11: Some Attributes and Work Load Metric for the Coverage Count Program

1 State	2 Mileage Monitored (Road Miles)	3 No. of Coverage Count Stations	4 No. of Road Miles per Coverage Count Station	5 Count Duration (Hours)	6 Count Cycle (Year)	7 No. of Field Staff (Short Duration)	8 No. of Coverage Counts / Year / Field Staff
Tennessee	95560	12327	8 miles	24 hours	Used to be 1 year (moving to a cycle of 2 years)	6	2055
California	15100	3203	5 miles	48 hours or 7 days	3 years	26.19 person years (districts); person-years are 1736 hours per year	122
Florida	29600	17784	2 miles	48 hours for urban; 24 hours for rural; Most are 48-hours	1 year	8 DOT staff; 16 consultants	741
Georgia	125130	8951	14 miles	48 hours	2 years - 4067 stations; 4 year-1821 stations; 6 years-1713 stations; mixed-1350 sta.	2 in-house staff (21% of counts) + contractor staff (79% counts)	448
Indiana	95861	22563	4 miles	48 hours	Interstate -2 years; state routes -3 years, non-state owned highway system (class 5 or 6) and rural -6 year cycle	8	940
Kentucky	28500	10800	3 miles	48 hours	3 years for most; 1 year for some	12	300
North Carolina	79585	43000	2 miles	48 hours	2 years; annually on interstates; 2 years for large urban areas; annually on primary roadways outside of urban areas	12	1792
Texas	313596	75000-85000 (annually); 25000-35000 urban counts	4 miles	24 hours	Annually for all on-system roads; rotating 5-year cycle on all off-system roads; 3-6 Districts counted annually	3 DOT; 18 contractor	781
Utah	10000	6005	2 miles	48 or 72 hours; some 7-day counts	3 years	5	400
Virginia	58000	17000	3 miles	48 hours	3 years; 6 years for ramps; 6-12 years for local secondary roads depending on the development	1 (93% of counts done by consultants, 7% in-house staff)	405

The majority of states though follow FHWA’s recommendation of conducting coverage counts for 48 hours every three years. TDOT undertakes counts on a one-year cycle, making it different from the majority of state DOTs.

2.6.2.3. Number of Field Staff for Coverage Counts

The number of field staff for undertaking coverage counts is reported in column 7 of Table 10. Five of the surveyed states rely solely on in-house staff to undertake their counts while four states rely on a combination of both in-house and contractor staff. Similar to the majority of states, TDOT relies solely on in-house staff for its counts. The number of in-house field staff though varies considerably across state DOTs ranging from Virginia DOT's 1 in-house staff to California's 26. In general, states that have fewer in-house staff rely more heavily on consultants for their counts. For states in which only in-house staff undertake all the counts, the number of staff ranges from 5 to 26. TDOT has 6 field staff.

2.6.2.4. Number of Coverage Counts Undertaken per Year per Field Staff

With such differences across the surveyed state DOTs in terms of number of stations, count cycle, and number of field staff that perform counts, a metric is defined for comparison of field staff work load. This metric is the number of coverage counts per year per field staff. It is evaluated for each state DOT and reported in column 8 of Table 11. It ranges from a low of 122 counts/year/field staff for Caltrans to a high of 1,792 counts/year/field staff for North Carolina DOT. Georgia DOT’s 448 counts/year/field staff is the median. TDOT’s counts per year per field staff is 2,055 making it much higher than that for any of the surveyed state DOTs. Even with a two-year count cycle, TDOT staff will still have one of the highest workloads, exceeded by only the field staff of North Carolina DOT.

Chapter 6 of this report provides an analysis of the investigation of two alternative coverage count durations and cycles namely 24-hour counts performed on an annual cycle (TDOT) and 48-hour counts performed on a three-year cycle (FHWA), in order to provide TDOT with a recommendation as to which counting procedure provides superior estimates of AADT.

2.6.2.5. Number of Coverage Count Stations

The methodology used to determine the number of coverage count stations varies across the surveyed states (column 2 of Table 12), but the underlying reasons for their determination is to ensure all traffic links in the system are counted or meet the HPMS requirements for each functional classification. States such as Florida, Georgia, Indiana, Texas, and Utah determine the number of coverage count stations based on FHWA TMG and HPMS requirements and then add station locations if the changes in AADT or traffic volumes exceed a state specified percentage.

Table 12: Determination of Coverage Count Stations

1 **States**	2 **How is the number of coverage count stations determined?**
Tennessee	By using all NHS, all functional classes, Interstate Ramps, Some Urban Freeway Ramps, High Traffic routes
California	-
Florida	Selected to cover state highway system and volume and functional classification by HPMS; Districts where traffic changes significantly may warrant a separate count station
Georgia	Determined by HPMS needs, budget, geographic coverage, changes in traffic patterns, etc.
Indiana	Originally set up in accordance with TMG, any changes are based on the 10% difference requirement, that is, greater than 10% difference in traffic volumes between two stations.
Kentucky	By segmenting the roadways based on volume patterns. Also, the number of coverage stations are balanced between the amount of data needed and the staff available to collect and process it.
North Carolina	Work with the planning department based on: MPO needs, locations for traffic concerns , trip generations, FHWA's need for data on state maintained roads (HPMS)
Texas	Legacy count locations remain intact and are reviewed each year internally. New locations are added upon District and MPO request that are not duplicative and within budget constraints.
Utah	State and Federal Aided Roadways are the coverage stations. Number of sites for each road, are added if AADT variation is greater than 5-10%.
Virginia	Every traffic link in the system gets counted.

2.6.2.6. Growth Factor Development

For states that do not perform coverage counts each year, a growth factor is required to obtain an AADT estimate for the years in which no count is conducted. Data from the permanent traffic count stations are required to develop these growth factors. There were only three states that supplied detailed information as to how the growth factors are calculated and these are stated in column 2 of Table 12. California uses a ratio of the AADT in the current year of interest to the AADT of the preceding year, while Florida uses growth rates based on historical trends, population growth, etc. Although Indiana computes growth factors similar to California, the growth factors for each functional classification are averaged across the different groups and are then applied to the coverage counts. Chapter 6 presents a brief discussion of alternative procedures for the development of growth factors and whether or not the growth factors should be averaged across all stations within a functional classification or computed individually for each station. An analysis is performed and AADT estimates are evaluated to determine which methodology produces more accurate estimates of AADT.

2.6.2.7. Quality Control Checks

The various quality control checks are discussed in column 3 of Table 13. The collected data are checked for completeness by comparing to historical count data (Indiana, North Carolina), general patterns of traffic, repeating values or consecutive zeroes. Florida, Texas, and Virginia discuss the processing software used for validity checks. The responses for the criteria used to determine if a recount of traffic at a location/station is warranted was somewhat mixed. Similar to TDOT's criteria for triggering a recount of traffic at a location/station, if the data fails some of the mentioned quality control checks, then a recount is required as noted in column 4 (e.g., California, Indiana, Kentucky, and Utah). On the other hand, states such as Florida, North Carolina, Texas, and Virginia noted that equipment failures trigger a recount, which could be due to construction, equipment malfunctions, vandalism, weather, etc.

Table 13: Growth Factor Determination, Validation of Coverage Counts, and Ramp Counts (Spans 2 pages)

1 States	2 How are growth factors determined for the non-count year?	3 How is data collected at coverage count stations validated?	4 What would trigger a recount of traffic at a location/station?	5 Are ramp counts conducted?
Tennessee	Yet to be determined	-	"+ or -" 15% of previous count or bad data	Yes; 24 hours annually, but not on ramp sections
California	By using a simple average of the ratio of AADT in the year of interest to AADT in the preceding year to calculate growth factors	Data set is reviewed for completeness (null, zero, error code, consecutive repeating value, low value, high value); general patterns of traffic characteristics are checked	Consecutive series of zero values; consecutive series of error codes, consecutive series of repeating values; random series of very large or very small data values; no reported data values at all; data collected during atypical periods (e.g., holidays, weekends, special events, weather conditions, construction, accidents); using GIS, if a traffic count is inconsistent with other traffic counted during the same period on the same roadway, and the reason for this discontinuity is not apparent	Yes; Between 48 hours or the typical seven-day period or continuous
Florida	Vehicle growth rates are determined by performing a historical trend analysis projection based on available historical counts, population growth, gasoline sales, or other appropriate growth indicators (several methodologies include linear growth, exponential growth, and decaying exponential growth)	The edits performed by SPS alert the Districts to possible problems with the quality and accuracy of the counts by comparing each traffic survey to information stored in two tables – the Station Inventory and the Variance Factors tables. If there are discrepancies, SPS creates error messages for analysis by District personnel. The operator can verify the accuracy of the count, make corrections to the input data files, or update the Station Inventory.	Field – One or more of the machines at a designated count station mechanically fails to properly complete the count period; One or more tubes were damaged or come loose; An incomplete or inaccurate classification or volume count occurs for any portion of the count period; The count was made in the wrong location; The count was affected by an abnormal occurrence, such as a construction detour, long delay, special event, emergency incident, or adverse weather conditions. Office – When the Survey Processing Software (SPS) check detects errors and subsequent tabulation and review of count results verify the need for a recount	Yes, when need arises; Conducted Annually for a 48-hour period
Georgia	-	Refer to the Georgia Traffic Monitoring Program document - Quality Control Rules for Short-Term Monitoring Sites	Table 2 on page 16-17	No, rather estimates are obtained by using Step Down Method, a computer program also known as ramp balancing
Indiana	Developed by comparisons of previous years AADTs and averaged for the 5 factor groups (FG);	Conducting a Check for completeness; comparison with previous years (greater variability)	If a variance of 20 percent, before a flag is sent up, if a count falls outside that variance then another count is set up to be taken, if second count falls outside variance then traffic change is confirmed and second count is used; if second count is similar to historical data then it used and first count was not used	Yes; 48 hours on a 2-year cycle for the interstates

1 **States**	2 **How are growth factors determined for the non-count year?**	3 **How is data collected at coverage count stations validated?**	4 **What would trigger a recount of traffic at a location/station?**	5 **Are ramp counts conducted?**
Kentucky	We generate only one growth factor – the 20 year growth rate for HPMS.	Quality control – compare to historical data (if fails, determine cause and adjust accordingly or recount	A failed quality control test when compared to historical data; AADT allowable percentage difference based on volume	Yes; Minimum of 48 hours on a 3 year cycle
North Carolina	-	Maintain current collection and 3 years of historical data (compare against last 3 years)	Tubes malfunctioning, unrealistic growth factors	Yes; Ramps annually beginning in the fall (Sept/Oct); interstate ramps every year, non-interstate freeway ramps - on a 6-year cycle (based on FHWA TMG)
Texas	No method currently for the off-system 5 year cycle	Using STARS II, counts at a given location are compared with historical counts, regionally similar counts on adjacent or nearby roadways, and counts up and downstream on the same roadway	Machine failure, tube cut, wrong location, short-term construction, plus comprehensive error checking for mismatches, invalid coding, missing information, etc.	Yes; They have been traditionally collected the same as all short-term tube counts. However, we are currently exploring available technology and methods to increase safety during the collection at these locations.
Utah	CCS sites and groups determine Growth Factors.	Annually collect data at CCS sites with short duration counts, to very both short duration and CCS equipment	Data less than 48 hours; data collected reports (+/-) 5 to10% change in growth in comparison to historical AADT. GPS data collected reporting count was located a different or wrong spot	Yes, Same as short term count schedule for both duration and cycle.
Virginia	Growth factors are based on continuous count data.	Prior to submitting data, the contractor is required to review the collected data for any obvious anomalies. After submission to VDOT, all data will be reviewed and analyzed by VDOT technicians and/or processed by VDOT's Traffic Data processing software for validity. Data that does not pass the validity tests may be subject to further investigation	Events, equipment malfunction, vandalism, weather, construction	Yes; Ramp counts are for 48 hours continuous and performed on a 6 year cycle.

2.6.2.8. Ramp Counts

In column 5 of Table 13, it is important to note that all states, excluding Georgia, conduct ramp counts. Most states conduct these counts for a duration of 48 hours. However, the cycle varies from state to state, with the shortest cycle being one year for Florida, the longest cycle being six years for Virginia, and some being either two or three years. Rather than performing counts at ramp locations, Georgia estimates their ramp counts using a ramp balancing method.

2.6.2.9. Coverage Count Staff (In-House and/or Contractor)

Tennessee was among three other surveyed states that undertake 100% of their coverage counts by in-house staff (e.g., California, North Carolina, and Utah), while on the other hand, Florida and Texas contract out 100% of their short duration counts (column 3 of Table 14). For percent of counts undertaken by in-house staff, the median of the nine states is 33.3% (Indiana), and the mean is 50% of counts conducted by in-house staff. For percent of counts undertaken by consultants, the median is 25% for Indiana, and the mean is 40%. Tennessee is well above the mean and median for assigning coverage counts to in-house staff rather than contracting them out but is not the sole state relying 100% on in-house staff as shown in columns 2 and 3.

2.6.2.10. Number of Counts Set Up by Staff

The number of counts set up by field staff ranged from 1 per day for California to 10 per month for Texas (column 4 of Table 14). The mean number of counts is slightly over 12 per day, and the median is about 2.5 counts set up per day for the nine surveyed states. On average, TDOT's staff set up 8 counts per day, which is less than the mean for the surveyed states but greater than the median. As noted in Chapter 6, were TDOT to begin conducting coverage counts for 48 hours on a three-year cycle, then the field staff will not be required to set up as many coverage counts as they currently do.

Similar to TDOT, the geographic area of responsibility designated by each state DOT for each staff is defined either by the number of districts in the state or the number of counties in which counts are to be undertaken (see column 5 of Table 14).

2.6.2.11. Other Responsibilities of Staff and Data Sharing

Whether or not traffic monitoring personnel have other responsibilities besides conducting and maintaining coverage count locations is mixed across the surveyed states as noted in column 6. Half of the state DOTs have in-house staff perform only coverage counts while others have them perform other maintenance activities or place the staff in charge of conducting other counts at locations such as ramps. Six of the nine states are similar to TDOT in that they maintain coverage count equipment in-house (column 8). However, Florida, Kentucky, and Virginia, have either some or all of the equipment maintained by consultants on a contractual basis.

Out of the nine surveyed states, five do not have any agreements with other jurisdictions for collecting and sharing data collected from short duration counts. Florida, Indiana, Texas, and Virginia have contractual agreements to share data with other jurisdictions or make them available to the public (column 7).

Table 14: Count Staff Work Load, Data Sharing, and Maintenance (Spans 2 Pages)

1 State	2 % of Coverage Counts undertaken by in-house staff	3 % of Coverage Counts undertaken by Consultants	4 Number of counts set-up by Field Staff within a given period	5 How are the geographic area responsibilities for each field staff defined?	6 Do the traffic monitoring personnel have other responsibilities	7 Any agreements with other jurisdictions for collecting and sharing short term count data?	8 Is the maintenance of the equipment for coverage count program done in-house?
Tennessee	100	0	40/week	According to the number Counties and Stations that need to be counted	Yes	No	Yes
California	100	0	1/day	District Traffic Census are responsible for each district.	No	No	Yes
Florida	0	100	-	-	-	Yes, shared online for the general public; DVD is sent out upon request; done by district offices	No; Performed on a Consultant contract basis
Georgia	21	79	55-60/day	Refer to GDOT's Challenges of the Day-to-Day Operation of a Traffic Monitoring Program	Yes; conduct ramp traffic volume counts, vehicle classifications near bridges, and non-directional and directional traffic volume; collect Portable Traffic Monitoring Station (PTMS) data, and supervise CCS maintenance/installations.	No	Yes
Indiana	33.3	25	15/week	According to County Divisions	Yes; Required to participate in snow plowing in winter.	Yes; with MPOs and RPOs, also made available to the public	Yes
Kentucky	96	4	It varies from District to District, depending on the size of the district	By KYTC Districts	Yes, some may; depends upon the District	No formal agreements with any other jurisdictions but KYTC Division of Planning shares data upon request.	Minor station repairs are done by in-house staff; external contracts cover major (in-pavement) station repair.

1 State	2 % of Coverage Counts undertaken by in-house staff	3 % of Coverage Counts undertaken by Consultants	4 Number of counts set-up by Field Staff within a given period	5 How are the geographic area responsibilities for each field staff defined?	6 Do the traffic monitoring personnel have other responsibilities	7 Any agreements with other jurisdictions for collecting and sharing short term count data?	8 Is the maintenance of the equipment for coverage count program done in-house?
North Carolina	100	0	90/week	3 areas, eastern, western, central (each region works within their region but share numbers across territories)	No	No	Yes
Texas	0	100	10/month	Statewide	Yes; they handle data requests/PIO inquiries (including those from the Transportation Commission, Legislature, researchers, and the public); Perform GIS mapping work, (including the production of Traffic Map products); assist with the development of Travel Demand Models, and provide technical support.	Yes; Through our District operations, data is exchanged for the purposes of supplying information needed to satisfy TxDOT contractual requirements regarding Pass-Through-Financing (PTF) projects.	Yes
Utah	100	0	2/day	Geographic area is split into two: Southern and Northern Utah. Responsibilities are equally shared among staff	No	No	Yes
Virginia	7	93	At most 12/week	In-House staff travel state-wide to perform coverage counts. The contractor staffs the region based on annual count requirements and the workload.	No	Yes; data collected by the short term coverage counts is available to multiple internal and external customers. Traffic data from other localities is generally shared with VDOT and loaded into our database. Additionally, regional/local offices can use our contract as a vehicle to obtain counts from a specific location or area.	In-House staff is responsible for battery maintenance on a regular basis; Contractor equipment is maintained by the contractor

2.6.2.12. Performing Coverage Counts on Mondays/Fridays and Locations near Educational Institutions

Surveyed state DOT responses to questions on the practical aspects of undertaking coverage counts are presented in Table 15. For the responses of how counts are handled on Mondays and Fridays, none of the states commented on performing counts on Mondays, but there were variations as to how counts are conducted on Fridays as noted in column 2. Six of the nine states do not conduct short duration counts on Fridays, while Florida and Kentucky are the same as TDOT in that counts are only performed for half of the day on Fridays. Indiana either conducts half-day counts or no count depending on what is necessary.

The presence of major educational institutions does not influence the scheduling of counts in three states, namely California, Georgia, and Utah (column 4). TDOT should continue to schedule counts based on the major educational institutions' academic calendar since six of the nine surveyed states have it as a determinant of the timing of coverage counts.

2.6.2.13. Number of Coverage Count Equipment Each State DOT Vehicle can Carry

The fifth column contains information on the number of short duration count devices that vehicles used by field staff can carry. It ranges from 30 devices per vehicle for Utah and Virginia up to 110 devices per vehicle for North Carolina. The median number of devices per vehicle for the nine states is 60 for Georgia and Indiana, and the mean is 57 devices per vehicle. TDOT's vehicles are able to carry 32 short duration count devices only, which is about half the median number of devices carried by the vehicles of the nine surveyed state DOTs.

2.6.2.14. Travel by Field Staff Associated with Setup/Retrieval of Count Equipment

Finally, column 6 of Table 15 indicates whether or not field staff return to the office daily for pick-up and installation of the next day's count equipment for 48-hour short duration counts. Georgia and Virginia DOT field staff do not return to the office, but the other five states that responded do return to the office to pick up the next day's count equipment since the areas are vast or for other scheduling reasons.

Table 15: Practical Issues in Undertaking Coverage Counts (Spans 2 Pages)

1 States	2 How are counts on Mondays and Fridays handled?	3 How are equipment left over the weekend, secured against theft or being damaged?	4 Do the presence of major educational institutions influence the scheduling of counts?	5 How many short-term count devices can vehicles used by field staff carry?	6 For 48-hour counts, do field staff return to the office daily for pick-up of the next day's count equipment and installation?
Tennessee	Half-day on Fridays	NA	Yes	32	NA
California	No count on Fridays	NA	No, Educational institution academic calendar in general does not influence timing of counts. However, counts are not scheduled during major events (annual events) at these educational institutions.	Vans can carry 44 portable counters; depends on weight	Ramp counts, put out counters Monday and Tuesday and then come back Thursday or Friday and go back to the office
Florida	Half-day on Fridays	NA	Yes; Seasonally, the influx of university students varies with high generation rates in the Fall, Winter and Spring. Low generation rates are typically in the Summer when most students are not enrolled. It is prudent to avoid holidays and special events such as sporting events since these can significantly influence the traffic count. Additionally, some institutions have very high commuter rates, i.e. students driving to school, while others have high transit rates. Consequently, travel mode is impacted seasonally.	Determined by consultants	It depends since the area is vast.
Georgia	No count on Fridays	NA	No	Fifty to sixty count devices depending on weight of other equipment in vehicle (road tube, nails, etc.)	No; OTD's two in-house Field Technicians have their necessary equipment with them and are based out of their home counties.
Indiana	Either no count on Fridays or half-day where necessary	NA	Yes	Full-sized vans can carry about 60 TimeMark devices.	Varies, most field technicians prefer to return to office at the end of the day (HQ or district office); has the option of taking home the vehicle (not as often used because of significant paperwork); interstate crew may stay overnight in hotel and return the next day

1 States	2 How are counts on Mondays and Fridays handled?	3 How are equipment left over the weekend, secured against theft or being damaged?	4 Do the presence of major educational institutions influence the scheduling of counts?	5 How many short-term count devices can vehicles used by field staff carry?	6 For 48-hour counts, do field staff return to the office daily for pick-up of the next day's count equipment and installation?
Kentucky	Half-day on Fridays	NA	Yes; counts in the vicinity of ALL educational institutions are scheduled when school is in session.	Each field technician has a van or large pickup truck that can accommodate more data collectors than they can place in 2.5 days (the amount of time we allow them to set counts out).	Yes, if needed.
North Carolina	No count on Fridays	NA	Yes; as much as possible, scheduling is done when in school is in session	With field staff, they are home-based; devices are the size of a phone, 90-110 in truck, includes tubing and nails/hammer	-
Texas	No count on Fridays	NA	Yes; schedules (particularly off-system counts) are adjusted to count only when school in in session (for example, we avoid collecting counts during the local week of Spring Break)	In-house staff uses ½-ton pickup trucks to carry equipment, tubing, and anchors/brackets/nails. The maximum is about 65.	NA
Utah	No count on Fridays	NA	No	25-30 typically, along with a one Radar trailer.	4-10 Schedule, place counters on Monday, pick them up Thursday. Returning to office depends on how nearby they are to office. Many counties require overnight stay
Virginia	No count on Fridays	NA	Yes; Locations where educational institutions influence traffic are typically counted while classes are in session. Normal traffic is considered to be when classes are in session since a normal school year influences traffic patterns for 9 out of 12 months of a calendar year. A recount can be triggered if a location influenced by an educational facility is counted while school is not in session.	Based on a standard work pickup truck or van and assumed necessities, it is possible to carry ~30 road tube counters or ~12 non-intrusive radar based counters	No; It is not typical of the field crews to return to the contractor's office on a daily basis.

2.6.2.15. Technology Used at Coverage Count Stations

Table 16 includes the details on the technology and software used for data collection of short duration traffic counts. The technology used for short-term counts is fairly consistent across the surveyed states and includes road tubes, inductive loops, and/or piezoelectric sensors, automatic traffic recorders, and radar (column 2). Many states, including Tennessee, have issues with the performance of technology in weather such as heavy rain/flooding, snow, and ice as reported in column 3. Florida, Utah, and Virginia indicated that their technology is not affected by weather. Besides Utah, all states including Tennessee indicated that their technology does not work properly in multiple lanes, slow/congested traffic, high traffic, or atypical volume conditions (column 4); however, Utah does not experience difficulties with their technology in varying traffic conditions. Six of the nine states as shown in column 5 provided a response to the number of devices available for short-term counts. It ranges from a low of 200 devices for Indiana and Utah to 2,950 devices for Texas. The median number of devices is 488 while the mean is 1,088 devices. Tennessee has 180 devices for short-term counts available, which is less than the lowest reported number of devices of the surveyed states.

The replacement cycle of these short-term count devices depends on the extent of the wear and tear of the equipment or until they break down or are no longer accurate. Six out of the nine states provided a number of years of the estimated replacement cycle for these devices, as shown in column 6. The years range from 7 years for Texas to 20 years for California, and the median is 10 years while the mean is 12 years. If the lifespan of Tennessee's equipment is longer than 10 to 12 years, then the current equipment being used is deemed adequate as compared to the surveyed states.

2.6.2.16. Reliability, Accuracy, and Issues with Technology

The reliability and accuracy of the short duration count technologies (columns 7 and 8) is either unknown or varies among the states. It is difficult to provide merit to TDOT's procedure since these percentages are not statistically determined but rather an estimate. The amount of training was reported by two states: one day for Indiana and two weeks for Florida. TDOT provides training for their field personnel for a longer duration than provided by any of the surveyed states. Indiana and Florida reported the number of staff required for a setup of the equipment for a single count to be either one or two personnel (column 9).

Table 16: Technology and Software for Data Collection – 1 (Spans 2 Pages)

1 **States**	2 **Technology Used for Short Term Counts**	3 **Is the technology affected by weather?**	4 **Is the technology affected by traffic conditions?**	5 **Number of devices available for short term counts**	6 **What is the replacement cycle for these devices?**	7 **Reliability of the mentioned technologies**	8 **Accuracy of technologies in counting traffic**	9 **Training requirements for a setup/ Number of staff required**
Tennessee	Diamond Software/Unicorn and Phoenix Counters	Yes; does not take counts in snow or ice.	Yes	30 portable counters per field person (6 Field persons)	Replacement is done at the end of its lifespan	85%	Good	4-8 weeks training field personnel on software and how to use the equipment; 1 trainer required.
California	Road tubes; small magnetic sensor placed in the middle of the roadway; non-intrusive sensors or semi-permanent data sites that utilize either intrusive or non-intrusive technologies (inductive loops and /or piezoelectric sensors); trailer-mounted systems on extendable poles; pole-mounted systems	Yes; Pole-mounted systems can't be used in the rain. If it starts raining, they are left out longer to get the full data	Yes; Road tubes do not work well in high traffic volume conditions - heavy trucks can rip tubes off the pavement. Some district personnel go out once a day to make sure the tubes are still placed on the pavement accurately.	Total 2,203 counters, some of the counters are used for quarterly counts and ramps.	Most of our Peek and Diamond counters currently used are about 20 years old and are still functioning; counters are serviced with maintenance contracts.	95%; may fail but not very often; modem may quit working	98% (estimated); as long as the counter is in good condition	Newly recruited technicians are paired with the experienced and are taught how to handle the devices; Only 1 or 2 staff are needed for setup.
Florida	Road tubes (rubber hoses), loops and sensors	Not really	Yes; affected by slow and congested traffic	-	8 or 10 years or maybe more, replaced when road gets milled, or if a semi-tractor trailer if a tire is blown, if the pavement starts rutting or wearing.	-	Very accurate for volumes; not very accurate for classification	A minimum of two weeks of training by accompanying an experienced field technician who is collecting traffic data; all personnel must be provided training in first aid techniques and be familiar with safety procedures listed on p. 28 in the TMG.
Georgia	Portable traffic loop counter, 1+ pneumatic tubes, PEEK ADR 1000 portable traffic counter/classifier (in-house), MetroCount 5600 series roadside unit (contractor)	Yes; If tubes are not properly secured, they can separate from the ground.	Yes	At least 225 devices for in-house staff.	10 to 15 years	90%	85% accurate for class and 95% accurate for volume in ideal conditions	Training by an experience field tech is required for the setup of technology; One staff member is required for setup.

1	2	3	4	5	6	7	8	9
Indiana	Pneumatic road tubes (predominantly), Miovision video technology in large urban areas and on interstates	Yes; snow and rain has a some impact; not much though	Yes, challenges could arise when performing counts on multiple lanes (beyond two lanes without a median)	~200 devices	None defined; Used until they break down or are no longer accurate	95%	95%	New traffic counters must go through certification program (1 day of classroom training on safety and setup situations, followed by a field examination – setup counters under supervision); 1 person crews, consultants may work with 2-person crews
Kentucky	Pneumatic road tubes, ~450 stations with in-pavement inductive loops and/or piezoelectric sensors, and automatic traffic recorders	Yes (snow, torrential rain, etc.) – pickup or not scheduled when adverse weather is expected.	Yes; counting schedules are avoided during events that may cause atypical traffic volumes	~750 automatic data collectors.	None defined; depends on the availability of funds	Unknown	Unknown	When hired, staff is trained by someone from the Central Office field crew. Additional training is made available if needed; one (1) staff for setup.
North Carolina	-	-	-	-	-	-	-	-
Texas	Road tubes: ITC/IRD, Diamond Unicorn, Peek ADR 1000	No, except in a situation floodind is experienced	Yes; When Class is above 3000 AADT, Axle is limited to 3 lanes of traffic	450 TxDOT, 2,500 Contractor	6 to 7 years	90%	95%	Training is handled OJT; 1 or 2 depending on how busy a location is.
Utah	Tubes, Radar	Yes, but not directly; Snow Plows affect the equipment more than weather itself.	No	200+	5-10 years	Varies	Pretty accurate	Safety, operational, and maintenance training are required. Typically 1 staff member is only needed to set up a single count
Virginia	Road Tube technology, Dual side fire radar, Machine Vision Technology	No	Yes; some may be affected by slow and congested traffic	-	Expected life cycle of greater than 10 years if properly maintained. Replacement determined by the extent of wear and tear	98%	95%	Road tube setup requires a two (2) person crew. Non-intrusive technology Can be done using a 1-person crew.

The technologies the surveyed states have experience with is Peek (most common among the states), Pointis, Censys, Diamond, Pico, Metrocount, and laser technology as listed in column 2 of Table 17. The reliability is reported in column 3. However, as mentioned previously, the percentages are either unknown or are estimates that are not statistically determined, making it difficult to compare Tennessee's equipment reliability to that reported for other states, or for that matter to serve as a basis for making any recommendations for improvements (column 3).

The issues with current and previous technologies differ among the states and only five of the nine responded to the question as noted in column 4. The most common problems have to do with the life of road tubes and inabilities to count multiple lanes. As reported in column 5, two states in addition to Tennessee do not plan on changing the technology that is currently in place for short-term traffic counts. However, five states plan on using a different technology in the future. The increased interest in the additional advantages to using new technologies is the primary reason for planning to switch to alternative technologies (column 6).

2.6.2.17. Bid Costs for a Two-Lane Roadway and Software Used

The seventh column provides the information on the bid cost for supply and installation of data collection equipment for a two-lane roadway. Only California, Kentucky, and Virginia provided a range of costs, which were wide ranges that varied among the states ($200 to $17,000). Most states have custom software that was either developed in-house or by consultants for the generation of AADT from short-term traffic count data. Kentucky and Utah were the only two states that use the same software, which is TRADAS (column 8). As noted in column 9 of Table 16, each state's software allows for changes in the duration and cycle of short-term counts.

Table 17: Technology and Software for Data Collection-2 (Spans 2 Pages)

1 States	2 What other technologies do you have experience with?	3 How reliable were they?	4 Issues with Current and Previous Technologies	5 Any Plans to use a different technology in the future?	6 If yes, what is the reason for the planned switch?	7 What is the bid cost for supply and installation of data collection equipment for a 2-lane roadway?	8 What software is used to generate AADT from short term count data?	9 Does it allow for changes in duration and cycle of short term counts?
Tennessee	Peek	45%	Inability of road tubes to count more than 2 lanes per direction; Peek, not user-friendly	No	NA	~ $6,000	Diamond Software (ADAM Program)	Yes
California	None	NA	Cars that change lanes may not get counted – sensor might miss them; Too much traffic on a bending plate affects the accuracy of count	Yes	Added advantages	$5,000-$10,000 to install the loop on both sides, includes labor, contracted out, Caltrans oversees the work	Transportation System Network, Performance Measurement System (PeMS)	Yes
Florida	None	NA	-	Yes	Open to new technologies	-	Oracle	-
Georgia	Pointis (railroads and bridges)	90%	Battery Power	-	-	-	Transmetric Traffic Server	Yes
Indiana	Aware of new metrics counter (small device glued to roadway and uses magnetic collection); Censys is size of hockey puck imbedded in pavement and communicates wirelessly with roadside counter (may last 10 years); pneumatic road tube counter manufacturers (PEEK, Diamond, Pico)	All offer 95 percent accuracy (standard for industry)	-	No	NA	Determined by Qualified purchase agreement	Traffic Count Database program (by Midwestern Software Solutions)	Yes
Kentucky	Time stamped axle counters (PEEK and Metrocount).	Unknown	Tube life	No	NA	Costs can vary from ~$3,000 up to as much as $17,000 depending on the kind of installation	TRADAS (soon migrating to Jackalope)	Yes

1	2	3	4	5	6	7	8	9
North Carolina	-	-	-	-	-	We do not contract portable counts and collect all of this data ourselves. Our Mobility and Safety Division does. Here is a link to their price listing including short term Volume-Class-Speed (VSC) counts https://connect.ncdot.gov/resources/safety/Pages/Traffic-Data.aspx	-	-
Texas	-	-	-	Yes	Added advantages; Exploring non-intrusive video count technology to supplement tube counts, especially in urban areas	Axle tube count $25.71 and Class tube count $33.75	Stars II	To an extent; numerous customized reports and tools have been incorporated to address count needs.
Utah	Peek	Varies	Binned data vs per vehicle data.	Yes	Open to new technologies	Varies	TRADAS	Moderately flexible
Virginia	Infra-Red, such as TIRTL, Laser technology	Less than acceptable by our program	Water getting into Road tubes and counter; Axle over-counting	Yes	Merits of a "hybrid ATR"; research into methods that can save costs by reducing recounts due to operator setup errors.	Bid costs vary based on contractor and region. Generally varies from $ 200 - $550	Custom developed in-house software is used by VDOT to generate AADT's	Yes; can be updated to accommodate changes through the assistance of in-house developer resources.

2.6.2.18. Truck Weight Program

Information on truck weight programs and estimation of vehicle miles traveled (VMT) on local roads are reported in Table 18. Currently, TDOT does not have a truck weight program. However, all states except North Carolina have a truck weight program, as shown in column 2. The third column indicates the number of sites monitored throughout each state. Out of the eight states that responded to the question, the number of truck weight sites monitored range from 1 site for Utah to 140 sites in California. The median is slightly over 30 sites, and the mean is slightly over 40 sites.

The most common types of equipment used for the truck weight program included bending plates, piezo sensors, and inductive loops (column 4). As stated in the fifth column, out of the eight states that collect weight data, all states have in-ground equipment whereas Georgia has some that are portable/mobile while others are in-ground.

2.6.2.19. Vehicle-Miles Traveled

The last column in Table 18 presents the methodologies for estimating VMT on local roads for each of the surveyed states. The procedures differ across the surveyed state DOTs. Some make use of sampling techniques to yield a VMT estimate. Others use default values of AADTs and apply them to the local road mileage. Based on the brevity of the descriptions provided, judgment cannot be rendered with certainty as to whether any of the procedures of the nine surveyed states would result in more accurate estimates of VMT on local roads in Tennessee. A more in-depth discussion of VMT estimation is provided in Chapter 8.

Table 18: Truck Weight Program and Estimation of Vehicle Miles Traveled on Local Roads

1 States	2 Do you have a Truck Weight Program?	3 How many sites are monitored?	4 Type of equipment used	5 Is the equipment portable/mobile or in-ground?	6 How is VMT estimated on local roads?
Tennessee	-	-	-	-	Queries are run in TRIMS through MITS software(Custom written) to produce VMT by Admin Sys, VMT by functional class, FC Mileage, Local Rural and Urban ADT
California	Yes	22 WIM sites for the SHRP Truck Weight Study program but we have 140 WIM sites and counting	Bending Plate	In-ground	1.) Calculate segment VMT following the formula (length x AADT) 2.) Sum up all segments within each respective local jurisdiction to get VMT for all jurisdictions in California.
Florida	Yes	33	1-2 bending plate systems, all others are piezos	In-ground	VMT is calculated using counts and distances derived from Florida's permanent count stations.
Georgia	Yes	11 permanent and 34 non-permanent	Piezo-loop-piezo sensor configuration	Some are portable, others are in-ground	On local roads, OTD collect a small number of samples to derive and compute VMT statistics for Federal reporting purposes.
Indiana	Yes	49	Inductive loops to get speed and class; axle weight is piezo sensors and Kistler equipment	In-ground	For HPMS reporting, a set of default AADTs assigned to road that do not have data collected. The default values are updated every 3 years. The default values are assigned based on area type and county character. Each default AADT is multiplied by the applicable centerline miles of that roadway type in each county; and this is rolled up into statewide totals;
Kentucky	Yes	Typically about 30 (based on sensor functionality) permanent ATR sites are WIM (collected continuously)	PEEK ADRs, 'BL' brass linguine piezo sensors	In-ground	We take the Minor Collector DVMT for each county and divide it by the Minor Collector miles in that county to produce a county-wide Minor Collector ADT. We then apply the equation Local ADT = 3.3439×(Minor Collector ADT)$^{0.6248}$ to develop a county-wide Local ADT for each county.
North Carolina	Weight data not used	NA	NA	NA	By using the Local VMT Estimation methodology
Texas	Yes	29	Bending Plate and quartz	In-ground	The Traffic Analysis Section supplies a year-end traffic data file to the Data Management Section, who applies the data to the roadway inventory file to produce VMT.
Utah	Yes	1 within Traffic Monitoring, in addition to Port of Entry sites with Motor Carriers.	PEEK	In-ground	HPMS collects and reports AADT and growth from local governments, and calculates VMT based on total mileage.
Virginia	Yes	10	Loop, piezo, and Kistler sensors and one bending plate site	In-ground	DVMT is estimated based on AADT multiplied by length of the traffic link.

2.6.2.20. Vehicle Occupancy Program

Vehicle occupancy details are listed in Table 19. It is noted that only two of the surveyed states, California and Florida, determine vehicle occupancy. California performs occupancy counts in HOV lanes while Florida determines ridership through annual surveys conducted by the local transit agencies. Since vehicle occupancy counts are not commonly performed by most states, no recommendations pertaining to it based on best practices are made to TDOT.

Table 19: Characteristics of Vehicle Occupancy Program

States	How is the number of locations for occupancy counts determined?	What is the typical duration of vehicle occupancy counts?	How are vehicle occupancy counts performed?	What technology is used? How reliable and accurate are they under different traffic and weather conditions?	What vehicle categorization is used for reporting occupancy data?	How is occupancy of Public Transit Vehicles determined?	How is the occupancy of vans determined?
Tennessee	Vehicle Occupancy counts not conducted	NA	NA	NA	NA	NA	NA
California	Performed in HOV lanes, may be in the planning department, may not even do it	-	-	-	-	-	-
Florida	-	-	-	-	-	Ridership is determined through annual surveys done by the local transit agencies.	-
Georgia	Vehicle Occupancy counts not conducted	NA	NA	NA	NA	NA	NA
Indiana	Vehicle Occupancy counts not conducted	NA	NA	NA	NA	NA	NA
Kentucky	Vehicle Occupancy counts not conducted	NA	NA	NA	NA	NA	NA
North Carolina	Vehicle Occupancy counts not conducted	NA	NA	NA	NA	NA	NA
Texas	Vehicle Occupancy counts not conducted	NA	NA	NA	NA	NA	NA
Utah	Vehicle Occupancy counts not conducted	NA	NA	NA	NA	NA	NA
Virginia	-	-	-	-	-	-	-

2.6.3. Vehicle Classification Count Program

The survey of state DOTs included questions on the vehicle classification count program. Of specific interest are the vehicle class categories, cycle and duration for counting, number of counts, selection of locations, productivity of field staff, technologies used, and validation procedures. The program characteristics reported are summarized in comparison to the TDOT program in the following subsections.

2.6.3.1. Duration and Cycle of Classification Counts

Presented in Table 20 is information on the staffing and number of classification counts, as well as the duration and cycle of vehicle classification counts. As shown in Columns 3 and 4, six out of nine states (Florida, Georgia, Indiana, Kentucky, Utah and Virginia) conduct vehicle classification counts for a duration of 48 hours. While different states have different cycles for conducting the 48-hour classification counts, generally, a cycle of three years appears to be a common practice. For some states however, the adoption of a particular cycle for the 48-hour duration is dependent on the kind of road for which the classification count is being done. For instance, Indiana adopts a three-year cycle for state-owned routes, a three- or six-year cycle for non-state-owned routes and a two-year cycle for interstates routes. California and North Carolina conduct vehicle classification counts for a duration of seven days. Currently, Tennessee conducts vehicle classification counts for 24 hours on a five-year cycle (to be changed to a three-year cycle).

2.6.3.2. Number of Classification Count Stations

From Column 2, it is observed that California conducts the lowest number of classification counts (330), while Indiana conducts the highest (18,050). On average, the number of classification counts conducted by most of the states is 2,600. Tennessee conducts 2,000 classification counts, which is close to the mean number of classification counts conducted across most of the surveyed states.

2.6.3.3. Classification Count Staff (In-House/Contractor)

Classification counts are conducted by either in-house staff or contractors. From the information gathered (shown in Column 5) it appears most states use contractors for vehicle classification counts, and so could not give the exact number of field staff used for the classification counts. However, Texas and Utah stated the number of field staff used for classification counts to be five; Tennessee uses six staff for its counts.

2.6.3.4. Road Mileage Monitored per Classification Count per Year

Using the road miles monitored by a state (shown in column 2) and the number of classification counts undertaken by a state (reported in column 3), the number of monitored miles per classification count station was calculated and is reported in column 9. This serves as a useful metric for comparison of an aspect of TDOT's program to that of other state DOTs. This metric ranged from 4 miles per class count for Utah to 392 miles per class count for Texas. The median number of miles per class count is 11 while the mean is 63 miles per class count, which was equal to that of Georgia. Tennessee has 48 monitored road miles per classification count station, which is more than the median, but less than the average of the nine surveyed states. A second metric was calculated in column 10, which is the number of monitored miles per class count station per year, ranging from 1 (for Utah DOT) to 392 (for Texas DOT) miles per class count per year. TDOT monitors 10 road miles per class count station per year which is slightly higher than the median of 7, but much lower than the mean of 52 miles per class count per year. It is apparent that the high value of this metric for Texas is responsible for the mean being this high - Texas DOT monitors 313,596 road miles.

Table 20: Characteristics of Classification Count Program

1 State	2 Mileage Monitored (Road Miles)	3 Number of Classification Counts	4 Duration	5 Cycle	6 Number of field staff	7 Number of office staff	8 Number of maintenance staff	9 No. of Monitored Miles per Class Count Station	10 No. of Monitored Miles per Class Count Station per Year
Tennessee	95,560	2,000	24 hours	Currently 5 years, going to 3 years	6	2	---	48	10
California	15,100	330	7-day period or continuously at a sample of sites	Every 3 years on the Interstate System and every 6 years on other roads	---	---	---	46	15
Florida	29,600	Permanent – 259; portable – 3,842	Typically 48 hours, can be 24 or 72 hours, some may request 7 days	Annually	0 (contracted out)	8	---	7	7
Georgia	125,130	2,000	48 hours	2- and 4 year	2	N/A	---	63	31
Indiana	95,861	18,050	48 hours (tube counts, state and non-state owned), 24 hours (non-state interstate video counts)	Same as AADT program, 3-year cycle for state-owned routes; 3- or 6-year cycle for non-state owned, and 2 years for interstates	---	---	---	5	2
Kentucky	28,500	2,600	Minimum of 48 hours	3 years for most; 1 year for interstates	---	---	---	11	4
North Carolina	79,585	3,143	7 days	Portable class counts are on a 3-year cycle	---	---	---	25	8
Texas	313,596	800	24 hours	Annually	1 TxDOT - 5 Contractor	2 TxDOT - 10 Contractor	N/A	392	392
Utah	10,000	2,307	48 hours minimum	3 year cycle	5 (same as short duration count)	1	---	4	1
Virginia	58,000	About 350 continuous and 6,000 short-term sites	48 hours or continuous	It is either continuous or follows the same cycle as the coverage count program	---	---	---	9	3

2.6.3.5. Number of Field Staff

Table 21 provides information on the field staff that conduct classification counts (column 2), if different from those who conduct the ramp and cycle counts, as well as the number of devices that are set up per day (column 3). The number of field staff ranged from 1 (California) to 8 (Indiana) for five of the nine surveyed states, where the median is 2 (Georgia and Utah) and the mean is about 3.5 field staff. Compared to the other five states that responded to this question on the survey, Tennessee has more field staff that are responsible for class counts with the exception of Indiana. Some of the states use contractors for their classification counts. The number of class counts that are set up per day ranges from 7 (North Carolina) to 38 (Texas), with a median of 10 (California) and the average number of class counts set up per day is about 16, which is similar to the number that Georgia DOT sets up. TDOT sets up about 12 to 18 classification count devices per day.

For Indiana, California, Kentucky, Texas, and Utah, the field staff have other responsibilities in addition to conducting classification counts. California and Georgia perform traffic counts, and Texas field staff provide technical support and assist with traffic map products and travel demand model development. Indiana's field staff take part in a variety of responsibilities that include equipment maintenance, data quality control, and re-counts that are necessary.

Table 21: Classification Counts Setup Daily and Other Responsibilities of the Staff

1 State	2 Number of field-staff responsible for class counts	3 Number that are setup per day	4 Other responsibilities
Tennessee	6	Random, according to schedules (2 or 3 per day) per field person	Yes
California	Field staff are the same as office staff in each district; staff that works in the census program are also engineers	5-10; it depends on what the actual task is, setting up tubes vs. just plugging in the counters	Yes, they do everything associated with traffic census
Florida	No field staff, all contracted out	---	---
Georgia	We have two in house staff and a vendor that provides class counts.	It depends. In-house staff can set-up an average of 15 classification counts per day.	Traffic counts but they do have other duties.
Indiana	Not different, same 8 people on staff, consultants, MPO, RPO	Metric is per week to setup, maintain, and process 15 (7-8 per day)	Snow plowing, equipment maintenance, uploading and quality control, determining re-counts, planning next week's activities
Kentucky	Included in duties of District ramp/cycle count staff.	It varies from District to District. Some staff are assigned significantly more counts in a given season than others based upon District size.	Varies from district to district
North Carolina	---	Maybe 4-7, portable radar may take 30 min to an 1.5 hour to install	---
Texas	Pneumatic tube: 18 contractors, Video: 5 contractors, and TxDOT: 4	30 pneumatic; 8 video	Handle data requests/PIO inquiries including perform GIS mapping work, including the production of Traffic Map products, assist with the development of Travel Demand Models, and provide technical support.
Utah	Same staff	Varies 0-100%	No
Virginia	N/A	N/A	N/A

2.6.3.6. Determination of Location and Number of Classification Count Stations

Table 22 summarizes the TDOT and other State DOTs' characteristics related to number of classification counts and locations of counts. Column 2 contains information on how class count stations are determined, and this varies among the states. In general, states, including Tennessee, determine site locations in order to capture varying traffic patterns (e.g., congestion) and to ensure a fair representation of primary routes for all functional classes. Some states, such as Florida, Georgia, Kentucky, and Virginia select stations based on the FHWA TMG and to meet all data quality and HPMS requirements.

In column 3, the number of classification count stations ranges from 230 for Georgia to 20,000 for Indiana. The average number of class count stations is about 5,500, and the median is 3,350.

2.6.3.7. Percentage of Coverage Count Stations that Perform Classification Counts

Column 4 shows that the percentage of coverage count stations that are also classification count stations ranges, among those responding to this question, from 9% for Texas to 80% for Indiana. Of Tennessee's coverage count stations, 17% are also class count stations, which is below the average of 32.5% and median of almost 29%. The FHWA TMG recommends that "State highway agencies initially aim to collect 25 to 30 percent of their short-duration counts with classification counting equipment. Agencies that can exceed this figure are encouraged to do so" (p.3-63). The FHWA TMG also recommends the use of continuous classification counts for higher quality (p. 3-25) and cites a method used by Virginia DOT for determining truck volume factors. Virginia DOT reported about 350 continuous count sites used for classification counts, Florida DOT reported 259, and Georgia reported 230 continuous count locations. The responses from other State DOTs were not specific as to whether the class count sites were for continuous or short duration counts.

Table 22: Number and Location of Classification Counts

1 State	2 How number and location of stations are determined	3 Number of class count stations	4 Percentage of coverage count stations that are also class count stations	5 Number of sets of equipment each State DOT has
Tennessee	If roadway has more than one traffic pattern	About 2,000	17%	30 counters each per field person (180 total)
California	Roadways for which axle-correction factors are to be used for the road in question	330	30% (not a verified number)	Diamond counters can be used to classify and but Peek can too
Florida	Make sure all functional classifications for all volume groups are covered according to HPMS requirements	Permanent – 259; portable – 3,841	13,900 total PTMS counts (3,841 portable class)	Do not have portable equipment, all done with loops and piezos in-pavement
Georgia	TMG	230 permanent, short duration are based on funding	25%	Over 225
Indiana	For areas with congestion or condensed traffic signals - try to get at least 1 out of 4 collected with video along route	Of the 22,000+ stations, over 20,000 have classification	80%	Same number estimated for volume counts (200 devices)
Kentucky	Try to get 25% to 30% of existing required traffic station locations as recommended in the TMG. Locations are selected based upon known truck patterns from our District Offices. We try to make sure that all roads classified above minor collector have at least one classification station inside of each urban area and at least one classification station on rural roads between two urban areas. Typically a station that is gathering classification data will not span an intersecting route that is part of the NTN or NHS.	2,600	2,600 total, the percent of classification counts in a given year approaches 25% of the coverage counts	We have approximately 300 non-ATR permanent stations from which we collect classification data provided the sensors are functioning correctly
North Carolina	Try to maintain a collection site between primary routes	---	---	---
Texas	---	Approximately 7,700 axle class and 800 video classification	Approximately 9%	450 pneumatic tube counters
Utah	Same as short duration	2,307	30+%	Same equipment as short duration
Virginia	One third of coverage count locations are class count sites, safety and data quality are factors considered when determining the locations of class sites.	6,000 coverage count sites	33%	Contracted out

2.6.3.8. Number of Classification Count Devices

Lastly, in column 5, the number of equipment each State DOT has ranges from 200 to 450 devices, most of which are portable equipment devices. Tennessee has 180 devices which is less than the mean of 275 and the median of 225. Based on the comparison with the nine surveyed states, Tennessee has fewer class count stations. It also has a lower percentage of coverage count stations that are also class count stations. Finally, the number of classification count devices Tennessee has is also smaller than the average for the surveyed state DOTs.

2.6.3.9. Use of the 13 FHWA Vehicle Classes

From column 2 in Table 23, TDOT and the nine other state DOTs in the survey use the 13 FHWA vehicle classes for classification counts without modification. North Carolina DOT uses the FHWA classes without modification but may also aggregate the data into four categories if useful. Additionally, Indiana DOT uses the FHWA classes for counts with tube and loop technologies. However, for video, six vehicle classes are specified: motorcycles, cars, white trucks, buses, and two other truck classes. California DOT uses the basic FHWA categories but splits Class 9 into two classes – one for conventional five-axle tractor-semitrailer combinations and a second (Class 14) for five-axle truck trailer combinations (primarily of three-axle trucks with two-axle full trailers. A Class 15 is also specified to capture vehicles not identified in the other classes.

2.6.3.10. Quality Control Checks

Various procedures are used to validate vehicle classification counts (column 3). Similar to Tennessee, other states use historical data or the previous year's AADT to validate class counts (i.e., California, Georgia, Kentucky, Texas, and Utah). Also, Florida, North Carolina, and Virginia perform quality control checks, the results of which are further reviewed by an analyst before determining whether a re-count is necessary.

1 State	2 Does State DOT use 13 FHWA vehicle-classes? If no, what categories?	3 Count validation procedure
Tennessee	Yes	Compare AADT and the last year the count was made
California	Expansion, splits FHWA Class 9 into two classes – one for conventional five-axle tractor-semitrailer combinations, and a second (Class 14) for five-axle truck trailer combinations (primarily of three-axle tracks with two-axle full trailers); a Class 15 is also used to capture vehicles not identified in the other classes.	Check to ensure they look like similar numbers from previous years (3 years ago). If class 15 is too high, they know it needs to be recounted. They verify it in the database, Peek software is what does the checking, they have their own software (Oracle based) that also has formulas that can complete all of the calculations
Florida	Yes	Same QC process that is applied to volumes is used for class counts (TPAS software), a person reviews the results and reports monthly
Georgia	Yes	Validated with traffic software
Indiana	Yes, works great with tubes and loops. For video, it gives 6 vehicle-classes namely, motorcycles, cars, white trucks, buses, 2 other truck classes)	---
Kentucky	Yes	Quality Control – compare to historical data (if fails, determine cause and adjust accordingly or recount)
North Carolina	Yes, but can aggregate to a 4-scheme if needed	Data is collected by lane at each class station. Portable counts are validated through direct observation comparing to what is being recorded in the counter at the time of installation and pickup. Continuous class stations are validated by comparison using a partial day of video. All class data goes through quality control after capture to validate the data was collected properly for the duration of the count by comparing it to previously validated data and rules that apply expected ranges for valid data.
Texas	Yes	Counts at a given location are compared with historical counts, regionally similar counts on adjacent or nearby roadways, and counts up and downstream on the same roadway.
Utah	Yes	Visual, Historical, and Regional Comparison
Virginia	Yes	QC checks

Table 23: Vehicle Classes for Classification Counts and Validation of Class Counts

2.6.3.11. Technology and Software Used at Classification Count Stations

Table 24 summarizes the details on the technology and software used for data collection of vehicle classification counts on two-lane roadways. The technology used for vehicle class counts on these roadways is fairly consistent across the surveyed states and includes road tubes, inductive loops, and/or piezoelectric sensors, automatic traffic recorders, video, and radar (column 2).

2.6.3.12. Reliability, Accuracy, and Issues with Technology for a Two-Lane Roadway

The reliability is reported in column 3; however, as mentioned previously, the percentages are either unknown or are estimates that are not statistically determined, making it difficult to compare Tennessee's reliability to other states' and therefore to make recommendations on improvements (column 3). Under typical weather conditions, five of the nine states indicated the accuracy under typical weather conditions is 95%. Georgia also noted that road tubes had a 90% accuracy and 85% accuracy for video-manual classifications, as noted in column 4. Many states, including Tennessee, have issues with the performance of technology in weather such as strong rain/flooding, snow, and ice as reported in column 5. Of the five states that responded, Georgia and Indiana indicated that their technology is not affected by weather. All states, including Tennessee, indicated that their vehicle classification count technology does not work properly in multiple lanes, slow/congested traffic, high traffic, or atypical volume conditions (column 6). California and Texas obtain an overall accuracy of 95% under different traffic conditions.

Table 24: Technology for Vehicle Classification on 2-Lane Roads and their Characteristics

1 State	2 Technology used	3 Reliability	4 Accuracy under typical weather conditions	5 List of any significant weather conditions	6 Accuracy under different traffic conditions
Tennessee	Road tubes	Varies	---	Snow and ice	Too much congestion will affect it
California	Road tubes; contact closure and other switches; piezoelectric sensors; ultrasonic systems; AVI systems; manual counts	90%	100%	Pavement must stay in good condition, if concrete chips and water flows into the ground, the loops have problems with water collecting around them, piezo same way. If it is really wet out the road tubes may not stick to the ground well (the tape could come up)	95%
Florida	Loops and piezos, can also be done with road tubes but unsure of accuracy	Varies	Fine	---	Works well as long as it is not stop and go traffic, 10 mph or higher it works well; under 10 mph it is not accurate
Georgia	In Road Sensors (loops and piezos); Road Tubes; Video - Manual Classifications	95% for in road sensors, 90+% for road tubes, 100 % for video manual classifications	95%-- In-road Sensors; 90%-- Road Tubes; 85%-- Video-Manual Classifications	None	Queuing of traffic and traffic speeds that fall below 5 mph for long durations
Indiana	Pneumatic road tubes	Very reliable: 85%, other 15% is due to dead battery or damage	95%	None	Low- great accuracy with tubes, Moderate- great accuracy with tubes, At or near capacity- decreased accuracy with stop and go traffic when close to capacity
Kentucky	Piezo, loops, tubes	---	---	---	---
North Carolina	WIM, ATR, radar	---	---	---	---
Texas	Loops, road tubes, or piezo sensors	98%	95%	Video at night has some issues	Pneumatic tubes limited to 3 lanes (95% to 98%)
Utah	TimeMark & Wavetronix	Varies	---	---	Low volume: Good Moderate volume: Good At or near capacity: Varies based on speed
Virginia	Road tubes	98%	95%	Snow	---

2.6.3.13. Technology and Software Used on a Multi-Lane Roadway

Table 25 summarizes the details on the technology and software used for data collection of vehicle classification counts on multi-lane roadways (i.e., roadways with more than two lanes) and their reliability as well as performance under different weather and traffic conditions. The technology used for vehicle class counts on multi-lane roads is fairly consistent across the surveyed states and includes road tubes that are isolated between lanes, inductive loops, and/or piezoelectric sensors, automatic traffic recorders, video, and radar (column 2). Tennessee uses embedded detector loops (EDLs) for their vehicle classification counts on roadways with more than two lanes.

2.6.3.14. Reliability, Accuracy, and Issues with Technology for a Multi-Lane Roadway

The reliabilities of equipment used by the state DOTs are reported in column 3. Only five states reported a percentage, ranging from 90% to 95%. As previously mentioned, the percentages are either unknown or are estimates that are not statistically determined, making it difficult to compare Tennessee's reliability to other states or to serve as a basis for making recommendations for improvements. Five of the nine surveyed states indicated the accuracy under typical weather conditions is 90% to 95%. Georgia noted that video-manual classifications have an accuracy of 85% (column 4).

Many states, including Tennessee, have issues with the performance of technology in weather such as strong rain/flooding, snow, and ice as reported in column 5. Texas noted that the quality of the video can be impacted by wind and during the night. California noted in column 6 that the accuracy of their technology works well under different traffic conditions. Five of the nine surveyed states indicated that their vehicle classification count technology does not work properly in multiple lanes, slow/congested traffic, high traffic, or atypical volume conditions.

Table 25: Technology for Vehicle Classification on Multilane Roads and their Characteristics

1 State	2 Technology used	3 Reliability	4 Accuracy under typical weather conditions	4 List of any significant weather conditions	5 Accuracy under different traffic conditions
Tennessee	EDLs	Unknown	---	Snow and ice	Varies
California	Contact closure and other switches; piezoelectric sensors; ultrasonic systems; AVI systems; manual counts	Contact closure, piezo, loops 95%	90% sometimes modem fail for communication	---	All work well
Florida	Loops and piezos, can also be done with road tubes but unsure of accuracy	Varies	Fine	---	Works well as long as it is not stop and go traffic, 10 mph or higher it works well; under 10 mph it is not accurate
Georgia	In Road Sensors (loops and piezos); Road Tubes; Video - Manual Classifications	Our equipment is 90% reliable for portable and 95% permanent	95%-- In-road Sensors; 90%-- Road Tubes; 85%-- Video-Manual Classifications	---	Queuing of traffic and traffic speeds that fall below 5 mph for long durations
Indiana	Pneumatic road tubes	90%	95%	None	Low volume: Laser works well Moderate volume: Laser works well At or near capacity: Lasers have same issue as road tubes do
Kentucky	Piezo/loops where we have them and they're functional. Two tubes per lane elsewhere.	---	---	Tubes and snow plows do not get along well	---
North Carolina	---	---	---	---	---
Texas	Video recording through contractors	95%	90%	Night, rain, wind, and ice can all impact the quality of the video	Depends on the individual counting the video
Utah	TimeMark & Wavetronix	Varies	---	---	Low volume: Good Moderate volume: Good At or near capacity: Varies depending on speeds
Virginia	Road tubes isolated between lanes	98%	95%	Snow	---

2.7. Summary

2.7.1. Summary of Permanent Count Program Survey Results

- Tennessee's average of 12 stations per ATR group is on the lower end of the spectrum of the selected nine states. In order to reach the mean and median of the surveyed states, Tennessee would need to operate twice as many stations than it currently does.
- Since each of Tennessee's ATR stations is currently monitoring on average 1,593 miles, variations in traffic volumes, and ultimately AADT, are not being adequately represented. To match the average number of miles per ATR station of nine states, the state would need to operate 3½ times the number of ATR stations it currently has in service.
- The six field staffing personnel at TDOT are more than what seven of the nine states have for their permanent count program, and the one office staff position is common amongst the majority of the selected states. TDOT is also similar to other states in that the maintenance of their equipment is done in-house.
- The majority of states have their traffic monitoring personnel participate in other activities such as data processing, quality control, etc.
- There is no clear sense that states use a statistical procedure for estimating the number of ATR stations required in each group; most use the recommendations provided in the FHWA TMG.
- Quality control checks among the states include comparison to historical trends, consecutive counts of zero values, repeated values, extensive missing data, etc.
- TDOT computes SFs similarly to the procedures employed by the majority of the surveyed states; however, eight of the nine surveyed states use only one year of SFs while TDOT averages the current year's SFs with the previous four years' SFs. An analysis would need to be performed (one year versus five years) to determine which procedure yields more accurate estimates of AADT.
- All selected states use inductive loop technologies for traffic counts, as does TDOT, and collect vehicle speeds at their ATR stations; however, TDOT does not currently collect speed data at these sites. Radar, piezoelectric, video, and bending plate technologies were also mentioned. Half of the state DOTs experience weather-related problems with their technology, similar to Tennessee.

2.7.2. Summary of Coverage Count Program Survey Results

- Tennessee averages 8 miles per coverage count undertaken, which is higher than that reported by eight of the nine surveyed state DOTs.
- The majority of states follow the FHWA TMG (2013) recommendation of 48 hours for the coverage count duration and three years for the coverage count cycle which is in contrast to TDOT's count duration of 24 hours and count cycle of one year. Some states,

however, have cycles other than the mentioned three years. These cycles are set based on roadway functional classification.

- Five states rely on in-house staff for conducting coverage counts while four states rely on both in-house staff and contractors for performing these counts. Typically, states that have fewer in-house staff depend on consultants more heavily. For the states that use in-house staff for undertaking coverage counts, TDOT's six field staff are on the lower end of the spectrum.
- TDOT's count work load of 2,055 coverage counts per year per field staff is much higher than that obtained for any of the nine surveyed states.
- The number of coverage counts undertaken by all state DOTs is determined by the requirements spelled by the FHWA TMG and HPMS for each roadway functional classification.
- To determine if a re-count is warranted, quality control checks among the states include comparison to historical trends, consecutive counts of zero values, repeated values, extensive missing data, etc. The various procedures among the states are mixed.
- Tennessee is well above the average and median for assigning coverage counts to in-house staff rather than contracting them out and is among three other surveyed states that undertake 100% of their coverage counts with in-house staff. TDOT's field staff set up about 8 counts per day, which is less than the average of the selected states but greater than the median. Note: the field staff would not be required to set as many up each day if coverage counts were to be conducted for 48 hours every three years. As reported by other states, only one or two personnel are required for set up of a single count, and TDOT only needs one staff person to set up a count.
- The survey showed mixed results for the responsibilities of in-house staff beyond the conduct of coverage counts. Half of the states only have in-house staff perform coverage counts, whereas other states require in-house staff to perform other maintenance activities or perform other types of traffic counts.
- TDOT trains their field personnel for 4 to 8 weeks, which is longer than reported by the nine selected state DOTs. Only Indiana and Florida provided responses ranging from 1 day to 2 weeks.
- TDOT vehicles can carry 32 short duration count devices, which is only half of what the majority of the surveyed state DOT vehicles carry. Tennessee has 180 coverage count devices which is fewer than the number of owned devices reported by the nine surveyed state DOTs.
- The equipment/technology used in coverage counts was fairly consistent among the surveyed states in that road tubes, inductive loops, piezoelectric sensors, automatic traffic recorders, and radar are the various technologies used for collection of such volumes. In terms of their reliability and accuracy, most states, including Tennessee, have issues with the performance of their count equipment in extreme weather and atypical traffic conditions.
- The life of portable road tubes and their inability to count multiple lanes is typically the most common problem with this technology. Five of the nine surveyed states plan on

using different technologies due to increased interest in the additional advantages the new technologies offer.
- All states except Tennessee and North Carolina have a truck weight program, with an average of slightly over 30 sites.
- Procedures for estimating VMT differ by surveyed state. Since the only information available are just the brief descriptions provided of each method, it is impossible to prima facie state that a method used by any of the nine other states would yield more accurate estimates of VMT on local roads compared to TDOT's current procedure.
- Vehicle occupancy counts are not undertaken by the majority of the surveyed states. Therefore, TDOT is not atypical in not undertaking such counts.

2.7.3. Summary of Vehicle Classification Count Program Survey Results

- Generally, states conduct vehicle class counts on a three-year cycle for a 48-hour duration. However, the duration may be dependent on the functional class of the road on which the class count is made.
- Tennessee conducts 2,000 classification counts, which is close to the average number of class counts conducted by the nine selected states (average of 2,600 counts).
- TDOT uses 6 field staff for performing class counts, and Texas and Utah stated that they use 5 field staff. The remaining states use contractors and could not provide an exact number. Tennessee has more field staff that are responsible for class counts than most of the surveyed states.
- Tennessee has 48 monitored road miles per classification count station, which is more than the median of 11 but less than the average of 63 miles per class count station for the nine selected states. Tennessee also monitors 10 road miles per class count station per year, which is slightly higher than the median of 7 but lower than the average of 52 miles per class count per year.
- TDOT's field staff set up between 12 and 18 class count devices per day, which is similar to the average of 16 devices set up per day for the nine surveyed state DOTs.
- Other responsibilities for field staff noted in the survey, in addition to class counts, included equipment maintenance, data quality control, and any necessary re-counts.
- Seventeen percent of TDOT's coverage count stations are also vehicle classification count stations, which is below the average of 32.5% and median of almost 29% for the surveyed nine states and below the FHWA TMG recommendation of 25 to 30%. Based on the comparison with the nine surveyed states, Tennessee has fewer classification count stations, a lower percentage of coverage count stations that are also class count stations, and a smaller number of class count devices than the average among the surveyed state DOTs.
- All surveyed states, along with Tennessee, use the 13 FHWA vehicle classification categories.
- Technologies for undertaking class counts on roadways with two lanes include road tubes, inductive loops, and/or piezoelectric sensors, automatic traffic recorders, video, and radar. When class count equipment fails, the surveyed state DOTs, including TDOT,

indicate the primary causal factors to be adverse weather conditions (heavy rain/flooding, snow, and ice) and atypical volume conditions (multiple lanes, slow/congested traffic, high traffic volumes).

- Technologies for undertaking class counts on roadways with more than two lanes include road tubes that are isolated between lanes, inductive loops, and/or piezoelectric sensors, automatic traffic recorders, video, and radar. Including TDOT, the surveyed state DOTs indicate that when failure of the equipment occurs, it is primarily due to adverse weather conditions (heavy rain/flooding, snow, and ice) and atypical volume conditions (multiple lanes, slow/congested traffic, high traffic volumes).

Chapter 3. Review of Technologies Available for both Continuous and Coverage Counts

3.1. Introduction

The purpose of this chapter is to provide information about current technologies for permanent and coverage counts. The chapter begins with a brief description of the types of technology available. The middle portion of the chapter provides a comparison of the technologies, including capabilities, applications, and pros and cons. The chapter concludes with some basic recommendations regarding technology choices.

Available technologies, technology capabilities, and relative benefits and costs of technologies were first identified through questions in the 10-state survey discussed earlier in this report. As most of these surveys were answered by office personnel, a follow-up survey was sent to field personnel and field supervisors. This allowed the research team to gather information directly from those who use the field equipment.

One important finding during the process is that, in many states, there is a disconnection between data collection and data processing. Data collection is typically performed by field personnel while data processing is performed by office personnel. This disconnect means that:

1) personnel who place the equipment may never look at the data they have collected, so there is no learning about best practices for placement,
2) personnel who place the equipment will not know if the data they collected are complete or reasonable, and
3) personnel who process the data will have no knowledge of site conditions or equipment placement decisions.

A possible impact of this disconnect is reduced data quality. Options for overcoming this issue include 1) cross-training office and field personnel so that each understands both roles and 2) frequent communication between office and field personnel so that assumptions and issues are identified and addressed.

3.2. Brief Overview of Available Technologies

None of the available technologies identified by this research are “new” technologies – all have a reasonable history of use in the industry. In this context, a “new” technology would be one which either is only available in limited markets or has been available nationally for less than one year. Nevertheless, a brief description of each technology and how it works is provided below. The list is sorted alphabetically, not by capability or preference.

- **Inductive loops** use large coils of wire in the roadway to detect vehicles, like a metal detector. A vehicle's metallic mass changes the electrical field in the coils, and that change is detected and interpreted.
    - Closely related to the inductive loop is the **magnetic** sensor. This sensor uses the same principle as the inductive loop, but replaces the large coil of wire with a small sensor.
- **Infra-red** devices can be either active or passive.
    - **Active infra-red** devices detect vehicles by transmitting energy and measuring the reflected energy. The reflected energy is detected and interpreted.
    - **Passive infra-red** devices detect vehicles by measuring the heat energy given off by the vehicle. The device continually scans a zone. When a vehicle enters that zone, the heat energy signature of the zone changes, and that change is detected and interpreted.
- **Load cell platform (bending plate)** sensors detect traffic by measuring stress/strain/bending in plate scales located in the roadway. The stress/strain/bending is detected and interpreted.
    - Because different weight vehicles create different stress/strain/bending in the plate scale, this technology can be used for weight-in-motion.
- **Microwave (radar)** sensors detect vehicles by broadcasting a signal and analyzing the return (reflected) signal. When a vehicle enters a zone, it changes the return signal. That change in the return signal is detected and interpreted
- **Piezoelectric (quartz piezo, quartz piezoelectric)** sensors detect vehicles by converting a compression force into electricity. When a vehicle crosses the sensor, its tires compress the sensor, and that compression is converted into an electrical current which is detected and interpreted.
    - Because different levels of compression create different electrical impulses, this technology can be used for weight-in-motion.
- **Pneumatic road tubes** detect vehicles by counting air compression events. Hollow tubes, sealed at one end, are stretched across the roadway. When a vehicle crosses the tube, the air within the tube is compressed, and that compression is detected and interpreted.
- **Video**-based sensors detect vehicles through advanced image processing. When a vehicle enters a predefined detection zone, the color characteristics of the zone change. These changes are detected and interpreted.
    - More advanced video detection systems can identify a vehicle's characteristics and track it across multiple frames in a continuous video stream.

Together, these seven technologies represent the state-of-the-practice choices available for use for both permanent count and coverage count sites.

3.3. Comparison of Technologies

Table 26 provides an overview of the typical capabilities of the detection technologies discussed above. The listed capabilities were determined from both the original and the supplemental agency surveys.

Table 26. Summary of Typical Detection Technology Capabilities

Technology	Volume	Speed	Classification	Weight	Occupancy
Inductive Loops (Magnetic Sensors)	✓	✓	✓		
Infra-red	✓	✓	✓		✓
Load Cell Platform (Bending Plate)	✓			✓	
Microwave (Radar)	✓	✓	✓		
Piezoelectric (Quartz Piezo) (Quartz Piezoelectric)	✓	✓	✓	✓	
Pneumatic Road Tubes	✓	✓	✓		
Video	✓	✓	✓		✓

All of the technologies discussed in this chapter have the ability to determine vehicle counts. Most can also determine speed and classification; the notable exception being load cell platforms. The method by which they determine classification varies by technology. Pneumatic tubes, for example, identify classification by pattern matching axle locations. Several of the technologies determine classification primarily by vehicle length. Only two technologies, namely load cell platforms and piezoelectric sensors, can detect vehicle weight, and only infra-red and video can determine occupancy.

There is a difference between the typical capabilities listed above and the specifications for a particular product. A manufacturer could sell a sensor that uses microwave technology, for example, but only provide volume data – not speed or classification. Even though the microwave technology is capable of determining speed and classification, that particular sensor does not.

In addition to their common capabilities, different detection technologies have different applications. In the context of this report, application refers to temporary or permanent installation. Technologies commonly used via temporary installation are candidates for use in coverage counts while technologies commonly used via permanent installation are candidates for use at permanent count stations. Table 27 provides an overview of the common application of each detection technology.

Table 27. Summary of Common Detection Technology Applications

Technology	**Permanent Installation**	**Temporary Installation**
Inductive Loops (Magnetic Sensors)	✓	
Infra-red	✓	✓
Load Cell Platform (Bending Plate)	✓	
Microwave (Radar)	✓	✓
Piezoelectric (Quartz Piezo) (Quartz Piezoelectric)	✓	
Pneumatic Road Tubes		✓
Video	✓	✓

All of the technologies discussed except pneumatic road tubes are commonly used with a permanent installation, but only four are commonly used with a temporary installation. Of the four commonly used with temporary installations, three – infra-red, microwave, and video – can be installed without the need for a lane closure.

The table above lists common applications and is not intended to be exhaustive. There are, for example, piezoelectric sensors that can be installed on a temporary basis. This is, however not how that technology is commonly used.

Each detection technology also has its pros and cons. Table 28 gives a brief overview of those pros and cons. This list is based on combined information from the original agency survey, the supplemental survey, and follow-up phone interviews.

Table 28. Detection Technology Pros and Cons

Technology	Pros	Cons
Inductive Loops (Magnetic Sensors)	• Considered the standard that all others are judged by • Good life-cycle cost if correctly installed in good pavement	• Requires lane closure for installation/maintenance • Requires cuts in pavement which reduces pavement life
Infra-red	• Non-intrusive installation • Some roadside installation options	• Weather-related issues
Load Cell Platform (Bending Plate)	• Can be used for weigh-in-motion	• Very large pavement cut required for installation
Microwave (Radar)	• Non-intrusive installation • Roadside installation • Multiple lane coverage	• Occlusion • Height requirements for multiple lanes
Piezoelectric (Quartz Piezo) (Quartz Piezoelectric)	• High accuracy count data • Can be used for weigh-in-motion	• Large pavement cut required for installation
Pneumatic Road Tubes	• Quick, easy install • Multiple lanes	• Tubes wear out quickly • More error with high volume
Video	• Non-intrusive installation • Roadside installation • Advanced features (vehicle tracking)	• Higher end processing required • Occlusion and shadow issues

No single detection technology is perfect for all applications. Even inductive loop detectors, long the standard by which other detection technologies were judged, have issues which need to be considered as part of the design process.

In addition to these comparisons, the supplemental survey asked field personnel and field supervisors for any general comments about the technologies they were using. There were three themes identified from these comments. The first theme was the use of inductive loops and piezoelectric sensors in combination for permanent count stations. The loop-piezo-loop configuration supposedly improves data quality. The second theme was of a shift away from the use of pneumatic road tubes for coverage counts. This change is primarily for personnel safety.

The third theme, noted by more states than the prior two themes, is a trend away from inductive loops and toward microwave radar for permanent count sites. Multiple states indicated that microwave installations are similar in cost to inductive loops. Other reasons for the theme relate to the ease of installation of radar – no traffic control is required because the radar can be mounted on the roadside and still detect multiple lanes. One state mentioned having over 200 permanent microwave radar sites, and another noted that they are using radar for their coverage counts instead of pneumatic tubes.

3.4. Conclusions Regarding Technology Choices

Currently, TDOT typically uses inductive loops for permanent count stations and pneumatic road tubes for coverage counts. While there is not another technology that is clearly better than either of those technologies, there are other technologies that compete favorably. The research team does not recommend that TDOT undertake a mass replacement program to change from the current technologies; however, TDOT should give fair consideration to other technologies as current stations require upgrading/replacement or as new stations are added to the system.

Of the available technologies, the most promising one identified in this study is microwave (radar). Microwave has the same capabilities as inductive loops, can be used in either permanent or temporary installations, and has the advantage of being a non-intrusive, roadside installation. Chapter 4, which discusses institutional agreements, will include further discussion of an opportunity to incorporate data from existing microwave sensors. Acquisition of this data should provide an excellent opportunity to gain experience with this technology, which should help guide decisions about what technology to use moving forward.

Chapter 4. Potential Institutional Agreements with Other Agencies Taking Counts

4.1. Introduction

The purpose of this chapter is to present the research team's investigation into opportunities for TDOT's TMP to cultivate institutional agreements that either reduce the number of required permanent count stations, reduce the number of required coverage count locations, or increase the available dataset of either permanent or coverage count locations. The first portion of the chapter discusses an opportunity for an institutional agreement with TDOT's Traffic Operations Division for permanent count station data. Next, the chapter discusses the potential for institutional agreements with Tennessee's cities for coverage count data. The chapter concludes with a brief discussion of the choice between reducing the number of stations/counts required and increasing the available dataset and a summary of the research team's recommendations.

4.2. Institutional Agreement with TDOT's Traffic Operations Division

On February 2, 2016, the research team met with Brad Freeze, Director of the TDOT Traffic Operations Division (hereafter TOD), to 1) provide him with an overview of this project, 2) determine what data from the traffic monitoring program was used by the TOD, and 3) to determine if the TOD had any resources that could be beneficial to the TMP. (Freeze, 2016) During this interview, Mr. Freeze mentioned that the Traffic Operations Division maintains roadway detection systems in major urban areas which can provide both volume and speed data on interstate highways. These detection systems record data continuously and could potentially replace or supplement the existing TMP permanent count stations. It is worth noting that these sensors use the microwave technology noted in the prior chapter.

For such use, the data collected by these sensors would have to be 1) convertible for input into ADAM and 2) of reasonable quality for TMP use. Of these, conversion for input into ADAM should only require the development of a spreadsheet or conversion software tool. While its development is beyond the scope of this project, the research team does not believe it will be a significant hurdle, and thus it should not prevent exploration of this option. In terms of the data quality, the research team found two prior TDOT research projects which help to determine the usability of this data. Summaries of each study are provided below.

4.2.1. The TDOT TRMS Data Quality Study

This first study was a preliminary investigation into the quality of the data provided by the remote traffic microwave sensors (RTMS) which are installed along interstates in Tennessee's major metropolitan areas. (Han & Wegman, 2009) The stated purpose of the study was to determine the quality of data reported by the Remote Traffic Microwave Sensors (RTMS) installed by TDOT in Tennessee's major urban areas. The study focused on the volume data. The study compared RTMS volume data with manual counts taken from video of the subject traffic. The study concluded that the reported data “proved to be very useful and of reasonable quality.” The study also identified some occlusion and error detection issues which needed to be investigated more fully.

4.2.2. A Proposed Framework for Using TDOT’s Existing ITS Sensors as Continuous Count Stations

The second study, a follow-up to the first, was directly focused on the use of the noted RTMS data to replace or supplement permanent count stations. (Han & Wegman, 2010) As with the prior study, this investigation began by comparing RTMS volume data with manual counts from video of the subject area, and, also as before, determined that the volume data were of reasonable quality. Specifically, the study found a mean average percent error (MAPE) of 3.24% at the subject location. This compared favorably with error ranges reported by other studies.

As noted above, the first study identified some error detection issues which needed investigation. The primary issue was with missing data. The second study took an inventory of all the RTMS locations in Knoxville to determine, at that point in time, which stations were reporting correctly and which had missing data. The study summarized this inventory by stating that “about 72% [of the >200 RTMS locations in Knoxville] are reporting data in all lanes with virtually no missing data, [and] 25% have limited missing data at times or in certain lanes.”

The study went on to describe the types of missing data, including short cyclic omissions (i.e., reporting for every other minute instead of every minute), long cyclic omissions (i.e., missing data for several hours or even days, then resuming normal data), and poor station data (i.e., 1’s or 0’s in all reports). The study concluded that these are not RTMS issues, but rather are caused by communication and client/server issues. These same issues are present in TDOT’s current permanent count station data.

The study concludes with a plan to help ensure quality RTMS data and a reassertion of the benefits of using this data as continuous count data.

4.2.3. Potential Impacts of This Agreement

Based on the two studies discussed above, existing RTMS data is of acceptable quality for use for either reducing the number of required permanent count stations or increasing the available dataset. Currently, there are approximately 1,000 such stations operating. (TDOT, 2017) These stations are located in Tennessee’s major urban areas – specifically Chattanooga, Knoxville, Memphis, and Nashville.

If used to increase the available dataset, TDOT could improve data quality for urban freeways, but with little to no impact elsewhere. If used to reduce the number of required permanent count stations, the impacts could be broader. This broader impact depends on what happens to decommissioned equipment. If that equipment can be relocated for use in another category, then those categories that receive new permanent count stations should also see improved data quality. If TDOT chooses this course, it may be prudent to keep a few of the existing permanent count stations on urban freeways online during a transition period for error checking.

The value of including RTMS data as permanent count station data will only increase over time. Long range goals include instrumentation of a larger portion of the freeways in Tennessee, and once TDOT's TMP has the capability to include these data, any new RTMS site could become a new permanent count station.

4.3. Institutional Agreements with Tennessee's Cities

The research team investigated two different types of institutional agreements with Tennessee's cities. The first included contact with both small and large city planning or public works departments to inquire about local coverage count efforts. The second included contact with larger city traffic operations departments to inquire about data available from traffic signal and arterial management programs.

4.3.1. Agreements with City Planning or Public Works Departments

The project team investigated the potential for TDOT's TMP to use coverage count data taken by Tennessee's cities to either reduce the number of required coverage count locations or to increase the size of the coverage count dataset. One small urban area, Cookeville, and one large urban area, Knoxville, were considered as representative samples in this process. Note that these cities were not randomly selected, nor would results from two cities result in broad statistically validity – neither condition was needed to investigate the potential for data availability.

4.3.1.1. Sample Small Urban Area – Cookeville, TN

Tommy Winningham, Traffic Division Supervisor, provided information about Cookeville's coverage count program. Specific dates are not available for all conversations, as these discussions included phone and email contact over multiple weeks. Most of these conversations occurred in summer 2016, though some clarification was made later in 2016 and 2017. Cookeville has an active coverage count program across the city. Counts are preferably taken annually at each location, but occasionally counts are taken in alternating years. Count duration varies from 48 hours to 7 days.

The city publishes the results of their count program via the city website on an Average Daily Traffic Count Map (City of Cookeville, 2016). This map combines information from TDOT TMP count reports with City of Cookeville counts, presenting both sets of counts together. A sample section from this map is shown in Figure 1.

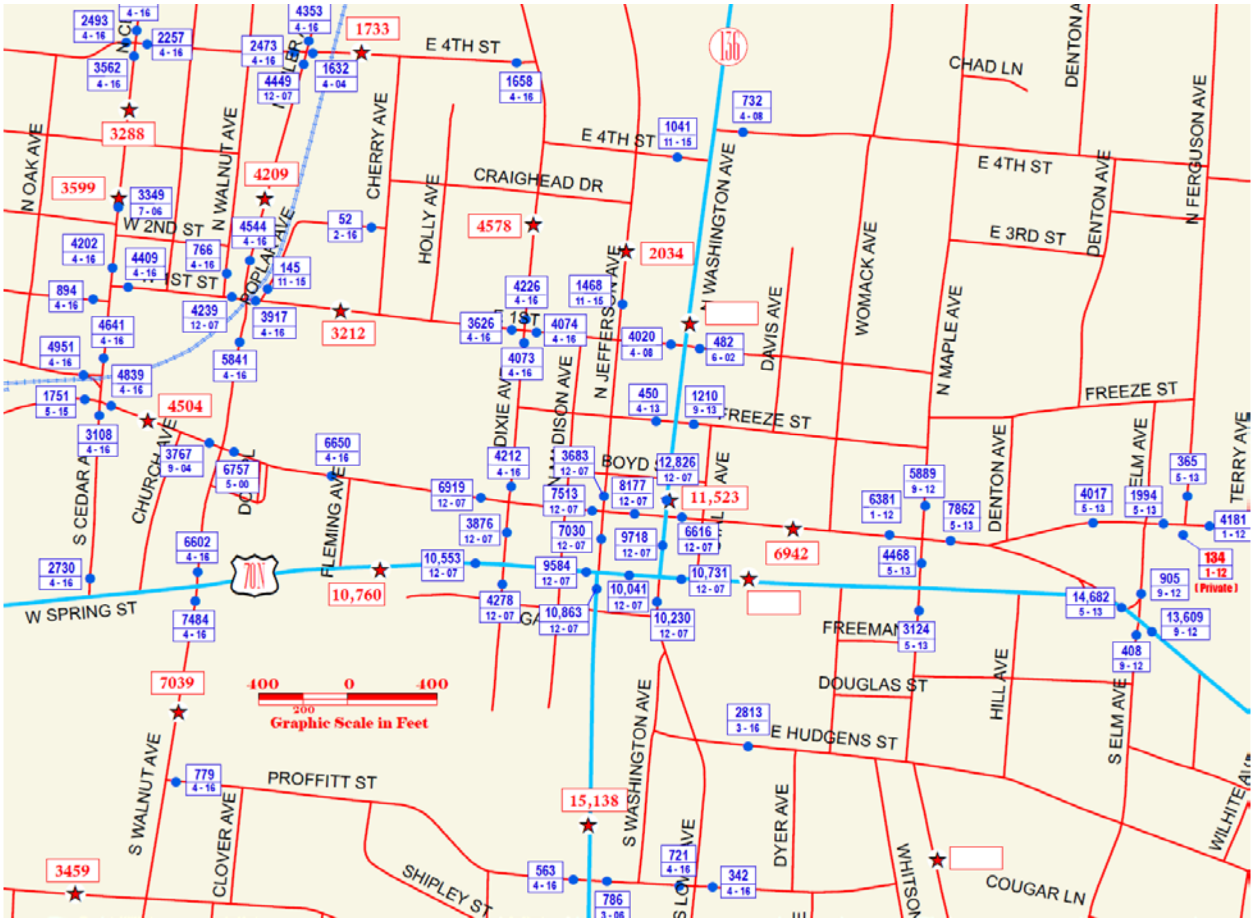

Figure 1. Sample Section from the City of Cookeville's Average Daily Traffic Count Map (City of Cookeville, 2016)

Red stars indicate the location of TDOT counts, with that year's count shown nearby in red text. Blue dots indicate the location of City of Cookeville counts, with that year's count shown nearby in blue text. City of Cookeville counts also show the month/year the count was taken. TDOT counts have been adjusted with seasonal factors, so no count date is provided. City of Cookeville counts have not been adjusted with seasonal factors.

Close inspection of the full map identified 29 locations where both TDOT and the City of Cookeville performed a count in the same roadway segment. While these counts were not necessarily taken at the exact same location, there were no cross streets or major driveways noted between the two counts. The research team undertook a comparison between the TDOT and City of Cookeville count volumes. The initial findings are shown in Figure 2.

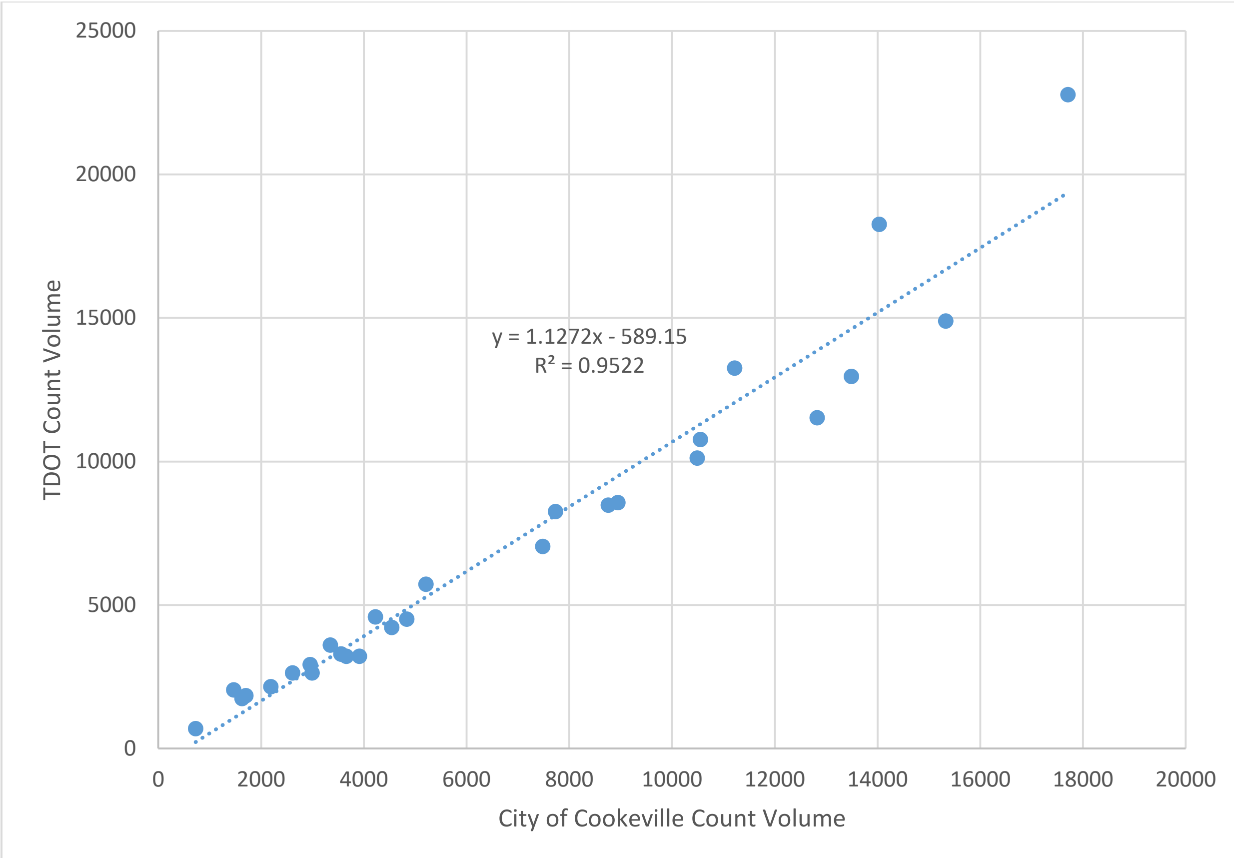

Figure 2. Initial Comparison of TDOT and City of Cookeville Count Volumes

Each point indicates a segment in which both TDOT and Cookeville performed a coverage count. The dashed line is a linear least-squares fit to those points, the details of which are given in the equation shown. The purpose was not to develop a valid regression equation for prediction purposes but to examine the best-fit line and assess its reasonableness. The R^2 value of 0.9522 indicates a high quality of fit, indicating that the equation is a good indicator of the relationship between the two datasets. The best fit line's slope is 1.1272, and the 95% confidence interval is (1.0275, 1.2269). This interval does not contain the value zero, which indicates that the slope is significantly different from zero for a 5% level of significance; thus, a relationship appears to exist between City of Cookeville counts and TDOT counts. The slope value of 1.1272 indicates that the TDOT counts could be about 13% higher than the City of Cookeville counts. This is tempered by the intercept of -589.15 with a 95% confidence interval of (-1397.0, 218.69), which indicates that TDOT counts are about 589 vehicles per day lower than the City of Cookeville counts. The confidence interval for the intercept contains the value of zero, so the hypothesis that the intercept is zero cannot be rejected at the 5% level of significance.

Further inspection of the comparison chart indicated that the two highest counts may be excessively affecting the results. Since the City of Cookeville counts are not adjusted with seasonal factors while the TDOT counts are, it is possible that Cookeville took these counts during lower volume periods, which would result in a lower volume than TDOT's adjusted volume. The research team thus removed these two points and repeated the fit process. These results are shown in Figure 3.

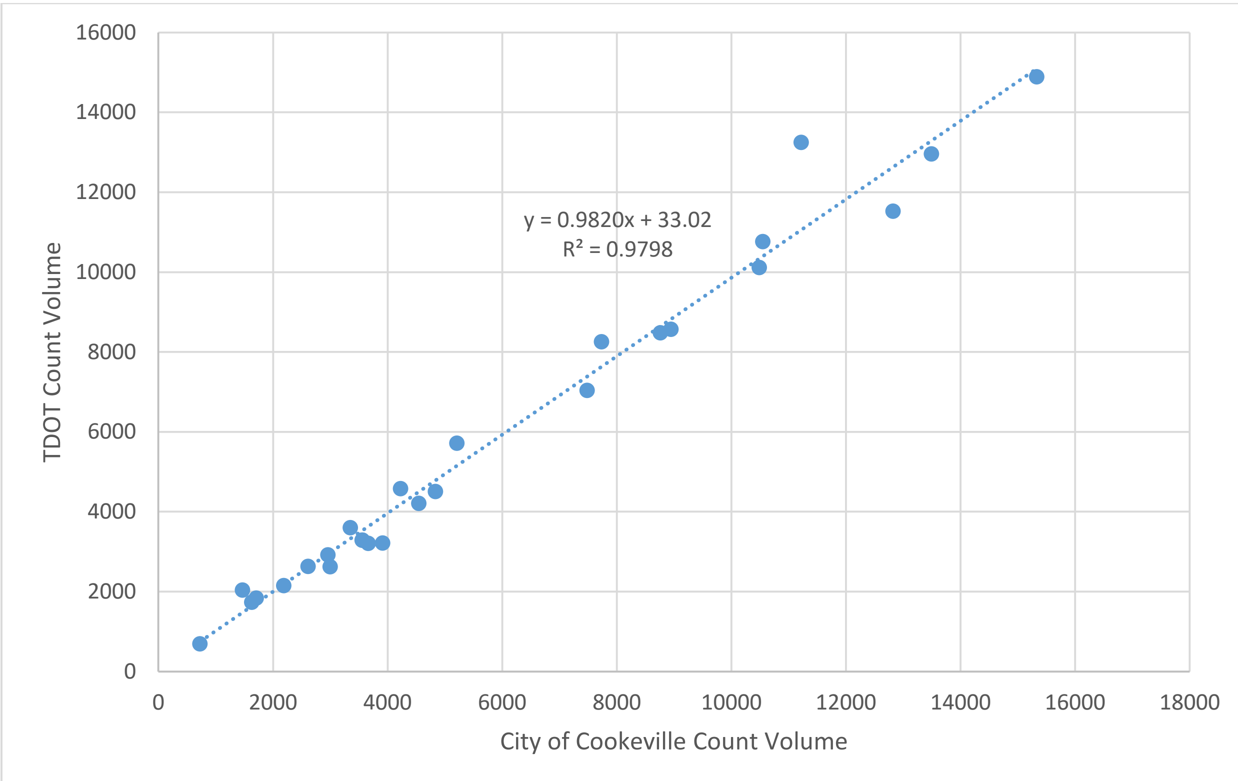

Figure 3. Revised Comparison of TDOT and City of Cookeville Cunt Volumes

This revised comparison has a higher R^2 value than the prior, which is not unexpected after the removal of the two points that possibly represent different sampling times. It also has a slope value of 0.9820 with a 95% confidence interval of (0.9239, 1.0402), which contains the value 1.0. The hypothesis that the slope equals zero can be rejected at the 5% level of significance, and the hypothesis that the slope equals 1.0 cannot be rejected at the 5% level of significance. The intercept is 33.020 with a 95% confidence interval of (-384.72, 450.76), which contains the value zero, so the hypothesis that the intercept is zero cannot be rejected. This means that the City of Cookeville counts are essentially the same as the TDOT counts.

In addition, a paired t-test of means for the TDOT versus City of Cookeville count volumes shows no statistically significant difference in the mean counts at a 5% level of significance. In addition, an F-test of variances shows no statistically significant difference in the variances of the two count volumes at a 5% level of significance. These test results provide additional evidence to support the conclusion that the Cookeville data reasonably represent the TDOT data.

Based on these results, the study team concludes that the coverage counts taken by the City of Cookeville are reasonable for use by TDOT's TMP.

4.3.1.2. Sample Large Urban Area – Knoxville

Following the determination that Cookeville's coverage count program would provide data reasonable for use by TDOT's TMP, the research team investigated the availability of data from a large urban area in Tennessee. The combination of initial contact with Knoxville and web searches led the research team to a web site that catalogues counts taken by both TDOT and the Knoxville Region Traffic Count Program. A cropped sample of the website is shown below in Figure 4.

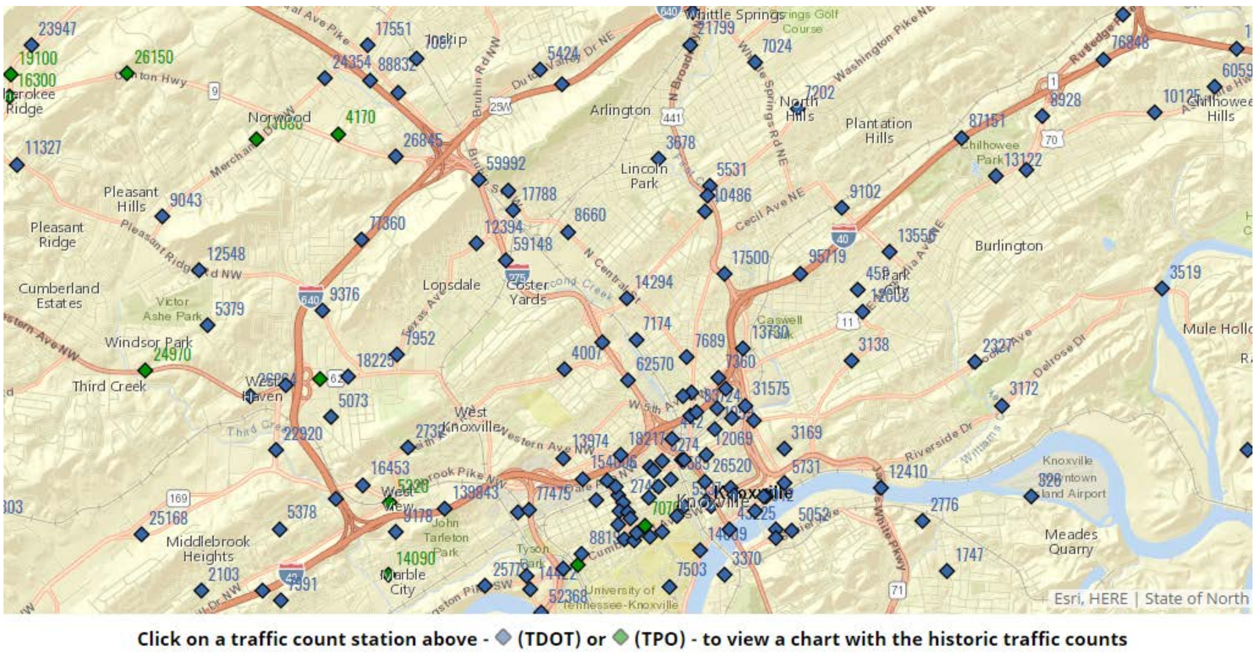

Figure 4. Cropped Sample of the Knoxville Regional Traffic Count Program Web Interface (Knoxville Regional TPO, 2017)

As noted on the figure, this interface provides access to both TDOT and Knoxville TPO count information. When a particular station is selected, the user can both view a bar chart showing the change in annual traffic volume over time and download a file with that chart data. Unlike Cookeville, the City of Knoxville does adjust their counts using seasonal factors.

A direct comparison between City of Knoxville and TDOT count volumes was beyond the scope of this project, but given compatible count duration and methodologies, data collected by the city will likely be reasonable for use by the TDOT.

4.3.1.3. Potential Impacts of These Agreements

Based on the two sample cities discussed above, the research team recommends that TDOT begin developing institutional agreements with Tennessee cities that have their own coverage count programs in place, provided those count programs have a reasonable frequency. More information on a "reasonable frequency" can be found in Chapter 6**.**

These agreements could be used to either reduce the number of required coverage count locations or increase the data available to TDOT. Based on the two samples, it is unlikely that any city's program would include all the locations where TDOT currently counts. Those locations which are counted by both agencies are candidates for removal from TDOT's required sites. There is also the potential to identify city counts which are located close enough to TDOT count sites that a gradual switch from the TDOT site to the city site could be made. Either of these options would reduce the number of sites that TDOT would need to count, which could either 1) allow TDOT to increase the duration of their counts to improve data quality, 2) allow TDOT to count at additional locations to improve the dataset, or 3) reduce the demands for TDOT personnel and equipment.

Regardless, both sample cities performed counts at significantly more locations than TDOT. Inclusion of the additional data would allow a significant increase in the available dataset, which should lead to increased data quality. Incorporation of city count data into ADAM would require development of a potentially large collection of spreadsheets or conversion software tools, as each city may have its own data format which would need conversion. Existing data conversion tools and the reasonably small number of vendors who provide data collection equipment for coverage counts should help to minimize the total number of conversion applications that would be required.

4.3.2. Agreements with City Traffic Operations Departments

The project team investigated the possibility of TDOT's TMP incorporating data from traffic signal systems in large urban areas. Traffic signal systems typically include arterial detection with the ability to record count data. In addition to these arterial counts, newer technologies have also been developed for use at signalized intersections. These detection technologies have the ability to determine intersection turning movement counts which could then be converted into coverage count data for each leg of the intersection.

Two urban areas, Knoxville and Nashville, were contacted to determine the availability of traffic signal system data. Nashville's system currently does not allow for logging/transmitting of volume data from the system to a storage location. Knoxville, however, is in the process of upgrading over 100 of its traffic signals to include the detection technologies noted above. Until these upgrades are complete, there is no way to compare data collected in this manner with permanent count or coverage count station data.

The research team recommends that TDOT's TMP follow up with Knoxville and perform a comparison between the data collected by the traffic signal system with both permanent count and coverage count station data. If the traffic signal data are reasonable for use as either permanent count or coverage count data, the data could either be used to reduce the number of stations needed or to increase the size of the dataset.

4.4. Conclusions and Considerations

The purpose of this chapter was to present the research team's investigation into opportunities for TDOT's TMP to cultivate institutional agreements that either reduce the number of required permanent count stations, reduce the number of required coverage count locations, or increase the available dataset of either permanent or coverage count locations.

4.4.1. Considerations: Reducing vs. Increasing

Once one or more institutional agreements are in place, TDOT's TMP will need to consider how to react to the influx of new data. During a short transition period, the current permanent and coverage counts will still need to be collected for comparison with the new data sources. After this transition period, TDOT will have options regarding their current data collection efforts.

One option is for TDOT to continue counting at all current permanent and coverage count locations. In this option, existing TDOT count locations would be used as a continual error checking/confirmation dataset to help ensure the outsourced data remains reasonable for use. This approach would also provide the largest possible dataset for use in planning.

Another option is for TDOT to discontinue counting in locations where the new, agreement-provided count data exist. There are two conditions in which TDOT could discontinue a count, as noted below.

1) If an agreement-provided count site is in the same segment as the original TDOT count site and checks using past data confirm a reasonable match, TDOT could immediately suspend counts at this location.
2) If a new group of agreement-provided count sites provide sufficient counts in a particular group, TDOT could wait for a reasonable data history and then choose to suspend counts at other TDOT count sites in that group. Note that if the agreement-provided count site has sufficient, reliable historical data available, then there may be no need for a delay. If the agreement-provided site has no or incomplete historical data, suspension of another site will have to wait until sufficient data accumulates. Depending on site type, TDOT's current practices require up to a five-year count history.

Regardless of why or when TDOT chooses to suspend its data collection at a current count site, this resource can also be used in either of two ways. One way is to reduce the demand for TDOT personnel and resources. The current workload required to maintain the TMP is expensive, both in work-hours and equipment. Reallocation of funds could allow for improved maintenance of the remaining equipment, which could reduce issues with missing data and thereby improve the data quality.

Another way is for TDOT to redistribute equipment and effort to new count sites. In the case of permanent count stations, equipment from suspended sites could be moved to new locations. This relocated equipment could be used to increase the sample size in categories with fewer sites. In the case of coverage counts, TDOT could use released resources to either increase the number or the duration of their coverage counts. More information about potential benefits from increasing coverage count duration can be found in Chapter 6.

The two options presented represent the endpoints of a spectrum of choices. TDOT will most likely benefit most from a combination approach – to continue counting at a small number of sites for which agreement-provided data are also available, to suspend counts at some locations and thereby reduce the demand for TDOT personnel and resources, and to suspend counts at other locations and then relocate that equipment and effort to both new count locations and longer count durations. TDOT will likely need either a working group or another research project to determine the best balance between these options.

4.4.2. Summary of Institutional Agreement Conclusions

Based on these investigations, the research team recommends that TDOT initiate two different types of institutional agreements, namely:

- An internal agreement with TDOT's TOD for access to the RTMS data. This agreement, along with a spreadsheet or software application for data conversion, will provide access to hundreds of urban freeway stations providing data like current permanent count stations. As this system expands, data may also become available for rural freeways and/or major urban arterials.
- External agreements with Tennessee's cities for access to their coverage count data. These agreements, along with a collection of spreadsheets or software applications for data conversion, will provide access to hundreds, even thousands, of coverage counts across multiple facility types.

In addition, the research team makes the following recommendations for future actions:

- TDOT should maintain contact with Knoxville and other major urban areas and keep track of when they install modern traffic signal and signal system data collection devices. The data from these devices should be evaluated to determine the suitability for use as either permanent count station data or coverage count station data.
- As institutional agreements are made, TDOT should either establish a working group or research project to determine that proper balance of sites where TDOT counts continue, sites that are suspended to reduce demand on TDOT personnel and resources, and sites that are suspended so that equipment and effort can be reallocated.

Together with ongoing TDOT count efforts, institutional agreements have great potential for both improving the overall quality of TDOT's TMP dataset and reducing overall demand for TDOT personnel and resources.

Chapter 5. Estimation of Seasonal Variation Factors and Outlier Identification Procedure

5.1. Introduction

Presented in this chapter is a review of TDOT's procedure for estimating seasonal factors from traffic volume data collected at permanent count stations. The concerns with TDOT's documented procedure and how they might be addressed are outlined.

Given the importance of the quality of traffic volume data to the accuracy of AADT estimates and the seasonal variation factors derived from them, the chapter reports on a procedure rooted in statistics for identifying outlier daily volumes so they can be deleted.

Seasonal factors estimated from collected daily traffic volume data before and after implementation of the outlier identification procedure are presented to demonstrate the effectiveness of the method.

5.2. Current TDOT Procedure for Estimating Seasonal Factors and Concerns about that Procedure

An additional task assigned by the TDOT project panel was the development of seasonal variation factors (also referred to as seasonal adjustment factors or, simply, seasonal factors) for year 2015. Since TDOT has a documented procedure for estimation of these seasonal factors, it was reviewed for this purpose.

5.2.1. Tennessee Department of Transportation (TDOT)'s Procedure for Estimating Seasonal Variation Factors

Tennessee Department of Transportation (TDOT)'s procedure for estimating seasonal factors is documented in their monitoring guide. The steps of this procedure, quoted verbatim, are as follows: (TDOT, 2015)

1) Calculate the average count for each day of the week, for each month of the year for every ATR station of the SVF group.
2) Calculate the monthly averages (i.e. the average 24-hour count for the month) for the SVF group.
3) Calculate factors for each day of the week for each ATR station – each daily average is divided by the station's monthly average.
4) Average the factors of the group, producing a group factor for each day of the week for every month of the year.
5) Finally, average the factors with the previous years – each monthly day-of-week factor is averaged with the factors of the previous 4 years.

5.2.2. Concerns with TDOT's Procedure

Two aspects of the outlined procedure require correction. First, the seasonal variation factors are confused with seasonal variation ratios. One is the inverse of the other (TRB, 2005). The steps prescribed in TDOT's procedure above result in the computation of seasonal traffic ratios; yet they are applied as though they were seasonal traffic factors.

Second, the final seasonal variation ratios computed for each day-type in each month (there are 84 of the seasonal day-type ratios) are based on the monthly average daily traffic (MADT) rather than the annual average daily traffic (AADT). Application of the seasonal day-type ratios based on MADTs to adjust the counts obtained at coverage stations will result in estimates of MADTs at these coverage stations rather than the desired AADT estimates.

To address this error, a monthly ratio based on the AADT has to be determined as well. This will result in an additional 12 factors. The end result will be a total of 96 factors for adjusting counts made at coverage stations into AADT estimates.

5.2.3. Addressing Concerns with TDOT's Procedure

5.2.3.1. Method 1: Corrected Procedure for Estimating Seasonal Variation Factors

The corrected procedure for estimating seasonal variation factors from data collected at each ATR station in each group is as follows:

1) Calculate the average volume for each day-type in each month of the year, e.g., average Sunday traffic volume in January, … , average Saturday traffic volume in January.
2) Calculate the monthly average daily traffic (MADT) for each month of the year.
3) Calculate a daily adjustment factor (DF) by dividing the MADT for a month by the average volume obtained for each day-type in that month obtained in point 1 above. This results in the estimation of 84 daily factor values.
4) Calculate the AADT for the ATR station using all the daily volume data collected at the station in the year.
5) Calculate monthly adjustment factors by dividing the AADT by the MADT for each month. This results in the estimation of 12 factor-values.
6) The DFs and MFs for the stations in an ATR group are then averaged to obtain DFs and MFs for that ATR group in a given year.
7) Based on TDOT's procedures, DFs and MFs to be used in adjusting counts obtained at coverage stations into estimates of AADTs are obtained by averaging the average DFs and MFs for each ATR group over the most recent five-year period.

5.2.3.2. Method 2: Modified Method 1 Procedure for Estimating Seasonal Variation Factors

The procedure above can with a minor change result in a reduction in the number of factors to be estimated from 96 factors to 84 factors. The modified procedure, that is, with the minor change is as follows:

Step 1: Calculate the average volume for each day-type in each month of a given year, e.g., average Sunday traffic volume in January of the given year,…, average Saturday traffic volume in December of the given year.

Step 2: Calculate the AADT for the ATR station using all the daily volume data collected at the station in the given year.

Step 3: Calculate a seasonal adjustment factor (SF) by dividing the AADT for the given year by the average volume obtained for each day-type in each month for the given year obtained in Step 1 above. This results in the estimation of 84 seasonal adjustment factors.

Step 4: The SFs for the stations in an ATR group are then averaged to obtain SFs for that ATR group in a given year.

Step 5: Based on TDOT's procedures, the SFs to be used in adjusting counts obtained at coverage stations into estimates of AADTs are obtained by averaging the average SFs for each ATR group over the most recent five-year period.

The flow chart of the modified procedure is presented in Figure 5 below.

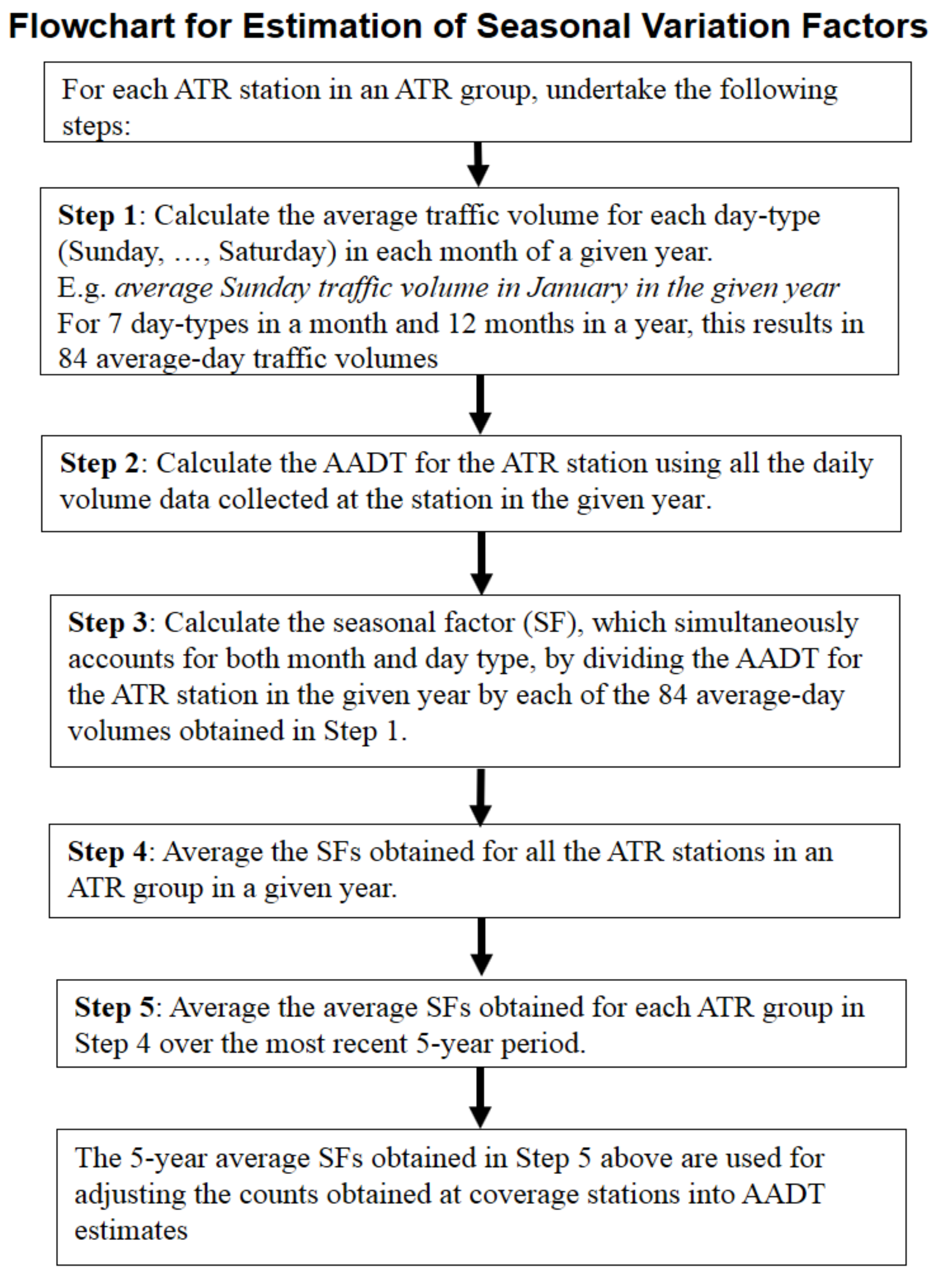

Figure 5: Flowchart of Estimation Procedure for Seasonal Adjustment Factors

Mathematically, the steps of the above procedure to be performed on traffic volumes collected at each ATR station belonging to an ATR group in a given year *y* are as follows:

Step 1: Calculate the average volume for each day-type d_i, i=1,…,7 in each month *m* of a given year *y*. Based on this notation, $d_1 \equiv$ Sunday, $d_2 \equiv$ Monday, …, and d_7 = Saturday. The mathematical expression of the above is given as follows:

$$V^{y}_{m\bar{d}_i} = \frac{\sum_{j=1}^{N^{y}_{md_i}} V^{y}_{md_{i_j}}}{N^{y}_{md_i}}$$, for m = 1,…,12 and i = 1,…,7

Where

$V^{y}_{md_{i_j}}$ is the traffic volume obtained at an ATR station on the j^{th} occurrence of day-type i, in month m and in year y, and

$N^{y}_{md_i}$ is the number of times day-type d_i occurs in month m in year y for an ATR station.

Descriptively, examples of the outcome from implementing this step are "the average Sunday traffic volume in January of year *y*", …, "the average Saturday traffic volume in December of year *y*".

Step 2: Calculate the $AADT^{y}$ for an ATR station using all the daily volume data collected at the station in year *y*. The AADT is the total volume of vehicle traffic of a roadway segment for a year divided by the number of days in the year. Mathematically, the latter definition is expressed as:

$$AADT^{y} = \frac{\text{vehicle volume count for the year}}{\text{number of days in the year}} = \frac{\sum_{m=1}^{12}\sum_{i=1}^{7}\sum_{j=1}^{N^{y}_{md_i}} V^{y}_{md_{i_j}}}{\sum_{m=1}^{12}\sum_{i=1}^{7} N^{y}_{md_i}} = \frac{\sum_{m=1}^{12}\sum_{i=1}^{7}\sum_{j=1}^{N^{y}_{md_i}} V^{y}_{md_{i_j}}}{365\,(366\text{ days for leap year})}$$

The above expression is premised on all the days of the year having traffic volume data available. When there are days for which traffic volumes are missing, the denominator of the above expression has to be adjusted to reflect only the number of days for which volume counts are available (FHWA, 2013).

The FHWA Traffic Monitoring Guide (FHWA, 2013) points out that using the above expression for AADT estimation when data are missing can yield results that are biased. Hence, when traffic volume data are not available for each day of the year, a recommended alternative for estimating the AADT is by the equation put forward by AASHTO (FHWA, 2013).

$$AADT^{y}_{AASHTO} = \frac{1}{12}\left(\sum_{m=1}^{12}\frac{1}{7}\left(\sum_{i=1}^{7}\frac{1}{N^{y}_{md_i}}\sum_{j=1}^{N^{y}_{md_i}} V^{y}_{md_{i_j}}\right)\right)$$

The AASHTO method though requires that each day-type in each month have at least one acceptable non-zero daily volume recorded.

Step 3: Calculate a seasonal factor (SF) for each day-type d_i, i=1,…,7 in each month m, m=1,…,12 by dividing the $AADT^y$ for year y by the average volume obtained for each day-type d_i in each month m obtained in Step 1 above. This results in the estimation of 84 SF values.

The mathematical expression of the above is given as follows:

$$SF^y_{md_i} = \frac{AADT^y}{V^y_{m\bar{d}_i}}, \text{ for } m = 1,\ldots,12; \text{ and } i = 1,\ldots,7$$

Step 4: Average the SFs obtained for all the ATR stations in an ATR group in year y. Mathematically, for each ATR group, this is expressed as follows:

$$\overline{SF}^y_{md_i} = \frac{\sum_{k=1}^{N^y_g} \left(SF^y_{md_i}\right)_k}{N^y_g}, \text{ for } m = 1,\ldots,12; \; i = 1,\ldots,7; \text{ and } g = 1,\ldots,G$$

Where

N^y_g is the number of ATR stations in ATR station group g in year y.

Step 5: Average the average SFs obtained for each ATR group in Step 4 over the most recent 5-year period. Mathematically, this is expressed as follows:

$$\overline{\overline{SF}}_{md_i} = \frac{\sum_{y=1}^{5} \overline{SF}^y_{md_i}}{5}, \text{ for } m = 1,\ldots,12; \; i = 1,\ldots,7$$

5.2.3.3. Method 3: Alternative Procedure for Developing Seasonal Variation Factors

An alternative procedure for obtaining seasonal adjustment factors requires the estimation of 7 daily factors (DFs) and 12 monthly factors (MFs) (Roess, Prassas, & McShane, 2011). A key underlying assumption to the procedure is that the daily variation pattern in traffic volumes over the 7-day week (from Sunday to Saturday) is identical for all the weeks of a year. Hence, an annual average of the traffic volumes for each day-type can be used to capture the daily variation in traffic volumes over the week. The steps for estimating both sets of factors are as follows:

Daily Factors

1) Compute the average traffic volume for each day-type d_i, $V_{d_i}^{y}$, using the vehicular volumes obtained on that day-type d_i, i=1,…, 7 in year y, y = 2010, …, 2015. Mathematically, it is expressed as:

$$V_{d_i}^{y} = \frac{\sum_{m=1}^{12} \sum_{j=1}^{N_{md_i}^{y}} V_{md_{i_j}}^{y}}{\sum_{m=1}^{12} N_{md_i}^{y}}, \qquad i = 1,....,7$$

where $N_{md_i}^{y}$ is the number of times day-type d_i occurs in month m in year y.

2) Compute the average of the average day-type traffic volumes for year y, $\bar{V}^{y}$. Mathematically, it is expressed as:

$$\bar{V}^{y} = \frac{\sum_{i=1}^{7} V_{d_i}^{y}}{7}$$

3) Compute the daily factors (DFs) for year y.

$$DF_{d_i}^{y} = \frac{\bar{V}^{y}}{V_{d_i}^{y}}, \qquad i = 1,\ldots,7$$

Monthly Factors

1) Compute the average traffic volume for each month m in year y, $\bar{V}_m^{y}$.

$$\bar{V}_m^{y} = \frac{\sum_{i=1}^{7} \sum_{j=1}^{N_{md_i}^{y}} V_{md_{i_j}}^{y}}{\sum_{i=1}^{7} N_{md_i}^{y}}, \quad m = 1,...,12$$

2) Compute the monthly factors (MFs) for year y.

$$MF_m^{y} = \frac{AADT}{\bar{V}_m^{y}} \qquad m = 1,....,12$$

Seasonal Factors

1) Compute seasonal factors $SF^{y}_{md_i}$ for each day-type d_i, i=1,…,7 in month m, m = 1,…,12
$SF^{y}_{md_i} = DF^{y}_{d_i} \times MF^{y}_{m}$

5.2.4. Adjustment of a Coverage Count to an AADT Estimate

A volume obtained from a 24-hour count at a coverage count station (*cov*) on day-type d_i in month *m* of year *y*, V^{y}_{24,md_i} , can be adjusted into an estimate of the $AADT_{cov}$ for the station by multiplying the volume from the 24-hour coverage count by the corresponding daily and monthly factors or alternatively, the seasonal factor.

$$AADT^{y}_{\mathrm{cov}} = V^{y}_{24,md_i} \times DF^{y}_{d_i} \times MF^{y}_{m} = V^{y}_{24,md_i} \times SF^{y}_{md_i}$$

Note that the seasonal factors from Method 3 can also be averaged over a 5-year period prior to their application to adjust coverage counts into estimates of AADT.

This method for obtaining seasonal adjustment factors is particularly applicable when some of the recorded daily volumes at a permanent count station are deleted after implementation of quality control procedures or are simply missing. It is noted though that the method is more restrictive compared to Method 2 because of the assumption of the daily variation in traffic volumes over a week being identical for all the weeks in a year. Hence Method 2, which requires the direct estimation of 84 seasonal factors, is used in this research.

Given the error in TDOT's current seasonal factor estimation procedure, the next step was to estimate seasonal adjustment factors for the different ATR groups in Tennessee based on Method 2. TDOT provided the necessary traffic volumes obtained from counts undertaken at its ATR stations from 2010 to 2015 and which had been processed with ADAM, its traffic data software. The received data were processed to yield daily volume records at each ATR station in each year. The number of days in each month of a year for which traffic volumes were recorded are presented in Appendix D. There were only 10 stations that had a complete set of daily volumes available for all 365 days of the year and this occurred in just one year for 9 of the stations (these are highlighted in yellow in the tables). Station 7 is the only one that had two years with 365 daily volumes available. Imputation of daily volumes was not a part of the study; hence days in the received data on which no volume records were made did not have any imputed values assigned to them.

Thereafter, Method 2 for estimating seasonal factors was implemented. The initial estimates of the seasonal factors based on the received traffic volumes showed some to be of very large magnitude prompting a detailed examination of the received data. This showed some of the daily traffic volumes collected in some years at some of the ATR stations to be inconsistent with volumes obtained at these ATR stations in other years and, in some instances, to be also inconsistent with expected 24-hour/daily capacity of some of the facilities on which the counts were made. These errant volumes are considered outliers and a systematic procedure was required for their identification. Since TDOT did not have a documented outlier identification procedure, it requested that one be developed for this purpose. Given the time frame for the project, the procedure developed is based on daily traffic volumes. It should be possible to refine the developed procedure by incorporating into the analysis the hourly capacities of facilities on which the permanent count stations are located.

The basic principles governing the outlier identification procedure are 1) the reasonableness of year-to-year percentage changes in traffic volumes as measured by year to year changes in AADT; 2) the reasonableness in year-to-year percentage changes in average traffic for each day-type in each month; 3) the comparability of the magnitude of variability/dispersion in traffic volumes collected on a given day-type in a month from one year to the next; and 4) the comparability of individual daily volumes collected on a given day-type in a month to the average daily volume computed for that day-type in the month. The identification criteria were arrived at based on a cyclical process which consisted of defining a criterion/criteria and then applying it to the data to determine how effective it was in identifying outliers. Where it was judged not to be fully effective, an additional criterion was specified and then followed by the testing of the new set of criteria, and so forth until a set of criteria was eventually arrived at that was satisfactory in identifying outliers.

The more specific details of the procedure are described below.

5.3. Procedural Steps for Identifying Outliers in Traffic Volume Data Collected at an ATR Station over Several Years

The steps for identifying daily volumes that are likely to be outliers in the data collected at permanent count stations each year are outlined below. The following variables are defined for use in the procedural steps:

m: month *m*, where m = 1, …,12. $m = 1 \equiv$ January,…, $m = 12 \equiv$ December

d_i: day-type *i*, i=1, …,7, where d_1 = Sunday, …, d_7 = Saturday

$V_{md_{i_j}}^{y}$: traffic volume obtained at an ATR station on the j^{th} occurrence of day-type *i*, in month *m* and in year *y*

$V_{m\bar{d}_i}^{y}$: average traffic volume for each day-type *i* in month *m* and in year *y*

Major Step 1: Deletion of daily traffic volumes with a magnitude of zero

The process begins with the deletion of the daily volumes that have a magnitude of zero from data collected in each year *y* (for this study, *y* = 2010, …, 2015) at each ATR station.

Major Step 2: Organization of each ATR station's traffic volumes by year

Arrange the traffic volume data collected at each ATR station by year with the first being the oldest (in this study, the oldest data were collected in year 2010), followed by the next oldest, and in that order, until the most recent year for which data are available.

Major Step 3: Flagging of some daily volumes for deletion and questionable daily volumes for further scrutiny

Three things are accomplished in Major Step 3.

a) First, the ratio of the estimated annual average daily traffic at the ATR station in the previous year (*y* – 1) to each of the actual daily volumes in the current year (*y*) is computed. For ratios that fall outside of the defined acceptable range, the associated daily volume in the current year is flagged and then deleted.

b) Second, the year-to-year growth in average traffic volume for each day-type in each month is estimated. This year-to-year growth is reported as a ratio of corresponding average day-type volume values for successive years.

   E.g., *average traffic volume for a Monday in January in year y is divided by the average traffic volume for a Monday in January in year y* – 1.

   If appropriate data are available for each month in each year, there will be 84 ratio-values computed for each year. This ratio is subsequently referred to as Factor 1.

c) Third, the dispersions in traffic volumes for each day-type in each month in each year are estimated and a ratio obtained of corresponding values for successive years.

   E.g., *year-to-year changes in the dispersion of traffic volumes collected on Tuesdays in February*.

   The measure of dispersion used is the coefficient of variation (CV). If appropriate data are available for each month in each year, there will be 84 CV values for each year. This ratio is subsequently referred to as Factor 2.

Where either of the ratios computed in points (b) and (c) above falls out of the defined acceptable range, the traffic volumes of the given day-type d_i in a specified month *m* in a given year *y* are flagged for further checks.

Major Step 4: Identification of which flagged volumes in Major Step 3 are to be deleted

a) Compute the ratio of the average volume for each day-type *i* in month *m* and in year *y* to the actual *j* individual volumes of each day-type *i* occurring in month *m* in year *y*. If this ratio falls out of the defined acceptable range for any of the *j* volumes, it is flagged for deletion. This first outlier check is particularly important for identifying outliers in traffic volume data collected at an ATR station in year *y* for which there are no corresponding monthly day-type volume data available from year *y* – 1; hence ratios relating to growth cannot be computed. This ratio is subsequently referred to as Factor 3.
b) Compute the ratio of the average volume for each day-type *i* in month *m* and in year *y* – 1 to the actual *j* individual volumes of each day-type *i* occurring in month *m* in year *y*. If this ratio falls out of the defined acceptable range for any of the *j* volumes, it is flagged for deletion. This ratio is subsequently referred to as Factor 4.
c) Compute the ratio of the estimated annual average daily traffic at the ATR station in year *y* to each of the actual daily volumes in year *y*. If this ratio falls out of the defined acceptable range, the applicable daily volume is flagged for deletion. This third outlier check is particularly important for identifying outliers in traffic volume data collected at an ATR station in year *y* for which there are no corresponding monthly day-type volume data available from year *y* – 1; hence ratios relating to growth cannot be computed. This ratio is subsequently referred to as Factor 5.

Presented in Figure 6 are the steps of the outlier identification procedure in flowchart format.

Major Step 1: Deletion of daily traffic volumes with a magnitude of zero (0)

Delete daily volumes with a magnitude of zero from all the datasets collected at the ATR station

Major Step 2: Organize the ATR's traffic volume data by year

Arrange the traffic volume data collected at the ATR station by year with the first being the oldest, and then the next oldest, and in that order, until the most recent year for which data is available.

Begin the analysis with the first year of data, that is, the oldest dataset. E.g., *for this project, in the majority of instances, it was year 2010*

For the oldest dataset only, proceed to parts (a) and (c) of **Major Step 4**

For subsequent years, proceed to **Major Step 3**

Major Step 3: Flagging of obviously inconsistent daily volumes for deletion and other daily volumes for further scrutiny

(a) Compute the ratio of the estimated annual average daily traffic at the ATR station in the previous year to each of the actual daily volumes in the current year. For ratios that fall outside of the acceptable range defined by lower and upper bound values, flag and delete the associated traffic volumes in the current year.

(b) Compute the ratio of year-to-year growth in average traffic volume for each day-type in each month in each year.

E.g., *Year-to-year growth in average traffic volume for Monday in January*.

(c) Compute the ratio of year-to-year growth in dispersion in traffic volumes for each day-type in each month in each year.

E.g., *Year-to-year growth in dispersion of traffic volumes collected on Tuesdays in February*.

Bounds are set for the defined ratios in (b) and (c). Where the computed ratio falls outside the acceptable interval defined by the bounds, the traffic volume records associated with that day-type are flagged for further analysis.

Major Step 4: Identification of which flagged volumes in Major Step 3 are to be deleted

(a) Compute the ratio of the average traffic volume for each day-type in each month in a current year to each of the individual volumes of that day-type in the same month and year.

E.g., *Compute the average traffic volume for Monday in January in year 2012 divided by each of the traffic volumes collected on Monday in January in year 2012*.

(b) Compute the ratio of the average traffic volume for each day-type in each month in a preceding year to each of the individual volumes of that day-type in the same month in the current year.

E.g., *Compute the average traffic volume for Monday in January in year 2011 divided by each of the volumes collected on Monday in January in year 2012*.

(c) Compute the ratio of the estimated annual average daily traffic at the ATR station in the current year to each of the actual daily volumes in the current year.

Bounds are set for each of the above ratios. Where the computed ratio falls outside the acceptable interval defined by the bounds, the associated traffic volume record is flagged for deletion.

Figure 6: Flowchart of Procedural Steps for Identifying Outliers in Traffic Volume Data Collected at an ATR Station over Several Years

The above procedure for identifying the outliers in the traffic volume data collected at ATR stations over several years can be couched in more mathematical terms as follows:

Major step 1: Deletion of daily traffic volumes with a magnitude of zero (0)

For *m* =1,…,12; *i* =1,…,7, and *j* =1,…, $N^{y}_{md_i}$, if $V^{y}_{md_{i_j}} = 0$, then delete the observation from the dataset for the ATR station, where $N^{y}_{md_i}$ = the number of times day-type d_i occurs in month *m* in year *y*,.

Major step 2: Organization of the ATR traffic data by year

Organize the traffic volume data collected at each ATR station by year with the oldest dataset appearing first.

Major step 3: **Flagging of obviously inconsistent daily volumes for deletion and of other questionable daily volumes for further scrutiny**

a) Compute the ratio of the annual average daily traffic (AADT) at a given ATR station in year *y* – 1 to each of the individual daily volumes collected at that station in year *y*.

$$\frac{AADT^{y-1}}{V^{y}_{md_{i_j}}}$$

Where the ratio falls out of the defined acceptable range, the associated volume $V^{y}_{md_{i_j}}$ is flagged for deletion.

b) For each month *m* (*m* =1,…,12) in year *y* (*y* = 2010, …, 2015 for this study) compute $V^{y}_{m\bar{d}_i}$ the average volume for each day type d_i, *i*=1,…,7, where d_1 = Sunday,… , d_7 = Saturday.

$$V^{y}_{m\bar{d}_i} = \frac{\sum_{j=1}^{N^{y}_{md_i}} V^{y}_{md_{i_j}}}{N^{y}_{md_i}}$$

Then compute the ratio of the average volume for each day-type d_i, *i*=1,…7, $V^{y}_{m\bar{d}_i}$,

to the average volume for each day-type *i* in month *m* and year $y-1$, $V^{y-1}_{m\bar{d}_i}$, that is,

$$\frac{V^{y}_{m\bar{d}_i}}{V^{y-1}_{md_i}} \quad \forall\, i,\ \forall\, m,\ y = 2011, \ldots, 2015$$

Where the value of the ratio falls outside the acceptable range defined by the set lower and upper bound values, the volume records in year *y* used in computing $V^{y}_{m\bar{d}_i}$ are flagged for further scrutiny.

c) For each month *m* (*m* =1, …, 12) in year *y*, (*y* = 2010, …, 2015 for this study), estimate the standard deviation of the volumes for each day type d_i, *i*=1,…, 7, where d_1 = Sunday,…, d_7 = Saturday, using $V^{y}_{md_{i_j}}$, where *j* is the counter for the number of occurrences of day-type d_i in month *m*.

$$\sigma^{y}_{md_i} = \left[\frac{\sum_{j=1}^{N^{y}_{md_i}} \left(V^{y}_{md_{i_j}} - V^{y}_{m\bar{d}_i}\right)^2}{N^{y}_{md_i}}\right]^{\frac{1}{2}}$$

Using each average day-type volume $V^{y}_{m\bar{d}_i}$ estimated in Step (b) above and each estimated standard deviation $\sigma^{y}_{md_i}$, estimate the coefficient of variation (*CV*) for each day-type in a given month in a given year as follows:

$$CV^{y}_{md_i} = \frac{\sigma^{y}_{md_i}}{V^{y}_{m\bar{d}_i}} = \frac{\left[\frac{\sum_{j=1}^{N^{y}_{md_i}} \left(V^{y}_{md_{i_j}} - V^{y}_{m\bar{d}_i}\right)^2}{N^{y}_{md_i}}\right]^{\frac{1}{2}}}{V^{y}_{m\bar{d}_i}}$$

Then compute the ratio of the coefficient of variation of traffic volumes collected on day-type d_i in month *m* in year *y* to the coefficient of variation of traffic volumes collected on day-type d_i in month *m* in year *y* – 1. Mathematically, this is expressed as:

$$\frac{CV^{y}_{md_i}}{CV^{y-1}_{md_i}}$$

If the above computed ratio falls out of the defined acceptable range, the volume records associated with the average for day-type d_i in month *m* in year *y* must be flagged for further analysis.

Note that Major Step 3 cannot be accomplished for the earliest year for which data are available (in this study, it is year 2010). Thus for the earliest year for which traffic volume data are available, only the steps presented in points (a) and (c) of Major Step 4 below are applicable.

Major Step 4: Identification of which flagged volumes in Major Step 3 are to be deleted

a) For the flagged volumes in Major Step 3 above, compute the ratio of the average volume for each day-type, $V_{m\bar{d}_i}^{y}$,in month *m* and year *y* to each of the *j* actual volumes collected for that day-type, $V_{md_{i_j}}^{y}$ in month *m* and year *y*. Mathematically, this is expressed as:

$$\frac{V_{m\bar{d}_i}^{y}}{V_{md_{i_j}}^{y}}$$

Where this ratio falls out of the acceptable range, which is defined by specified lower and upper bound values of the ratio, the associated volume $V_{md_{i_j}}^{y}$ is flagged for deletion.

b) Also, compute the ratio of the average volume for each day-type d_i in month *m* in year $y-1$, $V_{m\bar{d}_i}^{y-1}$, to each of the *j* actual volumes for that day-type in analysis year *y*, $V_{md_{i_j}}^{y}$. Mathematically, this is expressed as:

$$\frac{V_{m\bar{d}_i}^{y-1}}{V_{md_{i_j}}^{y}}$$

Again, where this ratio falls out of the defined acceptable range, the associated daily volume $V_{md_{i_j}}^{y}$ is flagged for deletion.

c) Finally, compute the ratio of the annual average daily traffic at a given ATR station in year *y* to each of the individual daily volumes collected at that station in year *y*.

$$\frac{AADT^{y}}{V_{md_{ij}}^{y}}$$

Where the ratio falls out of the defined acceptable range, the associated volume $V_{md_{ij}}^{y}$ is flagged for deletion.

It should be noted that based on TDOT's policy on what constitutes acceptable traffic volume data for a month, months for which traffic volume data are not available for at least the 7 different days of the week are to be excluded in any further analysis.

5.4. Determination of the Lower and Upper Bound Values for each of the Ratios Defined in the Outlier Identification Procedure

In the outlier identification procedure described in section 5.3, each ratio has an acceptable range defined by the specification of lower bound (LB) and upper bound (UB) values for the ratio. LB and UB are to be specified by the analyst to be consistent with the policy of a state DOT or through a statistical procedure. As an example, based on traffic trends, a state DOT could specify that year-to-year changes in traffic volumes should not exceed 25 percent. In that case, LB would be set to 0.75 while UB would be set to 1.25. Values of the ratio that fall below 0.75 or exceed 1.25 would be flagged for deletion. In this research a simple procedure, involving descriptive statistics, is used to define LB and UB. The steps are as follows:

For an ATR group

a) Select one of the ratios defined in section 5.3
b) Compute values of the selected ratio using data from all the ATR stations in the group and all the years available
c) Generate a histogram of the values of the ratio
d) Select a value for LB and UB such that it would be rare to find a value of the ratio that is outside the limits set by LB and UB. From statistics, typically LB and UB are set such that any value of the ratio that deviates from the mean by three standard deviations is flagged as an outlier ((Smith, 1962); and (Hargrove, Lim, Han, & Freeze, 2016)). It corresponds to a 99.74 percent chance of a ratio selected at random falling between the defined LB and UB. The latter is applicable where the distribution is at least approximately normal (Smith, 1962). Since the distributions of the ratios could not be characterized as normal, a similar percentage was retained but the bounds were set to be asymmetric

about the mean, which is not uncommon in traffic applications (Hargrove, Lim, Han, & Freeze, 2016). Setting LB and UB such that the percentage of outliers was less than 1 percent did not prove to be as useful for outlier identification – the bounds were so wide that some of the daily traffic volumes that were not identified to be outliers but which were at the extremities of the acceptable range so influenced some of the estimated seasonal factor values that they were not consistent with expectation. Ultimately, the bounds had to be tightened resulting in considerable data loss – asymmetric bounds about the mean were set such that the percent chance of a ratio selected at random falling between the defined LB and UB did not exceed 70 percent. The bounds set varied with functional group and are presented below.

e) Go to the next ratio and repeat steps (b) to (d)
f) Stop when all ratios have been analyzed and LB and UB set for each
g) Go to the next ATR group and repeat steps (a) to (f)
h) Stop when all ATR groups have been analyzed

The charts of the distributions of the different ratios are presented in Appendix E. The selected LB and UB for each ATR group were then employed in the outlier identification procedure.

Table 29: Lower and Upper Bound Values for the Ratios Defined in the Outlier Identification Procedure

Acceptable LBs and UBs for Computed Ratios						
Procedural Step:	Major Step 3a	Major Step 3b	Major Step 3c	Major Step 4a	Major Step 4b	Major Step 4c
Ratio:	$\frac{AADT^{y-1}}{V^{y}_{md_{i_j}}}$	$\frac{V^{y}_{\overline{md}_i}}{V^{y-1}_{md_i}}$	$\frac{CV^{y}_{md_i}}{CV^{y-1}_{md_i}}$	$\frac{V^{y}_{\overline{md}_i}}{V^{y}_{md_{i_j}}}$	$\frac{V^{y-1}_{\overline{md}_i}}{V^{y}_{md_{i_j}}}$	$\frac{AADT^{y}}{V^{y}_{md_{i_j}}}$
Recreational Group	0.50 - 2.00	0.90 - 1.10	0.00 - 2.25	0.25 - 2.50	0.25 - 2.50	0.50 - 2.00
Rural Interstate Group	0.60 - 1.50	0.90 - 1.10	0.00 - 2.25	0.25 - 2.50	0.25 - 2.50	0.60 - 1.50
Rural Non-Interstate Group	0.75 - 1.60	0.90 - 1.10	0.00 - 2.25	0.25 - 2.50	0.25 - 2.50	0.75 - 1.60
Urban Interstate Group	0.70 - 1.70	0.90 - 1.10	0.00 - 2.25	0.25 - 2.50	0.25 - 2.50	0.70 - 1.70
Urban Non-Interstate Group	0.80 - 1.80	0.90 - 1.10	0.00 - 2.25	0.25 - 2.50	0.25 - 2.50	0.80 - 1.80

5.5. Results of Estimation of Seasonal Factors for each ATR Group using Traffic Data from before and after Implementation of the Outlier Identification Procedure

The results from implementing Method 2 for the estimation of seasonal factors are reported for two cases. In the first, the received traffic volume data from TDOT were used to develop the 5-

year average of seasonal factors without implementing the outlier identification procedure. In the second, the received traffic volume data were first processed with the outlier identification procedure. Identified outlier daily volumes were deleted after which the 5-year averaged seasonal factors were estimated. The results are presented by ATR group in Table 30 to Table 33. The impact of the outlier identification procedure is particularly evident in the 5-year averaged seasonal factors obtained for the month of May for the Urban group (Table 30). Without the outlier procedure, seasonal factor values range from about 48 to about 96. After implementation of the outlier procedure and subsequent deletion of outlier volumes, the obtained 5-year averaged seasonal factors ranged from 0.90 to 1.24. Not as large but still as important are the changes that occurred in the estimated seasonal factors for the month of June for the Rural Interstate group (Table 31). The seasonal factors ranged from 1.65 to 2.00 prior to deletion of outliers. After deletion of outliers, they ranged from 0.78 to 1.01.

Table 30: Urban Interstate and Non-Interstate Seasonal Factors (5-year Average for 2011 to 2015)

Weekday	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sunday	1.56[a]	1.44	1.31	1.30	96.75	1.27	1.28	1.28	1.33	1.29	1.40	1.44
	(1.46)[b]	(1.40)	(1.24)	(1.23)	(1.24)	(1.24)	(1.24)	(1.26)	(1.26)	(1.27)	(1.32)	(1.34)
Monday	1.18	1.11	1.05	1.02	96.51	0.98	1.01	0.99	1.07	0.98	1.04	1.09
	(1.08)	(1.02)	(1.00)	(0.98)	(1.01)	(0.97)	(0.99)	(0.97)	(1.02)	(0.98)	(0.99)	(1.02)
Tuesday	1.15	1.07	1.02	0.98	64.60	0.98	0.98	0.96	1.00	0.96	1.02	1.07
	(1.05)	(0.99)	(0.97)	(0.95)	(0.94)	(0.96)	(0.96)	(0.95)	(0.95)	(0.96)	(0.96)	(1.00)
Wednesday	1.13	1.06	0.99	0.97	96.42	0.95	0.98	0.96	0.98	0.95	1.01	1.07
	(1.06)	(1.00)	(0.95)	(0.94)	(0.93)	(0.94)	(0.97)	(0.94)	(0.94)	(0.94)	(0.96)	(1.00)
Thursday	1.10	1.05	1.00	0.94	48.65	0.93	0.95	0.93	0.95	0.93	1.05	1.03
	(1.03)	(0.98)	(0.92)	(0.91)	(0.90)	(0.91)	(0.94)	(0.92)	(0.91)	(0.91)	(0.99)	(0.97)
Friday	1.03	0.92	0.96	0.90	96.36	0.86	0.90	0.85	0.87	0.86	0.93	0.96
	(0.96)	(0.90)	(0.92)	(0.87)	(0.85)	(0.86)	(0.90)	(0.85)	(0.84)	(0.85)	(0.93)	(0.93)
Saturday	1.32	1.20	1.16	1.08	96.55	1.05	1.08	1.05	1.10	1.09	1.17	1.20
	(1.23)	(1.14)	(1.11)	(1.04)	(1.04)	(1.04)	(1.08)	(1.04)	(1.05)	(1.06)	(1.10)	(1.13)

a. x.xx ≡ seasonal factor value before deletion of outliers

b. (y.yy) ≡ seasonal factor value after deletion of outliers

Table 31: Rural Interstate Seasonal Factors (5-year Average for 2011 to 2015)

Weekday	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sunday	1.25[a]	1.23	1.03	0.99	1.03	1.94	1.02	1.00	1.05	0.90	0.96	1.04
	(1.21)[b]	(1.18)	(1.01)	(1.00)	(1.02)	(0.93)	(0.89)	(0.99)	(1.05)	(0.92)	(0.97)	(1.05)
Monday	1.27	1.27	1.07	1.10	1.05	1.80	1.15	1.10	1.08	1.00	1.11	1.07
	(1.19)	(1.19)	(1.09)	(1.09)	(1.04)	(1.00)	(0.99)	(1.08)	(1.07)	(1.04)	(1.09)	(1.08)
Tuesday	1.19	1.19	1.05	1.10	1.07	1.83	1.15	1.07	1.11	1.06	1.02	1.05
	(1.17)	(1.14)	(1.06)	(1.10)	(1.07)	(1.01)	(1.02)	(1.05)	(1.09)	(1.03)	(1.00)	(1.04)
Wednesday	1.13	1.17	1.01	1.06	1.03	1.65	1.09	1.04	1.06	1.02	0.95	1.04
	(1.14)	(1.11)	(1.03)	(1.05)	(1.01)	(0.95)	(0.98)	(1.01)	(1.05)	(1.00)	(0.98)	(1.01)
Thursday	1.11	1.11	0.92	0.96	0.94	2.00	1.02	0.95	0.97	0.92	1.02	0.98
	(1.11)	(1.06)	(0.91)	(0.95)	(0.93)	(0.88)	(0.89)	(0.93)	(0.96)	(0.91)	(1.00)	(0.97)
Friday	1.01	0.95	0.82	0.85	0.85	1.65	0.95	0.84	0.86	0.80	0.90	0.92
	(1.01)	(0.92)	(0.84)	(0.87)	(0.84)	(0.78)	(0.81)	(0.84)	(0.86)	(0.81)	(0.89)	(0.88)
Saturday	1.17	1.20	0.92	1.02	1.04	1.95	1.02	0.97	1.06	0.97	0.99	1.00
	(1.17)	(1.15)	(0.94)	(1.02)	(1.02)	(0.88)	(0.94)	(0.96)	(1.06)	(0.99)	(0.98)	(0.99)

a. x.xx ≡ seasonal factor value before deletion of outliers

b. (y.yy) ≡ seasonal factor value after deletion of outliers

Table 32: Rural Non-Interstate Seasonal Factors (5-year Average for 2011 to 2015)

Weekday	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sunday	1.45[a]	1.39	1.24	1.14	1.18	1.09	1.11	1.12	1.18	1.19	1.27	1.36
	(1.40)[b]	(1.34)	(1.23)	(1.17)	(1.15)	(1.15)	(1.17)	(1.17)	(1.19)	(1.22)	(1.28)	(1.31)
Monday	1.24	1.23	1.07	1.02	1.01	0.96	0.98	0.98	1.04	0.99	1.05	1.11
	(1.14)	(1.07)	(1.04)	(1.01)	(1.00)	(0.97)	(0.98)	(0.97)	(1.03)	(0.99)	(1.02)	(1.05)
Tuesday	1.23	1.17	1.01	0.99	0.97	0.97	0.97	0.96	1.01	1.00	1.03	1.14
	(1.10)	(1.04)	(1.01)	(0.98)	(0.95)	(0.97)	(0.97)	(0.95)	(0.96)	(0.97)	(0.99)	(1.03)
Wednesday	1.21	1.19	1.03	0.98	0.96	0.93	0.95	0.96	1.01	0.97	1.01	1.11
	(1.11)	(1.06)	(1.00)	(0.97)	(0.94)	(0.95)	(0.96)	(0.94)	(0.96)	(0.95)	(0.98)	(1.02)
Thursday	1.19	1.18	1.03	0.94	0.93	0.90	0.94	0.92	0.96	0.94	1.03	1.09
	(1.08)	(1.04)	(0.96)	(0.93)	(0.91)	(0.92)	(0.95)	(0.91)	(0.92)	(0.93)	(1.00)	(1.00)
Friday	1.09	1.02	0.96	0.87	0.84	0.83	0.86	0.82	0.85	0.85	0.91	1.01
	(1.01)	(0.94)	(0.93)	(0.87)	(0.85)	(0.85)	(0.89)	(0.84)	(0.84)	(0.85)	(0.91)	(0.94)
Saturday	1.22	1.15	1.07	0.97	1.00	0.92	0.95	0.93	0.98	0.98	1.06	1.15
	(1.19)	(1.12)	(1.08)	(1.00)	(0.98)	(0.98)	(1.01)	(0.98)	(0.99)	(0.99)	(1.07)	(1.11)

a. x.xx ≡ seasonal factor value before deletion of outliers

b. (y.yy) ≡ seasonal factor value after deletion of outliers

Table 33: Recreational Group Seasonal Factors (5-year Average for 2011 to 2015)

Weekday	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sunday	1.48[a]	1.40	1.05	0.87	0.83	0.71	0.74	0.79	0.79	0.78	1.04	1.58
	(1.27)[b]	(1.23)	(1.04)	(0.92)	(0.88)	(0.73)	(0.76)	(0.82)	(0.81)	(0.81)	(1.04)	(1.19)
Monday	2.01	1.85	1.26	1.25	1.07	0.92	0.93	1.13	1.06	1.01	1.40	1.76
	(1.52)	(1.58)	(1.25)	(1.22)	(1.13)	(0.95)	(0.97)	(1.17)	(1.10)	(1.05)	(1.34)	(1.28)
Tuesday	2.13	1.96	1.27	1.19	1.12	0.87	0.89	1.08	1.12	1.04	1.48	1.97
	(1.49)	(1.73)	(1.22)	(1.22)	(1.15)	(0.90)	(0.92)	(1.13)	(1.16)	(1.07)	(1.43)	(1.52)
Wednesday	2.24	1.93	1.32	1.12	1.12	0.86	0.88	1.08	1.10	1.00	1.39	1.79
	(1.57)	(1.66)	(1.25)	(1.15)	(1.15)	(0.89)	(0.91)	(1.12)	(1.14)	(1.04)	(1.38)	(1.43)
Thursday	2.07	1.86	1.22	1.08	1.08	0.82	0.83	0.99	1.03	0.94	1.15	1.79
	(1.57)	(1.63)	(1.20)	(1.05)	(1.11)	(0.85)	(0.86)	(1.03)	(1.07)	(0.96)	(1.2)	(1.35)
Friday	1.65	1.36	1.01	0.87	0.92	0.74	0.74	0.85	0.86	0.78	1.02	1.51
	(1.40)	(1.26)	(1.01)	(0.90)	(0.94)	(0.76)	(0.76)	(0.88)	(0.89)	(0.81)	(1.06)	(1.11)
Saturday	1.34	1.01	0.84	0.76	0.77	0.63	0.66	0.66	0.72	0.64	0.86	1.42
	(1.07)	(0.97)	(0.86)	(0.79)	(0.82)	(0.65)	(0.69)	(0.70)	(0.76)	(0.69)	(0.89)	(0.94)

a. x.xx ≡ seasonal factor value before deletion of outliers

b. (y.yy) ≡ seasonal factor value after deletion of outliers

5.6. Summary

This chapter presented TDOT's procedure for estimating seasonal adjustment factors from data collected at ATR stations followed by proposed modifications to address outlined concerns with TDOT's procedure. The modified procedure was applied to estimate revised seasonal factors. The initial estimates were in some instances unusually high prompting the development of a procedure to identify outliers and delete them. Seasonal factor estimates obtained after implementation of the outlier procedure were more credible.

Chapter 6. Comparison of Two Alternative Count-Duration and Count-Cycle Traffic Data Collection Specifications in Their Estimation of Annual Average Daily Traffic

6.1. Introduction

Presented in this chapter is a comparison of the accuracy of AADT estimates based on data collected according to two alternative count-duration and count-cycle specifications. The first is TDOT's current specification which is for a count-duration of 24 hours on a one year count-cycle. The second is FHWA's recommended specification, which is for a count-duration of 48 hours on a three-year count-cycle.

The motivation for this comparison arises from the federal government requirement of each state having to estimate the annual vehicle-miles traveled (VMT) on its roadway network. A required input for estimating the annual VMT is the estimated AADT for each segment of roadway. Theoretically, determination of the AADT for each road segment would require a count of the vehicular traffic that uses the roadway segment for all the days in a year and then to divide that yearly volume by the number of days in the year. Given the very large number of such homogeneous road segments in a state's road network and the otherwise very large number of count-devices that would be required for such a count effort, states employ a sampling plan which requires much fewer count devices to develop AADT estimates for all the road segments. The sampling plan consists of selection of a relatively small number of roadway segments to be permanent count locations at which whole-day counts are made for every day of the year. These selected stations are also referred to as automatic traffic recorder (ATR) stations. At the non-ATR stations, vehicle-counts are undertaken for shorter durations and according to a specified cycle. The collected data at ATR stations are used to develop seasonal adjustment factors which are then used to adjust the shorter duration counts at non-ATR stations (coverage count stations) into AADT estimates.

FHWA Traffic Monitoring Guide (FHWA, 2013) recommends that states undertake 48-hour coverage counts on a three-year cycle. States that adopt this specification, each year, undertake counts at one-third of all their coverage stations such that at the end of a three-year period, a count would have been made at each coverage station just once. TDOT's coverage count specification, as stated above, differs from the FHWA's - it specifies a count-duration of 24 hours and a count-cycle of one year at all coverage stations. TDOT, at the time of undertaking this study, reported having 12,327 coverage stations. Were the FHWA recommendation to be operative in Tennessee, it would call for the undertaking of 4,109 coverage counts annually each of duration 48 hours. However, based on TDOT's policy, 12,327 coverage counts are undertaken annually each of duration 24 hours.

Eight of the nine states surveyed have coverage count programs that follow the count-duration and count-cycle specified by FHWA. Based on TDOT's vehicle-count protocol, the total number of hours equipment actively count at these coverage stations in a year is 295,848 hours. Were the FHWA recommendation to be followed the total number of hours vehicle-count equipment would actively be engaged in counting at the state's coverage stations in a year would be 197,232 hours. Thus, on an annual basis, TDOT's count protocol results in an additional 98,616 hours count-equipment are in service not to mention the hours that are put in by field staff to make these counts possible. The hours are 50 percent more than would be the case had FHWA's specification been operative in Tennessee.

Given its much greater service-hour requirements and the very high count workloads for TDOT field staff, the question that had to be addressed is whether TDOT's count protocol, in comparison to the FHWA's recommended count protocol, results in more accurate estimates of the AADT for various roadway segments (that is, at coverage count stations). The investigation into this is presented in the rest of the chapter.

6.2. Methodology

Figure 7 illustrates the procedure for performing the analysis to compare the two count specifications. This analysis is performed for each station within the following ATR groups: rural interstate (RI), rural non-interstate (RNI), urban interstate (UI), and urban non-interstate (UNI) that have data available for years 2013, 2014, and 2015 as noted in Step 1 of the flow chart. The recreational (R) group is excluded from the analysis because it did not have a complete set of seasonal factors in Year 2015. For Step 2 in the analysis, the estimated AADT based on the AASHTO formula is used as the "true" AADT for Years 2013, 2014, and 2015, which hereafter are denoted as Year 1, Year 2, and Year 3 respectively for simplicity. Estimates of AADT that are obtained in the analysis are compared against the "true" AADT. In Step 3, to be consistent with TDOT's procedure for conducting coverage counts, the days of the week whose traffic data are used in the analysis are the Tuesdays, Wednesdays, and Thursdays within each month. By denoting Sunday as day-type 1, Monday as day-type 2, and so on, the selected days whose volumes will be used in the analysis are Tuesday, which is denoted as day-type 3; Wednesday, which is denoted as day-type 4; and Thursday which is denoted as day-type 5. Steps 4 through 7 outlined in the flowchart shown in Figure 7 are further discussed in more detail in the following sections.

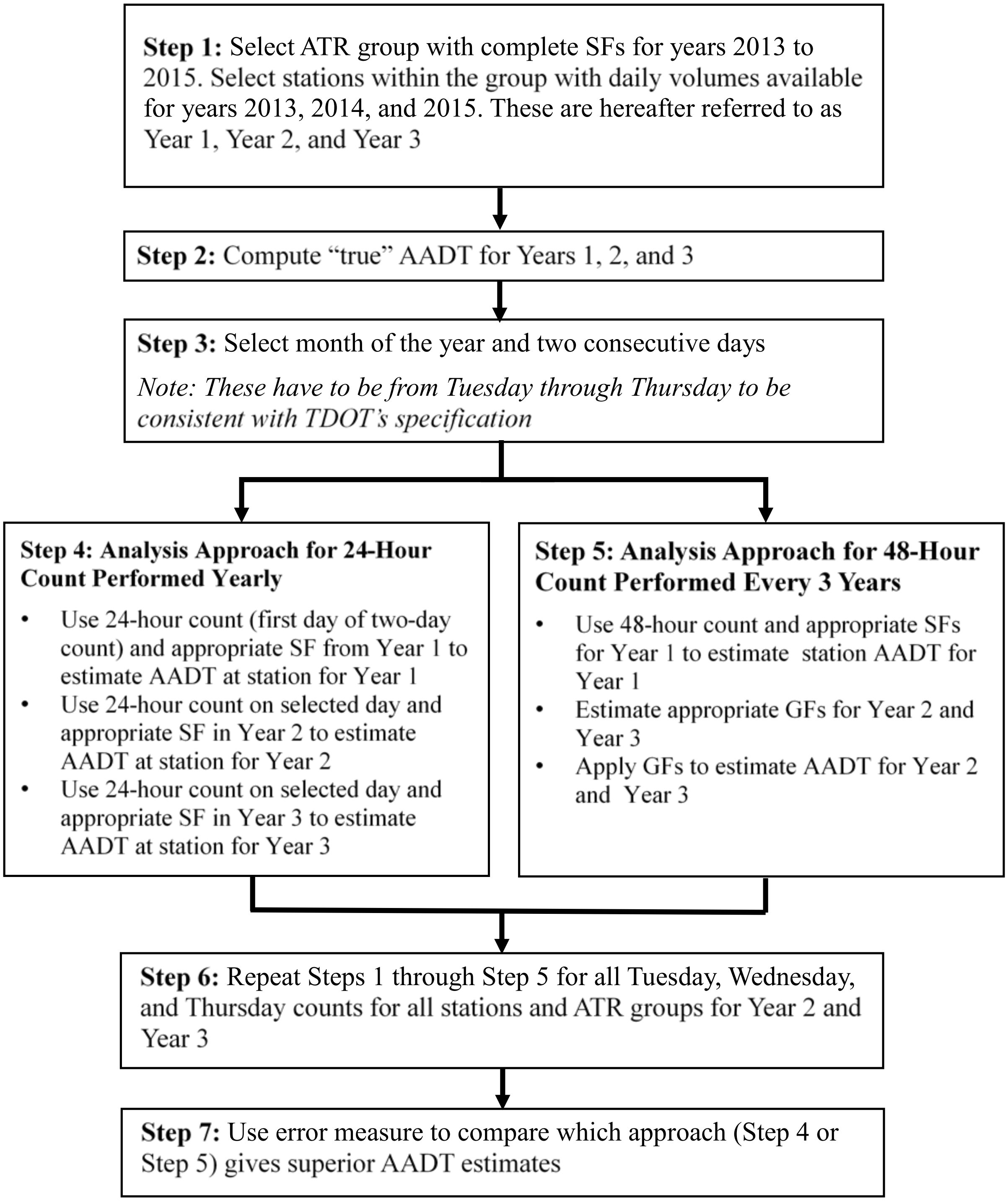

Figure 7. Flowchart of Count Duration, Count Cycle, and Growth Factor Analysis

6.2.1. 24-Hour Duration and Yearly Cycle Test Procedure

In Step 4, beginning with Year 1, each 24-hour count undertaken at a selected station on Tuesday, Wednesday, and Thursday respectively of each week in each month of Year 1 is used to estimate the station AADT. For this, the seasonal factor corresponding to day-type d_i in month m in Year 1, $SF_{md_i}^{\text{Year 1}}$, $V_{24,md_i}^{\text{Year 1}}$ i=3, 4, and 5; m=1,…12 is applied to each of the 24-hour counts $V_{24,md_i}^{\text{Year 1}}$ i=3, 4, and 5; m=1,…12 as follows:

$$AADT_{estimate}^{\text{Year 1}} = V_{24,md_i}^{\text{Year 1}} \times SF_{md_i}^{\text{Year 1}}$$

The above is then repeated for Year 2 and then for Year 3 for the selected station.

As an example, the expression for estimating an AADT using a selected Tuesday in July in Year 2013 based on this notation is written as follows:

$$AADT_{estimate}^{\text{Year 1}} = V_{24,7d_3}^{\text{Year 1}} \times SF_{7d_3}^{\text{Year 1}}$$

As noted in Step 6 of Figure 7, this analysis is repeated for all Tuesday through Thursday counts for each station within the RI, RNI, UI, and UNI groups that had available data in 2013, 2014, and 2015.

6.2.2. 48-Hour Duration and Three-Year Cycle Test Procedure

For Step 5 in this analysis, the collected ATR volumes for Tuesday-Wednesday and Wednesday-Thursday are assumed to be a 48-hour coverage counts. Each available Tuesday-Wednesday and Wednesday-Thursday consecutive count was analyzed for each station in 2013 with available data from 2013 to 2015. For Year 1, each 24-hour count was multiplied by a seasonal factor, $SF_{md_i}^{\text{Year 1}}$, that was based on the day-type d_i and month m the coverage count was conducted, in order to convert the 24-hour count into an AADT estimate for the station. An AADT is estimated for each Tuesday, Wednesday, and Thursday in each month for Year 1 given by the expression:

$$AADT_{estimate}^{\text{Year 1}} = V_{24,md_i}^{\text{Year 1}} \times SF_{md_i}^{\text{Year 1}}$$

In order to estimate an AADT from a 48-hour coverage count, the two AADT estimates obtained from each of the constituent 24-hour counts are averaged using the following expressions for a Tuesday-Wednesday count:

$$AADT_{d_3,d_4}^{Year\,1} = \frac{AADT_{d_3}^{Year\,1} + AADT_{d_4}^{Year\,1}}{2}$$

Where

$AADT_{d_3,d_4}^{Year 1}$ is the AADT estimate for a Tuesday-Wednesday count in Year 1,

$AADT_{d_3}^{Year 1}$ is the AADT estimate for a Tuesday count in Year 1, and

$AADT_{d_4}^{Year 1}$ is the AADT estimate for a Wednesday count in Year 1.

The expression below was used for a Wednesday-Thursday count:

$$AADT_{d_4,d_5}^{Year 1} = \frac{AADT_{d_4}^{Year 1} + AADT_{d_5}^{Year 1}}{2}$$

Where

$AADT_{d_4,d_5}^{Year 1}$ is the AADT estimate for a Wednesday-Thursday count in Year 1,

$AADT_{d_4}^{Year 1}$ is the AADT estimate for a Wednesday count in Year 1, and

$AADT_{d_5}^{Year 1}$ is the AADT estimate for a Thursday count in Year 1.

For Year 2, coverage counts are not conducted. However, a growth factor (GF) is determined and applied to the AADT estimated in Year 1 to provide an estimate of the AADT in Year 2. The following expression is applicable for a Tuesday-Wednesday count:

$$AADT_{d_3,d_4}^{Year 2} = AADT_{d_3,d_4}^{Year 1} \times GF^{12}$$

Where

$AADT_{d_3,d_4}^{Year 2}$ is the AADT estimate for a Tuesday-Wednesday count in Year 2,

$AADT_{d_3,d_4}^{Year 1}$ is the AADT estimated for a Tuesday-Wednesday count in Year 1,

and

GF^{12} is the developed GF from Year 1 to Year 2.

The expression below is used for a Wednesday-Thursday count:

$$AADT_{d_4,d_5}^{Year 2} = AADT_{d_4,d_5}^{Year 1} \times GF^{12}$$

Where

$AADT_{d_4,d_5}^{Year\,2}$ is the AADT estimate for Year 2 based on a Wednesday-Thursday count made in Year 1,

$AADT_{d_4,d_5}^{Year\,1}$ is the AADT estimate for Year 1 based on a Wednesday-Thursday count made in Year 1, and

GF^{12} is the growth factor from Year 1 to Year 2.

For each year that had traffic volumes that were collected at the ATR station, an AADT was calculated based on the AASHTO formula. The ratio of the station AADT computed for Year 2 to the station AADT computed for Year 1 gave the growth factor to be applied.

$$GF^{12} = \frac{AADT_T^{Year\,2}}{AADT_T^{Year\,1}}$$

where

$AADT_T^{Year\,1}$ is the "true" AADT for Year 1 calculated using the AASHTO method, and

$AADT_T^{Year\,2}$ is the "true" AADT for Year 2 calculated using the AASHTO method.

The procedure above is followed to obtain an estimate of the AADT for Year 3. Again, a growth factor was determined and applied to the AADT estimated in Year 2 to yield an estimate of the AADT for Year 3 since under the count protocol no coverage counts would be conducted in the third year as well. For Tuesday-Wednesday counts, the following expression provides an estimate of the AADT:

$$AADT_{d_3,d_4}^{Year\,3} = AADT_{d_3,d_4}^{Year\,2} \times GF^{23}$$

Where

$AADT_{d_3,d_4}^{Year\,3}$ is the AADT estimate for Year 3 based on a Tuesday-Wednesday count made in Year 1,

$AADT_{d_3,d_4}^{Year\,2}$ is the AADT estimate for Year 2 based on a Tuesday-Wednesday count in Year 1, and

GF^{23} is the developed GF for Year 2 to Year 3.

The expression below was used for a Wednesday-Thursday count:

$$AADT_{d_4,d_5}^{Year\,3} = AADT_{d_4,d_5}^{Year\,2} \times GF^{23}$$

Where

$AADT_{d_4,d_5}^{Year\,3}$ is the AADT estimate for Year 3 based on a Wednesday-Thursday count made in Year 1,

$AADT_{d_4,d_5}^{Year\,2}$ is the AADT estimate for Year 2 based on a Wednesday-Thursday count made in Year 1, and

GF^{23} is the developed *GF* for Year 2 to Year 3.

For each year that had traffic volumes that were collected at the ATR station, an AADT was calculated. The AASHTO calculated AADT was used to develop a *GF* that was applied to the estimated AADT from Year 2. The *GF* represents the growth experienced at a particular station from Year 2 to Year 3, and is given by the ratio:

$$GF^{23} = \frac{AADT_T^{Year\,3}}{AADT_T^{Year\,2}}$$

Where

$AADT_T^{Year\,2}$ is the "true" AADT at the station for Year 2 calculated using the AASHTO method, and

$AADT_T^{Year\,3}$ is the "true" AADT at the station for Year 3 calculated using the AASHTO method.

As noted in Step 6 of Figure 7, this analysis was repeated for all Tuesday through Thursday counts for each station within the RI, RNI, UI, and UNI groups that had data available in years 2013, 2014, and 2015.

6.2.3. Alternative Approach to Estimating Growth Factor

In Section 6.2.2, growth factors used in adjusting a previous year AADT at a station into a current year AADT at the station were estimated on a station-by-station basis. If each coverage count station is specifically assigned to a particular permanent count station, then the latter approach for growth factor development would be fully applicable. However, if each coverage count station is not assigned specifically an ATR station, then a growth factor for an ATR group is what would be applied to Year 1 AADTs to give estimates of Year 2 AADTs and, similarly, to Year 2 AADTs to give Year 3 AADTs at the coverage count stations. Hence, an alternative approach to estimating growth factors was also investigated. These ATR-group growth factors are a weighted average of the station-growth-factors in each ATR group, the weights being the previous year's "true" station AADTs ($AADT_T$). Mathematically, this is expressed as:

$$\text{ATR Group Average}\, GF^{12} = \frac{\sum_{s=1}^{n} AADT_{T,s}^{Year\,1} \times GF_s^{12}}{\sum_{s=1}^{n} AADT_{T,s}^{Year\,1}}$$

which simplifies to:

$$\text{ATR Group Average}\, GF^{12} = \frac{\sum_{s=1}^{n} AADT_{T,s}^{Year\,2}}{\sum_{s=1}^{n} AADT_{T,s}^{Year\,1}}$$

In the above expressions, *s* represents a station in an ATR group.

6.3. Measure of Accuracy of AADT Predictions to be Used in the Comparison

The last step, Step 7, calls for the comparison of the accuracies of the two count specifications. As stated earlier, the error measure used to assess accuracy of AADTs obtained from predictions based on the two alternative coverage count specifications is the mean absolute percent error (MAPE).

For the error analysis on AADT predictions based on 24-hour coverage counts, MAPE is calculated for each station in an ATR group, for each day-type (Tuesday through Thursday) and within each year, that is, 2013, 2014, and 2015. These errors are then averaged across the stations in an ATR group and across the three analysis years for the ATR group to provide overall error values by functional group, that is, RI, RNI, UI, and UNI.

Similarly, for the error analysis on AADT predictions based on 48-hour coverage counts, MAPE is calculated for each station in an ATR group, for each consecutive day-type combination (Tuesday-Wednesday and Wednesday-Thursday) and within each year, that is, 2013, 2014, and 2015. These errors are then averaged across the stations in an ATR group and across the three analysis years for the ATR group to provide overall error values by functional group, that is, RI, RNI, UI, and UNI.

The overall error measure values are particularly useful given the numerous AADT predictions that were made.

6.4. Summary of Errors Evaluated on AADT Predictions Based on the Two Alternative Coverage Count Specifications

A summary of the evaluated error measures based on the two count specifications are presented in Table 34.

Table 34: Summary of Overall Error Values for AADT Prediction by the Two Alternative Coverage Count Specifications

Group-Averaged MAPE for AADT Estimates Obtained from Alternative Coverage Count Durations and Cycles			
1 Functional Classification	**2 24-Hour Counts Performed Annually**	**3 48-Hour Counts Performed Every 3 Years with Individual GFs**	**4 48-Hour Counts Performed Every 3 Years with Group-Averaged GFs**
Rural Interstate	13.89%	9.77%	19.71%
Rural Non-Interstate	9.78%	8.90%	10.70%
Urban Interstate	10.04%	10.90%	15.68%
Urban Non-Interstate	9.10%	6.64%	10.51%

With the exception of the Urban Interstate group, the results show that AADT predictions at stations based on 48-hour counts undertaken every 3 years are more accurate than AADT predictions at stations based on 24-hour count performed annually (see columns 2 and 3 of Table 34). This is based on using individual growth factors computed on a station-by-station basis to adjust a previous year AADT into a current year AADT. Indeed, for the Rural Interstate group, the straightforward difference in the absolute percent error (MAPE) is 4.12 percent which translates into an almost 30 percent improvement of the 48-hour count based AADTs over the 24-hour count based AADTs. In the case of the Urban Non-Interstate group, the straightforward difference in the mean absolute percent error (MAPE) is 2.46 percent which translates into an almost 27 percent improvement of the 48-hour count based AADTs over the 24-hour count based AADTs. In the case of the Rural Non-Interstate group, the straightforward difference in the mean absolute percent error (MAPE) is 0.88 percent which translates into an almost 9 percent improvement of the 48-hour count based AADTs over the 24-hour count based AADTs. It is only for the Urban Interstate group that the 24-hour count based AADTs show a better performance compared to the 48-hour count based AADTs. The straightforward difference in the mean absolute percent error (MAPE) is 0.86 percent which translates into an almost 8 percent improvement over the 48-hour count based AADTs.

Where the growth factors applied are the weighted average for the entire ATR group, the 48-hour count based AADTs have greater errors in them compared to the 24-hour count based AADTs (see columns 2 and 4 of Table 34).

This discrepancy between results from application of individual station growth factors and group averaged growth factors points to the need to explore alternative ways of grouping

ATR stations such that the ATR stations in each group are relatively similar in specified important characteristics which, based on the analysis reported above, should presumably consider year-to-year growth in AADT at stations.

6.5. Summary

A framework was developed for comparing the accuracy of AADT predictions based on two alternative coverage count specifications, namely, 48-hour coverage counts performed every three years (FHWA) and 24-hour counts performed every year (TDOT). The mean absolute percent error (MAPE) was used to assess the accuracy of AADT predictions. Based on the results obtained, AADT predictions based on 48-hour counts performed every three years are more accurate than AADT predictions based on 24-hour counts performed annually. However, the latter finding was arrived at based on the use of growth factors developed on a station-by-station basis, which would mean that in practice each coverage station would have to be indexed to a specific permanent count station for that permanent count station's growth factor to be applied in adjusting a previous year's AADT at a coverage count station into a current year AADT.

Chapter 7. Review of Statistical Methods for Determining Sample Size

One of the project objectives was to review the statistical methods for determining the number of permanent count stations or automated traffic recorders (ATRs) needed to develop accurate adjustments for coverage counts to produce Average Annual Daily Traffic estimates. This chapter provides a review of the method outlined in the TDOT Traffic Monitoring Guide and summarizes approaches from other State DOTs as reported in the surveys.

7.1. Review of TDOT TMG Statistical Methods for Determining Sample Size

As discussed in Chapter 6, TDOT has five permanent count (ATR) station groups: rural interstate, urban interstate, rural non-interstate, urban non-interstate, and recreational. These functional groups are the factor groups used in developing adjustments for coverage counts to estimate AADT. According to the FHWA TMG, (FHWA, 2013)

> “the reliability levels recommended are 10 percent precision with 95 percent confidence for each individual seasonal group, excluding recreational groups where no precision requirement is specified. When these reliability levels are applied, the number of continuous count locations needed is usually five to eight per factor group, although cases exist where more locations are needed. The actual number of locations needed is a function of the variability of traffic patterns within that group and the precision desired; therefore, the required sample size may change from group to group.”

TDOT currently has sixty permanent count stations for the five factor groups as shown in Table 35, thus meeting the guidelines in the FHWA TMG of five to eight locations per factor group other than recreational. However, as noted in the FHWA TMG, cases exist where more locations are needed to achieve the precision and confidence levels desired.

Table 35. Number of Stations for Each Factor Group

Factor Group	Number of ATR Stations
Rural Interstate	5
Urban Interstate	9
Rural Non-Interstate	20
Urban Non-Interstate	24
Recreational	2
Total	60

One of the project deliverables for the objective discussed in this chapter is a revised procedure for determining sample size, which is recommended to replace the procedure outlined in the TDOT TMG. Another deliverable is a calculation of the sample size required for each factor group to achieve 10% precision with 95% confidence. These deliverables are given in the following subsections.

7.1.1. Procedure to Determine Sample Size for a Factor Group

Section 2.6.2 of the TDOT TMG (TDOT, 2015) describes the process for determining sample size and correctly specifies the t distribution as appropriate in this situation. A table for t distribution values is also provided on pages 11 and 12 of the document. It should be noted that an Excel function can also be used for determining t distribution values, and it is available for values not contained in the table. (The Excel function is T.INV.2T with input parameters of probability and degrees of freedom for the t distribution.) The formula given for sample size in the TDOT TMG is

$$n = \left(\frac{t_\alpha CV}{PL}\right)^2$$

where
- n = sample size (i.e., number of ATR Stations);
- t_α = (1 - α)th percentile of the t distribution with (n-1) degrees of freedom;
- α = 1 - (percent of confidence level chosen / 100);
- CV = coefficient of variation; and
- PL = precision level (i.e., $\pm$ percentage error of the mean acceptable for the chosen confidence interval)

The formula for the coefficient of variation is given by

$$CV = \frac{s}{\bar{x}}(100\%)$$

where
- s = standard deviation of the sample, and
- $\bar{x}$ = mean of the sample.

The CV gives a relative measure of the variability of a sample. The CV is unitless and therefore can be used to compare variability for samples when their means differ.

The FHWA TMG and TDOT TMG both specify a 95% confidence level and a 10% precision level for determining sample size. In practical terms, the 95% confidence level means that 95% of the confidence intervals developed using the correct procedures with a sample from the given population will contain the true mean.

The value of t_α is found in the t table in the TDOT TMG or by using Excel for a particular value of the degrees of freedom, i.e., the sample size minus one (n - 1). Note: The Excel function to be used is T.INV.2T (probability, degrees of freedom), where probability is the value of α, i.e., 0.05 for 95% confidence.

In this case where sample size is the value to be calculated, the procedure begins by assuming an infinite value for degrees of freedom. Table 36 provides a detailed list of the steps needed to determine the sample size for a particular factor group to achieve 10% precision with

95% confidence. The procedure specified in Table 36 differs from the procedure in the TDOT TMG for determining the standard deviation to use in the calculation of CV. In particular, changes were needed in steps 3 through 6 of the TDOT TMG procedure to correctly calculate the CV for a factor group.

Table 36. Procedure to Determine Sample Size for a Factor Group

Step	Revised Procedure
1	For a selected ATR station in the selected factor group, calculate the ADT using 24-hours of count data and the appropriate ACF such that ADT = (24 Hour Count) x (ACF).
2	Repeat Step 1 for all 365 days of the year, thus obtaining 365 ADTs throughout the year at the ATR station.
3	Calculate the average of the 365 ADTs to obtain the AADT at the ATR station. (See Note 1).
4	Repeat steps 1-3 for each ATR station in the factor group.
5	Calculate the average and standard deviation of the AADTs for all of the ATRs in the factor group.
6	Calculate the coefficient of variation (CV) for the factor group using the average and standard deviation calculated in Step 5. (See Note 2). CV = $\frac{AADT\ standard\ deviation}{AADT\ average}$ (100%)
7	Choose precision level (PL) and confidence level (1-α)%. (See Note 3.)
8	Determine the required number of ATR stations for the specified precision level and confidence level using an iterative procedure, beginning with degrees of freedom = ∞. (See Note 4.) Calculate n = $\left(\frac{t_\alpha CV}{PL}\right)^2$. Round up to the next higher integer for any fractional value.
9	Find the t_α value for (n-1) degrees of freedom in the TDOT TMG Table 2 or use Excel to calculate the resulting PL, where PL = $\frac{t_\alpha CV}{\sqrt{n}}$ If the calculated PL is greater than the specified PL, increase n by 1. If not, stop.
10	Repeat step 9 until calculated PL does not exceed specified PL.
11	Repeat steps 1 through 10 for each factor group.

Note 1: The AADT volumes from each ATR are calculated using the procedures described in Chapter 5.

Note 2: The TDOT Traffic Monitoring Guide (2015 Update*)* provided an example but did not list steps beyond finding the coefficient of variation.

Note 3: TDOT has a goal of at least within a 10% precision level with 95% confidence for each ATR group, as recommended in the FHWA TMG.

Note 4: For 95% confidence, (1-α) = 0.95, so α = 0.05. For degrees of freedom = ∞, $t_\alpha = t_{0.05} = 1.96$, using the values of the t distribution in Table 2 of the TDOT TMG.

7.1.2 Example Calculation of Sample Size for a TDOT Functional Group

This subsection provides an example of the sample size calculations for the Rural Interstate (RI) factor group using the steps in the revised procedure, as follows.

Steps 1 and 2: *Determine ADT for each day of the year for a selected ATR in the factor group.*

These steps were completed as part of the project objective resulting in a procedure for identifying outliers and for calculating seasonal factors as discussed in Chapter 6. Data from this part of the study were provided for the 2015 revised AADTs for each ATR in each factor group. Data for the Rural Interstate group are summarized in Table 37. Thus, the procedure begins with data at steps 3 and 4 of the procedure, in the Rural Interstate group.

Steps 3 and 4*: Determine the AADT for each ATR in the factor group.*

Table 37. 2015 AADT Data for Rural Interstate factor group.

ATR	AADT
38	47,697
39	30,687
44	35,225
69(169-369)	37,854
41(241-441)	19,813

Step 5: *Calculate the average and standard deviation of the AADTs for all of the ATRs in the functional group.*

AADT average = $\bar{x} = 34{,}255.4$

AADT standard deviation = s = 10,196.6

Step 6. *Calculate the coefficient of variation (CV) using the average and standard deviation calculated in the previous step.*

$$CV = \frac{AADT\ standard\ deviation}{AADT\ average}(100\%) = \frac{10{,}196.6}{34{,}255.4}(100\%) = 29.77\%$$

Step 7. *Choose precision level (PL) and confidence level (1-α)%.*

PL = 10%

(1-α)% = 95%

Step 8. *Determine required number of ATR stations for the specified precision level and confidence level using an iterative procedure, beginning with degrees of freedom = ∞.*

Calculate n = $\left(\frac{t_\alpha CV}{PL}\right)^2$. Round up to the next higher integer for any fractional value.

For degrees of freedom = ∞, $t_\alpha = t_{0.05} = 1.96$

$$n = \left(\frac{1.96 \cdot 29.77\%}{10\%}\right)^2 = 34.04$$

Rounding up, n = 35.

Step 9. *Find the t_α value for (n-1) degrees of freedom in Table 2 of the* TDOT TMG *or using Excel, and calculate the resulting PL, where PL =* $\frac{t_\alpha CV}{\sqrt{n}}$

n = 35, so degrees of freedom = 34

TDOT TMG Table 2 does not include t_α values for degrees of freedom = 34.

Using Excel, $t_{0.05}$ = 2.0322.

$$PL = \frac{2.0322 \cdot 29.77\%}{\sqrt{35}} = 10.23\%$$

If the calculated PL is greater than the specified PL, increase n by 1. If not, stop.

PL > 10%, so let n = 36.

Step 10. *Repeat step 9 until calculated PL does not exceed specified PL.*

Repeating Step 9: For n= 36, degrees of freedom = 35.

TDOT TMG Table 2 does not include t_α values for degrees of freedom = 35.

Using Excel, $t_{0.05}$ = 2.0301.

$$PL = \frac{2.0301 \cdot 29.77\%}{\sqrt{36}} = 10.07\%$$

PL > 10%, so let n = 37.

Repeating Step 9: For n= 37, degrees of freedom = 36.

TDOT TMG Table 2 does not include t_α values for degrees of freedom = 36.

Using Excel, $t_{0.05}$ = 2.0281.

$$PL = \frac{2.0281 \cdot 29.77\%}{\sqrt{37}} = 9.92\%$$

Since PL < 10%, stop.

Sample size = n = 37.

For 95% confidence and a precision level of 10%, the required sample size, i.e., number of ATRs, based on the 2015 AADT values is 37 for the Rural Interstate factor group, in contrast to the current sample size of 5. Using the PL equation for the current sample size of 5 reveals that the level of precision ($\pm$ percentage error in estimating the mean AADT) is currently 36.96% for a 95% confidence level.

7.1.3. Example of the Effect of Reducing Variation in the Functional Group

The large sample size is a result of the variability in the AADT data within the functional group. If the AADT data had less variability, the CV would be smaller and the required sample size would be smaller. An example to demonstrate the effect of reducing variability follows for the Rural Interstate group.

An examination of the ATR data summarized in Table 38 shows that the AADT for ATR station 41(241-441) is significantly different from the other AADT values in the RI group. In addition, the data for this station represented only 21 days in three months of the year. Omitting ATR station 41(241-441) from the calculation of the mean and standard deviation for the RI group yields the results shown below Table 4.

Table 38. Expanded Data for Rural Interstate Factor Group

ATR	AADT	Days	Months
38	47,697	330	11
39	30,687	222	10
44	35,225	170	8
69(169-369)	37,854	156	8
41(241-441)	19,813	21	3

Revised AADT average = $\bar{x} = 37{,}865.9$

Revised AADT standard deviation = s = 7,191.7

$$CV = \frac{AADT\ standard\ deviation}{AADT\ average}(100\%) = \frac{7{,}191.7}{37{,}865.9}(100\%) = 18.99\%$$

Applying the sample size procedure for 95% confidence and a 10% precision level results in a sample size of 17, based on the selected 2015 AADT data from four of the five ATRs. Although the sample size is still larger than the current sample size of 5, this example illustrates the impact on sample size of reducing the variability in the data. Less variability in the AADT values within a functional group will result in smaller sample sizes required to achieve the specified confidence and precision levels. (Note: This example was intended only to show the effect of reduced variability in the AADT values and does not imply that any AADT values can be eliminated from the factor group.)

7.1.4. Sample Size Calculations for Each TDOT Functional Group

In this subsection, summary data and sample sizes are given for each of the remaining four TDOT functional groups. Data from 2015 for the Urban Interstate group are shown in Table 39.

Table 39. 2015 Data for the Urban Interstate Factor Group

ATR	AADT	Days	Months
32	62,074	69	3
33	167,625	353	12
42	62,990	353	12
45	12,770	346	12
30(230-430)	106,608	231	11
31(231-431)	145,120	164	6
34(234-434)	70,156	289	12
35(235-435)	1,824	4	1
37(237-437)	100,710	310	11

AADT average = $\bar{x} = 81{,}097.6$

AADT standard deviation = s = 55,208.4

$$CV = \frac{AADT\ standard\ deviation}{AADT\ average}(100\%) = \frac{55{,}208.4}{81{,}097.6}(100\%) = 68.08\%$$

n = 181

Whereas the current number of ATRs in this group is 9, the required sample size for 95% confidence and a 10% precision level is 181, based on the 2015 AADT data. It should be noted that the AADT data within the Urban Interstate group range from a low of 1,824 to a high value of 167,625. Choosing ATR locations for AADT data that are more similar could significantly reduce the ATR sample size requirements.

Data for the Rural Non-Interstate group are shown in Table 40.

Table 40. 2015 AADT Data for Rural Non-Interstate Factor Group

ATR	AADT	Days	Months
7	17,824	343	12
12	3,360	344	12
14	1,159	269	10
15	2,300	261	10
16	13,888	295	11
17	18,976	276	12
18	4,421	292	12
19	2,775	217	12
28	2,349	252	12
29	7,522	316	12
36	8,467	217	12
40	19,346	243	10
59	881	337	12
60	1,792	354	12
61	664	267	10
62	2,430	228	8
63	7,659	252	10
64	2,651	303	12
65	2,040	312	12
66	207	73	9

AADT average = $\bar{x} = 6{,}035.5$

AADT standard deviation = s = 6,388.9

$$\text{CV} = \frac{AADT\ standard\ deviation}{AADT\ average}(100\%) = \frac{6{,}388.9}{6{,}035.5}(100\%) = 105.85\%$$

n = 433

Whereas the current number of ATRs in the Rural Non-Interstate group is 20, the required number of ATRs (sample size) for 95% confidence and a 10% precision level is 433, based on the 2015 AADT data.

Data for the Urban Non-Interstate group are shown in Table 41.

Table 41. 22015 AADT Data for Urban Non-Interstate Factor Group

ATR	AADT	Days	Months
4	25,353	24	8
5	15,284	256	11
6	10,864	300	11
8	4,527	228	12
9	1,524	76	11
10	2,455	248	12
13	2,368	263	11
20	16,312	249	9
21	7,699	321	12
22	7,888	33	5
23	11,889	234	10
24	5,061	168	8
25	1,852	301	11
26	4,357	187	11
27	5,086	274	10
43	2,387	307	11
46	1,988	88	7
47	662	39	3
512	8,266	138	9
513	2,820	353	12
516	7,035	354	12
540	15,376	260	12
553	17,451	104	5
555	14,901	48	9

AADT average = $\bar{x} = 8{,}058.5$

AADT standard deviation = s = 6,500.8

CV = $\frac{AADT\ standard\ deviation}{AADT\ average}$ (100%) = $\frac{6{,}500.8}{8{,}058.5}$ (100%) = 80.67%

n = 253

Whereas the current number of ATRs in the Urban Non-Interstate group is 24, the required sample size for 95% confidence and a 10% precision level is 253, based on the 2015 AADT data.

The data in Table 42 are for the Recreational factor group.

Table 42. 2015 AADT Data for Recreational Factor Group

ATR	AADT	Days	Months
3	31,996	179	8
75	1,393	242	10

AADT average = $\bar{x} = 16{,}694.7$

AADT standard deviation = s = 21,639.3

CV = $\frac{AADT\ standard\ deviation}{AADT\ average}$ (100%) = $\frac{21{,}639.3}{16{,}694.7}$ (100%) = 129.62%

n = 648

Whereas the current number of ATRs in the Recreational factor group is 2, the required sample size for 95% confidence and a 10% precision level is 648, based on the 2015 AADT data.

However, the FHWA TMG specifically excludes the Recreational factor group from the requirement for five to eight locations, stating,

> "Recreational factor groups usually are monitored with a smaller number of continuous counters, simply because recreational patterns tend to cover a small number of roads; it is not economically justifiable to maintain five to eight stations to track a small number of roads. The number of stations assigned to the recreational groups depends on the importance assigned by the planning agency to the monitoring of recreational travel, the importance of recreational travel in the State, and the different recreational patterns identified." (p. 3-14)

7.1.5 Summary of Sample Size Calculations for TDOT Factor Groups

A summary of the results for all factor groups is shown in Table 43. It is clear that the sample sizes required are not realistic for implementation by TDOT.

Table 43. Current and Required Number of Stations for Each Factor Group for 95% Confidence and 10% Precision

Factor Group	Current Number of Stations	Required Number of Stations for 95% Confidence and 10% Precision Level
Rural Interstate	5	37
Urban Interstate	9	181
Rural Non-Interstate	20	433
Urban Non-Interstate	24	253
Recreational	2	648
Total	60	1,552

7.2. Investigation of the Impact of Increasing the Number of Factor Groups within a Functional Group

TDOT's current factor groups are the same as the defined functional groups, but some State DOTs define different factor groups. This section reports on an investigation of whether sample sizes might be reduced by a different definition of factor groups within a functional group. Two cases were examined:

Case 1: Factor groups based on road categories

Case 2: Factor groups based on AADT volumes

7.2.1. Factor Groups Based on Road Categories

The Rural Non-Interstate and Urban Non-Interstate functional groups both had high CV values, resulting in extremely large sample sizes required for 95% confidence and a 10% precision level. It was hypothesized that variability might be reduced by defining road category groups within each of these functional groups. The road category for each ATR station was identified, and sample sizes were determined for each road category group using the approach of section 7.1.1. Table 44 summarizes the results obtained from this approach. Calculating sample sizes for road categories within a functional group resulted in smaller CV values in some but not all cases, which in turn led to a smaller sample size than calculated for the functional group. However, summing the road category sample sizes within a functional group shows that the total sample size required for 95% confidence and a 10% precision level far exceeded the sample size requirement for the total functional group. Thus, this approach is not recommended for the current selection of ATR locations.

Table 44. Sample Sizes for Road Categories within a Functional Group

Functional Group	CV	Sample Size	Road Category within Functional Group	CV	Sample Size
Rural Non-Interstate	105.85%	431	RMJC	81.87%	260
			RMNC	98.52%	376
			RPA	72.53%	205
			Total	--	841
Urban Non-Interstate	80.67%	250	UFE	35.04%	50
			UMJC	83.14%	268
			UMNA	73.94%	213
			UPA	59.11%	137
			Total	--	668

7.2.2. Factor Groups Based on Volume

Specifying factor groups based on volume was investigated as another approach to reduce variability. Using the Rural Non-Interstate (RNI) and Urban Non-Interstate (UNI) functional groups, the AADT values for each group were sorted from smallest to largest. Groups of similar AADT values were identified, and those ATR groups were defined as the factor groups. Each factor group was required to have at least two members so that the coefficient of variation could be calculated. Table 45 and Table 46 summarize the required sample sizes for each factor group resulting from this approach.

Table 45. Sample Sizes for Factor Groups Based on Volume (RNI Functional Group)

Functional Group	CV	Sample Size	Factor Groups Based on AADT Vo.lume			CV	Sample Size
			Group	ATR	AADT		
Rural Non-Interstate	105.85%	433	1	14 59 61 66	207 664 881 1159	55.20%	120
			2	60 65 15 28 62 64 19	1792 2040 2300 2349 2430 2651 2775	14.50%	11
			3	12 18	3360 4421	19.27%	17
			4	29 63 36	7522 7659 8467	6.48%	5
			5	16 7 17 40	13888 17824 18976 19346	14.27%	11
			Total				164

Table 46. Sample Sizes for Factor Groups Based on Volume (UNI Functional Group)

Functional Group	CV	Sample Size	Factor Groups Based on AADT Volume			CV	Sample Size
			Group	ATR	AADT		
Urban Non-Interstate	80.67%	250	1	47 9 25 46	662 1524 1852 1988	39.55%	63
			2	13 43 10 513	2368 2387 2455 2820	8.44%	6
			3	26 8 24 27	4357 4527 5061 5086	7.80%	5
			4	516 21 22 512	7035 7699 7888 8266	6.67%	5
			5	6 23	10864 11889	6.37%	5
			6	555 5 540 20 553 4	14901 15284 15376 16312 17451 25353	22.82%	23
			Total				107

The total sample size requirement for the Rural Non-Interstate group was reduced from 433 to 164, and the requirement for the Urban Non-Interstate group was reduced from 253 to 107. An examination of Table 46 and factor groups 4 and 5 shows that each of these two groups currently has four ATR stations, and the requirement is 5. On the other hand, factor group 1, which consists of the lowest volume stations in the UNI group, also currently has four ATR stations but the requirement is 63. Additional ATR stations with volumes in the range of factor group 1 would be an effective way to increase the confidence level or decrease the estimation error. Likewise, Table 45 shows a similar situation with factor group 1 in the RNI functional group. This approach demonstrates the potential value in specifying factor groups by volume so that variability within the groups is reduced.

However, the investigation of factor groups based on volume for the Rural Interstate group and the Urban Interstate group did not identify any factor groups that would reduce sample size requirements for either functional group. Table 47 illustrates why factor groups based on volume are not effective in reducing sample size for these two groups, given the current ATR stations. In both cases, the requirement for a minimum of two ATR stations (AADT values) to define a volume-based factor group requires disparate AADT volumes to be grouped together, thus resulting in a high CV for the factor group and a higher total sample size requirement than for the functional group. For example, in the Urban Interstate group, the low-volume factor group might be defined as the first two AADT values in Table 47, resulting in a required sample size of 433 for that group alone. Alternatively, the low-volume factor group might be defined as the first five AADT values, resulting in a required sample size of 227 for that group alone. Both of these sample size calculations exceed the sample size of 181 required for a single factor group containing all AADT values for the functional group.

Table 47. AADT Volumes for Rural Interstate and Urban Interstate Functional Groups

Rural Interstate Functional Group		**Urban Interstate Functional Group**	
ATR	**AADT**	**ATR**	**AADT**
41(241-441)	19,813	35(235-435)	1,824
39	30,687	45	12,770
44	35,225	32	62,074
69(169-369)	37,854	42	62,990
38	47,697	34(234-434)	70,156
		37(237-437)	100,710
		30(230-430)	106,608
		32(231-431)	145,120
		33	167,625

Thus, the selection of factor groups must be carefully considered. The FHWA TMG describes the “traditional approach” and statistical clustering as methods to define factor groups, and each has advantages and disadvantages. The following section provides conclusions and recommendations based on the results of this chapter and on the results from the benchmarking survey of state DOTs on the topic of sample sizes and factor groups.

7.3. Conclusions and Recommendations

Chapter 2 previously summarized the results related to sample size estimation from the benchmarking survey of State DOTs. It was noted that TDOT meets the requirements specified in the FHWA TMG but has fewer ATR factor groups and a smaller average number of ATR stations per factor group than do most other states. In addition, TDOT has a greater roadway mileage monitored per ATR than any other State DOT in the survey. The number of monitored miles per ATR can mean that the counts are not as representative as they need to be and can be especially problematic when equipment failures or other issues result in missing data.

In this chapter, section 7.1 provided a revised procedure for estimating the number of ATRs for a factor group to meet a specified confidence level and precision. The previous method in the TDOT TMG did not correctly calculate the coefficient of variation. It also demonstrated that the current numbers of ATRs for the TDOT factor groups are inadequate to meet the confidence and precision goals specified by TDOT and the FHWA TMG. Section 7.2 demonstrated the potential value from defining volume-based factor groups for reduced variability.

These findings lead to the following conclusions and recommendations.

- The revised procedure specified in subsection 7.1.1 should be used for determining the sample size, i.e., the number of ATR locations, for a specified confidence and precision level.
- None of the current TDOT factor groups have the required number of ATR stations to be 95% confident that the AADT estimates are within 10% of the true mean AADT. A redefinition of factor groups and the addition of new ATR stations in strategic locations may be needed for TDOT to satisfy their stated confidence and precision goals.
- A re-definition of factor groups based on similar volumes has the potential to provide the desired confidence and precision levels with fewer added ATRs than might be required for the current functional groups.

Chapter 8. Methods for Estimating VMT on Local Roads

8.1. Introduction

The purpose of this chapter is to present the research team's findings related to methods for estimating VMT on local roads. The chapter begins with a description of the current TDOT method for estimating VMT on local roads and a brief discussion of its relative merit. The chapter continues by providing information gleaned from the survey regarding how other states estimate VMT. The chapter concludes with conclusions and recommendations regarding this estimate.

8.2. TDOT's Method for Estimating VMT

Currently, TDOT uses a four-step procedure for estimating VMT on local roads. The steps in this process are:

- If possible, determine the current year average bridge ADT for the county. Existing bridge counts are adjusted via growth rates to the year of interest, then averaged.
- Estimate local rural ADT using the appropriate local rural ADT regression equation. There are different equations based on the availability of bridge data.
- Estimate local urban ADT using the appropriate local urban ADT regression equation. As with local rural ADT, there are different equations based on the availability of bridge data.
- Estimate the DVMT for both local rural and local urban roads by multiplying the length of local/rural roadways by the estimated local/rural ADT.

TDOT's current method is highly dependent on two factors: average bridge ADT for the county and the regression equations for estimating local road ADT. The reliability of average bridge ADT is dependent on the frequency with which these counts are taken and the accuracy of the growth factors used to adjust past counts to the year of interest. While no specific investigation has been completed, the study team is not aware of any issues related to the reliability of either the average bridge ADT or the growth factors used in determining average bridge ADT. There are, however, potential concerns regarding the regression equations.

Documentation for the estimation procedure suggests that the regression equations were developed in approximately 2000 using an extensive stepwise regression analysis study and implemented in 2001. The documentation does not indicate that the regression equations have been updated in the years since 2001. It cannot be assumed that regression equations based on historical data from 2000 and earlier years are still applicable in 2017. The coefficients in the regression equations, and potentially even the independent variables, may no longer be appropriate for estimating the county DVMT and total local ADT mean. Regression equations require periodic updating and validation to ensure that they provide good estimates. Assuming TDOT chooses to keep using the current procedure, regularly scheduled reviews of [and updates to] the regression equations should be undertaken.

8.3. Survey Response Review: How Other States Estimate Local VMT

As noted above, the survey of states undertaken as part of this research included questions regarding how each state estimates local VMT. Response quality varied by state, but what follows is a brief summary of each state's response. Unlike prior chapters, these responses were too lengthy to include in tabular format. Responses are presented alphabetically by state.

California: The California Department of Transportation uses annual count contracts to outsource collection of roadway segment counts by jurisdiction. These counts are used to determine segment ADTs, which are used to calculate segment VMTs. No specific information was given about the number, type, or duration of the outsourced counts.

Florida: The Florida Department of Transportation uses a methodology developed during research conducted between 2002 and 2004. Their method involves classifying roads based on population and ownership and using that classification to predict ADT. Estimates from 2015 were provided and are shown in Table 48.

Table 48. Florida Estimated ADT by Classification

Owner: **Population:**	**City/County**	**Federal**
Rural (Population < 5,000)	684	255
Small Urban (Population < 50,000)	811	612
Small Urbanized (Population < 200,000)	1065	612
Large Urbanized (Population ≥ 200,000)	1820	612

No information was provided regarding how the estimated ADTs were determined for the different classifications.

Georgia: The Georgia Department of Transportation uses a sampling process to estimate local VMT. Between 800 and 1600 random ADT samples are collected across six different types of local roads: Urban Local (Atlanta), urban Local (Not Atlanta), Small Urban Local, Rural (Paved), Rural (Unpaved), and Dead End/Cul-de-Sac. These samples are used with local road miles to estimate local VMT.

Indiana: The Indiana Department of Transportation assigns default values of ADT to local roadways without specific count data. Assignment of default values is based on location (county) and area type. Default values are updated every 3 years to account for population growth. No information was provided regarding how the original default values were calculated or what the current default values are.

Kentucky: The Kentucky Department of Transportation used research from 2000 to develop a regression equation for estimating local road ADT in a given county based on average minor collector ADT for that county. This estimate of ADT is used in determining local road VMT. The regression equation was reported as:

$$LocalADT = 3.3239 \times AvgMinorCollectorADT^{0.6248}$$

Additional research was performed in 2009 to review and, if needed, update the regression equation. At that time, no changes were deemed necessary.

North Carolina: The North Carolina Department of Transportation appears to back-calculate local VMT by first estimating total state VMT. First, previous year to current year growth factors are determined for each county based on data from non-local roadways. These growth factors are applied to the prior year's county VMTs, and those estimates combined to determine a current year, estimated, statewide VMT. Current year VMT estimates for non-local roads are then subtracted from the estimated statewide VMT, leaving the estimated local VMT. The provided information did indicate that growth factors sometimes need adjustments, but gave no specifics about when or how those adjustments are made.

Texas: The Texas Department of Transportation uses a sophisticated sampling method to estimate ADT on local roads for use in estimating local VMT. The process begins with a precise grid that overlays on the state transportation map. Each cell in the grid has been numbered, and software is used to randomly select among the cells in the grid. When a cell is randomly selected, a local road within that cell is identified and a count taken. If there are no local roads within the cell, another is randomly selected instead. The selection process continues until enough sites have been identified for a reliable estimate. No specific information was provided about how many sites are selected each year.

The FHWA has approved this process and identified its development as noteworthy.

Utah: The Utah Department of Transportation did not provide details about their process. Their description indicated that they rely on local governments to provide local road ADTs for use in estimating local VMT.

Virginia: The Virginia Department of Transportation provided even less information than Utah. They indicated that local VMT is the product of ADT and link length, but gave no indication as to where/how they determine ADT.

8.4. Conclusions and Recommendations

Based on the information provided in the survey process, there is no consensus among states about how to calculate local VMT. The method of assigning default ADT by classification is used by two states, namely Florida and Indiana. Regression equations have been developed by two states, namely Kentucky and Tennessee. Each of the other states surveyed used a method unique to that state. There is no significant motivation in these findings to suggest that Tennessee needs to change methods to be like other states.

Also, as noted above, there is no fundamental flaw with the underlying methodology TDOT currently uses. Given acceptable frequency of bridge ADT datasets and reliable growth factors, the use of a regression equation is reasonable. Assuming TDOT chooses to continue with the current method, TDOT should schedule periodic validation/update efforts to ensure the quality of their estimates, similar to those undertaken by Kentucky for their regression model.

If, despite the findings noted in this chapter, TDOT decides to change methods, the Texas method should be strongly considered. It provides local VMT based on a random annual sample and has been approved by FHWA.

Chapter 9. Conclusions and Recommendations

The purpose of this report was to document the findings of research undertaken for TDOT's Long Range Planning Department by Tennessee Tech University's Civil and Environmental Engineering Department. The overarching purpose of this research was to determine best practices for a traffic monitoring program based on an in-depth review of the Traffic Monitoring Program of other State Departments of Transportation and the Federal Highway Administration's Traffic Monitoring Guide.

The project included six key research objectives, namely 1) to review and compare Tennessee Department of Transportation's Traffic Monitoring program with that of other States; 2) to investigate the cost of improving the Traffic Monitoring Program with the results of the best practices; 3) to investigate new technologies for traffic data collection methods and traffic data statistical analysis such as seasonal factors and variances; 4) to develop a ruleset designed to help remove questionable data reported by the permanent count stations; 5) to calculate seasonal factors based on the 2015 dataset; and 6) to review TDOT's current process for estimating vehicle miles travelled on local roads.

The purpose of this chapter is to highlight key conclusions and recommendations from the entire document. It is not intended to be a comprehensive repetition of all the findings noted previously. For ease of access to background, context, and additional findings, the conclusions and recommendations are organized based on how they impact TDOT Traffic Monitoring activities. The conclusions are numbered "C.X" for ease reference. Where a conclusion led to specific recommendations, those recommendations are numbered "R.Xx" presented in nested fashion below the related conclusion.

9.1. Conclusions and Recommendations Regarding the Permanent Count Program

C.1 - TDOT's reported quality check of the data collected at ATR stations is for each month of the year to have at least seven days of volume records. Other checks must be incorporated into the quality control process to ensure outlier data are identified and deleted. They otherwise will have a profound impact on the station AADT and on the seasonal factors they are used to generate.

R.1a - TDOT should explicitly incorporate additional quality control measures in its assessment of data collected at its permanent count station. Additional checks to be made could include comparisons with historical data collected at an ATR station, the directional splits and volumes, hourly volumes that are out of range, and consecutive volumes of zero magnitude.

R.1b - Some of these checks should be incorporated into the software that processes the data as it is received to ensure field staff can promptly be alerted to attend to the equipment at a permanent count station that transmits questionable data, e.g., a series of zero volumes. The latter occurred in several instances in the volume records received from TDOT.

C.2 - TDOT's permanent count program currently uses only one detection technology: inductive loop detectors. In comparison, many surveyed states use more than one type of detection technology. The most promising technology identified was the microwave (radar) technology, currently in use both by many of the surveyed states and by TDOT's Operations Division.

R.2a - TDOT should begin using microwave (radar) at permanent count sites. If there is internal resistance to this change, then TDOT should commission research that would install multiple test sites near existing permanent count stations to confirm the viability of this technology.

C.3 - TDOT currently has no internal or external institutional agreements in place with other agencies that are performing counts. However, TDOT's Operations Division currently operates a significant number of urban freeway detectors which have the ability to collect count data on a continuous basis, and could therefore be used as permanent count sites.

R.3a - TDOT should select appropriate sites from among the Operations Division urban freeway detectors and begin using them as permanent count stations.

R.3b - TDOT should commission or internally develop the required data conversion tools needed to most efficiently incorporate the Operations Division data into current tools and databases.

C.4 - TDOT currently has five ATR groups namely, Urban Interstate, Urban Non-Interstate, Rural Interstate, Rural Non-Interstate, and Recreational. Given their broad definitions, there is considerable variability in the AADTs within each group. This variability greatly influences the number of permanent count stations required to meet the statistical criteria TDOT has. Further, how traffic volumes vary by day of week could be different for the facilities within an ATR group and this could have implications for the seasonal adjustment factors developed with the ATR data. The mean and median number of ATR groups for the six state DOTs that addressed this in the survey is 10.

R.4a - TDOT should increase its number of ATR groups with the objective of obtaining better quality estimates of seasonal adjustment factors. AASHTO recommends that as much as possible factor groups should be distinguished from each other on the basis of roadway characteristics such as functional class and location. Hence, a possible scheme would be to break the Urban Non-Interstate group into Urban Freeways, Urban Major Arterials, Urban Minor Arterials, and Urban Collectors. Similarly, the Rural Non-Interstate group could be further broken into Rural Freeways, Rural Major Arterials, Rural Minor Arterials and Rural Collectors. This, together with the Urban Interstate and Rural Interstate groups, would give a total of 10 ATR groups.

R.4b - When creating new ATR groups, TDOT should incorporate volume thresholds to help further reduce variance within the groups, thus reducing the sample size required for a desired confidence and precision level.

R.4c - When the volume on a particular facility passes the threshold, it should be automatically reclassified into a different ATR group.

C.5 - TDOT's permanent count program meets the FHWA recommendation of having five to eight ATR stations per ATR group. However, in comparison to the surveyed states, the number of ATR stations TDOT has in service falls short based on two metrics defined in the study. Further, traffic volumes collected at all the ATR stations from 2010 to 2015 show many missing records on account of equipment malfunction, weather, construction, etc. This reduces the amount of ATR data available for estimation of AADT at the permanent count stations, for estimation of growth factors, and for development of seasonal factors and therefore of the reliabilities of these estimates. The number of permanent count stations should be determined to accommodate the failures that occur in the data collection process.

R.5a - TDOT should increase its number of permanent count stations. Based on the metrics used in the analysis of the survey results, increasing it to 150 stations from the current 60 stations would be a good starting point.

R.5b - TDOT should use the revised sample size procedure outlined in Chapter 7 to determine the number of ATR stations needed in each ATR group based on meeting desired confidence and precision levels.

R.5c - TDOT should be strategic in selection of new ATR stations so as to reduce variability within groups.

R.5d - TDOT should use some of the sites selected from the Operations Division urban freeway detectors as one way to increase the number of stations.

C.6 - TDOT's procedure for developing seasonal adjustment factors is consistent with that of the majority of surveyed states. However, TDOT uses an average of five years of seasonal factors whereas eight of the surveyed states use just one year of seasonal factors. Use of a five-year average is not analytically more burdensome – it only requires seasonal factors to be stored. However, the issue relates to the accuracy of the AADT estimates that result from application of the five-year average seasonal factors to coverage counts that were made only in the preceding year.

R.6a - TDOT should research into whether use of a five-year average gives more accurate estimates of AADT compared to just use of one year of seasonal factors.

9.2. Conclusions and Recommendations Regarding the Coverage Count Program

C.7 - TDOT field staff have a count workload that is more than two times the count workload of the staff of any of the surveyed state DOTs.

R.7a - TDOT should consider increasing the number of field staff for undertaking coverage counts. Doubling the current staff level to twelve will be a big improvement, although this will still keep the count workload well above that for the majority of the surveyed states.

R.7b - TDOT should change the way they have implemented FHWA's requirements for a coverage count program. Options for such changes are presented as additional conclusions and recommendations in this section. Note that some of these changes will not only reduce TDOT's workload, but will also improve the resulting data quality.

C.8 - TDOT's coverage count specification of 24-hour counts done every year is far more demanding of staff time than the count specifications in operation in all the surveyed states - with the exception of Texas, all the states follow the FHWA TMG recommendation of conducting 48-hour coverage counts every three years. Following the FHWA recommendation would significantly reduce the count workload of TDOT field staff.

R.8a - TDOT should adopt the FHWA TMG count specification of 48-hour counts conducted every three years. This will both provide more accurate estimates of AADT and reduce TDOT's workload.

C.9 - TDOT did not report any data collection agreements with local or county governments. These governments undertake traffic counts in their jurisdictions and with cooperative agreements with them covering, among others, quality control measures, it can either reduce the workload of TDOT field staff through elimination of duplicity in counts or add to counts in TDOT's database.

R.9a - TDOT should initiate institutional agreements with local and county governments to provide TDOT with access to local and county count data.

R.9b - TDOT should commission or internally develop the required data conversion tools needed to most efficiently incorporate local and county count data into current tools and databases.

R.9c - TDOT should identify locations where local and county data collection duplicates current state data collection. TDOT should discontinue state data collection efforts at these sites and use the local or county data instead, thus reducing TDOT's workload.

R.9d - TDOT should identify locations where local and county data do not duplicate current state data. TDOT should choose a reasonable number of these sites and add them to the current database, thus improving overall data quality.

9.3. Conclusions and Recommendations Regarding the Classification Count Program

C.10 - The percentage of TDOT's coverage counts that provide vehicle classification counts (known as count nesting) is 17 percent. The FHWA TMG recommendation is for 25 to 30 percent of coverage count sites to also provide classification counts. The average for the surveyed states is almost 33%.

R.10a - TDOT should increase the number of count nested stations to at least attain the FHWA TMG recommended percentage.

R.10b - TDOT should commission research to investigate use of the classification feature with the Operations Division's microwave (radar) detectors noted in R.3a and R.5b, above. If their classification data are shown to be as reliable as their count data, count nesting would be available at all these sites.

R.10c - As part of the institutional agreements with local and county agencies noted in R.9a, above, TDOT should identify and acquire any available classification data collected.

9.4. Conclusions and Recommendations Regarding VMT on Local Roads

C.11 - Among the states surveyed, there is no consensus method for determining VMT on local roads. TDOT's current use of a regression model is reasonable, though the model has not been reviewed or updated since its first use in 2001.

R.11a - If TDOT chooses to keep their current method, they should undertake regularly scheduled reviews and implement updates as needed.

R.11b - If TDOT chooses to change methods, the Texas method should be strongly considered. It provides local VMT based on a random annual sample and has been identified as noteworthy by FHWA.

9.5. Acknowledgements

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Appendix A. TDOT Responses to Questions about Its Traffic Monitoring Guide*

* **Note:** The contents of the appendices are in a separate document. They are listed here only as place markers.

Appendix B. Final Version of the Study Survey*

*** Note:** The contents of the appendices are in a separate document. They are listed here only as place markers.

Appendix C. Completed Questionnaires by the Surveyed State Departments of Transportation on their Traffic Monitoring Program*

*** Note:** The contents of the appendices are in a separate document. They are listed here only as place markers.

Appendix D. Number of Days in Each Month of a Year for Which Traffic Volumes Were Recorded*

*** Note:** The contents of the appendices are in a separate document. They are listed here only as place markers.

Appendix E. Empirical Distribution of the Values of Ratios Defined in the Outlier Identification Procedure*

*** Note:** The contents of the appendices are in a separate document. They are listed here only as place markers.